

**The origin of Chinese glasses and the glass trade along the Silk  
Road from the Warring States (475 BC – 221 BC) to the Han  
Dynasty (202 BC – AD 220)**

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## **Abstract**

The Silk Roads played significant roles in the trade of glass products. Natron glass from the Mediterranean, potash glass and mineral soda alumina glass from South and Southeast Asia have been discovered in different provinces in China. This article-based thesis mainly consists of three individual papers.

1) Lead-barium glass appeared during the late Warring States period in China and was considered a Chinese invention due to the unique presence of high barium. However, the glass replication in this research indicates that lead-barium glass could be a mixture of natron glass and lead-barium minerals, which also explains a high  $\text{Na}_2\text{O}$  concentration in this type of glass.

2) To further test this theory, fifty samples, including natron glass, lead-barium glass and lead-barium faience, were analysed through laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS). We produced a piece of code that allows us to perform 3D kernel density estimation on four variables (i.e., four-element concentrations) in a tetrahedron plot. Then, we combined Maximum Mean Discrepancy with hypothesis testing to trace the potential silica source for producing lead-barium glass. The result confirmed that the Syro-Palestinian coast was a possible source region for the raw glass used to make lead-barium glass. Moreover, the silica source for producing lead-barium glass was not related to lead-barium faience.

3) In this DPhil project, we analysed twenty-seven mineral soda alumina (m-Na-Al) glass and eighty-seven mineral potassium glass beads unearthed in different provinces in China through LA-ICP-MS. The trace element analysis indicates that m-Na-Al glass and most of the potash glass unearthed from Guangxi were presumably produced somewhere in Southeast Asia and exported through the Maritime Silk Road. M-Na-Al glass in Henan and the rest of the potash glasses from other regions in China were probably produced in southern India or Sri Lanka through the North and Southwest Silk Roads. The connection between the spread of Indo-Pacific beads and Buddhism is discussed.

In summary, this DPhil project shows detailed research on various types of glass in China through multiple methods, and the conclusion contributed by this thesis can provide new ideas for archaeologists to rebuild the Eurasian Steppe Road. The future archaeological and archaeological science research on glasses from Central Asia will certainly provide a strong link on how glasses were traded from the Mediterranean to China.

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### **Statement of authorship**

We hereby give permission to Qian Ma, to use our joint work (cited below) as contribution towards his DPhil (PhD) thesis in Archaeological Science, to be submitted for examination at the University of Oxford.

Ma, Q., Braekmans, D., Shortland, A., Pollard, A.M., 2021. The Production and Composition of Chinese Lead-Barium Glass through Experimental Laboratory Replication. *Journal of Non-Crystalline Solids* 551, 120409.

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We confirm that to the best of our knowledge, the author contribution statement below is accurate and that as the first author, Qian Ma's contribution towards the work is greater than that of any other co-author.

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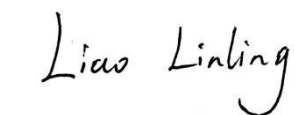
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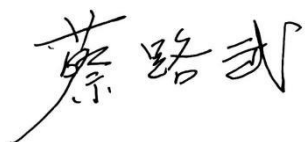
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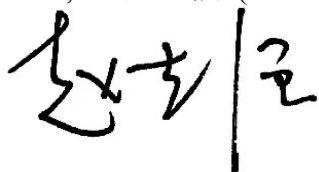
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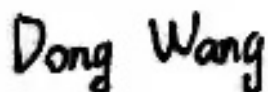
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# Chapter 1 Introduction

## 1.1 The origin of Chinese glass

There is no absolute answer to the question of what was the origin of Chinese glass; current views can be summarised in two main hypotheses. Some scholars consider that the technology of Chinese glass making was introduced from western Asia, while others believe that the Chinese invented glass making on their own. These two hypotheses will be explored below.

Glazed ceramic stoneware production began in 16<sup>th</sup>- 11<sup>th</sup> century BC in China. The firing temperature for stoneware could reach 1100-1200 degrees C, with wood ash used as the fluxing agent for the glaze (Chen *et al.*, 1999). The wood ash is a by-product in the wood-fired kiln that adheres to the surface of the pottery to form a wood ash glaze. The firing temperature could reach such a temperature due to the invention of the updraft kiln, while the bonfire was commonly used for producing earthenware before the Shang Dynasty (~1600 – 1046 BC: Gan, 2016, p. 253). The updraft kiln was built directly into the earth and consisted of a hearth, burner, flame path and chamber. In an updraft kiln, the flame path is above the hearth and the chamber is either in front of or above the hearth. The bottom of the chamber is circular or square and the diameter or width ranges from 1 to 1.5 m, the chamber gradually narrows to the top and is capped with a chimney (Gu, 2007). Sometimes a drop of wood ash glaze flowed down from the stoneware during the firing process to produce a glass drop. Gan *et al.* (2007) analysed

some drops of glaze unearthed from Boluo, Guangzhou Province, and they considered that these drops of glaze were the prototype of Chinese glass, and also that these glaze drops were rare and valuable, which were only consumed by the nobles as a decorative glass inlaid on the sword. Yet, the chemical composition of those glaze drops is completely different from the typical wood ash glass, as the  $K_2O$  is lower than 3% and both  $Al_2O_3$  and  $CaO$  are over 14%.

Hou (1989) suggested that the decorative glass drop on a sword unearthed from Jiangling Wangshanqiao M1 Chu Mausoleum (496 – 464 BC) was an example of wood ash glass through proton-induced X-ray emission (PIXE) qualitative analysis, and its spectrum was similar to the glaze on the early stoneware. Gan *et al.* (2007) suggested that wood ash was not used in the production of glasses from contemporary Egypt and the Mediterranean, which in their view proved that this decorative glass was produced in China. Therefore, they believed that Chinese glass was evolved from stoneware glazes made using wood ash. This conclusion is untenable from my understanding. Through the qualitative analysis, it might be difficult to differentiate between wood ash glass and potash glass if the  $MgO$  and  $Na_2O$  concentrations remain unknown. The glass drop on the sword could be a mineral potassium glass bead rather than wood ash glass, as potash glass was commonly discovered in China during the mid-first millennium BC. Moreover, the drops of wood ash glaze are rarely found in China (except for the two analysed by Gan *et al.* (2007) as shown above), whereas natron glass, potash glass and plant ash glass were circulating in China from the Eastern Zhou Dynasty (770 – 256 BC). Therefore, it is open

to question whether Chinese glass evolved from stoneware glaze.

The earliest discovered glass eye beads were from Ancient Egypt, in the 18<sup>th</sup> Dynasty (1550 – 1307 BC: Beck, 1928). In fact, some clay eye beads can be dated back to the 4<sup>th</sup> Dynasty (2575 – 2465 BC Lucas and Harris, 1963). In Central China, an eye bead was found in Gushihou Gudui M1 Mausoleum (504 BC), the chemical composition of which showed that the eye bead is natron glass (Gan *et al.*, 2007). Some types of eye beads were produced in China (discussed in Chapter 2.3.3), and their glass-working technology was certainly influenced by the Egyptian eye bead glass. Therefore, it is unreasonable to consider that the Chinese invented eye beads in isolation. According to the typology and compositional analysis, the eye beads unearthed from the Wupu site (Xinjiang) and the Tomb of Marquis Yi of State Zeng were identical to the eye beads found in the Black Sea region during the Warring States period (475 – 221 BC: Lü *et al.*, 2021). Lü *et al.* (2021) suggested that some of natron glasses found in Italy, Greece, Kyrgyzstan, Georgia, Russia and Xinjiang during the 1<sup>st</sup> millennium BC were produced on the Syro-Palestinian coast, and transported via the Black Sea.

## **1.2 The impact of the Silk Road**

### **1.2.1 The definition of the Silk Road**

The concept of ‘Seidenstraße’ or ‘Silk Road’ was first proposed by Ferdinand von Richthofen in 1877. The original definition of Silk Road was the trade route from China to India via

Transoxiana from 114 BC to AD 127 (von Richthofen, 1882). Richthofen (1882) believed that the beginning of the Silk Road was after *Zhang Qian's* 张骞 second journey to the Central Asian countries, as *Zhang Qian* proposed that there was no lacquer or silk in these regions. Herrmann (1910) redefined the concept of the Silk Road and suggested that the Silk Road should be extended to the trade route from China to Syria in the far west, as Chinese silk was transported to the Roman Empire shortly after *Zhang Qian* reopened the trade between the Han Empire and the Central Asian region. In 65 BC, Pompeio led the Roman Expeditionary Force which conquered the eastern coast of the Mediterranean, and then Syria was absorbed into the territory of the Roman Empire. Therefore, Herman (1910) proposed that cultural exchanges along the Silk Road were not limited to China, Central Asia and India, but also existed between China and Rome. As shown in Figure 1.1, the Silk Road is a complex trade network comprised of multiple maritime and land routes.

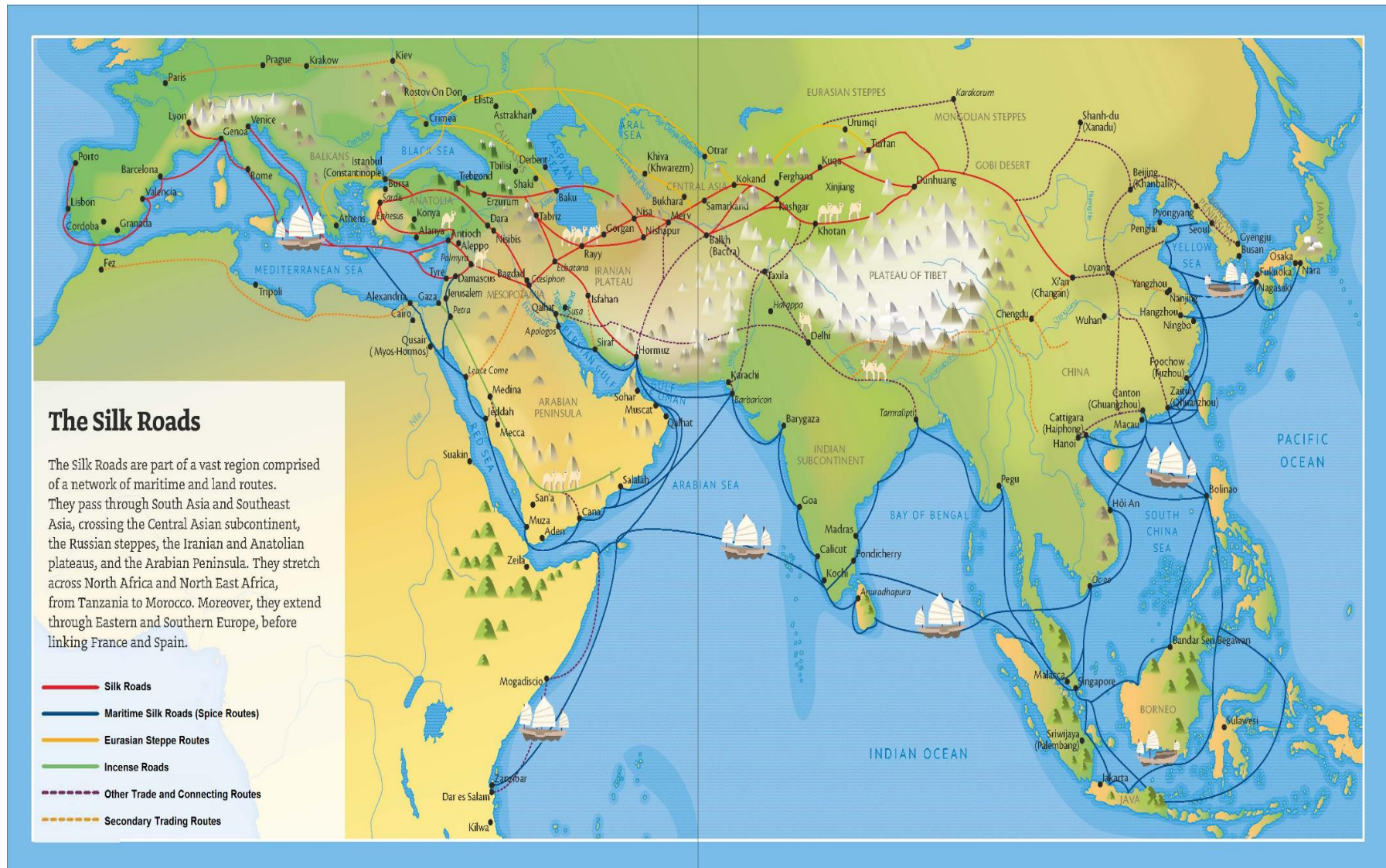


Figure 1.1 The Silk Roads (<https://en.unesco.org/silkroad/about-silk-roads>).

### 1.2.2 The origins of the Silk Road

Due to the low-taxation policy starting from the Early Western Han Dynasty (202 BC – AD 9), people were wealthy both spiritually and materially by the time of Emperor *Wu Di* 汉武帝 (140 – 87 BC). According to the *Han Shu- Shi Huo Zhi* (chronicles of foods and goods) 汉书-食货志 (edited by *Ban Gu* 班固 in AD 105; Ban, 2007), ‘The strings of coins in the national treasury rotted as they were stored for a long time, and the total amount of those coins was difficult to count; The grain stock in the national warehouse overflowed and partly rotted’. When capital has accumulated to a certain level, it is necessary to find a way out. As the development of the domestic market in the Han Empire reached its limit, it was imperative to open up foreign markets.

The Xiongnu were one of the powerful groups of nomads around ancient China, and they mainly occupied the Mongolian Plateau during the Han and Qin period. The use of iron tools boosted their agricultural productivity, which caused the rise of slavery in the 3<sup>rd</sup> century BC (Zheng, 2016, p. 57). The regime was therefore ruled by slave owners and nobles, and the supreme leader of the Xiongnu was called ‘Chan Yu’. As documented in *Han Shu- Biography of the Xiongnu* 汉书-匈奴传 (Ban, 2007), Chan Yu - Mo Du (? – 174 BC) broke the peace treaty that had been signed with the Han Empire and invaded ‘He Nan’ (the southern Ordos city of Hetao, Inner Mongolia) in 177 – 176 BC. He punished his official - King Youxian who advocated peace with the Han Empire and commanded him to attack the Yuezhi (a nomadic group in the western

part of Chinese Gansu province). The Yuezhi were driven from the Hexi Corridor to the northern region of the Tianshan Mountains. The Xiongnu then fully occupied the western part of the Hexi Corridor, and its force expanded into regions in the north and south of the Tianshan Mountains. Since the Xiongnu ruled most of the territories of the Tianshan Mountains, they adopted a series of new policies, including levying land and commercial taxes. These new policies influenced the trade between the Han Empire and the Central Asian regions, especially acting against Emperor *Wu Di* 's ambition to explore the foreign markets. Emperor *Wu Di* followed the policy of making peace with the Xiongnu which was originally designated by Emperor *Wen Di* 汉文帝 (203 – 157 BC) and Emperor *Jing Di* 汉景帝 (188 – 141 BC) in his early years. Yet, Emperor *Wu Di* was dissatisfied with the peace policy and he believed his Empire was capable of fighting against the Xiongnu. The war between the Han Empire and the Xiongnu started in 129 BC and lasted for 30 years, with the aim of breaking the Xiongnu's long-term occupation of the main trade routes between the Han Empire and the West. According to the *Han Shu- Biography of the Xiongnu* 汉书- 匈奴传 (Ban, 2007), there were three major battles:

1): In 127 BC, General *Wei Qing* 卫青 retook the Hetao Plain (currently alluvial plains along the Yellow River in Inner Mongolia Autonomous Region and Ningxia Hui Autonomous Region), which lifted the Xiongnu's threat to the Capital Chang'an (Xi'an). Shuofang County was established here to consolidate border defences.

2): In 121 BC, General *Huo Qubing* 霍去病 led troops and entered the Xiongnu's



territory from the west for more than 500 km. King Huxie killed King Xiutu and surrendered to the Han Empire with over forty thousand people. Emperor *Wu Di* later set up several counties (i.e., Jiuquan, Wuwei, Zhangye, and Dunhuang) which used to be occupied by King Hunxie and King Xiutu. This opened up a direct route between the Central Plains and the Western Regions.

3): In 119 BC, Emperor *Wu Di* commanded *Wei Qing* and *Huo Qubing* to lead troops in Dingxiang County (southeast of Hohhot, Inner Mongolia) and Dai County (Yu County, Hebei) respectively to attack the Chan Yu in Mobei (north of the Gobi Desert on the Mongolian Plateau). *Wei Qing* crossed the Gobi Desert and reached the Zhaoxin City (north of the Hangai Mountains in Mongolia) and wiped out more than nineteen thousand enemies. *Huo Qubing* pursued and attacked King Zuoxian to the Langjuxu Mountain (Kent Mountain, Mongolia) and captured more than seventy-four thousand enemies. The Han Empire thereby took over the Hexi Corridor.

Emperor *Wu Di* was very aware of the increasingly acute conflicts between the Western Regions and the Xiongnu. Therefore, he planned to form an alliance with the Yuezhi for a pincer attack on the Xiongnu. Indeed, Emperor *Wu Di* commanded officer *Zhang Qian* to investigate the past trade routes between China and the west. He also asked *Zhang Qian* to persuade the western regions to form an alliance to fight against the Xiongnu. According to the *Han Shu- Biography of Zhang Qian* 汉书- 张骞传 (Ban, 2007), *Zhang Qian* failed to persuade Yuezhi to ally with the Han Empire during his

first journey to the west in 139 BC. During *Zhang Qian*'s second journey to the west in 116 BC, he again failed to persuade *Wusun* 乌孙 people (a nomadic group in the northern piedmonts of Tianshan Mountains). However, *Wusun* sent envoys with gifts and accompanied *Zhang Qian* back to Chang'an 115 BC. The envoy witnessed the prosperity of the Han Empire and reported back to *Wusun*. *Wusun* was therefore willing to make peace with the Han Empire. During the *Yuan Feng* 元封 period (110 – 105 BC), Princess *Liu Xijun* 刘细君, daughter of King Jiangdu of the Han clan, married the King of *Wusun*.

As documented in *Shi Ji- Biographies of Dayuan* 史记- 大宛列传 (edited by *Sima Qian* 司马迁 in AD 104; Sima, 2016), when *Zhang Qian* arrived in Bactria (modern Afghanistan) in 122 BC, he noticed that Shu Cloth (made by bamboo fibre) and Bamboo stick produced in the Shu State (modern Sichuan) were circulating here. The local people told him that these products were traded by merchants from Sindu (India), and Sindu merchants imported these products from Shu merchants. There was a potential trade route from Sichuan to India via Yunnan controlled by minorities in Yunnan (i.e., Dian, Gouding, Ailao), and *Zhang Qian* persuaded Emperor *Wu Di* to conquer these minorities, to take control of the Shu-Sindu road (Southwest Silk Road). Yet, after over ten years of the battle between the Han Empire and minorities in Yunnan, *Wu Di* only conquered the Dian people. In AD 69, the Ailao people surrendered to the Han Empire, and the Eastern Han Empire (AD 25 – 220) was therefore able to build

economic and cultural exchanges with Myanmar, and the merchants were allowed to enter Afghanistan through Myanmar and India. Since then, the exploration of the Southwest Silk Road started by Emperor *Wu Di* was finally completed.

According to the documentation in *Hou Han Shu- Biography of the Western Regions* 后汉书-西域传 (edited by *Fan Ye* 范晔 in AD 445: Fan, 2007), in the 9<sup>th</sup> year of the *Yan Xi* 延熹 period (AD 166), a year after the Fifth Emperor - Marcus Aurelius - defeated the Parthian Empire, envoys from the Roman Empire paid tribute to the Han Empire by the Maritime Silk Road via Annam (Vietnam). It is possible that the Roman Empire tried to form an alliance with the Han Empire to attack the Parthian Empire, yet there was no record of this matter in Roman literature (Zheng, 2016, p. 105). *Hou Han Shu- Biography of the Western Regions* 后汉书-西域传 recorded that the land Silk Road was blocked due to the rebellion in the western regions during the Eastern Han Dynasty (AD 25 – 220), and the trade from the Han Empire to the Roman Empire was subsequently through the Maritime Silk Road via India (Fan, 2007). The sailing routes from *Hepu* 合浦 (a port in Guangxi) to Southeast Asia were documented in *Han Shu- Geography* 汉书-地理志 (Ban, 2007): ‘The distance between *Hepu* to *Duyuan State* 都元国 (inconclusive, east coast of Malay Peninsula or Isthmus of Kra in Thailand) was five months by ship; the ship could reach *Yilumei State* 邑卢没国 (inconclusive, South Thailand or Thaton in Myanmar) by sailing for another four months; after over twenty-days of sailing the ship could further reach *Chenli State* 谿离国 (inconclusive,

South Myanmar or Prome)’.

### 1.2.3 The trade along the Silk Road

The silk trade played a significant role in this exchange network, however, the silk trade was not the main trade from the beginning. Trans-Eurasian trade preceded the date for the origins of the Silk Roads by at least two millennia, and the trade took place almost entirely through the mediation of pastoralist communities living in the Central Asia (Christian, 2000). There were a variety of commodities circulated along the Eurasian Steppe Route. The main commodities that nomads required from the sedentary societies were agricultural and handicraft products, while the sedentary societies experienced a need for livestock (e.g., horses used in transportation and war) and related secondary products such as wool and hides (Khazanov, 2019). The Shang and Zhou Empires in the Chinese Central Plains expanded to the north in search of horses and to the south in search of metals (Rawson *et al.*, 2020). The Scythian aristocracy paid tribute, such as grain and slaves to the dependent cultivators on the Greek markets, and received refined artwork, jewellery, pottery and wine in return (Khazanov, 2019). Nomads carved out the trade route across Eurasia, and their merchandise included ‘*copper, tin, and turquoise from Iran, gold from the Altai Mountains of Mongolia, lapis lazuli and rubies from Afghanistan, furs from Siberia, incense from Arabia, cottons from India, and their own products like wool, hides, and livestock*’ (Franck and Brownstone, 1986, p. 39). Hellenic aristocracy showed an interest in Chinese silk clothes from the 6<sup>th</sup> century BC to the 3<sup>rd</sup> century BC (Gan 2006). As introduced from the previous section, the

commodity circulation between China and Europe was almost suspended during the 1<sup>st</sup> century BC, due to the wars that Xiongnu people started with neighbouring countries and the robbery of trade caravans in Middle Asia (Liu, 2012). *Zhang Qian's* two journeys in 139 BC and 119 BC started the prosperous age of commodity circulation along the Northwest (Desert) Silk Road, as Egyptians and Romans began purchasing silk products from the Parthians, which had been imported from the Han Empire (Liu, 2012).

After the Han Dynasty, China entered an era of warfare, which seriously affected the trade between China and other areas. However, this situation ended when the Tang Empire reunited China, initiating the second prosperous age of the Silk Road. The Tang Dynasty (AD 618 – 907) played an indispensable role in Chinese history, taking a leading position in economics, politics, culture, and trade in the world during that period. The categories of products traveling along the Silk Road became more diverse, and included glass products. The spread of the Islamic religion and culture, especially, brought in Islamic glass. Some of the most exquisite Islamic glass products known from this period were excavated at the Famen Temple 法门寺 in Shaanxi, China (Li *et al.*, 2016).

Four great empires contributed to the development of the Silk Road in the 1<sup>st</sup> to 5<sup>th</sup> centuries AD, which were the Eastern Han Dynasty of East Asia, the Roman Empire (27 BC – AD 476) of Europe, the Parthian Empire (247 BC – AD 224) of Western Asia

and the Kushan Empire (AD 30 – 375) of Middle Asia. As mentioned above, the ambassador of the Han Dynasty, *Zhang Qian* changed the indirect contact between the Chinese, Indian, West Asian, and Greco-Roman cultures. These four empires guaranteed the unimpeded use of the Silk Road and promoted the exchange between China and the rest of the world. For example, the main duty of Protectorate of the Western Regions 西域都护府 which was set up by the Han Empire in Xinjiang was to guard the border and coordinate the contradictions and disputes between the countries of the neighbouring regions, in order to secure the Silk Road trade. After the Eastern Han Dynasty, glass products from the Roman and Sasanian Empires were imported into China by the Great Yuezhi People. The Southern (Sea) route was opened up after the Eastern Han Dynasty, when glass products were imported to the south coast of China and transported to Central China (Zhong, 2015).

Various types of imported glass artefacts have been unearthed in China dating to the first millennium BC and later. A map of the find locations of different types of beads, including the beads introduced and analysed in this thesis, is shown in Figure 1.2. An (1996) noticed that the eye beads discovered from Gilan (Iran) were typologically identical to the eye beads discovered in China during the Late Spring and Autumn Period (770 – 476 BC), and she suggested that Hurrians, who lived in Anatolia, Syria and Northern Mesopotamia, introduced eye beads into the Central Plains of China from West Asia through the Eurasian steppe via Xinjiang in the middle of the first millennium BC. Based on the archaeological findings of eye beads, the transfer of eye bead working

technique was likely after the Spring and Autumn period. It is difficult to determine exactly when this working technique was transferred to China, yet, the lead-barium glass eye beads that occurred during the Warring States period suggests that Chinese craftsmen had mastered the production of eye beads by then. For instance, a lead-barium glass eye bead analysed in this thesis dating to the Late Warring States period unearthed in Jiang Ling Jiu Dian Site, Hubei (discussed in Chapter 5).

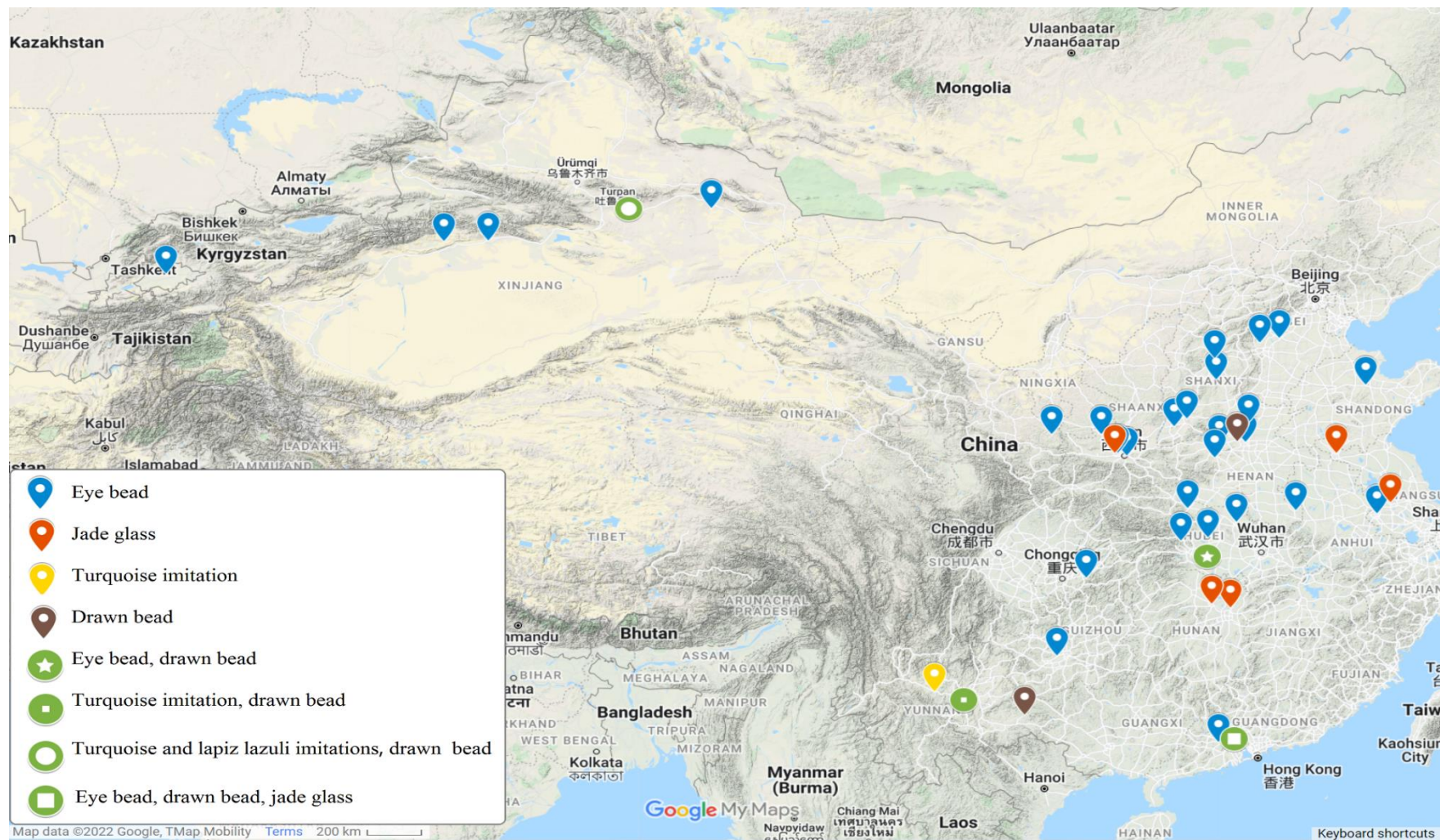


Figure 1.2 A map of the find locations for all beads mentioned in this thesis.



The moulding and engraving techniques were applied to glass working in the early Han Dynasty, which was time-consuming. Therefore, glass products such as ear-cups, bowls and plates were consumed only by the nobility. For example, 16 lead-barium glass cups were excavated at the Tomb of the Chu King of the Western Han Dynasty (202 BC – AD 8) in Beidong Mountain, Xuzhou; two lead-barium glass ear-cups and one lead-barium glass plate were excavated at the Tomb of Jing King of Western Han Dynasty in Mancheng, Hebei (An, 2000a, p. 36). As mentioned in the previous section, envoys from the Roman Empire paid tribute to the Han Empire by the Maritime Silk Road via Annam (Vietnam) in AD166, possibly to ally with the Han Empire to attack the Parthian Empire. Trade between the Han Empire and the Roman Empire may have been established as a result. Blown glassware as merchandise or tribute were imported into China during the 2<sup>nd</sup> century AD, such as a Roman blown glass unearthed at a Eastern Han tomb in Luoyang (An, 2000a, p. 64). However, the spread of technology was slower than that of commodity circulation, as the immigration of craftsmen was the main mechanism for technology to spread. The glass-blowing technique was introduced into China along the Silk Road during the Northern Wei (AD 386 – 534), which is documented in the book *Wei Shu- Darouzhi* 魏书 大月氏 (edited by Wei Shou 魏收 in AD 555: Wei, 1997). It states that West Asian merchants brought the glass blowing technique into China, and the first glass blowing workshop was set up during Emperor Shizu's reign (AD 424 – 428) at Pingcheng (Datong), the capital of the Northern Wei. Blown glass unearthed from the tower base in Ding County, Hebei, Northern Wei Dynasty with identifiable Chinese aesthetic preferences (e.g., gourd shape) is solid

evidence that the blowing technique transferred into China during this period (An, 2000a, p. 91).

The Southwest Silk Road originated before the Qin period (221 – 207 BC). Arikamedu, as one of the most famous archaeological sites located on the south-eastern coast of India, is considered to be a glass-working centre from 200 BC to AD 200 and is well-known for its drawing technique to make Indo-Pacific glass bead (Dussubieux *et al.*, 2010; Pion and Gratuze, 2016). As documented in ‘Shi Ji- Biographies of Nanyi’ 史记西南夷列传 (Sima, 2016), there were two routes from Sichuan Province to Yunnan Province which were named the 五尺道 Wuchi Road and the 零关道 Lingguan Road; the route from Yunnan Province to Myanmar was called the 永昌道 Yongchang Road; the route from Myanmar to India was called the 缅印道 Mianyin Road (Duan, 2014). Indo-Pacific glass beads were likely merchandise along the Silk Roads. Yet, as Indo-Pacific glass beads and Buddhism appeared in China contemporaneously during the Han period, it is worth further exploring the possibility of whether drawn beads were related to the spread of Buddhism. For instance, in Puluo county (part of Khotan State in the past), Buddha statues have been unearthed at urban sites, and different colours of monochrome glass beads have been unearthed at contemporaneous tomb sites dating to the Han period (Li, 1981; Yu, 2018). Details of this discussion can be found in Chapter 6. Drawn beads were only discovered in potash glass and m-Na-Al glass originating from South and Southeast Asia, and there is no evidence that glass drawing technique was used on other types of glasses in China. There is also a debate

whether potash glass can be produced in China, thus, it is difficult to determine whether the glass drawing technique was transferred into China with the spread of Buddhism.

### 1.2.4 Religion spread along the Silk Road

From the Han to the Tang Dynasties, a variety of western religions were spread into China through the Silk Road, including Buddhism, Zoroastrianism, Manichaeism, Nestorianism and Islam. Buddhism was founded by Siddharta Gautama in ancient India sometime between the 6<sup>th</sup> and 4<sup>th</sup> centuries BC. Buddhism was spread to the Central Plains of China during the Eastern Han Dynasty. As recorded in *Mou Zi Li Huo Lun* 牟子理惑论 (edited by Mou Zi 牟子 during the Late East Han Dynasty: Mou, 2020), Emperor Ming (AD 28 – 75) sent thirteen envoys to transcribe the *Sutra of the Forty-two Sections* 四十二章经 in Yuezhi through the North Land (Desert) Silk Road. In AD 68, the first Buddhist temple, the White Horse Temple, was built in Luoyang (Henan Province) to collect the Sutra transcribed from Yuezhi. Some archaeological findings suggest that Buddhism might also have been introduced in China through the Southwest and Maritime Silk Roads. A pottery figure of Buddha was unearthed in M2 cliff tomb in Zhaotong dating to the Eastern Han period (He, 2019, p. 102), which could be one of the first pieces of evidence of Buddhist spread to Yunnan province. Some of the cliff stone statues on Kongwang Mountain dating to the late Eastern Han Dynasty (Lianyungang, Jiangsu province) were considered to be Buddha status (Yu and Xin, 1981). Chinese Buddhism reached its peak in the Tang Dynasty, and almost all Buddhist scriptures were translated into Chinese. As recorded in the *Old Book of Tang* 旧唐书

(edited by *Liu Xu* 刘洵 in AD 945: Liu, 1975), Chinese Buddhist monk *Xuan Zang* 玄奘 brought back 657 Buddhist scriptures from India in AD 629 – 645 and managed to translate 75 of them. Buddhism originated in India, and was gradually localized in China during the Tang Dynasty. Ten Buddhist sects headed by the Zen sect emerged during the Tang Dynasty. There were a large population of Buddhist believers during this period, including some of the emperors. Emperors *Tai Zong* 唐太宗 (AD 598 – 649) and *Gao Zong* 唐高宗 (AD 628 – 683) both wrote prefaces for the translation of Buddhist scriptures. The numerical increase of Buddhists and monks eventually led to a reduction of tax revenue (Buddhist monks paid no tax), thus, Emperor *Wu Zong* decreed to exterminate Buddhism in the 5<sup>th</sup> year of the *Hui Chang* 会昌 period (AD 845). More than 4,600 Buddhist temples were demolished, and over 260,000 monks and nuns were forced to resume secular lives.

Zoroastrianism, founded by the prophet Zoroaster, was one of the oldest religions. It was the state religion of the ancient Iranian empires over a thousand years from roughly 600 BC to AD 650, but it fell with the Muslim conquest of Persia and the resulting persecution of the Zoroastrians in the 7<sup>th</sup> century AD (Hourani, 1947, p. 87). Its teachings certainly have an impact on later religions, such as Manichaeism, Christianity and Islam (Boyce, 2001, p. 29). Zoroastrianism was introduced into China in the Southern and Northern Dynasties (AD 420 – 589), and the Northern Wei Dynasty named it '*Hu Tian* 胡天' (Zheng, 2016, p. 192). In the early Tang Dynasty, Zoroastrian monasteries were built in the place where the Persians lived, including three in the

northwest of Chang'an. Zoroastrianism was not widely spread in China due to the limited missions during the Tang Dynasty, and there was no translation of their scriptures. Zoroastrianism, Nestorianism, and Manichaeism were banned at the same time during the period of Huichang Persecution of Buddhism.

Manichaeism was founded in the 3<sup>rd</sup> century AD by the Parthian prophet Mani, however, it was not recognised by the Sasanian Empire. When Mani was executed, his followers fled and spread Manichaeism into Central Asia. The religion partly absorbed some ideas from Buddhism, Christianity, and Zoroastrianism to form its own doctrine. According to the *Fo Zu Tong Ji* - Biography of the Buddhism 佛祖统纪 (edited by Zhi Pan 志磐 in AD 1269: Zhi, 2012), Manichaeism was introduced to the Tang Empire in the 1<sup>st</sup> year of the *Yan Zai* 延载 period (AD 694). Persian missionaries led by Fuduo brought two scriptures into the Tang Empire and built Manichaeism monasteries in Chang'an and Luoyang. Manichaeism was the state religion of the Uighur in Xinjiang. Due to a good relationship between the Tang Empire and the Uighurs, Manichaeism was allowed to be well-developed in China. During the *An Lushan Rebellion* 安史之乱 (AD 755 – 763), the Tang Empire sought help from the Uighur to quell the rebellion. However, as documented in *Old Book of Tang - Biography of Emperor Wu Zong* 旧唐书-武宗本纪 (Liu, 1975), due to the Huichang Persecution of Buddhism by Emperor *Wu Zong* 唐武宗 (AD 814 – 846) in AD 842, 72 female Manichaeans in Chang'an were killed and their properties were confiscated.

Nestorianism is one of the sects in Christianity that originated from Syria, and it was founded by Nestorius in the 4<sup>th</sup> century AD. Nestorianism was excluded by the orthodox Christian doctrine due to its different cognition of the Holy Spirit, and Nestorius himself was expelled by the Eastern Roman Empire. Nestorianism was later developed and spread in Asia with 25 archdioceses, and the 11<sup>th</sup> archdiocese was set up in China during the Tang Dynasty (Zheng, 2016, p. 211). According to the '*Nestorian Stele*' 大秦景教流行中国碑 (in Forest of Stone Stelae Museum in Xi'an), in the 9<sup>th</sup> year of the Zhen Guan 贞观 period (AD 635), Alopen Abraham arrived in Chang'an and preached Nestorianism. As Nestorianism originated from Persia, its monasteries were originally referred to as 'Persian monasteries' in China, and the monks were called 'Persian monks'. In the 4<sup>th</sup> year of the *Tian Bao* 天宝 period (AD 745), Emperor *Xuan Zong* 唐玄宗 (AD 685 – 762) decreed to rename the 'Persian monasteries' to 'Daqin (Roman) monasteries'.

Islam was founded by Muhammad in the early 7<sup>th</sup> century and is one of the three largest religions in the world. According to the *Old Book of Tang- Biography of Emperor Gaozong* 旧唐书-高宗纪 (Liu, 1975), Da Shi (Arab Empire) first sent envoys to the Tang Empire in the 2<sup>nd</sup> year of the *Yong Hui* 永徽 period (AD 651). In the early *Kai Yuan* 开元 period (AD 713 – 741), Islam was introduced to the Tang Empire with the envoys from Da Shi. During the *An Lushan Rebellion*, the Tang Empire borrowed Da Shi troops to quell the rebellion, and those people later settled in China. Islam might have been introduced in the Tang Empire both through the Maritime and Land Silk

Roads (Zheng, 2016, p. 192). The introduction of Islam into China has a direct and important influence on the formation of the Hui minority. In the early 13<sup>th</sup> century AD, Genghis Khan's westward expedition caused a large number of Muslims from Central Asia to move eastward and come to China. They settled and intermarried with various ethnic groups in China, and their offspring were referred as to the Hui minority.

### **1.3 Thesis Structure and Objectives**

The priority of this research is to evaluate if the Chinese mastered primary glass production during the 1<sup>st</sup> millennium BC. If so, where were the sources of raw materials to produce the glass and how were the raw materials processed; if not, the source of the raw glass needs to be explored. During the Warring States and the Han periods, various types of glass working technologies were observed. It is important to further examine the use of glass objects in various social, economic and ritual contexts. In addition, the use of eye beads and jade glass disappeared after the Han Dynasty, thus, related political and economic reasons need to be discussed.

Chapter 2 first reviews the chronology of ancient glass in China from the Zhou Dynasty (1046 – 256 BC) to the Han Dynasty; then the glass production with various analytical techniques is introduced. The glasses analysed in this research were unearthed from five provinces in China. The background of the sample sites is introduced in Chapter 3, and analysis of samples can be found in Chapters 5 and 6. Chapters 4 – 7 serve specific goals respectively to refine the objective of this thesis.

The glass replication experiments in Chapter 4 aims to test if lead-barium glass was simply a mixture of lead, barium and silica sources, or if it can be produced by mixing natron glass and lead-barium minerals. This chapter focuses on the interpretation of high sodium concentration observed in lead-barium glass. In Chapter 5, through laser-ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS) analysis, 50 glass and faience samples dating to the Warring States and the Han periods from five provinces in China successfully generated 104 data sets. To source the origin of these glass samples, their trace elements were used to compare with 362 published data of glass samples from the Mediterranean and Mesopotamia and vitreous material from China dating to the Late Bronze age and Iron Age. In this chapter, a piece of code is produced to perform 3D kernel density estimation on four variables (i.e., four-element concentrations) in a tetrahedron plot, and Maximum Mean Discrepancy is used to explore the similarity between different groups of glasses. The trace elements associated with the silica raw materials are used to track the glass primary production. The analysis of other trace elements related to colourants or opacifiers are less focused in this study, as they could be added during glass primary or secondary production. This assumption also applies to Chapter 6.

Chapter 6 switches the focus from lead-barium glass to potash and mineral soda alumina glasses. One hundred and eight m-Na-Al and potash glass samples dating to the Warring States and the Han periods from four provinces in China were analysed



through LA-ICP-MS. This chapter aims to use trace element analysis to source their origins, specifically, to see if glasses from India (South Asia) and Southeast Asia can be differentiated. Furthermore, as most glass beads are defined as monochrome drawn beads, their relationship with the spread of Buddhism is worth exploring.

Chapter 7 summarises the *chaîne opératoire* of glasses found in China during the 1<sup>st</sup> millennium BC, that is to say, a) where were the raw materials used to produce these glasses, b) how they were produced, c) how the use of glass objects was adapted to various social, economic and ritual contexts and d) why some types of glasses were discontinued. In Chapter 8, the implications of this research project have been concluded, and further research related to glass in China has been suggested.

In summary, the research aims can be summarised as:

- 1) The replication experiment aims to explore the different possibilities of how lead-barium glass could have been produced by testing a series of probable recipes with varying proportions of each raw material.
- 2) The trace element analysis of lead-barium glass aims to test the hypothesis that lead and barium minerals were added to imported glass during the secondary production process, and, if this proves plausible, to find the chemical relationships between Chinese lead-barium glass and western soda-lime-silica glass.
- 3) The trace element analysis of potash glass and m-Na-Al glass aims to distinguish their possible origins and discuss the potential link between the glass trade and the

early spread of Buddhism in China.

- 4) Through the scientific analysis and the review of the historical context, the *chaîne opératoire* of glasses found in China during the Warring States and the Han periods needs to be assessed.

## **Chapter 2 The history of glass in China**

### **2.1 Chronology of ancient glass in China**

#### **2.1.1 The development of Eye beads**

##### **The use of eye beads in Egypt and China**

There is no doubt that the origin of the glass eye bead was in Egypt. As mentioned above, the earliest glass eye bead dates to the 18<sup>th</sup> Dynasty of ancient Egypt (Beck, 1928). It was not until the second half of the 15<sup>th</sup> or the first half of 14<sup>th</sup> century BC that eye beads appeared in Western Asia (Spaer, 2001, p. 78). The eye bead was commonly embedded into the coffin, mummy masks or small statues, which related to a concept of the 'Evil Eye' (Lucas and Harris, 1963). This originated from an old and widespread belief in Western Asia, North Africa and Europe, in which people believed that the power of the 'Evil Eye' in certain individuals can cause death and destroy inanimate objects. The first glance by the 'Evil Eye' creates the strongest power, therefore, the function of the eye bead is to absorb this power and let people deal with the subsequent relatively weaker damage. Not only did people wear eye beads, but they were also used for animals and inanimate objects, such as farm tools (Galt, 1982; Hardie, 1923; Sode, 1995). Eye beads prevailed across the east coast of the Mediterranean, the Black Sea and the Caspian Sea coasts during the mid-1<sup>st</sup> millennium BC, and Gilan in Iran was the one of the secondary production centres for eye beads (An, 1996).

When western eye beads were first imported into Central China during the Spring and

Autumn period, the number of eye beads was limited due to the need for long-distance transport along the Silk Road. Since this type of object was rare in China, the high price of imported eye beads means that they were only consumed by the nobility (Cai, 2017; Xia *et al.*, 2014; Yu and Chen, 2011; Zhao, 2012). For instance, eye beads were excavated in Henan Gushihou Gudui M1 Tomb: the owner of the tomb was the wife of *Fuchai* 夫差 (King of the Wu State, 528 – 473 BC), the sister of *Jinggong* 景公 (King of the Song state ? – 469 BC: Xiao, 2004). A Pyramid Eye Bead was discovered in M1 Langjiazhuang Tomb, and the owner was the minister of the Qi State during the Eastern Zhou Dynasty (Shandong Museum, 1977). Eye beads in China could either be merchandise or tribute from western envoys. ‘*Guan Zi*’ 管子 written by *Guan Zhong* 管仲 (723 – 645 BC) during the Spring and Autumn period documents that the elite would have paid a high price for eye beads, such as the King, Queen and Prince of the Jingjue State (a small country near the Niya River along the Silk Road). Therefore, the eye bead more likely became a symbol of social status and the wealth among the nobility.

### **The chronological and spatial distribution of eye beads in China**

Over one thousand eye beads have been excavated from eighteen provinces in China, and the majority of these eye beads date from the Western Zhou Dynasty (1046 – 771 BC) to the Eastern Han Dynasty (Figure 2.1: Zhao, 2016, p. 242, 2012). A few eye beads have been excavated from contexts dated to after the Han Dynasty, e.g., the Jin Dynasty (AD 266 – 420) Shaanxi Binxian Cemetery; the Six Dynasties (AD 222 – 589) Nanjing Fuguishan Cemetery; the Southern and Northern Dynasties Guizhou Qingzhen

Ludi M87 Cemetery; the Sui Dynasty (AD 581 – 618) Xi'an Dongjiao Buddhist Relics Cemetery, Dingzhou Jingzhi Temple Buddhist Relics Tower (An, 2002; Gao, 1960; Liu, 2007; Yang, 2004). However, they might be residual from former dynasties (An, 1996).



**Figure 2.1** Numbers of eye beads unearthed in different provinces of China from the Zhou to the Han period (Zhao, 2016, p. 242, 2012).

The eye beads first appeared in Xinjiang around the Mid- Western Zhou to the Mid- the Spring and Autumn Period. The earliest eye bead was found in Qunbake IM27 Tomb (Luntai county, Xinjiang: Cong and Chen, 1991). The tomb is located in the southern foothill of the Tianshan Mountain, on the northern edge of the Tarim Basin. According to <sup>14</sup>C dating with Oxcal calibration (Bronk Ramsey, 2001; Ramsey, 1995), the cemetery started from the Zhou Dynast. The eye bead was decorated with six double- ring ‘eyes’ (Figure 2.2-1). Baicheng ‘Kizil Tomb is located in the southern foothills of

the Tianshan Mountains and 'Kizil hill, and the main occupation period of this site was about 1000 – 600 BC according to the radiocarbon dating and the characteristics of funeral objects (Li *et al.*, 2014; Zhang *et al.*, 2006). Both eyes beads are decorated with two blue and white double-ring 'eyes' (Figure 2.2-2).



**Figure 2.2 1: Qunbake IM27 Tomb eye bead; 2: Kizil cemetery XJ-1E eye bead**  
(Cong and Chen, 1991; Li *et al.*, 2014; Yu and Chen, 2011).

It was not until the Late Spring and Autumn Period that the use of eye beads spread into the Central Plains of China. However, there are only a few eye beads excavated and they are mainly distributed in Northern China, especially in Shanxi and Henan provinces. The Jin State Zhao Qing Tomb was excavated in 1988, and it is located 15 km north of Taiyuan City, Shanxi Province. Over 3421 cultural relics were recovered including 13 eye beads (Hou and Qu, 1989). Multiple blue and white double-ring 'eyes' were embedded in a blue glass matrix (Figure 2.3-1). Niujiapo M7 Tomb (Changzhi county, Shanxi) was a Jin State tomb located in the northern Changzhi Basin and the southern foothills of the Taihang Mountains (Tao and Li, 1984). The decoration on the eye beads unearthed in this tomb was much simpler than that on the eye beads mentioned above (Figure 2.3-2). M1 Guishihou Gudui Tomb (Gushi county, Henan)

produced a number of beads, and one eye bead had a ring shape with the triple-ring ‘eyes’ (Figure 2.3-3: Xiao, 2004).

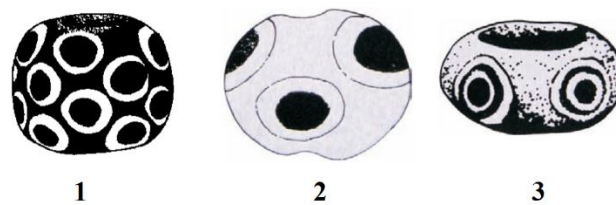


**Figure 2.3 1 Jin State Zhao Qing Tomb eye bead, 2 M7 Niujiapo Tomb eye bead, 3 M1 Guishihou Gudui Tomb eye bead (Hou and Qu, 1989; Tao and Li, 1984; Xiao, 2004; Yu and Chen, 2011).**

The majority of the eye beads found in China date to the Warring States Period (475 – 221 BC), and have been mainly recovered from the Chu State tombs which are distributed across Hunan and Hubei provinces. Figure 2.4 shows political divisions during the Warring States period (Shaughnessy, 2000, p. 27). Over 100 Chu State tombs have yielded eye beads in Changsha City, Hunan. The tomb of Marquis Yi of the Zeng State (Suizhou, Hubei) produced 173 eye beads (Figure 2.5: Tan, 2003; Wang, 2007). Zeng State was a tributary of the Chu State during the Early Warring States Period, and was soon conquered by the Chu State. Some of the eye beads were made from lead-barium faience during the Warring States period, and were Chinese imitations of western glass eye beads (examples can be found in Chapter 5: Appendix B).

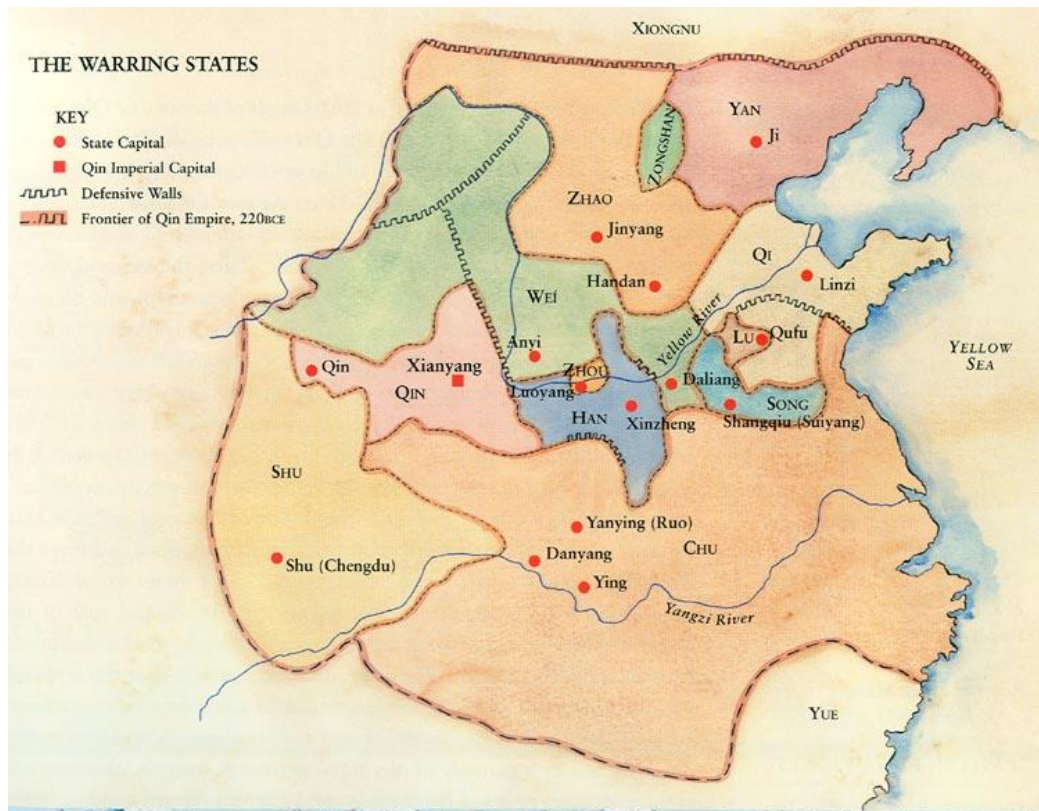


**Figure 2.4 State distribution during the Warring States period (Shaughnessy, 2000, p. 27).**



**Figure 2.5 Eye beads from the tomb of Marquis Yi of the Zeng State (Figure 5: Yu and Chen, 2011).**

During the Middle Warring States Period, due to the impact of the Chu culture, eye beads were also popular in the Qin State, Lu State, Qi State and Wei State, as evidenced at Majiayuan Cemetery (Gansu), Songshan County Cemetery (Zhaoqing, Guangzhou), Zhongshan King Cemetery (Pingshan, Hebei) (Xie and Liu, 2012; Xu, 1974; Zhang *et*



*al.*, 1979). Moreover, the lower levels of the nobility could also use eye beads during this period (e.g., Qinjiazui Cemetery (Jiangling, Hubei), Luopogang Chu Cemetery (Jingmen, Hubei), M1 Guweicun Cemetery (Hui county, Henan)), probably because by then glass making technology was controlled by Chinese glass makers (Chen, 1988; Wen, 2005; Zhang, 1994).

During the late Warring States Period, the Chu State declined. The Qin State in the southwest of China adopted and exploited the cultures from the Chu, Wei and Qi States, which laid the foundation for a unified China. When *Xiaogong* 孝公 (King of the Qin State 381 – 338 BC) moved the capital to Xianyang City, he gathered citizens from different States to live in Taerpo (Northeast of Xianyang). This explains why eye beads were excavated from Taerpo Qin Cemetery (Xie, 2006). However, when Shi Huang (First Emperor of the Qin Dynasty, 259 – 210 BC) unified China, eye beads were only discovered from King Nanyue Cemetery, Fanyu, Guangzhou (Ye, 2009). Thousands of monochrome glass beads were excavated, and the rest of the glass objects include a few glass Bi disks and eye beads. After the Qin Dynasty, eye beads have rarely been found, and these are considered to be a legacy from the earlier periods. Therefore, the eye beads only existed in Central China from the Late Spring and Autumn Period until the Qin Dynasty. The Chu people made a great contribution to the development of eye beads, but eye beads gradually disappeared after the Qin Empire conquered the Chu State. The disappearance of the eye beads might have been related to the rise of the nomads, who blocked the trade route between the Qin Empire and the Central Asia

regions.

### **2.1.2 Indo-Pacific Monochrome Drawn Glass Beads during the Han Dynasty**

The term ‘Indo-Pacific Beads’ was first proposed by Peter Francis (2002), and it refers to monochrome glass beads found in Indo-Pacific regions. This type of glass was not only discovered in South Asia, but throughout the Indian Ocean littoral (from the Red Sea to southern Africa to Southeast Asia and Japan: Abraham, 2016). Moreover, they have also recently been identified in European Merovingian graves (Pion and Gratuze, 2016). Francis (2002, pp. 19–21) compared the glass waste debitage that resulted from various stages of modern production from Papanaidupet (India) and the glass beads from the site of Arikamedu, an Early Historic port site on the southeastern Indian coast. The Indo-Pacific glass beads from Arikamedu dating to the 1<sup>st</sup> centuries BC/AD were visually identical to those from modern Papanaidupet village. Francis (2002, pp. 19–21) suggested that the earliest production of Indo-Pacific glass beads was in South India as early as the 2<sup>nd</sup> century BC. Francis (2002, pp. 27–50) believed the technique of drawn beads was spread to other regions from Arikamedu, such as Karaikadu in India, Mantai in Sri Lanka, Khlong Thom and Khuan Lukpad in Thailand, Oc-Eo in Vietnam.

Over ten thousand Indo-Pacific drawn beads have been discovered in China dating to the Han Dynasty. Figure 2.6 shows the numbers of drawn beads discovered from different provenances in China according to Zhao (2016, 2012). In this research, we have also collected drawn beads in Henan and Hubei. The distribution of drawn beads

discovered in China indicates that the North, Southwest and Maritime Silk Roads all played roles in the transmission of Indo-Pacific Monochrome Drawn Beads.



**Figure 2.6 Numbers of drawn beads discovered from different provenances in China** (numbers in red were summarized by Zhao (2016, 2012); numbers in black are drawn glass beads analysed in this study).

### 2.1.3 The invention of Chinese jade glass

As mentioned above, craftsmen from the Chu State seemed to control the glass making technique during the Early Warring States. Due to the unique chemical properties of the lead-barium glass, it was used not only for the imitation of eye beads, but also for the imitation of Chinese jade. The reaction between barium and silica can generate barium silicate ( $\text{BaSi}_2\text{O}_5$ ) as an opaque phase which simulates a jade appearance in the glass. Chinese culture had a strong preference for jade, and jade was frequently used for burial

objects by the nobility, which were called burial jade (Zhou, 2014). Robert Brill was one of the first archaeological scientists who contributed fundamental work on lead-barium glass, including chemical composition analysis, isotopic analysis and glass replication. A summary and discussion of his work can be found in Chapter 2.4.4. The use of jade can show the wealth and social status of the owner, and it can also exorcise evil spirits. *Zhou Li* 周礼 written by *Zhou Gongdan* 周公旦 as a Confucian classic during the Qin Dynasty documents that jade Bi were put on the top of the corpse to guide the spirit to heaven (Zhou, 2000). In general, high status burials may still use burial jade, but lower status burials may use lead-barium glass as a replacement. For instance, Ganquanshan Han Cemetery in Yangzhou (Jiangsu province) discovered hundreds of glass sheets covering a female corpse as an imitation of a jade burial suit. The jade burial suit was specifically used for the Han royal family members. The owner of the suit, *Moshu* 莫书, was a concubine and may have had a relationship with the *Shanyang* 山阳 King. ‘Moshu’ was not qualified to use the jade suit, but a glass suit was used as a replacement (Zhang, 2004; Zhou, 2014).

Glass Bi is the major type of jade imitation. The colour of glass Bi is normally white, light green or dark green (Figure 2.7). According to archaeological excavation, there are over 200 glass Bi found in China and over 85% of them were unearthed in Hunan province (Fu and Xu, 2010). The earliest glass Bi is from the M 132 Chu Cemetery Changsha Guiguayuan dating to the Early Warring States, and is thin and small (Gao, 2000). Glass Bi were relatively small, and the number found is limited during the Early

Warring States. It was not until the Middle Warring States that the craft of glass Bi manufacture reached maturity, when the glass Bi became larger and thicker, and the majority of glass Bi date to this period. The largest glass Bi was excavated from the tomb near the Mao Mausoleum (Shaanxi, the Han Emperor Liu Che, 157 – 87 BC: Yu, 2002a). The diameter is 23.4 cm and the weight is 1.9 kg, whereas the average diameter of glass Bi unearthed in Hunan is 7.9- 9.4 cm and the average weight is 40- 60 g (n= 201). The development of jade glass is similar to that of the eye bead - both of them arose during the Early Warring States, became popular during the Middle Warring States, and vanished after the Han Dynasty.



**Figure 2.7 three major colours of glass Bi** (Fu and Xu, 2010: Figures 33,35,36).

## 2.2 Historical documentation for ancient Chinese glass

There was not a uniform terminology for glass in ancient China. ‘*Liu Li*’ 琉璃 (流离, 陆离) and ‘*Bo Li*’ 玻璃 (颇黎, 颇璆) were most the frequently used terms to describe vitreous materials, such as glass, faience and glaze. Although ‘*Bo Li*’ and ‘*Liu Li*’ may both indicate glass, ‘*Bo Li*’ and ‘*Liu Li*’ may represent imported glass and Chinese glass respectively. ‘*Wu Lin Jiu Shi*’ 武林旧事 written by Zhou Mi 周密 in AD 1290 mainly documents the economic culture, citizen’s life, city landscape and court etiquette during

the Southern Song Dynasty (AD 1127 – 1279: Zhou, 2007). In Volume Two, 'The Lantern Festival' Chapter, it documents glass lanterns from different places: 'The Su Lantern is the biggest, which is made up of five-coloured 'Liu Li'; The lantern from 'Xin An' 新安 is called a 'non-skeleton lantern', because the lantern is fully made up of 'Liu Li' without supports inside the lantern. However, in the 'Flowers' Chapter of Volume Two, it is also documented that the 'Bo Li' bottles were imported from the Middle East. The author therefore intentionally used two different terms to describe Chinese glass and imported glass.

Brill (1990) discussed the origin of the term '*Bo Li*' in Chinese. 'Bolos' in Greek represents semi-finished products. In the Hebrew Dictionary edited by Jastrow (1903), 'bolos' is unformed glass ingots for secondary production. Barag believes that 'Bolos' started to be used by the Jews before AD 200, and Hirth considered that '*Bo Li*' is derived from 'Bolor', and 'Bolor' means glass in several Middle Asian languages (Brill, 1990). 'Bolos' and 'Bolor' both shared the same meaning as glass or glass ingot, and 'Bo Li' in Chinese shared a similar pronunciation to 'Bolos' and 'Bolor'. Primary glass ingots from the Mediterranean were traded to the Near East, such as the raw glass found in the Serce Liman shipwreck (Bass and Van Doorninck, 1978). Brill (1990) considered that it is possible that glass ingots were also traded into China and the term 'Bolos' was hence transferred into China. 'Bolos' was gradually transliterated into '*Bo Li*' in Chinese. Brill's theory happens to have the same view as the documentation in '*Wu Lin Jiu Shi*' 武林旧事, that 'Bo Li' represents imported glass.

Wang Chong 王充 in AD 87 first documents the glass formulation in '*Lun Heng Shuai Xing Pian*' 论衡 率性篇 (Wang, 1907). Taoists used '*Wu Shi*' 五石 (five different components) to produce imitations of jade or the sun flint (magnifying glass) after polishing. '*Wu Shi*' including Dan Sha 丹砂 (mercuric sulphide  $\text{HgS}$ ), Xiong Huang 雄黄 (realgar  $\text{As}_4\text{S}_4$ ), Bai Fan 白矾 (alum  $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ), Zeng Qing 曾青 (copper sulphate  $\text{CuSO}_4$ ) and Ci Shi 慈石 (magnetite  $\text{Fe}_3\text{O}_4$ ), were mainly used as ingredients for the elixir of life. Indeed, these five components cannot produce glass, but it suggests that there may be some connection between glass and alchemy.

Records in '*Formula of Tai Qing Elixir*' 太清丹经要诀 written by Sun Simiao 孙思邈 in the Late Sui and the Early Tang Dynasty may support this hypothesis (Sun, 2017).

1) The white '*Tai Qing*' elixir was made by mixing and firing 100 g *Shui Jing* 水精 (silica crystal) powder with 1000 g lead oxide ( $\text{PbO}$ ), and this fits the formula for high lead glass. 2) The 'Jade' recipe: '500 g shell ( $\text{CaCO}_3$ ) is ground into powder and sealed in the bamboo pipe with saltpetre ( $\text{KNO}_3$ ); then the bamboo pipe is soaked in acetic acid ( $\text{CH}_3\text{COOH}$ ) for twenty days; 500 g silica quartz powder is poured into the bamboo pipe after twenty days and directly fired with coal'. Shell functioned as the stabilizer and saltpetre was the flux. The 'jade' referred to in this book was actually a potash glass.

'*Liu Li*' documented in '*Jin Hua Yu Ye Elixir*' 金华玉液大丹 (anonymous) during the Tang Dynasty was a mixture of 250 g lead oxide ( $\text{PbO}$ ), 100 g saltpetre ( $\text{KNO}_3$ ) and

100 g borax ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ). This formula fits the  $\text{PbO-Na}_2\text{O-K}_2\text{O}$  glass during the Tang Dynasty. '*Dan Fang Yuan Jian*' 丹方鑑原 (anonymous unknown date) documents that borax was exploited in Nanchong City, Sichuan Province. The formula was only known by a few Taoists due to the inadequate transportation to exploit the borax, thus, this formula was not widely spread and soon disappeared (Gan, 2016, p. 115).

Another type of 'Liu Li' was documented in '*Duo Neng Bi Shi*' 多能鄙事 written by Liu Ji 刘基 in the Early Ming Dynasty (Liu, 1996). '200 g lead, 150 g saltpetre ( $\text{KNO}_3$ ), 100 g alum ( $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ), 100 g silica quartz are ground and mixed, then fired with coal'. The formula of 'Liu Li' in this case was also potash glass.

'*Tian Gong Kai Wu*' 天工开物 written by Song Yingxing 宋应星 in AD 1637 documents that 'Liu Li' was made by mixing and firing saltpetre, lead, beads and copper wires (Song, 1966). Saltpetre and lead were the fluxes as mentioned above, and the copper wires could be the colourant which turned glass a blue colour. The beads in this text could be quartz beads, or it could indicate vitreous beads, which suggests the 'Liu Li' in this case could actually be recycled glass.

According to the documentation above, it seems that Chinese glass makers could make high lead glass and potash glass after the Han Dynasty. Chinese lead-barium glass only existed during the Warring States and the Han Dynasty, and there is no clear



documentation about the formula for lead-barium glass. In this research, the lead-barium glass replication experiment can be found in Chapter 4. The jade imitation documents in '*Lun Heng Shuai Xing Pian*' 论衡 率性篇 may indicate lead-barium glass, but the formula may be mis-documented (firing those five components cannot form glass). Moreover, soda lime glasses such as natron glass and plant ash glass have been excavated in China, but there is no documentation about the production of these glasses. Therefore, formulae for natron glass and plant ash glass may not have been transferred into China with their glass products.

## **2.3 Faience and glass primary and secondary production**

### **2.3.1 The link between faience and glass production**

It is unlikely that any type of vitreous material was invented out of thin air, while there must have been certain patterns or logic for these inventions. For instance, the development of ceramics has gone through three stages - earthenware, stoneware and porcelain. The progression from earthenware to porcelain follows a basic logic, which is the development of technology, including the better selection and processing of raw materials, the higher firing temperatures and the development of the kiln design. As for ancient glass, it is believed that its production presents a certain degree of similarity with glazed steatite, Egyptian blue and faience (Henderson, 2013, p. 13). In other words, the production of glass might have been inspired and evolved through faience production. The production of faience is simply the mixture of crushed quartz, plant ash and copper minerals (e.g., malachite). According to Tite and Bimson (1986), there are

mainly three techniques for producing faience. 1) The *efflorescence* procedure entailed combining the raw materials with water to form a mouldable paste, and letting it dry to deposit fluxing salts on the surface; 2) The *Qom* procedure primarily moulds the faience body and submerges it in a glaze slurry; 3) The third procedure entails applying glaze slurry directly to the faience body. The raw materials used to make plant ash glass and faience are comparable, and their *chaîne opératoire* may have undergone similar early preparation steps. Yet, the glass formation requires higher levels of flux and firing temperature (Henderson, 2013, p. 14). Thus, the first glass might have been accidentally produced with poor compositional control of overheated faience (Hodges, 1992, p. 125; Tite *et al.*, 2002).

### **2.3.2 Glass primary production and glass types from the Late Bronze Age to the Early Roman period.**

Compared with faience production, glass production takes place in two steps - primary production and secondary production. Primary production is where the raw glass is made from raw materials. Both production steps can be achieved in one site or separately far apart. Glass is made up of network formers, network modifiers, and intermediates, with SiO<sub>2</sub> serving as the primary network former in ancient glass (Degryse, 2014, p. 20). The fluxes Na<sub>2</sub>O and K<sub>2</sub>O and the stabilizer CaO are network modifiers, which disrupt the continuity of the silica network, changing the physical and chemical properties. Oxides such as Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> are intermediates that can either enter the network as a network former or occupy interstitial holes as network modifiers,

but are unable to form glasses themselves. Due to the level of impurities (e.g., Fe) and firing conditions, the raw glass commonly appears a pale greenish or blueish colour. The colouring agents can be added during primary or secondary production. Yet, opacifiers might not have been added during the primary production. Opacifiers could separate out and remain on the glass top surface when the raw glass naturally cools down in the closed furnace (details in Chapter 4). Henderson (2013, p. 18) suggested that the indication of the primary production should be the evidence of fritting, specifically, the evidence of fritting oven. If only the frit is discovered from the site, it cannot rule out the possibility that it might have been imported from other primary production centres. Evidence of fritting has been discovered in 13<sup>th</sup> century BC Qantir and 14<sup>th</sup> century BC Tell el-Amarna (Rehren and Pusch, 2005; Smirniou and Rehren, 2011). Samples analysed in this thesis mainly correspond in date to the Hellenistic period, yet only one primary production site in Beirut dating to the 1<sup>st</sup> century BC has so far been discovered (Henderson, 2013, p. 215)

There are mainly two silica sources for glass production, sand and crushed quartz. The difference between these two sources is that crushed quartz contains fewer impurities, such as iron oxide. The calcium source was either from limestone or shells enriched in beach sand (Degryse and Shortland, 2009; Freestone *et al.*, 2003; Shortland *et al.*, 2007). The calcium source in natron glass was from the shells, and the CaO% normally shows a larger variation compared with the CaO% in Islamic plant ash glass. This is due to the variation of CaO level in different beach sand sources, while limestone was

intentionally added in the Islamic plant ash glass. The terminology of different types of ancient glass was based on the flux source.

The majority of the ancient glass can be classified as alkaline glass, due to the concentrations of  $K_2O$  and  $Na_2O$ , while some of the ancient glass in China, Japan and Korea used  $PbO$  as the flux with  $PbO$  concentrations over 35% (Henderson, 2013, p. 123). One of the high lead glass samples in Korea dates to the 1<sup>st</sup> century BC (Lee *et al.*, 1991). The alkali source for soda-lime-silica glass from western Eurasia could either be a natron (evaporite mineral) source, often identified as Wadi El-Natron in Egypt, or ash derived from burnt salt-tolerant plants, which functioned as an essential flux to lower the sand's melting temperature (Brems and Degryse, 2013; Shortland *et al.*, 2007). The difference between natron glass and plant ash glass is that plant ash glass contains higher levels of  $K_2O$  and  $MgO$  (both  $>1.5\%$ ). Mixed-alkali glass contains similar concentrations of  $K_2O$  and  $Na_2O$ , and has been discovered in Europe (mainly in northern Italy and Switzerland) and Southeast Asia (Henderson, 2013, pp. 90, 126, 1988). The European mixed-alkali glass contains between 4%-9%  $Na_2O$ , 6%-12%  $K_2O$ , 0.5%-1.0%  $MgO$ , 1.0%-3%  $Al_2O_3$ , 1.0%-3.5%  $CaO$  and 0.25%-1.5%  $Fe_2O_3$  (Henderson *et al.*, 2015). Such a low level of  $MgO$  indicates the alkali source could be a mixture of natron and saltpetre ( $KNO_3$ ) rather than plant ash. The Southeast Asian mixed-alkali glass contains higher levels of  $MgO$  and  $CaO$ , suggesting a different flux source compared with the European mixed-alkali glass (Henderson, 2013, p. 126), and perhaps a plant ash source was used. The potash glass was mainly discovered in South

and Southeast Asia, where a saltpetre was used for this type of glass with low concentrations of  $\text{Na}_2\text{O}$  and  $\text{MgO}$  ( $<1.5\%$ ). Lankton and Dussubieux (2006) summarised three subtypes of potash glass according to concentrations of  $\text{CaO}$  and  $\text{Al}_2\text{O}_3$ . This difference reflects the change of the selection in silica source, flux and stabilizer. Mineral soda–alumina (m-Na–Al) glass has appeared in South and Southeast Asia from around the 5<sup>th</sup> century BC (Dussubieux *et al.*, 2010). Mineral soda–alumina glass has low  $\text{MgO}$  concentrations ( $\leq 1.5\%$ ) and low  $\text{K}_2\text{O}$  concentrations ( $\leq 3\%$ ), which indicates a mineral sodium source- soda-rich efflorescence similar to reh (Brill, 1986). Reh source in India is a mixture of  $\text{Na}_2\text{CO}_3$ ,  $\text{Na}_2\text{SO}_4$  and  $\text{NaCl}$  with low proportions of  $\text{CaO}$  and  $\text{MgO}$ , and  $\text{Al}_2\text{O}_3$  in m-Na–Al glass varies from 5 to 15% due to the reh content (Dussubieux *et al.*, 2010).

### **2.3.3 Glass secondary production**

Secondary production is the conversion of this primary glass into artefacts, where recycling and mixing can take place, and colourants or opacifiers can also be added. Moreover, glass secondary production is commonly associated with a range of glass-working techniques, such as blowing, shaping, moulding, decorating and manipulating (Henderson, 2013, p. 18), Materials related to glass-working are expected to be found in the excavation of secondary production sites, such as the moulds, crucibles, blowing metal tubes, metal rods. These are strong evidence for glass secondary production. Compared with raw glass, broken glass shards can be used as evidence for secondary production (recycling process). It needs to be noted that the application of trace element

analysis to define the glass silica source is normally associated with primary production, as the silica source should have been close to the site of primary production. The chemical composition study of the colourant cannot reveal whether it was added during the primary or secondary production. The typological study of the glass is related to the secondary production, as various glass working techniques can be conducted. There are certainly a few glass-working techniques throughout the development of glass secondary production, such as blowing glass, cameo glass, mosaic glass, twisted glass, cut glass. This thesis will not further discuss those techniques as glass samples analysed in this research were beads, including eye beads, monochrome moulded glass beads and monochrome drawn beads (Figure 2.8). The technique of moulding monochrome beads is relatively simple compared with the other two techniques, and the decoration on the bead is simply achieved by the carving and shaping of the mould. Below is an introduction to the other two techniques.

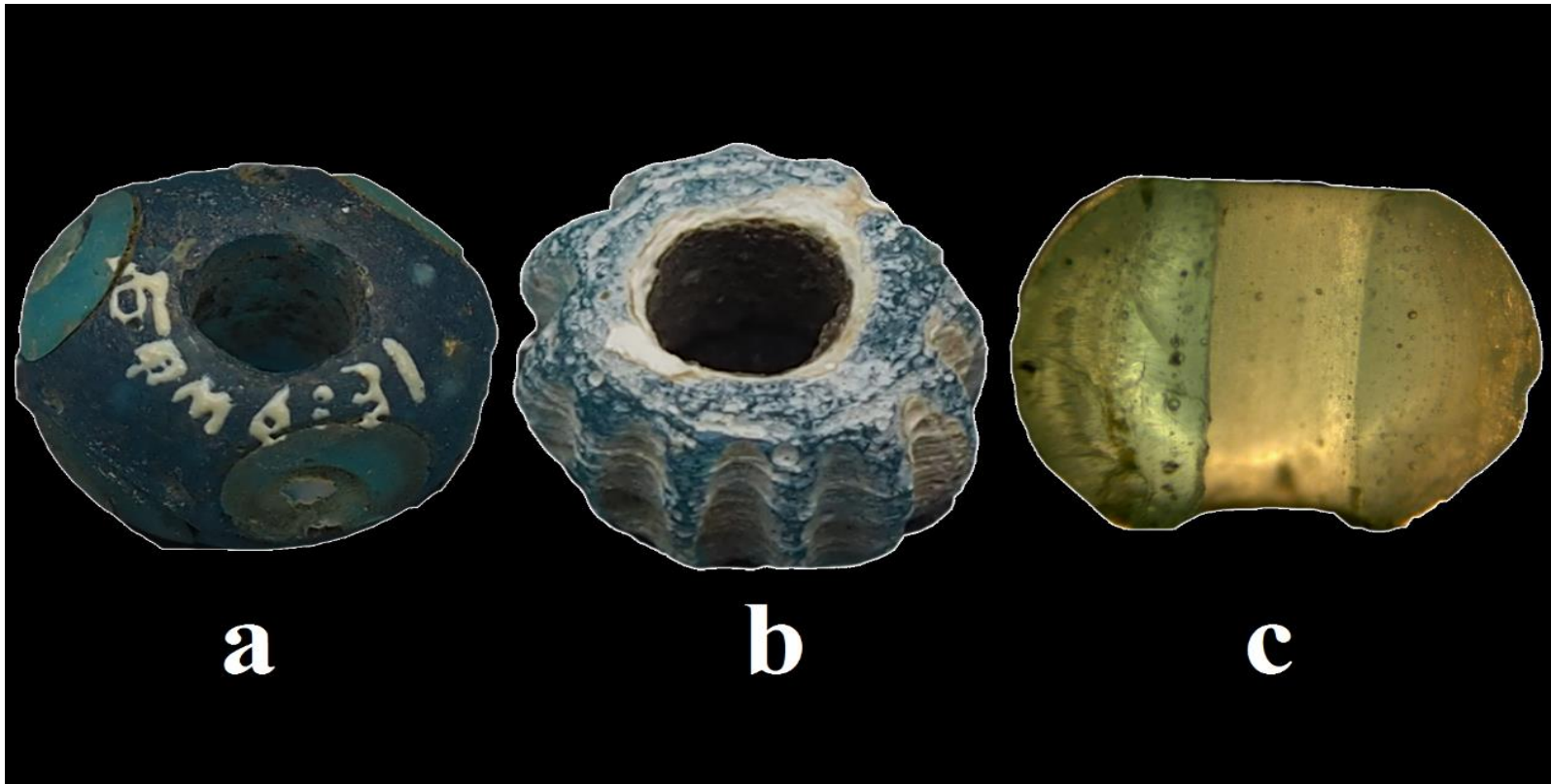


**Figure 2.8 Three types of glass beads analysed in this research.** a: Eye bead, S6-148A, excavated at Jinning Shizhaishan cemetery, Yunnan; b Monochrome moulding glass bead, S12-97-2, ditto; c: Monochrome drawn bead, GMG-11, excavated at Muyi Site, Yunnan.

### **Monochrome drawn beads**

The Indo-Pacific Beads have also been named Indo-Pacific Monochrome Drawn Glass Beads due to the related glass-making technique. Drawn beads are obtained by cutting thin glass tubes (Figure 2.9: Cummings, 2002, p. 49). A mass of molten glass is gathered on the end of a hollow metal rod (a pontil or blowpipe) and then a hole is poked within the molten glass, either by blowing or by inserting a metal rod. The hole is then covered by a patty of glass. Next, a tool which is called *lada* is attached to the molten glass to gradually draw the glass into a tube (Pion and Gratuze, 2016). There are two ways of cutting the tube: hot and cold cutting. The craftsman places about a dozen of tubes side by side on the cutting edge of a blade fixed on the ground and then cuts these tubes into small cylinders using a second blade (Pion and Gratuze, 2016). This method will leave sharp edges for both sides of the beads. To shape the roundness of the beads, heat treatment is carried out. Beads, mud, dung and ashes are mixed in a ceramic container to ensure that they do not stick to each other and the holes do not close during the heat treatment (Pion and Gratuze, 2016). The container is only heated for several minutes to soften the glass bead, and consequently, the sharp edge gets smoothed. As for the hot cutting, the glass tube is reheated and then squeezed at regular intervals. The edges of the beads commonly show an umbilical shape, which requires further cold polishing or heat treatment.



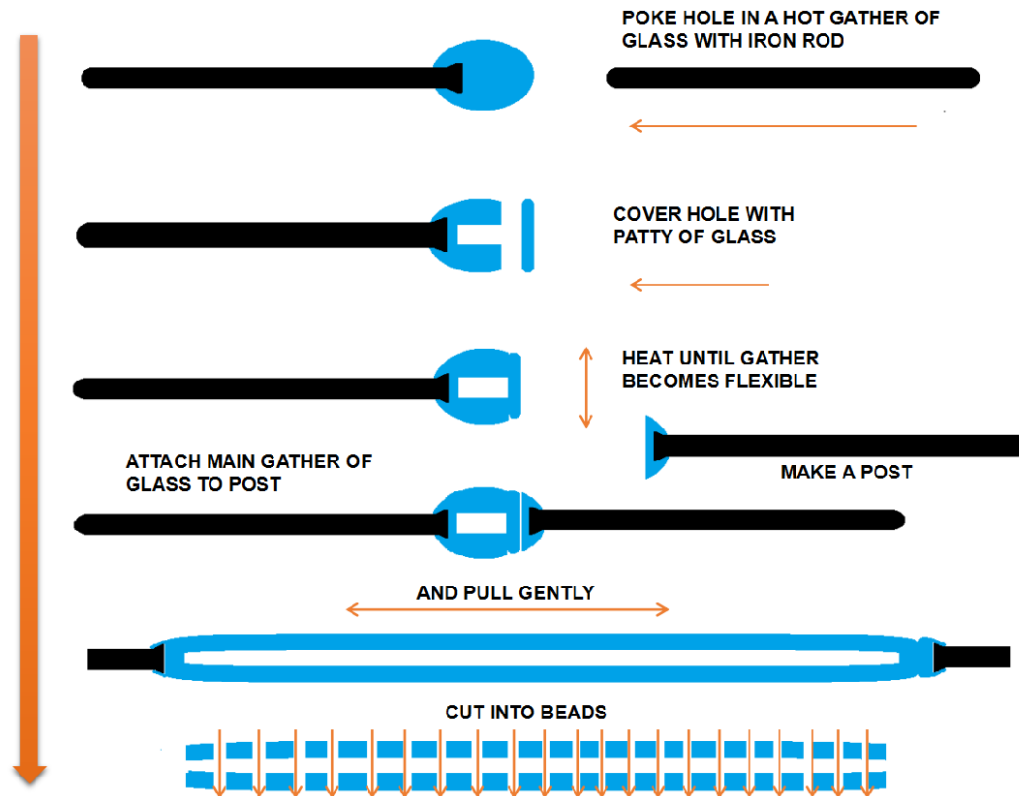


**Figure 2.9 The glass drawing technique** (Cummings, 2002, *A History of Glassforming*, A&C Black Visual Arts, an imprint of Bloomsbury Publishing Plc).

## Eye beads

According to the shape and technology of the eye beads, six types of eye beads are summarised below (Beck, 1928; Eisen, 1916; Spaer, 2001; Zhao, 2012).

**Type A Stratified Eye Bead** (Figure 2.10): Stratified eye bead was the most common type of decorated glass beads during the 6<sup>th</sup> – 4<sup>th</sup> century BC both in the Mediterranean and China. One way to produce this type of eye beads could be by dropping different colours of molten glass onto the matrix glass bead to create different layers when the matrix glass bead is not fully cooled, with each layer of molten glass smaller than the former layer. Yet, sometimes layers of eyes can be premanufactured and inlaid on the

matrix glass bead, which requires a further grinding process (Zhao, 2012). The number of eye layers is commonly even. A majority of the stratified eye beads were spherical or compressed spherical in shape during the 6<sup>th</sup> – 3<sup>rd</sup> century BC and only a few were elongated in shape afterwards. Each layer of molten glass can be placed either to the centre of the previous layer or to one side of the previous layer, which gives rise to the two sub-types: Concentric Eye Bead and Eccentric Eye Bead. The Eccentric Eye Bead is considered to be an innovation by Chinese glassmakers and this type of eye bead is only found in China. Spaer (2001, p. 78) further classified 5 subtypes according to the patterns of eyes on stratified eye beads: ‘Beads with fewer than ten eyes’, ‘Paired eye beads’, ‘Three-plus-four eye beads’, ‘Beads with ten or more eyes’ and ‘Beads with divergent eyes’.



**Figure 2.10 Concentric Eye Bead and Eccentric Eye Bead (Ashmolean Museum collection, Warring States period).**

**Type B Spot Eye Bead** (Figure 2.11): This type of eye bead is produced by embedding glass drops into the matrix when the matrix is not fully cooled. Spot Eye Bead can also be divided into two sub-types, Flush Spot Eye Bead and Raised Spot Eye Bead. The glass drop is fully embedded into the matrix for the Flush Spot Eye. In contrast, the

glass drop stands out from the matrix for the Raised Spot Eye Bead. This type of glass mainly was circulated in northern parts of China from the Mid-Warring States period to the decline of the Qin Dynasty (Zhao, 2012).

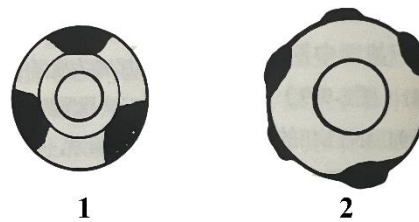


**Figure 2.11 Flush Spot Eye Bead and Raised Spot Eye Bead.** 1: Flush spot eye bead excavated at M4 Xiaoxitian, Fuling, Chongqing, Warring States period; 2: Raised spot eye bead excavated at M7229 Houmaqiao county, Shanxi, Warring States period (Zhao, 2016, p. 60).

**Type C Horned Eye Bead** (Figure 2.12): There are two types of eyes on horned eye beads, stratified horned eyes and mosaic horned eyes. The stratified horned eye bead is considered to be a sub-type of ‘Beads with divergent eyes’ (Spaer, 2001, p. 85), in which a horn/ pyramid shape was formed by multiple layers of eyes. The mosaic horned eyes have a monochrome profile, whereas the stratified horned eyes appear horizontally striped (Spaer, 2001, p. 85).

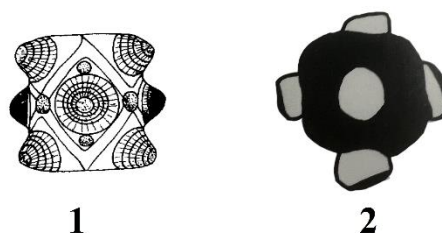


**Figure 2.12 Horned Eye Bead.** 1: Stratified horned eye bead excavated at M703 Jianglingjiudian, Hubei (Zhao, 2016, p. 62); 2: Mosaic horned eye bead from Eastern

Mediterranean, Late Hellenistic or Roman period, Israel Museum collection (Spaer, 2001, p. 94).

**Type D Compound Eye Bead** (Figure 2.13): Another subtype of ‘Beads with divergent eyes’ - Compound eye beads are known as beads with eyes made up of many small eyes, and this type was most commonly produced in Egyptian, Carthaginian or other western sites (Spaer, 2001, p. 85). The compound eye bead can be further divided into two subtypes, stratified and mosaic compound eye beads. The mosaic compound eye is defined as the eye consisting of several single layer spots on a joint two-layer ground, whereas the stratified compound eye has several two-layer spots on a joint two-layer ground (Spaer, 2001, p. 85).



**Figure 2.13 Compound Eye Beads.** 1: Mosaic compound eye bead excavated at Beth Shean, Late Bronze Age; 2: Stratified compound eye bead from the Mediterranean (Egypt?), 4<sup>th</sup> century BC, Israel Museum collection (Spaer, 2001, p. 85;93).

**Type E Multilayer Eye Bead** (Figure 2.14): This type of eye bead does not rely on embedded molten glass drops to create the ‘eye’. The molten glass is intertwined on a metal bar, and then another colour of molten glass is covered on the top of the first glass layer. This process can be repeated several times.

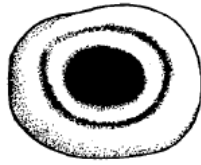


**Figure 2.14 Holistic Eye Bead** excavated at CIM5269 Knitwear Mill, Luoyang, Henan (Zhao, 2016, p. 64).

**Type F Dotted Line Eye Bead** (Figure 2.15): This type of eye bead is decorated with a dotted line, which can be a looped line surrounding the stratified eye, or it can be a straight line to separate the ‘eye’. Some of them are only decorated with the dotted line without the ‘eye’. The Dotted Line bead is only found in China and is considered to be another innovation of the eye bead by Chinese glass makers.



**Figure 2.15 Dotted Line Eye Bead** excavated at King Nanyue Cemetery, Fanyu, Guangzhou (Zhao, 2016, p. 64).

**Type F Trailed Eye Beads** (Figure 2.16): The origin of trailed eye bead can be dated to the 9<sup>th</sup> century BC, and three trailed protruding eyes are the signature of this type of glass (Spaer, 2001, p. 79). Three eyes are attached to the matrix bead with an identical colour, and a layer of eye ring in opaque white or yellow is used to cover the seam between the matrix glass and the eye. Due to the three protruding eyes, this type of bead

discovered in Sinai, Syria-Palestine, Cyprus, the Aegean and Asia Minor is commonly triangular. Yet, trailed eye beads found in Italy, Slovenia and Croatia dating to the 8<sup>th</sup> – 9<sup>th</sup> century BC have flush eyes without triangular appearance, and some of them also have the addition of zigzag trails and dots (Spaer, 2001, p. 80).



**Figure 2.16 Trailed Eye Beads from the 9<sup>th</sup> – 7<sup>th</sup> century BC.** 1: IAA 86-400, City of David, Jerusalem; 2: IAA 48-713, Achziv, Israel (Spaer, 2001, p. 80).

## **2.4 Previous methods to identify the source of raw materials of ancient glasses**

Glass production can be divided into two steps, primary production and secondary production. The primary production implies the production of the raw glass, and the secondary production implies the production of the finished glass product. The raw materials, for example, the silica source, was commonly close to the primary production centre. Sourcing the raw materials can be used to provenance the primary production centres. Many features of the raw materials, such as mineralogy, grain size, and form, are lost during glass melting, leaving just bulk chemical and isotopic data (Brems, 2012). There are quite a few techniques were used to trace the raw materials for producing

glass, such as trace element analysis, rare earth element patterns and isotopic fingerprints (Degryse and Schneider, 2008; Degryse and Shortland, 2009; Freestone *et al.*, 2003; Henderson *et al.*, 2005; Shortland *et al.*, 2007; Wedepohl and Baumann, 2000).

### **2.4.1 Major and minor element analysis**

The early chemical composition analysis on glass mainly focused on the major and minor elements, and this is simply due to the lack of advanced instrumental techniques for trace elements. Still, those early works provided fundamental knowledge about ancient glass research, which laid the foundation for the current study. There were quite a few commonly used techniques during the last century, such as X-ray fluorescence (XRF), particle-induced X-ray emission (PIXE), wet chemistry and electron micro probe analyser (EMPA). The limitations of XRF can be found in Chapter 2.4.4. The classification of glass types is mainly based on the identification of flux type that relies on major and minor element analysis. For instance,  $K_2O\%$  and  $MgO\%$  in natron glass are both lower than 1.5%, whereas plant ash glass shows over 1.5%  $K_2O\%$  and  $MgO\%$  (Rehren and Freestone, 2015). Yet, if the  $Al_2O_3\%$  ranges between 5-15%, instead of a natron source, the glass might have used the reh source as the flux (Brill, 1986; Dussubieux *et al.*, 2010). The concentration of  $Fe_2O_3$  as an impurity in Roman natron glass results in a pale yellowish or greenish colour. The identification of colourants in glass is also achieved by minor element analysis. For instance,  $Cu^{2+}$  and  $Co^{2+}$  are two widely used colourants throughout glass history, which result in a turquoise and blue

colour respectively. It is important to recognize that the  $\text{Cu}_2\text{O}$  in glass results in an opaque red colour instead of a turquoise appearance (Dussubieux, 2016), and this cannot be differentiated through XRF and PIXE analysis. Similarly, reducing Sb and Mn function as decolourants commonly in Roman glass, while oxidizing Sb function as the opacifier and oxidizing Mn appears as a purple colour in the glass. In general, major and minor element analysis is a useful tool to identify glass types (i.e., flux, silica, (de)colourant, opacifier), but it shows limited use to identify the source of raw materials. The identification and differentiation of the glass raw materials rely on trace and isotopic analysis.

### 2.4.2 Isotopic analysis

In terms of isotopic analysis, Sr and Nd isotopic ratios are powerful tracers for sediments. The isotopic fractionation of the different Sr and Nd isotopes is insignificant in this context due to their comparatively large masses and modest relative mass differences (Banner, 2004). As a result, it is assumed that isotopic ratios of  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  can be the fingerprints of the source of the raw materials. The lime-bearing substance is thought to have incorporated the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios in the Roman glass. (Freestone *et al.*, 2003; Wedepohl and Baumann, 2000). Therefore, Sr isotope can be applied as an indicator for the source of lime. Indeed, feldspar and mica in the sand source can also have an impact on the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the glass batch (Freestone *et al.*, 2003), yet this impact could be minor as the main source of lime in Roman glass is contributed by the shells in beach sand. Thus, the Sr isotopic ratio can be an indicator



of the sand source for Roman glass because shells coexist with the beach sand. Limestone was intentionally added as the lime source in Islamic plant ash glass. The Sr isotopic ratio in Islamic plant ash glass is, therefore, an indicator of the lime source rather than the silica source. Freestone *et al.* (2003) used the Sr (ppm) -  $^{87}\text{Sr}/^{86}\text{Sr}$  plot to differentiate Byzantine and Early Islamic glass from the Near East. Two groups of glass from Bet Eli'ezer and Bet She'an, in Israel, have high concentrations of Sr and ratios of  $^{87}\text{Sr}/^{86}\text{Sr}$  close to the level of modern marine shell because the lime source in these two groups of glass was from the broken shells in beach sand. Two other groups of glass Tel el Ashmunein, Middle Egypt and Banias, Israel have low concentrations of Sr and different  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, due to the use of limestone or limestone-rich sand and plant ash respectively.

The source terrain's Nd isotopic signature is often maintained in the resulting sediments (Degryse, 2014, p. 53). As a result, changes in Nd isotopic composition can be used as fingerprints in sediment provenance studies (Banner, 2004; Grousset and Biscaye, 2005; Linn and DePaolo, 1993). A trace amount of Nd concentrations can be detected in sand sources that have a weak, but positive correlation with  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$  and  $\text{P}_2\text{O}_5$  concentrations. Such a correlation would imply that Nd indeed is related to the heavy mineral fraction of the sand, and the  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio reflects the signature of the total heavy mineral species (Degryse, 2014, p. 64). Therefore, the Nd isotopic ratio can be used as an indicator for sand sources. Degryse presents a database of  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  isotopic ratios of beach sand deposits from the western part of the

Mediterranean area, some of which were identified as suitable raw materials for Roman natron glass production (Degryse, 2014). Through the strontium and neodymium isotopic signatures, most polychrome and colourless 8<sup>th</sup> – 4<sup>th</sup> century BC glass artefacts from Pieria, Greece most likely derive from a Syro-Palestinian production site (Blomme *et al.*, 2017).

B (boron) is associated with the alkaline flux used in glass-making. Due to the natural B isotope fractionation, B isotopic fingerprints (ranging from -20 to +40‰  $\delta^{11}\text{B}$ ) vary in different geological sources of  $\text{Na}_2\text{CO}_3$  (Degryse, 2014, p. 89). As a result, different types of alkaline flux were used in primary glass production, thus, the B isotopic ratio can be used to distinguish multiple sources of natron flux (Degryse, 2014, p. 89). Devulder *et al.* (2014) analysed 33 natron glass samples and 18 natron samples from different sources. By using the box plot of the B isotopic compositions, they concluded that the B isotopic values in Greco-Roman natron glass have relatively homogenous values that are close to the value of natron samples from the Wadi Natrun. Yet, the average value in natron glass is slightly lower than the natron sample, due to a small amount of B with a low isotopic value in the sand source. A summary of isotopic ratios used to source the glass raw materials is listed in Table 1.1.

**Table 2.1 isotopic ratios used to identify glass sources.**

| <b><i>Isotopic ratios</i></b>     | <b>Source</b>                                        | <b>References</b>                                                                                                                                                                |
|-----------------------------------|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $^{143}\text{Nd}/^{144}\text{Nd}$ | Silica source (e.g., sand and quartz)                | (Degryse and Schneider, 2008; Freestone, I.C. <i>et al.</i> , 2013; Ganio <i>et al.</i> , 2012)                                                                                  |
| $^{87}\text{Sr}/^{86}\text{Sr}$   | Lime lime-bearing material (e.g., Lime and seashell) | (Brems <i>et al.</i> , 2013; Degryse, 2014, p. 51; Freestone <i>et al.</i> , 2003; Freestone, I.C. <i>et al.</i> , 2013; Ganio <i>et al.</i> , 2012; Wedepohl and Baumann, 2000) |
| $^{10}\text{B}/^{11}\text{B}$     | sodium carbonate (e.g., natron)                      | (Degryse, 2014, p. 89)                                                                                                                                                           |

### 2.4.3 Trace element analysis

The inclusion of trace elements in the glass can assist in the separation of the groups (Freestone *et al.*, 2000). Laser-ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS) is a virtually a non-destructive technique that has excellent sensitivity, analytical precision and accuracy, and is reasonably quick (Norman *et al.*, 1998). The high spatial resolution of this technique allows the investigation of compositional variations in the trace and minor elements in glasses to a greater degree at the ppm level (Norman *et al.*, 1998).

The mineralogy of evaporitic deposits determines the concentration of elements such as Cl and S (Brill and Rising, 1999). A certain level of Cl and S can be detected in natron glass due to the use of natron flux (Brems and Degryse, 2013). Cl and S in natron source will partly fuse in glass, and the rest escape in the form of gas during the firing process (Bateson and Turner, 1939; Gerth *et al.*, 1998; Salviulo *et al.*, 2004; Shugar and Rehren, 2002).

The nature of the source rocks and the local geological setting controls the types and quantities of accessory minerals in sand deposits (Degryse, 2014, p. 71). Sand with varied mineralogical compositions that show different trace element fingerprints are valuable tracers for their origin (Degryse, 2014, p. 71). Elements such as Zr–Ti (Aerts *et al.*, 2003), Zr–Ti–Cr–La (Reade, 2009; Shortland *et al.*, 2007; Walton *et al.*, 2009) and Zr–Sr–Ba (Freestone *et al.*, 2000; Paynter, 2006; A. Silvestri *et al.*, 2005; Silvestri, 2008) can be used to distinguish between different sand raw materials, since they are usually unrelated to the (de)colouring agents that may have been added to the glass batch on purpose. However, for Mn-decoloured glass, we must keep in mind that Mn ores are likely to contribute some trace levels of Ba and potentially Sr to the glass (Brill, 1988; Foster and Jackson, 2010; Jackson, 2005; Paynter, 2006; Silvestri, 2008). Other elements possibly related to the sand raw materials include Li, Be, Ge, Y, Nb, Mo, Te, Cs, La, Ta, W, Tl, Bi and Th (Reade, 2009; Shortland *et al.*, 2007; Walton *et al.*, 2009; Wedepohl *et al.*, 2011). B, P and U concentrations in glass are contributed by the silica source and the natron flux (Degryse, 2014, p. 71; Shortland *et al.*, 2007). Sr in the glass is contributed by the feldspar and mica in the sand and the lime source (i.e., shell and limestone: Brems *et al.*, 2013). The Mn-rich glass may have also contributed to a certain level of Sr provided by the Mn ore (Ganio *et al.*, 2012). Table 1.2 summarises the trace elements discussed above.

**Table 2.2 Using trace elements to source the glass raw materials.**

| <b>Elements</b>       | <b>sources</b>            | <b>limit</b>                                                                                   | <b>References</b>                                                                                                                                                                                              |
|-----------------------|---------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Cl-S</i>           | Natron source             | /                                                                                              | (Bateson and Turner, 1939; Brems and Degryse, 2013; Brill and Rising, 1999; Salviulo <i>et al.</i> , 2004; Shugar and Rehren, 2002)                                                                            |
| <i>Ti-Zr-La-Cr-Ba</i> | Silica source             | Ba is enriched in lead-barium glass; Mn ores are likely to contribute some minor amounts of Ba | (Aerts <i>et al.</i> , 2003; Freestone <i>et al.</i> , 2000; Paynter, 2006; Reade, 2009; Shortland <i>et al.</i> , 2007; Alberta Silvestri <i>et al.</i> , 2005; Silvestri, 2008; Walton <i>et al.</i> , 2009) |
| <i>Sr</i>             | Silica and lime sources   | Mn-rich glasses, some of the Sr may also be provided by the Mn ore.                            | (Brill, 1988; Foster and Jackson, 2010; Freestone <i>et al.</i> , 2000; Jackson, 2005; Paynter, 2006; Alberta Silvestri <i>et al.</i> , 2005; Silvestri, 2008)                                                 |
| <i>B, P and U</i>     | Silica and natron sources | /                                                                                              | (Brems <i>et al.</i> , 2013; Ganio <i>et al.</i> , 2012; Shortland <i>et al.</i> , 2007)                                                                                                                       |

#### **2.4.4 Limitations of Chinese ancient glass research**

Following the early work of Brill, Gan Fuxi was the pioneer to apply archaeological science to study Chinese ancient glass, and made great contributions to the classification of ancient glass based on the chemical composition analysis. During the 1980s, XRF was used for the chemical composition analysis for glass research, but after 2015, more advanced techniques such as LA-ICP-AES were applied. During the past decades, glass samples from different periods have been analysed by Chinese archaeological scientists. As illustrated above, it is obvious that different periods of glass history have been dominated by different features. It cannot be denied that Chinese archaeological scientists have made great contributions to research on Chinese glass. However, their limitations also cannot be ignored.

In one of the first modern discussions of the chemistry of lead-barium glass, five varieties were summarised by Brill and Wosinski (1991). Although the PbO/BaO (wt%) ratios appear to have been fixed at either 3/1 or 3/2, the significant difference between these five groups was the total concentrations of PbO and BaO. Following decades of research on lead-barium glass, it appears that its chemical composition is more complicated than this, implying that it can no longer be categorised into just five categories. Although Brill and Wosinski's (1991) classification was later demonstrated to be overly simplistic, patterns in the PbO/BaO ratio for glass found from various sites in China can still be seen. Brill *et al.* (1991b) suggested that the addition of barium could either be the flux acting as an alkali in soda-lime glass or the stabilizer acting as lime in plant ash glass. Yet, it also might have been associated with the addition of lead in lead-barium glass (Brill *et al.*, 1991b). Brill (2001) suggested that the high sodium in the lead-barium glass might be a result of mixing PbO:BaO:SiO<sub>2</sub> (low sodium) glasses with soda-lime glasses, and Cui *et al.* (2011) also believe that the Na<sub>2</sub>O and CaO may have originated from independent materials. Cui *et al.* (2011) also believed that witherite (BaCO<sub>3</sub>) rather than barite (BaSO<sub>4</sub>) was used for the production of lead-barium glass, as their replication experiments showed that a poorly melted glass filled with unreacted BaSO<sub>4</sub> was produced with the addition of barite, whereas a well melted, transparent and homogenous glass was produced with the addition of witherite (Brill *et al.*, 1991b). Yet, besides the transparent lead-barium glass, most of the discovered lead-barium glass samples were opacified or translucent. In Chapter 4, we once again test the use of BaSO<sub>4</sub> with several different recipes to replicate lead-barium glass.

Early lead isotopic study of archaeological artefacts from diverse places and dates reveals that Chinese objects are divided into two groups. Objects with lower ratios of  $^{208}\text{Pb}/^{206}\text{Pb}$  and  $^{207}\text{Pb}/^{206}\text{Pb}$  are considered to use radiogenic lead ores ( $^{207}\text{Pb}/^{206}\text{Pb}$  approximately lower than 0.75), and the rest are referred to as common lead ores. Brill *et al.* (1991a) suggested that most Chinese glasses are entirely different from the western lead objects, therefore, these glasses might have been made in China rather than elsewhere. He also found that both radiogenic and common lead ores were used on glasses before the Han Dynasty, yet, the radiogenic lead ores were no longer used for Chinese glasses in the Tang Dynasty (probably depleted after the Han Dynasty). However, with more and more data published in recent years, we now can be certain that some of the Chinese glasses indeed show similar ratios of  $^{208}\text{Pb}/^{206}\text{Pb}$  and  $^{207}\text{Pb}/^{206}\text{Pb}$  to western lead objects (Liu *et al.*, 2018). Moreover, it is important to be aware that if the lead exists as a trace element in an original object and an extra lead source is intentionally added during the recycling process (which commonly happened in bronze and glass recycling processes), then the lead isotopic ratios for the original object can move towards those of the new lead source added during the recycling (Jin *et al.*, 2017; Liu *et al.*, 2019, 2015). Glass production can be divided into two steps, primary glass ingots and finished glass products can be achieved from different workshops, and glass can be recycled. Therefore, we always need to bear in mind that lead isotopic ratios can determine lead ore sources, but they cannot indicate the provenance of objects, especially for a glass sample containing lead.

In the majority of Chinese glass research, Chinese archaeological scientists have mainly focused on identifying the type of the glass rather than the source of raw materials used for the primary glass production. The type of glass is mainly determined by the flux, and most glass research by Chinese scholars stays at this level. Chinese scholars use typology and the type of flux to determine the provenance of ancient glass before the Han Dynasty, since they believe that plant ash and natron glasses were imported, whereas lead-barium glass was produced in China due to its unique high proportion of barium (An, 2000a; Gan, 2016; Hou, 1989; Li, 1996; Qin *et al.*, 2016; Shi and Zhou, 1990; Wen *et al.*, 2016a). It seems that using the flux type to determine the glass provenance is imprecise, since it cannot exactly ascertain the origin of imported glass. Similarly, lead-barium glass was considered to be a Chinese invention, but the exact provenance is also unknown. Moreover, it is actually inaccurate to determine the glass provenance by identifying the flux type and typology. For instance, the chemical composition of one type of plant ash could show a large variation, and the plant burning process, ash purification process and the firing conditions during the glass production can all influence its chemical composition (Barkoudah and Henderson, 2006; Brill, 1970). Besides, one glass production centre may have used various sources of different plant ashes (Gerth *et al.*, 1998). For glass production, the primary glass melting and the secondary glass making can occur in different glass workshops. The typology of the glass may only indicate the provenance of the secondary production rather than the source of glass raw materials. As is also known, glass can be recycled multiple times,



so it is therefore true that the typology may only indicate the provenance of the place where the glass was last recycled.

Most Chinese ancient glasses were analysed by surface non-destructive techniques, such as pXRF (e.g., Dong *et al.*, 2012; Fu *et al.*, 2014; Li *et al.*, 2013; Xia *et al.*, 2013; Zhao *et al.*, 2015). Through these previous publications, we can summarise the following issues:

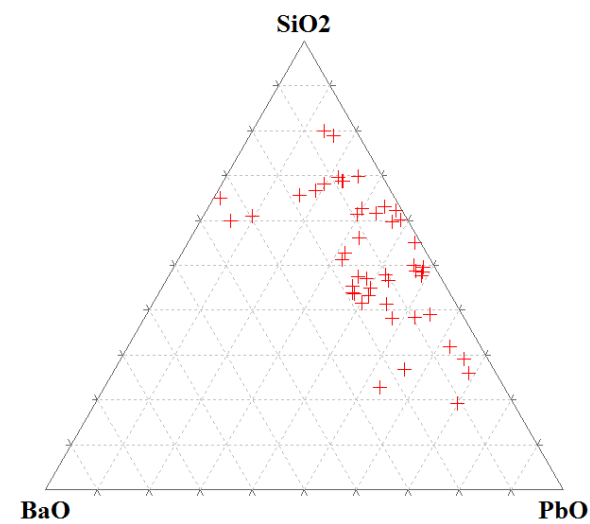
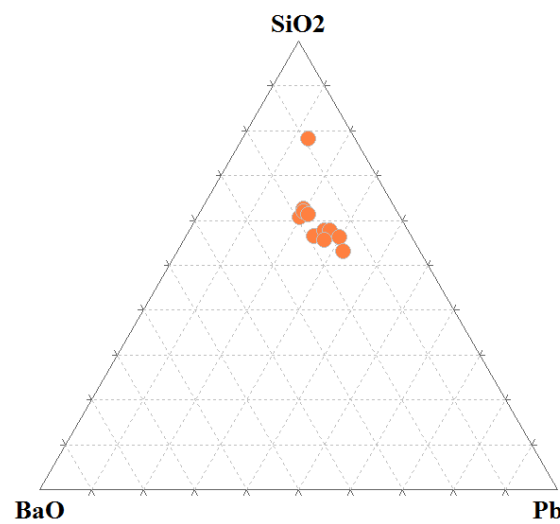
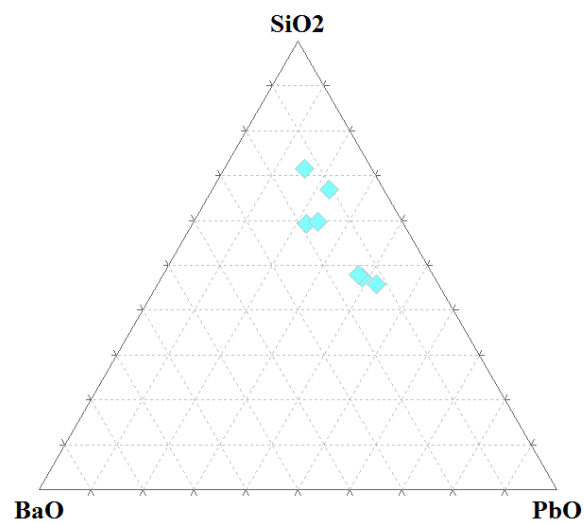
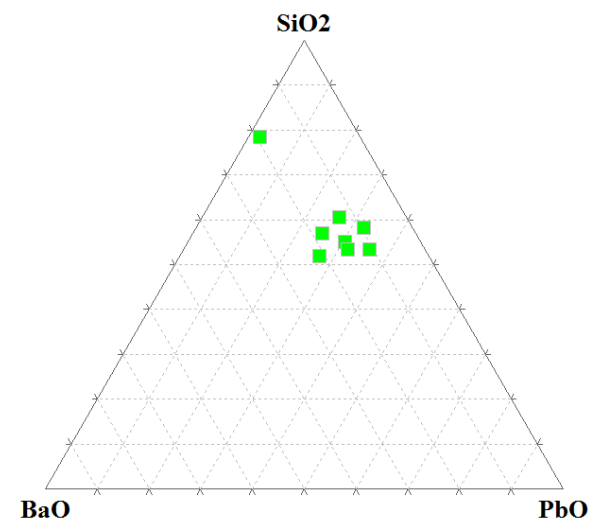
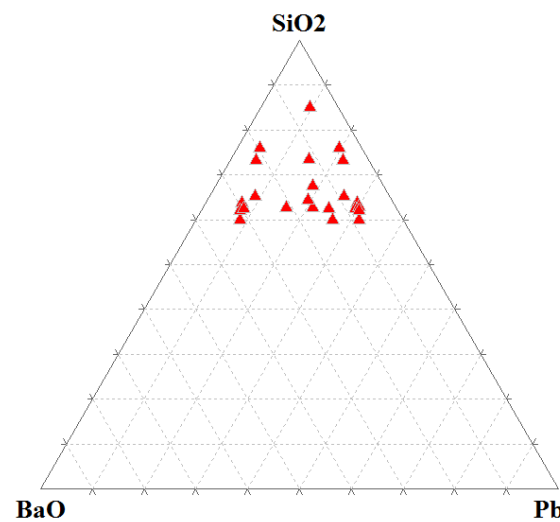
- 1) Due to the detection limits, the quantitative accuracy cannot reach the ppm level, so pXRF is mainly applied for the major and minor element analysis of the glass. The data cannot therefore be applied to study the source of glass raw materials, such as the sand source and the flux source.
- 2) pXRF cannot accurately measure light elements, such as sodium, which is a major component in soda-lime glasses.
- 3) Weathered glass surface shows a sodium loss, which also causes inaccuracy by pXRF surface analysis.

In conclusion, we certainly cannot ignore the contribution of the glass chemical compositional data done by most Chinese researchers, which provides fundamental knowledge about different types of ancient glass circulated in China throughout the history. However, limited research has been carried out to determine the source of the glass materials.

## 2.5 Tri-plots of previously published data of lead-barium glass

Figure 2.17 shows PbO-BaO-SiO<sub>2</sub> tri-plots (normalized so that PbO+BaO+SiO<sub>2</sub> = 100%) for lead-barium glass unearthed from different areas in China, which can reflect the relationship between three major elements in lead-barium glass. The published data with references can be found in Data file S1. It needs to be highlighted that samples unearthed from different areas do not necessarily have to have been produced locally. Yet samples from Hunan, Hubei, Guizhou, Shaanxi and Gansu all show different chemical patterns, which may indicate that there were multiple workshops for the secondary production of lead-barium glass. There is a large variation in the proportions of SiO<sub>2</sub> in the tri-plots, ranging between 90%-40%. The high proportion of SiO<sub>2</sub> in tri-plots is caused not only by relatively low lead-barium proportions, but also due to high concentrations from other elements, such as Al<sub>2</sub>O<sub>3</sub> and CaO. Samples from neighbouring provinces of Hunan and Hubei show similar PbO/BaO ratios around 1:4. However, the total lead-barium proportions for Hunan glass samples were significantly lower than Hubei glass samples. Moreover, Hubei glass samples show a higher Al<sub>2</sub>O<sub>3</sub> concentration. If samples from Hunan and Hubei are considered as two distinct types of lead-barium glasses, why do they have such similar PbO/BaO ratios? Glass unearthed from Jiangsu may help answer this question.

| Location    |            |
|-------------|------------|
| ▲ Chongqing | ■ Gansu    |
| ◆ Guangdong | ● Guizhou  |
| + Henan     | ◆ Hubei    |
| ● Hunan     | ▼ Jiangsu  |
| × Qinghai   | ▼ Shaanxi  |
| ● Sichuan   | ★ Xinjiang |



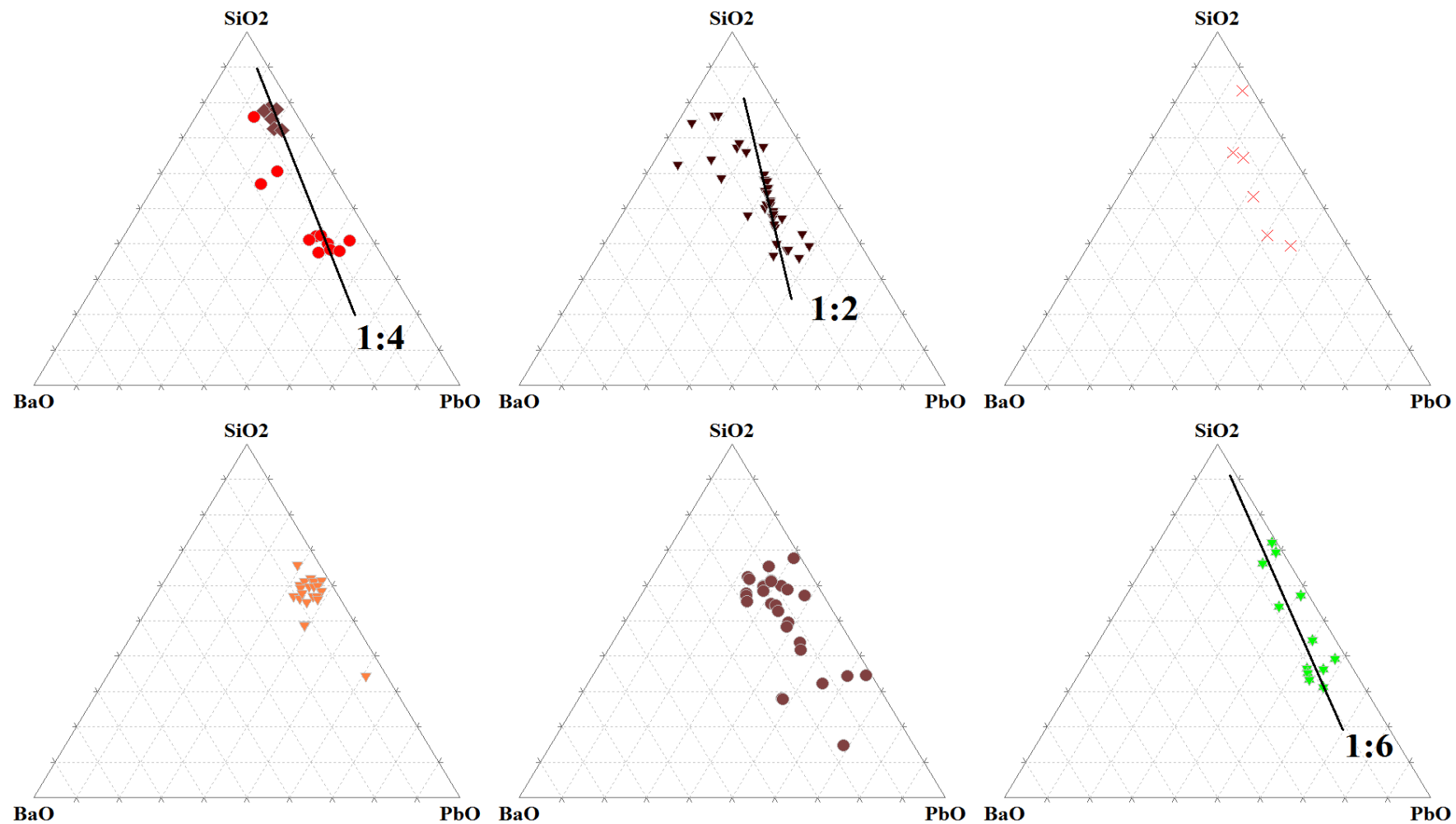


Figure 2.17 PbO-BaO-SiO<sub>2</sub> tri-plots (wt%) of previously published data of lead-barium glass from different provinces in China.

The PbO/BaO/SiO<sub>2</sub> concentrations for glass samples from Jiangsu, Henan and Xinjiang show a large variation, which could be caused by using varied raw materials in the glass fusion process. However, it is still possible to find the linear relations for glasses in these areas, especially for some of the glass samples unearthed from Jiangsu. These samples were an imitation of chimes (musical stones) and were unearthed from the same site. Therefore, it is unlikely that these glass samples were produced in different workshops. The PbO/BaO ratios for some Jiangsu glass chimes fit a linear relation approximately equal to 2, but the SiO<sub>2</sub> varies between 45% to 60% in the tri-plot. It is impossible to change the SiO<sub>2</sub> contents during primary glass production, as the SiO<sub>2</sub>% is fixed by the starting ingredients and the firing conditions. However, the SiO<sub>2</sub> proportion can be altered during secondary glass production. The recycled glass or ingots can be diluted by repeatedly adding lead-barium minerals to the crucible in an open furnace. This could help to maintain glass yields, but the SiO<sub>2</sub> concentration in the glass will fall. Lead and barium minerals could have been mixed with a certain ratio before adding to the glass batch. This could explain why there was a stable PbO/BaO ratio but variable SiO<sub>2</sub> concentrations. The recipe of mixing lead and barium minerals in Hubei and Hunan could have been similar, but they might have used different sources of glass or added different amounts of lead-barium minerals during secondary production. This theory might also be applicable to glass samples from Xinjiang, where the PbO/BaO ratios equal approximately 6 and the proportion of SiO<sub>2</sub> varies between 30% to 80% in the tri-plot. In summary, different assemblages observed from tri-plots

indicate there might have been multiple workshops for producing lead-barium glass, and the linear relations due to the stable PbO/BaO ratios and variable SiO<sub>2</sub> concentration suggested these were secondary glass production workshops.

## **Chapter 3 Background to the Sites from which Glass Beads Have Been Analysed in This Thesis**

One hundred and sixty-three samples analysed in this thesis are collected from five provinces in China. The background to the sites is introduced in this chapter. Detailed information about samples can be found in Chapters 5 and 6. Two hundred and twenty data generated from this research and 161 published data of Mesopotamian and Mediterranean glass used for comparison can be found in Data files S2 and S3. Samples for this study came from Henan, Hubei, Yunnan, Guangxi and Xinjiang in China, provided by the local museums and archaeological institutes (Location of eight sites: Figure 3.1). Sites from Xinjiang, Yunnan and Guangxi were chosen for this research, as they are connected with the North, Southwest and Maritime Silk Roads respectively. These sites are burial sites and were owned by local nomads and minorities. These regions played roles in the cultural and technological exchange between the Central Plains and the West as was introduced in Chapter 1.2. The chemical study of the glass should help to reveal the connections between the Central Plain of China and nomads from the border regions. Broadly speaking, if the glass products from different regions are chemically identical, then we might assume glass products were traded along these regions. The glass samples are all excavated from tomb sites in this study rather than from glass production sites. As a matter of fact, we currently have no archaeological evidence for glass production in China during this period. The trace element analysis

of the glass samples from the border regions, when compared with western glasses, will reveal whether those glasses were locally produced and traded to the Central Plains or were imported from western regions and traded to the Central Plains via the border regions. The number of glass beads available for analysis was strictly controlled by curators. With a limited sample size, our sampling strategy was based on sample typology. Different types of glasses (chemically and typologically) were analysed in this study to reduce the risk of coming up with a biased conclusion. The combination of typological study and chemical study of the glass will help us to understand if there was primary or only secondary glass production in China, despite the lack of archaeological evidence. For instance, if the glass is chemically close to western glass, but typologically has a unique Chinese aesthetics (e.g., jade imitation), this would indicate that the secondary production was performed in China during this period; if the glass is chemically unmatched with any western glass and its typology fits the local preference, then this would suggest both primary and secondary glass production in this region.





**Henan.** Xingyang is a county-level city located near the provincial capital Zhengzhou. Xingyang is considered to be a significant birthplace of the Chinese nation and Chinese culture, since it is the original place of silkworm domestication around 4500 years ago (Zhang and Gao, 1999). Xingyang was a hotly contested spot where several battles took place, including the battle between the Jin and Chu States during the Spring and Autumn period, and battles between the Overlord of Western Chu and the Emperor *Gaozu* 汉高祖 of the Han Dynasty during the late Qin Dynasty. In 2008, thirty-six tombs dating from the Han Dynasty to the Ming Dynasty were excavated during the construction of the Sigma European Industrial Park in Xingyang. Twenty monochrome glass beads were analysed from this site.

**Guangxi.** *Hepu* is considered to be one of the starting points of the Maritime Silk Road in China. During the Han Dynasty, Chinese merchants traded ceramics, silk, to India, Egypt and Rome from *Hepu* Ports, whereas western products were also traded into the Central Plains through *Hepu* Ports, such as glass beads (Xiong and Li, 2011; Zhao, 2016). Jiuzhiling Burials Site is located 4 km south of *Hepu* county. Five tombs were excavated dating to the Eastern Han Dynasty, including four brick-chambered tombs and one timber and brick-chambered tomb. The excavated objects include pottery, bronze objects, iron objects, as well as jade, gold, silver, crystal, agate, amber and glass ornaments (Xiong *et al.*, 2003). Over 5200 glass beads were recovered from the right side of the head of the individual in tomb M5 and on the chest of the individual interred

in tomb M6a. Twenty-seven monochrome glass beads were analysed from this site.

**Yunnan.** As introduced in Chapter 1.2, The trade routes from Sichuan to India via Yunnan were controlled by minorities in Yunnan (e.g., Dian, Gouding and Ailao) before the Eastern Han Dynasty. Samples from Yunnan province are from two sites dating to the Western Han period. Shi Zhai Shan Site is located 6 km west of the Jinning county, 3 km north of the Junior Liang King Mountain, 1 km east of the Zuowei Mountain and 2 km southeast of the Jinsha Mountain. From 1955 to 1996, five excavations were conducted with a total of 86 tombs unearthed. According to the archaeological finds and  $^{14}\text{C}$  dating, this burial site is believed to have been owned by the Dian royal family and the related nobles dating from the Warring States period to the Western Han period (Yang, 2011). Objects unearthed from this site include bronze vessels, gold wares, silver wares, iron wares, jade, agate, and glass, among others. The most significant find is the gold seal owned by the Dian King unearthed in M6 Tomb (Jiang, 1998). According to *'Shi Ji- Biographies of Nanyi'* 史记 西南夷列传 (Sima, 2016), this gold seal was awarded by the Han Wu Emperor in 109 BC. This seal represented the incorporation of the Dian State into the Han Empire, but the Han Wu Emperor still allowed the Dian King to govern his people. Sixteen glass samples were analysed from this site, including 6 glass tubes, 2 melon glass beads, 2 stratified eye beads and 6 monochrome glass beads.

The Mu Yi Site is located in Muyi, Heizhiguo Township, Guangnan County, Wenshan

Zhuang and Miao Autonomous Prefecture. The Mu Yi site is considered to relate to the 'Gouding Culture' during the Han period. According to '*Shi Ji- Biographies of Nanyi*' 史记 西南夷列传 (Sima, 2016), Gouding was a tribe in the same period as the Dian tribe, and the leader was also the Second King authorized by the Han Empire after the Dian King. Combining archaeological discoveries and historical records, the Mu Yi Site previously occupied by the Gouding royal family was about 5 square kilometres centred on the current Mu Yi Dam area. The Mu Yi Site can be divided into eleven zones, including six burial zones, four residential zones and one smelting zone (Yang *et al.*, 2014). Zone 4 located in the centre of the Mu Yi Site is a noble burial zone. M1 Tomb is located in the centre of the noble burial zone and yielded a large number of beads, including glass, turquoise, calcite, and agate beads. Forty-seven monochrome glass beads were analysed from this site.

**Xinjiang.** Xinjiang was mainly controlled by the nomads before the Han Dynasty, and it impacted the trade between the Central Plains of China and the Central Asia regions. The victory of Emperor Wu of the Han Dynasty against the Xiongnu ensured the reopening of the North Silk Road (Details in Chapter 1.2). The Sheng Jin Dian Burial Site is located on the northern slope of Flaming Mountain in Sheng Jin Dian Village, 40 km west of Turpan, Xinjiang. Thirty tombs were excavated from 2007 to 2008. Three types of tombs were identified in this site, 21 rectangular vertical pit tombs, two rectangular vertical pit tombs with a layer of timber covered with crop stalks on the top

of the coffin, and seven rectangular vertical pits with extra caves at one side of the bottom pit (Zhang *et al.*, 2013). Unearthed objects include wooden vessels, pottery, metal wares, leather and wool products, silk textiles, glass beads and wheat seeds. Moreover, mummified corpses are well-preserved at this site. Combining the burial types and archaeological finds, these tombs were dated between 2200 BP and 2050 BP by  $^{14}\text{C}$  dating. The burial types and archaeological finds indicate that this burial site is related to the Jushi 姑师 people. The Jushi kingdom is considered as one of the ‘thirty-six western kingdoms’ established by the indigenous people of the Turpan basin during the 1<sup>st</sup> millennium BC (Mair, 2008). Twelve monochrome glass beads were analysed from this site.

**Hubei.** Hubei was part of the Chu State from the Spring and Autumn period to the Warring States period. Chu State was the largest State among the other six states during the early Warring State period. In 223 BC, the Chu State was conquered by the Qin State. Jiu Lian Dun Cemetery is located in the west of Dongzhaohu Village and Wujin Village, Zaoyang City (Wang, 2003). Nine tombs were discovered on a north-south low hill of the Dahong Mountain. There are three boreholes with a diameter of 0.1 meters in the west of the M2 tomb left by tomb robbers in 1997. Thus, a team with sixty members organized by Hubei Provincial Archaeological Institute conducted a rescue excavation for M1-2 Tombs in 2002. M1 Tomb unearthed 617 objects and M2 Tomb unearthed 587 objects. The unearthed objects include various types of ritual

bronzewares, lacquerwares and ninety musical instruments of seven types. Two horse and chariot pits were discovered to the west of the tombs respectively. The first horse and chariot pit is regarded as the largest in the Chu State so far unearthed with 33 chariots and 72 horses, and the second unearthed seven chariots and 17 horses. According to the unearthed objects and the shape of the tombs, two tombs were classified as the Chu-style tomb dating to the Mid-Late Warring States period. Moreover, the official position of the M1 tomb owner was 'Da Fu' 大夫 (a senior official in feudal China), and the M2 tomb owner could be his wife. One stratified eye bead and two inlaid ring eye beads were analysed from this site.

Marquis Yi was the monarch of Zeng State during the late Western Zhou Dynasty (Early Warring States period). The Tomb of Marquis Yi of Zeng is located at Lei Gu Dun, which is two kilometres west of Suizhou City, Hubei (Tan, 2003). The tomb was classified as a vertical pit tomb with a wooden coffin. The tomb is oriented north-south with an area of 200 m<sup>2</sup>. The Zeng State was a small state during the Warring States period, and no historical record has been found. Still, this tomb unearthed 15,404 objects, such as ritual bronze vessels, musical instruments, weapons, lacquerwares, glass beads. A large number of inscriptions on music theory and rhythm carved on to the bronze chimes indicates Marquis Yi's enthusiasm for the manufacture of musical instruments and the study of rhythm during his lifetime. Finely cast bronze treasures in the tomb, as well as fine paintings, sculptures, and calligraphy were not burial objects

artefacts but were used by Zeng Houyi during his lifetime. Five glass samples were analysed from this site, including 4 stratified eye beads and 1 inlaid ring eye bead.

Jiang Ling Jiu Dian Site is located 1.2-1.5 km southwest of Jinan City, 8.5 km south of Jinzhou City and 2 km north of the Jiudian. At this site, 597 tombs were excavated from 1978 to 1989 and were divided into two groups. According to the pottery typology (no radiocarbon dates were obtained), the first group, consisting of 19 tombs, was dated from the late Western Zhou period to the mid-late Spring and Autumn period; the second group, consisting of 578 tombs, was dated from the mid-late Spring and Autumn period to the end of the Warring States period (Hubei Provincial Institute of cultural relics and Archaeology, 1995; Yang and Han, 1995). Objects unearthed from this site include metal wares, lacquer wares, wooden wares, bamboo slips, leather, silk fabric, jade, glass beads. A majority of the tombs were classified as rectangular vertical pit tombs. Only five cave tombs with a few burial objects were excavated and probably owned by soldiers or prisoners of war from the Qin State. Eight glass samples were analysed from this site, including 3 glass tubes, 2 broken stratified eye beads and 3 inlaid ring eye beads.

# **Chapter 4 The Production and Composition of Chinese Lead-Barium Glass through Experimental Laboratory Replication**

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## **Abstract**

Lead-barium glass appeared during the late Warring States period in China (457 – 221 BC) and was considered as a Chinese invention due to the unique presence of high barium. There is no indication as to how it was made. A set of twenty-four different combinations of possible raw materials were melted to test and systematically evaluate the possible recipes for lead-barium glass. Specifically, the function and source of sodium in lead-barium glass were explored. The results show that sodium source is



crucial for lead-barium a glass forming in this particular system. This paper explores an alternative formulation since sodium flux is not reported in historical Chinese sources, in which the  $\text{Na}_2\text{O}$  is provided by including soda-lime glass in the mixture. This particular formulation provides a potential explanation for the source of the sodium.

**Keywords:** Lead-barium glass; Crucibles; Sodium; Opacifier; Chinese glass

## 4.1. Introduction

Gan *et al.* (2007) argued that the origins of glass-making in China might have been attributed to an accidental by-product of ceramic glaze manufacture. The Chinese term ‘proto-porcelain’ (which in the West is referred to as ‘stoneware’) refers to the low-fired glazed ceramics which appeared from the Shang (~1600 – 1027 BC) to the Zhou (1027 – 221 BC) dynasties. During the production process, it appears that drops of glaze can flow down from the stoneware during the firing process and subsequently produce a glass drop. According to the analysis of glass drops found in the Henglingshan Tomb Site in Boluo, Guangzhou, dating the Early Spring and Autumn period (770 – 476 BC), Gan *et al.* (2007) argued that these drops of glaze were the prototype of Chinese glass beads. Given their rarity and value, they could have been used as jewels or ornaments in the swords of nobles. Hou (1989) suggested that the decorative glass drop on a sword unearthed from M1 Jiangling Wangshanqiao Chu Mausoleum (496 – 464 BC) was an example of wood ash glass through the proton-induced X-ray emission (PIXE) qualitative analysis, and its spectrum was similar to the glaze on the early stoneware.

Through the qualitative analysis, it might be difficult to differentiate between wood ash glass and mineral potassium glass if the MgO and Na<sub>2</sub>O concentrations remain unknown. The glass drop on the sword could be a potash glass bead rather than wood ash glass, as potash glass was commonly discovered in China during this period. Moreover, the wood ash glaze was rarely found in China (except for two analysed by Gan *et al.* (2007) as shown above), whereas natron glass, potash glass and plant ash glass were circulated in China since the Eastern Zhou Dynasty (770 – 256 BC). Therefore, it is open to question whether Chinese glass evolved from stoneware glaze.

The intercultural contacts between nomads along the Eurasia Steppe can be dated to the Bronze Age (Frachetti, 2009; Kuzmina, 2015; Parzinger, 2008). According to scientific research and historical records, the trade between Mediterranean and China through the Eurasian Steppe can be dated to the 10<sup>th</sup> century BC, which was the Late Shang and the Early Zhou Dynasty (He and Wan, 1998). Merchants brought marine products such as shells from the eastern coastal region of China to Taklamakan in the Shang Dynasty (Bao, 2015). Silk was exported from China to Europe in the 4<sup>th</sup> century BC (Gan, 2006). Nomadic people conquered some of the areas of Middle Asia through which the Steppe Route passed in the 1<sup>st</sup> century BC, and the wars that these nomadic people started with neighbouring countries and the robbery of trade caravans almost suspended the commodity circulation between China and Europe (Liu, 2012). When the Qin Empire (221 – 207 BC) united China after the Warring States period, it was soon replaced by

the Han Empire fifteen years later. Due to the low-taxation policy starting from the Early Han Dynasty (202 BC – AD 220), people were wealthy both spiritually and materially by the time of Emperor Wu period (140 – 87 BC). Later, Emperor *Wu Di* 汉武帝 (156 – 87 BC), the 7<sup>th</sup> emperor of the Han Dynasty, commanded officer *Zhang Qian* 张骞 to investigate the old trade route between China, the Middle East and Europe. *Zhang Qian* started his first journey from the city of Chang'an (modern Xi'an) in 139 BC. Merchants joined with *Zhang Qian* for his second investigation in 119 BC, and they gained huge profits during this trip by exchanging their products with foreigners. The prosperous age of commodity circulation along the Northwest (Desert) Silk Road began then, as Egyptians and Romans began purchasing silk products from the Parthians, which had been imported from the Han Empire (Liu, 2012).

Lead-barium glass was invented in China during the Warring States period, probably due to technology exchange with the western world. It has, however, commonly been considered to be a uniquely Chinese-made glass due to its high proportion of barium. This type of glass arose during the Late Warring States period (around the 5<sup>th</sup> century BC) and suddenly disappeared after the Han Dynasty (Li, 1996). A few contemporary documents mention glass, but none of them clearly refer to lead-barium glass. A few glass making recipes have been introduced in Chapter 2.2. In one of the first modern discussions of the chemistry of such glass, Brill and Wosinski (1991) summarised five types of Chinese lead-barium glasses. The main difference between these five groups

was the total concentrations of PbO and BaO, although the PbO/BaO ratios appear to have been fixed at either 3/1 or 3/2. During the last few decades of research on lead-barium glass, it seems that its chemical composition is more complicated than this, meaning that it can no longer be simply summarised as five types. Although the original classification of Brill and Wosinski (1991) has subsequently been shown to be too simplistic, patterns can still be seen in the PbO/BaO ratio for the glass excavated from different regions in China. For example, the average PbO% and BaO% for lead-barium glass excavated from the Shirenzigou Site (Xinjiang) are 49.63% and 7.64% (Wen *et al.*, 2016b). In contrast, PbO/BaO ratios for glass unearthed in Dayunshan Site (Zhejiang) are close to 2 (Gan, 2005, p. 34), whereas the average PbO/BaO ratio for lead-barium glass unearthed in Xi'an is also around 6 (Zhao *et al.*, 2015). Li (1996) collected 534 lead isotopic measurements from ores and compared them with over 250 lead isotopic measurements from glass. The results show that some lead-barium glass with radiogenic lead signature could have been manufactured in Yunnan Province. PCA analysis for lead-barium glass unearthed from different provinces also indicates that there could be multiple workshops producing lead-barium glass in the past (Wen *et al.*, 2016b). These examples not only indicate that there was probably more than one workshop producing lead-barium glass, but also that, given the range of variation measured in the PbO/BaO ratio, the lead-barium minerals were probably separately added to the glass batch.

From the literature, we have assembled a representative database of the composition of Chinese Pb-Ba glass containing in excess of 400 samples (Data file S1), although not all samples report all elements. Taking the median of each major element oxide, we can suggest that a ‘typical’ example of Pb-Ba glass has the following composition (by weight):  $\text{SiO}_2 = 51.39\%$ ,  $\text{PbO} = 27.25\%$ ,  $\text{BaO} = 9.02\%$ ,  $\text{Na}_2\text{O} = 2.27\%$ ,  $\text{Al}_2\text{O}_3 = 3.00\%$ ,  $\text{SO}_3 = 2.20\%$ ,  $\text{CaO} = 1.50\%$ ,  $\text{Cl} = 1.22\%$ . From the BaO-PbO-SiO<sub>2</sub> phase diagram (Toropov *et al.*, 1974), the lowest melting point in the system is approximately 700°C, but for glass of typical Chinese composition the melting point is likely to be in excess of 1000°C – by no means unachievable in ancient furnaces, and illustrating the fluxing power of the PbO. Nevertheless, from the analyses, it is clear that Pb-Ba glass contains low but significant levels of alkalis (median  $\text{Na}_2\text{O} = 2.27\%$ ,  $\text{K}_2\text{O} = 0.57\%$ ) and alkaline earths ( $\text{CaO} = 1.24\%$ ,  $\text{MgO} = 0.53\%$ ). It must be acknowledged that there are limitations in the dataset assembled, particularly in terms of measurements of  $\text{Na}_2\text{O}$ , and also because it is not always certain that the reported samples are glass rather than faience. Many of the analyses were achieved by either XRF or PIXE, and hence the  $\text{Na}_2\text{O}\%$  was either unreported, or may have been underestimated due to the high detection limits of X-ray analytical techniques with respect to light elements (e.g., Li *et al.*, 2005; Zhao *et al.*, 2015). Only 258 of the 401 analyses assembled contain definite values for  $\text{Na}_2\text{O}$ . However, according to wet chemistry and LA-ICP-AES analyses, some lead-barium glass samples can show over 6%  $\text{Na}_2\text{O}$  (e.g., Brill and Rising, 1999; Wen *et al.*, 2016). Figure 4.1 shows the distribution of  $\text{Na}_2\text{O}$  in the dataset, indicating

that a small proportion of samples do indeed have values greater than 6%. Henderson (2013) believes that the contents of  $K_2O$  and  $Na_2O$  are generally negligible in most lead-barium glass, but he classifies those with  $Na_2O$  ranging between 5.29-9.3% as soda-lead-barium glass.

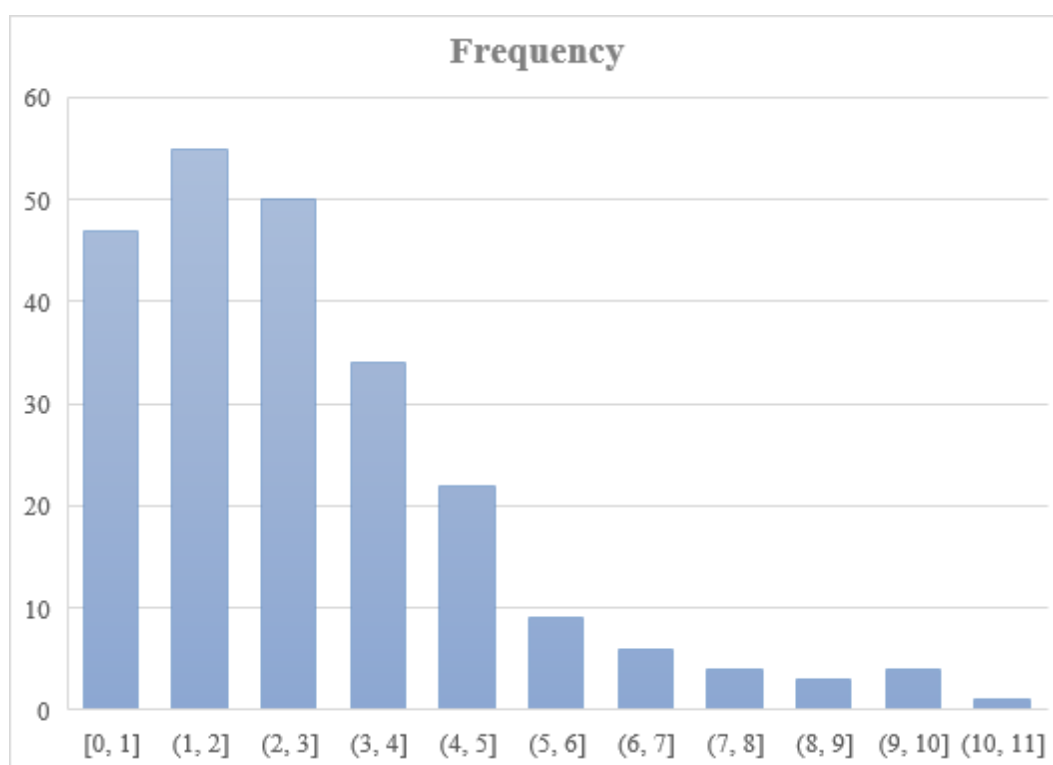


**Figure 4.1 Distribution of %Na<sub>2</sub>O in published analyses of Pb-Ba glass.**

There is no doubt that  $PbO$  functioned as the main flux in lead-barium glass, but there is evidence that other fluxes, especially  $Na_2O$ , also played a role, as discussed above. Cui *et al.* (2011) suggested that the  $Na_2O$  was from a sodium/lime bearing material. Gan (2016) believed that the  $Na_2O$  in lead-barium glass was sourced from mirabilite (Glauber's salt:  $Na_2SO_4 \cdot 10H_2O$ ), which is an evaporite mineral sometimes associated with gypsum ( $CaSO_4 \cdot 2H_2O$ ), perhaps also explaining the  $CaO$  content in lead-barium

glass. Saltpetre ( $\text{KNO}_3$ ) was a commonly used flux for potash glass from the 5<sup>th</sup> century BC to the 4<sup>th</sup> century CE in India, Thailand, Vietnam, China, Korea and Japan (Lankton *et al.*, 2006; Lankton and Dussubieux, 2006; Siqin *et al.*, 2014). Both Qin *et al.* (2016) and Chen (2014) have successfully replicated lead-barium glass by mixing and firing  $\text{SiO}_2$ ,  $\text{PbO}$ ,  $\text{BaCO}_3$  and sodium feldspar (albite -  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ ). They gave no justification for using albite as the source of alkali, but were probably influenced by the use of albite in the bodies of later porcelains (Pollard and Wood, 1986). Brill (2001) suggested that the high sodium in lead-barium glass might be a result of mixing  $\text{PbO}:\text{BaO}:\text{SiO}_2$  (low sodium) glasses with soda-lime glasses, and Cui *et al.* (2011) also believe that the  $\text{Na}_2\text{O}$  and  $\text{CaO}$  may have originated from independent materials. This paper investigates if the alkali is provided by the use of re-cycled soda-lime-silica glass. The average concentration of  $\text{SiO}_2$  is significantly lower in lead-barium glass than in soda-lime glass, so our working hypothesis is that lead-barium glass was made from a mixture of soda-lime glass with lead and barium minerals.

Other synthetic barium-containing materials also have a Chinese origin, Chinese Blue ( $\text{BaCuSi}_4\text{O}_{10}$ ) and Chinese Purple ( $\text{BaCuSi}_2\text{O}_6$ ), regarded as the Chinese analogues of Egyptian Blue (Chen, 2014; Li, 2014). These are synthetic pigments invented during the Qin (221 – 207 BC) and Han dynasties (Xia *et al.*, 2014). Both pigments were used as the blue and purple decoration on the surface of the Terracotta Warriors (Chen, 2014, p. 5; Fitzhugh and Zycherman, 1992). The main difference between lead-barium glass

and lead-barium faience is that the glass has higher  $\text{Na}_2\text{O}$  and  $\text{PbO}$ , and lower  $\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ , and  $\text{CaO}$ , resulting in the lead-barium faience being less vitrified. According to Chen's (2014) replication experiment, 1) by mixing and burning  $\text{BaO/BaCO}_3$ ,  $\text{CuO}$  and  $\text{SiO}_2$  without  $\text{PbO}$  as a flux, Chinese purple were first generated when the temperature reached over  $800^\circ\text{C}$ ; by increasing the temperature with sufficient  $\text{SiO}_2$ , Chinese purple turned into Chinese blue. 2) By mixing  $\text{BaO/BaCO}_3$ ,  $\text{CuO}$  and  $\text{SiO}_2$  with  $\text{PbO}$ , Chinese blue were first generated (over  $800^\circ\text{C}$ ), but then turned into Chinese purple when the temperature kept increasing without sufficient  $\text{SiO}_2$ . Li's (2014) replication experiment shows that by mixing  $\text{CuO}$  and  $\text{SiO}_2$  with lead sources as catalyst,  $\text{BaCO}_3$  is a better source compared with  $\text{BaSO}_4$  to produce Chinese blue and purple. Chinese blue can be produced when the temperature reached  $700^\circ\text{C}$  by using  $\text{BaCO}_3$ , while the firing temperature needs to reach  $1000^\circ\text{C}$  to produce Chinese blue by using  $\text{BaSO}_4$ . As for  $\text{PbO}$ ,  $\text{PbS}$  and  $\text{PbCO}_3$ , they all can be used as flux for producing Chinese blue and purple, but  $\text{PbCO}_3$  shows better catalytic effect compared with the other two.

The aim of this replication experiment is therefore to explore the different possibilities of how lead-barium glass could have been produced by testing a series of probable recipes with varying proportions of each raw material. This paper emphasizes and explores the significance of sodium in the technological process of lead-barium glass production. This is important because although it has been suggested elsewhere that sodium is necessary to produce Pb-Ba glass, it is noteworthy that many analyses either



record low values for  $\text{Na}_2\text{O}$ , or do not report  $\text{Na}_2\text{O}$ , meaning that the role of sodium in the process is not clear. Two hypotheses are tested: (1) whether lead-barium glass can be directly produced by mixing lead, barium and silica sources with controlled ratios, and (2) if it can be produced by mixing natron glass with lead-barium minerals. Moreover, it is also important to understand how different lead and barium minerals could influence the process of glass forming.

## 4.2 Materials and Methods

The aim of this series of experimental firings was to answer a series of questions:

- i) to confirm that melts without a source of sodium did not produce glass at temperatures consistent with ancient glass furnace technologies;
- ii) to estimate the minimum amount of sodium required to produce glass;
- iii) to test the effects of varying the mineralogy of the various sources of lead and barium.

The raw materials used were barite  $\text{BaSO}_4$ , witherite  $\text{BaCO}_3$ , galena  $\text{PbS}$ , lead oxide  $\text{PbO}$ , silica quartz  $\text{SiO}_2$ , lime  $\text{CaCO}_3$ , natron  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ , sodium feldspar (albite)  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ , borax  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ , and copper carbonate  $\text{Cu}_2(\text{OH})_2\text{CO}_3$ , all purchased as laboratory reagents from either Thermo Fisher Scientific or Potclays (<https://www.potclays.co.uk/>). All materials are of greater than 99% purity. In addition, replicated Roman natron glass was provided by Professor Andrew Shortland from

In total, 24 different combinations were fired in high-alumina ceramic crucibles, as listed in Table 4.1. The weight of each batch was approximately 30g in total. For the glass replications a Monometer EF laboratory electric muffle furnace was used, and the firing was conducted in air. The heating rate up to the maximum temperature of 1050°C for six hours was 5°C/min, except in the range 90–110°C when a slower heating rate of 1°C/min was used in order to eliminate humidity. The cooling rate was 2.5°C/min down to 700°C after which the furnace cooled naturally. The furnace was opened after twelve hours. All experimental mixtures were heated in ceramic crucibles, and the outer layer in contact with the crucible was subsequently removed in order to minimize contamination for subsequent analysis. The first five crucibles (1-5 in Table 4.1) were to test whether lead-barium glass can be produced directly by mixing a silica source with different combinations of lead and barium minerals. This helps to confirm that sodium is a necessary component for making lead-barium glass. As for lead and barium sources, differences between BaSO<sub>4</sub> vs BaCO<sub>3</sub> and PbO vs PbS were tested. Crucible 5 additionally contains CuCO<sub>3</sub> to produce a green colour. Crucibles 6-11 were designed to test if lead-barium glass can be directly produced by controlled ratios of soda-lime glass with different lead and barium minerals. Differences between the use of BaSO<sub>4</sub> vs BaCO<sub>3</sub> and PbO vs PbS in the crucible charges were again tested. Crucible 7 additionally contains CuCO<sub>3</sub> to produce a green colour. Crucible 12 was designed to

test if lead-barium glass can be replicated by mixing sodium feldspar (albite) with lead and barium minerals. Crucibles 13-24 can be divided into three groups of four, with each group aimed at replicating one of three published chemical compositions for ancient lead-barium glass, as shown in Table 4.4 (Cui *et al.*, 2009; Shi and Zhou, 1990). The oxides% were converted to minerals% and then re-normalized to 100%. The main difference between the three compositions is the percentage of sodium (1.35%, 2.83% and 9.31% Na<sub>2</sub>O). Each group contains four crucibles, which were designed to test different lead and barium minerals for glass forming. One of the four crucibles in each set was without Na<sub>2</sub>O, again to test the importance of sodium in the charge. The chemical composition of replicated Roman glass is shown in Table 4.4.

**Table 4.1 The weight% of the raw materials for 24 crucibles.**

| Weight%     | SiO <sub>2</sub> | BaCO <sub>3</sub> | BaSO <sub>4</sub> | PbO | PbS | CaCO <sub>3</sub> | Na <sub>2</sub> CO <sub>3</sub> | Na <sub>2</sub> O·Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub> | Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O | Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub> | soda-lime glass |
|-------------|------------------|-------------------|-------------------|-----|-----|-------------------|---------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------|-----------------|
| Crucible 1  | 40               | 15                | -                 | 45  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 2  | 40               | -                 | 15                | -   | 45  | -                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 3  | 30               | -                 | 20                | 50  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 4  | 60               | 10                | -                 | 30  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 5  | 35               | 15                | -                 | 45  | -   | -                 | -                               | -                                                                   | -                                                                 | 5                                                 | -               |
| Crucible 6  | -                | 10                | -                 | 40  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | 50              |
| Crucible 7  | -                | 10                | -                 | 40  | -   | -                 | -                               | -                                                                   | -                                                                 | 5                                                 | 45              |
| Crucible 8  | -                | -                 | 10                | -   | 40  | -                 | -                               | -                                                                   | -                                                                 | -                                                 | 50              |
| Crucible 9  | -                | -                 | 10                | 40  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | 50              |
| Crucible 10 | -                | 20                | -                 | 30  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | 50              |
| Crucible 11 | -                | -                 | 10                | 30  | -   | -                 | -                               | -                                                                   | -                                                                 | -                                                 | 60              |
| Crucible 12 | -                | 10                | -                 | 40  | -   | -                 | -                               | 50                                                                  | -                                                                 | -                                                 | -               |
| Crucible 13 | 55               | 15                | -                 | 25  | -   | 2.5               | 2.5                             | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 14 | 57               | 15                | -                 | 25  | -   | 3                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 15 | 55               | -                 | 15                | 25  | -   | 2.5               | 2.5                             | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 16 | 55               | 15                | -                 | -   | 25  | 2.5               | 2.5                             | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 17 | 33               | 10                | -                 | 45  | -   | 3                 | 5                               | -                                                                   | -                                                                 | 4                                                 | -               |
| Crucible 18 | 33               | 10                | -                 | 50  | -   | 3                 | -                               | -                                                                   | -                                                                 | 4                                                 | -               |
| Crucible 19 | 30               | -                 | 15                | 45  | -   | 2.5               | 4                               | -                                                                   | -                                                                 | 3.5                                               | -               |
| Crucible 20 | 30               | 10                | -                 | -   | 50  | 2.5               | 4                               | -                                                                   | -                                                                 | 3.5                                               | -               |
| Crucible 21 | 43               | 15                | -                 | 25  | -   | 2                 | 15                              | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 22 | 43               | -                 | 15                | 25  | -   | 2                 | 15                              | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 23 | 48               | 20                | -                 | 30  | -   | 2                 | -                               | -                                                                   | -                                                                 | -                                                 | -               |
| Crucible 24 | 30               | 10                | -                 | 20  | -   | 1                 | -                               | -                                                                   | 39                                                                | -                                                 | -               |

After firing and cooling, the crucibles were sectioned by electric saw for cross-sectional observation using SEM-EDS. After carbon coating the sections were analysed using a JSM 5910 scanning electron microscope (SEM) equipped with an Oxford Instrument INCA 300 energy dispersive analyser (EDA). Observations were made primarily in secondary electron mode and EDS analysis was performed using a 20 kV accelerating voltage and a live count time of 100 seconds. Primary standards (type GP40, prepared by P&H Developments Ltd: Table 3.2) were used to quantify the data. Table 3.3 shows the data accuracy and precision by testing Corning standards.

**Table 4.2 RLAHA primary standard block.**

| Standard | Element | Standard Material | Standard | Element   | Standard Material    |
|----------|---------|-------------------|----------|-----------|----------------------|
| 1        | Ti      | Metal             | 21       | Ba        | Barite               |
| 2        | Na      | Albite            | 22       | Ta        | Metal                |
| 3        | Mg      | Pericla           | 23       | Al        | Corundum             |
| 4        | Si, Ca  | Wollastonite      | 24       | Ca, F     | Fluorite             |
| 5        | Ga, P   | Gallium Phosphide | 25       | Sr, F     | Strontium fluoride   |
| 6        | Cr      | Metal             | 26       | Sn        | Cassiterite          |
| 7        | Fe, S   | Pyrite            | 27       | Cd, S     | Cadmium sulphide     |
| 8        | K       | Orthoclase        | 28       | In, As    | Indium arsonide      |
| 9        | Fe      | Metal             | 29       | Hg, Te    | Mercury telluride    |
| 10       | Co      | Metal             | 30       | Bi        | Metal                |
| 11       | Ni      | Metal             | 31       | Au        | Metal                |
| 12       | Cu      | Metal             | 32       | Pt        | Metal                |
| 13       | Zn      | Metal             | 33       | V         | Metal                |
| 14       | Ge      | Metal             | 34       | Andradite | synthetic glass      |
| 15       | Sb      | Metal             | 35       | Pb, Te    | lead telluride       |
| 16       | Rh      | Metal             | 36       | Se        | selenium             |
| 17       | Mo      | Metal             | 37       | Y         | Metal                |
| 18       | Ag      | Metal             | 38       | Mn        | Metal                |
| 19       | Nb      | Metal             | 39       | La, B     | Lanthanum hexaboride |
| 20       | W       | Metal             | 40       | Zr        | Metal                |

**Table 4.3 Precisions and accuracies for major and minor elements based on Corning A, B, and D standards. (Brill and Rising, 1999).**

| Standard  | Elements | Certified | Measured<br>(n=20) | %Error | S.D. | %R.S.D. |
|-----------|----------|-----------|--------------------|--------|------|---------|
| Corning A | Na       | 14.3      | 12.4               | 15.4   | 0.1  | 1.0     |
|           | Mg       | 2.7       | 2.4                | 9.8    | 0.1  | 2.6     |
|           | Al       | 1.0       | 0.8                | 25.2   | 0.1  | 6.0     |
|           | Si       | 67.1      | 69.3               | -3.2   | 0.3  | 0.5     |
|           | K        | 2.9       | 3.1                | -8.1   | 0.1  | 1.7     |
|           | Ca       | 5.0       | 5.2                | -2.9   | 0.1  | 1.5     |
|           | Ti       | 0.8       | 0.9                | -6.6   | 0.0  | 5.0     |
|           | Cu       | 1.2       | 1.2                | -4.3   | 0.1  | 6.0     |
|           | Ba       | 0.6       | 0.6                | 1.4    | 0.1  | 10.3    |
|           | Pb       | 0.1       | 0.0                | /      | 0.0  | /       |
| Corning B | Na       | 17.0      | 14.7               | -13.4  | 0.2  | 1.3     |
|           | Mg       | 1.0       | 0.9                | -8.4   | 0.0  | 3.7     |
|           | Al       | 4.4       | 3.8                | -13.6  | 0.1  | 1.4     |
|           | Si       | 62.3      | 64.7               | 3.9    | 0.3  | 0.5     |
|           | K        | 1.0       | 1.2                | 17.5   | 0.0  | 2.3     |
|           | Ca       | 8.6       | 9.0                | 5.1    | 0.0  | 0.5     |
|           | Ti       | 0.1       | 0.0                | /      | 0.0  | /       |
|           | Cu       | 2.7       | 2.9                | 8.7    | 0.1  | 3.4     |
|           | Ba       | 0.1       | 0.0                | /      | 0.0  | /       |
|           | Pb       | 0.6       | 0.9                | 39.7   | 0.1  | 10.0    |
| Corning D | Na       | 1.2       | 1.1                | 8.3    | 0.1  | 5.0     |
|           | Mg       | 3.9       | 3.6                | 10.5   | 0.1  | 1.5     |
|           | Al       | 5.3       | 4.5                | 17.8   | 0.1  | 1.4     |
|           | Si       | 55.5      | 55.1               | 0.7    | 0.3  | 0.6     |
|           | K        | 11.3      | 11.7               | -3.4   | 0.1  | 1.1     |
|           | Ca       | 14.8      | 14.4               | 2.9    | 0.2  | 1.1     |
|           | Ti       | 0.4       | 0.4                | -10.4  | 0.1  | 17.2    |
|           | Cu       | 0.4       | 0.4                | 0.9    | 0.1  | 14.1    |
|           | Ba       | 0.5       | 0.4                | 16.4   | 0.0  | 5.0     |
|           | Pb       | 0.5       | 0.4                | 9.4    | 0.0  | 10.3    |

## 4.3 Results

A detailed description, including photographs, SEM secondary electron images of cross sections and chemical analyses (where available), is given for each sample in Appendix A. Table 4.4 shows the chemical results (by energy dispersive spectrometry) for 23 crucibles, with the omission of crucible 1, which only retained a limited amount of material after firing.

The results of the experiment can be divided into three broad categories – those which produced transparent glass (6, 7, 8, 9, 10, 11, 17, 18, 19, 20, 21 22, 24) those which produced opaque partially vitrified material (12, 13, 14, 15), and those which gave opaque granular material (2, 3, 4, 5, 16, 23). Crucibles 17 and 18 produced only a thin layer of glass, and their chemical compositions are more close to lead-barium glaze with a low  $\text{Na}_2\text{O}$  concentration (Wood, 1999, p. 193), probably because a large proportion of the crucible charge was lost due to outgassing of  $\text{BaCO}_3$  and  $\text{Cu}_2(\text{OH})_2\text{CO}_3$ . Although crucibles 19 and 20 formed glass, they were considered to be failures since they were high lead glass instead of lead-barium glass according to the EDS analysis (Table 3.4). The transparent glass is generally produced by those crucible charges with the highest input of  $\text{Na}_2\text{O}$ , which is discussed in more detail below. All of the samples made with the synthetic Roman glass (crucibles 6-11) produced transparent glass, apart from the sample made with  $\text{PbS}$  (8, which produced black glass and a thick layer of white  $\text{BaSO}_4$ ). Those glasses made using Roman glass with  $\text{BaCO}_3$  tended to



be yellowish in colour, whereas those with Roman glass and  $\text{BaSO}_4$  were greenish. Crucibles charged with  $\text{SiO}_2$ ,  $\text{PbO}$ ,  $\text{CaCO}_3$ ,  $\text{Na}_2\text{CO}_3$  and either  $\text{BaCO}_3$  (17, 21) or  $\text{BaSO}_4$  (19, 22) all produced translucent glass. Crucible 18 is somewhat exceptional, in that it is the only one to produce transparent glass which contained no  $\text{Na}_2\text{CO}_3$ . It does have a high proportion of  $\text{PbO}$  (and some  $\text{Cu}_2(\text{OH})_2\text{CO}_3$ ) which presumably provided sufficient flux to produce a glass. Crucible 20 used  $\text{PbS}$  as the lead source, and gave a multi-layered product which included a yellow transparent glass as well as a black and green layer. Crucible 24, in which the sodium source was borax  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  also produced a greenish-yellow transparent glass. Our analyses for crucibles 19 and 20 shows that they are high lead glasses with only 1% barium oxide.

The group which produced white or ivory coloured partially vitrified opaque material (12-15) in general had a lower sodium and higher silica content than those in the above group. The least vitrified material (2-5, 16, 23) retained a granular appearance, and had either no or very low sodium.

**Table 4.4 EDS semi-quantitative results (wt.%) for 23 crucibles.**

| Crucible            | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>2</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO  | BaO   | PbO   | Description                                                                          |
|---------------------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|------|-------|-------|--------------------------------------------------------------------------------------|
| 2                   | -                 | -    | -                              | 51.52            | -                             | 0.97            | -                | -    | 1.66             | -    | 5.76  | 40.10 | Pale green opaque granular material                                                  |
| 3                   | -                 | -    | 0.15                           | 23.72            | -                             | 7.97            | -                | -    | 1.53             | -    | 18.63 | 48.01 | White opaque granular material                                                       |
| 4                   | -                 | -    | -                              | 70.43            | -                             | -               | -                | -    | -                | -    | 4.92  | 24.65 | White opaque granular material, partially vitrified                                  |
| 5                   | -                 | -    | -                              | 47.20            | -                             | -               | -                | -    | 0.34             | 3.87 | 11.12 | 37.48 | Dark blue opaque granular material                                                   |
| 6                   | 6.78              | 0.83 | 1.56                           | 34.81            | -                             | -               | 0.63             | 3.23 | -                | -    | 8.86  | 43.33 | Yellowish transparent glass with cracks                                              |
| 7                   | 6.23              | 0.81 | 1.44                           | 32.79            | -                             | -               | 0.55             | 3.11 | -                | 3.70 | 8.45  | 42.94 | Blue transparent glass with cracks                                                   |
| 8                   | 6.49              | 1.09 | 1.55                           | 44.61            | -                             | -               | 0.66             | 4.31 | -                | -    | 8.62  | 32.69 | Black transparent glass with a layer of white dendritic crystalline material         |
| 9                   | 7.07              | 0.92 | 1.73                           | 44.31            | -                             | -               | 0.88             | 4.47 | -                | -    | 5.60  | 35.02 | Greenish transparent glass with a layer of white flocculent material                 |
| 10                  | 7.79              | 0.83 | 1.37                           | 37.87            | -                             | -               | 0.56             | 3.49 | -                | -    | 17.14 | 30.98 | Yellowish transparent glass with cracks and partial layer of white opaque crystals   |
| 11                  | 6.90              | 0.88 | 1.79                           | 39.25            | -                             | -               | 0.59             | 3.77 | -                | -    | 5.85  | 40.98 | Greenish transparent glass with white opaque layer on top                            |
| 12                  | 3.85              | -    | 9.65                           | 33.39            | -                             | -               | 0.44             | 0.74 | -                | -    | 10.55 | 41.40 | Ivory opaque partially vitrified material with air bubbles on the top layer          |
| 13                  | 1.01              | -    | -                              | 60.66            | -                             | -               | -                | 1.07 | -                | -    | 10.97 | 26.30 | White opaque partially vitrified material with big gas bubbles                       |
| 14                  | -                 | -    | -                              | 64.92            | -                             | -               | -                | 1.65 | -                | -    | 11.39 | 22.05 | White opaque partially vitrified material with big gas bubbles                       |
| 15                  | 1.14              | -    | -                              | 68.95            | 0.47                          | -               | -                | 1.46 | -                | -    | 2.47  | 25.53 | White opaque partially vitrified material                                            |
| 16                  | 1.09              | -    | -                              | 67.37            | -                             | 1.39            | -                | 1.21 | 0.59             | -    | 4.87  | 23.49 | Pale blue opaque granular material with large bubbles                                |
| 17                  | 2.54              | -    | 0.22                           | 35.39            | -                             | -               | 0.44             | 1.96 | -                | 3.20 | 8.99  | 47.27 | Emerald green translucent glass                                                      |
| 18                  | -                 | -    | -                              | 35.28            | -                             | -               | -                | 1.75 | -                | 3.45 | 7.98  | 51.54 | Emerald green translucent glass                                                      |
| 19                  | 1.92              | -    | -                              | 37.26            | -                             | -               | 0.13             | 1.93 | -                | 3.00 | 1.71  | 54.06 | Green transparent glass with a layer of green and white opaque crystalline material  |
| 20                  | 1.45              | -    | -                              | 37.58            | -                             | -               | -                | 1.83 | -                | 1.28 | 1.09  | 56.78 | Yellow transparent glass with a layer of green and white opaque crystalline material |
| 21                  | 7.51              | -    | -                              | 48.11            | -                             | -               | 0.28             | 1.40 | -                | -    | 14.15 | 28.56 | Greenish transparent glass with cracks                                               |
| 22                  | 5.84              | -    | -                              | 59.59            | -                             | -               | -                | 1.23 | -                | -    | 6.00  | 27.35 | Greenish transparent glass with white opaque crystalline material on the top surface |
| 23                  | -                 | -    | -                              | 51.08            | -                             | -               | -                | 1.05 | 1.13             | -    | 20.19 | 26.57 | White granular opaque material with big gas bubbles                                  |
| 24                  | 8.48              | -    | 0.68                           | 46.04            | -                             | -               | 0.63             | 1.00 | -                | -    | 12.05 | 31.14 | Greenish-yellow transparent glass                                                    |
| Natron glass        | 15.93             | 1.61 | 2.88                           | 70.89            | -                             | -               | 0.80             | 7.89 | -                | -    | -     | -     | Transparent                                                                          |
| White glass Bead    | 1.35              | 0.20 | 1.10                           | 55.57            | 0.14                          | -               | 1.05             | 1.26 | 0.08             | 0.42 | 11.62 | 26.64 | (Cui <i>et al.</i> , 2009)                                                           |
| Green glass Bi disk | 2.83              | 0.28 | 1.15                           | 34.75            | 0.10                          | -               | 0.29             | 1.71 | 0.03             | 1.48 | 8.54  | 48.46 | (Cui <i>et al.</i> , 2009)                                                           |
| Glass Earring       | 9.31              | 2.16 | 1.66                           | 45.85            | -                             | -               | 0.34             | 0.77 | -                | -    | 12.93 | 27.25 | (Shi and Zhou, 1990)                                                                 |

## 4.4. Discussion

### 4.4.1 The prerequisite of a sodium source

PbO is classified as an intermediate in terms of glass structure, meaning that it cannot itself form a glass, but that it can enter the network of other glass-forming oxides (in this case, SiO<sub>2</sub>). When the PbO concentration is above c. 50 mol%, the co-ordination number of Pb is about 3, and PbO switches from being a network modifier to a network former, in which the network consists of PbO<sub>3</sub><sup>2-</sup> trigonal pyramids linked to SiO<sub>4</sub><sup>2-</sup> tetrahedra (Takaishi *et al.*, 2000). As shown in Figure 4.1, the previously analysed examples of Chinese Pb-Ba glass tend to contain amounts of Na<sub>2</sub>O up to 10%. The question to be addressed here is why, with so much PbO available to act as a network modifier, does Na<sub>2</sub>O appear to be necessary to form lead-barium glass? Table 4.5 compares calculated sodium compositions according to the recipes presented in Table 3.1 with the measured chemical compositions for each crucible (from Table 4.4). The calculated value was obtained by mathematically converting each component in the charge into an oxide formulation, and then normalizing the sum of these oxides to 100%. Figure 4.2 shows the SiO<sub>2</sub>-Na<sub>2</sub>O-PbO+BaO phase diagrams of components in charge and in product. As shown, a certain amount of Na<sub>2</sub>O plays an essential role for lead-barium glass forming compared with failures. Transparent glass (or crucibles containing a component of transparent glass) was formed most easily when the charge contained high levels of Na<sub>2</sub>O – apart from crucible 17 and 18 (with low or no Na<sub>2</sub>O), all charges

contained greater than 7% being more typical. Conversely, the crucibles which did not vitrify contained  $<1.5\%$   $\text{Na}_2\text{O}$ , with the exception of crucible 12, which contained 5.92%  $\text{Na}_2\text{O}$  in the form of albite ( $\text{NaAlSi}_3\text{O}_8$ ). It is therefore clear that under the conditions of this experiment sodium can facilitate glass formation in the lead-barium-silica system.

**Table 4.5 The comparison of calculated and measured chemical compositions for crucibles formed glass.**

| Crucible                   | Charge                                                                                                                                                            | Result                                                                               | %Na <sub>2</sub> O in Charge | %Na <sub>2</sub> O in Product |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------|-------------------------------|
| Transparent glass          |                                                                                                                                                                   |                                                                                      |                              |                               |
| 6                          | 10 BaCO <sub>3</sub> /40 PbO/50 RG                                                                                                                                | Yellowish transparent glass with cracks                                              | 8.0                          | 6.8                           |
| 7                          | 10 BaCO <sub>3</sub> /40 PbO/45 RG/5 Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub>                                                                            | Blue transparent glass with cracks                                                   | 7.2                          | 6.2                           |
| 8                          | 10 BaSO <sub>4</sub> /40 PbS/50 RG                                                                                                                                | Black transparent glass with a layer of white dendritic crystalline material         | 8.0                          | 6.5                           |
| 9                          | 10 BaSO <sub>4</sub> /40 PbO/50 RG                                                                                                                                | Greenish transparent glass with a layer of white flocculent material                 | 8.0                          | 7.1                           |
| 10                         | 20 BaCO <sub>3</sub> /30 PbO/50 RG                                                                                                                                | Yellowish transparent glass with cracks and partial layer of white opaque crystals   | 8.0                          | 7.8                           |
| 11                         | 10 BaSO <sub>4</sub> /30 PbO/60 RG                                                                                                                                | Greenish transparent glass with white opaque layer on top                            | 9.6                          | 6.9                           |
| 17                         | 33 SiO <sub>2</sub> /10 BaCO <sub>3</sub> /45 PbO/3 CaCO <sub>3</sub> /5 Na <sub>2</sub> CO <sub>3</sub>                                                          | Emerald green translucent glass                                                      | 2.9                          | 2.5                           |
| 18                         | 33 SiO <sub>2</sub> /10 BaCO <sub>3</sub> /50 PbO/3 CaCO <sub>3</sub> /4 Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub>                                        | Emerald green translucent glass                                                      | 0.0                          | 0.0                           |
| 19                         | 30 SiO <sub>2</sub> /15 BaSO <sub>4</sub> /45 PbO/2.5 CaCO <sub>3</sub> /4 Na <sub>2</sub> CO <sub>3</sub> /3.5 Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub> | Green transparent glass with a layer of green and white opaque crystalline material  | 2.3                          | 1.9                           |
| 20                         | 30 SiO <sub>2</sub> /10 BaCO <sub>3</sub> /50 PbS/2.5 CaCO <sub>3</sub> /4 Na <sub>2</sub> CO <sub>3</sub> /3.5 Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub> | Yellow transparent glass with a layer of green and white opaque crystalline material | 2.3                          | 1.5                           |
| 21                         | 43 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /25 PbO/2 CaCO <sub>3</sub> /15 Na <sub>2</sub> CO <sub>3</sub>                                                         | Greenish transparent glass with cracks                                               | 8.8                          | 7.5                           |
| 22                         | 43 SiO <sub>2</sub> /15 BaSO <sub>4</sub> /25 PbO/2 CaCO <sub>3</sub> /15 Na <sub>2</sub> CO <sub>3</sub>                                                         | Greenish transparent glass with white opaque crystalline material on the top surface | 8.8                          | 5.8                           |
| 24                         | 30 SiO <sub>2</sub> /10 BaCO <sub>3</sub> /20 PbO/1 CaCO <sub>3</sub> /39 Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> .12H <sub>2</sub> O                       | Greenish-yellow transparent glass                                                    | 6.3                          | 8.5                           |
| Opaque partially vitrified |                                                                                                                                                                   |                                                                                      |                              |                               |
| 12                         | 10 BaCO <sub>3</sub> /40 PbO/50 albite                                                                                                                            | Ivory opaque partially vitrified material with air bubbles on the top layer          | 5.9                          | 3.9                           |
| 13                         | 55 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /25 PbO/2.5 CaCO <sub>3</sub> /2.5 Na <sub>2</sub> CO <sub>3</sub>                                                      | White opaque partially vitrified material with big gas bubbles                       | 1.5                          | 1.0                           |
| 14                         | 57 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /25 PbO/3 CaCO <sub>3</sub>                                                                                             | White opaque partially vitrified material with big gas bubbles                       | 0.0                          | 0.0                           |
| 15                         | 55 SiO <sub>2</sub> /15 BaSO <sub>4</sub> /25 PbO/2.5 CaCO <sub>3</sub> /2.5 Na <sub>2</sub> CO <sub>3</sub>                                                      | White opaque partially vitrified material                                            | 1.5                          | 1.1                           |
| Opaque granular            |                                                                                                                                                                   |                                                                                      |                              |                               |
| 2                          | 40 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /45 PbO                                                                                                                 | Pale green opaque granular material                                                  | 0.0                          | 0.0                           |
| 3                          | 40 SiO <sub>2</sub> /15 BaSO <sub>4</sub> /45 PbS                                                                                                                 | White opaque granular material                                                       | 0.0                          | 0.0                           |
| 4                          | 60 SiO <sub>2</sub> /10 BaCO <sub>3</sub> /30 PbO                                                                                                                 | White opaque granular material, partially vitrified                                  | 0.0                          | 0.0                           |
| 5                          | 35 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /45 PbO/5 Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub>                                                             | Dark blue opaque granular material                                                   | 0.0                          | 0.0                           |
| 16                         | 55 SiO <sub>2</sub> /15 BaCO <sub>3</sub> /25 PbS/2.5 CaCO <sub>3</sub> /2.5 Na <sub>2</sub> CO <sub>3</sub>                                                      | Pale blue opaque granular material with large bubbles                                | 1.5                          | 1.1                           |
| 23                         | 48 SiO <sub>2</sub> /20 BaCO <sub>3</sub> /30 PbO/2 CaCO <sub>3</sub>                                                                                             | White granular opaque material with big gas bubbles                                  | 0.0                          | 0.0                           |

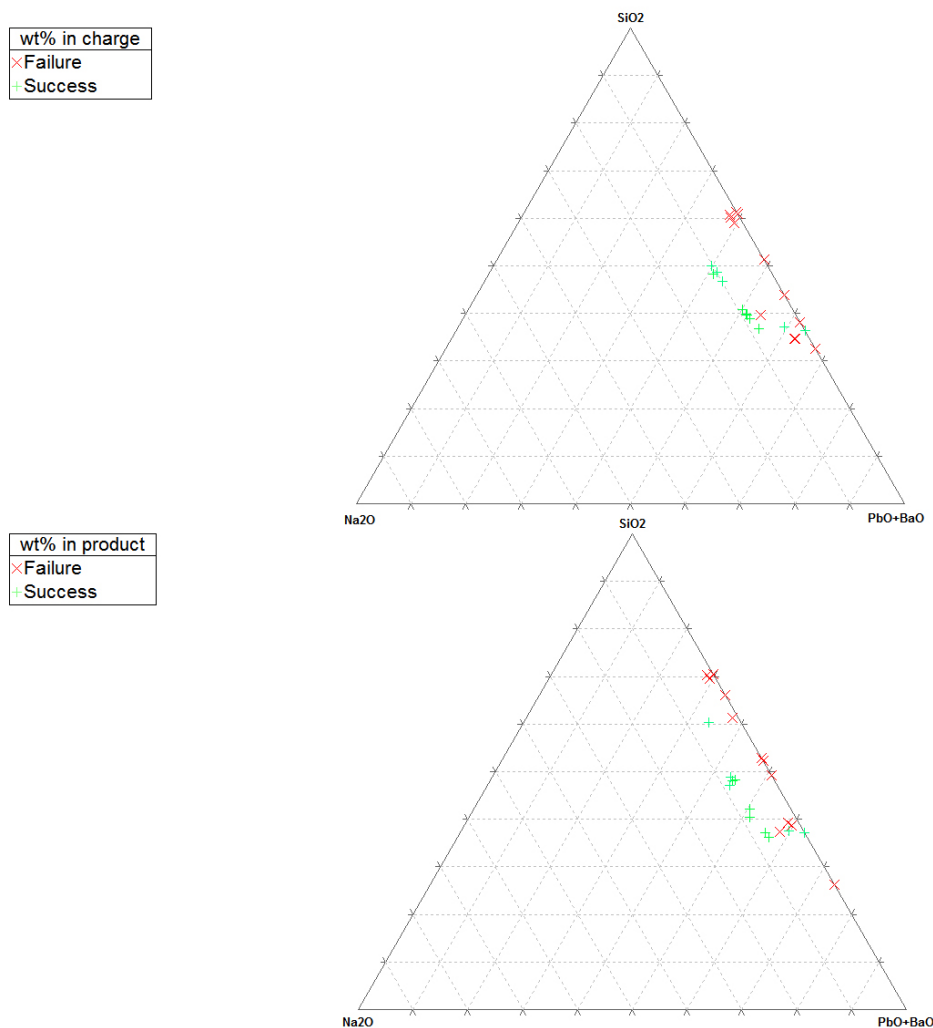


**Figure 4.2 SiO<sub>2</sub>-Na<sub>2</sub>O-PbO+BaO phase diagrams of components in charge and in product.**

The data in Table 4.5 and Figure 4.2 show that the measured Na<sub>2</sub>O% values are lower than the calculated Na<sub>2</sub>O%, which could be a flux loss during the melting process. Still, it is noticeable that the crucibles using BaSO<sub>4</sub>, such as 11 and 22, show a higher loss of Na<sub>2</sub>O (about 3%). According to the EDS chemical data and the mapping results (Appendix A), the white material (opacifier phase) in crucibles 11 and 22 contain a certain amount of Na<sub>2</sub>SO<sub>4</sub>, suggesting that Na<sub>2</sub>O partly separated out of the glass phase and formed Na<sub>2</sub>SO<sub>4</sub> in opacifier phase. This would explain the loss of Na<sub>2</sub>O in the glass phase. Nevertheless, it is immediately apparent that all the samples which produced

transparent glass generally contain more than 7% Na<sub>2</sub>O, whereas comparison with Figure 4.1 shows that most of the lead-barium glass analysed to date appears to have values around 2%. As noted above, there are two other possible reasons why Na<sub>2</sub>O% might be underestimated in the literature: i), XRF analysis can underestimate Na<sub>2</sub>O%, and ii) weathering effects can result in the loss of Na<sub>2</sub>O.

There are three possibilities for the deliberate addition of sodium to these Pb-Ba glasses:

- i) direct addition of a mineral which contains sodium (e.g., natron, albite, mirabilite),
- ii) direct addition of a soda-rich plant ash,
- iii) indirect addition, via the re-use of glass which already contains sodium.

There is no archaeological evidence to suggest that Chinese glass makers could produce soda-lime glass during the Warring States period and the Han Dynasty, and nor are there any literary sources which suggest that other contemporaneous Chinese vitreous materials used a mineral or plant-based sodium source as the flux during this period. According to *Wei Shu- Darouzhi* 魏书 大月氏 (edited by Wei Shou 魏收 in AD 555: Wei, 1997), during the *Wei Taiwu* 魏太武 period (AD 408 –452), the merchants from Middle Asia taught the Chinese to produce primary coloured glass (Bezboradov and Zadneprovskii, 1967). This is the earliest documentation about glass making in China. Thus, although there are numerous soda-lime silica glass beads found in early China, they are all assumed to be imported from Western Asia (Li *et al.*, 2013). Commonly

used flux for the silicate materials during the Warring States and the Han periods were lead and wood ash rather than a natron source. As for Chinese lime based ceramic glazes, the source of lime initially was from wood ash, and subsequently replaced by limestone (Wood, 1999). The low-temperature lead-glazed ceramics (and lead-barium glazed) appeared no later than the Han Dynasty, and were only used for burial and architectural objects (Wang *et al.*, 2019; Wood, 1999; Yin *et al.*, 2020). According to the published data for lead-barium glass, the potassium and magnesium concentrations (medians 0.57% and 0.53% respectively from the published literature) are too low to represent a plant ash flux (Wen *et al.*, 2016b), where typical values would be both greater than 1.5% respectively (Rehren and Freestone, 2015). This effectively rules out the direct production of Pb-Ba glass using soda-rich plant ash, as was common in Western Asia. The known mineral soda-rich sources used in ancient western Eurasian glass could either be a natron (evaporite) source, such as that from Egypt, or a reh (saline soil) source from the Indo-pacific region, both of which have analogous occurrences in China. A mineral source of sodium cannot therefore be ruled out in the production of Pb-Ba glass, and both the experiments reported here (crucibles 17-22, 24) and those of previous researchers (Chen, 2014; Li, 2010; Qin *et al.*, 2016) have shown that this is plausible. There is, however, no evidence that the Chinese knew the function of mineral forms of sodium in the production of vitreous artefacts during this period. Also, the minor element composition of Pb-Ba glass (i.e., K<sub>2</sub>O, CaO, MgO, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>) could also be explained by the use of imported soda-lime glass as the sodium source. The Levantine coast appears to have been the location of large-scale glass making in



antiquity (Degryse, 2014), which could be source of soda-lime glass.

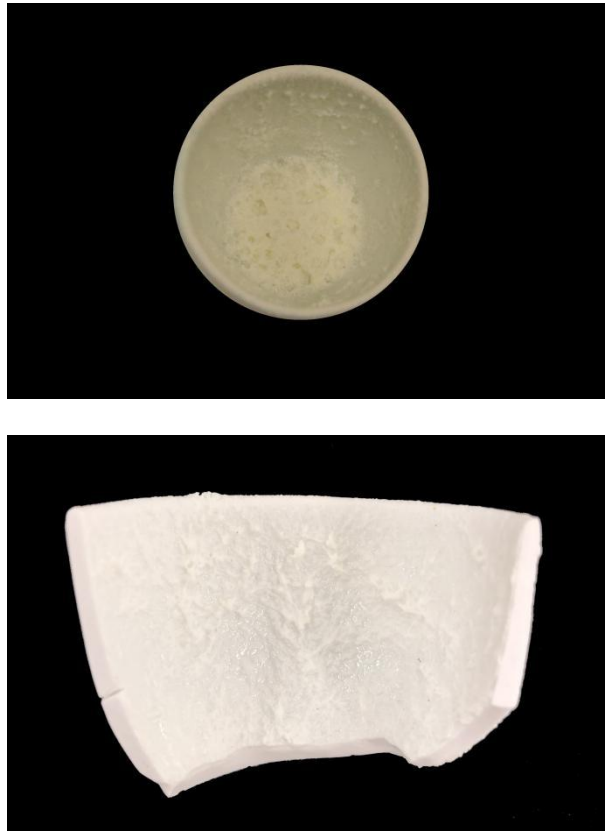
#### 4.4.2 Opaque Glass

Chinese Pb-Ba glass can be either transparent or opaque. Many of the products listed in Table 4.4 show that a clear glass is produced but with an opaque crystalline material on the surface (crucibles 8-11, 19, 20, 22). In most cases this white material is identified as  $\text{BaSO}_4$  and  $\text{BaSi}_2\text{O}_5$  from the stoichiometry of the chemical analysis (Appendix A: crucible 11). According to this replication experiment, it is apparent that more white opaque material can be generated by mixing  $\text{BaSO}_4$  and  $\text{PbO}$  with natron glass rather than by using  $\text{BaCO}_3$  as the barium source. It is possible, therefore, that both  $\text{BaSO}_4$  and  $\text{BaCO}_3$  were used selectively in the past to control for the degree of opacity. In our work, the crucibles with  $\text{BaSO}_4$  generated both  $\text{BaSi}_2\text{O}_5$  and unmelted  $\text{BaSO}_4$  which can function as opacifiers, although in our replications  $\text{BaSO}_4$  forms on the top of the glass rather than being uniformly dispersed within the glass. It might not be possible to produce white opaque lead-barium glass during primary glass production due to potential separation of the opaque materials during the slow cooling down process. As colouring and opacifying agents could be added to the glass batch during the secondary production or the recycling process (Abd-Allah, 2010; Freestone, 2015), we suggest that the products of the primary melting might have needed to be re-melted to mix the opacifier into the glass.

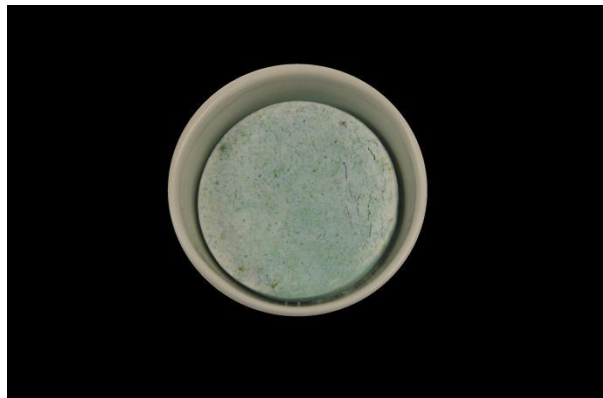
## 4.5. Conclusions

The direct mixing and firing of lead and barium minerals with silica cannot easily produce lead-barium glass, and the chemical analysis of a large number of Chinese Pb-Ba glasses show that the  $\text{Na}_2\text{O}$  concentration is typically between 2 and 10%, suggesting that a source of sodium was deliberately included in the melt as an additional flux. The use of a source of sodium to successfully achieve lead-barium glasses is connected with the fact that it could also lower the melting point of this kind of glasses. As the high proportion of BaO influences the vitrification process, thus, additional  $\text{Na}_2\text{O}$  is necessary. Indeed, increasing PbO content could contribute to the glass formation, but the relatively lower BaO proportions might no longer function as the opacifier. The experiments reported here have shown that lead-barium glass can easily be achieved by mixing imported soda-lime glass with mineral sources of PbO and either  $\text{BaCO}_3$  or  $\text{BaSO}_4$ . The direct use of PbS was less successful, but in practice prior roasting would have converted this to the oxide form. If we accept that soda-lime silica glass was imported into China from the west during the Warring States period (which it must have been if we believe that China did not make soda-lime silica glass), then it is easy to see how some of this material could have been used as a raw material to locally make Pb-Ba glass. The impetus for this would probably have been the desire to produce synthetic jade. The disappearance of this type of glass could then subsequently be explained by the disruption of trade at the end of the Han Dynasty, in which no more primary glass was imported across the Silk Roads. The frequent change of dynasties after the Han Dynasty might have played a crucial role in these developments.

## 4.6. Appendix A

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                   |                                       |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|
|  | <p><b>Description</b><br/><b>Crucible 1</b><br/><b>White opaque.</b><br/><b>Failure</b><br/><b><math>\text{SiO}_2/\text{BaCO}_3/\text{PbO}=40/15/45</math></b></p> <p>The mixture escaped from the crucible during the firing, and only an inhomogeneous thin layer of white material with granular structure remains on the bottom and wall of the crucible.</p> | <p><b>SEM-EDS:</b><br/><b>N/A</b></p> |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|

**Chemical composition: N/A**

|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 2</b><br/> <b>Pale green opaque.</b><br/> <b>Failure</b><br/> <b>SiO<sub>2</sub>/BaCO<sub>3</sub>/PbS=40/15/45</b></p> <p>The mixture shrank after the firing, which generated a pale green opaque material with granular structure separated from the crucible wall. Crucible was contaminated by CuCO<sub>3</sub> from other crucibles during the firing process, resulting in green colour.</p> <p>The material at the bottom is black, probably due to the PbS. The upper layer shows bigger gas bubbles.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|

**Chemical composition:**

|      | 2 | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>2</sub> | K <sub>2</sub> O | CaO | TiO <sub>2</sub> | CuO | BaO  | PbO  |
|------|---|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|-----|------------------|-----|------|------|
| Bulk | - | -                 | -   | 51.52                          | -                | 0.97                          | -               | -                | -   | 1.66             | -   | 5.76 | 40.1 |

|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                             |                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 3</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <b>SiO<sub>2</sub>/BaSO<sub>4</sub>/PbO=30/20/50</b></p> <p>A red dot can be observed on the top centre of the white opaque material with granular structure, which is unmelted PbO. The edge of this material seems loosened, probably due to the trapped gas bubbles.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|

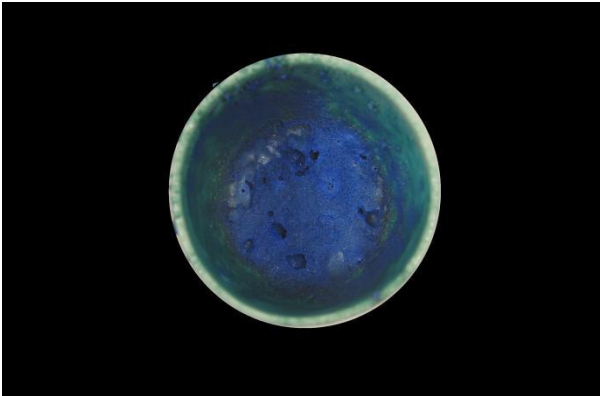
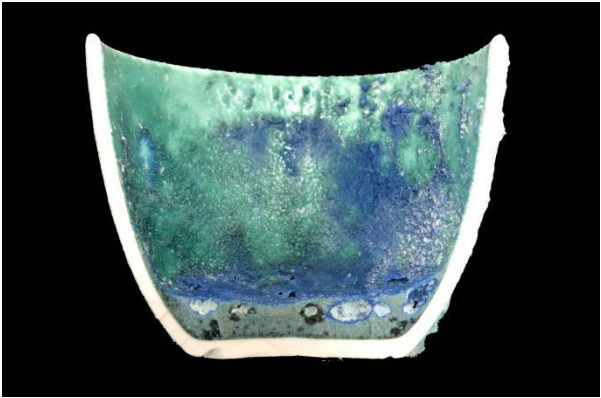
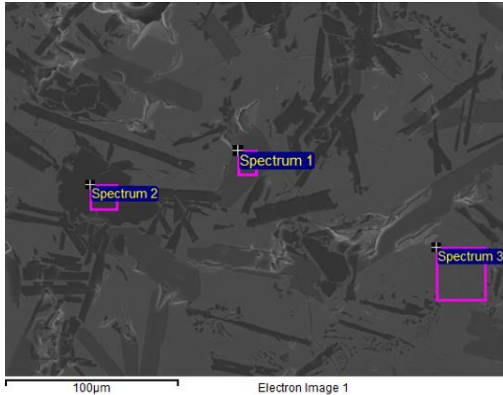
**Chemical composition:**

| 3    | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>2</sub> | K <sub>2</sub> O | CaO | TiO <sub>2</sub> | CuO | BaO   | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|-----|------------------|-----|-------|-------|
| bulk | -                 | -   | 0.15                           | 23.72            | -                             | 7.97            | -                | -   | 1.53             | -   | 18.63 | 48.01 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                      |                                        |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 4</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <b>SiO<sub>2</sub>/BaCO<sub>3</sub>/PbO=60/10/30</b></p> <p>The white material with granular structure partly separated from the crucible wall. The trapped air bubbles can be observed between the white material and the crucible wall.</p> <p>Part vitrified material can be observed from the cross-section.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                      |                                        |

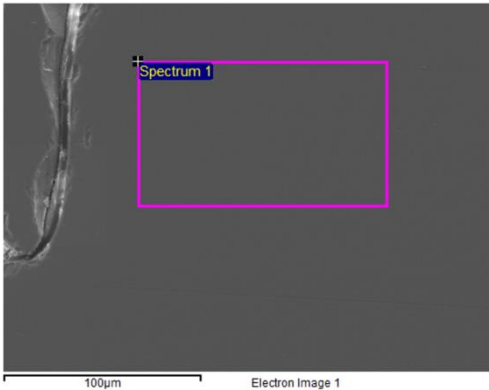
**Chemical composition:**

| 4    | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>2</sub> | K <sub>2</sub> O | CaO | TiO <sub>2</sub> | CuO | BaO  | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|-----|------------------|-----|------|-------|
| bulk | -                 | -   | -                              | 70.43            | -                             | -               | -                | -   | -                | -   | 4.92 | 24.65 |

|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 5</b><br/> <b>Green opaque on glaze surface and Dark blue opaque at the bottom.</b></p> <p><b>Failure</b><br/> <b><math>\text{SiO}_2/\text{BaCO}_3/\text{PbO}/\text{CuCO}_3=35/15/45/5</math></b></p> <p>The mixture escaped from the crucible during the firing, and an inhomogeneous thin layer of material with granular structure remains at the bottom and partly on the wall of the crucible. Some parts of the crucible wall show a green colour rather than a blue colour, probably due to melted <math>\text{CuCO}_3</math> into the crucible glaze.</p> <p>The cross section shows a greenish colour and dark dots can also be observed.</p> | <p><b>SEM-EDS: body</b></p>  <p>Spec1: Chinese blue<br/> Spec2: Silica quartz<br/> Spec3: Virtified phase</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

#### Chemical composition:

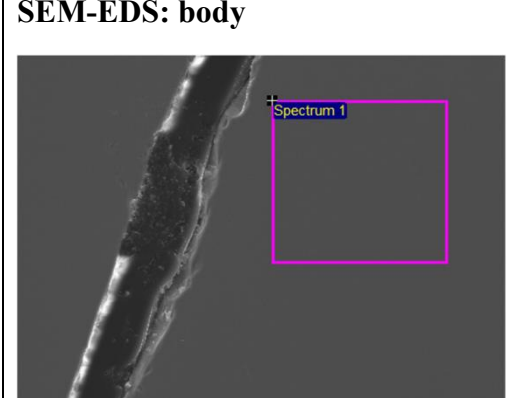
| 5    | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO | TiO <sub>2</sub> | FeO | CuO   | BaO   | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|-----|------------------|-----|-------|-------|-------|
| Bulk | -                 | -   | -                              | 47.2             | -                             | -               | -                | -   | 0.34             | -   | 3.87  | 11.12 | 37.48 |
| Sp1  | -                 | -   | -                              | 48.48            | -                             | -               | -                | -   | -                | -   | 17.38 | 32.3  | 1.84  |
| Sp2  | -                 | -   | -                              | 100.00           | -                             | -               | -                | -   | -                | -   | -     | -     | -     |
| Sp3  | -                 | -   | -                              | 31.06            | -                             | -               | -                | -   | -                | -   | 2.83  | 10.64 | 55.46 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                 |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b></p> <p><b>Crucible 6</b></p> <p><b>Yellowish transparent with white opaque on the top edge.</b></p> <p><b>Success</b></p> <p><b>Roman glass/BaCO<sub>3</sub>/PbO=5/1/4</b></p> <p>A thin layer of white flocculent material separated out of the glass and remains on the top edge. Cracks can be observed in the glass.</p> <p>Small gas bubbles can be observed from the cross-section.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                 |

**Chemical composition:**

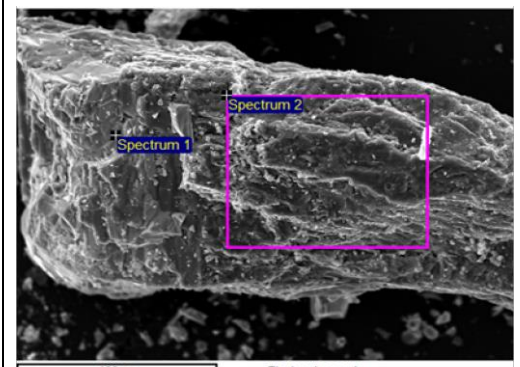
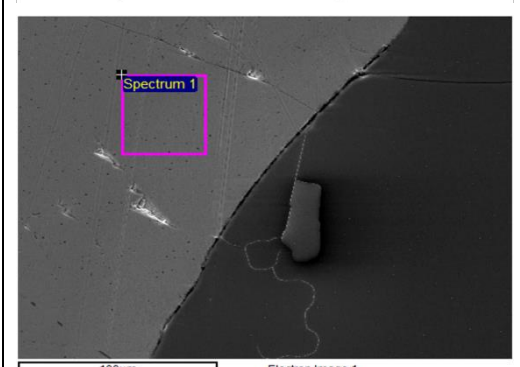
| 6    | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | FeO | CuO | BaO  | PbO   |
|------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|------|-------|
| bulk | 6.78              | 0.83 | 1.56                           | 34.81            | -                             | -               | 0.63             | 3.23 | -                | -   | -   | 8.86 | 43.33 |
| Sp1  | 7.03              | 0.78 | 1.84                           | 33.63            | -                             | -               | 0.65             | 3.40 | -                | -   | -   | 8.98 | 43.69 |



|                                                                                    |                                                                                                                                                                                                                                                              |                                                                                                                 |
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|   | <p><b>Description</b><br/> <b>Crucible 7</b><br/> <b>Blue translucent.</b><br/> <b>Success</b><br/> <b>Roman</b><br/> <b>glass/BaCO<sub>3</sub>/PbO/CuCO<sub>3</sub>=9/2/8/1</b><br/> Only a few cracks can be observed on the top surface of the glass.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                              |                                                                                                                 |

**Chemical composition:**

| 7    | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO  | PbO   |
|------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|------|-------|
| bulk | 6.23              | 0.81 | 1.44                           | 32.79            | -                             | -               | 0.55             | 3.11 | -                | 3.7 | -   | 8.45 | 42.94 |
| Sp1  | 8.23              | 0.88 | 1.69                           | 35.71            | -                             | -               | 0.66             | 3.37 | -                | -   | 2.9 | 8.67 | 37.89 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                 |
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|   | <p><b>Description</b><br/> <b>Crucible 8</b><br/> <b>Black translucent with white opaque on the top</b><br/> <b>Failure</b><br/> <b>Roman glass/BaSO<sub>4</sub>/PbS=5/1/4</b><br/> A layer of white dendritic crystal material separated out of the glass and fully covers on top of the glass.</p> <p>The cross section shows a black vitreous material. Silvery material can be observed from the cross-section which is separated PbS.</p> | <p><b>SEM-EDS: surface and body</b></p>   |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                 |

**Chemical composition:**

| 8           | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO  | BaO   | PbO   |
|-------------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|------|-------|-------|
| bulk        | 6.49              | 1.09 | 1.55                           | 44.61            | -                             | -               | 0.66             | 4.31 | -                | -   | -    | 8.62  | 32.69 |
| Sp1 surface | 0.96              | -    | -                              | -                | -                             | 31.87           | -                | -    | -                | -   | -    | 65.27 | 1.91  |
| Sp2 surface | 30.5              | -    | -                              | -                | -                             | 60.27           | 4.12             | 1.96 | -                | -   | -    | 1.34  | 1.82  |
| Sp1 body    | -                 | -    | -                              | -                | -                             | 26.69           | -                | -    | -                | -   | 1.45 | -     | 71.86 |



### Description

#### Crucible 9

**Greenish transparent with white opaque layer on top.**

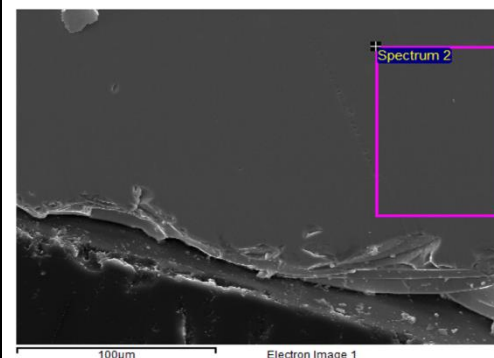
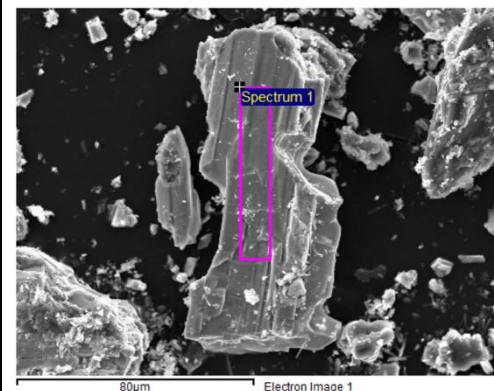
#### Success

**Roman glass/BaSO<sub>4</sub>/PbO=5/1/4**

A layer of white flocculent material separated out of the glass and fully covers on the top of glass.

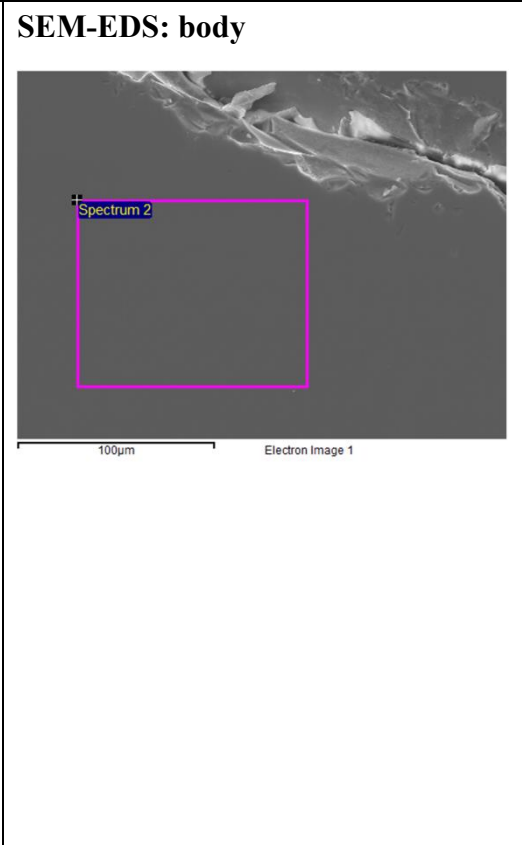
There is a clear edge between the white material and the glass.

### SEM-EDS: surface and body



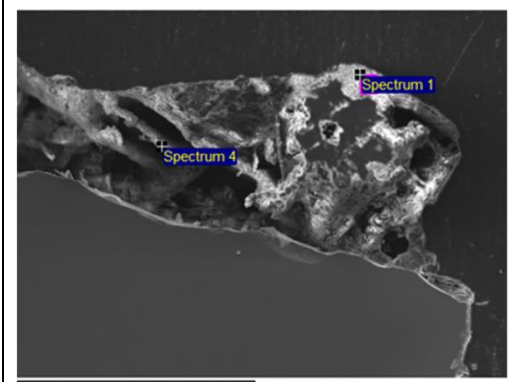
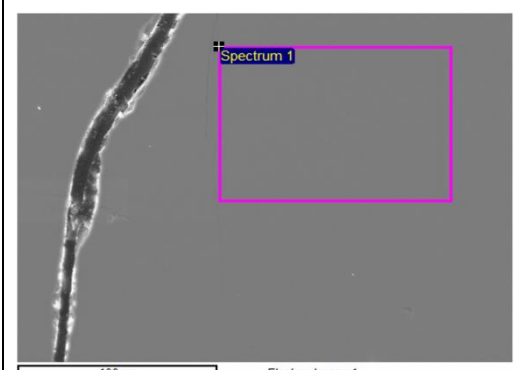
### Chemical composition:

| 9    | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk | 7.07              | 0.92 | 1.73                           | 44.31            | -                             | -               | 0.88             | 4.47 | -                | -   | -   | 5.60  | 35.02 |
| Sp1  | 1.23              | -    | -                              | -                | -                             | 33.14           | -                | -    | -                | -   | -   | 63.09 | 2.54  |
| Sp2  | 7.12              | 1.00 | 1.77                           | 40.09            | -                             | -               | 0.7              | 3.85 | -                | -   | -   | 6.89  | 38.59 |

|                                                                                    |                                                                                                                                                                                                                                                                                                        |                                                                                                                  |
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|   | <p><b>Description</b></p> <p><b>Crucible 10</b></p> <p><b>Yellowish transparent with white opaque on the top middle.</b></p> <p><b>Success</b></p> <p><b>Roman glass/BaCO<sub>3</sub>/PbO=5/1/4</b></p> <p>A thin layer of white flocculent material separated out of the glass on the top middle.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                        |                                                                                                                  |

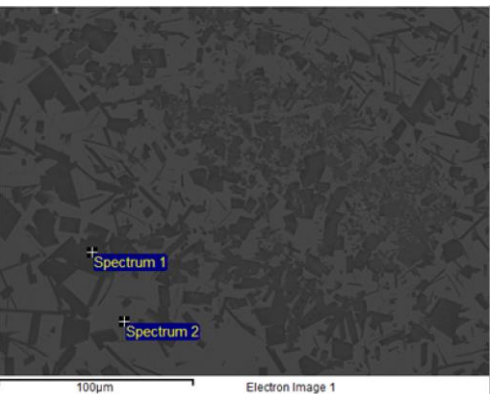
**Chemical composition:**

| 10   | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk | 7.79              | 0.83 | 1.37                           | 37.87            | -                             | -               | 0.56             | 3.49 | -                | -   | -   | 17.14 | 30.98 |
| Sp2  | 7.96              | 0.77 | 1.59                           | 36.16            | -                             | -               | 0.74             | 3.65 | -                | -   | -   | 17.56 | 31.58 |

|                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <p><b>Description</b><br/> <b>Crucible 11</b><br/> <b>Greenish transparent with white opaque layer on top.</b><br/> <b>Success</b><br/> <b>Roman glass/BaSO<sub>4</sub>/PbO=6/1/3</b><br/>         An ice-like material separated out of the glass and fully covers on the top of glass.<br/><br/>         There is a clear edge between the white material and the glass.</p> | <p><b>SEM-EDS: surface and body</b></p>   |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

**Chemical composition:**

| 11          | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|-------------|-------------------|------|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk        | 6.90              | 0.88 | 1.79                           | 39.25            | -                             | -               | 0.59             | 3.77 | -                | -   | -   | 5.85  | 40.98 |
| Sp1 surface | 31.41             | -    | -                              | -                | -                             | 63.09           | 0.69             | 4.81 | -                | -   | -   | -     | -     |
| Sp4 surface | 20.72             | -    | -                              | 16.03            | -                             | 26.11           | -                | -    | -                | -   | -   | 37.14 | -     |
| Sp1 body    | 7.89              | 0.96 | 1.73                           | 42.38            | -                             | -               | 0.61             | 4.21 | -                | -   | -   | 5.47  | 36.75 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                 |
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|   | <p><b>Description</b><br/> <b>Crucible 12</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <math>\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 / \text{BaCO}_3 / \text{PbO} = 5/1/4</math><br/> Gas bubbles can be observed on the top layer of an ivory pasty like material. Compared with other failures, it shows a lustrous surface, probably due to the partly vitrification of the mixture after the firing.</p> <p>Gas bubbles cannot be observed inside the material, and the texture is similar to porcelain body.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                 |

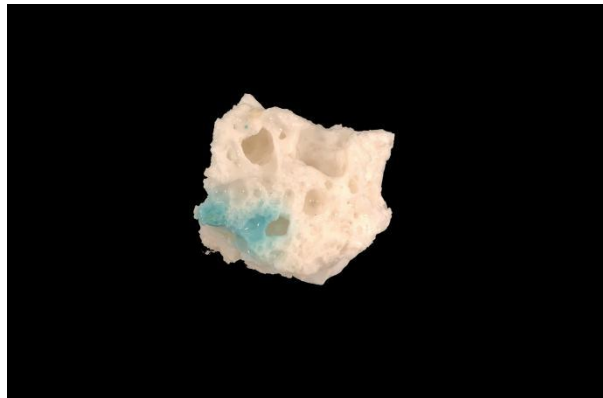
**Chemical composition:**

| 12   | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk | 3.85              | -   | 9.65                           | 33.39            | -                             | -               | 0.44             | 0.74 | -                | -   | -   | 10.55 | 41.40 |
| Sp1  | 4.31              | -   | 23.18                          | 47.66            | -                             | -               | 0.57             | -    | -                | -   | -   | 22.92 | 1.36  |
| Sp2  | 5.88              | -   | 6.8                            | 33.37            | -                             | -               | -                | 0.79 | -                | -   | -   | 2.28  | 50.88 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                            |                                        |
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|   | <p><b>Description</b><br/> <b>Crucible 13</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbO=3/5 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>The white material with granular structure is similar to Sample No. 4, but the texture seems looser.</p> <p>Big gas bubbles can be observed from the cross section.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|  |                                                                                                                                                                                                                                                                                                                                                                            |                                        |

**Chemical composition:**

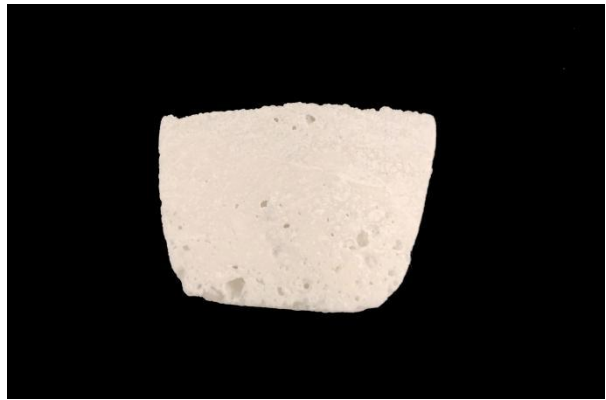
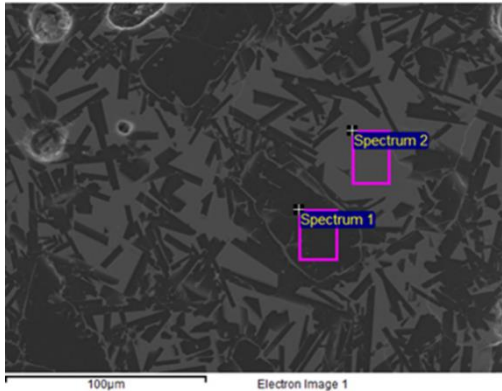
| Crucible | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|----------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| 13       | 1.01              | -   | -                              | 60.66            | -                             | -               | -                | 1.07 | -                | -   | -   | 10.97 | 26.30 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                      |                                 |
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|   | <p><b>Description</b><br/> <b>Crucible 14</b><br/> <b>White opaque with green opaque on the top edge.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbO=3/5 without Na<sub>2</sub>CO<sub>3</sub>)</b><br/> The texture is similar to Sample No.13, the green colour on the top edge is caused by CuCO<sub>3</sub> contamination from other crucibles.</p> | <p><b>SEM-EDS:</b><br/> N/A</p> |
|  |                                                                                                                                                                                                                                                                                                                                                                                      |                                 |

**Chemical composition:**

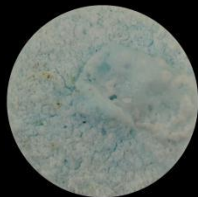
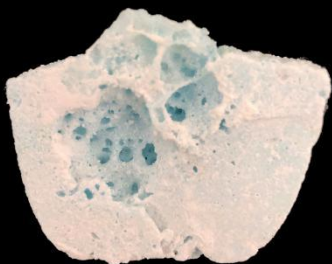
| Crucible | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|----------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| 14       | -                 | -   | -                              | 64.92            | -                             | -               | -                | 1.65 | -                | -   | -   | 11.39 | 22.05 |



|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 15</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaSO<sub>4</sub>/PbO=3/5 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>The white material with granular structure fully separated from the crucible, and the texture is similar to Sample No. 4.</p> <p>Gas bubbles mainly remain at the bottom.</p> | <p><b>SEM-EDS: body</b></p>  <p>Spec1: Silica quartz<br/> Spec2: Vitrified phase</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

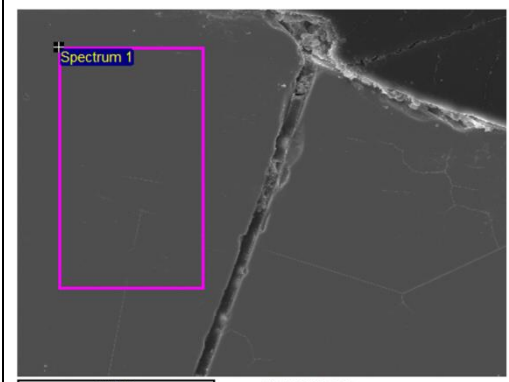
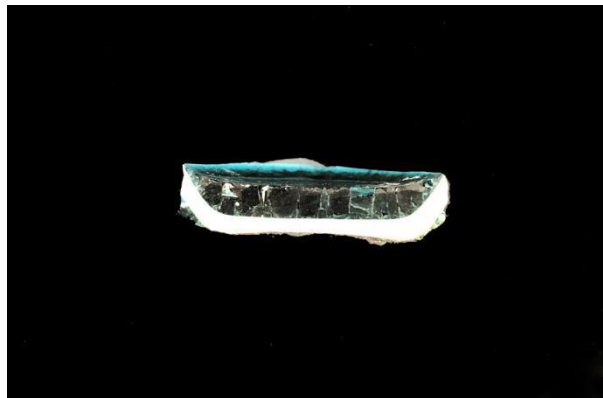
**Chemical composition:**

| 15   | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO  | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|------|-------|
| bulk | 1.14              | -   | -                              | 68.95            | 0.47                          | -               | -                | 1.46 | -                | -   | -   | 2.47 | 25.53 |
| Sp1  | -                 | -   | 0.32                           | 98.75            |                               | -               | -                | -    | -                | -   | -   | -    | 0.93  |
| Sp2  | 3.06              | -   | -                              | 38.5             |                               | -               | -                | 2.91 | -                | -   | -   | 3.15 | 52.38 |

|                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                        |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|  | <p><b>Description</b><br/> <b>Crucible 16</b><br/> <b>Pale blue opaque.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbS=3/5 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>The pale blue material with granular structure fully separated from the crucible, and the texture is similar to Sample No. 4. The pale blue colour is caused by CuCO<sub>3</sub> contamination from other crucibles.</p> <p>Big gas bubbles can be observed on the top centre from the cross section. Yellow dots can be observed on the surface.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                        |

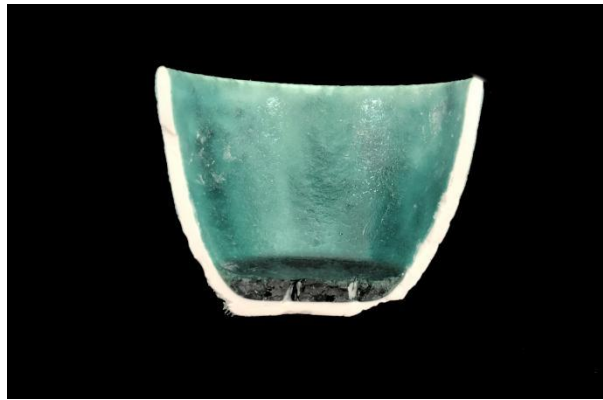
**Chemical composition:**

| 16   | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO  | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|------|-------|
| bulk | 1.09              | -   | -                              | 67.37            | -                             | 1.39            | -                | 1.21 | 0.59             | -   | -   | 4.87 | 23.49 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                 |
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|   | <p><b>Description</b><br/> <b>Crucible 17</b><br/> <b>Emerald green translucent.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbO=2/9 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>The mixture escaped from the crucible during the firing. The crucible broke and a thin layer of vitreous material generated at the crucible bottom. Sections of gas bubbles can be observed from the cross section.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                 |

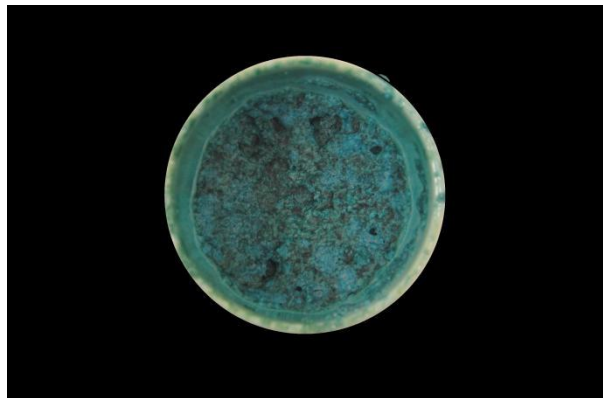
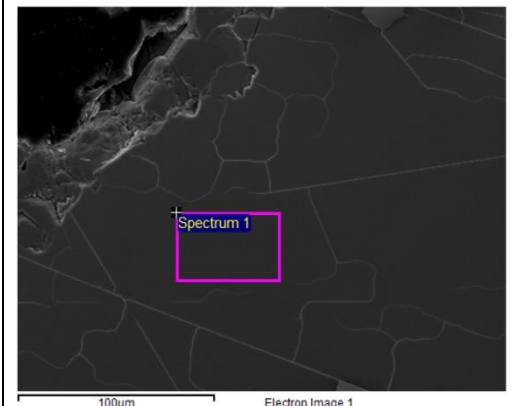
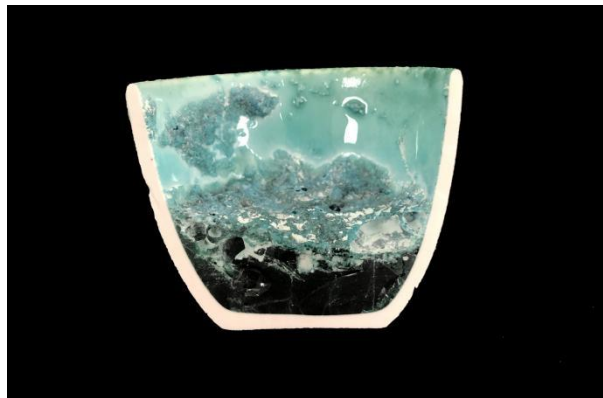
**Chemical composition:**

|      | 17 | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO  | FeO  | BaO  | PbO   |
|------|----|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|------|------|------|-------|
| bulk |    | 2.54              | -   | 0.22                           | 35.39            | -                             | -               | 0.44             | 1.96 | -                | 3.20 | -    | 8.99 | 47.27 |
| Sp1  |    | 2.96              | -   | -                              | 33.9             | -                             | -               | -                | 1.89 | -                | -    | 4.33 | 8.53 | 48.4  |

|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 18</b><br/> <b>Emerald green translucent.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (<math>\text{BaCO}_3/\text{PbO}=1/5</math> without <math>\text{Na}_2\text{CO}_3</math>)</b></p> <p>The mixture escaped from the crucible during the firing. The texture is similar to Sample No. 17, but the crucible remains intact after the firing. The green glaze of the crucible might be caused by <math>\text{CuCO}_3</math> from the mixture.</p> <p>A thin layer of vitreous material generated at the bottom crucible. Sections of gas bubbles can be observed from the cross section.</p> | <p><b>SEM-EDS:</b><br/> <b>N/A</b></p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|

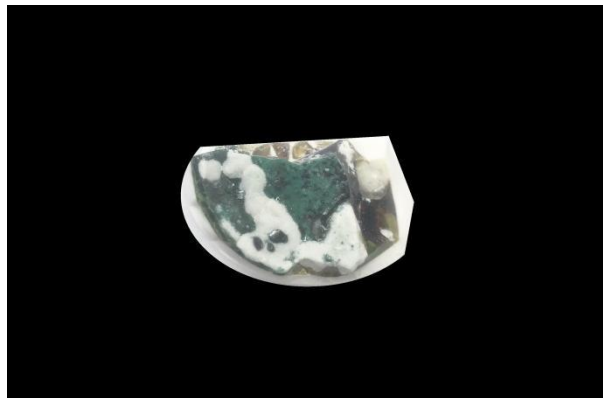
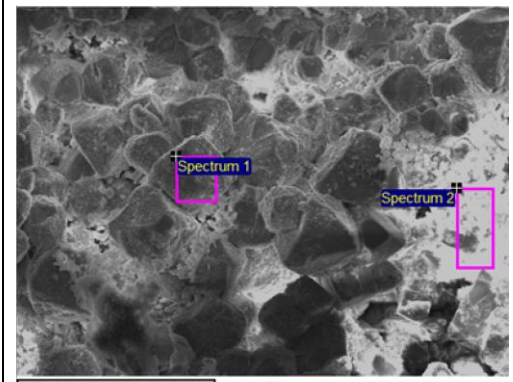
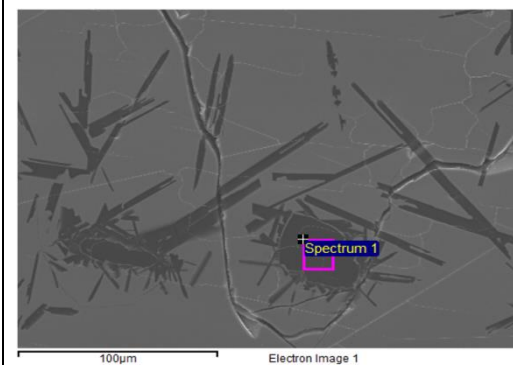
**Chemical composition:**

| 18   | $\text{Na}_2\text{O}$ | $\text{MgO}$ | $\text{Al}_2\text{O}_3$ | $\text{SiO}_2$ | $\text{P}_2\text{O}_5$ | $\text{SO}_3$ | $\text{K}_2\text{O}$ | $\text{CaO}$ | $\text{TiO}_2$ | $\text{CuO}$ | $\text{FeO}$ | $\text{BaO}$ | $\text{PbO}$ |
|------|-----------------------|--------------|-------------------------|----------------|------------------------|---------------|----------------------|--------------|----------------|--------------|--------------|--------------|--------------|
| bulk | -                     | -            | -                       | 35.28          | -                      | -             | -                    | 1.75         | -              | 3.45         | -            | 7.98         | 51.54        |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                 |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 19</b><br/> <b>Green opaque.</b><br/> <b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbO=3/9 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>Sections of gas bubbles can be observed on the top of the green material with granular structure. The mixture partly spilt out of the crucible, which dyed the crucible glaze in green.</p> <p>Vitreous dark material can be observed at the bottom by cross section. It seems that CuCO<sub>3</sub> and BaSO<sub>4</sub> are not well-mixed with vitreous material, which separated out on the top surface.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                 |

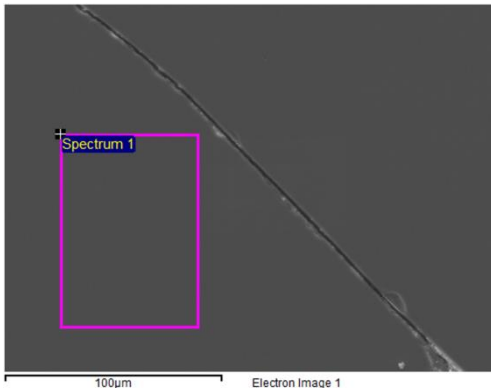
**Chemical composition:**

| 19   | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO  | FeO  | BaO  | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|------|------|------|-------|
| bulk | 1.92              | -   | -                              | 37.26            | -                             | -               | 0.13             | 1.93 | -                | 3.00 | -    | 1.71 | 54.06 |
| Sp1  | 2.54              | -   | -                              | 36.51            | -                             | -               | -                | 1.78 | -                | -    | 2.73 | 1.83 | 54.61 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 20</b><br/> <b>Yellow transparent with green and white opaque on the top.</b></p> <p><b>Failure</b><br/> <b>Cui <i>et al.</i> 2009 (BaCO<sub>3</sub>/PbS=1/5 with Na<sub>2</sub>CO<sub>3</sub>)</b></p> <p>The crucible broke into two pieces after firing. The white and green materials remained on the inside surface of the crucible and top of the yellow vitreous material.</p> <p>Spec1 surface: mixture of barium sulphate and lead sulphate</p> <p>Spec2 surface: mixture of barium sulphate and sodium sulphate</p> | <p><b>SEM-EDS: surface and body</b></p>   |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                  |

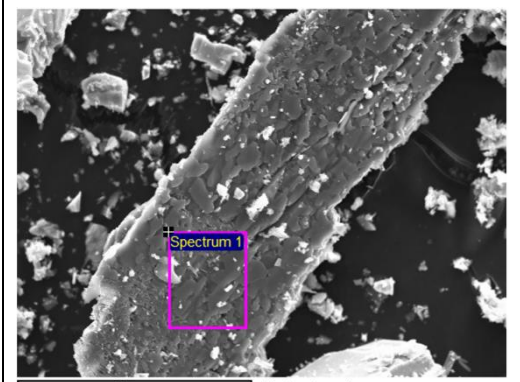
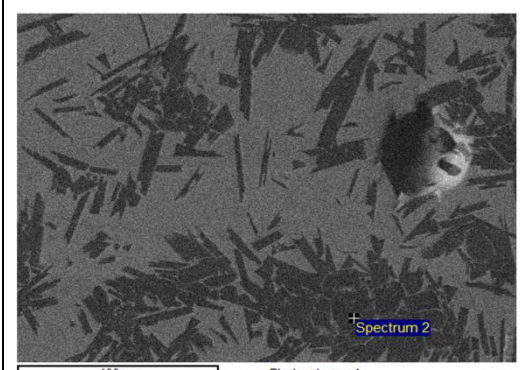
#### Chemical composition:

| 20          | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO  | FeO | BaO   | PbO   |
|-------------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|------|-----|-------|-------|
| bulk        | 1.45              | -   | -                              | 37.58            | -                             | -               | -                | 1.83 | -                | 1.28 | -   | 1.09  | 56.78 |
| Sp2         | 22.98             | -   | 0.91                           | -                | -                             | 41.91           | 0                | -    | -                | -    | -   | 27.91 | 6.28  |
| Surface     |                   |     |                                |                  |                               |                 |                  |      |                  |      |     |       |       |
| Sp1 surface | 2.46              | -   | 1.05                           | 1.46             | -                             | 30.27           | -                | -    | -                | -    | -   | 54.38 | 10.38 |
| Sp1 body    | -                 | -   | -                              | 100              | -                             | -               | -                | -    | -                | -    | -   | -     | -     |

|                                                                                    |                                                                                                                                                                                                                                                            |                                                                                                                 |
|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/><b>Crucible 21</b><br/><b>Greenish transparent.</b><br/><b>Success</b><br/><b>Shi and Zhou 1990</b><br/><b>(BaCO<sub>3</sub>/PbO=3/5 with Na<sub>2</sub>CO<sub>3</sub>)</b><br/>Various cracks can be observed in the glass.</p> | <p><b>SEM-EDS: body</b></p>  |
|  | <p>Sections of gas bubbles can be observed from the cross-section.</p>                                                                                                                                                                                     |                                                                                                                 |

**Chemical composition:**

|      | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk | 7.51              | -   | -                              | 48.11            | -                             | -               | 0.28             | 1.40 | -                | -   | -   | 14.15 | 28.56 |
| Sp1  | 8.21              | -   | -                              | 45.24            | -                             | -               | -                | 1.47 | -                | -   | -   | 14.38 | 30.71 |

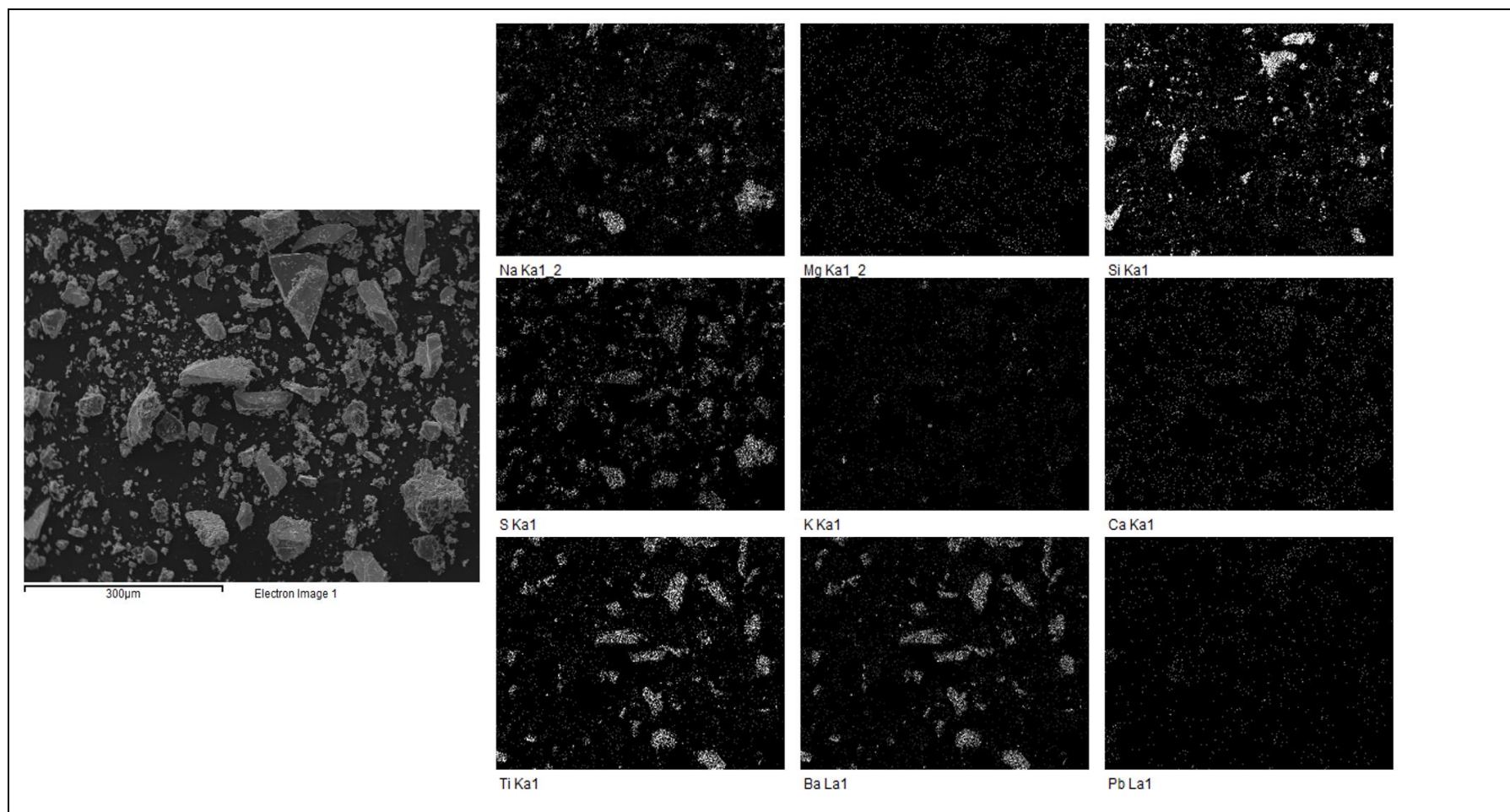
|                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 22</b><br/> <b>Greenish transparent with white opaque layer on top.</b><br/> <b>Success</b><br/> <b>Shi and Zhou 1990 (BaSO<sub>4</sub>/PbO=3/5 with Na<sub>2</sub>CO<sub>3</sub>)</b><br/> A blocky crystal-like material fully covers on top of the glass. The blue colour on the crucible glaze and the glass is caused by CuCO<sub>3</sub> contamination from other crucibles.</p> <p>The white material inhomogeneous spread in the glass.</p> <p>Spec1: mixture of barium sulphate and sodium sulphate</p> | <p><b>SEM-EDS: surface and body</b></p>   |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                  |

#### Chemical composition:

| 22   | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk | 5.84              | -   | -                              | 59.59            | -                             | -               | -                | 1.23 | -                | -   | -   | 6.00  | 27.35 |
| Sp1  | 12.89             | -   | -                              | 1.66             | -                             | 56.68           | 6.65             | 1.56 | -                | -   | -   | 20.57 | -     |
| Sp2  | -                 | -   | 0.36                           | 99.64            | -                             | -               | -                | -    | -                | -   | -   | -     | -     |



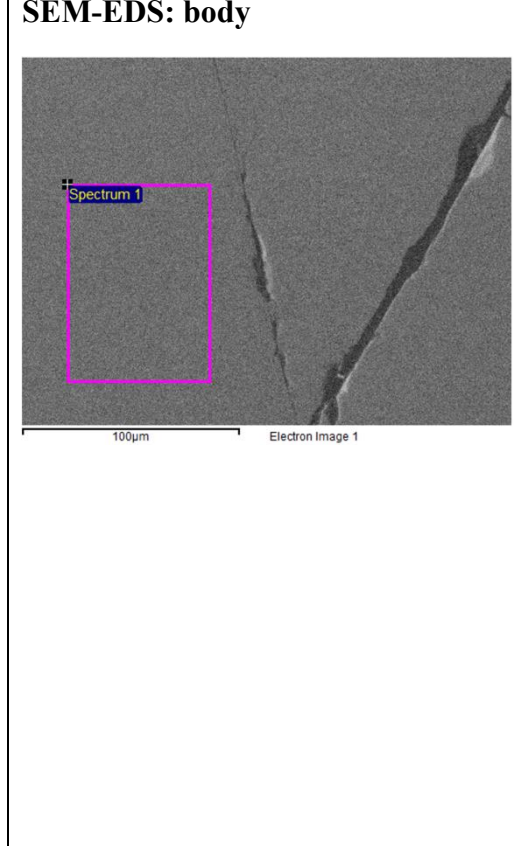
# EDS mapping result of the white material for crucible 22



|                                                                                    |                                                                                                                                                                                                                                                                                                                                               |                                 |
|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 23</b><br/> <b>White opaque.</b><br/> <b>Failure</b><br/> <b>Shi and Zhou 1990</b><br/> <b>(BaCO<sub>3</sub>/PbO=2/3 without Na<sub>2</sub>CO<sub>3</sub>)</b><br/> The texture is similar to Sample NO. 13, but with more gas holes.</p> <p>Big gas holes can be observed from the cross section.</p> | <p><b>SEM-EDS:</b><br/> N/A</p> |
|  |                                                                                                                                                                                                                                                                                                                                               |                                 |

**Chemical composition:**

| Crucible | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|----------|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| 23       | -                 | -   | -                              | 51.08            | -                             | -               | -                | 1.05 | 1.13             | -   | -   | 20.19 | 26.57 |

|                                                                                    |                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                  |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
|   | <p><b>Description</b><br/> <b>Crucible 24</b><br/> <b>Yellowish transparent.</b><br/> <b>Success</b><br/> <b>Shi and Zhou 1990</b><br/> <b>(BaCO<sub>3</sub>/PbO=1/2 with Na<sub>2</sub>B<sub>4</sub>O<sub>7</sub>·10H<sub>2</sub>O)</b><br/> The glass remains at the bottom of the glaze in perfect condition without any crack inside the glass.</p> | <p><b>SEM-EDS: body</b></p>  |
|  |                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                  |

**Chemical composition:**

|      | 24 | Na <sub>2</sub> O | MgO | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | CuO | FeO | BaO   | PbO   |
|------|----|-------------------|-----|--------------------------------|------------------|-------------------------------|-----------------|------------------|------|------------------|-----|-----|-------|-------|
| bulk |    | 8.48              | -   | 0.68                           | 46.04            | -                             | -               | 0.63             | 1.00 | -                | -   | -   | 12.05 | 31.14 |
| Sp1  |    | 8.92              | -   | 0.86                           | 43.77            | -                             | -               | 0.67             | 0.93 | -                | -   | -   | 12.74 | 32.12 |

# **Chapter 5 Laser Ablation Inductively Coupled Plasma Mass Spectrometry Analysis of Chinese Lead-Barium Glass: Combining Multivariate Kernel Density Estimation and Maximum Mean Discrepancy to Reinterpret the Raw Glass Used for Producing Lead-Barium Glass**

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Provincial Museum, 6393 Guangfu Road, Kunming, 650206, China.<sup>8</sup> Hunan Provincial Institute of Cultural Heritage and Archaeology, 129 Dongfeng Road, Changsha, 410008, China.<sup>9</sup> University of Science and Technology of China, 96 Jinzhai Road, Hefei, 230026, China.

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## **Abstract**

Lead-barium glass, which appeared during the Mid-Late Warring States period (475 – 221 BC) in China, is considered to be a purely Chinese invention due to the unique presence of high barium. However, lead-barium glass was rarely referred to in contemporary Chinese literature and disappeared after the Han Dynasty (202 BC – AD 220). In this paper, fifty samples excavated from five provinces in China have been analysed by LA-ICP-MS for trace element composition. We offer a piece of code to perform multivariate kernel density estimation on four variables in a tetrahedron plot, and then we used Maximum Mean Discrepancy with the null hypothesis testing for cluster analysis. The results suggest that lead-barium glass was a secondary product made by mixing Chinese lead and barium minerals with imported natron glass, and the

Syro-Palestinian coast was the possible source region for the raw glass used to produce lead-barium glass.

**Keywords:** Lead-barium glass; Natron glass; LA-ICP-MS; Kernel density estimation; Maximum Mean Discrepancy

## 5.1 Introduction

Glass is made up of network formers, network modifiers, and intermediates, with  $\text{SiO}_2$  serving as the primary network former in ancient glass (Degryse, 2014, p. 20). The fluxes  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  and the stabilizer  $\text{CaO}$  are network modifiers, which disrupt the continuity of the silica network, changing the physical and chemical properties. Oxides such as  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  are intermediates which can either enter the network as a network former or occupy interstitial holes as network modifier, but are unable to form glasses themselves. The alkali source for soda-lime-silica glass from western Eurasia could either be a natron (evaporite mineral) source, often identified as Wadi El-Natrun in Egypt, or ash derived from burnt salt-tolerant plants, which functioned as an essential flux to lower the sand's melting temperature (Brems and Degryse, 2013; Shortland *et al.*, 2007). Shell fragments from beach sand provided a calcium source that acts as a chemical stabilizer in the glass (Degryse and Shortland, 2009; Freestone *et al.*, 2003).

During the Mid-Late Warring States period, a unique type of glass appeared in China - lead-barium glass - which had no antecedents in the western world. This type of glass then disappeared suddenly after the end of the Han Dynasty. In lead-barium glass, BaO is a modifier oxide with a high optical basicity and refractive index (Othman *et al.*, 2019). PbO is an intermediate in the glass, and it acts as a network modifier when the mol% is lower than 70% (Takaishi *et al.*, 2000). There were two main uses of lead-barium glass in the Central Plains of China, both of which were to act as imitations – one for western eye beads, and one for Chinese jade. In the West, eye beads were commonly inlaid in coffins, mummy masks and small statutes, which relates to the concept of the ‘Evil Eye’ (Lucas and Harris, 1963). However, since western eye beads were rare in China, they were mainly consumed by the Chinese nobility and may have lost their original purpose. Eye beads were only discovered in noble tombs, such as the Tomb of Marquis Yi of Zeng State from Hubei and Shi-Zhai-Shan Cemetery owned by the Dian King royal family from Yunnan (Tan, 2003; Yang, 2011). Chinese glass makers added their own unique aesthetic taste to the design of the eye beads. For instance, the ‘Eccentric Eye Bead’ is designed in such a way that an ‘eye’ is embedded in the glass bead, but not in the centre of the circle. This has only been found in China and is considered to be a Chinese innovation (Zhao, 2012). In addition, from the Neolithic onwards, Chinese culture had a strong preference for jade. Lead-barium glass

was therefore also produced as an imitation of jade, and mostly functioned as a replacement for jade in the lower ranks of the nobility. Ganquanshan Han Cemetery in Yangzhou (Jiangsu province) discovered hundreds of glass plates covering a female corpse, in an imitation of a jade burial suit. The jade burial suit was specifically used for the members of the Han royal family. The owner of this suit, 'Moshu' 莫书, was a concubine who might have had a relationship with the *Shanyang King* 山阳王. 'Moshu' was not qualified to use a jade suit, but a glass suit was used as a replacement (Zhang, 2004; Zhou, 2014).

Other synthetic barium-containing materials were also invented during the Qin (221 – 207 BC) and Han dynasties, namely lead-barium faience and Chinese Blue ( $\text{BaCuSi}_4\text{O}_{10}$ ) and Purple ( $\text{BaCuSi}_2\text{O}_6$ ). The lead-barium faience samples in this research are sintered crush quartz covered with different colours (i.e., blue, purple, red, yellow, white) of semi-vitrified lead-barium glaze to imitate eye beads. thirteen lead-barium faience eye beads were analysed in this research. Chinese blue and purple are regarded as the Chinese analogues of Egyptian Blue (Chen, 2014; Fitzhugh and Zycherman, 1992). Both pigments were used to give the blue and purple decoration on the surface of the Terracotta Warriors in the Tomb of Qin Shi Huang (Chen, 2014, p. 5; Fitzhugh and Zycherman, 1992). The main chemical difference between lead-barium



glass and lead-barium faience is that the glass has higher Na<sub>2</sub>O and PbO, and lower Al<sub>2</sub>O<sub>3</sub>, K<sub>2</sub>O, and CaO.

From the literature, we have assembled a database of 388 chemical analyses of Chinese lead-barium glasses from 15 publications (data and reference list in Data file S1). The median major element content of this glass is SiO<sub>2</sub> 51.4%, PbO 27.1% and BaO 9.02%. Such a high amount of PbO makes most scholars believe that it was used as a flux to lower the silica melting temperature, and that the barium would react with the silica to generate a BaSi<sub>2</sub>O<sub>5</sub> phase, acting as an opacifier (Li, 2014; Ma *et al.*, 2021). Significantly, in the context of this paper, it is important not to ignore the relatively high levels of Na<sub>2</sub>O in lead-barium glass. According to the previously published data of lead-barium glasses, although the median value is 2.3%, the range (in those samples where Na<sub>2</sub>O is reported) is 0.01 to 10.1%. According to the lead-barium glass replication experiment (Chapter 4), lead-barium glass should contain about 6% Na<sub>2</sub>O to form glass. Most lead-barium glass objects exhibit some degree of weathering due to the chemical instability of high lead content, resulting in a loss of Na<sub>2</sub>O concentration. This suggests that the sodium was intentionally added to the glass batch, rather than being an impurity or a contamination from other sources. Brill (2001) suggested that the high sodium in lead-barium glass might be a result of mixing PbO:BaO:SiO<sub>2</sub> (low sodium) glasses with

soda-lime glasses, and Cui *et al.* (2011) also believe that the Na<sub>2</sub>O and CaO may have originated from independent materials. Specifically, our recent glass firing experiment testifies that sodium is essential in lead-barium glass (> 6% Na<sub>2</sub>O), and simply firing a mixture of PbO, BaO and SiO<sub>2</sub> cannot form glass (Ma *et al.*, 2021). There could be several reasons causing the low levels of sodium detected in lead-barium glass:

- 1) The detection error caused by non-destructive surface XRF analysis;
- 2) The weathering effect causing the loss of sodium;
- 3) The sodium loss during the re-melting/recycling process;
- 4) When re-melting natron glass with PbO and BaSO<sub>4</sub>, sodium was detected in the white opacifier in the form of Na<sub>2</sub>SO<sub>4</sub>, which caused a sodium loss from the glass phase (Ma *et al.*, 2021).

Although mineral sources of sodium can also produce such glass with lead and barium minerals, the lack of any evidence (literary or archaeological) for the production of soda-lime-silica glass or glazes during the Warring States to the Han Dynasty suggests that the use of mineral soda for glassmaking was unknown in Central China, while flux such as lead and wood ash were more commonly used for vitrified silicate materials (e.g., lead glaze, wood ash glaze) during this period. This indicates that the production model suggested here (re-melting of imported soda-lime-silica glass with lead and

barium minerals) deserves further examination. In general, glass production takes place in two steps - primary production and secondary production. Primary production is where the raw glass is made from raw materials (sand, alkali and lime sources). Secondary production is the conversion of this primary glass into artefacts, where recycling and mixing can take place, and colourants or opacifiers can also be added. The aim of this paper is to test the hypothesis that lead and barium minerals were added to imported glass during the secondary production process, and, if this proves plausible, to find the chemical relationships between Chinese lead-barium glass and western soda-lime-silica glass.

## **5.2 Materials and Methods**

The published data of lead-barium glass gathered together in Data file S1 are, however, not generally of sufficient quality to address these questions. They are produced by a range of analytical techniques, not all of which are sensitive to the lighter elements in glass, and especially to sodium (e.g., XRF). Nor is there a uniform set of trace elements measured. Moreover, it is not always clear that the objects analysed were actually lead-barium glass, as opposed to other synthetic material such as lead-barium faience. For the purposes of this work, therefore, a new set of analyses was obtained on 50 samples of various types of glass and faience beads dating from the Early Warring States to the

Han Dynasty excavated in China (except for sample 5.772 from Hubei dating to the Jin Dynasty (AD 266 – 316); listed in Appendix B Table 5.2. Geographical coordinates of the sites mentioned in this study can also be found in Appendix B Table 5.2. Samples for this study mainly came from Henan, Hubei, Yunnan and Xinjiang Provinces in China, provided by the local museums and archaeological institutes (Appendix B Figure 5.7). The number of glass beads available for analysis was strictly controlled by curators. With a limited sample size, our sampling strategy was based on the sample typology. Photographs of the bead samples can be found in Appendix B Table 5.3. Because most eye beads consist of multiple components of different coloured glass, where possible, each colour was analysed separately, resulting in 104 individual analyses.

Major and trace element analysis was carried out by laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS), performed at the Key Laboratory of Crust-Mantle Materials and Environments, University of Science and Technology of China. Analyses were carried out with a Coherent GeoLas Pro laser ablation system in conjunction with a Perkin-Elmer/SCIE Elan DRC II Type ICP-MS. Samples were directly put into the sample chamber without pretreatment and laser ablated under an atmosphere of helium. Detailed operating conditions for the laser and the ICP-MS

instrument are listed in Appendix B Table 5.4. USGS reference glasses BCR-2G, BHVO-2G and BIR-1G were used as reference materials for calibration in this study. Liu *et al.* (2008) designed a calibration strategy for LA-ICP-MS analysis of anhydrous minerals and glasses, in which the data quantification does not require an internal standard. The accuracy of the data as determined by using the reference materials as unknowns is shown in Appendix B Figure 5.8. Appendix B Table 5.5 shows the accuracy and precision of the data by reporting the standard deviations of major elements and trace elements for the reference materials.

## **5.3 Results**

### **5.3.1 Major element oxides**

Quantitative results for the 50 glass and faience samples by LA-ICP-MS can be found in Data file S2, and previously published data of soda-lime-silica glass used for comparison can be found in Data file S3. Each of the new analyses is classified initially as being either glass or lead-barium faience, based primarily on physical appearance (see photographs in Appendix B Table 5.3). The glass samples are then classified on the basis of their chemical analysis as either lead-barium glass or natron glass. Natron glass shows both K<sub>2</sub>O and MgO lower than 1.5%.

Figure 5.1 shows a strong negative linear relationship between  $\text{Na}_2\text{O}$  and  $\text{PbO}+\text{BaO}$  in the lead-barium glass, but not for the lead-barium faience. The correlation between  $\text{Na}_2\text{O}\%$  and  $\text{PbO}+\text{BaO}\%$  for lead-barium glass is  $R^2=-0.881$ , and the intercept ( $\text{PbO}+\text{BaO} = 0$ ) is  $\text{Na}_2\text{O} = 16.56\%$ . This is consistent with the suggestion that the source of sodium in lead-barium glass could be from the mixing of imported glass with lead and barium minerals, and that the average value of  $\text{Na}_2\text{O}$  in the added glass is 16.56%.

The variable concentration of  $\text{Na}_2\text{O}\%$  in lead-barium faience may be related to impurities, such as sodium feldspar. Moreover, the low concentrations of  $\text{K}_2\text{O}$  and  $\text{MgO}$  indicate the sodium in lead-barium glass is from a mineral sodium source rather plant ash source. One more strong piece of evidence for the hypothesis that Chinese lead-barium glass is made by adding lead and barium minerals to imported glass is shown in Figure 5.2. This plots on a logarithmic scale the median of the major oxides in natron glass excavated in China together with the same oxides in Chinese lead-barium glass, after mathematically removing the  $\text{PbO}$  and  $\text{BaO}$  and re-normalizing, using the data in Data file S2. The close correlation across most oxides suggests that this hypothesis of the re-use of imported natron glass is at least plausible, and that the levels of most oxides in lead-barium glass can be explained using this model. The formation of lead-barium glaze/faience does not require the addition of  $\text{Na}_2\text{O}$ , yet, it can be observed that some lead-barium faience data show relatively higher  $\text{Na}_2\text{O}$  concentrations. There are

several points that lead us to believe that sodium in lead-barium faience was not from natron glass. 1) the  $\text{Na}_2\text{O}$  proportions in lead-barium faience were quite random compared with lead-barium glass, which shows a negative linear relationship, as can be observed in Fig 5.1. 2) The random proportions of  $\text{Na}_2\text{O}$  in lead-barium faience was likely contributed by impurities, such as sodium feldspar, which also explains the high level of  $\text{Al}_2\text{O}_3$  in lead-barium faience. It needs to be highlighted that the  $\text{Na}_2\text{O}$  concentration in lead-barium glass was not contributed by the feldspar, as the replication experiment indicates that the mixture of sodium feldspar, silica, lead and barium minerals cannot form glass (Chapter 4: Ma *et al.*, 2021).

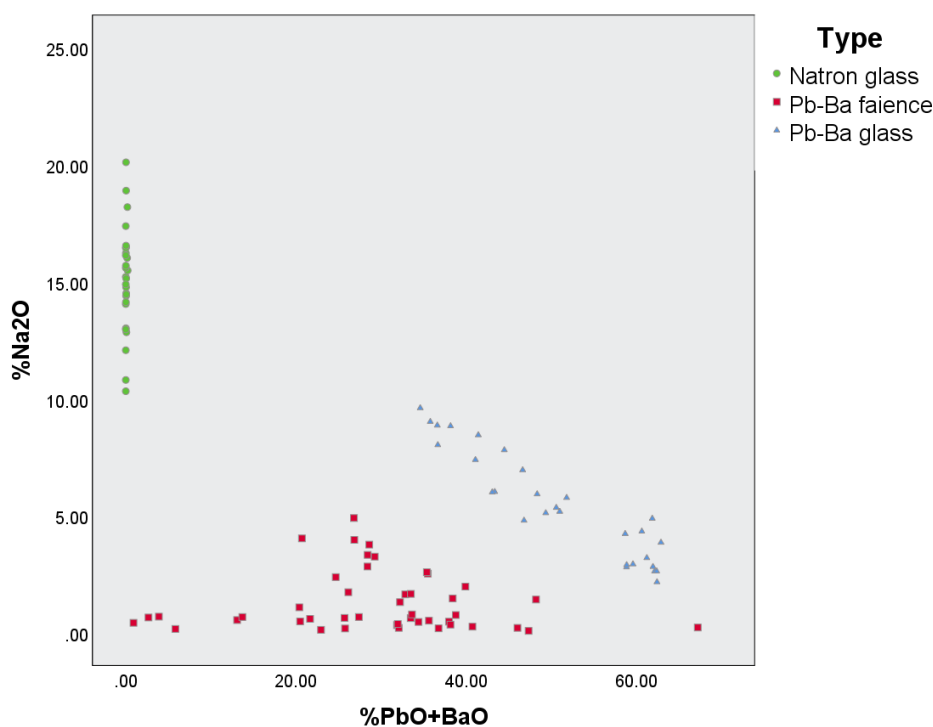


**Figure 5.1 Na<sub>2</sub>O vs PbO+BaO (oxide%) for two types of glasses and lead-barium faience from different sites in China (Data file S2).** The correlation between Na<sub>2</sub>O% and PbO+BaO% in Pb-Ba glass is  $R^2=0.881$ .

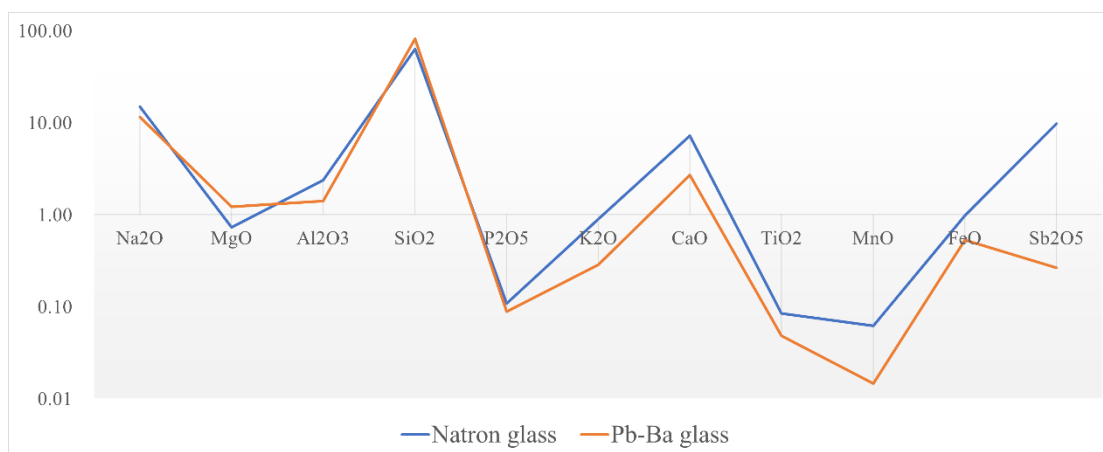


**Figure 5.2 Comparison of median values of major element oxides in natron glass excavated in China, and Chinese lead-barium glass after mathematically removing the PbO and BaO and re-normalizing (Data file S2).** The difference in Sb<sub>2</sub>O<sub>5</sub> is due to the presence of a number of examples of opaque glass (opacified with Sb<sub>2</sub>O<sub>5</sub>) amongst the natron glasses, but not in the lead-barium glasses.



### **5.3.2 Kernel approaches for trace element analysis**

Trace element analysis can provide geological information about the source of the raw materials used to produce glass. Sand deposits can contain a variety of mineral types and amounts, depending on the nature of the source rocks and the geological context. Different trace element signatures from various sand mineralogical compositions could be valuable tracers for determining their origin (Brems and Degryse, 2013). Elements such as Ti, Zr, and Cr are widely employed to identify various magma types in the geological classification of igneous rocks, as their concentrations vary more between different magma types than between samples of the same magma type (Pearce and Cann, 1973). Furthermore, secondary processes such as weathering and metamorphism have little effect on these three components. (Cann, 1970; Pearce and Cann, 1971). The Ti-Zr diagram can be used to distinguish low-potassium tholeiites and calc-alkali basalts from island arcs (Pearce and Cann, 1973). Rare earth elements (REE) such as La and Y are regarded as the least soluble trace elements, as well as being stable to low-grade metamorphism, weathering and hydrothermal alteration (Michard, 1989). A combination of Ti, Zr, La, and Cr displays the most difference between the two regions when analysing the raw material of the sand source in glass making. The concentrations of these four element vary in different geological environments, and their inter-element ratios are unaltered by the high temperatures used in either manufacturing or after

reprocessing, as they are refractory and non-volatile (Shortland *et al.*, 2007). As a result, variation in these trace elements most likely indicates different sand raw materials. Promising groupings of glass can be made based on combinations of elements such as Zr-Ti (Aerts *et al.*, 2003), Zr-Ti-Cr-La (Reade, 2009; Shortland *et al.*, 2007; Walton *et al.*, 2009) and Zr-Sr-Ba (Freestone *et al.*, 2000; Paynter, 2006; Alberta Silvestri *et al.*, 2005; Silvestri, 2008). In general, they are usually unrelated to any (de)colouring agents that may have been deliberately introduced to the glass batch.

Figure 5.3 shows the Cr-La and Zr-Th concentrations of different types of glasses and faience. The published data of Mediterranean natron glass were dated to within the 1<sup>st</sup> millennium BC, and a majority of them are Hellenistic natron glass (323 – 31 BC). Figure 5.3a shows that the Cr and La concentrations of natron glass unearthed in China match with the Mediterranean natron glass (three outliers from Mediterranean natron glass suggesting a potential different source region), whereas the Cr and La concentrations in lead-barium glass are lower than any other types of glasses. Trace element, such as Cr, La, Zr and Ti which used as fingerprints of the silica source, their concentrations in lead-barium glass and lead-barium faience are completely unrelated. For instance, Cr and La concentrations of lead-barium faience are plotted in Figure 5.3b as a reference to show the variation of Chinese silica source. Clearly, lead-barium glass

used different silica source compared with lead-barium faience. Moreover, the Cr and La concentrations of lead-barium faience are much higher than any of the glasses in this study. A comparison between other contemporary Chinese silicate materials and lead-barium glass can be found in Appendix B Figure 5.9, and it also suggests that the silica source for producing lead-barium glass was not from China. Lü *et al.* (2021) summarised four subtypes of the natron glass during the 1<sup>st</sup> millennium BC by further plotting the Th, Sr and Ba concentrations. Three subtypes of natron glass are presented in Figure 5.3c, except for Type I<sub>0</sub> natron glass due to the small dataset. There is only one natron glass sample, dating to the Jin Dynasty in China, which falls within the range of Type III natron glass, and the rest of the natron glass samples dating to the Warring States and the Han periods all match with Type II natron glass. The concentrations of Ba, Sr and Th show enough resolution to differentiate subtypes of natron glasses, yet they cannot be used to trace the raw glass used for producing lead-barium glass. Apparently, barium was intentionally added to the glass, and it elevated the Sr concentration as observed in this case; the high level of lead also influenced the Th concentration in a certain degree.

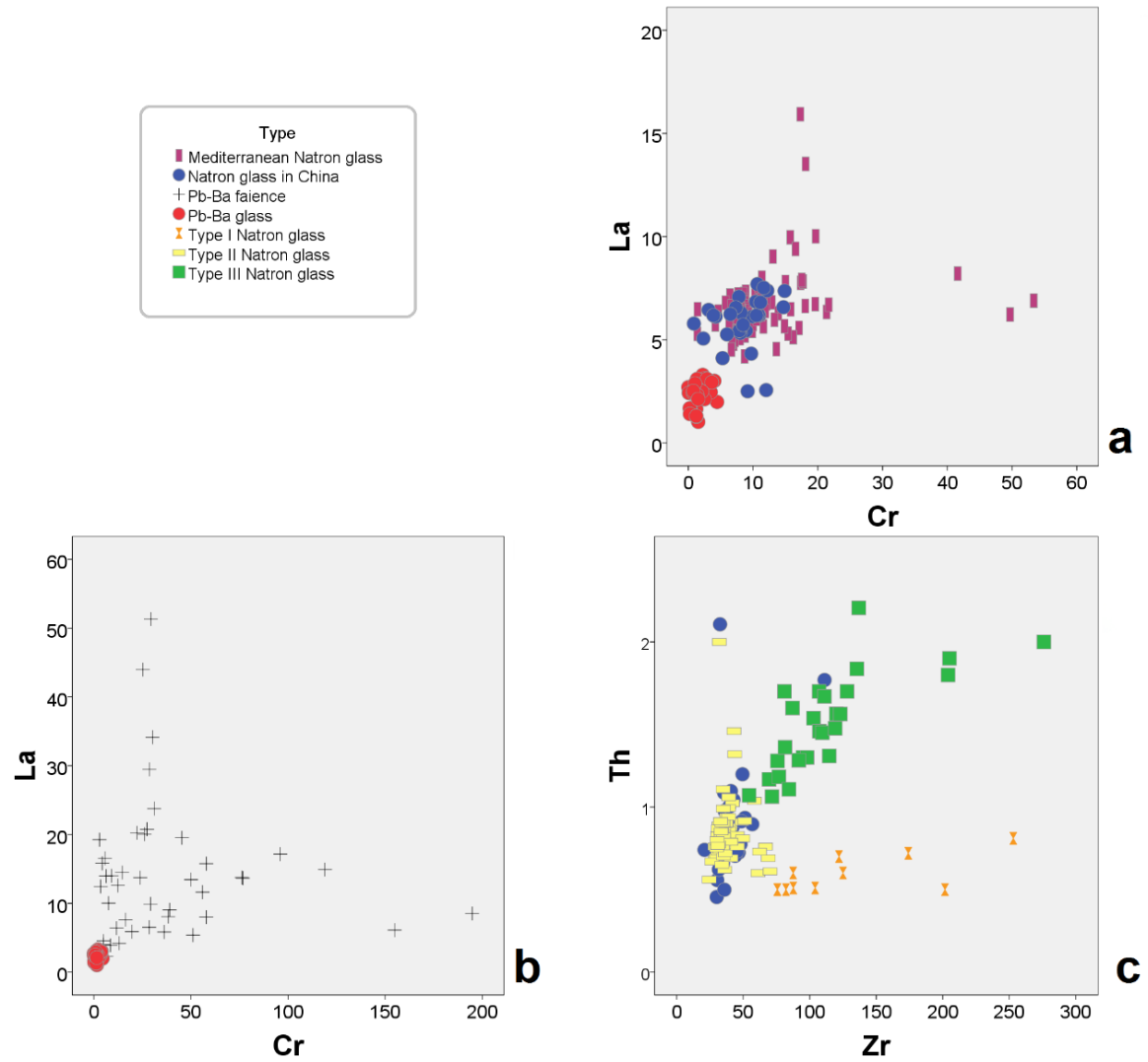


**Figure 5.3 Cr-La and Th-Zr concentrations (ppm) for glasses unearthed from different sites.** The published data of three subtypes of natron glasses can be found in Data file S3 (Blomme *et al.*, 2017; Conte *et al.*, 2019, 2016; Lü *et al.*, 2021; Oikonomou *et al.*, 2018; Panighello *et al.*, 2012; Tzankova and Mihaylov, 2019; Van Strydonck *et al.*, 2018).

Using ratios of trace elements can eliminate the dilution effect caused by other components in glass, such as lead and barium additions. In this paper, we produce a piece of code that allows us to perform 3D kernel density estimation on four variables (Zr-Ti-Cr-Y) in a tetrahedron plot. This 3D plot was performed through R – the full

code can be viewed in Appendix B. Kernel Density Estimation (KDE) is a non-parametric estimation of the probability density function of a random variable. KDE is a fundamental data smoothing method that allows for inferences about the population to be made, based on a finite data sample (Guidoum, 2015). Here, the Ti concentration is divided by 10, as its concentration is much higher than the other three trace elements. Directly plotting Ti concentrations in the tetrahedron graph will cause the points to be biased towards the Ti axis, which makes it impossible to differentiate each assemblage. As known, Mesopotamian glass was produced by a different silica source compared with natron glass in Mediterranean (Shortland *et al.*, 2007). However, there is limited published data on the trace element analysis of Mesopotamian glass during the Iron Age period. As a reference group, the published data of Mesopotamian glass discovered from Rhodes, Greece dating to the 7<sup>th</sup> century BC in Figure 5.4 can be differentiated from other groups of glasses (Oikonomou and Triantafyllidis, 2018). The natron glass in China correlated with Type II natron glass. Although the range of four trace elements in lead-barium glass is a bit scattered, they indeed overlap with the natron glass in China and Type II natron glass.

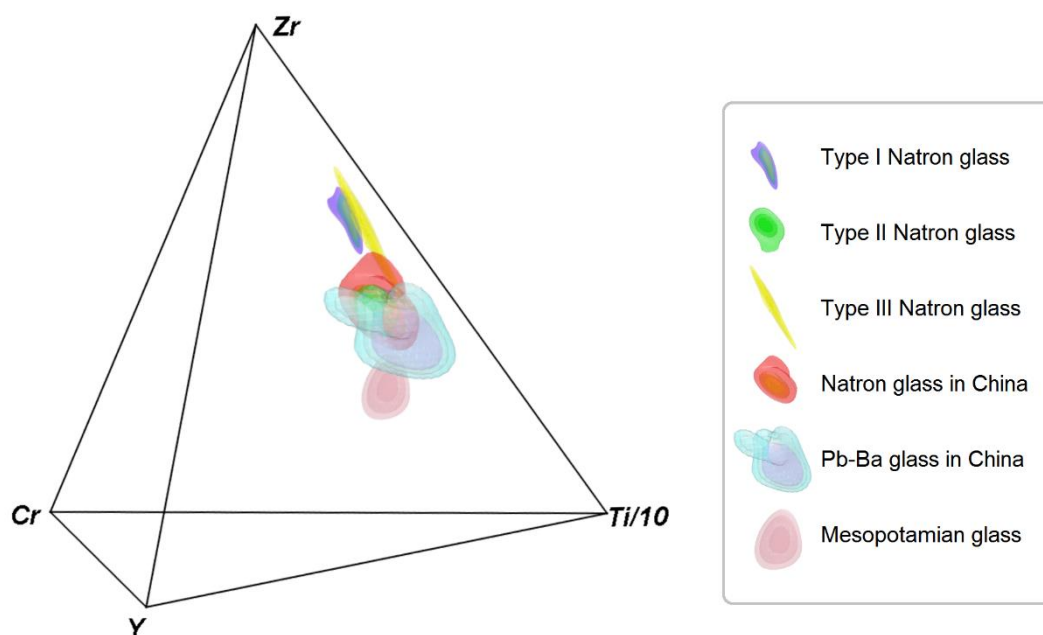


**Figure 5.4 Multivariate Kernel Density Estimation of glasses unearthed from different sites in a tetrahedron plot.** The published data can be found in Data file S3 (Blomme *et al.*, 2017; Conte *et al.*, 2019, 2016; Lü *et al.*, 2021; Oikonomou *et al.*, 2018; Oikonomou and Triantafyllidis, 2018; Panighello *et al.*, 2012; Tzankova and Mihaylov, 2019; Van Strydonck *et al.*, 2018).

In order to further estimate the similarity between different groups, Maximum Mean Discrepancy (MMD) and hypothesis testing were applied. MMD is a distance in the probability space which has found numerous applications in machine learning and nonparametric testing (Tolstikhin *et al.*, 2016). This distance is based on the notion of embedding probabilities in a reproducing kernel Hilbert space. When two groups show exactly the same distribution, their MMD equals 0. In this study, Gaussian Radial Basis kernel was used in MMD. By using the function "kmmd" in r package 'kernlab', the random sampling between two groups causes the variability of the automatic sigma

estimation (sigma is the hyperparameter for Gaussian Radial Basis kernel). This will cause a small degree of fluctuation (approximately 10%) in the MMD value between two fixed sets of data each time running the code, while it does not affect the hypothesis testing results. Detailed hypothesis testing steps and algorithms can be viewed from Gretton *et al.* (2008). When MMD value (1<sup>st</sup> order MMD statistic) > the rademacher bound, we reject the null hypothesis; MMD value < the rademacher bound, we accept the null hypothesis (Gretton *et al.*, 2008). We first rejected null hypothesis under  $\alpha=0.05$  significance level (null hypothesis  $H_0$ : distribution  $P(X)=Q(Y)$ , group X and group Y comes from same distribution; alternative hypothesis  $H_1$ : distribution  $P(X)\neq Q(Y)$ , group X and group Y comes from different distribution). However, by running the code repeatedly/multiple times, the uncertainty of whether to reject the null hypothesis between Type II natron glass and lead-barium glass was observed, which indicates that the p-values fluctuates around 0.05. This uncertainty was eliminated when the  $\alpha$  was changed to 0.01 (accept the null hypothesis under 1% significance level). Table 5.1 shows hypothesis testing results between each two groups. MMD values can be tested through the code provided in Appendix B. However, MMD values were not presented in Table 5.1 as the it fluctuates with the change of the sigma value. The null hypotheses between Type II natron glass, natron glass in China and Pb-Ba glass are accepted, which further confirms what has been observed from Figure 5.4. This means the silica source

for producing lead-barium glass was similar to natron glass in China and Type II natron glass. The study of cobalt source through Co-Ni plot also supports this finding (Appendix B Figure 5.10). Arsenic concentration was not counted due to the choice of the quantification standards.

**Table 5.1 Zr-Ti-Cr-Y Hypothesis testing results between each two groups**  
( $\alpha=0.05$ , except for Hellenistic Mediterranean - Pb-Ba glass; accept null hypothesis implies that two groups are indistinguishable).

|                         | 1-Natron glass in China | 2-Pb-Ba glass            |
|-------------------------|-------------------------|--------------------------|
| 1-Natron glass in China | -                       | Accept                   |
| 2-Pb-Ba glass           | Accept                  | -                        |
| 3-Type I Natron glass   | Reject                  | Reject                   |
| 4-Type II Natron glass  | Accept                  | Accept ( $\alpha=0.01$ ) |
| 5-Type III Natron glass | Reject                  | Reject                   |
| 6-Mesopotamian glass    | Reject                  | Reject                   |

## 5.4 Discussion

Glass is called 'Boli' in Chinese literature. 'Bolos' in Greek represents semi-finished glass products. The link between 'Boli' and 'Bolos' has been discussed in Chapter 2.2.

It is possible that glass ingots were also traded into China and the term 'Bolos' was also transferred into China. 'Bolos' was later gradually transliterated into 'Boli' in Chinese.

This supports the analysis result in this study that Mediterranean natron glass was used to produce lead-barium glass.



Indeed, the use of glass as jade imitation is a Chinese invention, but the use of opacifier for glass from Mediterranean and Mesopotamia was much earlier than in China. Antimony combined with lead and calcium to create yellow and white opacifiers were used for glass production in the Mediterranean and Mesopotamia around 1500 BC through into the Roman period (Turner and Rooksby, 1959). Thus, it can be assumed that the concept of making opacified glass was transmitted to the Central Plains of China along with the opacified soda-lime-silica glass. A majority of the natron eye bead glass samples from Hubei analysed in this case show a certain level of Sb, and the opaque white eye glass contains higher amount of opacifier up to 28% of Sb (e.g. 5.39178 white glass area). The quantity of jade glass discovered in the Chu State cemeteries during the Warring States is significantly higher than any other regions in China, such as over 120 pieces of glass bi disk unearthed from Hunan (An, 2000a, p. 27). We believe Hunan and Hubei where the Chu State was located are the origin of the jade glass during the Warring States Period. Still, Lead-barium glass beads unearthed from the borderland of China, such as Xinjiang and Yunnan, seem to be produced for other purposes rather than jade imitation. As shown in Figure 5.5, lead-barium glass unearthed from these two regions are more likely to be imitations of turquoise and lapis lazuli rather than jade. This suggests that lead-barium glass might not be a unique invention of the Chu State, and there were likely more workshops that might have

controlled the production of lead-barium glass to imitate different precious stones in China. As a secondary glass product, there is no doubt that lead-barium glass was a Chinese invention, yet our analysis indicates the primary raw glass for producing this type of glass originated from the Mediterranean.

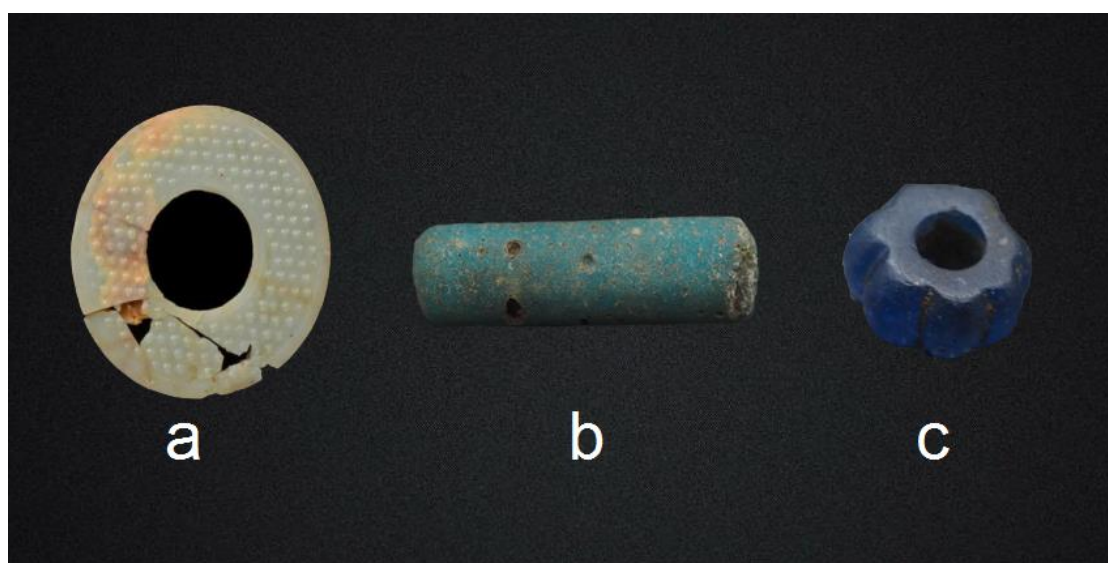


**Figure 5.5 Lead-barium glass as imitations of turquoise and lapis lazuli.** a. Sample 1301Bi, a glass bi disk to imitate jade bi disk, Warring States period, Hunan, China; b. Sample SJMIS-1, a glass tube to imitate turquoise, Warring States period, Yunnan, China; c. TSS-33-4, a blue petal shaped glass bead to imitate lapis lazuli, Han Dynasty, Xinjiang, China.

According to Figure 5.3 and Figure 5.4, it seems the addition of BaO and PbO diluted the Zr, Ti, Cr, Y and La contents in lead-barium glass compared within the natron glass. This can be explained that these trace elements only enrich in the vein quartz rather than in lead and barium minerals. For example, the La content can be over 800 ppm in barite associated carbonatite and pegmatite (Niu *et al.*, 1996), whereas the La content

is around 1 ppm in barite (Zhao *et al.*, 2017; Zou *et al.*, 2016). If there is a proper pretreatment before they are added to the glass batch, it is possible to remove the silica impurity and lower the level of trace elements. For instance, the metallic appearance and silvery colour of galena (PbS) make it visually distinguishable compared with its vein quartz. A simple crushing and roasting processing can separate them and yield pure PbO. As testified through the multivariate KDE plot and MMD hypothesis test, we can now be certain that the raw glass for natron glass and lead-barium glass during the Warring States and the Han periods is highly correlated with Type II natron glass. According to Lü *et al.*(2021), Type II shows similar but not identical chemical composition as the Levantine-I type of Roman glass (Brems and Degryse, 2013). The oxygen isotopic signature of Type II natron glass supports that the raw materials originated along the Syro-Palestinian coast (Blomme *et al.*, 2017). Sidon in Lebanon was recorded as a Roman glass making centre, and the mouth of Belus River was a source for glassmaking sand (Brems *et al.*, 2012). There is only one archaeological evidence that a late Hellenistic site in Beirut dating to the 1<sup>st</sup> century BC was a primary glass production centre (Henderson, 2013, p. 215). Only one sample dating to the Jin Dynasty identified as Type III natron glass. Yet, only one sample cannot reveal if there was a source change of the natron glass traded in China, or simply more sources of natron glass were traded in China after the Han period. Type III natron glass was

originated from the upper Nile region due to its high level of heavy minerals (Hedrick and Waked, 1989).

According to the typology and chemical composition analyses of the natron eye beads found in Italy, Bulgaria, Greece, Spain, Poland, Georgia, Kyrgyzstan, Russia, Northern China and Central China, it can be concluded that Type II natron glass in Xinjiang was traded through the Eurasian Steppe during the Hellenistic period (Lü *et al.*, 2021). Consequently, we suggest that Type II natron glass from Hubei in this case could also be a result of glass trade through the Eurasian Steppe. Over one thousand eye beads have been excavated from eighteen provinces in China, and the majority of these eye beads date from the Western Zhou Dynasty (1046 – 771 BC) to the Eastern Han Dynasty (Zhao, 2016, p. 241). More than half of the eye beads were discovered from the Chu State cemeteries and its number was larger than any of the neighbouring regions. This implies that there was a certain demand for the eye beads of the Chu people. Thus, there might have been a direct trade rather than a step by step, indirect trade of glass between the Mediterranean and the Chu State during the 1<sup>st</sup> millennium BC. Moreover, two glass samples from Yunnan identified as Type II natron glass may reveal another transmission route. Kopia, India as a major glass manufacturing centre of the 5<sup>th</sup> century BC discovered Mediterranean natron glass (Kanungo and Brill, 2009), and we suggest

this glass trade could further extend to Southern China through the Southwest Silk Road.

A small piece of a glass tube (Figure 5.6) was unearthed from Heimajing Site in Yunnan dating to the Late Warring States period to the Han Dynasty, typologically corresponding to the Hellenistic period (Yunnan institute of cultural relics and Archaeology, 2013). Thus, hypothetically, there could be at least two trade routes of the natron glass discovered in the Chu State. Moreover, as the raw glass for producing lead-barium glasses in Xinjiang and Yunnan are also identified as Type II natron glass, and this means both raw glasses and finished glass products were traded in China through the Eurasian Steppe and the Southwest Silk Road. Still, we cannot exclude the possibility that lead-barium glass was produced by mixing recycled natron glass rather than primary raw glass with domestic lead-barium minerals. The lead-barium glass from Xinjiang used both cobalt and copper as colourants, and this could suggest a recycling process. However, according to Smirniou and Rehren (2013), they believed that there might be other three possibilities for the Co-Cu glass: 1) It could be a result of adding copper source to the cobalt glass; 2) Copper may well be part of a group of transition metals that are known to coexist with cobalt in the Western Desert's alum deposits; 3) Some of the copper might come from bronze containers where the cobalt colourant was prepared through a series of wet chemical procedures. Thus, further research is needed to identify if lead-barium glass was a secondary production or

recycled production.

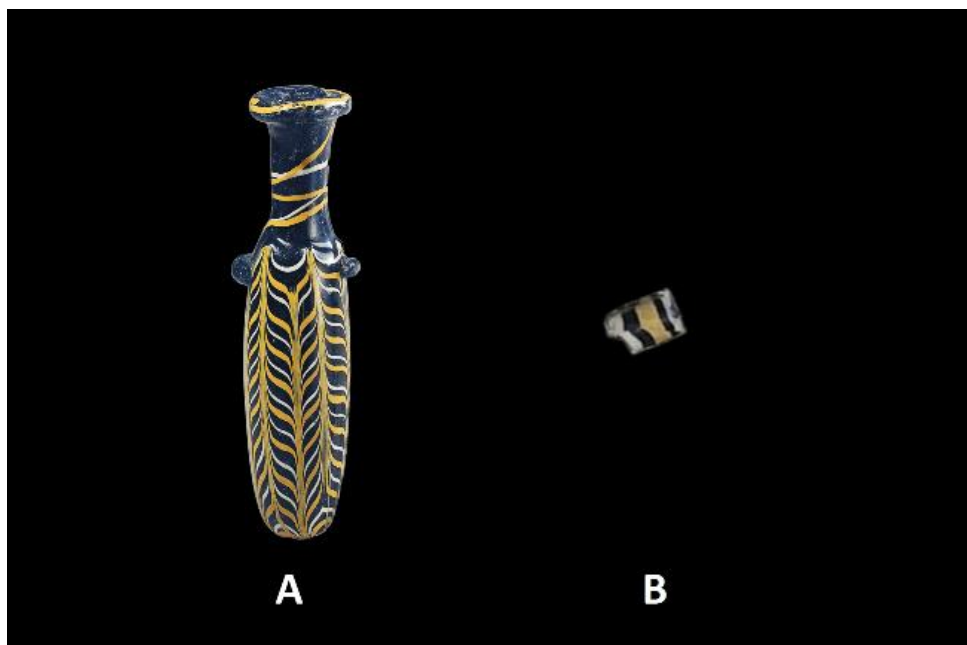


**Figure 5.6 A glass tube and a Mediterranean glass bottle with a similar decoration pattern.** A. An Eastern Mediterranean Core-Formed Glass Alabastron, Middle 2<sup>nd</sup> – Early 1<sup>st</sup> century BC; B. Glass tube, 221 BC – AD 220, Han Dynasty, Yunnan, China.

## 5.5 Conclusions

Combining trace element analysis and kernel approaches, natron glass and lead-barium glass in China dating to Warring States and the Han periods show similar trace element signatures to the Type II natron glass. There is only one glass sample from Hubei dating to the Jin Dynasty classified as Type III natron glass. Type II and Type III natron glasses originated from the Syro-Palestinian coast and Egypt respectively. It is highly possible that both the Eurasian Steppe and Southwest Silk Road played roles of raw glass and

finished glass product trade during the 1<sup>st</sup> millennium BC. There were multiple secondary production workshops for lead-barium glass in China, yet, lead-barium glass is considered a mixture of imported natron glass with Chinese lead-barium minerals. The early Chinese glass industry is still uncertain since both the literature and the archaeological evidence are lacking. However, ancient glass beads show some clear clues based from the analysis. Although the Chinese lead-barium glass is unique in aesthetics and function, it is clear that the manufacture was inspired by the western glass products rather than invented by local craftsman. The Chinese glass industry largely relied on the cross regional primary glass supply chain. The prosperity of the Silk Road ensured that the long-distance material transfer was safe and efficient. It might be the reason why the lead-barium glass almost disappeared after the Han Dynasty when the Silk Road declined. This study suggests that the east part of the Eurasia continent was already involved in the glass production network as early as twenty-five hundred years ago. The future research for lead-barium glass may help identify more sources, such as the glass from Mesopotamia and South Asia. Isotopic analysis, such as Nd isotope and Hf isotopes to trace the silica source (Barfod *et al.*, 2020; Degryse, 2014, p. 51), B isotopes to trace the natron source (Degryse, 2014, p. 89), can certainly be useful to source the raw materials for producing lead-barium glass. Last but not least, the further archaeological evidence for glass findings along the Eurasian Steppe and the Southwest

Silk Road can refine our standing of the glass transmission routes from the Mediterranean to China.

**Notes** Packages ‘rgl’, ‘ks’ and ‘kernlab’ were used in our code; Figure 5.6A is an Auction item from Christie’s:

[https://www.christies.com/lotfinder/lot\\_details.aspx?from=salesummery&intobjectid=5684651&lid=4](https://www.christies.com/lotfinder/lot_details.aspx?from=salesummery&intobjectid=5684651&lid=4)



## 5.6 Appendix B

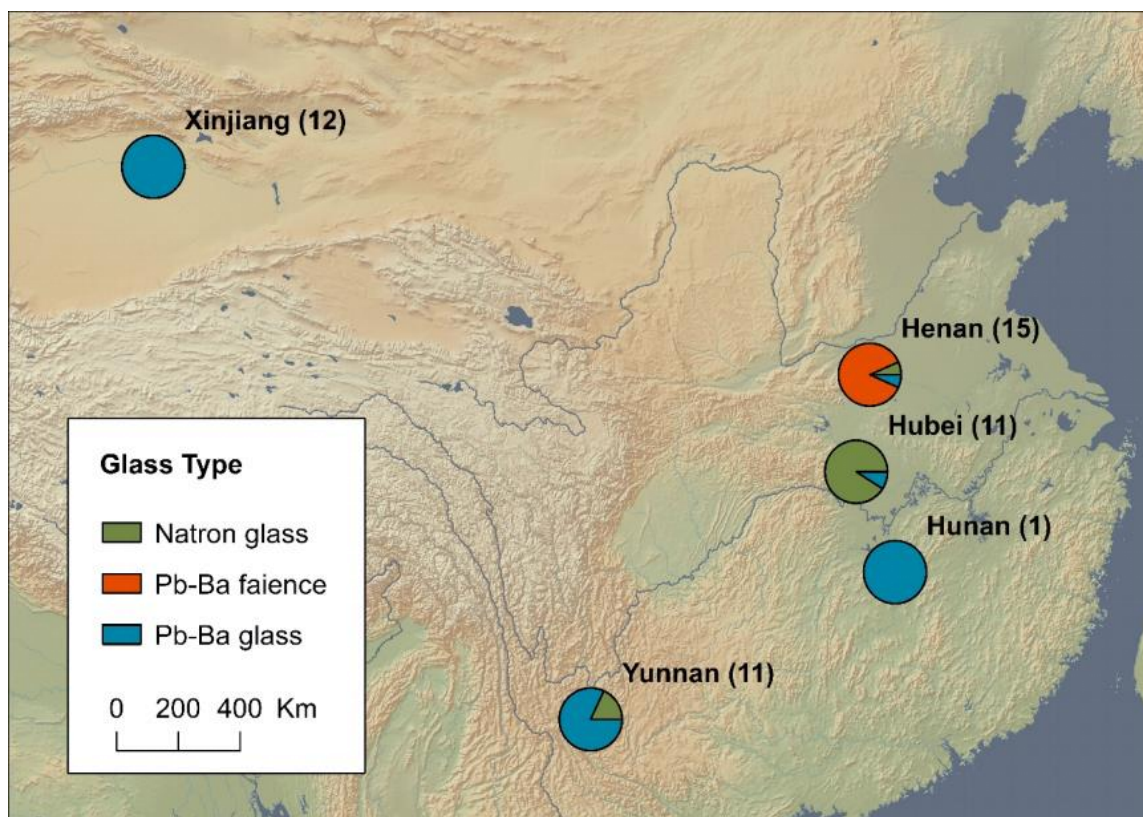


**Figure 5.7 Sample distribution.** Samples are from five different provinces in China, and the proportions of each type of glass in each region have been summarised as pie charts.

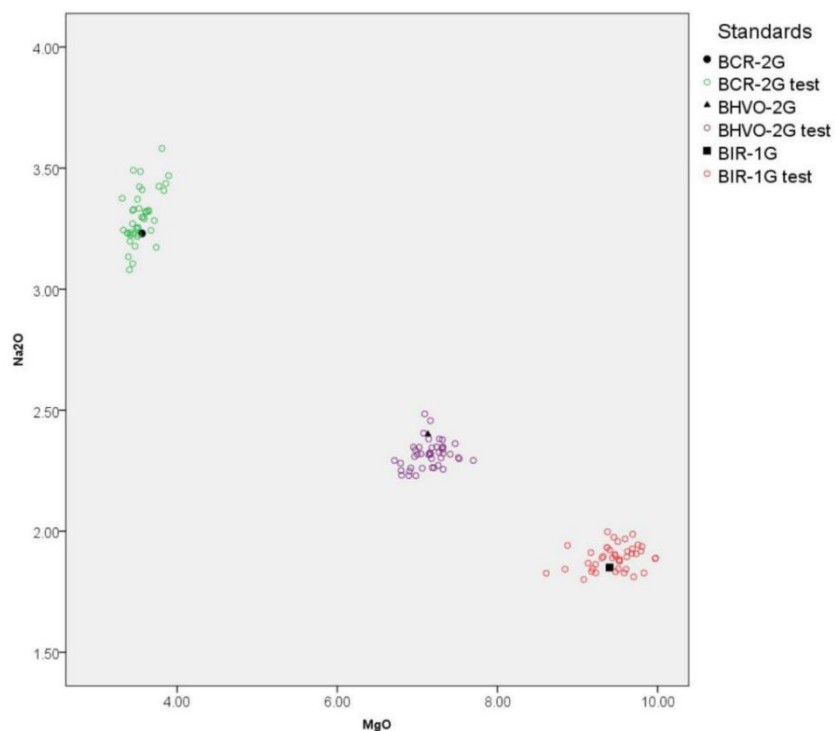


**Figure 5.8** The accuracy of the data by testing the reference materials (wt%). **The black dots represent the reference values for three standards, and coloured circles represent the tested values for three standards.**

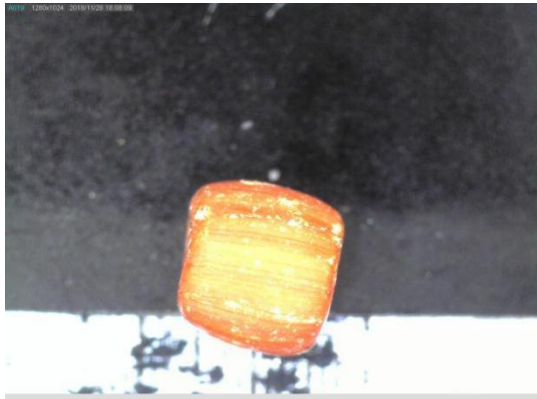
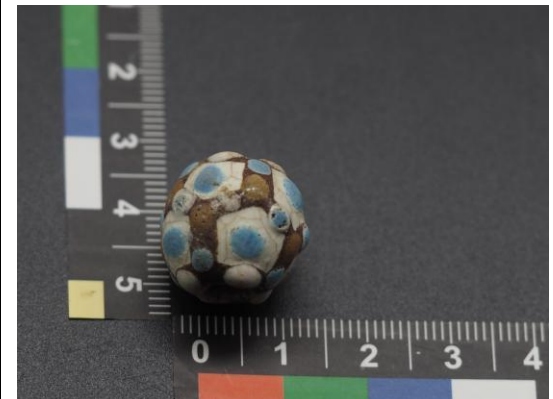
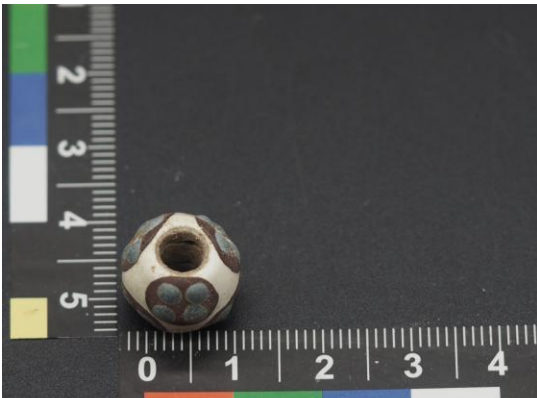
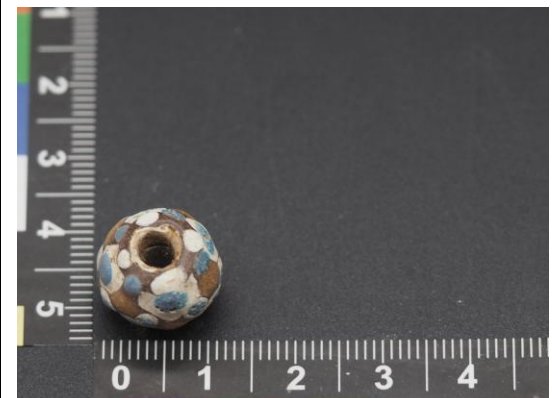
**Table 5.2 Sample Information.**

| Type         | Sample    | Location | Site                    | Date                 | Geographical Coordinates | Reference                                         |
|--------------|-----------|----------|-------------------------|----------------------|--------------------------|---------------------------------------------------|
| Pb-Ba glass  | C3-3      | Yunnan   | Chuxiong Wanjiaba       | Warring States       | 101.528278,25.044855     | Baidu map/ Site                                   |
| Natron glass | 5.772     | Hubei    | Han Yang Cai Dian M1:14 | Late West Jin        | 114.037011,30.590454     | Baidu map/ Closest modern town- Han Yang Cai Dian |
| Natron glass | LM1285-1  | Hubei    | Jiang Ling Jiu Dian     | Late Warring States  | 112.228707,30.446277     | Baidu map/ Closest modern town- Shi Jia Wa        |
| Natron glass | LM1285-2  | Hubei    | Jiang Ling Jiu Dian     | Late Warring States  | 112.228707,30.446278     | Baidu map/ Closest modern town- Shi Jia Wa        |
| Pb-Ba glass  | 5.29754   | Hubei    | Jiang Ling Jiu Dian     | Late Warring States  | 112.228707,30.446279     | Baidu map/ Closest modern town- Shi Jia Wa        |
| Natron glass | M1ZC-4    | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720462     | Baidu map/ Site                                   |
| Natron glass | SJM1S-2   | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720463     | Baidu map/ Site                                   |
| Pb-Ba glass  | S12-97-2  | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720464     | Baidu map/ Site                                   |
| Pb-Ba glass  | S13-370-1 | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720465     | Baidu map/ Site                                   |
| Pb-Ba glass  | S22-60    | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720466     | Baidu map/ Site                                   |
| Pb-Ba glass  | S6-148A   | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720467     | Baidu map/ Site                                   |
| Pb-Ba glass  | SJM16     | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720468     | Baidu map/ Site                                   |
| Pb-Ba glass  | SJM1S4    | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720469     | Baidu map/ Site                                   |
| Pb-Ba glass  | SJMIS-1   | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720470     | Baidu map/ Site                                   |
| Pb-Ba glass  | SR15-12   | Yunnan   | Jinning Shizhaishan     | Warring States       | 102.701644,24.720471     | Baidu map/ Site                                   |
| Natron glass | 5.39178   | Hubei    | Jiu Lian Dun            | Mid Warring States   | 112.84837,31.991417      | Baidu map/ Site                                   |
| Natron glass | 5.39205   | Hubei    | Jiu Lian Dun            | Mid Warring States   | 112.84837,31.991417      | Baidu map/ Site                                   |
| Pb-Ba glass  | TSS-33-1  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953405      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-33-2  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953406      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-33-3  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953407      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-33-4  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953408      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-33-5  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953409      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-33-6  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953410      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43-1  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953411      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43-2  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953412      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43-3  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953413      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43-4  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953414      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43-5  | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953415      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | TSS-43    | Xinjiang | Sheng Jin Dian          | Han                  | 89.651094,42.953416      | Baidu map/ Closest modern town- Sheng Jin Cun     |
| Pb-Ba glass  | 1301Bi    | Hunan    | Yiyang Luojiuzui        | Late Warring States  | 112.361516,28.559711     | Baidu map/ Closest modern town-Yi Yang            |
| Natron glass | 5.43632   | Hubei    | Zeng Marquis Yi M1      | Early Warring States | 113.357009,31.734337     | Baidu map/ Site museum                            |
| Natron glass | 5.43633   | Hubei    | Zeng Marquis Yi M1      | Early Warring States | 113.357009,31.734338     | Baidu map/ Site museum                            |
| Natron glass | 5.43621   | Hubei    | Zeng Marquis Yi M1      | Early Warring States | 113.357009,31.734339     | Baidu map/ Site museum                            |
| Natron glass | 5.43561   | Hubei    | Zeng Marquis Yi M1      | Early Warring States | 113.357009,31.734340     | Baidu map/ Site museum                            |
| Natron glass | 5.43668   | Hubei    | Zeng Marquis Yi M1      | Early Warring States | 113.357009,31.734341     | Baidu map/ Site museum                            |

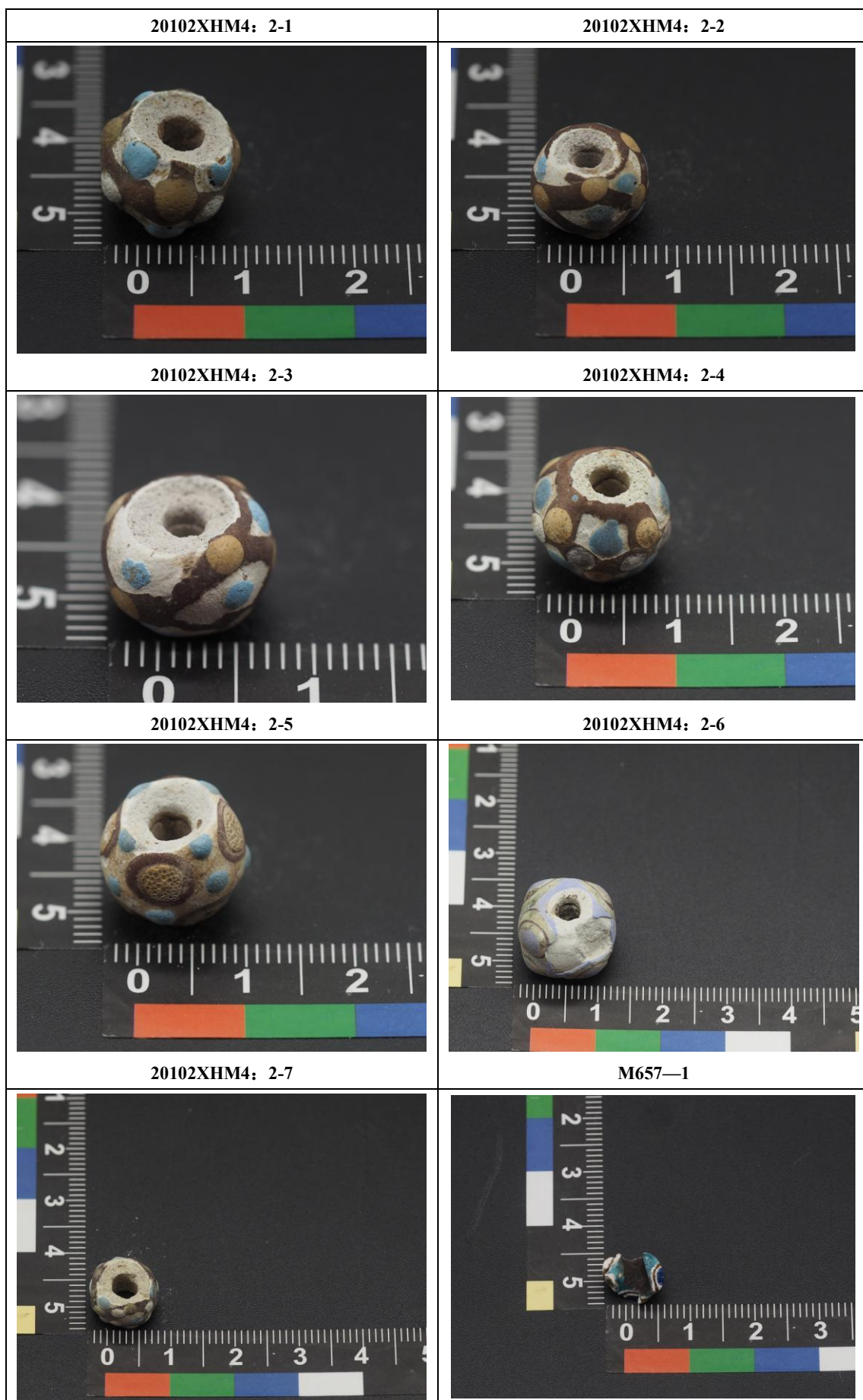
|               |                 |       |           |                |                      |                                            |
|---------------|-----------------|-------|-----------|----------------|----------------------|--------------------------------------------|
| Natron glass  | 08XYXM18-11     | Henan | Zhengzhou | Han            | 113.637185,34.758149 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | M19-3           | Henan | Zhengzhou | Warring States | 113.637185,34.758150 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 2018ZHCM226-7   | Henan | Zhengzhou | Warring States | 113.637185,34.758151 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 2018ZHCM398-3-1 | Henan | Zhengzhou | Warring States | 113.637185,34.758152 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 2018ZHCM398-3-2 | Henan | Zhengzhou | Warring States | 113.637185,34.758153 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-1   | Henan | Zhengzhou | Warring States | 113.637185,34.758154 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-2   | Henan | Zhengzhou | Warring States | 113.637185,34.758155 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-3   | Henan | Zhengzhou | Warring States | 113.637185,34.758156 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-4   | Henan | Zhengzhou | Warring States | 113.637185,34.758157 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-5   | Henan | Zhengzhou | Warring States | 113.637185,34.758158 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-6   | Henan | Zhengzhou | Warring States | 113.637185,34.758159 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | M657-1          | Henan | Zhengzhou | Warring States | 113.637185,34.758160 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | 20102XHM4-2-7   | Henan | Zhengzhou | Warring States | 113.637185,34.758161 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba faience | M657-3          | Henan | Zhengzhou | Warring States | 113.637185,34.758162 | Baidu map/ Closest modern town- Zhengzhou* |
| Pb-Ba glass   | M-4-YD          | Henan | Zhengzhou | Warring States | 113.637185,34.758163 | Baidu map/ Closest modern town- Zhengzhou* |

\* Samples from Zhengzhou are discovered from various excavations in City Zhengzhou related to the city construction, the coordinate presented here is the location of Zhengzhou City Institute of Cultural Heritage and Archaeology.

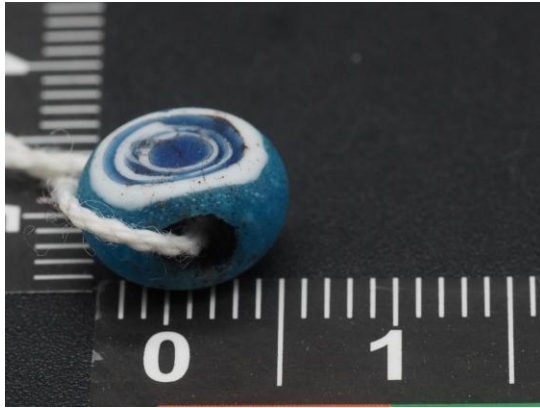
**Table 5.3 Sample Photos.**

|                                                                                                             |                                                                                                              |
|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
|  <p>08XYXM18-11</p>        |  <p>M-19-3</p>             |
|  <p>M-4-YD</p>            |  <p>2018ZHCM226: 7</p>    |
|  <p>2018ZHCM398: 3—1</p> |  <p>2018ZHCM398: 3—2</p> |
|                          |                          |



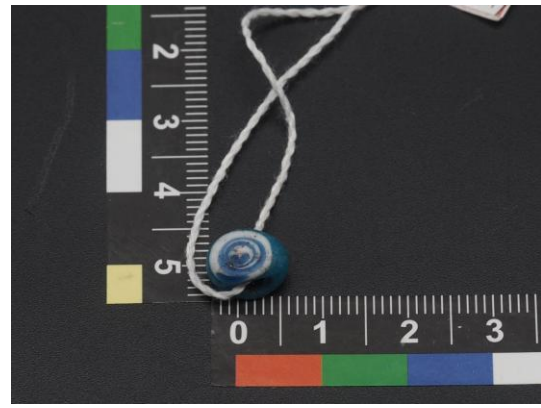


M657—3



5.43632

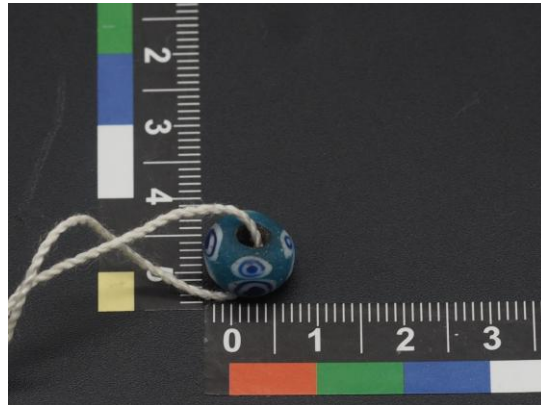
LM1285-1



5.43633



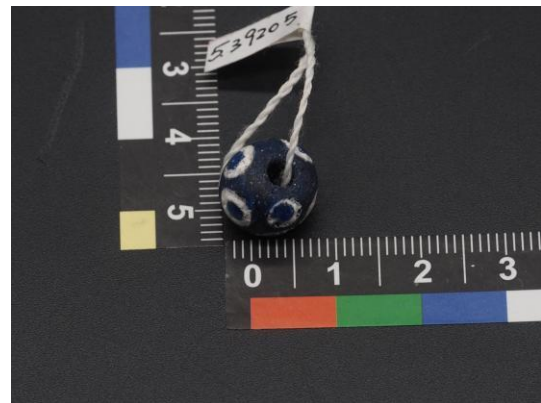
5.43621



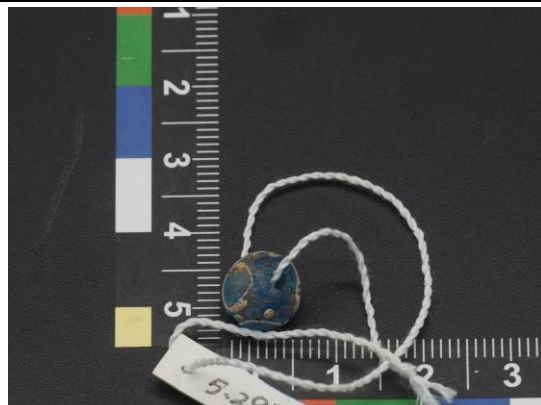
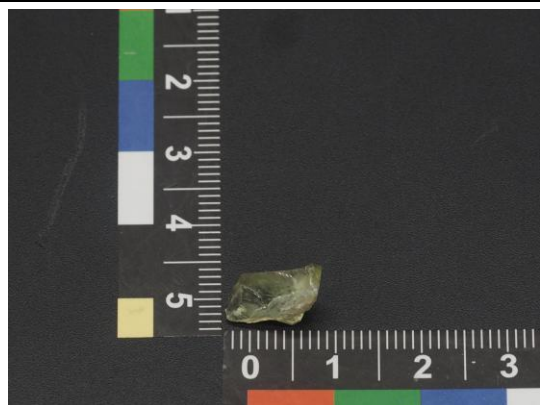
5.43561



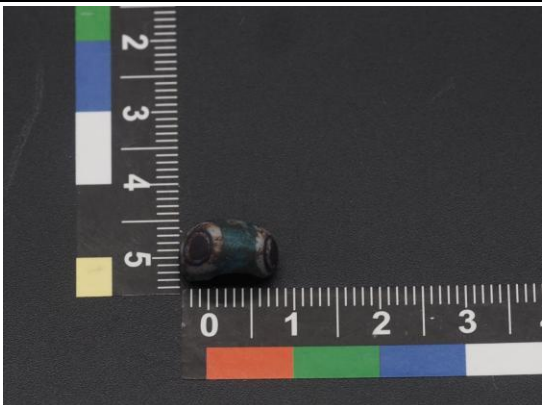
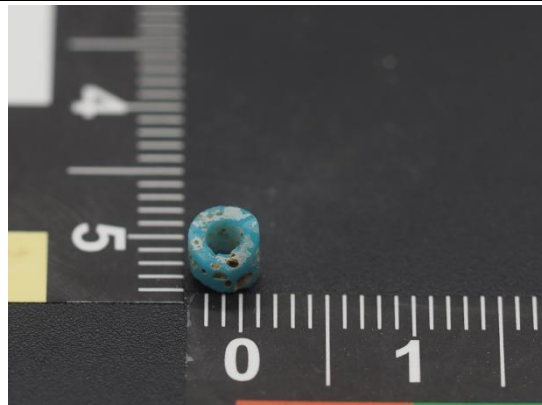
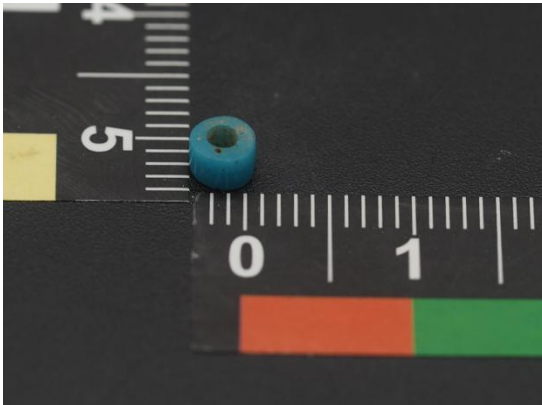
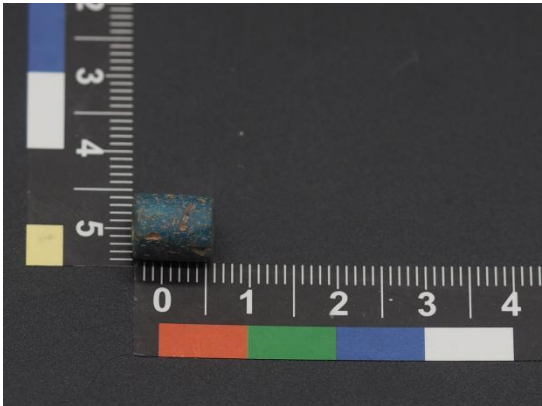
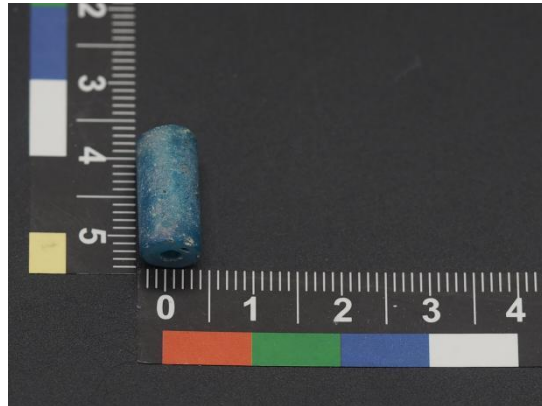
5.39178



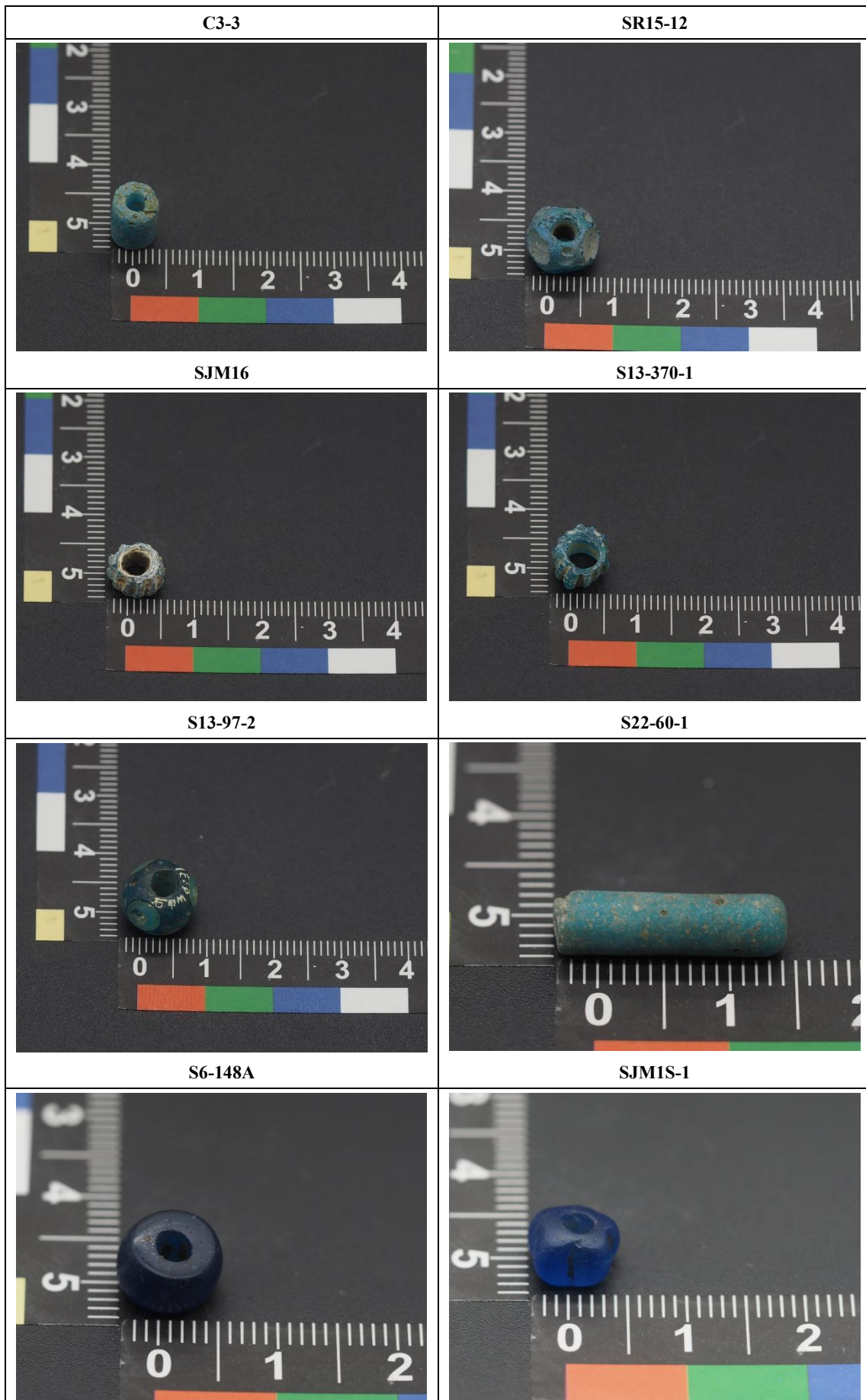
5.39205

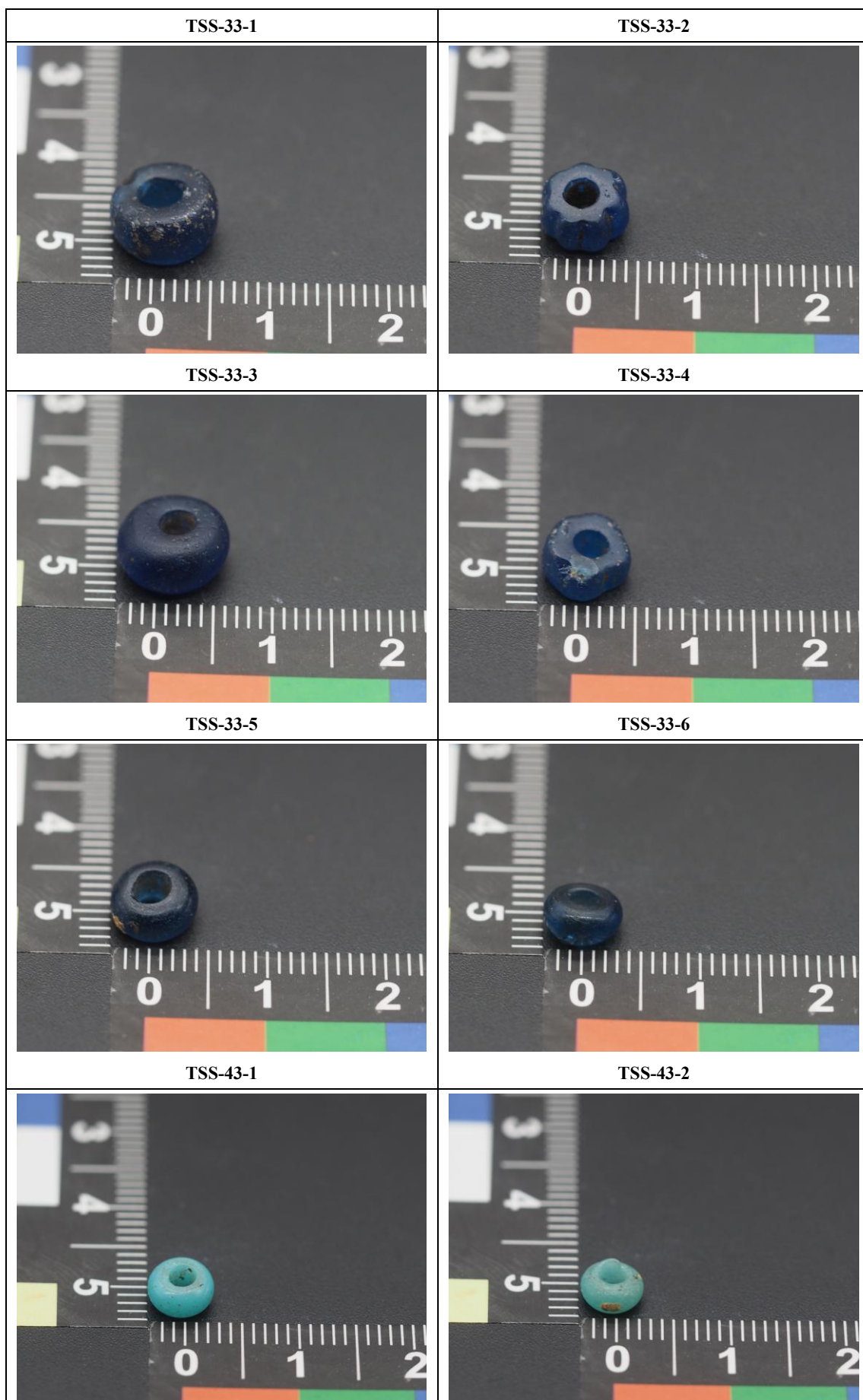




|                                                                                                               |                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| <p>5772</p>  <p>LM1285-2</p> | <p>5.29754</p>  <p>5.43668</p> |
|  <p>1301Bi</p>              |  <p>SJM1S-2</p>               |
|  <p>M1ZC-4</p>             |  <p>SJM1S-4</p>              |
|                            |                              |







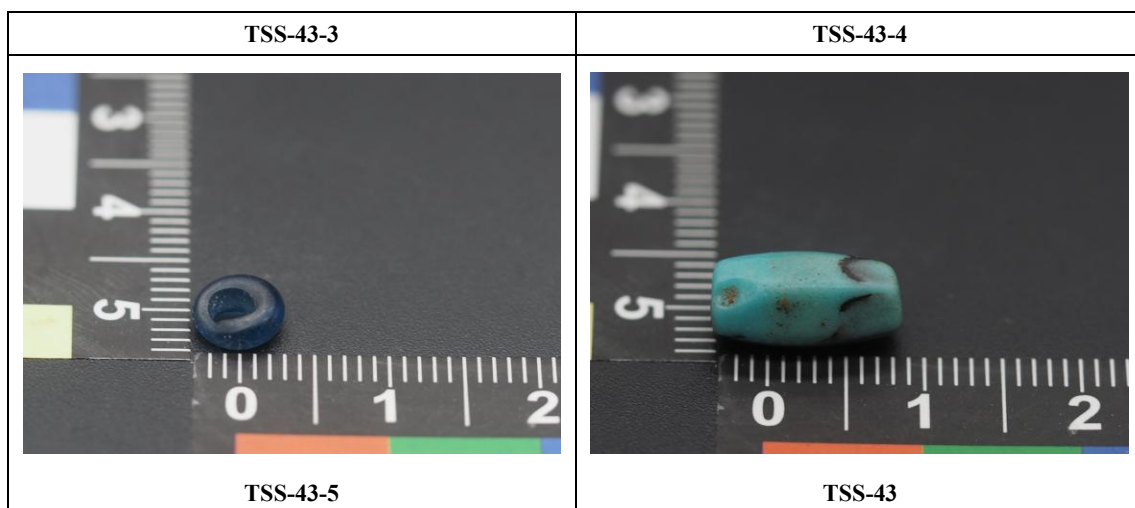


**Table 5.4 Typical operation conditions for LA-ICP-MS analysis.**

| ICP-MS conditions  |                                               |
|--------------------|-----------------------------------------------|
| RF power           | 1350 W                                        |
| Plasma gas         | 15 L min <sup>-1</sup> Ar                     |
| Auxiliary gas      | 1 L min <sup>-1</sup> Ar                      |
| Make-up gas        | 1 L min <sup>-1</sup> Ar                      |
| Sampling depth     | 5.4 mm                                        |
| Detector           | Dual (pulse and analog counting)              |
| Dwell time/mass    | 6 ms                                          |
| Laser parameters   |                                               |
| Wavelength         | 193 nm                                        |
| Energy density     | 14 J cm <sup>-2</sup>                         |
| Carrier gas        | He (optimized to get the highest sensitivity) |
| Ablation style     | Single spot                                   |
| Ablation spot size | 32 µm                                         |
| Repetition rate    | 8 Hz                                          |
| Laser pulse        | 400                                           |

**Table 5.5 Accuracy and precision of the reference materials.**

| Analyte                        | Mean   | Relative error | S.D   | Consensus |
|--------------------------------|--------|----------------|-------|-----------|
| BCR-2G                         |        |                |       |           |
| Na <sub>2</sub> O              | 3.29   | 1.93%          | 0.10  | 3.23      |
| MgO                            | 3.54   | -0.62%         | 0.14  | 3.56      |
| Al <sub>2</sub> O <sub>3</sub> | 13.69  | 2.20%          | 0.36  | 13.40     |
| SiO <sub>2</sub>               | 54.27  | -0.26%         | 1.49  | 54.41     |
| K <sub>2</sub> O               | 1.85   | 3.19%          | 0.56  | 1.79      |
| CaO                            | 7.24   | 2.51%          | 0.31  | 7.06      |
| TiO <sub>2</sub>               | 2.41   | 2.26%          | 0.54  | 2.35      |
| Cr                             | 15.01  | -11.71%        | 2.98  | 17.00     |
| MnO                            | 0.21   | 2.77%          | 0.01  | 0.20      |
| FeO                            | 12.46  | 0.50%          | 1.51  | 12.40     |
| Co                             | 36.88  | -2.94%         | 1.42  | 38.00     |
| Ni                             | 12.02  | -7.57%         | 1.84  | 13.00     |
| Y                              | 36.00  | 2.87%          | 2.03  | 35.00     |
| Zr                             | 188.46 | 2.43%          | 7.95  | 184.00    |
| Ba                             | 689.44 | 0.94%          | 37.10 | 683.00    |
| La                             | 24.54  | -0.67%         | 4.23  | 24.70     |
| Pb                             | 11.27  | 2.43%          | 1.10  | 11.00     |
| BHVO-2G                        |        |                |       |           |
| Na <sub>2</sub> O              | 2.31   | -3.80%         | 0.05  | 2.40      |
| MgO                            | 7.15   | 0.30%          | 0.22  | 7.13      |
| Al <sub>2</sub> O <sub>3</sub> | 13.58  | -0.10%         | 0.30  | 13.60     |
| SiO <sub>2</sub>               | 49.90  | 1.21%          | 0.88  | 49.31     |
| K <sub>2</sub> O               | 0.58   | 12.73%         | 0.26  | 0.51      |
| CaO                            | 11.41  | 0.07%          | 0.33  | 11.40     |
| TiO <sub>2</sub>               | 2.74   | 0.90%          | 0.25  | 2.72      |
| Cr                             | 293.60 | 0.21%          | 19.60 | 293.00    |
| MnO                            | 0.18   | 3.53%          | 0.00  | 0.17      |
| FeO                            | 11.29  | -0.10%         | 1.16  | 11.30     |
| Co                             | 44.53  | 1.22%          | 1.46  | 44.00     |
| Ni                             | 119.36 | 2.89%          | 4.94  | 116.00    |
| Y                              | 24.86  | -4.39%         | 1.45  | 26.00     |
| Zr                             | 167.42 | -1.52%         | 5.69  | 170.00    |
| Ba                             | 127.67 | -2.54%         | 8.47  | 131.00    |
| La                             | 14.94  | -1.74%         | 0.57  | 15.20     |
| Pb                             | 1.69   | -0.47%         | 0.47  | 1.70      |
| BIR-1G                         |        |                |       |           |
| Na <sub>2</sub> O              | 1.89   | 2.20%          | 0.05  | 1.85      |
| MgO                            | 9.46   | 0.65%          | 0.29  | 9.40      |
| Al <sub>2</sub> O <sub>3</sub> | 15.33  | -1.12%         | 0.25  | 15.50     |
| SiO <sub>2</sub>               | 47.36  | -0.32%         | 0.58  | 47.51     |
| K <sub>2</sub> O               | 0.03   | 16.30%         | 0.01  | 0.02      |
| CaO                            | 13.21  | -0.70%         | 0.31  | 13.30     |
| TiO <sub>2</sub>               | 0.94   | 4.31%          | 0.06  | 0.90      |
| Cr                             | 397.91 | 1.51%          | 17.33 | 392.00    |
| MnO                            | 0.18   | -4.93%         | 0.00  | 0.19      |
| FeO                            | 10.77  | 3.53%          | 0.87  | 10.40     |
| Co                             | 52.83  | 1.60%          | 1.29  | 52.00     |
| Ni                             | 177.14 | -0.48%         | 5.56  | 178.00    |
| Y                              | 14.94  | 4.48%          | 1.00  | 14.30     |
| Zr                             | 13.64  | -2.54%         | 2.42  | 14.00     |
| Ba                             | 7.63   | 17.45%         | 8.77  | 6.50      |
| La                             | 0.61   | -0.46%         | 0.10  | 0.61      |
| Pb                             | 3.51   | -5.24%         | 0.42  | 3.70      |

### **Comparison with other Chinese silicate materials**

It is clear that lead-barium glass and lead-barium faience used different silica sources. The question that remains is if this represents two different silica sources for producing different lead-barium vitreous materials in China, and one of them is just coincidentally chemically close to the Egyptian and Italian silica source, or could it actually mean that the lead-barium glass was a mixture of Egyptian or Italian glass and Chinese lead-barium minerals? Figure 5.9 illustrates Ti/La ratios of earthenware and proto porcelain glazes dating to 1700 – 221 BC. The Ti/La ratios for earthenware, proto porcelain and Pb-Ba Faience shows a relatively larger variation and significantly higher than the same ratio in Pb-Ba glass. Both natron glass in China and lead-barium glass show similar and lower range of the Ti/La ratios. Moreover, the absolute Ti and La contents in earthenware, proto porcelain and lead-barium faience are still much higher than in lead-barium glass and natron glass in China. Earthenware and proto porcelain samples are all excavated from different sites in China; thus, they may represent the range of geological fingerprints for the silica raw material used in Chinese glazes, and yet lead-barium glass does not match with any one of them. This reinforces the suggestion made from Figure 5.4, i.e., that lead-barium glass may be a mixture of Egyptian or Italian glass and Chinese lead-barium minerals.

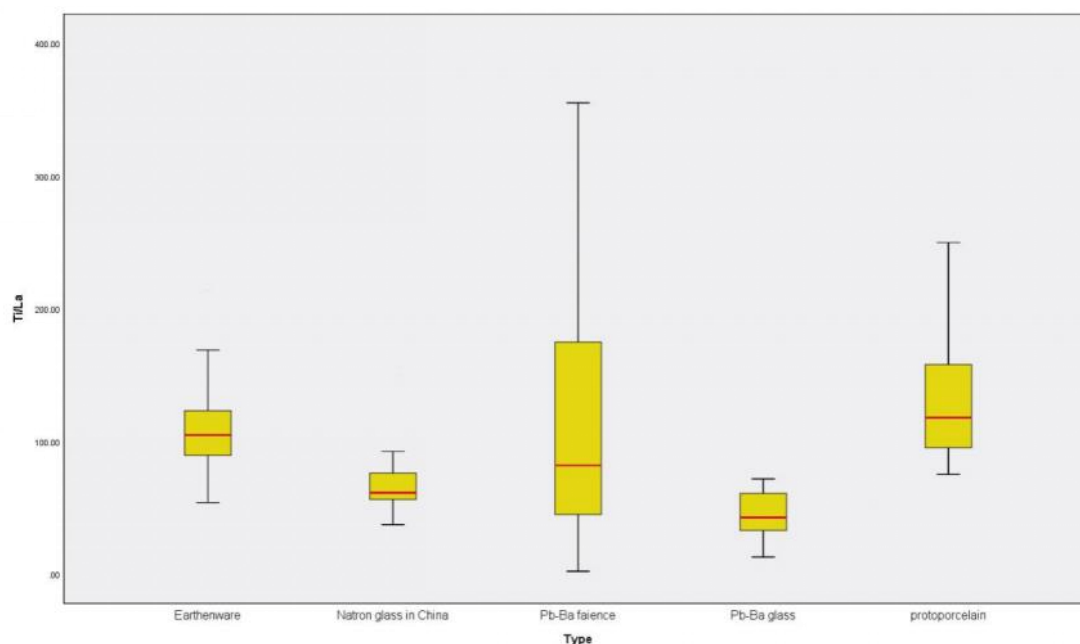


**Figure 5.9 The Ti/La ratios for different silicate materials in China.** The top and bottom of the yellow box represent the upper and lower quartiles respectively, and the red line represents the median. Outliers have been removed. Cr/La ratios for the glaze of earthenware and protoporcelain are contributed from published data in Supplementary Data file S3 (Chen *et al.*, 1999).

### Cobalt analysis

Cobalt is commonly associated with manganese, zinc, nickel and alumina in Egyptian New Kingdom vitreous materials and they show elevated levels in cobalt-coloured glasses (Wood and Hsu, 2019). Figure 5.10 shows the Ni and Co contents of blue glasses from China, Egypt and Mycenae. The Egyptian and Mycenaean glass from the Late Bronze age show a linear correlation between Co and Ni. This might indicate the use of smaltite ((Co, Fe, Ni)As<sub>2</sub>). The use of this type of cobalt declined in western Eurasia after the Late Bronze Age, and the later period cobalt sources used in glass all show low Ni enrichment (Wood and Hsu, 2019). The cobalt lead-barium glass in this case shows lower Co enrichment due to the dilution effect of lead and barium additions. As can be seen, the cobalt natron glass samples excavated in China all show the absence

of Ni, as well as the lead-barium glass. This indicates that both finished or semi-finished glass exported were from the later period. Since lead-barium glass occurred during the 4<sup>th</sup> – 3<sup>rd</sup> century BC, thus the best match would be with the Hellenistic Mediterranean glass.

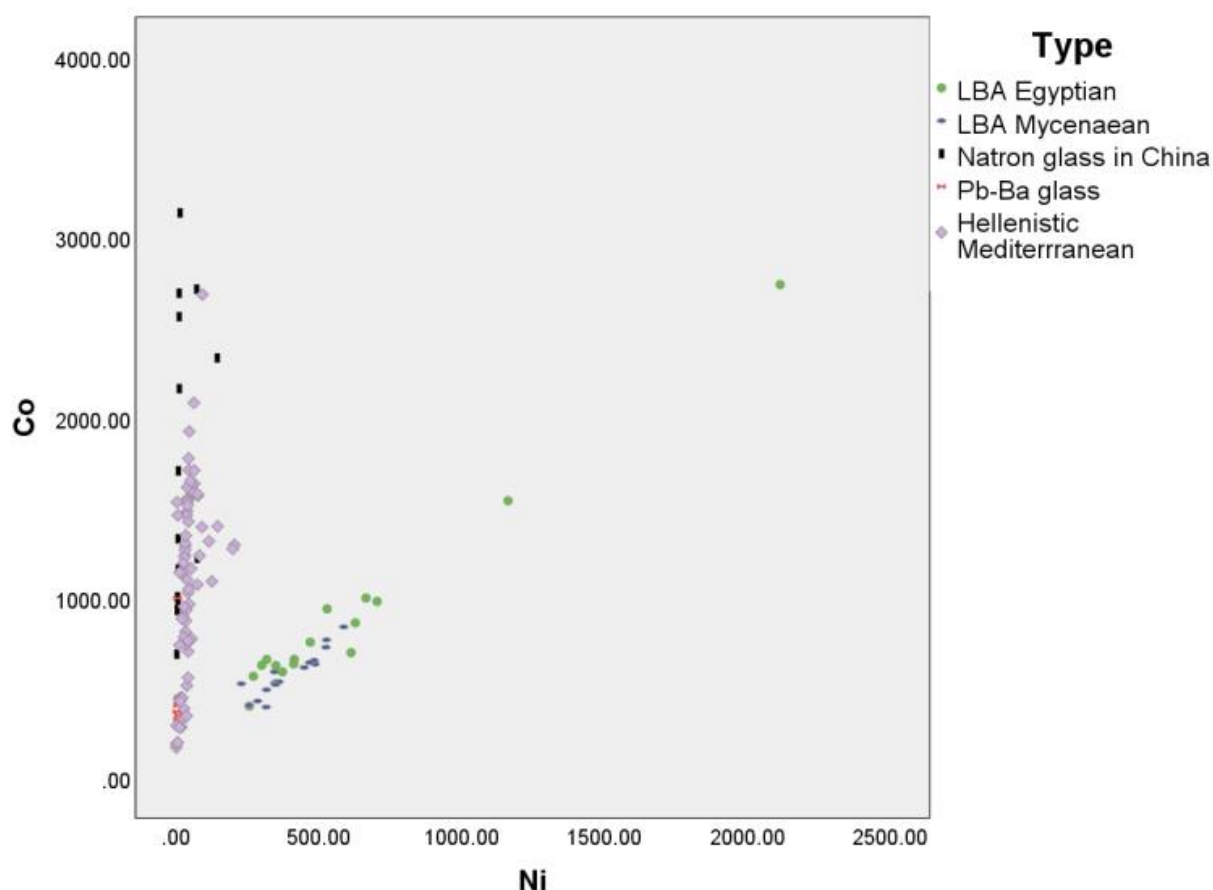


**Figure 5.10 Co and Ni contents for cobalt blue glasses from China, Egypt and Mycenaean (ppm).** Data of the Hellenistic Egyptian and Italian glass are referred as Hellenistic Mediterranean. Published data can be found in Supplementary Data file S3 (Oikonomou, 2018; Oikonomou *et al.*, 2018; Shortland *et al.*, 2007; Smirniou and Rehren, 2013; Varberg *et al.*, 2016, 2015; Walton *et al.*, 2009).



### Code for 3D kernel tetrahedron plot, Maximum Mean Discrepancy and null hypothesis test.

```
library('ks')
library('rgl')
library('kernlab')

# load data from csv file
data = read.csv("new plot.csv", stringsAsFactors=FALSE) # dimension: (310, 7)
names(data) = c('Type', 'Ti', 'Cr', 'Zr', 'Y')

# Natron glass China
X_Natron_China = subset(data, data[,1] == 'Natron glass China') # shape: (28,5)
X_Natron_China = data.frame(X_Natron_China$Ti, X_Natron_China$Cr,
X_Natron_China$Zr, X_Natron_China$Y)
names(X_Natron_China) = c('Ti', 'Cr', 'Zr', 'Y')

# convert data into tetrahedron coordinates
# x = (r-l+1)/2
# y = sqrt(3)/2 * t + sqrt(3)/6 * f
# z = sqrt(6)/3 * f
X_Natron_China['x'] = (X_Natron_China['Ti'] + 1 - X_Natron_China['Cr'])/2
X_Natron_China['y'] = sqrt(3)/2 * X_Natron_China['Zr'] + sqrt(3)/6 *
X_Natron_China['Y']
X_Natron_China['z'] = sqrt(3)/6 * X_Natron_China['Y']
Natron_China_coord = data.frame(X_Natron_China$x, X_Natron_China$y,
X_Natron_China$z)

# PbBa glass
X_PbBa = subset(data, data[,1] == 'Pb-Ba glass')
X_PbBa = data.frame(X_PbBa$Ti, X_PbBa$Cr, X_PbBa$Zr, X_PbBa$Y)
names(X_PbBa) = c('Ti', 'Cr', 'Zr', 'Y')
X_PbBa['x'] = (X_PbBa['Ti'] + 1 - X_PbBa['Cr'])/2
X_PbBa['y'] = sqrt(3)/2 * X_PbBa['Zr'] + sqrt(3)/6 * X_PbBa['Y']
X_PbBa['z'] = sqrt(3)/6 * X_PbBa['Y']
PbBa_coord = data.frame(X_PbBa$x, X_PbBa$y, X_PbBa$z)

# Mesopotamian
X_Mesopotamian = subset(data, data[,1] == 'Mesopotamian glass')
X_Mesopotamian = data.frame(X_Mesopotamian$Ti, X_Mesopotamian$Cr,
X_Mesopotamian$Zr, X_Mesopotamian$Y)
names(X_Mesopotamian) = c('Ti', 'Cr', 'Zr', 'Y')
X_Mesopotamian['x'] = (X_Mesopotamian['Ti'] + 1 - X_Mesopotamian['Cr'])/2
X_Mesopotamian['y'] = sqrt(3)/2 * X_Mesopotamian['Zr'] + sqrt(3)/6 *
```

```

X_Mesopotamian['Y']
X_Mesopotamian['z'] = sqrt(3)/6 * X_Mesopotamian['Y']
Mesopotamian_coord = data.frame(X_Mesopotamian$x, X_Mesopotamian$y,
X_Mesopotamian$z)

# Type I_Natron glass
X_INatron = subset(data, data[,1] == 'I Natron glass')
X_INatron = data.frame(X_INatron$Ti, X_INatron$Cr, X_INatron$Zr, X_INatron$Y)
names(X_INatron) = c('Ti', 'Cr', 'Zr', 'Y')
X_INatron['x'] = (X_INatron['Ti'] + 1 - X_INatron['Cr'])/2
X_INatron['y'] = sqrt(3)/2 * X_INatron['Zr'] + sqrt(3)/6 * X_INatron['Y']
X_INatron['z'] = sqrt(3)/6 * X_INatron['Y']
INatron_coord = data.frame(X_INatron$x, X_INatron$y, X_INatron$z)

# Type II_Natron glass
X_IINatron = subset(data, data[,1] == 'II Natron glass')
X_IINatron = data.frame(X_IINatron$Ti, X_IINatron$Cr, X_IINatron$Zr,
X_IINatron$Y)
names(X_IINatron) = c('Ti', 'Cr', 'Zr', 'Y')
X_IINatron['x'] = (X_IINatron['Ti'] + 1 - X_IINatron['Cr'])/2
X_IINatron['y'] = sqrt(3)/2 * X_IINatron['Zr'] + sqrt(3)/6 * X_IINatron['Y']
X_IINatron['z'] = sqrt(3)/6 * X_IINatron['Y']
IINatron_coord = data.frame(X_IINatron$x, X_IINatron$y, X_IINatron$z)

# Type III_Natron glass
X_IIINatron = subset(data, data[,1] == 'III Natron glass')
X_IIINatron = data.frame(X_IIINatron$Ti, X_IIINatron$Cr, X_IIINatron$Zr,
X_IIINatron$Y)
names(X_IIINatron) = c('Ti', 'Cr', 'Zr', 'Y')
X_IIINatron['x'] = (X_IIINatron['Ti'] + 1 - X_IIINatron['Cr'])/2
X_IIINatron['y'] = sqrt(3)/2 * X_IIINatron['Zr'] + sqrt(3)/6 * X_IIINatron['Y']
X_IIINatron['z'] = sqrt(3)/6 * X_IIINatron['Y']
IIINatron_coord = data.frame(X_IIINatron$x, X_IIINatron$y, X_IIINatron$z)

# kernel density estimation (with optimal bandwidth)
fhat_Natron_China = kde(x = Natron_China_coord, H = Hscv(x=Natron_China_coord,
pre='sphere', optim.fun="optim"), compute.cont=TRUE)
fhat_PbBa = kde(x = PbBa_coord, H = Hscv(x=PbBa_coord, pre='sphere',
optim.fun="optim"), compute.cont=TRUE)
fhat_INatron = kde(x = INatron_coord, H = Hscv(x=INatron_coord, pre='sphere',
optim.fun="optim"), gridsize=rep(200, 3), compute.cont=TRUE)
fhat_IINatron = kde(x = IINatron_coord, H = Hscv(x=IINatron_coord, pre='sphere',
optim.fun="optim"), compute.cont=TRUE)
fhat_IIINatron = kde(x = IIINatron_coord, H = Hscv(x=IIINatron_coord, pre='sphere',

```

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optim.fun="optim"), compute.cont=TRUE)
fhat_Mesopotamian = kde(x = Mesopotamian_coord, H =
Hscv(x=Mesopotamian_coord, pre='sphere', optim.fun="optim"),
compute.cont=TRUE)

# draw tetrahedron in x/y/z coordinates
x_coord <- c(0, 1, 1/2, 1/2)
y_coord <- c(0, 0, sqrt(3)/2, sqrt(3)/6)
z_coord <- c(0,0,0, sqrt(3)/2)
plot3d(x_coord,y_coord,z_coord, add=TRUE)
par3d(cex=2.0)
text3d(x=-0.05,y=0,z=0,texts='Cr', col='black', font=4)
text3d(x=1.05,y=0,z=0, texts='Ti/10', col='black', font=4)
text3d(x=0.55,y=sqrt(3)/2,z=0,texts='Zr', col='black', font=4)
text3d(x=1/2,y=sqrt(3)/6,z=sqrt(3)/2 + 0.05,texts='Y', col='black', font=4)

segments3d(x_coord[1:2],y_coord[1:2],z_coord[1:2],col="black",lwd=2, add=TRUE)
segments3d(x_coord[2:3],y_coord[2:3],z_coord[2:3],col="black",lwd=2, add=TRUE)
segments3d(c(0,1/2),c(0, sqrt(3)/2),c(0,0),col="black",lwd=2, add=TRUE)
segments3d(c(0,1/2),c(0, sqrt(3)/6),c(0,sqrt(3)/2),col="black",lwd=2, add=TRUE)
segments3d(c(1,1/2),c(0, sqrt(3)/6),c(0,sqrt(3)/2),col="black",lwd=2, add=TRUE)
segments3d(c(1/2,1/2),c(sqrt(3)/2, sqrt(3)/6),c(0,sqrt(3)/2),col="black",lwd=2,
add=TRUE)

# kde contours for each group
plot(fhat_Mesopotamian, col.fun=colorRampPalette(c('pink')), col.pt =
'black',add=TRUE, drawpoints = FALSE, box=FALSE, axes=FALSE,display='rgl',
alpha=0.3)
plot(fhat_PbBa, col.fun=cm.colors, col.pt = 'black', add=TRUE, drawpoints = FALSE,
box=FALSE, axes=FALSE,col.axis = 'blue',display='rgl', alpha=0.3)
plot(fhat_Natron_China, col.fun=heat.colors, col.pt = 'black', add=TRUE, drawpoints
= FALSE, box=FALSE, axes=FALSE,display='rgl', alpha=0.3)
plot(fhat_IINatron, col.fun=colorRampPalette(c('yellow')), col.pt = 'black',add=TRUE,
drawpoints = FALSE, box=FALSE, axes=FALSE,display='rgl', alpha=0.3)
plot(fhat_IINatron, col.fun=colorRampPalette(c('green')), col.pt = 'black',add=TRUE,
drawpoints = FALSE, box=FALSE, axes=FALSE,display='rgl', alpha=0.3)
plot(fhat_INatron, col.fun=topo.colors, col.pt = 'black',add=TRUE, drawpoints =
FALSE, box=FALSE, axes=FALSE,display='rgl', alpha=0.3)
legend3d("bottomright", legend = c('Natron glass China', 'PbBa glass', 'Mediterranean
glass', 'Type I_Natron glass', 'Type II_Natron glass', 'Type III_Natron glass'), pch = 16,
col = c('orange', 'blue', 'green', 'black', 'purple', 'red'), cex=1, inset=c(0.02))

# save plot
rgl.snapshot(filename='13.png', fmt = "png", top = TRUE )

```

```
# kernel maximum mean discrepancy (MMD) and null hypothesis test for group x and
y (eg Pb-Ba glass and Mesopotamian glass)
# resample each group until same sample size (100)
x <- data.matrix(X_Mesopotamian[sample(nrow(X_Mesopotamian), 100, replace =
TRUE), 5:7])
y <- data.matrix(X_PbBa[sample(nrow(X_PbBa), 100, replace = TRUE), 5:7])
kmmd_test = kmmd(x, y, kernel='rbfdot', asymptotic = TRUE, alpha=0.05, ntimes =
1500, frac=1)
print(kmmd_test)
```

**Table 5.6 Re-normalized Data for Figure 4.4 (save as ‘new plot.csv’ and run the code above. Ti/10+Cr+Zr+Y=100%).**

| Type               | Ti/10       | Cr          | Zr          | Y           |
|--------------------|-------------|-------------|-------------|-------------|
| Natron glass China | 0.370231654 | 0.103959077 | 0.435204706 | 0.090604563 |
| Natron glass China | 0.379295904 | 0.049387925 | 0.479411527 | 0.091904644 |
| Natron glass China | 0.348642648 | 0.137567897 | 0.448864704 | 0.064924751 |
| Natron glass China | 0.390069272 | 0.094565556 | 0.444029068 | 0.071336104 |
| Natron glass China | 0.499781445 | 0.055399462 | 0.413723801 | 0.031095291 |
| Natron glass China | 0.417518252 | 0.095661428 | 0.402743662 | 0.084076658 |
| Natron glass China | 0.441271958 | 0.107312741 | 0.374025627 | 0.077389674 |
| Natron glass China | 0.462527038 | 0.041347127 | 0.419620654 | 0.076505181 |
| Natron glass China | 0.417052809 | 0.048208208 | 0.439335277 | 0.095403707 |
| Natron glass China | 0.437276999 | 0.075997818 | 0.410123854 | 0.07660133  |
| Natron glass China | 0.427983751 | 0.08491227  | 0.402329982 | 0.084773997 |
| Natron glass China | 0.428255559 | 0.118035217 | 0.385548625 | 0.0681606   |
| Natron glass China | 0.491840583 | 0.068797805 | 0.390190691 | 0.049170921 |
| Natron glass China | 0.409840135 | 0.119864392 | 0.39469147  | 0.075604002 |
| Natron glass China | 0.362218995 | 0.087885894 | 0.481150773 | 0.068744338 |
| Natron glass China | 0.396972094 | 0.113636357 | 0.4079687   | 0.081422849 |
| Natron glass China | 0.443748874 | 0.089181445 | 0.403954702 | 0.063114979 |
| Natron glass China | 0.382772538 | 0.124387375 | 0.410032683 | 0.082807403 |
| Natron glass China | 0.386568529 | 0.056995272 | 0.489496393 | 0.066939807 |
| Natron glass China | 0.386167954 | 0.106173875 | 0.432409396 | 0.075248775 |
| Natron glass China | 0.366614898 | 0.034184225 | 0.529391989 | 0.069808887 |
| Natron glass China | 0.402060937 | 0.055396047 | 0.484366155 | 0.058176861 |
| Natron glass China | 0.392341537 | 0.109987592 | 0.419497017 | 0.078173854 |
| Natron glass China | 0.49411894  | 0.007934751 | 0.449004263 | 0.048942046 |
| Natron glass China | 0.4044054   | 0.122811387 | 0.395362364 | 0.077420849 |
| Natron glass China | 0.409120721 | 0.099627884 | 0.423011634 | 0.06823976  |
| Natron glass China | 0.269044045 | 0.248120316 | 0.431103281 | 0.051732357 |
| Natron glass China | 0.326721297 | 0.138470346 | 0.49170648  | 0.043101877 |
| Natron glass China | 0.78635742  | 0.07252019  | 0.126002144 | 0.015120247 |
| Natron glass China | 0.829138402 | 0.035140373 | 0.124783027 | 0.010938198 |
| Pb-Ba glass        | 0.444855383 | 0.104949046 | 0.339729141 | 0.11046643  |
| Pb-Ba glass        | 0.344713192 | 0.234195202 | 0.208696048 | 0.212395559 |
| Pb-Ba glass        | 0.414158801 | 0.136926205 | 0.314950248 | 0.133964745 |
| Pb-Ba glass        | 0.447232595 | 0.100745864 | 0.324502281 | 0.127519261 |
| Pb-Ba glass        | 0.376391877 | 0.156965858 | 0.301865088 | 0.164777176 |
| Pb-Ba glass        | 0.446046976 | 0.049401711 | 0.347344725 | 0.157206588 |
| Pb-Ba glass        | 0.495770377 | 0.108593155 | 0.325887557 | 0.069748911 |
| Pb-Ba glass        | 0.474642467 | 0.080927726 | 0.367263331 | 0.077166476 |
| Pb-Ba glass        | 0.431542903 | 0.011377657 | 0.438914393 | 0.118165047 |
| Pb-Ba glass        | 0.499856229 | 0.080225599 | 0.342157203 | 0.077760969 |

|                    |             |             |             |             |
|--------------------|-------------|-------------|-------------|-------------|
| Pb-Ba glass        | 0.421812885 | 0.071153411 | 0.444453185 | 0.062580519 |
| Pb-Ba glass        | 0.492812469 | 0.032192804 | 0.393462375 | 0.081532352 |
| Pb-Ba glass        | 0.363260386 | 0.099457843 | 0.430078955 | 0.107202816 |
| Pb-Ba glass        | 0.446894139 | 0.003683822 | 0.445164934 | 0.104257105 |
| Pb-Ba glass        | 0.452521379 | 0.034255961 | 0.421072454 | 0.092150206 |
| Pb-Ba glass        | 0.528931222 | 0.075622005 | 0.325171657 | 0.070275116 |
| Pb-Ba glass        | 0.505935774 | 0.102365267 | 0.320534918 | 0.071164042 |
| Pb-Ba glass        | 0.431277136 | 0.015388491 | 0.343431855 | 0.209902518 |
| Pb-Ba glass        | 0.424882218 | 0.048956832 | 0.367309617 | 0.158851334 |
| Pb-Ba glass        | 0.32184736  | 0.079683963 | 0.395911837 | 0.202556839 |
| Pb-Ba glass        | 0.28119997  | 0.087035535 | 0.382287951 | 0.249476544 |
| Pb-Ba glass        | 0.396936443 | 0.088027001 | 0.412721297 | 0.102315258 |
| Pb-Ba glass        | 0.287391266 | 0.090018949 | 0.396295222 | 0.226294563 |
| Pb-Ba glass        | 0.308943202 | 0.060532478 | 0.408807219 | 0.2217171   |
| Pb-Ba glass        | 0.349725178 | 0.049376375 | 0.532676773 | 0.068221675 |
| Pb-Ba glass        | 0.557581293 | 0.047564581 | 0.345103524 | 0.049750602 |
| Pb-Ba glass        | 0.697562276 | 0.018990701 | 0.244679412 | 0.038767611 |
| Pb-Ba glass        | 0.874964123 | 0.016347279 | 0.091047078 | 0.01764152  |
| Mesopotamian glass | 0.483101392 | 0.238568588 | 0.238568588 | 0.039761431 |
| Mesopotamian glass | 0.47761194  | 0.26119403  | 0.223880597 | 0.037313433 |
| Mesopotamian glass | 0.555236729 | 0.172166428 | 0.229555237 | 0.043041607 |
| Mesopotamian glass | 0.49044586  | 0.212314225 | 0.25477707  | 0.042462845 |
| Mesopotamian glass | 0.397905759 | 0.104712042 | 0.418848168 | 0.078534031 |
| Mesopotamian glass | 0.386792453 | 0.075471698 | 0.490566038 | 0.047169811 |
| Mesopotamian glass | 0.52120383  | 0.191518468 | 0.24623803  | 0.041039672 |
| Mesopotamian glass | 0.49790795  | 0.181311018 | 0.278940028 | 0.041841004 |
| Mesopotamian glass | 0.483013294 | 0.206794682 | 0.280649926 | 0.029542097 |
| Mesopotamian glass | 0.490358127 | 0.192837466 | 0.275482094 | 0.041322314 |
| Mesopotamian glass | 0.494949495 | 0.230880231 | 0.230880231 | 0.043290043 |
| Mesopotamian glass | 0.498327759 | 0.217391304 | 0.234113712 | 0.050167224 |
| Mesopotamian glass | 0.51417004  | 0.188933873 | 0.256410256 | 0.04048583  |
| Mesopotamian glass | 0.348869088 | 0.082248115 | 0.534612748 | 0.034270048 |
| Mesopotamian glass | 0.588528678 | 0.137157107 | 0.249376559 | 0.024937656 |
| Mesopotamian glass | 0.527559055 | 0.204724409 | 0.236220472 | 0.031496063 |
| Mesopotamian glass | 0.491525424 | 0.152542373 | 0.322033898 | 0.033898305 |
| Mesopotamian glass | 0.513888889 | 0.173611111 | 0.277777778 | 0.034722222 |
| Mesopotamian glass | 0.492900609 | 0.182555781 | 0.283975659 | 0.040567951 |
| Mesopotamian glass | 0.478991597 | 0.218487395 | 0.268907563 | 0.033613445 |
| I Natron glass     | 0.288035451 | 0.050221566 | 0.642909897 | 0.018833087 |
| I Natron glass     | 0.278121137 | 0.054388133 | 0.64276885  | 0.024721879 |
| I Natron glass     | 0.31031031  | 0.058558559 | 0.610610611 | 0.020520521 |
| I Natron glass     | 0.325018896 | 0.073318216 | 0.572184429 | 0.029478458 |
| I Natron glass     | 0.248043818 | 0.079029734 | 0.642410016 | 0.030516432 |
| I Natron glass     | 0.325371207 | 0.080697224 | 0.564880568 | 0.029051001 |
| I Natron glass     | 0.229558865 | 0.046923293 | 0.710873841 | 0.012644001 |
| I Natron glass     | 0.286878566 | 0.06193969  | 0.616136919 | 0.035044825 |
| I Natron glass     | 0.269727403 | 0.070301291 | 0.628407461 | 0.031563845 |
| I Natron glass     | 0.272355646 | 0.071027082 | 0.638732754 | 0.017884517 |
| II Natron glass    | 0.422290928 | 0.1100093   | 0.403438655 | 0.064261117 |
| II Natron glass    | 0.400468384 | 0.093676815 | 0.418032787 | 0.087822014 |
| II Natron glass    | 0.399126532 | 0.103032876 | 0.406405435 | 0.091435157 |
| II Natron glass    | 0.379857797 | 0.107541151 | 0.427340021 | 0.08526103  |
| II Natron glass    | 0.393512698 | 0.09923309  | 0.41740005  | 0.089854161 |
| II Natron glass    | 0.374476584 | 0.097136956 | 0.44029368  | 0.088092779 |
| II Natron glass    | 0.363260145 | 0.100241407 | 0.447177837 | 0.089320612 |
| II Natron glass    | 0.370457763 | 0.086562058 | 0.460122699 | 0.08285748  |
| II Natron glass    | 0.37697885  | 0.102108075 | 0.433641315 | 0.08727176  |
| II Natron glass    | 0.365115422 | 0.096928035 | 0.444798592 | 0.093157951 |

|                 |             |             |             |             |
|-----------------|-------------|-------------|-------------|-------------|
| II Natron glass | 0.397769606 | 0.099466436 | 0.413391977 | 0.089371981 |
| II Natron glass | 0.318859347 | 0.346011125 | 0.291011369 | 0.044118159 |
| II Natron glass | 0.37041072  | 0.096524676 | 0.436866761 | 0.096197843 |
| II Natron glass | 0.401773826 | 0.11427976  | 0.41914157  | 0.064804844 |
| II Natron glass | 0.378900958 | 0.090557329 | 0.439754748 | 0.090786966 |
| II Natron glass | 0.372365803 | 0.097513295 | 0.434038889 | 0.096082014 |
| II Natron glass | 0.398836624 | 0.088811712 | 0.423380417 | 0.088971247 |
| II Natron glass | 0.393243787 | 0.099412503 | 0.419302111 | 0.088041599 |
| II Natron glass | 0.403003202 | 0.103676714 | 0.429502043 | 0.063818041 |
| II Natron glass | 0.368208352 | 0.095835204 | 0.437808711 | 0.098147732 |
| II Natron glass | 0.385039853 | 0.096873084 | 0.434089516 | 0.083997548 |
| II Natron glass | 0.415377097 | 0.088811579 | 0.410723012 | 0.085088311 |
| II Natron glass | 0.387681081 | 0.093423539 | 0.423517147 | 0.095378233 |
| II Natron glass | 0.368254923 | 0.084460644 | 0.440903853 | 0.10638058  |
| II Natron glass | 0.379019759 | 0.106242755 | 0.416791487 | 0.097945999 |
| II Natron glass | 0.372232242 | 0.096447804 | 0.428514781 | 0.102805173 |
| II Natron glass | 0.371473512 | 0.098055621 | 0.433943532 | 0.096527336 |
| II Natron glass | 0.381827367 | 0.10100215  | 0.421772384 | 0.095398099 |
| II Natron glass | 0.388040284 | 0.097716618 | 0.426171411 | 0.088071687 |
| II Natron glass | 0.383251549 | 0.10805067  | 0.417875521 | 0.09082226  |
| II Natron glass | 0.466990344 | 0.099573148 | 0.378223584 | 0.055212924 |
| II Natron glass | 0.423703257 | 0.082931242 | 0.440289505 | 0.053075995 |
| II Natron glass | 0.403579091 | 0.071747394 | 0.478775879 | 0.045897636 |
| II Natron glass | 0.449681638 | 0.094300655 | 0.398244917 | 0.05777279  |
| II Natron glass | 0.392600982 | 0.089757141 | 0.434126085 | 0.083515792 |
| II Natron glass | 0.41779149  | 0.091785577 | 0.408792904 | 0.08163003  |
| II Natron glass | 0.396329585 | 0.134349012 | 0.386925154 | 0.082396249 |
| II Natron glass | 0.448386302 | 0.109669869 | 0.36954915  | 0.072394678 |
| II Natron glass | 0.42597554  | 0.155817369 | 0.345264385 | 0.072942706 |
| II Natron glass | 0.392670157 | 0.104712042 | 0.421465969 | 0.081151832 |
| II Natron glass | 0.414746544 | 0.09562212  | 0.417050691 | 0.072580645 |
| II Natron glass | 0.410958904 | 0.092465753 | 0.416666667 | 0.079908676 |
| II Natron glass | 0.414746544 | 0.087557604 | 0.42281106  | 0.074884793 |
| II Natron glass | 0.421940928 | 0.098452883 | 0.405063291 | 0.074542897 |
| II Natron glass | 0.4         | 0.102666667 | 0.416       | 0.081333333 |
| II Natron glass | 0.412573674 | 0.155206287 | 0.360510806 | 0.071709234 |
| II Natron glass | 0.397350993 | 0.188741722 | 0.344370861 | 0.069536424 |
| II Natron glass | 0.41136141  | 0.113614104 | 0.413320274 | 0.061704212 |
| II Natron glass | 0.388601036 | 0.269430052 | 0.28238342  | 0.059585492 |
| II Natron glass | 0.443131462 | 0.128508124 | 0.360413589 | 0.067946824 |
| II Natron glass | 0.461538462 | 0.106730769 | 0.361538462 | 0.070192308 |
| II Natron glass | 0.475561427 | 0.099075297 | 0.348745046 | 0.07661823  |
| II Natron glass | 0.435967302 | 0.084468665 | 0.413260672 | 0.066303361 |
| II Natron glass | 0.398671096 | 0.091915836 | 0.430786268 | 0.0786268   |
| II Natron glass | 0.435176791 | 0.120580236 | 0.389845875 | 0.054397099 |
| II Natron glass | 0.215698023 | 0.532654284 | 0.216896345 | 0.034751348 |
| II Natron glass | 0.189993667 | 0.547815073 | 0.226092464 | 0.036098797 |
| II Natron glass | 0.401146132 | 0.154727794 | 0.388729704 | 0.055396371 |
| II Natron glass | 0.425531915 | 0.091016548 | 0.414893617 | 0.06855792  |
| II Natron glass | 0.426035503 | 0.082840237 | 0.418934911 | 0.072189349 |
| II Natron glass | 0.395170143 | 0.086717892 | 0.45115258  | 0.066959385 |
| II Natron glass | 0.416184971 | 0.134104046 | 0.373410405 | 0.076300578 |
| II Natron glass | 0.337620579 | 0.064308682 | 0.553054662 | 0.045016077 |
| II Natron glass | 0.364583333 | 0.0546875   | 0.529513889 | 0.051215278 |
| II Natron glass | 0.3969129   | 0.089305402 | 0.425578831 | 0.088202867 |
| II Natron glass | 0.405405405 | 0.097972973 | 0.416666667 | 0.079954955 |
| II Natron glass | 0.407701019 | 0.093997735 | 0.419026048 | 0.079275198 |
| II Natron glass | 0.425531915 | 0.095744681 | 0.401891253 | 0.076832151 |

|                  |             |             |             |             |
|------------------|-------------|-------------|-------------|-------------|
| II Natron glass  | 0.408626561 | 0.090805902 | 0.419977299 | 0.080590238 |
| II Natron glass  | 0.429082241 | 0.097735399 | 0.393325387 | 0.079856973 |
| II Natron glass  | 0.417149479 | 0.09617613  | 0.405561993 | 0.081112399 |
| II Natron glass  | 0.38961039  | 0.101298701 | 0.428571429 | 0.080519481 |
| II Natron glass  | 0.435308343 | 0.095525998 | 0.411124547 | 0.058041112 |
| II Natron glass  | 0.435835351 | 0.093220339 | 0.411622276 | 0.059322034 |
| II Natron glass  | 0.436893204 | 0.089805825 | 0.400485437 | 0.072815534 |
| II Natron glass  | 0.425531915 | 0.126477541 | 0.378250591 | 0.069739953 |
| II Natron glass  | 0.388644962 | 0.099718115 | 0.423314059 | 0.088322864 |
| II Natron glass  | 0.395071884 | 0.099821224 | 0.427926313 | 0.07718058  |
| II Natron glass  | 0.385923331 | 0.059558577 | 0.469522621 | 0.084995471 |
| II Natron glass  | 0.379839582 | 0.095293088 | 0.441200659 | 0.083666671 |
| II Natron glass  | 0.410736525 | 0.022220997 | 0.482907284 | 0.084135194 |
| II Natron glass  | 0.378897727 | 0.096114944 | 0.42906537  | 0.095921959 |
| II Natron glass  | 0.383708162 | 0.067424317 | 0.447328658 | 0.101538862 |
| III Natron glass | 0.442342434 | 0.067821839 | 0.460948425 | 0.028887302 |
| III Natron glass | 0.349779529 | 0.050379767 | 0.575768771 | 0.024071933 |
| III Natron glass | 0.452165778 | 0.064766451 | 0.453964846 | 0.029102925 |
| III Natron glass | 0.341207349 | 0.049152947 | 0.586972083 | 0.022667621 |
| III Natron glass | 0.419343326 | 0.062303712 | 0.485367595 | 0.032985368 |
| III Natron glass | 0.515513126 | 0.071599045 | 0.386634845 | 0.026252983 |
| III Natron glass | 0.409556314 | 0.066552901 | 0.494880546 | 0.029010239 |
| III Natron glass | 0.274959083 | 0.036333879 | 0.667757774 | 0.020949264 |
| III Natron glass | 0.27424094  | 0.035586027 | 0.669278485 | 0.020894548 |
| III Natron glass | 0.345007841 | 0.062205959 | 0.559330894 | 0.033455306 |
| III Natron glass | 0.312648034 | 0.051160587 | 0.606347703 | 0.029843676 |
| III Natron glass | 0.333745365 | 0.044499382 | 0.587144623 | 0.03461063  |
| III Natron glass | 0.328068044 | 0.041312272 | 0.595382746 | 0.035236938 |
| III Natron glass | 0.25842412  | 0.027362554 | 0.699265265 | 0.014948062 |
| III Natron glass | 0.310193542 | 0.044421841 | 0.618207304 | 0.027177312 |
| III Natron glass | 0.315842669 | 0.010132824 | 0.643896781 | 0.030127726 |
| III Natron glass | 0.37194694  | 0.046939269 | 0.559533188 | 0.021580603 |
| III Natron glass | 0.336318796 | 0.036051015 | 0.601317956 | 0.026312233 |
| III Natron glass | 0.350110605 | 0.054468962 | 0.570471548 | 0.024948885 |
| III Natron glass | 0.325945444 | 0.031859329 | 0.615169972 | 0.027025255 |
| III Natron glass | 0.372551993 | 0.068868799 | 0.531913486 | 0.026665723 |
| III Natron glass | 0.3752055   | 0.050769944 | 0.54615477  | 0.027869786 |
| III Natron glass | 0.307021825 | 0.046292667 | 0.622548923 | 0.024136585 |
| III Natron glass | 0.297456585 | 0.035505902 | 0.641869393 | 0.025168119 |
| III Natron glass | 0.287006394 | 0.043895096 | 0.645341174 | 0.023757336 |
| III Natron glass | 0.307327292 | 0.057923407 | 0.600010036 | 0.034739266 |

## **Chapter 6 The Circulation of Potash and m-Na-Al Glasses Follows the Spread of Buddhism in China**

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## **Abstract**

The Silk Road played important roles in the trade of glass products. Monochrome drawn beads were widely circulated in South and Southeast Asia during the Han Dynasty (202 BC – AD 220). Twenty-seven mineral soda alumina (m-Na-Al) glass and eighty-seven potash glass beads unearthed in different provinces in China were analysed by laser-ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS). Indian glass played a significant role in Buddhism. During the Han period, both Indian glass and Buddha artefacts appeared in Xinjiang and Yunnan simultaneously. The trace element analysis indicates the silica sources of m-Na-Al glass and most of the potash glass unearthed from Guangxi are geologically close, presumably produced somewhere in Southeast Asia and exported through the Maritime Silk Road. The silica sources of m-Na-Al glass in Henan and the rest of the potash glasses are identical, and probably produced in southern India or Sri Lanka. They might have been traded to China through the North Silk and Southwest Silk Roads with the spread of Buddhism.

**Key words:** m-Na-Al glass; Potash glass; Silk Road; Buddhism

## **6.1. Introduction**

Indo-Pacific glass beads are widely distributed in different provinces in China starting from the Warring States period (475 – 221 BC), such as Xinjiang, Yunnan, Guangxi, Hubei, Hunan, Sichuan, and Chongqing (Zhao, 2016, p. 260). Due to the lack of archaeological evidence for the primary and secondary glass production, there is an ongoing question, however, regarding the site of production for these early glass beads

unearthed in China and whether they were produced locally or imported via the Silk Road network. In order to address this question, this paper utilizes LA-ICP-MS to analyse 108 glass beads from archaeological sites dating to the Warring States and Han period from four provinces in China.

### **6.1.1 The Southwest and Maritime Silk Roads**

The concept of ‘Seidenstraße’ or ‘Silk Road’ was first proposed by Ferdinand von Richthofen in 1877. Since then, the definition of Silk Road has been redefined several times, as detailed in Chapter 1.2.1. The redefined "Silk Road" represents an ancient trade route between China, Central Asia, India, and Rome.

The Southwest Silk Road originated before the Qin period (221 – 207 BC). The concept of the Southwest Silk Road is more or less influenced and inspired by the definition of the North Silk Road. However, rather than considering it as a simple trade route from China to India (Shu- Sindu Road), it is more like a trade network with various regions in south/southeast Asia (Huang, 2002). As documented in *Shi Ji- Biographies of Dayuan* 史记- 大宛列传 (edited by Sima Qian 司马迁 in AD 104: Sima, 2016), when *Zhang Qian* arrived in Bactria (modern Afghanistan) in 122 BC, he noticed that Shu Cloth (made by bamboo fibre) and Bamboo stick produced in the Shu State (modern Sichuan) were circulating here. The local people told him that these products were traded by merchants from Sindu (India), and Sindu merchants imported these products from Shu merchants (Sima, 2016). Thus, there was likely a trade road leading

directly from Chengdu to India, but there might have been also indirect routes from other regions using land, river or maritime routes. Figure 6.1 shows trade routes from Chengdu to India, Myanmar and Vietnam. The Shu-Sindu Road can be divided into four parts: As documented in ‘*Shi Ji- Biographies of Nanyi*’ 史记 西南夷列传 (Sima, 2016), there were two routes from Sichuan Province to Yunnan Province which were named the 五尺道 *Wuchi* Road and the 零关道 *Lingguan* Road; the route from Yunnan Province to Myanmar was called the 永昌道 *Yongchang* Road; the route from Myanmar to India was called *the* 缅印道 *Mianyin* Road (Duan, 2014). The 进桑糜冷道 *Jinsang-Phong Châu* Road is also parts of the Southwest Silk Road from Yunnan to Vietnam (Huang, 2002). What is emphasized here is that the South Silk Road was a complex trade network, and no doubt it also had a strong connection with the Maritime Silk Road.

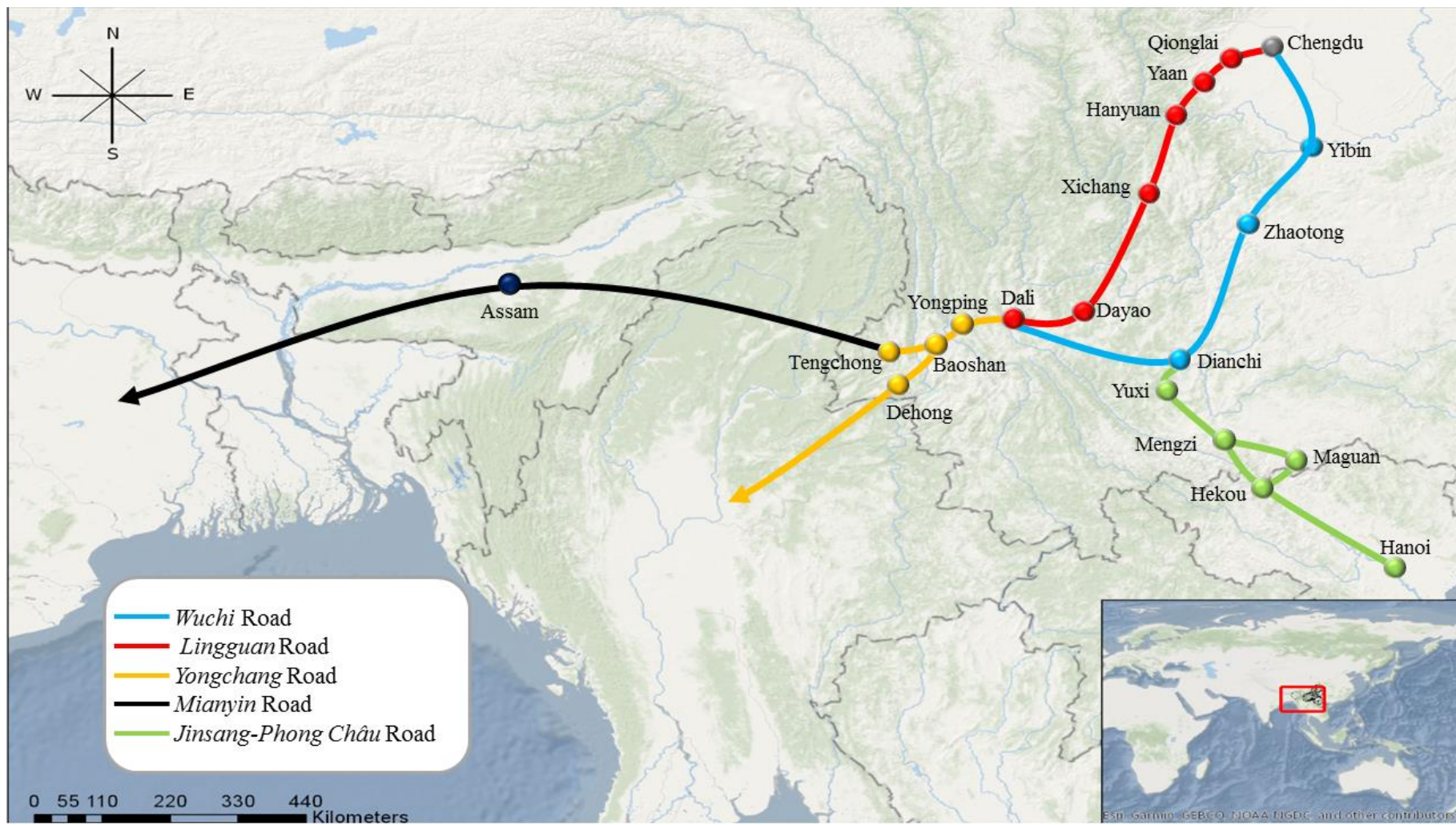


Figure 6.1 Trade routes of the Southwest Silk Road.

The Maritime Silk Road started from the South China Sea, passed through island South-east Asia, crossed the Indian Ocean, the Red Sea and the Nile to the Mediterranean, thus connecting Asia, Africa and Mediterranean (Gan, 2006). During the Spring and Autumn (770 – 476 BC) and the Warring States period, the Qi State had already discovered the trade routes to the Liaodong peninsula (southern Liaoning Province), the Korean peninsula, the Japanese islands and the regions to Southeast Asia along the coastline (Zhao, 2018). *Hou Han Shu- Biography of the Western Regions* 后汉书-西域传 recorded that the land Silk Road was blocked due to the rebellion in the western regions during the Eastern Han Dynasty, and the trade from the Han Empire to the Roman Empire was subsequently through the Maritime Silk Road via India (edited by Fan Ye 范晔 in AD 445: Fan, 2007). During the Han Dynasty, *Fanyu* (Canton) 番禺, *Xuwen* (Canton) 徐闻 and *Hepu* (Guangxi Province) 合浦 were three important trade ports as the starting points of the Maritime Silk Road (Liu, 2015). The sailing routes from *Hepu* (a port in Guangxi) to Southeast Asia were documented in *Han Shu- Geography* 汉书-地理志 (edited by Ban Gu 班固 in AD 105: Ban, 2007). For example, ‘The distance between *Hepu* to Duyuan State 都元国 (inconclusive, east coast of Malay Peninsula or Isthmus of Kra in Thailand) was five months by ship; the ship could reach *Yilumei State* 邑卢没国 (inconclusive, South Thailand or Thaton in Myanmar) by sailing for another 4 months; after over twenty-days of sailing the ship could further reach *Chenli State* 湛离国 (inconclusive, South Myanmar or Prome)’. Tens of thousands of glass beads were excavated from sites in *Hepu*, Guangxi province (Gan, 2006). There are also a variety of other objects discovered from *Hepu*, indicating

the trade along the Maritime Road. For instance, the typology study of the garnet beads excavated at M1 Nitrogen Fertilizer factory and a lion-shaped garnet object excavated at M6 Gear Factory in *Hepu* suggested they were probably manufactured in Arikamedu or Sri Lanka; A bronze bead covered with a layer of gold foil excavated at M5 Jiuzhiling Burial Site was likely manufactured from West Asia and traded to *Hepu* via India; The zebra-pattern etched carnelian beads excavated at M10 Fengmenling, M1 Jinjiling and M3 Honglingtou were probably manufactured in Arikamedu (Xiong and Li, 2011, pp. 166–177).

### **6.1.2 Indo-Pacific glass bead**

The earliest imported glass found in India dates to the period of Painted-Pottery Culture (1100 – 800 BC) in Northern India, such as Hastinapur, Rupar and Alamgripur (Brill, 1999). The Indian made glass occurred after 500 BC, mainly in the form of small objects, such as beads, earrings and necklaces, bracelet and seals. Arikamedu, as one of the most famous archaeological sites located on the southeastern coast of India, is considered to be a glass-working centre from 200 BC to AD 200 and is well-known for its drawing technique for the Indo-Pacific glass bead (Francis, 1991). The earliest glass found in Thailand is dated to the early 4<sup>th</sup> century BC; the earliest glass in Vietnam is dated to the 4<sup>th</sup> and 3<sup>rd</sup> century BC; glass unearthed at Kampong Sungei Lang in Malaysia is dated to around the 5<sup>th</sup> to 2<sup>nd</sup> century BC. The earliest glass unearthed at Bali and Gilimanuk in Indonesia is dated to 2020±165 BP; glass unearthed at Manunggul Cave is believed as the earliest glass found in the Philippines (2140±100 BP: Henderson and

Glover, 2001). The  $^{14}\text{C}$  dates above were calibrated by using H. Michael's calibration tables of April 1982 (Bronson and Glover, 1984). The uncalibrated dates were not given and cannot therefore now be re-calibrated by using Oxcal (Ramsey, 2009). Potash glass was widely unearthed in Southeast Asia. For instance, Ban Don Ta Phet and Khao Sam Kaeo dated to the 4<sup>th</sup> century BC and Phu Khao Thong dated to the 2<sup>nd</sup> century BC in Thailand all yielded potash glass. Lankton and Dussubieux (2006) summarised three subtypes of potash glass according to concentrations of CaO and Al<sub>2</sub>O<sub>3</sub>. This difference reflects the change of the selection of silica source and stabilizer. Dussubieux (2016) believes that there was a change of source of raw materials for producing potash glass between the 4<sup>th</sup> century BC and 2<sup>nd</sup> century BC in Thailand. The presence of chunks of raw glass and unfinished beads indicates that monochrome drawn beads were manufactured at Phu Khao Thong (Dussubieux, 2016). Huang (2004) notices that potash glass in Guangxi was not only found in tombs of higher ranks of the nobility, but also found in lower status tombs. Thus, he believed that potash glass was produced locally, since it was consumed by lower-status individuals. Zhao (2016) considers that potash glass was first imported from South or Southeast Asia during the Warring States and Western Han (202 BC – AD 8) periods, and was mainly consumed by the nobility.

### **6.1.3 The spread of Buddhism and its related artefacts found in China**

Buddhism was founded by Siddharta Gautama in ancient India sometime between the 6<sup>th</sup> and 4<sup>th</sup> centuries BC. Glass is considered to be one of the Buddhist Seven Treasures,

as documented in the ‘*Lotus Sutra*’ (*Saddharma-Pundarika Sutra*) 法华经, ‘*Amitabha sutra*’ 阿弥陀经 and ‘*Aparimitayur sutra*’ 无量寿经. Glass is believed to own the Buddha’s light and wisdom, which was used as a halidom for practicing Buddhism (Meng, 2014). Thus, it is regarded as the top of the Buddhist Seven Treasures. Moreover, according to the ‘*Dirghagama-sutra*’ 长阿含经, the centre of the Buddhist World is the Sumeru Mountain, which is made of gold, silver, glass and crystal. The southern part of the Sumeru Mountain is made of glass. In Chinese literature, glass is called ‘*Liuli*’, a term which may have originated from the Indian Sanskrit ‘*Pi Liuli* 毗琉璃’ (Virudhaka), one of the Four Heavenly Kings in Buddhism.

According to the ‘*Dazheng Buddhist Scriptures*’ 大正藏, Buddhism was spread to Central, South, and Southeast Asia during the Asoka period (302 – 232 BC). Around the 1<sup>st</sup> century BC, Buddhism was spread to Khotan and Qiuci in Xinjiang through the North Silk Road via Kashmir and Greater Yuezhi (Afghanistan: Wang, 2012, p. 13). According to the ‘*Lihi-yul-lun-bstan-pa*’ 于阗国授记, Buddhism started to prevail in the Khotan State around 82 BC. As recorded in ‘*Mou Zi Li Huo Lun*’ 牟子理惑论 written by *Mou Zi* 牟子 during the Late Eastern Han period (Mou, 2020), Han Ming Emperor (AD 28 – 75) dreamed about Buddha, then he commanded thirteen envoys to transcribe the ‘*Sutra of the Forty-two Sections*’ 四十二章经 in Yuezhi. In AD 68, the first Buddhist temple, the White Horse Temple, was built in Luoyang (Henan Province) to collect the Sutra transcribed from Yuehzhhi. Thus, Buddhism was spread to the Central Plains during the Eastern Han Dynasty. There are also quite a few archaeological



findings of Buddhism spread in the southwest part of China during the Han Dynasty. A unique type of bronze object - bronze Buddhism statue decorated with the money tree was commonly found in Sichuan (Shu region), Guizhou and Hubei. For instance, these bronze Buddhism statues were excavated at M5 and M14 Tujing cliff tomb, Zhong county, Sichuan (Zhang, 1985); M11 stone chamber tomb, Qing county, Guizhou (Guizhou Provincial Museum, 1959); Eastern Han brick-chamber tomb, Fang county, Hubei (Li and Liu, 2009). Moreover, Buddhism relief has been discovered on stone tomb gates during the Han Dynasty at M1 Mahao, Le Mountain, Sichuan (Tang, 1990) and M1 Shiziwan 1<sup>st</sup> zone, Le Moutain, Sichuan (He, 2019, p. 95). He (2019, p. 149) suggested that the Buddhism statues discovered in these regions were likely to be introduced from India through the Southwest Silk Road via Myanmar and Yunnan.

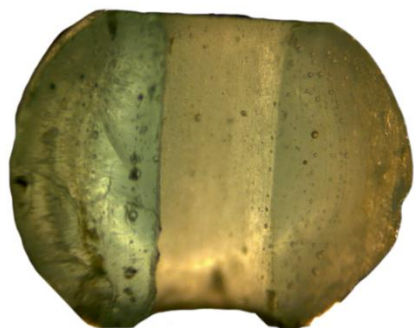
The earliest glass eye beads found in China can be dated to the late Spring and Autumn period (An, 2000a, p. 13), which were imported from the Mediterranean. There is no doubt that the eye beads were introduced to China much earlier than Buddhism. However, most glass samples were classified as monochrome drawn beads, and they were not found before the Han period in China. As Indian monochrome drawn beads and Buddhism appeared in China contemporaneously during the Han period, then if the glass drawn beads found in China was the result of the spread of Buddhism? Based on the major and trace element analysis of 108 glass samples, this paper aims to discuss the possible origins of glasses unearthed in different provinces in China and their connection with the spread of Buddhism.

## **6.2. Materials and Methods**

The 108 glass beads analysed in this study are from fix sites in four provinces in China, including Yunnan, Gunagxi, Henan and Hubei (Figure 6.2). Glass beads from Yunnan and Guangxi were selected to understand the role of the Southwest and Maritime Silk Roads for the glass trade respectively. Glass beads from Hubei and Henan were analysed to find if there was a connection of glass beads from the borderland of China. As samples are from museums and archaeology institutes, the sample size was strictly restricted by curators accordingly. With limited options, glass beads from four provinces are sampled according to their typologies. Samples from Yunnan, Guangxi, Henan are mainly monochrome drawn beads dating to the Han period (except for two glass ear pendants from Henan); samples from Hubei are eye beads and glass tubes dating to the Warring States period (Figure 6.3). Details about the sample information and photos can be found in Appendix C Table 6.1 and Table 6.2.



Figure 6.2 Glass beads analysed are from six sites in five different provinces in China.



**Drawn bead**



**Eye bead**



**Tubular bead**



**Ear pendant**

**Figure 6.3 Four types of glasses analysed in this study.** Drawn bead: GMG-11 in Guangxi; Eye bead: 5.29548 and 5.39316 in Hubei; Tubular bead: 5.2390-1 and 5.29390-2 in Hubei; Ear pendant: 2005ZHM3:12-1 in Henan. Details information can be found in Appendix C.

### 5.2.1 Sites background

Background to the sites from which glass beads have been analysed in this chapter can be found in Chapter 3.

### 5.2.2 LA-ICP-MS analysis

LA-ICP-MS analysis was performed at the Key Laboratory of Crust-Mantle Materials and Environments, University of Science and Technology of China, Chinese Academy of Sciences. Analyses were carried out with a Coheren GeoLas Pro laser ablation system in conjunction with a PerkinElmer/SCIE Elan DRC II ICP-MS. Samples were directly put on the sample chamber and ablated under an atmosphere of helium. Detailed operating conditions for the laser and the ICP-MS instrument are listed in Appendix C Table 6.3.

USGS reference glasses BCR-2G, BHVO-2G and BIR-1G were used as reference materials for calibration. Applying an AYCF and using these three reference materials for calibration, elements can be precisely analysed in situ by LA-ICP-MS without applying internal standardization (Liu *et al.*, 2008). The quantitative analysis of low-mass elements would be influenced by the mass-dependent sensitivity variation (Eggins *et al.*, 1997). By using a program *ICPMSDataCal*, all count rates for each analysis were firstly normalized by Si (Al for spinel), and then a time-drift correction was applied using a linear interpolation (with time) according to the variations of NIST SRM 610, which effectively reduce the uncertainty caused

by instrumental drift (Liu *et al.*, 2008). Appendix C Table 6.4 shows the accuracy and precision of the data by reporting the standard deviations of major elements for the reference materials.

### 5.3. Results

The chemical composition results can be found in Data file S4. As shown in Figure 6.4, two groups of glass beads can be classified according to their K<sub>2</sub>O and Na<sub>2</sub>O concentrations (Na<sub>2</sub>O+K<sub>2</sub>O+MgO=100%). This difference is caused by two types of flux used to produce these glass beads. Both groups show low concentrations of MgO, which suggests that both types of flux were derived from either mineral sodium or potassium sources rather than the use of plant or wood ash sources.

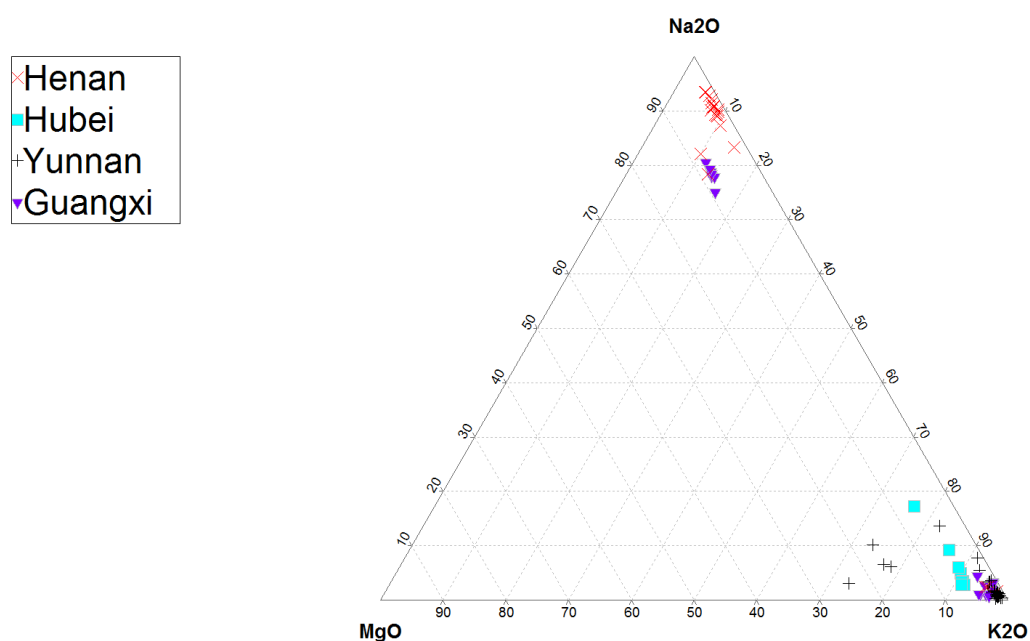


**Figure 6.4 Two types of flux identified by Na<sub>2</sub>O-MgO-K<sub>2</sub>O plot.**

### 5.3.1 High Sodium group

Samples identified as high sodium group are from two sites, Jiuzhiling Site (Guangxi) and Sigma European Industrial Park Site (Henan). Glass from Guangxi shows a turquoise colour with CuO enrichment. Two glass beads found in Henan are black with elevated MgO (1.43-1.48%) and FeO (2.03-2.08%) concentrations; The red colour of two glass beads found in Henan is most likely to be Cu<sub>2</sub>O given the high copper, which is commonly referred to as Indian red (Dussubieux, 2016). The rest of the Henan glass beads show a turquoise colour with CuO enrichment.

Mineral soda–alumina (m-Na–Al) glass has been mainly found in Africa and Asia, and appears from around the 5<sup>th</sup> century BC until the 19<sup>th</sup> century AD (Dussubieux *et al.*, 2010). Mineral soda–alumina glass has low magnesia concentrations ( $\leq 1.5\%$ ) and low potassium concentrations ( $\leq 3\%$ ), suggesting the use of soda taken from a mineral source (Brill, 1986). A soda-rich efflorescence similar to reh was certainly used as flux (Brill, 1986). Available in India, reh is a mixture of sodium carbonate, sodium sulphate and sodium chloride with low proportions of calcium and magnesium. Alumina contents in the m-Na-Al glass vary from 5 to 15% due to the use of reh. The composition of silica source is similar to that of granite and contains a small amount of potash and lime, and relatively high concentrations of iron, titanium and other trace elements, such as uranium (Dussubieux *et al.*, 2010). Therefore, the relatively higher proportions of alumina and potassium, lower calcium proportions can be used to



distinguish between natron glass and m-Na-Al glass.

Figures. 6.5 show the  $\text{Al}_2\text{O}_3$  vs CaO and MgO vs  $\text{K}_2\text{O}$  concentrations for m-Na-Al glasses from Guangxi and Henan analysed in this study and other regions in South and Southeast Asia (Lankton and Dussubieux, 2006). The higher and larger variation of  $\text{Al}_2\text{O}_3$  and lower CaO clearly indicate that the Henan glass can be identified as m-Na-Al glass. The proportions of  $\text{Al}_2\text{O}_3$  and CaO seem to be less dispersed than for the Guangxi glass. As for the Guangxi glass, although the  $\text{Al}_2\text{O}_3$  concentrations are around 5% and the CaO concentrations are slightly higher than the Henan glass, their concentrations show a certain degree of overlap compared with m-Na-Al glass discovered in India and Thailand. Based on the proportions of  $\text{K}_2\text{O}$ , CaO, MgO and  $\text{Al}_2\text{O}_3$ , there seem to be two different sources of raw materials used for Guangxi and Henan glasses. The variation of  $\text{Al}_2\text{O}_3$  and  $\text{K}_2\text{O}$  concentrations for Henan glass may indicate the use of a more variable reh and silica sources compared with that used for the Guangxi glass. Guangxi glass also shows higher MgO concentrations which represents a different flux source to that used for the Henan glass. However, two outliers amongst the Henan glass also show higher MgO proportions, so it could either be a different selection of reh source or the influence of the colourant and opacifier, since only these two samples were opaque black. Both opaque black glass beads show higher levels of FeO and MgO, possibly derived from a source of ferromagnesian minerals (e.g., olivine, pyroxene, amphibole, and biotite). Iron and magnesium cations are essential chemical components in ferromagnesian minerals. Although both Guangxi



and Henan m-Na-Al glasses show certain levels of overlap with m-Na-Al glasses discovered in India and Thailand, it is difficult to determine the origin of the m-Na-Al glasses in Guangxi and Henan through major element analysis.

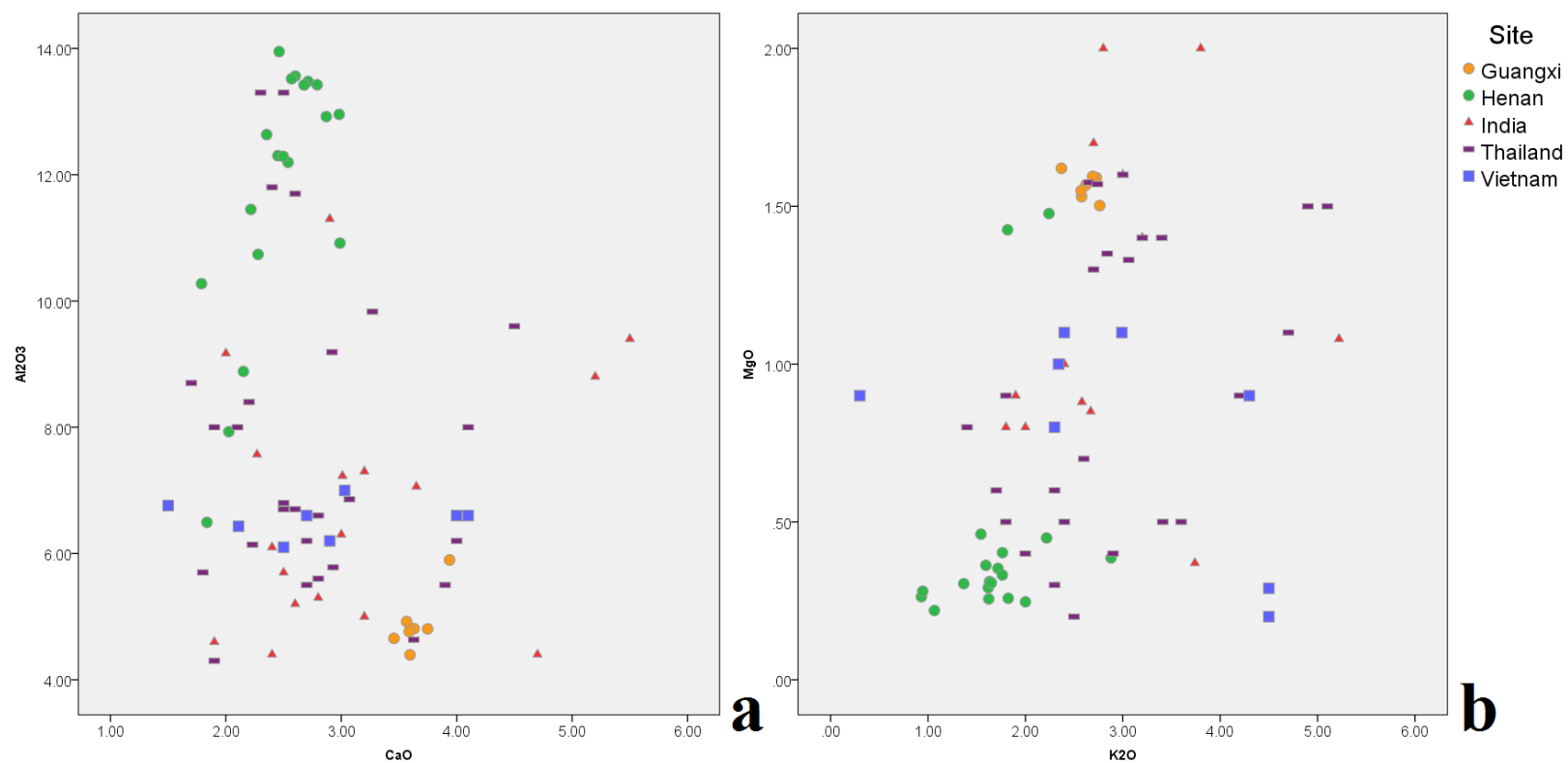


**Figure 6.5 Al<sub>2</sub>O<sub>3</sub>-CaO and MgO-K<sub>2</sub>O concentrations (oxide%) for m-Na-Al glasses from Guangxi, Henan and other regions in South and Southeast Asia.** Published data of m-Na-Al glass can be found in Data file S4 (Lankton and Dussubieux, 2006).

Rare earth elements (REE) analysis is beneficial in igneous, sedimentary, and metamorphic petrology. (Rollinson, 2014, p. 133). The common reference standard most commonly used to standardize rare earth element concentrations in rocks is a chondritic meteorite, because the chondritic normalization smooths the zigzag pattern and also allows the identification of any fractionation of the REE group relative to chondritic meteorites (Rollinson, 2014, p. 135). Unlike the other REE, plagioclase preferentially incorporates Eu, which can occur in a divalent form. Weathering, erosion, and sedimentary processes can enrich or deplete plagioclase, resulting in positive or negative Eu anomalies in the REE patterns of sandy sediments, which can be passed on into the glass (Degryse and Shortland, 2009; Wedepohl *et al.*, 2011). In this case, rare earth elements for Guangxi and Henan glasses were normalized by using Boynton (1984) standard (i.e.,  $C_{EN} = Lg (Abundance/chondritic\ meteorite)$ ). As can be seen in Figure 6.6, Guangxi glass beads show a negative europium anomaly. The ratio  $Eu/Eu^* = Eu_N / \sqrt{[(Sm_N) * (Gd_N)]}$  is a measure of the europium anomaly and a value of less than 1.0 indicates a negative anomaly. All the Guangxi glasses show a negative anomaly (Appendix C Table 6.5).  $Eu^{2+}$  is compatible with plagioclase and potassium feldspar, whereas the trivalent REE are incompatible (Rollinson, 2014, p. 138). The crystal fractionation or the partial melting of a rock from a felsic melt can remove the feldspar and the retained feldspar in the source gives rise to a negative Eu anomaly in the melt (Rollinson, 2014, p. 139). By comparing Eu anomalies, it is clear that Henan and Guangxi glass used different silica sources. The Henan glass beads look to be

heterogenous, which again confirms the theory of the variability of the raw materials.

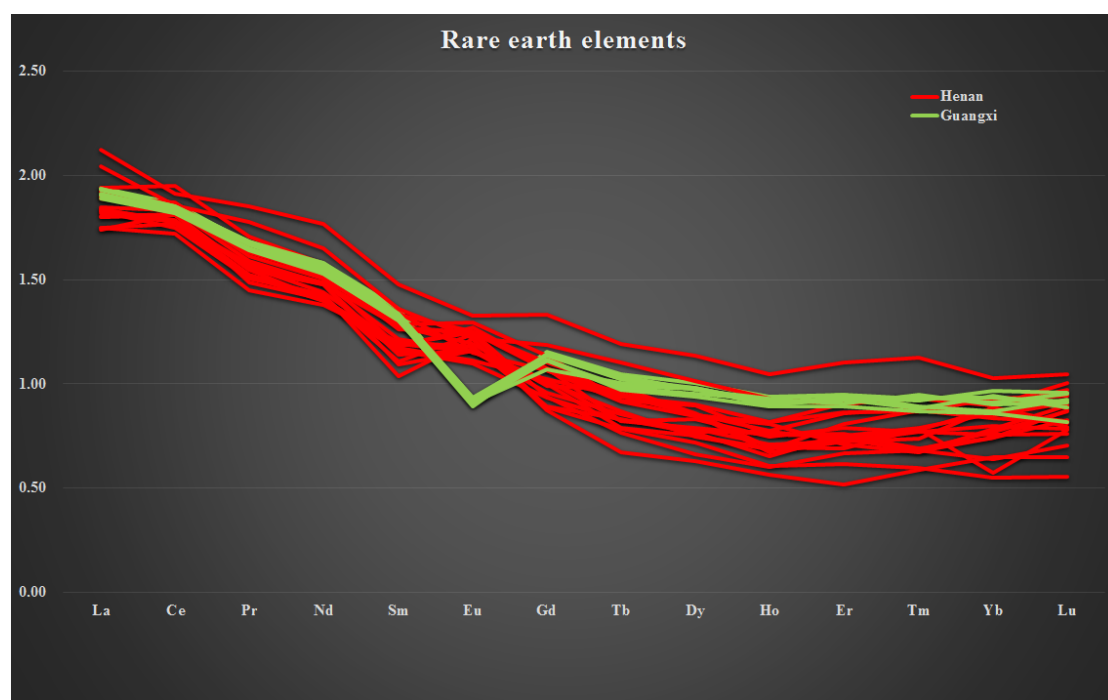


**Figure 6.6 Rare-earth Element Analysis for Guangxi and Henan glasses.**

Dussubieux *et al.* (2010) summarised 5 types of m-Na-Al by comparing the concentrations of U, Ba, Zr and Sr, but only Type 1 and Type 3 appeared since the mid-first millennium BC, which matched the date of the m-Na-Al glass samples analysed in this study. Figure 6.7 shows the Zr, Ba and U concentrations of Henan glass and Guangxi glasses, and they are similar to m-Na-Al-1 and m-Na-Al-3 respectively. The comparison of other major and trace elements was listed in Table 6.1. From the 4<sup>th</sup> century BC to the 5<sup>th</sup> century AD, the m-Na-Al-1 glass has been found in sites in south India, Sri Lanka, and Southeast Asia (Dussubieux *et al.*, 2010) The existence of furnaces with blocks of m-Na-A-1 raw glass at the site of Giribawa, Sri Lanka indicates that this type of glass might have been manufactured there (Bopearachchi, 1999;

Dussubieux *et al.*, 2010; Gratuze *et al.*, 2000). The m-Na-Al-3 glass is absent from south India and Sri Lanka, while its products have been found in Thailand, Cambodia and southern Vietnam (Lankton *et al.*, 2006). High concentrations of raw glass and artefacts of m-Na-Al-3 glass were discovered at Khao Sam Kaeo, located in the Upper Thai-Malay Peninsula, indicating a presence of glass producing centre, if not at this site, then at least somewhere nearby. As summarised, the Ba, Zr and Sr concentrations for m-Na-Al-1 glass show large variations. The major elements such as CaO, Al<sub>2</sub>O<sub>3</sub>, MgO and K<sub>2</sub>O and trace elements such as Ti, Zr, La and Cr in Henan glass also show variable concentrations. There might be quite a few factors that caused this issue. For instance, the selection and purification of the raw material was less refined, or the geochemistry of the raw material was variable.

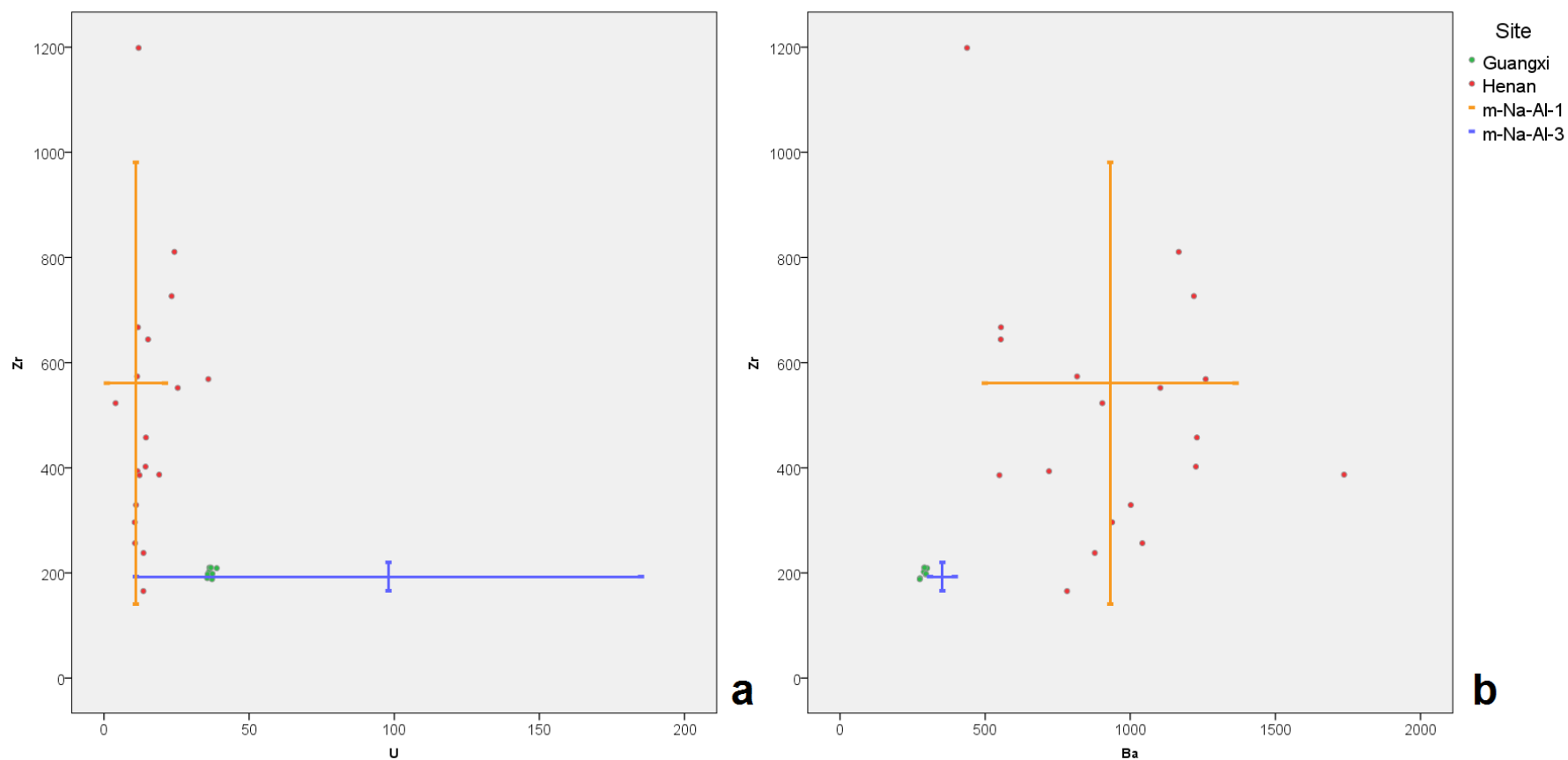


**Figure 6.7 U-Zr and Ba-Zr concentrations (ppm) for Guangxi and Henan glasses.** Average concentrations of Zr, Ba and U (ppm) with standard deviations of m-Na-Al-1 and m-Na-Al-3 glasses are referenced from (Dussubieux *et al.*, 2010).

**Table 6.1 Average concentrations in wt% of oxide or ppm of element with standard deviations of the different m-Na-Al glass groups.**

|                                    | m-Na-Al 1 | Henan            | m-Na-Al 3  | Guangxi          |
|------------------------------------|-----------|------------------|------------|------------------|
| SiO <sub>2</sub> (%)               | 62.5±5.2  | 62.06±3.61       | 66.8±2.9   | 66.1±1           |
| Na <sub>2</sub> O (%)              | 15.5±3.2  | 17.74±1.93       | 14.6±2.4   | 15.16±1.02       |
| MgO(%)                             | 0.7±0.7   | 0.44±0.36        | 1.3±0.2    | 1.57±0.04        |
| Al <sub>2</sub> O <sub>3</sub> (%) | 9.8±2.1   | 11.75±2.09       | 7.1±0.8    | 4.86±0.45        |
| K <sub>2</sub> O(%)                | 2.3±0.9   | 1.69±0.46        | 3.3±1.2    | 2.62±0.12        |
| CaO(%)                             | 3.0±1.3   | 2.46±0.35        | 2.9±1.0    | 3.64±0.14        |
| MnO (%)                            | 0.10±0.10 | 0.06±0.04        | 0.09±0.02  | 0.08±0           |
| Fe <sub>2</sub> O <sub>3</sub> (%) | 1.7±1.0   | 1.1±0.35 (FeO)   | 2.2±1.1    | 1.07±0.08 (FeO)  |
| Sc (ppm)                           | 5±2       | 7.42±1.47        | 7±1        | 5.69±0.46        |
| Ti (ppm)                           | 3595±1696 | 3389.73±1122.1   | 1919±323   | 1462.25±35.38    |
| V (ppm)                            | 114±47    | 58.11±14.4       | 63±19      | 34.37±1.02       |
| Cr (ppm)                           | 40±27     | 26.99±22.97      | 36±6       | 136.15±15.96     |
| Ni (ppm)                           | 60±104    | 33.29±17.55      | 27±30      | 222.07±9.52      |
| Co (ppm)                           | 24±72     | 10.39±3.64       | 13±18      | 20.16±0.56       |
| Cu(ppm)                            | 5974±7833 | 10247.38±7311.14 | 4000±10313 | 21286.28±2235.31 |
| Zn(ppm)                            | 102±124   | 48.69±31.15      | 78±23      | 925.02±140.97    |
| As (ppm)                           | 37±69     | /                | 23±29      | /                |
| Rb (ppm)                           | 58±25     | 34.36±13.7       | 88±14      | 64.03±2.75       |
| Sr (ppm)                           | 373±145   | 535.29±140.08    | 132±31     | 116.16±2.6       |
| Zr(ppm)                            | 561±420   | 503.99±242.3     | 193±27     | 200.65±8.78      |
| Nb (ppm)                           | 11±6      | 9.41±2.45        | 9±2        | 5.72±0.24        |
| Ag(ppm)                            | 20±32     | 6.98±6.75        | 1±2        | 2.86±0.77        |
| Sn(ppm)                            | 449±2621  | 944.66±468.51    | 369±2134   | 4633.17±4917.57  |
| Sb (ppm)                           | 8±22      | 16.63±7.45       | 4±12       | 5.91±1.21        |
| Cs(ppm)                            | 0.6±0.4   | 0.5±0.33         | 3.6±0.7    | 2.14±0.24        |
| Ba(ppm)                            | 931±432   | 953.64±321.97    | 353±43     | 288.98±9.28      |
| La (ppm)                           | 29±14     | 23.44±5.92       | 30±4       | 25.71±1.15       |
| Ce(ppm)                            | 59±19     | 54±7.26          | 60±8       | 56.08±2.09       |
| Pr(ppm)                            | 6±2       | 5.02±1.3         | 7±1        | 5.69±0.2         |
| Y(ppm)                             | 17±18     | 12.25±3.89       | 25±11      | 17.13±0.78       |
| Pb(ppm)                            | 4373±8084 | 2374.27±1594.26  | 2427±14985 | 8.3±0.71         |
| U(ppm)                             | 11±10     | 15.48±7.25       | 98±87      | 36.74±1.06       |
| Nd (ppm)                           | 21±8      | 19.25±4.92       | 24±3       | 21.45±1.05       |
| Sm (ppm)                           | 3.7±1.5   | 3.37±0.88        | 4.8±0.7    | 4.12±0.18        |
| Eu (ppm)                           | 1.0±0.3   | 1.19±0.17        | 0.5±0.1    | 0.6±0.02         |
| Gd(ppm)                            | 3.3±1.6   | 2.87±0.85        | 4.1±0.6    | 3.44±0.21        |
| Tb(ppm)                            | 0.4±0.2   | 0.38±0.12        | 0.6±0.1    | 0.49±0.03        |
| Dy (ppm)                           | 2.6±1.1   | 2.23±0.69        | 35±0.6     | 3.02±0.13        |
| Ho (ppm)                           | 0.5±0.2   | 0.41±0.12        | 05±0.1     | 0.59±0.02        |
| Er (ppm)                           | 1.5±0.6   | 1.29±0.42        | 2.2±0.3    | 1.77±0.08        |
| Tm (ppm)                           | 0.2±0.1   | 0.21±0.07        | 0.3±0.1    | 0.27±0.02        |
| Yb(ppm)                            | 1.7±0.7   | 1.35±0.37        | 2.1±0.3    | 1.72±0.14        |
| Lu (ppm)                           | 0.3±0.1   | 0.23±0.06        | 0.3±0.1    | 0.26±0.03        |
| Hf (ppm)                           | 15±8      | 11.5±5.21        | 6±1        | 4.92±0.21        |
| Th (ppm)                           | 12±8      | 8.75±1.8         | 12±2       | 12.37±0.49       |

### 6.3.2 High potassium group

The second group is identified as potash glass which used mineral saltpetre as the flux (Marshall, 1915). Eighty-seven potash glass beads were analysed in this study, including five colourless glass beads, twenty-nine blue glass beads with elevated CuO and CoO concentrations, five opaque yellow glass beads with elevated PbO and SnO<sub>2</sub> concentrations, fourteen purple glass beads with elevated MnO concentrations, twenty turquoise glass beads with elevated CuO concentrations, three opaque red glass beads most likely due to the Cu<sub>2</sub>O given the high copper, and eleven dark blue glass beads with elevated CuO and MnO concentrations.

When characterizing the raw material of the sand source in glass manufacture, a combination of Ti, Zr, La, Y, and Cr shows the greatest variation between different regions (Brems and Degryse, 2013; Cann, 1970; Pearce and Cann, 1973, 1971). This is not only because of their regional variability, but also because all four are refractory and non-volatile and their inter-element ratios are not affected by the high temperatures involved in either manufacture or subsequent reprocessing reference. The variation of these five trace elements therefore most probably represents different sand raw materials, rather than differential fractionation of the elements in glass formation. Distinct groupings of glass can be made based on combinations of elements such as Zr-Ti (Aerts *et al.*, 2003), Zr-Ti-Cr-La (Reade, 2009; Shortland *et al.*, 2007; Walton *et al.*, 2009) and Zr-Sr-Ba (Freestone *et al.*, 2000; Paynter, 2006; Alberta Silvestri *et al.*, 2005;



Silvestri, 2008). In general, they are usually not related to any (de)colouring agents that could have been deliberately added to the glass batch. Figure 6.8 shows the Cr-Y-La plot of potash glass classified by provinces where they were unearthed. The potash glass samples can be clearly divided into two sub-groups. Most Guangxi potash glass samples show higher concentrations of Cr, and only two Guangxi glass beads clustered with the rest of the potash glass beads unearthed from the other three provinces. Compared with Guangxi glass samples, the potash beads from the other three provinces show a relatively large variation of Cr, Y and La concentrations as shown in Figure 6.8. Based on the Cr, Y and La concentrations, at least two different silica sources were used to produce these potash glass beads.

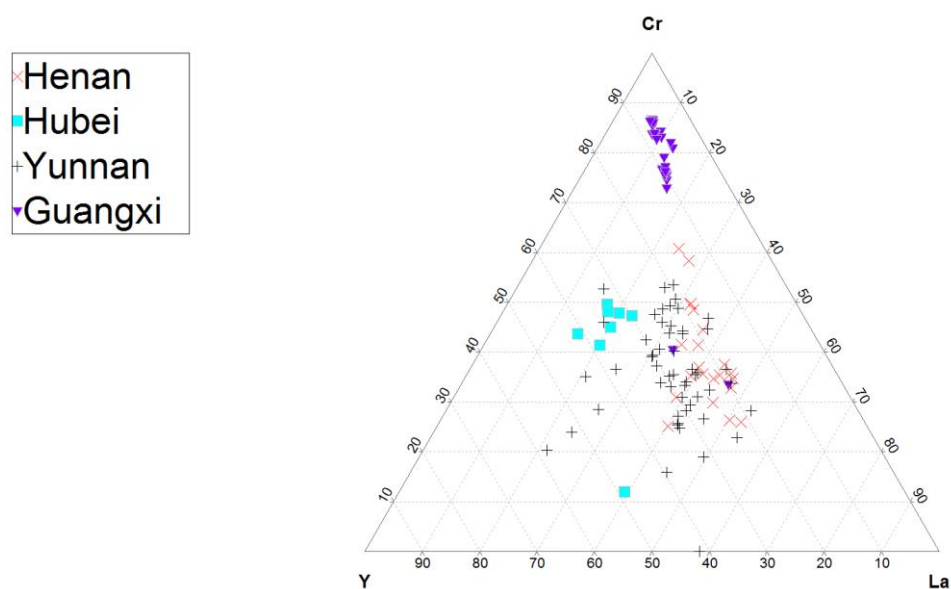


**Figure 6.8 Cr-Y-La plot of potash glass classified by provinces where they were unearthed.**

As the sources of m-Na-Al-1 and m-Na-Al-3 glasses are relatively clear, it is, therefore, plausible to use the concentrations of Zr, Ti, Cr and La to test if there was any connection of the sand sources for potash glass and m-Na-Al glasses. Figure 6.9 presents a new method to plot four trace elements in a tetrahedron graph. The Ti concentration is divided by 10, as its concentration is much higher than the other three trace elements. Directly plotting Ti concentrations in the tetrahedron graph will cause the points to be biased towards the Ti axis, which makes it impossible to differentiate each assemblage. The side, top and front views of the tetrahedron plot clearly show that there are mainly two different sand sources. Guangxi m-Na-Al-3 glass and Henan m-Na-Al-1 can be successfully distinguished by using this tetrahedron plot. Except for two potash glass beads unearthed in Guangxi that overlapped with the rest of the potash glasses, the majority of the potash glasses unearthed in Guangxi show different silica sources compared with the potash glasses unearthed from other regions. The relatively close variation of four trace elements in m-Na-Al-3 glass and most potash glasses unearthed in Guangxi indicates their silica sources are geologically close; silica sources of m-Na-Al-1 glass unearthed in Henan and the rest of the potash glasses from other regions are geologically close. In this case, some glass samples (See in Data file S4: Type Column) from Yunnan are weathered with over 80% SiO<sub>2</sub> due to the flux (K<sub>2</sub>O) loss after the data normalization. The flux loss will result in an increase in the proportion of all other elements. The ratios between these four trace elements are not affected, as they are related to the silica source. Still, ratios between Zr, Ti, Cr and La are not

affected and can still be plotted to trace the silica source.

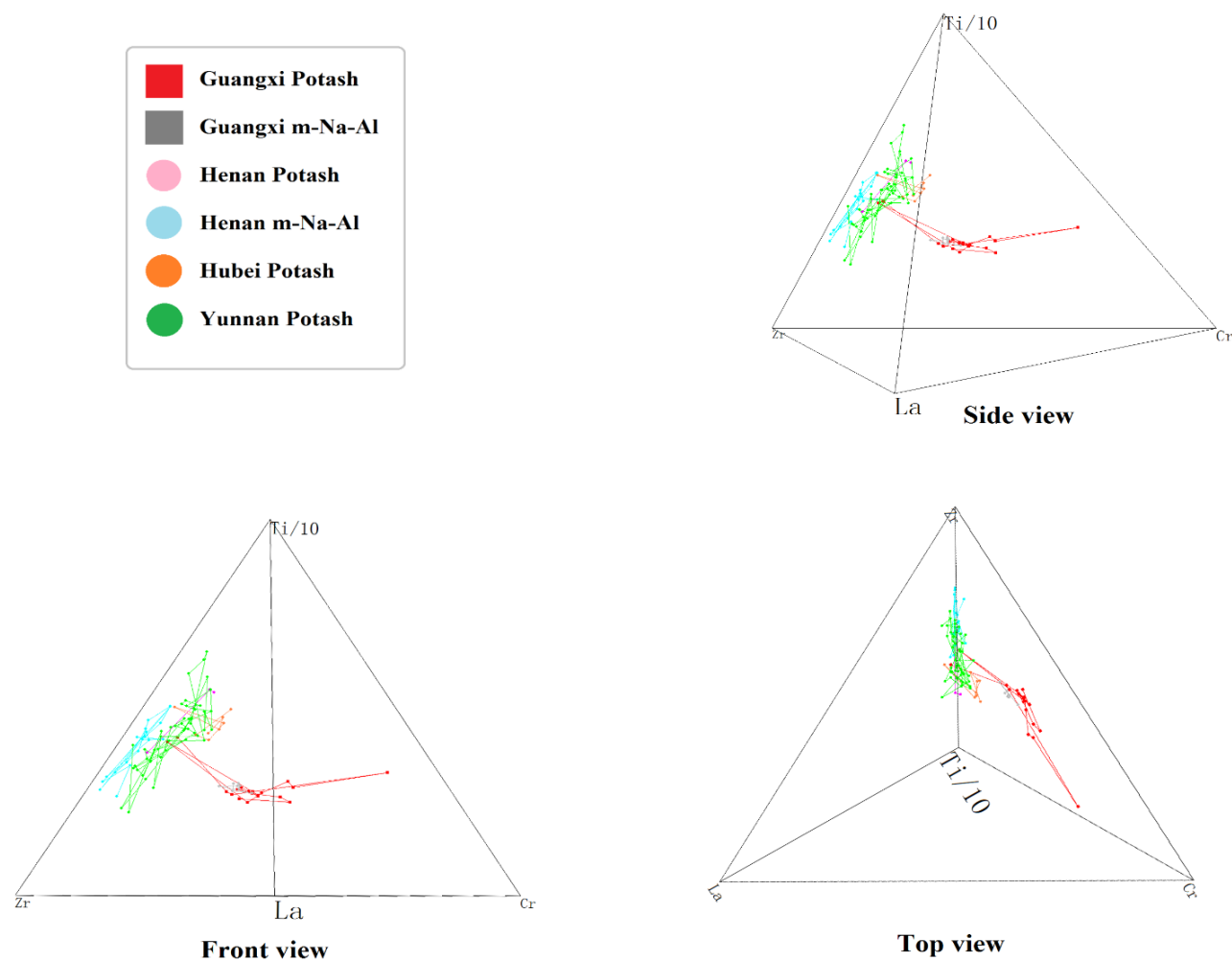


**Figure 6.9 Tetrahedron plot of four trace elements for m-Na-Al glass and potash glass unearthed in different provinces in China.**

## 6.4. Discussion

### 6.4.1 Made in China?

There has long been debate whether the Chinese could have produced glass during the Warring States period and the Han Dynasty. Here, this question should be refined as to whether the Chinese could produce primary raw glass or secondary finished glass products. Various types of glass have been discovered in China, yet, no primary or secondary glass production sites have been found for any of the glass types of this period. Glass ear pendants (Figure 6.3) have been commonly discovered in different regions in China during the Han Dynasty, which clearly shows uniqueness in the aesthetics and function. This provides evidence that Chinese artisans may have mastered the skill of producing secondary glass. Henderson *et al.* (2018) argue that it is very likely that primary potash glass was made in China, and the flux saltpetre used to produce potash glass occurs in southeast China. Saltpetre was used as a medicine during the Western Han period (Zhang, 1991). However, none of the other Chinese vitreous materials ever used saltpetre or reh as a flux during the Han Dynasty. The earliest documentation of using saltpetre in a glass recipe dated to the Tang Dynasty (AD 618 – 907). ‘Liu Li’(glass) documented in ‘*Jin Hua Yu Ye Elixir*’ 金 华 玉 液 大 丹 (anonymous) during the Tang Dynasty was a mixture of 250 g lead oxide (PbO), 100 g saltpetre (KNO<sub>3</sub>) and 100 g borax (Na<sub>2</sub>B<sub>4</sub>O<sub>7</sub>·10H<sub>2</sub>O). This formula fits the PbO-Na<sub>2</sub>O-K<sub>2</sub>O glass during the Tang Dynasty. m-Na-Al glass is rare compared with potash glass

unearthed in China during the Warring States and the Han period, and Henderson *et al.* (2018) suggest the primary production for this type of glass is certainly outside China. A few clues indicate sources of m-Na-Al-1 and m-Na-Al-3 glasses based on Dussubieux (2010) and Lankton *et al.* (2006) previous research. The trace element analysis in this study surprisingly shows that potash glass can be divided into two groups and they correlate with m-Na-Al-1 and m-Na-Al-3 glasses respectively. Although we cannot fully rule out the possibility that potash glass could be produced in southeast China, it is more reasonable to believe potash glasses were produced somewhere close to where the m-Na-Al glasses were produced, as their sand sources were geochemically similar. Thus, we believe the primary production of the potash glass eye beads analysed in this study was likely produced in southern India or Sri Lanka. Potash glass samples from Jiang Ling Jiu Dian Site, including two glass tubes and two eye beads, are dated to the Warring States period. There are limited historical records that we can use to deduce how these glasses were traded from Sri Lanka or southern India to the Chu State. As the Chu State was close to the Shu State, these glasses may have been traded through the Shu-Sindu Road. However, we cannot deny the possibility that secondary production of these eye beads was conducted in China, as lead-barium glass eye bead as a secondary production was indeed discovered in China since the Warring States period (Ma *et al.*, 2021).

## 6.4.2 Connection between glass and Buddhism in China

It is undeniable that eye beads arrived in China considerably earlier than Buddhism. The majority of the glass pieces, on the other hand, were categorised as monochrome drawn beads and were not discovered in China before the Han Dynasty. It seems there are quite a few cases to show the strong link between glass and Buddhism after the 4<sup>th</sup> century AD both in Xinjiang and Henan. An (2000b) reported the analysis of some glass beads unearthed from the Yongningsi Temple Site in Henan dating to the Northern Wei Dynasty (AD 368 – 534), and some of them were identified as m-Na-Al glass from India. A Buddhist temple at Tuoku Zisalai Site in Maralbexi County, Xinjiang, discovered a Sassanian glassware dating to the 4<sup>th</sup> – 5<sup>th</sup> century AD (Yu, 2018). Glasswares unearthed from Buddhist Famen Temple were identified as Islamic glass during the Tang period (AD 618 – 907: Li *et al.*, 2016). Indirect evidence also suggests their connection can be dated much earlier. For example, the Khotan State in Xinjiang believed in Buddha during the Han period. In Puluo county (part of Khotan State in the past), Buddha statues have been unearthed at urban sites, and different colours of monochrome glass beads have been unearthed at contemporaneous tomb sites dating to the Han period (Li, 1981; Yu, 2018), indicating a potential link between glass drawn beads and Buddhism during the Han period.

Various sects of Buddhism were developed to fit into local cultures as the Buddhist religion spread to different regions of Asia. The North Silk Road, Southwest Silk Road

and Maritime Silk Road all played indispensable roles in the transmission of Buddhism in China. Mahayana Buddhism prevailed in the Central Plains of China through the North Silk Road, and Theravada Buddhism was adopted in Southeast Asia, such as Myanmar and Thailand. Theravada Buddhism originated in Ceylon (Sri Lanka). Asoka sent his son Mahinda as the leader of the ninth mission to Ceylon to spread Buddhism during the 3<sup>rd</sup> century BC (Liang, 2019). As documented in ‘*Mou Zi Li Huo Lun*’ 牟子理惑论 (Mou, 2020), Sramana had trade contact in Jiaozhou (modern Guangxi, Guangdong and the North and centre of Vietnam) during the Han period. According to the chronicles ‘*Le Shi*’ 徼史 (anonymous, unknown date) written in Tai Lue language, Buddhism was spread in Xishuangbanna (Yunnan Province) in the year of 526 Buddhist Calendar Year (19 BC: Zhu, 1993). In 2000, the Yunnan Archaeological Institute excavated several cliff tombs in Zhaotong dating to the Eastern Han period. A terracotta figure of Buddha was unearthed in M2 tomb (He, 2019, p. 102), which could be one of the earliest pieces of evidence of Buddhist spread to Yunnan province. Contemporarily, a large quantity of monochrome drawn beads as was unearthed in Mu Yi and Shi Zhai Shan sites (Yunnan), which showed limited connection with the local culture. Combining the archaeological finds and Sutra documentations mentioned above, it cannot be denied that monochrome glass drawn beads that appeared in these regions could relate to the spread of Buddhism.



### 6.4.3 Transmission routes of monochrome drawn beads

We certainly cannot deny the possibility that these glass beads were traded to China by merchants or tribute brought by the envoys. However, based on the link between Buddhism and glass as discussed above, we can propose another possibility how the glass beads analysed in this study were transported to China. As discussed in the result section, the chemical composition fingerprint of m-Na-Al glass found in Henan in this research is highly consistent with the m-Na-Al-1 raw glass at the site of Giribawa, Sri Lanka, and the potash glass beads unearthed from Henan, Yunnan and Hubei show an identical silica source with the m-Na-Al glass in Henan. Still, it cannot be denied that some unknown primary glass production centres in southern India close to Sri Lanka might have produced m-Na-Al glass and potash glass showing similar geological fingerprints as in Sri Lanka. For example, the Arikamedu Site in southeastern India as a secondary production centre for monochrome drawn beads unearthed a large quantity of potash glass (Francis, 1991; Lal, 1952; Singh, 1989; Subramanian, 1950), and potentially primary glass production may have taken place nearby. Emperor Han *Wu Di* 汉武帝 (156 – 87 BC), the 7th emperor of the Han Dynasty, commanded officer *Zhang Qian* to investigate the past trade routes between China, the Middle East and Europe. *Zhang Qian*'s two journeys in 139 BC and 119 BC started the prosperous age of commodity circulation along the Northwest (Desert) Silk Road. Protectorate of the Western Regions 西域都护府 which was set up by the Han Empire in Xinjiang was to guard the border and coordinate the contradictions and disputes between the countries

of the neighbouring regions, to secure the Silk Road trade. No matter if the potash glass and m-Na-Al glass were produced in Sri Lanka or southern India, potash glass and m-Na-Al drawn glass beads in Henan could share the same transmission route along the North Silk Road during the Han Dynasty. Considering the status of glass in Buddhism and the time when Buddhism was introduced into Xinjiang and Central Plains as we previously discussed, we could make a hypothesis that monochrome drawn beads in Henan might be introduced in China with the spread of Mahayana Buddhism through Xinjiang into the Central Plains.

As introduced in the Introduction section (Chapter 6.1.1), there was a potential trade route from Sichuan to India via Yunnan controlled by minorities in Yunnan (i.e. Dian, Gouding, Ailao). *Zhang Qian* persuaded Emperor *Wu Di* to conquer these minorities, to take control of the Shu-Sindu road (Southwest Silk Road). Yet, after over ten years of the battle between the Han Empire and minorities in Yunnan, *Wu Di* only conquered the Dian people. Potash glass samples in Yunnan were unearthed from Dian (Shi Zhai Shan) and Gouding (Mu Yi) burial sites as introduced, and they were likely traded from Sri Lanka or southern India along the Southwest Silk Road. It needs to be reemphasized that the Southwest Silk Road was a complex trade network, with a strong link to the Maritime Silk Road. Potash glass either could be transported from Sindu to Yunnan via Myanmar or primarily shipped to Southeast Asia along the Maritime Silk Road and then traded to Yunnan through Jinsang-Phong Châu Road. Still, as we have introduced from

the previous section, Theravada Buddhism was spread in Xishuangbanna (Yunnan Province) in 19 BC as mentioned. Thus, the potash glass unearthed in Yunnan could originally be produced in southern India or Sri Lanka and traded to Southeast Asia, then entered Yunnan with the spread of Theravada Buddhism.

The chemical composition of m-Na-Al glass in Guangxi is close to the m-Na-Al-3 glass found in Khao Sam Kaeo. Except for two potash glass beads that show a possible southern Indian origin, the rest of the m-Na-Al and potash glass in Guangxi show close silica sources. However, Khao Sam Kaeo might not be the primary glass production centre for m-Na-Al-3 glass and potash glass. The unearthed raw glass and finished products without any archaeological evidence of primary glass furnace suggest Khao Sam Kaeo might be a port as an exchange network along the Maritime Silk Road. Lankton *et al.* (2006) and Dussubieux (2016) suggested that m-Na-Al-3 glass was quite likely manufactured in Northeastern India. Fifty-three glass samples in this study are from Yunnan, yet, no glass made in northeastern India was found in Yunnan, despite this region being geologically closer to northeastern Indian than Guangxi. There are quite a few sites in Southeast Asia that unearthed potash and m-Na-Al glasses with similar chemical composition as discovered in Khao Sam Kaeo, such as Phu Khao Thong as a secondary glass production centre, Khlong Thorn on the western coast of the Thai/Malay peninsula, Samon Valley, Myanmar, the southern Sa Huynh site of Giong Ca, Vietnam (possible primary and secondary production site), Hitam Cave in

Sarawak, and the Tabon Cave complex in Palawan (Lankton *et al.*, 2006). As the glass trade between India and Thailand lasted for centuries, it should come as no surprise to find evidence of primary glass production in Southeast Asia (potentially Thailand or Myanmar) that produced m-Na-Al-3 glass or potash glass. Although we cannot rule out the possibility that the m-Na-Al glass and most of the potash glass in Guangxi were from northeastern India, it is more likely their primary glasses were produced in Southeast Asia. *Hepu* was an important trade port as a starting point of the Maritime Silk Road, thus, we consider the m-Na-Al glass and most of the potash glass in Guangxi analysed presently could have been produced in Southeast Asia and transported through the Maritime Silk Road.

## 6.5. Conclusion

This paper focuses on the study of glasses in different provinces in China through major and trace element analyses. According to the major element analysis, glasses in this study can be classified as m-Na-Al glass and potash glass. According to trace element analysis, two different silica sources were used to produce these glasses. The Silica source for two eye beads and two tubular beads from Hubei dating to the Warring States period is chemically close to the m-Na-Al-1 glass. Two glass ear pendants from Henan dating to the Han Dynasty might have also used similar silica source as in m-Na-Al-1 glass. m-Na-Al-1 glass was produced Sri Lanka. For glass samples typologically identified as Indo-Pacific Monochrome Drawn Glass Beads, the m-Na-Al glass from

Henan and potash glass from Southwest and Central Plains of China were probably produced in southern India or Sri Lanka and traded in China through the North Silk and Southwest Silk Roads with the spread of Buddhism during the Han period; The m-Na-Al glass and most of the potash glass in Guangxi show similar silica sources, and they could have been produced in Southeast Asia and brought here through the Maritime Silk Road, potentially by the Sramana. Therefore, we believe that even glasses are typologically different and used different flux, their silica source might still originate from the same or close region. Previous research on Buddhism in China fully relies on the historical documentation and unearthed Buddha statues, yet this paper proposes a new perspective on the spread of Buddhism in China. The connection between monochrome drawn beads and Buddhism in China was clearly interpreted in this study, while such connection in South and Southeast Asia requires further evidence in future research.

## 6.6 Appendix C

**Table 6.2 Sample information.**

| Type         | Sample | Location | Site         | Date        | Colour    |
|--------------|--------|----------|--------------|-------------|-----------|
| Potash glass | jzl-01 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-02 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-03 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-04 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-05 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-08 | Guangxi  | Jiu Zhi Ling | Han Dynasty | dark blue |
| Potash glass | jzl-11 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-15 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-16 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-18 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-19 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-25 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-12 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-13 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-14 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-23 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-26 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| Potash glass | jzl-28 | Guangxi  | Jiu Zhi Ling | Han Dynasty | blue      |
| m-Na-Al      | jzl-09 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-10 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-20 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-21 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-22 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-27 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |
| m-Na-Al      | jzl-29 | Guangxi  | Jiu Zhi Ling | Han Dynasty | turquoise |

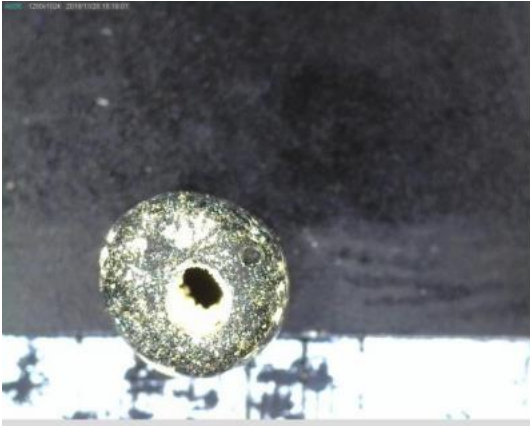
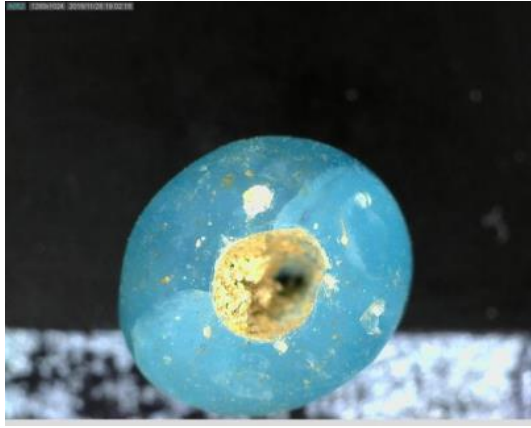
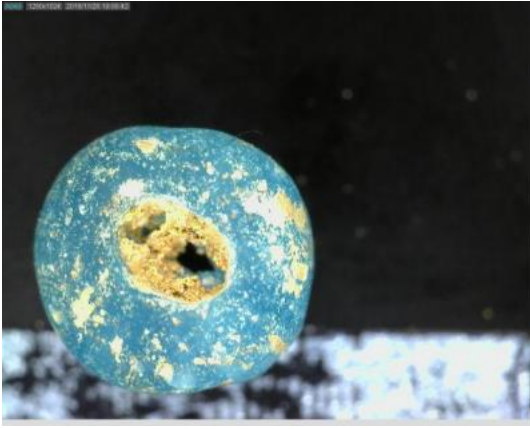
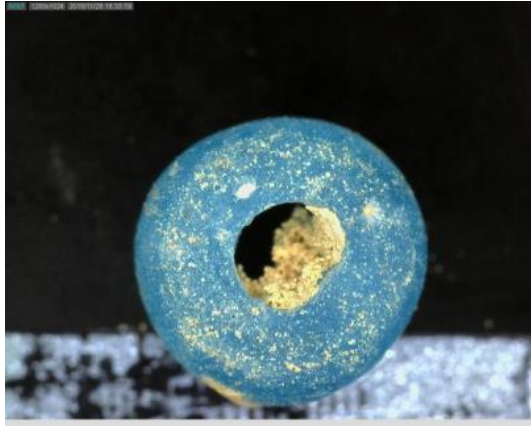
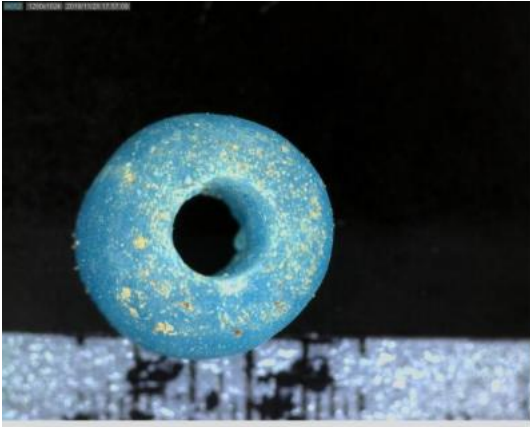
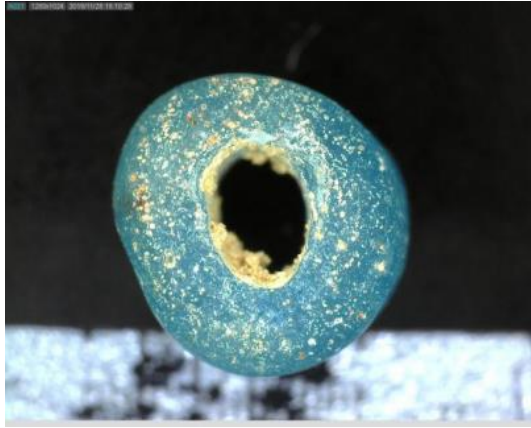
|              |              |         |                                |                       |             |
|--------------|--------------|---------|--------------------------------|-----------------------|-------------|
| m-Na-Al      | jzl-30       | Guangxi | Jiu Zhi Ling                   | Han Dynasty           | turquoise   |
| Potash glass | 1445         | Guangxi | Jiu Zhi Ling                   | Han Dynasty           | blue        |
| Potash glass | 08XYXM18-14  | Henan   | Sigma European Industrial Park | Han Dynasty           | blue        |
| Potash glass | 2005ZHM3-1   | Henan   | Zhengzhou                      | Han Dynasty           | blue        |
| Potash glass | 2005ZHM3-2   | Henan   | Zhengzhou                      | Han Dynasty           | blue        |
| m-Na-Al      | 08XYXM18-1   | Henan   | Sigma European Industrial Park | Han Dynasty           | black       |
| m-Na-Al      | 08XYXM18-10  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-12  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-13  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-15  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-16  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-17  | Henan   | Sigma European Industrial Park | Han Dynasty           | red         |
| m-Na-Al      | 08XYXM18-18  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-19  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-2   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-20  | Henan   | Sigma European Industrial Park | Han Dynasty           | red         |
| m-Na-Al      | 08XYXM18-21  | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-3   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-4   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-5   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-6   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-7   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| m-Na-Al      | 08XYXM18-8   | Henan   | Sigma European Industrial Park | Han Dynasty           | black       |
| m-Na-Al      | 08XYXM18-9   | Henan   | Sigma European Industrial Park | Han Dynasty           | turquoise   |
| Potash glass | 5.29390-1    | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 5.29390-2    | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 5.29390-3    | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 5.29461      | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 5.29548      | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 5.39316      | Hubei   | Jiang Ling Jiu Dian            | Warring States period | turquoise   |
| Potash glass | 2016M1GMG-39 | Yunnan  | Mu Yi                          | Han Dynasty           | transparent |
| Potash glass | 2016M1GMG-42 | Yunnan  | Mu Yi                          | Han Dynasty           | transparent |

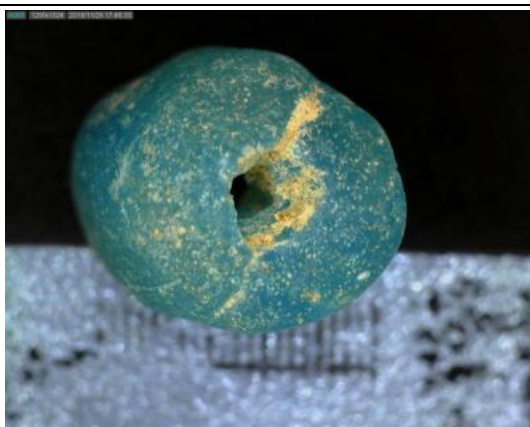
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|--------------|--------------|--------|-------|-------------|---------------|
| Potash glass | GMG-10       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-11       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-12       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-13       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-14       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-15       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-16       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-17       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-18       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-19       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | GMG-24       | Yunnan | Mu Yi | Han Dynasty | turquoise     |
| Potash glass | 2011M5GMG-26 | Yunnan | Mu Yi | Han Dynasty | red           |
| Potash glass | 2016M1GMG-40 | Yunnan | Mu Yi | Han Dynasty | transparent   |
| Potash glass | 2016M1GMG-41 | Yunnan | Mu Yi | Han Dynasty | transparent   |
| Potash glass | GMG-21       | Yunnan | Mu Yi | Han Dynasty | red           |
| Potash glass | GMG-22       | Yunnan | Mu Yi | Han Dynasty | red           |
| Potash glass | 2011M5GMG-27 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-28 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-29 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2011M5GMG-30 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2011M5GMG-31 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2011M5GMG-32 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2011M5GMG-33 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-34 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-35 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-36 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2011M5GMG-37 | Yunnan | Mu Yi | Han Dynasty | dark blue     |
| Potash glass | 2011M5GMG-38 | Yunnan | Mu Yi | Han Dynasty | purple        |
| Potash glass | 2016M1GMG-43 | Yunnan | Mu Yi | Han Dynasty | opaque yellow |
| Potash glass | 2016M1GMG-44 | Yunnan | Mu Yi | Han Dynasty | opaque yellow |
| Potash glass | 2016M1GMG-45 | Yunnan | Mu Yi | Han Dynasty | opaque yellow |
| Potash glass | 2016M1GMG-46 | Yunnan | Mu Yi | Han Dynasty | opaque yellow |



|              |              |        |                   |             |               |
|--------------|--------------|--------|-------------------|-------------|---------------|
| Potash glass | 2016M1GMG-47 | Yunnan | Mu Yi             | Han Dynasty | opaque yellow |
| Potash glass | GMG-1        | Yunnan | Mu Yi             | Han Dynasty | dark blue     |
| Potash glass | GMG-2        | Yunnan | Mu Yi             | Han Dynasty | purple        |
| Potash glass | GMG-20       | Yunnan | Mu Yi             | Han Dynasty | turquoise     |
| Potash glass | GMG-23       | Yunnan | Mu Yi             | Han Dynasty | turquoise     |
| Potash glass | GMG-25       | Yunnan | Mu Yi             | Han Dynasty | dark blue     |
| Potash glass | GMG-3        | Yunnan | Mu Yi             | Han Dynasty | blue          |
| Potash glass | GMG-4        | Yunnan | Mu Yi             | Han Dynasty | blue          |
| Potash glass | GMG-5        | Yunnan | Mu Yi             | Han Dynasty | dark blue     |
| Potash glass | GMG-6        | Yunnan | Mu Yi             | Han Dynasty | dark blue     |
| Potash glass | GMG-7        | Yunnan | Mu Yi             | Han Dynasty | purple        |
| Potash glass | GMG-8        | Yunnan | Mu Yi             | Han Dynasty | blue          |
| Potash glass | GMG-9        | Yunnan | Mu Yi             | Han Dynasty | purple        |
| Potash glass | M1ZC-1       | Yunnan | Shi Zhai Shan M1  | Han Dynasty | blue          |
| Potash glass | M1ZC-2       | Yunnan | Shi Zhai Shan M1  | Han Dynasty | blue          |
| Potash glass | S13-370-2    | Yunnan | Shi Zhai Shan M13 | Han Dynasty | transparent   |
| Potash glass | SJM1S-3      | Yunnan | Shi Zhai Shan M2  | Han Dynasty | blue          |
| Potash glass | SJM6-31-2    | Yunnan | Shi Zhai Shan M6  | Han Dynasty | blue          |
| Potash glass | SM24-11-1    | Yunnan | Shi Zhai Shan M24 | Han Dynasty | blue          |

**Table 6.3 Sample photos.**

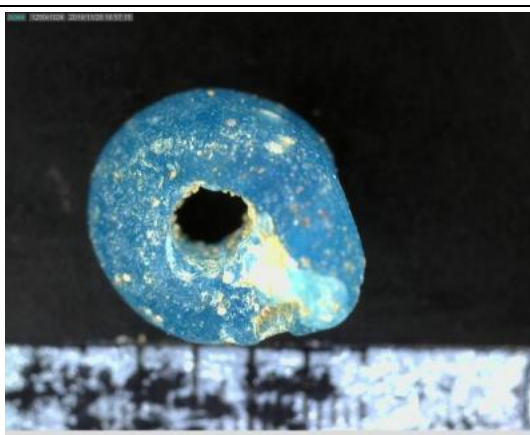
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|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|    |    |
| 2005ZHM3-1                                                                          | 2005ZHM3-2                                                                           |
|   |   |
| 2005ZHM3-3                                                                          | 2005ZHM3-4                                                                           |
|  |  |
| 2005ZHM3-5                                                                          | 2005ZHM3-6                                                                           |



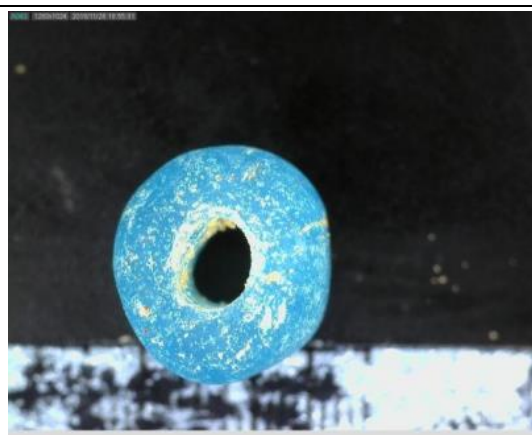
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2005ZHM3-8



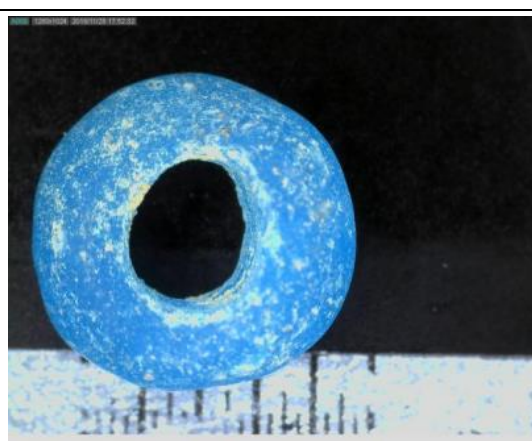
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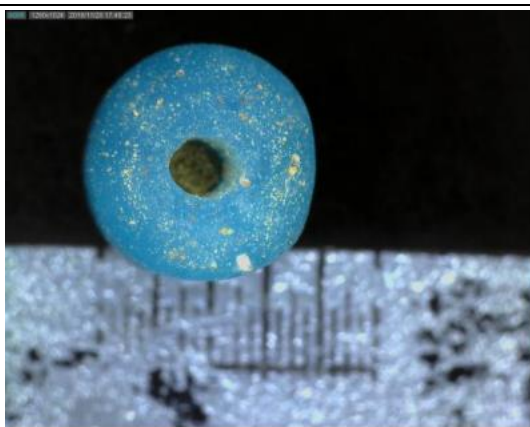
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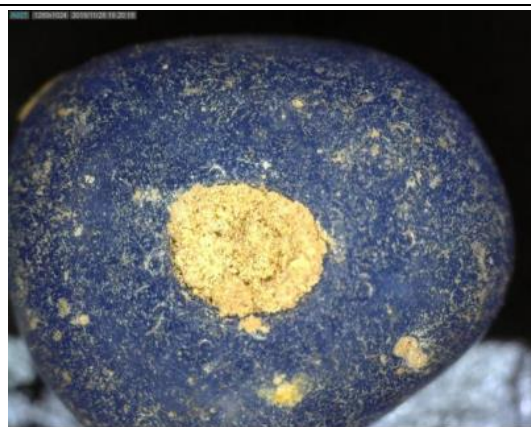
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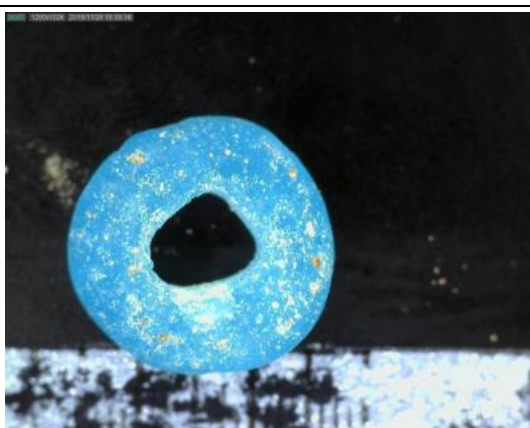
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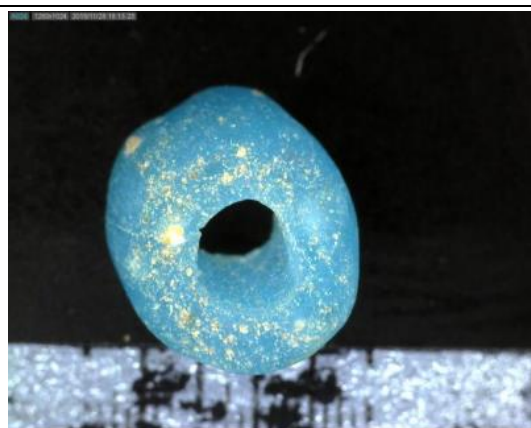
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2005ZHM3-14



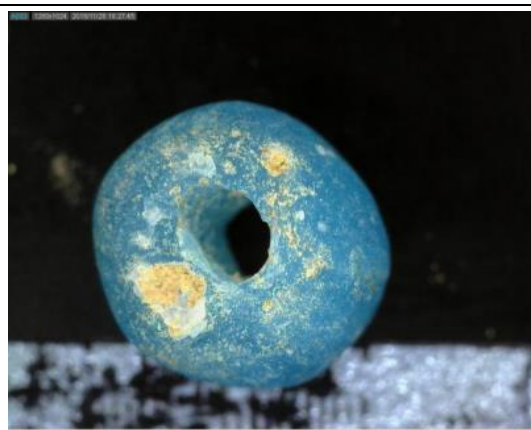
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2005ZHM3-16

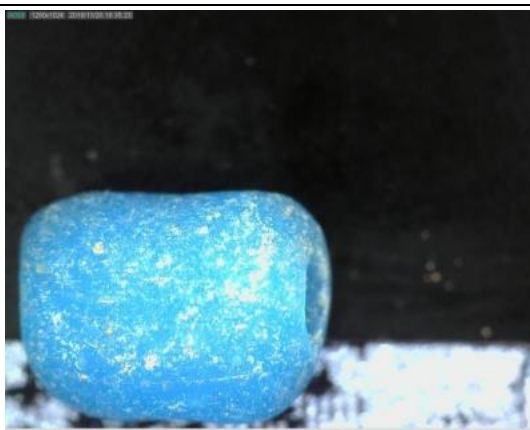


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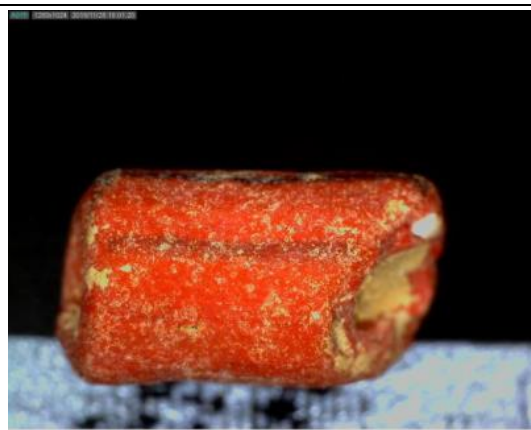


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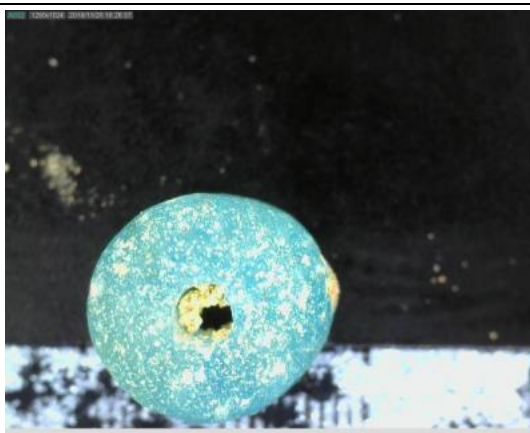




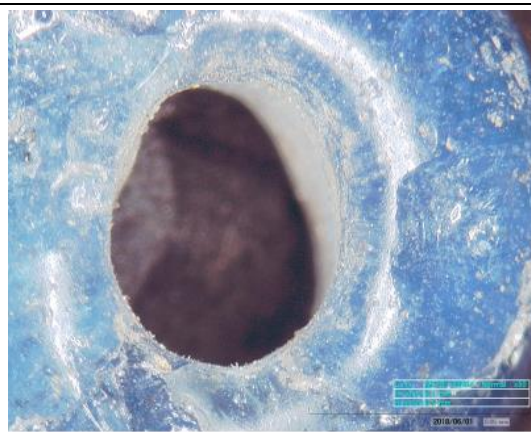
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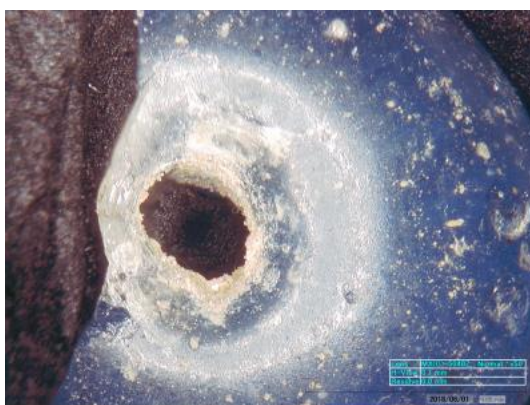
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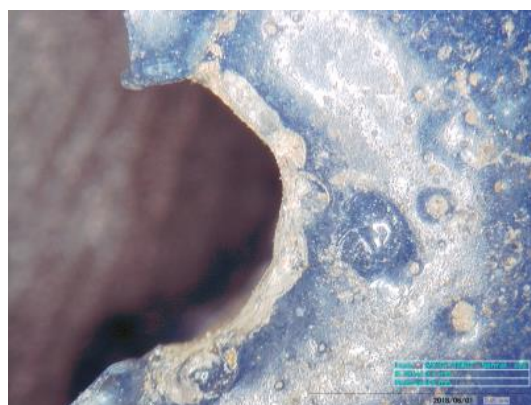
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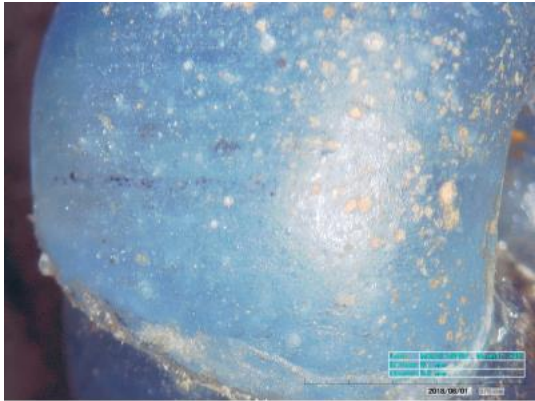
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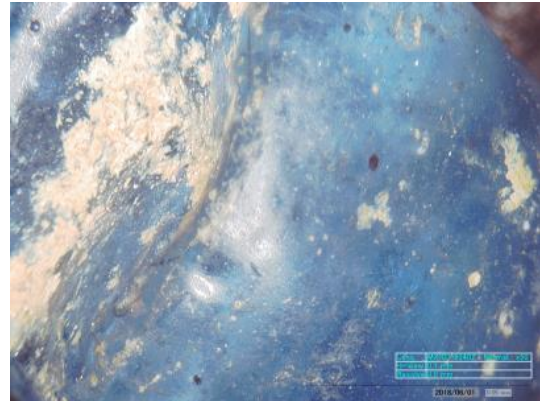
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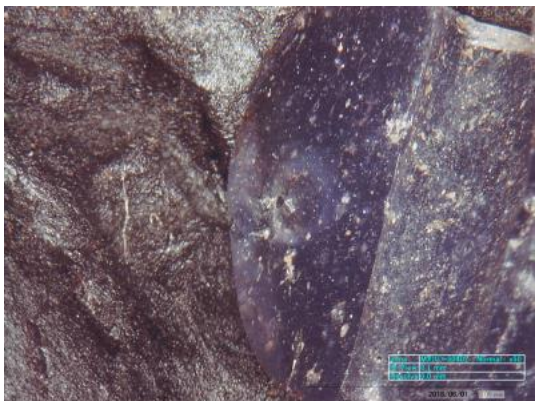
JZL-03



**JZL-04**



**JZL-05**



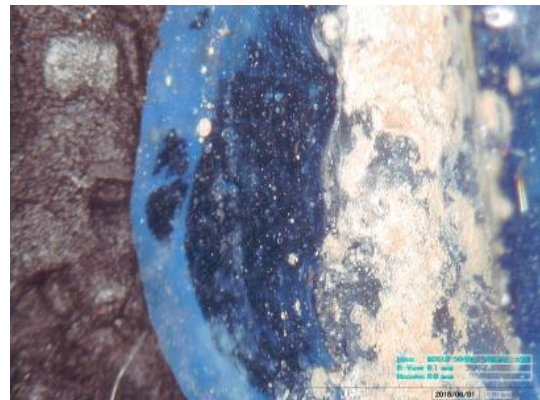
**JZL-08**



**JZL-09**

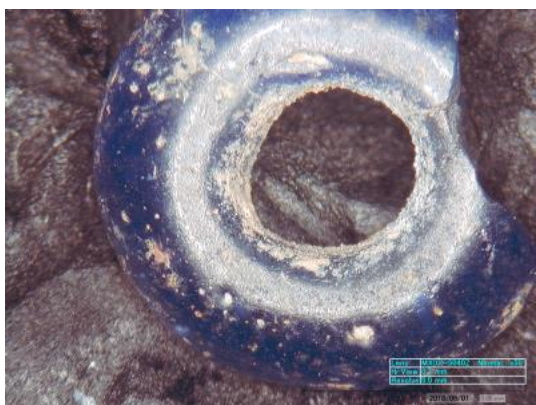


**JZL-10**

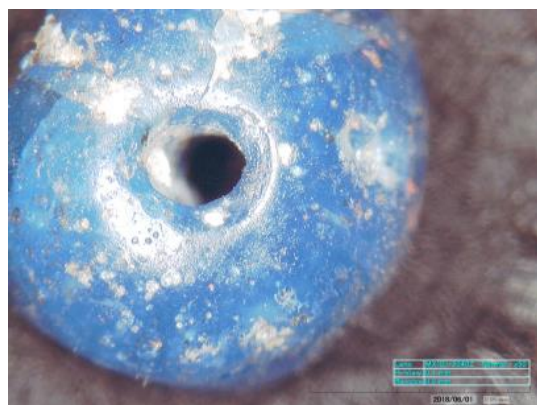


**JZL-11**





**JZL-12**



**JZL-13**



**JZL-14**



**JZL-15**



**JZL-16**



**JZL-18**



**JZL-19**



**JZL-20**



**JZL-21**



**JZL-22**



**JZL-23**



**JZL-25**

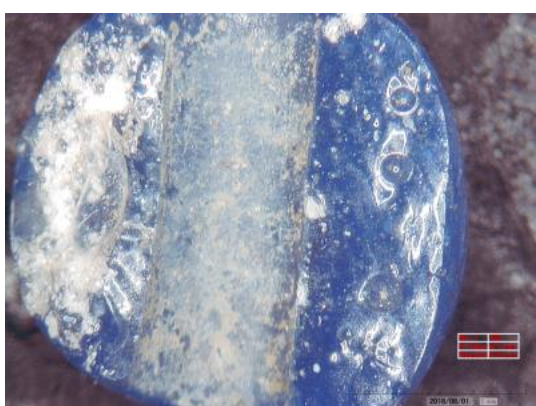




JZL-26



JZL-27



JZL-28



JZL-29

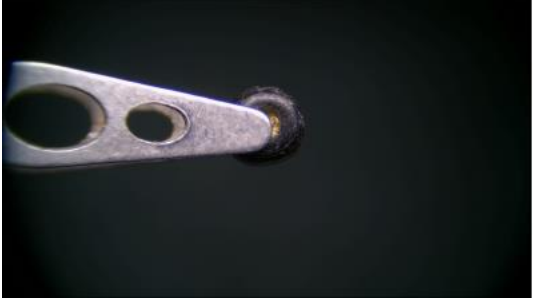
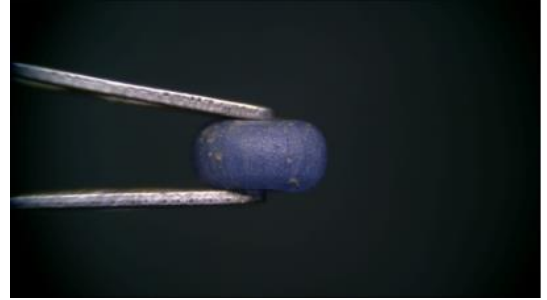
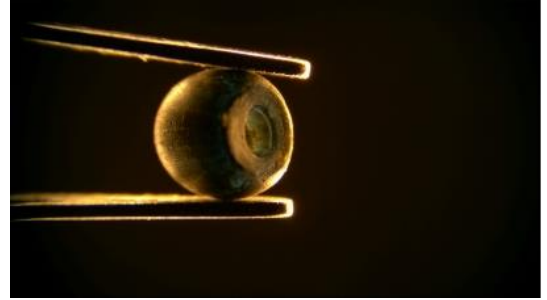
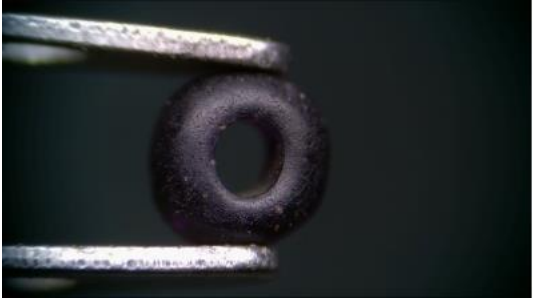


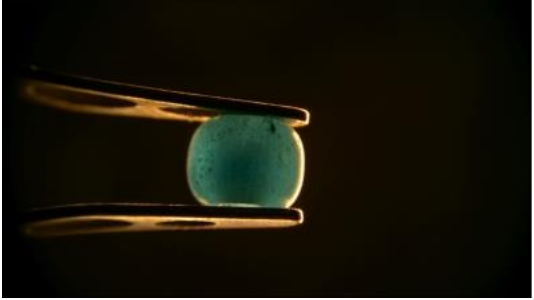
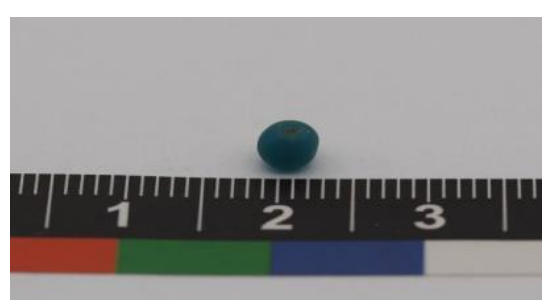
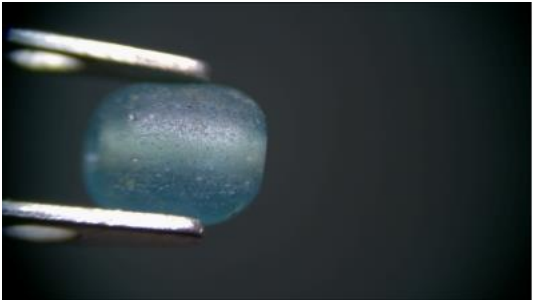
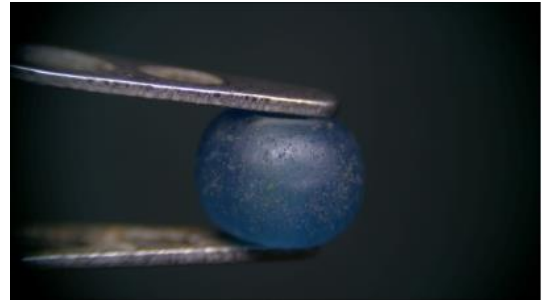
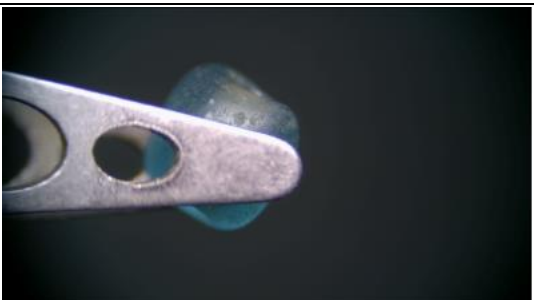
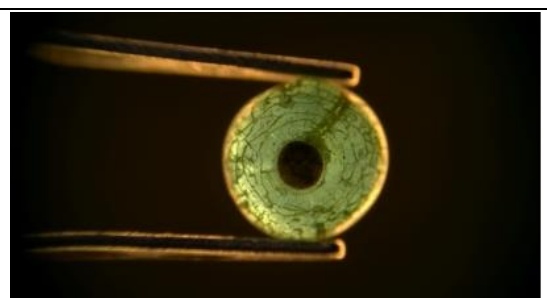
JZL-30



1445



|                                                                                     |                                                                                      |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <p>GMG-1</p>                                                                        | <p>GMG-2</p>                                                                         |
|    |    |
| <p>GMG-3</p>                                                                        | <p>GMG-4</p>                                                                         |
|    |    |
| <p>GMG-5</p>                                                                        | <p>GMG-6</p>                                                                         |
|  |  |
| <p>GMG-7</p>                                                                        | <p>GMG-8</p>                                                                         |
|  |  |
| <p>GMG-9</p>                                                                        | <p>GMG-10</p>                                                                        |
|  |  |

|                                                                                     |                                                                                      |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <p>GMG-11</p>                                                                       | <p>GMG-12</p>                                                                        |
|    |    |
| <p>GMG-13</p>                                                                       | <p>GMG-14</p>                                                                        |
|    |    |
| <p>GMG-15</p>                                                                       | <p>GMG-16</p>                                                                        |
|  |  |
| <p>GMG-17</p>                                                                       | <p>GMG-18</p>                                                                        |
|  |  |
| <p>GMG-19</p>                                                                       | <p>GMG-20</p>                                                                        |



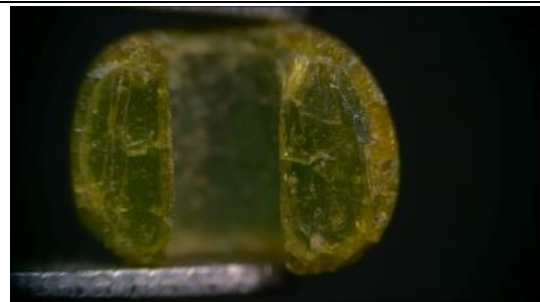
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GMG-22



GMG-23



GMG-24



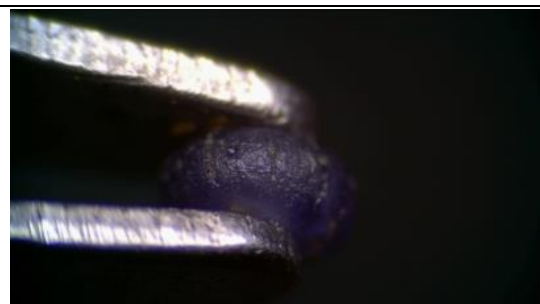
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GMG-26

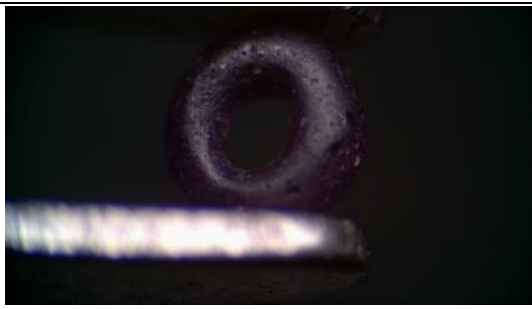


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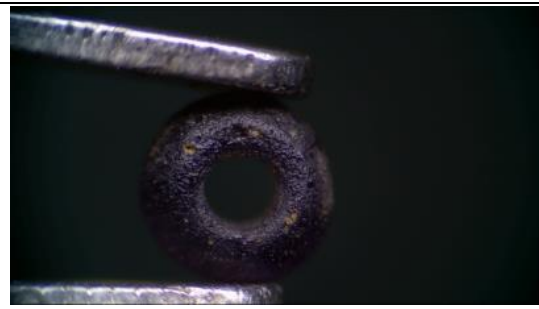


GMG-28





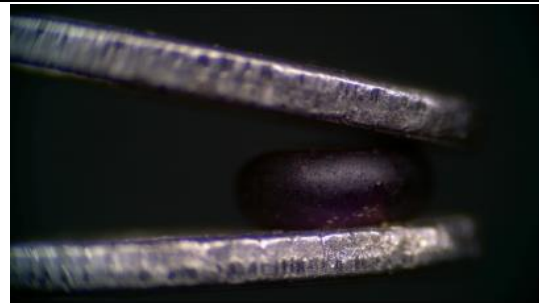
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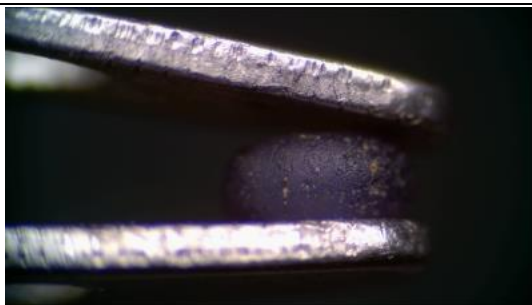
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GMG-31



GMG-32



GMG-33



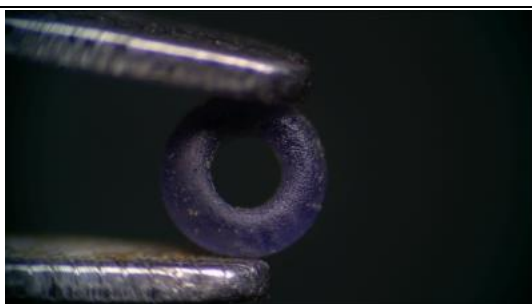
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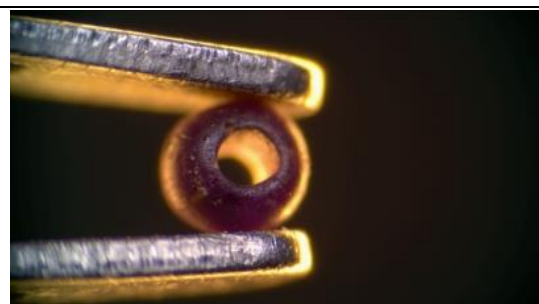
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GMG-36



GMG-37



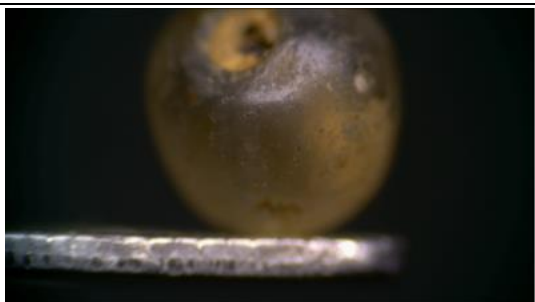
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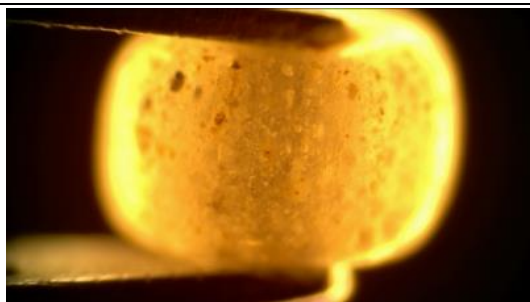
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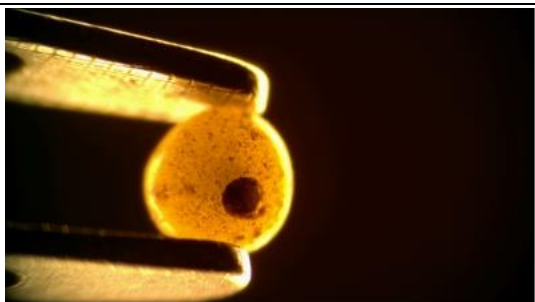
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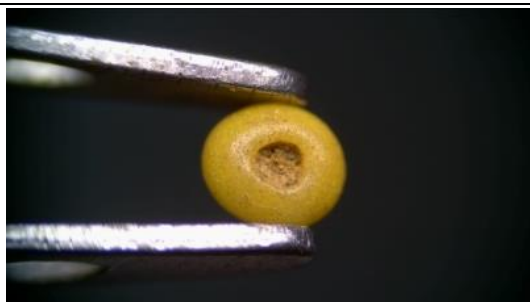
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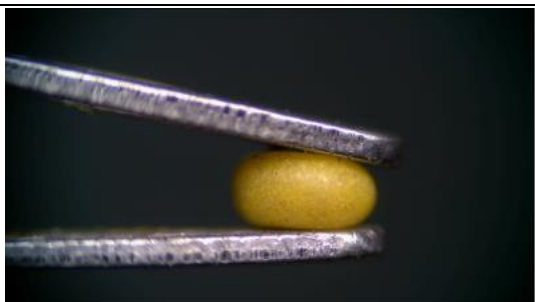
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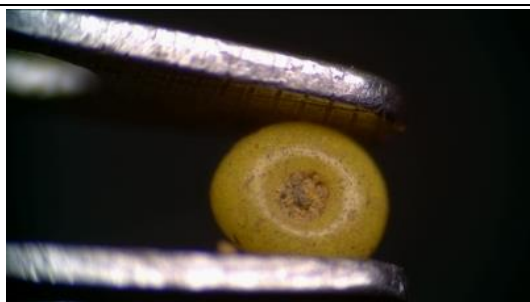
GMG-43



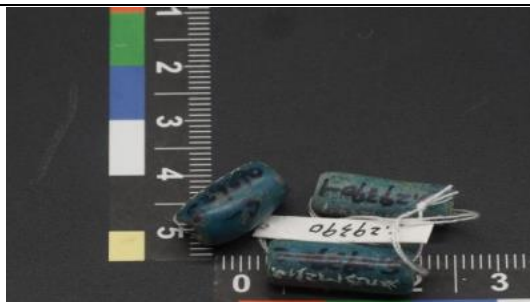
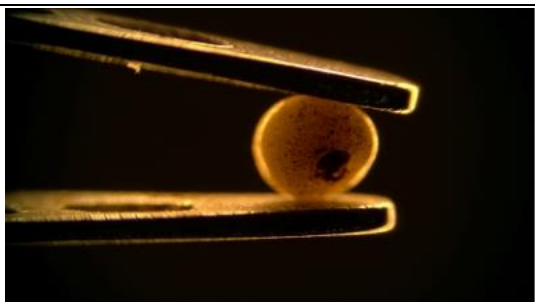
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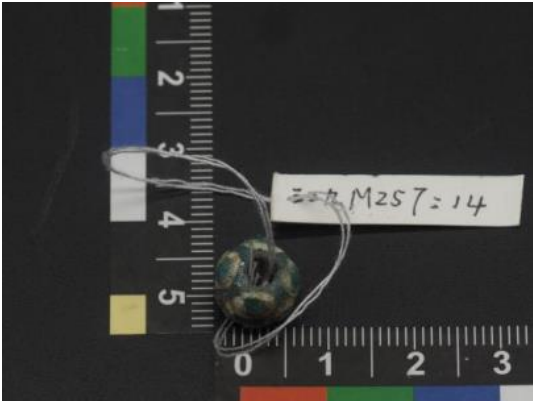
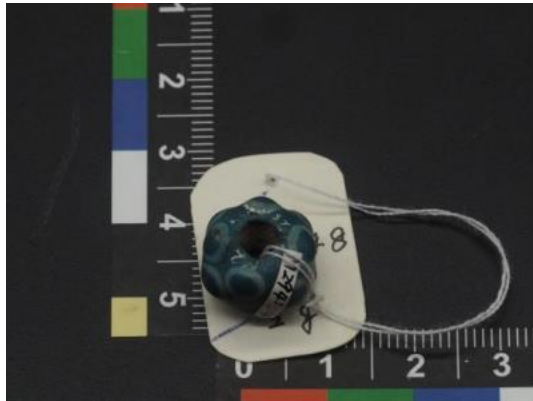
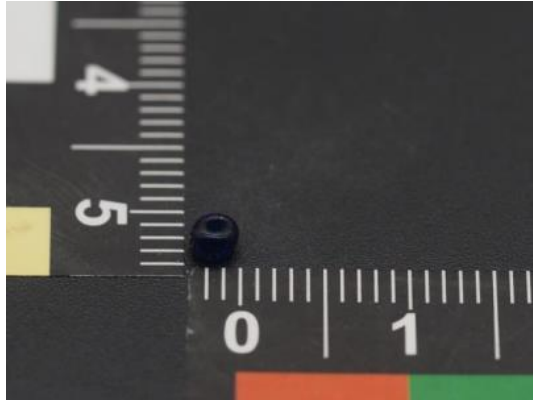
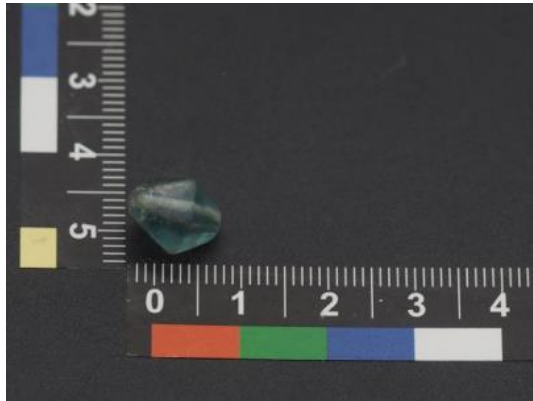


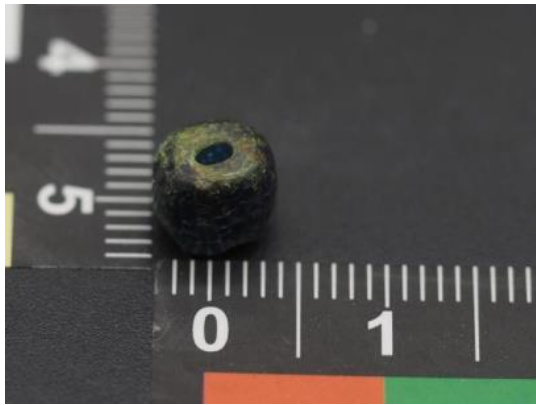
GMG-45



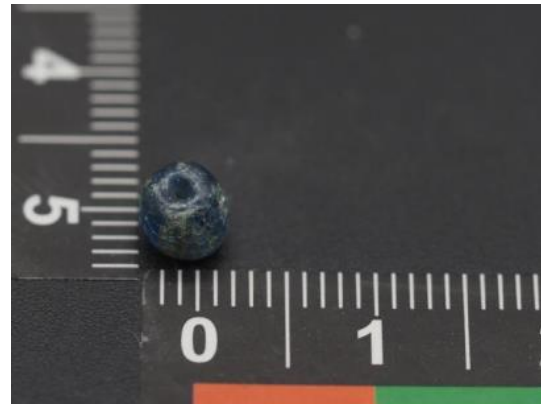
GMG-46



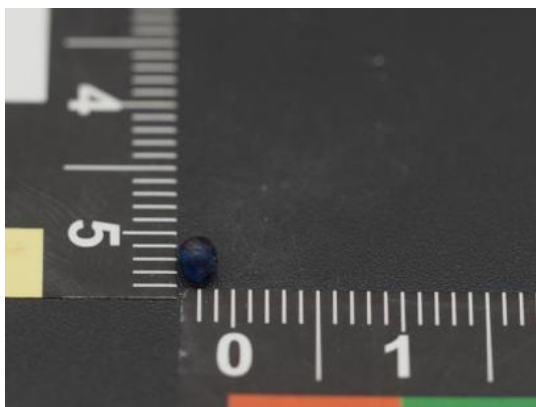
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|  <p>539316</p>  |  <p>M1ZC-1</p>     |
|  <p>M1ZC-2</p> |  <p>S13-370-2</p> |



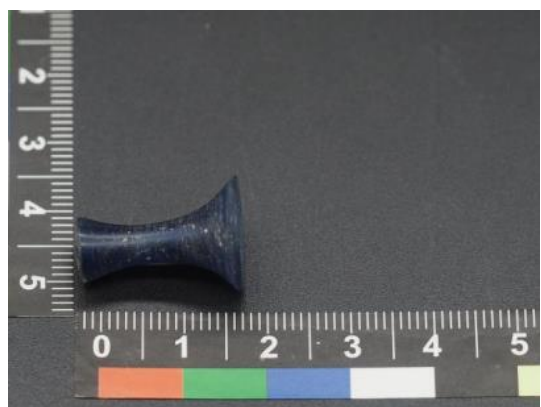
SJM1-S-3



SJM6-31-2



SM24-11-1



2005ZHM3-1



1318



**Table 6.4 Typical operation conditions for LA-ICP-MS analysis.**

|                         |                                               |
|-------------------------|-----------------------------------------------|
| ICP-MS conditions       |                                               |
| <b>RF power</b>         | 1350 W                                        |
| Plasma gas              | 15 L min <sup>-1</sup> Ar                     |
| Auxiliary gas           | 1 L min <sup>-1</sup> Ar                      |
| Make-up gas             | 1 L min <sup>-1</sup> Ar                      |
| Sampling depth          | 5.4 mm                                        |
| Detector                | Dual (pulse and analog counting)              |
| Dwell time/mass         | 6 ms                                          |
| <b>Laser parameters</b> |                                               |
| Wavelength              | 193 nm                                        |
| Energy density          | 14 J cm <sup>-2</sup>                         |
| Carrier gas             | He (optimized to get the highest sensitivity) |
| Ablation style          | Single spot                                   |
| Ablation spot size      | 32 µm                                         |
| Repetition rate         | 8 Hz                                          |
| Laser pulse             | 400                                           |

**Table 6.5 Accuracy and precision of the reference materials.**

| Analyte                        | Mean   | Relative error | S.D   | Consensus |
|--------------------------------|--------|----------------|-------|-----------|
| BCR-2G                         |        |                |       |           |
| Na <sub>2</sub> O              | 3.29   | 1.93%          | 0.10  | 3.23      |
| MgO                            | 3.54   | -0.62%         | 0.14  | 3.56      |
| Al <sub>2</sub> O <sub>3</sub> | 13.69  | 2.20%          | 0.36  | 13.40     |
| SiO <sub>2</sub>               | 54.27  | -0.26%         | 1.49  | 54.41     |
| K <sub>2</sub> O               | 1.85   | 3.19%          | 0.56  | 1.79      |
| CaO                            | 7.24   | 2.51%          | 0.31  | 7.06      |
| TiO <sub>2</sub>               | 2.41   | 2.26%          | 0.54  | 2.35      |
| Cr                             | 15.01  | -11.71%        | 2.98  | 17.00     |
| MnO                            | 0.21   | 2.77%          | 0.01  | 0.20      |
| FeO                            | 12.46  | 0.50%          | 1.51  | 12.40     |
| Co                             | 36.88  | -2.94%         | 1.42  | 38.00     |
| Ni                             | 12.02  | -7.57%         | 1.84  | 13.00     |
| Y                              | 36.00  | 2.87%          | 2.03  | 35.00     |
| Zr                             | 188.46 | 2.43%          | 7.95  | 184.00    |
| Ba                             | 689.44 | 0.94%          | 37.10 | 683.00    |
| La                             | 24.54  | -0.67%         | 4.23  | 24.70     |
| Pb                             | 11.27  | 2.43%          | 1.10  | 11.00     |
| BHVO-2G                        |        |                |       |           |
| Na <sub>2</sub> O              | 2.31   | -3.80%         | 0.05  | 2.40      |
| MgO                            | 7.15   | 0.30%          | 0.22  | 7.13      |
| Al <sub>2</sub> O <sub>3</sub> | 13.58  | -0.10%         | 0.30  | 13.60     |
| SiO <sub>2</sub>               | 49.90  | 1.21%          | 0.88  | 49.31     |
| K <sub>2</sub> O               | 0.58   | 12.73%         | 0.26  | 0.51      |
| CaO                            | 11.41  | 0.07%          | 0.33  | 11.40     |
| TiO <sub>2</sub>               | 2.74   | 0.90%          | 0.25  | 2.72      |
| Cr                             | 293.60 | 0.21%          | 19.60 | 293.00    |
| MnO                            | 0.18   | 3.53%          | 0.00  | 0.17      |
| FeO                            | 11.29  | -0.10%         | 1.16  | 11.30     |
| Co                             | 44.53  | 1.22%          | 1.46  | 44.00     |
| Ni                             | 119.36 | 2.89%          | 4.94  | 116.00    |
| Y                              | 24.86  | -4.39%         | 1.45  | 26.00     |
| Zr                             | 167.42 | -1.52%         | 5.69  | 170.00    |
| Ba                             | 127.67 | -2.54%         | 8.47  | 131.00    |
| La                             | 14.94  | -1.74%         | 0.57  | 15.20     |
| Pb                             | 1.69   | -0.47%         | 0.47  | 1.70      |
| BIR-1G                         |        |                |       |           |
| Na <sub>2</sub> O              | 1.89   | 2.20%          | 0.05  | 1.85      |
| MgO                            | 9.46   | 0.65%          | 0.29  | 9.40      |
| Al <sub>2</sub> O <sub>3</sub> | 15.33  | -1.12%         | 0.25  | 15.50     |
| SiO <sub>2</sub>               | 47.36  | -0.32%         | 0.58  | 47.51     |
| K <sub>2</sub> O               | 0.03   | 16.30%         | 0.01  | 0.02      |
| CaO                            | 13.21  | -0.70%         | 0.31  | 13.30     |
| TiO <sub>2</sub>               | 0.94   | 4.31%          | 0.06  | 0.90      |
| Cr                             | 397.91 | 1.51%          | 17.33 | 392.00    |
| MnO                            | 0.18   | -4.93%         | 0.00  | 0.19      |
| FeO                            | 10.77  | 3.53%          | 0.87  | 10.40     |
| Co                             | 52.83  | 1.60%          | 1.29  | 52.00     |
| Ni                             | 177.14 | -0.48%         | 5.56  | 178.00    |
| Y                              | 14.94  | 4.48%          | 1.00  | 14.30     |
| Zr                             | 13.64  | -2.54%         | 2.42  | 14.00     |
| Ba                             | 7.63   | 17.45%         | 8.77  | 6.50      |
| La                             | 0.61   | -0.46%         | 0.10  | 0.61      |
| Pb                             | 3.51   | -5.24%         | 0.42  | 3.70      |

**Table 6.6 Normalized rare elements by using Boynton (1984) standard for Guangxi and Henan glasses.**

| Location          | LaN  | CeN   | PrN   | NdN  | SmN   | EuN    | GdN   | TbN   | DyN   | HoN    | ErN  | TmN    | YbN   | LuN    | Eu/Eu* |
|-------------------|------|-------|-------|------|-------|--------|-------|-------|-------|--------|------|--------|-------|--------|--------|
| Boynton chondrite | 0.31 | 0.808 | 0.122 | 0.6  | 0.195 | 0.0735 | 0.259 | 0.474 | 0.322 | 0.0718 | 0.21 | 0.0324 | 0.209 | 0.0322 |        |
| Henan             | 2.12 | 1.91  | 1.85  | 1.77 | 1.48  | 1.33   | 1.33  | 1.19  | 1.14  | 1.05   | 1.1  | 1.13   | 1.03  | 1.05   | 1      |
| Henan             | 1.85 | 1.83  | 1.59  | 1.48 | 1.27  | 1.19   | 0.99  | 0.97  | 0.85  | 0.77   | 0.86 | 0.88   | 0.85  | 0.91   | 1.07   |
| Henan             | 1.84 | 1.78  | 1.57  | 1.49 | 1.22  | 1.16   | 1.01  | 0.87  | 0.75  | 0.69   | 0.81 | 0.87   | 0.84  | 0.82   | 1.13   |
| Henan             | 1.92 | 1.85  | 1.68  | 1.54 | 1.26  | 1.25   | 1.06  | 0.94  | 0.85  | 0.67   | 0.72 | 0.77   | 0.8   | 0.78   | 1.14   |
| Henan             | 1.84 | 1.78  | 1.56  | 1.48 | 1.14  | 1.16   | 0.96  | 0.85  | 0.77  | 0.77   | 0.74 | 0.68   | 0.74  | 0.87   | 1.17   |
| Henan             | 1.94 | 1.95  | 1.71  | 1.58 | 1.33  | 1.25   | 1.1   | 0.98  | 0.86  | 0.69   | 0.69 | 0.79   | 0.57  | 0.78   | 1.1    |
| Henan             | 1.74 | 1.82  | 1.49  | 1.4  | 1.17  | 1.11   | 1.02  | 0.94  | 0.9   | 0.82   | 0.91 | 0.93   | 0.9   | 0.97   | 1.06   |
| Henan             | 1.82 | 1.78  | 1.56  | 1.44 | 1.18  | 1.25   | 0.94  | 0.77  | 0.66  | 0.6    | 0.67 | 0.68   | 0.64  | 0.7    | 1.31   |
| Henan             | 1.83 | 1.75  | 1.5   | 1.43 | 1.04  | 1.22   | 0.87  | 0.67  | 0.63  | 0.56   | 0.52 | 0.59   | 0.65  | 0.65   | 1.46   |
| Henan             | 1.8  | 1.81  | 1.55  | 1.4  | 1.19  | 1.15   | 1     | 0.79  | 0.75  | 0.69   | 0.74 | 0.78   | 0.88  | 0.79   | 1.19   |
| Henan             | 1.8  | 1.81  | 1.55  | 1.48 | 1.09  | 1.16   | 1.02  | 0.82  | 0.79  | 0.76   | 0.76 | 0.69   | 0.77  | 0.87   | 1.23   |
| Henan             | 1.89 | 1.85  | 1.61  | 1.51 | 1.18  | 1.27   | 1.07  | 0.82  | 0.83  | 0.75   | 0.79 | 0.77   | 0.75  | 0.76   | 1.29   |
| Henan             | 1.75 | 1.77  | 1.52  | 1.4  | 1.16  | 1.1    | 0.93  | 0.83  | 0.79  | 0.71   | 0.72 | 0.74   | 0.89  | 0.81   | 1.12   |
| Henan             | 1.83 | 1.79  | 1.53  | 1.42 | 1.11  | 1.24   | 0.89  | 0.78  | 0.72  | 0.61   | 0.61 | 0.6    | 0.55  | 0.55   | 1.33   |
| Henan             | 1.93 | 1.84  | 1.68  | 1.54 | 1.34  | 1.15   | 1.07  | 0.91  | 0.85  | 0.81   | 0.71 | 0.67   | 0.78  | 0.9    | 1.04   |
| Henan             | 1.9  | 1.87  | 1.63  | 1.52 | 1.27  | 1.25   | 1.07  | 0.95  | 0.85  | 0.82   | 0.86 | 0.87   | 0.93  | 0.94   | 1.14   |
| Henan             | 1.9  | 1.85  | 1.65  | 1.51 | 1.28  | 1.3    | 1.13  | 0.92  | 0.9   | 0.76   | 0.75 | 0.79   | 0.86  | 0.82   | 1.19   |
| Henan             | 2.04 | 1.86  | 1.77  | 1.65 | 1.36  | 1.22   | 1.19  | 1.1   | 1.02  | 0.93   | 0.9  | 0.95   | 0.89  | 1      | 1      |
| Henan             | 1.75 | 1.72  | 1.45  | 1.38 | 1.2   | 1.18   | 0.89  | 0.83  | 0.77  | 0.65   | 0.76 | 0.69   | 0.74  | 0.83   | 1.18   |
| Guangxi           | 1.91 | 1.83  | 1.67  | 1.53 | 1.3   | 0.91   | 1.07  | 1     | 0.98  | 0.91   | 0.92 | 0.94   | 0.91  | 0.95   | 0.8    |
| Guangxi           | 1.93 | 1.85  | 1.68  | 1.55 | 1.31  | 0.89   | 1.14  | 1.02  | 0.98  | 0.9    | 0.93 | 0.92   | 0.97  | 0.96   | 0.77   |
| Guangxi           | 1.93 | 1.85  | 1.67  | 1.55 | 1.33  | 0.93   | 1.14  | 1.04  | 0.97  | 0.93   | 0.95 | 0.89   | 0.87  | 0.92   | 0.79   |
| Guangxi           | 1.91 | 1.84  | 1.67  | 1.57 | 1.32  | 0.91   | 1.12  | 0.98  | 0.95  | 0.93   | 0.9  | 0.95   | 0.9   | 0.91   | 0.81   |
| Guangxi           | 1.89 | 1.82  | 1.64  | 1.53 | 1.31  | 0.9    | 1.11  | 0.97  | 0.94  | 0.89   | 0.89 | 0.87   | 0.86  | 0.81   | 0.8    |
| Guangxi           | 1.93 | 1.85  | 1.68  | 1.58 | 1.34  | 0.93   | 1.14  | 1.02  | 0.98  | 0.91   | 0.93 | 0.93   | 0.93  | 0.92   | 0.8    |
| Guangxi           | 1.9  | 1.82  | 1.65  | 1.54 | 1.33  | 0.92   | 1.11  | 0.99  | 0.98  | 0.9    | 0.92 | 0.88   | 0.94  | 0.89   | 0.8    |
| Guangxi           | 1.94 | 1.87  | 1.68  | 1.58 | 1.36  | 0.91   | 1.15  | 1.05  | 1     | 0.94   | 0.95 | 0.93   | 0.92  | 0.89   | 0.76   |

## **Chapter 7 Discussion - chaîne opératoire of glasses unearthed in China from the 1<sup>st</sup> millennium BC**

This DPhil research focuses on the origin of various types of glasses unearthed in China. Through glass replication and compositional analysis, we argue that lead-barium glass was a secondary product made by mixing imported natron glass with domestic lead-barium minerals. The research on potash glass and mineral soda alumina glass has pointed out the potential connection between monochrome glass drawn beads and Buddhism. Not only the North Silk Road, but also the Southwest and Maritime Silk roads might have related to the spread of Buddhism. In this chapter, a comprehensive evaluation of the chaîne opératoire of glasses unearthed in China dating from the 1<sup>st</sup> millennium BC is made, starting with locating the raw materials and ending with the use of glass objects in various social, economic and ritual contexts (Figure 7.1).

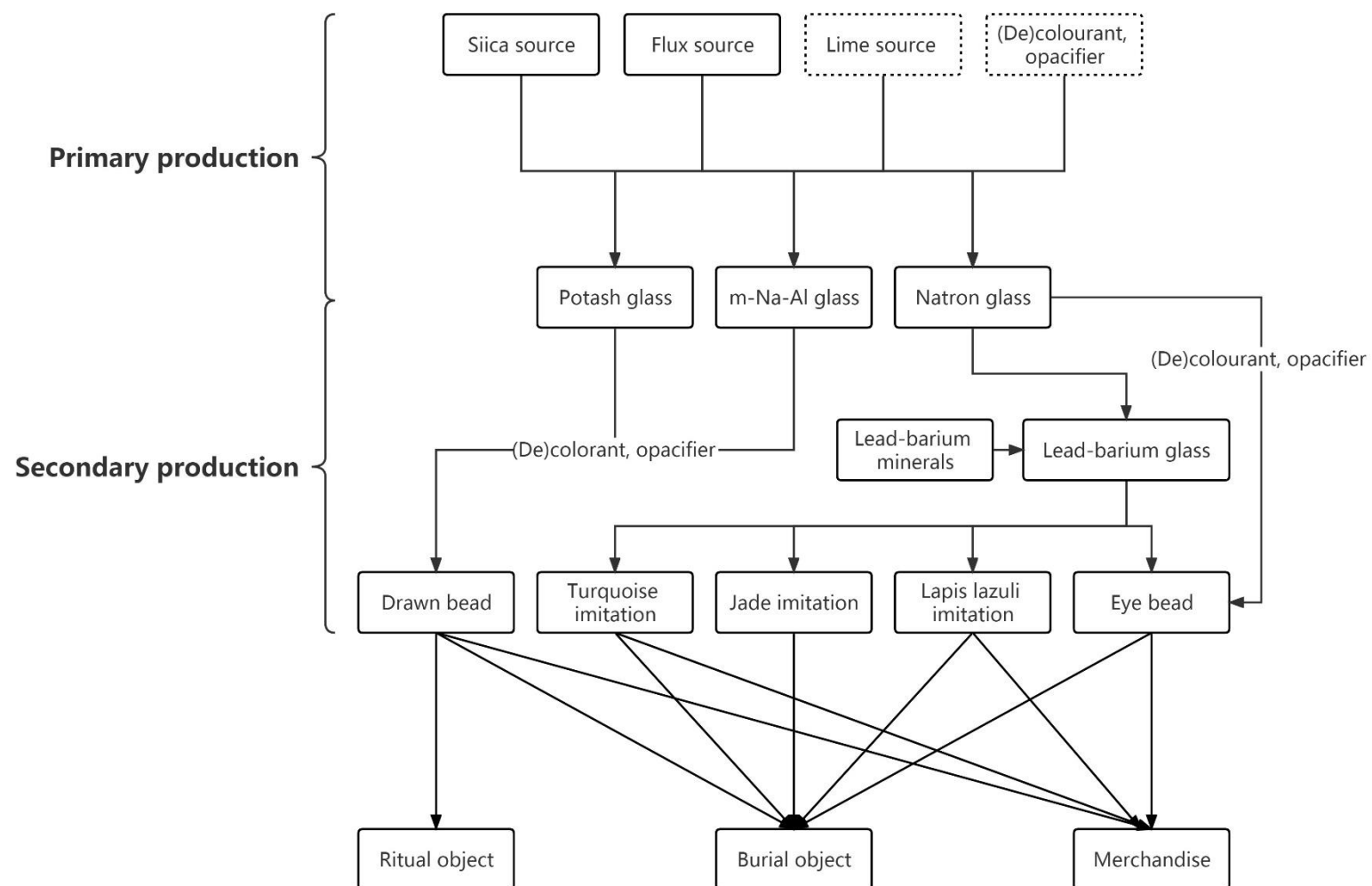


**Figure 7.1 Chaîne opératoire of glasses unearthed in China dating to the 1<sup>st</sup> millennium BC**

## 7.1 Selection of glass raw materials

Various types of glass appeared across Eurasia during the 1<sup>st</sup> millennium BC, and three types of raw glass were analysed in this thesis - natron glass, mineral soda alumina glass and potash glass. As introduced in the previous chapters, primary glass is a mixture of a silica source, stabilizer and flux with or without colourants and opacifiers. The definition of each type of glass is based on the source of the flux. The natron source ( $\text{Na}_2\text{CO}_3/\text{NaHCO}_3$ , evaporite mineral) identified as Wadi El-Natrun in Egypt shows low levels of  $\text{K}_2\text{O}$  and  $\text{MgO}$  (each  $<1.5\%$ ). The reh source (a salty surface crust found on the soil in parts of India) used in mineral soda alumina glass is a mixture of  $\text{Na}_2\text{CO}_3$ ,  $\text{Na}_2\text{SO}_4$  and  $\text{NaCl}$  with low proportions of  $\text{CaO}$  and  $\text{MgO}$ , and a high proportion of  $\text{Al}_2\text{O}_3$  varying from 5 to 15%. The potash glass used a mineral flux source - saltpetre ( $\text{KNO}_3$ ) with low concentrations of  $\text{Na}_2\text{O}$  and  $\text{MgO}$  (each  $<1.5\%$ ). The lime source in natron glass was either from broken shells associated with the beach sand source or intentionally added limestone (Freestone *et al.*, 2003). The  $\text{CaO}\%$  level in mineral soda alumina glass and potash glass also show large variations in their sub-types. Some of them with an extremely low level of  $\text{CaO}\%$  ( $<1\%$ ) indicate that the silica source might have not been the beach sand.

## 7.2 Primary glass production

**Natron glass mineral, soda alumina glass and potash glass.** The identification of the glass type is mainly achieved through major and minor element analysis, whereas locating the

primary glass production centre largely relies on trace element analysis and isotopic analysis. In general, the location of primary production is close to the silica source, as long-distance shipping certainly increases the cost. Due to the lack of archaeological and historical evidence of primary production in China during the Warring States and the Han periods, the question of whether the Chinese could produce primary glass during this period has not yet been resolved. In this study, trace element analysis is used to source the silica raw materials for glasses unearthed in China. Excavated beads made of natron glass, mineral soda alumina glass and potash glass were analysed by LA-ICP-MS. This technique provided us not only with relatively accurate concentrations of major and minor elements, but also concentrations of trace elements at ppm-level. Moreover, it is a virtually non-destructive analytical method (Norman *et al.*, 1998) that can be broadly accepted by the samples' curators. We performed 3D kernel density estimation on four variables (Zr-Ti-Cr-Y) in a tetrahedron plot, and we combined Maximum Mean Discrepancy with hypothesis testing to trace the potential silica sources. The result shows that the silica sources for producing the natron glass found in China during the 1<sup>st</sup> millennium BC matched with Type II natron glass from the Syro-Palestinian coast (Chapter 5.3: Figures 5.3 and 5.4). The trace element analysis also indicates that the m-Na-Al glass and most of the potash glass unearthed from Guangxi were presumably produced somewhere in Southeast Asia and exported through the Maritime Silk Road; the m-Na-Al glass in Henan and the rest of the potash glasses analysed in this case were probably produced in southern India or Sri Lanka (Chapter 6.3.2: Figure 6.9).

**Lead-barium glass.** Most scholars continue to believe that lead-barium glass was a Chinese invention due to the unique presence of barium in the glass, which was never used for western glasses, and the Chinese aesthetics of the glass when used as imitation of the burial jade (Brill *et al.*, 1991b; Yu, 2002b; Zhou, 2014). However, there is a logical fallacy in such a conclusion, since barium is only a component that functioned as an opacifier. For instance, antimony and tin are two commonly-used opacifiers for western glasses (Turner and Rooksby, 1959), but the source of the glass cannot be determined from the nature of the opacifier. Colourant agents and opacifiers could be added to glass during secondary glass production, so it does not provide any information to track the original source of the raw glass.

XRF as a non-destructive analytical method of chemical analysis is the most commonly used method to study various types of glasses. However, this non-destructive surface analysis cannot detect the light elements properly, and the result can also be easily distorted by glass surface corrosion and contamination. Sodium as a light element is used in various types of glasses, such as natron glass, plant ash glass, wood ash glass, mineral soda alumina glass and mixed alkali glass. A certain level of sodium in lead-barium glass was detected by using wet chemistry analysis (destructive), and Brill (2001) suggested that the high sodium in lead-barium glass might be a result of mixing  $\text{PbO}:\text{BaO}:\text{SiO}_2$  (low sodium) glasses with soda-lime glasses. In recent years, some new analytical methods such as LA-ICP-MS also show a certain amount of



sodium detected in lead-barium glass, which was previously unidentified by XRF analysis. This complicates the previous assumption that lead was the flux for lead-barium glass – if so, why is sodium present in lead-barium glass and was it contributed from a source of natron glass as Brill suggested?

To replicate lead-barium glass, different recipes with different combinations of the raw materials were tested (details in Chapter 4). According to the test results, it can be confirmed that sodium is essential to form lead-barium glass. There should be around 6 wt%  $\text{Na}_2\text{O}$  in the recipe to form lead-barium glass. However, sodium as the flux was not found in any other Chinese vitreous materials during the Warring States and the Han periods, where lead and wood ash were more commonly used to lower the melting temperature, such as in lead glaze and wood ash glaze during the Han Dynasty. Thus, we tested the hypothesis that lead-barium glass was a mixture of natron glass and lead-barium minerals by mixing replicated Roman natron glass with lead-barium minerals. The outcome supported this hypothesis, and also explains the high sodium concentration in lead-barium glass. We also noticed that  $\text{BaSO}_4$  is a better opacifier compared with  $\text{BaCO}_3$ . This explains why both opacified and translucent lead-barium glasses appeared during the Warring States and the Han periods (i.e., Chapter 5.4: Figure 5.5). The trace element analysis shows that the silica sources used for producing the natron glass and lead-barium glass found in China during the 1<sup>st</sup> millennium BC were identical, suggesting that the raw glass used for producing lead-barium glass was also Type II natron glass from the

Syro-Palestinian coast (Chapter 5.3: Figures 5.3 and 5.4). In contrast, lead-barium faience used a different silica source compared with lead-barium glass, as distinguished by higher levels of Cr and La observed in lead-barium faience (Chapter 5.3: Figure 5.3b). This result further confirms the hypothesis proposed in the glass replication experiment. As natron glass has been found in Italy, Bulgaria, Greece, Spain, Poland, Georgia, Kyrgyzstan, Russia, Northern China and Central China, we believe that both finished and semi-finished glasses (Chapter 5.4) were traded to China during the 1<sup>st</sup> millennium BC through the Eurasian Steppe.

The question that remains here is why the Chinese did not produce primary raw glass during the Iron Age? The following two points may help answer it.

1. The development of ceramic technology somehow restricted or constrained the development of glass technology in China. Lead-glazed and wood ash glazed ceramics were invented and developed from the Warring States period (Chen *et al.*, 1999). Glass and ceramic, as silicate materials, were both normally shaped in similar ways, such as bowls, bottles and plates. Civilians possessed the skill and were permitted to produce glass (primary and secondary) during the Song Dynasty (An, 2000a, p. 159), yet the ceramic industry is always much greater in scale than glass production. Five famous stoneware kilns emerged during the Song Dynasty, which were Ding, Ru, Guan, Ju Ge kilns (Yuan and Liu, 2021). In general, compared with stoneware manufacturing, the development of the glass industry was not very prominent.

2. Blockade on techniques. It is recognized that there were many more secondary glass workshops compared with primary glass workshops in the Mediterranean (Degryse, 2014). Archaeological evidence for primary production is limited, with only one late Hellenistic site in Beirut dating to the 1<sup>st</sup> century BC identified as a primary glass production centre (Henderson, 2013, p. 215). It is similar in the present day, in that quite a few enterprises are focused on high-tech end products (e.g., PC, phones), but there are only a few companies who can produce core chips for those products. It might be possible that the Chinese did not possess the skill of primary glass production during the Warring States and the Han periods, as there were sufficient finished and semi-finished glass products traded from the Mediterranean. There is an example that might support this hypothesis. European people valued the white body and transparent glaze of Chinese porcelain, and massive volumes of porcelain were traded to Europe by the Dutch East Indian Company since the 17<sup>th</sup> century AD. Delftware, as one of the best imitations, used tin oxide to produce an opaque white glaze to imitate the white porcelain body (Tomalino and Tulyaganov, 2021), since they did not know that the white porcelain body was simply contributed to by the crushed porcelain stone instead of any clay. Likewise, lead-barium faience in the form of eye bead from the Warring States period appears to be an imperfect imitation of the Mediterranean glass eye bead. This technique seemed to be kept as secret and the European craftsman could never imitate Chinese porcelain properly during that period (Pollard, 2015). It is also noticed that lead-barium glass disappeared after the Han period,

probably due to a shortage in the supply of raw glass from the Mediterranean. This shortage might have been caused by discord times during the late Eastern Han Dynasty and the early Three Kingdom period (AD 220 - 280).

### **7.3 Glass secondary production and use of glass objects in various social, economic and ritual contexts.**

In this research, we recognize that glass beads were traded into China through different Silk Roads, and they all served different purposes and functions. The glass working techniques involved, such as making eye beads and monochrome drawn beads, and how these techniques were adapted in China have been discussed in Chapter 2.1. The eye bead lost its symbol as an amulet to ward off the evil eye when it transferred to the Chu State during the 1<sup>st</sup> millennium BC, instead becoming a symbol of wealth and was primarily consumed by the nobility. As for monochrome drawn beads, their appearance seemed to coincide with the spread of Buddhism during the Han Dynasty. Glass is regarded as one of the Buddhist Seven Treasures, and it possesses a lofty status as documented in Buddhist sutras. Thus, the appearance of monochrome drawn beads could have been a by-product as Buddhism spread into China via the North, Southwest and Maritime Silk Roads (Chapter 6.4). These two types of glass beads served different functions as finished glass products when they were traded into China.

Although different types of secondary glass products have been discovered in China during the 1<sup>st</sup> millennium BC, archaeological and historical evidence for the primary or secondary glass production centres is absent. Nevertheless, typological study of the glass objects suggests that Chinese artisans may have mastered the skill of producing secondary glass. Some glass objects discovered in China clearly show uniqueness in terms of aesthetics and function, such as the lead-barium glass bi disk (Chapter 5: Sample 1301Bi) and ear pendant in potash glass (Chapter 6: Sample 2005ZHM3-1). These glass objects provide strong evidence that secondary glass production did exist in China. However, as we discussed in Chapter 5, the raw glass used for producing lead-barium glass was imported. We cannot deny the possibility that primary glass ingots were traded into China through different Silk Roads, even though there is a lack of archaeological evidence to support this point. Yet, lead-barium glass could also be produced by remelting/recycling natron glass beads. The ear pendant potash glass could be produced by remelting monochrome drawn beads; the lead-barium glass bi disk could be a result of mixing lead-barium minerals with natron glass beads (i.e., Chapter 5: Sample M1ZC-4 natron glass bead). This suggests that the original functions of the imported glass beads were altered, and they were simply used as 'raw materials' to produce glass objects more in line with Chinese aesthetics.

It is well known that both eye beads and jade glass disappeared after the Han Dynasty. China was divided into different kingdoms for the following 300 years, including the Three Kingdoms

periods (AD 220 – 280), Western and Eastern Jin period, and the Southern and Northern Dynasties (AD 420 – 589). The Chinese glass industry largely relied on the trans-regional primary glass supply chain, and the warfare after the Han Dynasty likely caused the broke down of Chinese market, resulting in reduced demand. Moreover, due to the invention of Roman blown vessels, Chinese glass after the Han Dynasty seems to undergo a functional transition from decorative glass to daily necessities, and an aesthetic transition from jade imitation to crystal imitation. The high lead content in the lead-barium glass leads to weathering and brittle properties, thus, lead-barium glass was rarely shaped into vessels for daily use. In contrast, the monochrome drawn bead still prevailed in China, South and Southeast Asia after the Han Dynasty due to its strong bond with Buddhism.

## Chapter 8 Conclusion

In summary, we notice that sodium is essential in lead-barium glass, yet sodium as a flux has not been identified in other contemporaneous Chinese vitreous materials. The glass replication experiment shows that lead-barium glass can be produced by mixing natron glass and lead-barium minerals. The Cr, La and Ti absolute concentrations in lead-barium glass did not match with any of the contemporaneous Chinese vitreous materials, including lead-barium faience, earthenwares and stonewares. Yet, the Cr-Y-Ti-Zr relative concentrations (in a tetrahedron plot) in lead-barium glass matched with natron glass in China and Type II natron glass from the Syro-Palestinian coast. This suggests that the trace element concentrations in lead-barium glass, such as Cr, Y, Ti, Zr and La, were diluted by lead-barium additions. This further supports our theory that lead-barium glass was made by mixing primary (imported) glass with Pb/Ba minerals. We here suggest that none of the raw glass used for producing alkaline glass and lead-barium glass originated in China during the Warring States and the Han periods. Specifically, there is no archaeological or literature evidence for primary glass production in China from the Warring States to the Han periods. However, we recognize that secondary glass production must have been practiced in China during this period, as lead-barium glass is believed to be a secondary product made by mixing imported natron glass and Chinese lead-barium minerals. Still, neither primary nor secondary glass workshops have been found during this period.

Further research should be conducted on the isotope analysis of lead-barium glass. Boron isotopes are used to trace the natron flux source as discussed in Chapter 2.4.2. The B isotopic analysis of lead-barium glass should differentiate between the use of imported natron glass or a domestic mineral sodium source in China as the sodium source. Nd isotopic study on lead-barium glass and a comparison of Nd isotopes for Hellenistic natron glass should be conducted to determine if they share a similar silica source. Furthermore, the Hf isotope analysis could identify the subtypes of the silica source in the Mediterranean (Barfod *et al.*, 2020). This will reveal if the silica source used for producing lead-barium glass was from a single natron glass source or multiple sources. Sr isotopic analysis is commonly combined with the Nd isotopic analysis to trace the lime source in the glass (Degryse *et al.*, 2009). If the lime source for natron glass is contributed by the shell fragments in beach sand, then the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios should be close to the modern marine level ( $0.709202 \pm 0.000003$ ). However, this cannot be applied to trace the lime source in lead-barium glass, as a higher level of Sr is detected in this study due to the addition of a barium source containing associated Sr. Thus, the Sr isotope analysis on lead-barium glass will act as an indicator of barium source. Combining the Pb and Sr isotopic analyses (if multiple sources of lead and barium sources are identified) will verify our assumption of several secondary glass workshops for producing lead-barium glass in China during the Warring States and the Han period (Chapter 2: Figure 2.17).



More trace element analysis on lead-barium glass samples from other regions in China should be carried out. In this study, we suggest that lead-barium glass is a secondary production in China made by mixing domestic lead and barium with imported natron glass. It is certainly worth trying to explore if other types of glasses were used to produce lead-barium glass, such as m-Na-Al glass, plant ash glass and potash glass. Further archaeological and archaeological science research on glasses from Central Asia is required to provide a strong link on how glasses were traded from the Mediterranean to China. This includes regions connected with the borderland of China, such as Kazakhstan, Afghanistan, and Tajikistan. The exploration of secondary glass furnaces for making lead barium glass might be difficult, since using lead can significantly lower the remelting temperature of the raw glass chunks, resulting in no need for proper furnaces to melt the glass. As for crucibles, it might be possible to determine if any crucibles were used both for glass and copper melting during the Warring States and the Han periods. Understanding crucible use through these methods will help refine our interpretation of how lead-barium glass was produced. For instance, if vitrified materials were observed in bronze crucibles, they should be collected and analysed to see if the chemical composition resembles that of lead-barium glass.

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# Data file S1

**Table 1 Published data of Pb-Ba glass wt%**

|                  | Inventory number | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | CaO  | BaO   | MgO | Na <sub>2</sub> O | K <sub>2</sub> O | PbO   | CuO  | TiO <sub>2</sub> | MnO  | P <sub>2</sub> O <sub>3</sub> | CoO  | Sb <sub>2</sub> O <sub>5</sub> | SnO <sub>2</sub> | SO <sub>3</sub> | Cl   | Cr <sub>2</sub> O <sub>3</sub> |
|------------------|------------------|------------------|--------------------------------|--------------------------------|------|-------|-----|-------------------|------------------|-------|------|------------------|------|-------------------------------|------|--------------------------------|------------------|-----------------|------|--------------------------------|
| Pb-Ba without Na | 24022011         | 64.06            | 5.70                           | 1.34                           | 1.64 | 16.57 |     |                   | 1.92             | 3.61  | 0.40 | 0.04             |      | 0.68                          |      |                                |                  | 2.87            | 1.19 | 0.00                           |
| Pb-Ba without Na | 24022012         | 67.82            | 2.70                           | 0.40                           | 0.59 | 20.17 |     |                   | 0.87             | 4.68  | 0.06 |                  |      | 3.91                          | 0.01 |                                |                  | 0.61            | 0.71 | 0.00                           |
| Pb-Ba without Na | 24022002         | 47.76            | 9.53                           | 1.72                           | 2.32 | 18.95 |     |                   | 4.45             | 6.44  | 0.10 | 0.21             |      | 0.00                          | 0.00 |                                |                  | 7.25            | 1.27 | 0.00                           |
| Pb-Ba without Na | 24022014         | 58.71            | 3.46                           | 0.22                           | 0.96 | 26.95 |     |                   | 0.34             | 6.49  | 0.42 |                  |      | 0.88                          |      |                                |                  |                 | 1.53 | 0.05                           |
| Pb-Ba without Na | 24022010         | 47.64            | 6.71                           | 4.00                           | 3.80 | 25.13 |     |                   | 2.92             | 6.76  | 0.30 | 0.05             |      | 0.94                          | 0.18 |                                |                  | 0.86            | 1.59 | 0.14                           |
| Pb-Ba without Na | 24022015         | 58.01            | 2.63                           | 0.27                           | 0.56 | 28.53 |     |                   | 0.51             | 6.91  | 0.63 |                  |      | 1.06                          |      |                                |                  |                 | 0.89 | 0.00                           |
| Pb-Ba without Na | 24022013         | 58.04            | 2.96                           | 0.30                           | 0.62 | 27.56 |     |                   | 0.35             | 7.40  | 1.00 |                  |      | 0.90                          | 0.01 |                                |                  |                 | 0.82 | 0.05                           |
| Pb-Ba without Na | 24022042         | 73.23            | 7.81                           | 1.57                           | 3.97 | 4.74  |     |                   | 0.20             | 8.21  | 0.05 |                  | 0.02 | 0.04                          | 0.02 |                                |                  |                 | 0.14 | 0.00                           |
| Pb-Ba without Na |                  | 33.75            | 7.83                           | 2.26                           | 1.65 | 11.36 |     |                   | 1.35             | 8.69  | 1.48 |                  |      | 28.92                         |      |                                |                  | 1.76            | 0.94 | 0.00                           |
| Pb-Ba without Na | /                | 34.06            | 7.90                           | 2.29                           | 1.67 | 8.77  |     |                   | 1.37             | 11.47 | 1.49 |                  |      | 29.20                         |      |                                |                  |                 |      |                                |
| Pb-Ba without Na | CQ-19            | 34.07            | 7.91                           | 2.29                           | 1.67 | 8.78  |     |                   | 1.37             | 11.47 | 1.49 |                  |      | 29.20                         |      |                                |                  | 1.78            |      |                                |
| Pb-Ba without Na | /                | 56.10            | 7.90                           | 2.30                           | 1.70 | 8.80  |     |                   | 1.40             | 11.50 | 1.50 |                  |      | 7.20                          |      |                                |                  | 1.80            |      | 0.00                           |
| Pb-Ba without Na | /                | 56.70            | 4.20                           | 1.00                           | 0.90 | 11.60 |     |                   | 0.50             | 15.80 | 1.50 |                  |      | 7.70                          |      |                                |                  |                 |      | 0.10                           |
| Pb-Ba without Na | /                | 64.82            | 5.77                           | 1.35                           | 1.65 | 3.65  |     |                   | 1.94             | 16.77 | 0.40 |                  |      |                               |      |                                |                  | 2.90            |      |                                |
| Pb-Ba without Na | CQ-10            | 64.83            | 5.77                           | 1.35                           | 1.66 | 3.65  |     |                   | 1.94             | 16.77 | 0.40 | 0.04             |      | 0.69                          |      |                                |                  | 2.90            |      |                                |
| Pb-Ba without Na | /                | 64.80            | 5.80                           | 1.40                           | 1.70 | 3.70  |     |                   | 1.90             | 16.80 | 0.40 |                  |      | 0.70                          |      |                                |                  | 2.90            |      | 0.00                           |
| Pb-Ba without Na | 24022037         | 58.72            | 3.65                           | 0.49                           | 1.31 | 14.65 |     |                   | 0.47             | 17.77 | 0.03 |                  | 0.05 | 1.07                          | 0.02 |                                |                  |                 | 1.37 | 0.06                           |
| Pb-Ba without Na | 24022038         | 59.74            | 3.71                           | 0.50                           | 1.33 | 14.90 |     |                   | 0.47             | 18.08 | 0.04 |                  | 0.05 | 1.09                          | 0.02 |                                |                  |                 |      | 0.06                           |
| Pb-Ba without Na | CQ-01            | 48.37            | 9.65                           | 1.74                           | 2.35 | 6.52  |     |                   | 4.51             | 19.20 | 0.11 | 0.21             |      |                               |      |                                |                  | 7.35            |      |                                |
| Pb-Ba without Na | /                | 68.30            | 3.70                           | 0.40                           | 0.60 | 4.70  |     |                   | 0.90             | 20.30 | 0.10 |                  |      | 0.40                          |      |                                |                  | 0.60            |      | 0.00                           |
| Pb-Ba without Na | /                | 68.30            | 3.73                           | 0.40                           | 0.60 | 4.72  |     |                   | 0.87             | 20.31 | 0.06 |                  |      | 0.39                          |      |                                |                  |                 |      |                                |
| Pb-Ba without Na | CQ-11            | 68.31            | 3.73                           | 0.40                           | 0.60 | 4.72  |     |                   | 0.87             | 20.32 | 0.06 |                  |      | 0.39                          |      |                                |                  | 0.61            |      |                                |
| Pb-Ba without Na | 24022036         | 57.34            | 3.05                           | 0.31                           | 0.85 | 12.07 |     |                   | 0.20             | 22.34 | 0.00 |                  |      | 1.58                          |      |                                |                  |                 | 1.31 | 0.00                           |
| Pb-Ba without Na | 24022029         | 54.36            | 4.47                           | 0.34                           | 0.70 | 12.32 |     |                   | 0.60             | 23.97 | 0.46 |                  |      | 1.58                          |      |                                |                  |                 | 2.17 | 0.04                           |
| Pb-Ba without Na | /                | 48.40            | 6.80                           | 4.10                           | 3.90 | 6.90  |     |                   | 2.10             | 25.50 | 0.30 | 0.10             |      | 1.00                          |      |                                |                  | 0.90            |      | 0.00                           |
| Pb-Ba without Na | CQ-09            | 48.41            | 6.82                           | 4.06                           | 3.86 | 6.87  |     |                   | 2.05             | 25.53 | 0.30 | 0.05             | 0.03 | 0.96                          |      |                                |                  | 0.87            |      |                                |

|                  |                          |       |       |      |      |       |      |      |      |       |      |      |      |       |  |      |      |  |
|------------------|--------------------------|-------|-------|------|------|-------|------|------|------|-------|------|------|------|-------|--|------|------|--|
| Pb-Ba without Na | /                        | 59.62 | 3.05  | 0.22 | 0.57 | 6.58  |      |      | 0.51 | 27.36 | 0.43 |      |      |       |  |      |      |  |
| Pb-Ba without Na | /                        | 59.61 | 3.51  | 0.22 | 0.98 | 6.58  |      |      | 0.35 | 27.36 | 0.43 |      | 0.89 |       |  |      |      |  |
| Pb-Ba without Na | SX-13                    | 59.62 | 3.51  | 0.22 | 0.98 | 6.59  |      |      | 0.35 | 27.37 | 0.43 |      | 0.89 |       |  |      |      |  |
| Pb-Ba without Na | /                        | 59.60 | 3.50  | 0.20 | 1.00 | 6.60  |      |      | 0.40 | 27.40 | 0.40 |      | 0.90 |       |  |      | 0.10 |  |
| Pb-Ba without Na | /                        | 58.51 | 2.98  | 0.30 | 0.63 | 7.47  |      |      | 0.35 | 27.79 | 1.00 |      | 0.91 |       |  |      |      |  |
| Pb-Ba without Na | SX-12                    | 58.52 | 2.98  | 0.30 | 0.63 | 7.47  |      |      | 0.35 | 27.79 | 1.00 |      | 0.91 |       |  |      |      |  |
| Pb-Ba without Na | /                        | 58.50 | 3.00  | 0.30 | 0.60 | 7.50  |      |      | 0.40 | 27.80 | 1.00 |      | 0.90 |       |  |      | 0.10 |  |
| Pb-Ba without Na | /                        | 59.50 | 2.20  | 0.30 | 0.60 | 6.70  |      |      | 0.50 | 28.50 | 0.80 |      | 0.80 |       |  |      | 0.00 |  |
| Pb-Ba without Na | /                        | 59.52 | 2.23  | 0.26 | 0.58 | 6.73  |      |      | 0.51 | 28.50 | 0.75 |      | 0.84 |       |  |      |      |  |
| Pb-Ba without Na | SX-15                    | 59.53 | 2.23  | 0.26 | 0.58 | 6.73  |      |      | 0.51 | 28.50 | 0.75 |      | 0.84 |       |  |      |      |  |
| Pb-Ba without Na | /                        | 58.52 | 2.65  | 0.27 | 0.57 | 6.97  |      |      | 0.51 | 28.78 | 0.64 |      | 1.07 |       |  |      |      |  |
| Pb-Ba without Na | SX-14                    | 58.53 | 2.65  | 0.27 | 0.57 | 6.97  |      |      | 0.51 | 28.78 | 0.64 |      | 1.07 |       |  |      |      |  |
| Pb-Ba without Na | /                        | 58.50 | 2.70  | 0.30 | 0.60 | 7.00  |      |      | 0.50 | 28.80 | 0.60 |      | 1.10 |       |  |      | 0.00 |  |
| Pb-Ba with Na    | MJY-M4-6-1               | 59.75 | 2.47  | 1.42 | 3.75 | 14.81 | 2.34 | 2.48 | 0.89 | 1.65  | 6.98 | 1.05 | 2.34 | 0.07  |  |      |      |  |
| Pb-Ba with Na    | MJY-M4-23-1              | 46.26 | 8.49  | 1.20 | 5.43 | 14.63 | 0.53 | 0.89 | 0.44 | 20.28 | 0.08 | 0.66 | 0.76 | 0..37 |  |      |      |  |
| Pb-Ba with Na    | /                        | 49.33 | 1.42  | 0.48 | 3.16 | 10.50 | 1.40 | 9.30 | 0.51 | 21.62 | 0.09 |      |      |       |  |      |      |  |
| Pb-Ba with Na    | MJY-M4-23                | 44.81 | 5.63  | 0.33 | 3.50 | 18.24 | 0.46 | 1.07 | 0.38 | 23.29 | 0.05 | 1.43 | 0.24 | 0.58  |  |      |      |  |
| Pb-Ba with Na    | MJY-M4-23-2              | 44.51 | 8.16  | 2.10 | 5.37 | 11.83 | 0.64 | 0.81 | 0.25 | 24.46 | 0.11 | 0.30 | 1.27 | 0.19  |  |      |      |  |
| Pb-Ba with Na    | /                        | 45.85 | 1.66  | 0.14 | 0.77 | 12.93 | 2.16 | 9.31 | 0.34 | 27.25 |      |      |      |       |  | 1.28 |      |  |
| Pb-Ba with Na    | MJY-M4-6-2               | 41.21 | 2.95  | 0.96 | 4.11 | 8.26  | 1.09 | 2.60 | 0.87 | 27.86 | 5.47 | 0.99 | 3.56 | 0.07  |  |      |      |  |
| Pb-Ba without Na | /                        | 51.84 | 3.27  | 0.68 | 1.30 | 8.46  |      |      |      | 28.89 | 2.81 |      |      |       |  |      | 0.02 |  |
| Pb-Ba without Na | GD01( <i>white eye</i> ) | 54.41 | 13.47 | 2.72 | 2.03 | 9.87  |      |      | 2.98 | 11.82 | 0.13 | 0.07 | 0.01 | 0.53  |  |      |      |  |
| Pb-Ba without Na | GD01                     | 49.95 | 9.01  | 1.43 | 2.87 | 15.82 |      |      | 1.81 | 18.58 | 0.06 | 0.00 |      | 0.45  |  |      | 0.03 |  |
| Pb-Ba without Na | /                        | 58.10 | 6.10  | 1.88 | 1.14 | 9.14  |      |      | 0.60 | 19.71 | 0.58 |      | 0.05 | 1.22  |  |      |      |  |
| Pb-Ba without Na | GD01( <i>blue eye</i> )  | 49.39 | 8.70  | 1.84 | 4.34 | 13.47 |      |      | 1.34 | 19.95 | 0.09 |      | 0.03 | 0.82  |  |      |      |  |
| Pb-Ba with Na    | /                        | 40.49 | 0.95  |      | 5.41 | 11.93 | 0.89 | 6.03 | 0.34 | 33.35 |      |      | 0.02 |       |  |      |      |  |
| Pb-Ba with Na    | /                        | 42.64 | 0.18  |      | 3.99 | 12.83 | 0.43 | 5.01 | 0.05 | 33.73 | 0.34 |      | 0.06 |       |  |      |      |  |
| Pb-Ba with Na    | /                        | 42.03 | 1.56  | 0.03 | 1.24 | 10.85 | 0.67 | 4.40 | 0.77 | 38.73 |      |      |      |       |  |      |      |  |
| Pb-Ba without Na | /                        | 72.10 | 3.90  | 0.70 | 0.70 | 8.30  |      |      | 0.40 | 11.70 | 0.30 |      |      | 0.90  |  | 1.30 | 0.00 |  |
| Pb-Ba without Na | GZH-5                    | 72.05 | 3.89  | 0.51 | 0.73 | 8.27  |      |      | 0.38 | 11.71 | 0.30 |      | 0.02 | 0.89  |  |      |      |  |
| Pb-Ba without Na | /                        | 38.80 | 11.70 | 3.90 | 2.00 | 12.40 |      |      | 6.40 | 12.70 | 4.10 |      |      | 2.30  |  | 5.60 | 0.00 |  |
| Pb-Ba without Na | GZH-9                    | 52.73 | 9.47  | 1.40 | 3.45 | 14.98 |      |      | 0.87 | 16.39 | 0.10 |      | 0.12 | 0.46  |  |      |      |  |
| Pb-Ba without Na | /                        | 52.70 | 9.50  | 1.40 | 3.50 | 15.00 |      |      | 0.90 | 16.40 | 0.10 | 0.00 | 0.10 | 0.50  |  |      | 0.10 |  |
| Pb-Ba without Na | GZH-4B                   | 55.13 | 6.42  | 1.07 | 2.31 | 16.04 |      |      | 0.72 | 17.70 | 0.02 |      | 0.17 | 0.39  |  |      |      |  |

|                  |              |       |       |      |       |       |      |      |      |       |      |      |      |                         |      |           |
|------------------|--------------|-------|-------|------|-------|-------|------|------|------|-------|------|------|------|-------------------------|------|-----------|
| Pb-Ba without Na | /            | 55.10 | 6.40  | 2.30 | 2.30  | 16.00 |      |      | 0.70 | 17.70 | 0.00 |      | 0.20 | 0.40                    |      | 0.00      |
| Pb-Ba without Na | /            | 58.70 | 2.20  | 0.90 | 0.90  | 16.80 |      |      | 0.20 | 20.20 | 0.00 |      | 0.00 | 0.50                    |      | 0.00      |
| Pb-Ba without Na | GZH-4A       | 58.73 | 2.16  | 0.46 | 0.91  | 16.84 |      |      | 0.16 | 20.23 | 0.03 |      | 0.00 | 0.49                    |      |           |
| Pb-Ba without Na | /            | 52.60 | 3.90  | 0.60 | 1.00  | 17.60 |      |      | 0.40 | 22.90 | 0.20 | 0.00 | 0.10 | 0.90                    |      | 0.10      |
| Pb-Ba without Na | GZH-11       | 52.56 | 3.89  | 0.62 | 0.99  | 17.63 |      |      | 0.36 | 22.91 | 0.04 |      | 0.09 | <sup>p2o3</sup><br>0.86 |      |           |
| Pb-Ba without Na | GZH-16       | 54.15 | 2.56  | 0.66 | 2.04  | 15.09 |      |      | 0.23 | 24.48 | 0.06 |      | 0.16 | 0.59                    |      |           |
| Pb-Ba without Na | /            | 54.20 | 2.60  | 2.00 | 2.00  | 15.10 |      |      | 0.20 | 24.50 | 0.10 |      |      | 0.60                    |      | 0.00      |
| Pb-Ba without Na | GZH-4C       | 54.59 | 2.42  | 0.56 | 1.03  | 14.28 |      |      | 0.34 | 25.55 | 0.35 |      | 0.03 | 0.85                    |      |           |
| Pb-Ba without Na | /            | 54.60 | 2.40  | 1.00 | 1.00  | 14.30 |      |      | 0.30 | 25.60 | 0.40 |      |      | 0.90                    |      | 0.00      |
| Pb-Ba without Na | GZH-14       | 53.10 | 1.68  | 0.41 | 1.64  | 16.43 |      |      | 0.09 | 25.95 | 0.01 |      | 0.04 | 0.57                    |      |           |
| Pb-Ba without Na | /            | 51.40 | 5.10  | 1.00 | 0.60  | 12.80 |      |      | 0.70 | 27.10 | 0.50 |      |      | 0.50                    | 0.20 | 0.00      |
| Pb-Ba without Na | GZH-6B       | 51.44 | 5.13  | 0.99 | 0.57  | 12.75 |      |      | 0.72 | 27.11 | 0.51 |      | 0.03 | 0.49                    |      |           |
| Pb-Ba without Na | /            | 51.40 | 1.30  | 0.40 | 0.40  | 14.30 |      |      | 0.10 | 30.80 | 0.50 | 0.00 | 0.00 | 0.80                    |      | 0.00      |
| Pb-Ba without Na | GZH-12       | 51.35 | 1.33  | 0.42 | 0.36  | 14.25 |      |      | 0.14 | 30.84 | 0.47 |      | 0.00 | 0.84                    |      |           |
| Pb-Ba with Na    | IINWK-V-63   | 56.08 | 2.64  | 0.43 | 0.64  | 29.22 | 0.27 | 2.63 | 1.01 | 1.03  | 5.97 |      |      | 0.07                    |      |           |
| Pb-Ba with Na    | IINWK-V-69   | 51.93 | 4.99  | 0.17 | 1.84  | 29.75 | 0.47 | 3.75 | 1.51 | 5.02  | 0.56 |      |      |                         |      |           |
| Pb-Ba with Na    | IINWK-V-69   | 50.11 | 6.72  | 1.86 | 3.25  | 24.29 | 0.92 | 1.32 | 1.79 | 7.74  | 2.00 |      |      |                         |      |           |
| Pb-Ba with Na    | HNLY-17c     | 54.50 | 12.60 | 1.39 | 3.41  | 4.29  | 1.85 | 1.63 | 1.39 | 9.46  | 0.12 |      | 0.05 | 7.01                    | 0.02 | 2.05 0.27 |
| Pb-Ba with Na    | IINWK-V-66   | 64.95 | 2.98  | 1.24 | 2.43  | 4.04  | 0.73 | 3.33 | N.D. | 13.28 | 4.61 |      |      | 2.42                    |      |           |
| Pb-Ba with Na    | IINWK-V-83   | 59.60 | 1.28  | 0.36 | 0.12  | 16.46 | 0.15 | 1.99 |      | 14.67 | 5.37 |      |      |                         |      |           |
| Pb-Ba with Na    | IINWK-V-84   | 60.67 | 1.16  | 0.35 | 0.01  | 13.26 | 0.24 | 2.35 |      | 17.11 | 4.85 |      |      |                         |      |           |
| Pb-Ba with Na    | NYWKL-5-1a   | 57.05 | 5.38  | 0.38 | 1.07  | 7.08  | 1.34 | 4.87 | 0.42 | 17.73 | 1.49 |      |      | 1.27                    |      |           |
| Pb-Ba with Na    | IINWK-V-82   | 61.56 | 1.71  | 0.35 | 0.22  | 11.00 | 0.26 | 2.10 |      | 17.81 | 4.99 |      |      |                         |      |           |
| Pb-Ba with Na    | NYWKL-5-2a   | 57.99 | 5.91  | 0.46 | 1.17  | 6.93  | 1.00 | 2.46 | 0.33 | 19.36 | 1.51 |      | 0.01 | 1.41                    |      | 0.03      |
| Pb-Ba with Na    | HNLY-03b     | 54.00 | 3.30  | 0.30 | 2.93  | 3.55  | 0.76 | 1.08 | 0.97 | 19.70 | 0.13 |      | 0.05 | 12.60                   |      | 0.59      |
| Pb-Ba with Na    | IINWK-V-68   | 59.63 | 2.22  | 2.96 | 1.87  | 7.07  | 0.41 | 2.20 | 0.11 | 19.91 | 3.61 |      |      |                         |      |           |
| Pb-Ba without Na | HNLY-20      | 51.50 | 2.93  | 0.16 | 1.31  | 6.19  | 0.75 |      | 0.11 | 24.60 | 0.86 |      | 0.10 | 11.20                   |      | 0.22      |
| Pb-Ba with Na    | HNWKII-88    | 51.80 | 4.43  | 0.47 | 3.21  | 7.69  | 1.43 | 2.11 | 0.09 | 24.90 | 0.35 |      |      | 1.44                    |      | 0.07      |
| Pb-Ba with Na    | /            | 44.46 | 1.33  | 1.33 | 4.94  | 13.29 |      | 8.38 |      | 26.51 |      |      |      |                         |      |           |
| Pb-Ba with Na    | /            | 44.46 | 1.33  | 1.33 | 4.94  | 13.29 |      | 8.38 |      | 26.51 |      |      |      |                         |      |           |
| Pb-Ba with Na    | /            | 43.41 | 4.80  | 0.14 | 0.69  | 14.37 |      | 7.28 | 0.27 | 26.88 |      |      |      |                         |      |           |
| Pb-Ba with Na    | HNWKII-84d*a | 30.08 | 1.34  | 0.17 | 14.44 | 6.82  | 0.40 | 0.23 | 0.44 | 27.75 |      |      |      | 15.58                   |      |           |
| Pb-Ba with Na    | NYWKL-5-2b   | 53.48 | 7.02  | 1.22 | 1.57  | 2.57  | 1.38 | 0.03 | 0.26 | 28.74 | 0.61 | 0.03 |      | 0.98                    | 0.04 | 0.06      |

|                  |              |       |      |       |       |       |      |      |      |       |               |      |       |      |      |      |      |      |
|------------------|--------------|-------|------|-------|-------|-------|------|------|------|-------|---------------|------|-------|------|------|------|------|------|
| Pb-Ba with Na    | IINWK-V-71   | 50.76 | 6.46 | 0.23  | 1.68  | 10.27 | 0.38 | 0.86 |      | 29.26 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-74   | 55.40 | 2.44 | 0.30  | 2.03  | 4.83  | 0.45 | 4.63 |      | 29.77 |               | 0.14 |       |      |      |      |      |      |
| Pb-Ba with Na    | /            | 36.53 | 7.36 | 0.25  | 1.69  | 15.49 | 0.39 | 4.72 |      | 31.83 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | NYWKI-5-1c   | 51.56 | 2.49 | 4.66  | 0.31  | 2.75  | 1.23 | 1.00 | 0.08 | 32.19 | 0.21          | 0.00 | 2.75  |      |      | 0.02 | 0.08 |      |
| Pb-Ba with Na    | IINWK-V-63   | 39.99 | 7.62 | 0.17  | 0.59  | 15.76 | 0.34 | 2.43 | 0.54 | 32.27 | 0.23          |      |       |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-87c   | 13.84 | 1.62 | 0.27  | 16.21 | 14.71 | 0.00 |      | 0.19 | 32.42 |               |      | 15.08 |      |      | 3.18 | 0.19 |      |
| Pb-Ba with Na    | IINWK-V-65   | 50.96 | 6.22 | 0.70  | 1.37  | 1.08  | 0.38 | 2.61 | 0.47 | 32.70 | 1.99          |      | 1.55  |      |      |      |      |      |
| Pb-Ba without Na | HNLY-17b     | 23.80 | 5.17 | 2.25  | 6.82  | 3.72  | 0.58 |      | 0.68 | 33.30 | 0.24          | 0.23 | 18.00 |      |      | 2.45 | 0.77 |      |
| Pb-Ba with Na    | IINWK-V-72   | 44.65 | 0.79 | 0.30  | 1.75  | 14.92 | 0.27 | 2.58 |      | 34.61 |               |      | 0.13  |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-77   | 60.15 | 1.19 | 0.28  | 0.19  | 1.08  | 0.08 | 0.85 |      | 35.30 | 0.87          |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-71   | 43.63 | 4.12 | 0.30  | 0.65  | 13.50 | 0.28 | 1.82 |      | 35.69 |               |      |       |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-87a   | 38.52 | 3.05 | 0.62  | 2.44  | 14.24 | 0.62 |      | 0.30 | 36.24 |               |      | 1.00  |      |      |      | 0.09 |      |
| Pb-Ba with Na    | NYWKI-5-1b   | 26.73 | 2.25 | 15.31 | 0.27  | 6.66  | 0.68 | 1.78 | 0.36 | 36.36 | 0.15          | 0.13 | 7.05  |      |      | 0.01 | 0.02 |      |
| Pb-Ba with Na    | IINWK-V-71   | 41.91 | 2.36 | 0.72  | 0.97  | 13.77 | 0.45 | 2.28 |      | 37.55 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-72   | 43.98 | 3.26 | 0.20  | 2.05  | 9.41  | 0.56 | 1.92 |      | 38.32 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | HNWKII-84d*c | 39.75 | 0.88 | 0.05  | 0.18  | 17.46 | 0.06 | 1.52 | 0.07 | 38.64 |               |      | 1.23  |      |      |      | 0.08 |      |
| Pb-Ba with Na    | IINWK-V-80   | 50.71 | 5.16 | 0.21  | 1.24  | 1.00  | 0.21 | 1.10 |      | 40.21 | 0.16          |      |       |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-85a   | 42.11 | 1.01 | 0.06  | 3.50  | 3.54  | 0.37 |      | 0.20 | 40.60 | 0.06          |      | 6.24  |      |      |      | 0.07 |      |
| Pb-Ba with Na    | HNWKII-84d*d | 37.15 | 0.78 | 0.04  | 3.27  | 12.04 | 0.20 | 0.56 | 0.14 | 40.73 |               |      | 4.13  |      |      |      | 0.04 |      |
| Pb-Ba with Na    | IINWK-V-79   | 46.06 | 1.32 | 2.26  | 1.46  | 3.45  | 0.42 | 2.28 |      | 42.57 | 0.18          |      |       |      |      |      |      |      |
| Pb-Ba with Na    | /            | 34.42 | 0.02 | 0.92  | 0.12  | 12.58 | 0.34 | 4.32 | 1.02 | 43.20 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-77   | 44.38 | 1.90 | 2.54  | 1.51  | 1.90  | 0.65 | 3.12 | 0.70 | 43.21 | 0.64          |      | 0.08  |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-84d*b | 12.10 | 1.70 | 0.22  | 15.32 | 6.86  | 1.05 |      | 0.14 | 44.08 | 0.05          | 0.13 | 15.45 |      |      | 1.27 | 0.23 |      |
| Pb-Ba with Na    | IINWK-V-78   | 44.42 | 1.89 | 2.02  | 1.15  | 2.71  | 0.37 | 2.47 | 0.01 | 44.57 | 0.41          |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-76   | 44.00 | 0.06 | 2.07  | 1.30  | 3.26  | 0.44 | 3.79 | 0.20 | 44.92 | 0.13          |      |       |      |      |      |      |      |
| Pb-Ba with Na    | IINWK-V-72   | 24.71 | 1.88 | 1.77  | 5.03  | 4.59  | 0.44 | 0.77 |      | 48.06 |               |      | 12.76 |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-85b   | 23.54 | 1.58 | 0.13  | 3.58  | 15.13 | 0.59 |      | 0.16 | 49.15 | 0.06          |      | 4.35  |      |      | 0.11 | 0.06 |      |
| Pb-Ba without Na | HNWKII-86b   | 25.33 | 1.76 | 0.21  | 2.91  | 4.03  | 0.68 |      |      | 57.85 |               |      | 4.26  |      |      |      |      |      |
| Pb-Ba without Na | HNWKII-86a   | 22.48 | 1.55 | 0.27  | 4.39  | 4.54  | 0.75 |      |      | 59.47 |               |      | 4.87  |      |      |      | 0.05 |      |
| Pb-Ba with Na    | /            | 37.56 | 4.95 | 0.49  | 1.75  | 16.07 | 1.41 | 4.47 |      | 32.00 |               |      |       |      |      |      |      |      |
| Pb-Ba with Na    | s: 7053      | 67.32 | 8.97 | 0.96  | 0.26  | 4.97  | 0.82 | 1.75 | 0.84 | 13.63 | 0.40          | n.d. |       | n.d. | n.d. | n.d. |      | 0.07 |
| Pb-Ba with Na    | s: 6855      | 71.33 | 4.45 | 0.44  | 0.59  | 6.51  | 0.33 | 1.85 | 0.39 | 14.01 | Cu:194<br>PPM | n.d. |       | 0.07 | n.d. | n.d. |      | 0.05 |
| Pb-Ba with Na    | s: 2271      | 67.89 | 4.62 | 0.61  | 1.08  | 3.47  | 0.62 | 4.21 | 0.61 | 15.57 | 1.17          | n.d. |       | n.d. | n.d. | n.d. |      | 0.04 |

|                  |                |       |       |       |      |       |      |      |      |       |               |      |      |      |      |      |
|------------------|----------------|-------|-------|-------|------|-------|------|------|------|-------|---------------|------|------|------|------|------|
| Pb-Ba with Na    | 5: 7053        | 66.63 | 7.17  | 0.54  | 0.03 | 5.79  | 0.71 | 1.93 | 0.44 | 15.97 | 0.61          | n.d. | n.d. | n.d. | n.d. | 0.10 |
| Pb-Ba with Na    | 5: 3491        | 66.32 | 2.05  | 0.63  | 1.48 | 6.76  | 0.51 | 3.32 | 0.10 | 18.42 | Cu:204<br>PPM | n.d. | 0.14 | n.d. | n.d. | 0.17 |
| Pb-Ba with Na    | 5: 3491        | 65.08 | 2.63  | 2.11  | 0.57 | 5.06  | 0.38 | 3.07 | 1.07 | 19.96 | Cu:175<br>PPM | n.d. | n.d. | n.d. | n.d. | 0.07 |
| Pb-Ba with Na    | GHD-G-13-Blue1 | 58.00 | 5.18  | 2.27  | 1.46 | 7.90  | 1.11 | 4.37 | 2.58 | 10.48 | 5.25          | 0.37 | 5.18 | 0.09 | 0.41 |      |
| Pb-Ba with Na    | GHD-G-13-Red1  | 30.66 | 3.54  | 31.54 | 1.85 | 9.80  | 0.54 | 0.85 | 1.11 | 13.28 | 0.03          | 0.35 | 3.54 | 0.04 | 6.02 |      |
| Pb-Ba with Na    | GHD-G-12-White | 55.57 | 1.10  | 1.75  | 1.26 | 11.62 | 0.20 | 1.35 | 1.05 | 24.64 | 0.42          | 0.08 | 1.10 | 0.05 | 0.36 |      |
| Pb-Ba with Na    | /              | 34.69 | 1.16  |       | 9.62 | 10.36 | 0.54 | 5.20 |      | 37.21 |               |      |      |      |      |      |
| Pb-Ba with Na    | /              | 37.16 | 0.62  | 0.16  | 1.95 | 13.40 | 0.40 | 3.32 | 0.27 | 39.80 | 0.03          |      |      |      |      |      |
| Pb-Ba with Na    | /              | 38.30 | 1.67  | 0.32  | 2.75 | 10.37 | 0.41 | 3.07 | 0.34 | 41.53 | 0.73          |      |      |      |      |      |
| Pb-Ba with Na    | /              | 36.57 | 0.64  | 0.15  | 2.10 | 10.10 | 0.21 | 3.72 | 0.10 | 44.71 | 0.02          |      |      |      |      |      |
| Pb-Ba with Na    | /              | 36.00 | 0.36  | 0.18  | 1.60 | 14.00 | 0.16 | 1.65 | 0.26 | 46.10 | 0.88          |      |      |      |      |      |
| Pb-Ba with Na    | GHD-G-11       | 35.91 | 0.71  | 0.17  | 2.00 | 10.58 | 0.42 | 2.92 | 0.12 | 46.94 | 0.06          | 0.02 | 0.71 | 0.03 | 0.03 |      |
| Pb-Ba with Na    | GHD-G-10       | 34.75 | 1.15  | 0.20  | 1.71 | 8.54  | 0.28 | 2.83 | 0.29 | 48.46 | 1.48          | 0.03 | 1.15 | 0.02 | 0.04 |      |
| Pb-Ba with Na    | GHD-G-01       | 38.00 | 1.47  | 0.19  | 1.07 | 5.11  | 0.31 | 3.54 | 0.18 | 49.83 | 0.01          | 0.04 | 0.04 | 0.06 | 0.05 |      |
| Pb-Ba with Na    | HSB 147-1      | 60.65 | 7.47  | 3.46  | 0.93 | 18.27 | 1.06 | 2.33 | 1.26 | 2.80  | 1.51          | n.d. | 0.00 |      | n.d. | 0.05 |
| Pb-Ba with Na    | HSB 147-5      | 52.76 | 8.69  | 0.45  | 0.49 | 26.60 | 0.72 | 2.41 | 0.83 | 4.99  | 1.28          | n.d. | 0.00 |      | 0.34 | 0.15 |
| Pb-Ba with Na    | HSB 147-1      | 65.33 | 6.05  | 0.92  | 1.02 | 13.71 | 1.02 | 2.32 | 0.77 | 6.40  | 2.17          | n.d. | 0.00 |      | n.d. | 0.06 |
| Pb-Ba with Na    | HSB 147-2      | 65.50 | 4.64  | 0.87  | 1.28 | 13.03 | 1.10 | 3.02 | 0.55 | 7.29  | 2.42          | n.d. | 0.00 |      | n.d. | 0.08 |
| Pb-Ba with Na    | HSB 147-5      | 53.32 | 8.07  | 0.52  | 0.83 | 19.19 | 0.65 | 2.62 | 0.94 | 10.98 | 2.12          | n.d. | 0.00 |      | 0.39 | 0.12 |
| Pb-Ba with Na    | HSB 147-1      | 54.34 | 10.89 | 2.29  | 0.39 | 12.38 | 0.79 | 1.23 | 2.91 | 14.10 | 0.02          | n.d. | 0.46 |      | n.d. | 0.06 |
| Pb-Ba with Na    | HSB 147-2      | 57.42 | 8.77  | 1.10  | 0.16 | 11.71 | 0.47 | 1.36 | 2.99 | 14.61 | 0.00          | n.d. | 1.22 |      | n.d. | 0.05 |
| Pb-Ba with Na    | HSB 147-5      | 50.47 | 7.74  | 0.57  | 0.32 | 20.00 | 0.72 | 2.09 | 0.87 | 15.56 | 0.40          | n.d. | 0.00 |      | 0.92 | 0.11 |
| Pb-Ba with Na    | HSB 147-2      | 54.33 | 9.54  | 0.83  | 0.27 | 11.21 | 0.53 | 1.40 | 3.08 | 16.63 | 0.16          | n.d. | 0.08 | 1.73 | n.d. | 0.06 |
| Pb-Ba without Na | MI: 3918-10    | 63.63 | 1.88  | 0.50  | 0.53 | 8.39  |      |      |      | 22.27 | 0.03          | 0.20 | 1.84 |      | 0.00 | 0.68 |
| Pb-Ba with Na    | /              | 41.63 | 1.52  | 1.46  | 1.96 | 19.46 | 0.76 | 4.23 | 0.15 | 25.64 |               |      |      |      |      |      |
| Pb-Ba without Na | MI: 3918-9     | 56.87 | 1.82  | 0.06  | 0.00 | 12.06 |      |      |      | 26.48 | 0.02          | 0.32 | 0.48 |      | 0.00 | 1.81 |
| Pb-Ba without Na | MI: 3918-4     | 55.37 | 2.92  | 0.16  | 0.27 | 12.71 |      |      |      | 26.87 | 0.05          | 0.34 | 0.40 |      | 0.00 | 0.85 |
| Pb-Ba without Na | MI: 3918-20    | 55.07 | 3.29  | 0.17  | 0.00 | 12.46 |      |      |      | 27.11 | 0.05          | 0.35 | 0.44 |      | 0.00 | 0.98 |
| Pb-Ba without Na | MI: 3918-15    | 55.39 | 2.18  | 0.08  | 0.00 | 12.26 |      |      |      | 28.03 | 0.01          | 0.32 | 0.53 |      | 0.02 | 1.11 |
| Pb-Ba without Na | MI: 3918-3     | 51.44 | 3.02  | 0.11  | 0.55 | 13.90 |      |      |      | 28.23 | 0.06          | 0.38 | 0.51 |      | 0.00 | 1.71 |
| Pb-Ba without Na | MI: 3918-7     | 44.35 | 1.70  | 0.12  | 6.69 | 15.34 |      |      |      | 28.75 | 0.03          | 0.37 | 0.64 |      | 0.02 | 1.91 |
| Pb-Ba without Na | MI: 3918-21    | 52.64 | 2.93  | 0.28  | 0.40 | 13.14 |      |      |      | 28.88 | 0.07          | 0.32 | 0.46 |      | 0.00 | 0.81 |

|                  |           |         |       |      |      |      |       |      |      |      |       |      |       |       |      |      |
|------------------|-----------|---------|-------|------|------|------|-------|------|------|------|-------|------|-------|-------|------|------|
| Pb-Ba without Na | MI        | 3918-6  | 53.07 | 2.34 | 0.25 | 0.00 | 13.00 |      |      |      | 28.91 | 0.03 | 0.37  | 0.82  | 0.00 | 1.12 |
| Pb-Ba without Na | MI        | 3918-11 | 51.42 | 1.30 | 0.12 | 1.12 | 13.81 |      |      |      | 29.24 | 0.03 | 0.39  | 0.61  | 0.00 | 1.88 |
| Pb-Ba without Na | MI        | 3918-13 | 47.12 | 3.48 | 0.28 | 4.19 | 13.53 |      |      |      | 29.56 | 0.04 | 0.38  | 0.56  | 0.01 | 0.76 |
| Pb-Ba without Na | MI        | 3918-5  | 47.74 | 2.17 | 0.11 | 1.39 | 15.34 |      |      |      | 30.16 | 0.04 | 0.42  | 0.66  | 0.00 | 1.88 |
| Pb-Ba without Na | MI        | 3918-2  | 46.13 | 1.81 | 0.10 | 4.71 | 14.15 |      |      |      | 30.19 | 0.03 | 0.42  | 0.52  | 0.01 | 1.83 |
| Pb-Ba without Na | MI        | 3918-15 | 48.22 | 3.28 | 0.26 | 1.70 | 13.94 |      |      |      | 30.57 | 0.08 | 0.33  | 0.69  | 0.00 | 0.85 |
| Pb-Ba without Na | MI        | 3918-14 | 42.52 | 2.20 | 0.15 | 6.05 | 14.94 |      |      |      | 31.41 | 0.03 | 0.43  | 0.50  | 0.00 | 1.68 |
| Pb-Ba without Na | MI        | 3918-17 | 45.17 | 2.24 | 0.14 | 3.78 | 14.31 |      |      |      | 31.83 | 0.03 | 0.43  | 0.50  | 0.00 | 1.48 |
| Pb-Ba without Na | MI        | 3918-16 | 42.80 | 1.54 | 0.10 | 5.54 | 14.77 |      |      |      | 32.28 | 0.01 | 0.44  | 0.58  | 0.00 | 1.83 |
| Pb-Ba without Na | MI        | 3918-9  | 44.80 | 1.28 | 0.12 | 3.15 | 14.83 |      |      |      | 32.54 | 0.03 | 0.41  | 0.73  | 0.00 | 2.01 |
| Pb-Ba without Na |           |         | 40.02 | 1.67 | 0.07 | 5.73 | 15.71 |      |      |      | 33.71 | 0.03 | 0.44  | 0.58  | 0.00 | 1.91 |
| Pb-Ba without Na | MI        | 3918-8  | 41.67 | 1.18 | 0.05 | 3.88 | 15.88 |      |      |      | 33.75 | 0.04 | 0.47  | 0.73  | 0.02 | 2.23 |
| Pb-Ba without Na | MI        | 3918-18 | 44.14 | 3.61 | 0.42 | 0.54 | 13.81 |      |      |      | 35.52 | 0.38 | 0.34  | 0.75  | 0.00 | 0.41 |
| Pb-Ba with Na    | /         |         | 38.44 | 0.11 | 0.08 | 0.16 | 18.80 | 0.08 | 2.11 | 0.06 | 38.59 | 0.00 | <0.01 |       |      |      |
| Pb-Ba with Na    | /         |         | 34.66 | 1.48 | 0.11 | 0.42 | 16.23 | 0.10 | 3.65 | 0.11 | 39.25 |      |       |       |      |      |
| Pb-Ba with Na    | /         |         | 34.40 | 1.56 | 0.13 | 0.36 | 15.84 | 0.10 | 3.57 | 0.18 | 39.51 | 0.10 |       |       |      |      |
| Pb-Ba with Na    | /         |         | 36.02 | 0.02 | 0.07 | 0.22 | 21.49 | 0.08 | 2.27 | 0.07 | 40.37 |      |       |       |      |      |
| Pb-Ba with Na    | /         |         | 39.18 | 0.96 | 0.20 | 0.85 | 11.15 | 0.10 | 3.66 | 0.26 | 41.28 |      |       |       |      |      |
| Pb-Ba without Na | MI        | 3918-22 | 35.45 | 1.77 | 0.40 | 3.95 | 10.99 |      |      |      | 43.46 | 0.04 | 0.39  | 1.32  | 0.02 | 2.11 |
| Pb-Ba without Na | MI        | 3918-19 | 34.28 | 2.59 | 0.23 | 0.27 | 15.47 |      |      |      | 45.31 | 0.15 | 0.34  | 0.88  | 0.00 | 0.43 |
| Pb-Ba with Na    | /         |         | 54.32 | 0.85 | 0.63 | 3.65 | 11.13 | 0.95 | 6.27 | 1.69 | 17.12 | 0.03 |       |       |      |      |
| Pb-Ba with Na    | /         |         | 52.26 | 2.33 | 0.34 | 2.31 | 9.51  | 2.07 | 9.16 | 1.48 | 19.33 |      | 0.37  |       |      |      |
| Pb-Ba with Na    | /         |         | 45.85 | 1.66 | 0.14 | 0.77 | 12.93 | 2.16 | 9.31 | 0.34 | 27.25 |      |       |       |      |      |
| Pb-Ba with Na    | /         |         | 39.18 | 0.38 | 0.22 | 0.45 | 15.79 | 0.12 | 4.62 |      | 37.26 | 0.13 |       |       |      |      |
| Pb-Ba with Na    | /         |         | 35.06 | 1.09 | 0.30 | 2.38 | 11.71 | 1.79 | 5.29 |      | 42.28 | 0.53 |       |       |      |      |
| Pb-Ba with Na    | Xi'an-16C |         | 78.68 |      | 0.00 |      | 2.40  | 0.72 | 4.22 |      | 13.29 | 0.68 |       |       |      |      |
| Pb-Ba with Na    | Xi'an-6b  |         | 58.70 | 6.28 | 0.51 | 1.96 | 4.68  | 1.20 | 0.66 |      | 25.94 |      | 0.07  |       |      |      |
| Pb-Ba with Na    | Xi'an-4   |         | 53.55 | 6.89 | 0.41 | 0.89 | 6.71  | 1.60 | 0.93 |      | 28.70 | 0.23 | 0.09  |       |      |      |
| Pb-Ba with Na    | Xi'an-9   |         | 36.13 |      | 0.11 | 8.92 | 8.72  | 0.45 | 1.08 |      | 28.81 |      |       | 15.78 |      |      |
| Pb-Ba with Na    | Xi'an-14  |         | 54.83 | 5.04 | 0.44 | 1.47 | 5.26  | 1.50 | 1.89 |      | 29.45 |      | 0.12  |       |      |      |
| Pb-Ba with Na    | Xi'an-12  |         | 54.09 | 0.31 | 0.16 | 1.22 | 10.02 | 0.44 | 2.91 |      | 30.84 |      |       |       |      |      |
| Pb-Ba with Na    | Xi'an-15b |         | 56.65 | 1.28 | 0.25 | 1.20 | 7.42  | 0.44 | 1.32 |      | 31.46 |      |       |       |      |      |
| Pb-Ba with Na    | Xi'an-9b  |         | 39.49 |      | 0.10 | 5.36 | 9.81  | 0.76 | 0.52 |      | 31.64 |      |       | 12.31 |      |      |
| Pb-Ba with Na    | Xi'an-13  |         | 58.67 | 1.67 | 0.29 | 1.05 | 3.78  | 0.53 | 1.91 |      | 32.00 |      | 0.10  |       |      |      |

|                  |           |       |      |       |      |       |      |      |      |       |      |      |      |       |  |      |      |
|------------------|-----------|-------|------|-------|------|-------|------|------|------|-------|------|------|------|-------|--|------|------|
| Pb-Ba with Na    | Xi'an-15  | 53.57 | 0.98 | 0.13  | 1.25 | 8.86  | 0.47 | 2.17 |      | 32.57 |      |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-5   | 56.15 | 1.18 | 0.23  | 0.16 | 7.85  | 0.55 | 0.76 |      | 33.11 |      |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-11  | 57.22 | 0.88 | 0.30  | 0.77 | 5.25  | 0.49 | 1.48 | 0.01 | 33.36 |      |      | 0.25 |       |  |      |      |
| Pb-Ba with Na    | Xi'an-15f | 58.35 | 0.27 | 0.18  | 1.15 | 3.57  | 0.61 | 2.31 |      | 33.56 |      |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-1   | 51.30 | 3.27 | 0.23  | 1.23 | 7.79  | 0.37 | 0.53 |      | 33.70 | 1.19 |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-15c | 56.46 | 1.02 | 0.21  | 0.98 | 4.26  | 0.65 | 2.55 |      | 33.74 |      |      | 0.13 |       |  |      |      |
| Pb-Ba with Na    | Xi'an-16  | 56.47 | 3.88 | 0.24  | 0.87 | 1.66  | 0.51 | 1.26 |      | 33.89 | 1.22 |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-6   | 52.34 | 4.32 | 0.60  | 1.53 | 5.48  | 0.69 | 0.69 |      | 34.04 |      |      | 0.09 | 0.23  |  |      |      |
| Pb-Ba with Na    | Xi'an-14b | 57.21 | 1.75 | 0.22  | 0.73 | 3.29  | 0.68 | 1.03 |      | 35.09 |      |      |      |       |  |      |      |
| Pb-Ba with Na    | Xi'an-15d | 54.28 | 0.00 | 0.14  | 1.66 | 3.05  | 1.07 | 4.22 |      | 35.46 |      |      | 0.12 |       |  |      |      |
| Pb-Ba with Na    | Xi'an-11b | 54.16 | 2.04 | 0.44  | 0.92 | 4.86  | 0.51 | 0.76 | 0.15 | 36.00 |      |      | 0.16 |       |  |      |      |
| Pb-Ba with Na    | Xi'an-15e | 52.86 | 0.36 | 0.19  | 0.98 | 5.11  | 0.65 | 3.41 |      | 36.30 |      |      | 0.15 |       |  |      |      |
| Pb-Ba with Na    | Xi'an-8   | 28.92 |      | 0.14  | 2.79 | 4.21  | 0.96 | 0.53 |      | 51.13 | 0.80 |      | 0.05 | 10.48 |  |      |      |
| Pb-Ba without Na | /         | 52.90 | 4.80 | 1.60  | 1.40 | 12.80 |      |      | 1.50 | 19.00 | 0.10 |      |      | 1.00  |  | 4.20 | 0.10 |
| Pb-Ba without Na | /         | 48.40 | 9.70 | 1.70  | 2.40 | 6.50  |      |      | 4.50 | 19.20 | 0.10 | 0.20 |      |       |  | 7.40 | 0.00 |
| Pb-Ba without Na | 44-18-36A | 52.92 | 4.78 | 1.62  | 1.36 | 12.82 |      |      | 1.45 | 19.78 | 0.09 |      |      | 0.96  |  | 4.18 | 0.06 |
| Pb-Ba without Na | 44-18-36C | 45.53 | 8.35 | 10.51 | 6.51 | 1.18  |      |      | 2.47 | 20.45 | 0.58 | 0.30 | 0.07 | 1.05  |  | 3.00 | 0.00 |
| Pb-Ba without Na | /         | 45.50 | 8.40 | 10.50 | 6.50 | 1.20  |      |      | 2.50 | 20.50 | 0.60 | 0.30 | 0.10 | 1.10  |  | 3.00 | 0.00 |
| Pb-Ba without Na | /         | 54.10 | 3.40 | 0.60  | 1.70 | 16.60 |      |      | 0.30 | 22.80 | 0.00 |      | 0.20 | 0.30  |  |      | 0.00 |
| Pb-Ba without Na | M27:2     | 54.10 | 3.41 | 0.59  | 1.74 | 16.63 |      |      | 0.27 | 22.80 | 0.04 |      | 0.15 | 0.27  |  |      | 0.00 |
| Pb-Ba without Na | /         | 52.86 | 3.23 | 0.94  | 2.04 | 16.75 |      |      | 0.45 | 22.85 | 0.12 |      | 0.28 | 0.45  |  |      |      |
| Pb-Ba without Na | /         | 52.90 | 3.20 | 0.90  | 2.00 | 16.80 |      |      | 0.50 | 22.90 | 0.10 |      | 0.30 | 0.50  |  |      | 0.00 |
| Pb-Ba without Na | /         | 53.50 | 3.60 | 0.60  | 2.00 | 11.40 |      |      | 0.70 | 24.30 | 2.60 |      |      | 1.40  |  |      | 0.10 |
| Pb-Ba without Na | M40:1     | 53.13 | 2.17 | 0.40  | 0.99 | 17.93 |      |      | 0.05 | 24.55 |      |      | 0.05 | 0.73  |  |      | 0.00 |
| Pb-Ba without Na | /         | 53.10 | 2.20 | 0.40  | 0.10 | 17.90 |      |      | 0.10 | 24.60 | 0.00 |      | 0.10 | 0.70  |  |      | 0.00 |
| Pb-Ba without Na | M13-15    | 54.72 | 3.05 | 0.44  | 1.27 | 11.82 |      |      | 0.47 | 25.16 | 2.54 | 0.00 |      | 0.50  |  |      | 0.04 |
| Pb-Ba without Na | /         | 54.70 | 3.10 | 0.40  | 1.30 | 11.80 |      |      | 0.50 | 25.20 | 2.50 |      |      | 0.50  |  |      | 0.00 |
| Pb-Ba without Na | /         | 48.40 | 6.82 | 4.06  | 3.86 | 6.87  |      |      | 2.05 | 25.53 | 0.30 |      | 0.03 | 0.96  |  |      |      |
| Pb-Ba without Na | /         | 53.50 | 3.00 | 0.40  | 1.10 | 12.30 |      |      | 0.40 | 25.70 | 2.90 |      |      | 0.70  |  |      | 0.00 |
| Pb-Ba without Na | /         | 53.46 | 2.99 | 0.39  | 1.14 | 12.25 |      |      | 0.44 | 25.72 | 2.86 |      |      | 0.73  |  |      |      |
| Pb-Ba without Na | /         | 56.90 | 2.70 | 0.50  | 1.30 | 9.50  |      |      | 0.80 | 26.30 | 0.40 |      |      | 0.50  |  | 0.80 | 0.00 |
| Pb-Ba without Na | 44-18-36D | 56.94 | 2.65 | 0.46  | 1.30 | 9.54  |      |      | 0.82 | 26.55 | 0.43 |      |      | 0.54  |  | 0.78 | 0.00 |
| Pb-Ba without Na | /         | 49.80 | 5.00 | 1.00  | 3.00 | 6.50  |      |      | 1.80 | 28.40 | 1.00 |      |      | 1.50  |  | 1.90 | 0.10 |
| Pb-Ba without Na | 44-18-36C | 49.80 | 5.03 | 0.98  | 2.98 | 6.51  |      |      | 1.78 | 28.44 | 1.04 |      | 0.02 | 1.51  |  | 1.87 | 0.06 |

|                  |                     |       |      |      |       |       |      |      |      |       |      |  |      |       |      |      |      |      |
|------------------|---------------------|-------|------|------|-------|-------|------|------|------|-------|------|--|------|-------|------|------|------|------|
| Pb-Ba without Na | /                   | 50.10 | 2.60 | 0.40 | 1.30  | 12.30 |      |      | 0.60 | 28.90 | 2.80 |  |      | 0.20  |      |      | 0.80 | 0.10 |
| Pb-Ba without Na | /                   | 49.70 | 2.30 | 0.60 | 1.10  | 11.50 |      |      | 0.70 | 30.30 | 1.00 |  |      | 0.60  |      |      | 2.30 | 0.00 |
| Pb-Ba without Na | /                   | 49.72 | 2.29 | 0.60 | 1.07  | 11.46 |      |      | 0.66 | 30.32 | 1.00 |  |      | 0.55  |      |      |      |      |
| Pb-Ba without Na | /                   | 47.80 | 2.80 | 0.60 | 1.00  | 11.70 |      |      | 0.70 | 31.30 | 0.90 |  |      |       |      |      | 3.20 | 0.00 |
| Pb-Ba without Na | M13:15(green eye)   | 47.83 | 2.75 | 0.63 | 1.01  | 11.69 |      |      | 0.68 | 31.31 | 0.89 |  | 0.00 | 0.00  |      |      |      |      |
| Pb-Ba without Na | 44-18-36A           | 40.95 | 4.80 | 0.49 | 1.88  | 10.04 |      |      | 2.46 | 31.78 | 0.64 |  |      | 2.37  |      |      | 4.55 | 0.04 |
| Pb-Ba without Na | /                   | 41.00 | 4.80 | 0.50 | 1.90  | 10.00 |      |      | 2.50 | 31.80 | 0.60 |  |      | 2.40  |      |      | 4.60 | 0.00 |
| Pb-Ba without Na | 44-18-36C           | 47.78 | 5.71 | 1.03 | 3.87  | 3.72  |      |      | 1.45 | 32.09 | 1.05 |  | 0.02 | 1.05  |      |      | 2.20 | 0.04 |
| Pb-Ba without Na | /                   | 47.80 | 5.70 | 1.00 | 3.90  | 3.70  |      |      | 1.50 | 32.10 | 1.10 |  |      | 1.10  |      |      | 2.20 | 0.00 |
| Pb-Ba without Na | /                   | 42.30 | 5.10 | 1.60 | 1.10  | 11.40 |      |      | 0.60 | 33.70 | 0.40 |  |      | 0.40  |      |      | 3.40 | 0.00 |
| Pb-Ba without Na | M13:16 (yellow eye) | 42.29 | 5.05 | 1.63 | 1.09  | 11.40 |      |      | 0.61 | 33.72 | 0.39 |  | 0.03 | 0.37  |      |      | 2.33 |      |
| Pb-Ba without Na | /                   | 19.80 | 4.60 | 2.00 | 5.40  | 17.20 |      |      | 1.10 | 33.80 | 0.50 |  |      | 7.70  |      |      | 7.90 | 0.10 |
| Pb-Ba without Na | 42-1-94             | 19.76 | 4.55 | 1.99 | 5.39  | 17.17 |      |      | 1.10 | 33.83 | 0.54 |  |      | 7.72  |      |      | 7.90 | 0.05 |
| Pb-Ba without Na | M13:15 (yellow eye) | 35.21 | 9.14 | 2.59 | 1.11  | 9.82  |      |      | 0.94 | 35.40 | 0.12 |  | 0.06 | 0.05  |      |      | 3.22 |      |
| Pb-Ba without Na | /                   | 35.20 | 9.10 | 2.60 | 1.10  | 9.80  |      |      | 0.90 | 35.40 | 0.10 |  | 0.10 | 0.10  |      |      | 5.50 | 0.10 |
| Pb-Ba without Na | M13:16(yellow eye)  | 34.49 | 7.24 | 2.60 | 1.27  | 10.85 |      |      | 0.74 | 37.35 | 0.22 |  | 0.02 | 0.36  |      |      | 3.42 |      |
| Pb-Ba without Na | /                   | 34.50 | 7.20 | 2.60 | 1.30  | 10.90 |      |      | 0.70 | 37.40 | 0.20 |  |      | 0.40  |      |      | 4.80 | 0.00 |
| Pb-Ba without Na | 42-1-95             | 23.08 | 3.44 | 0.56 | 8.08  | 9.10  |      |      | 0.72 | 39.27 | 1.28 |  |      | 14.43 |      |      | 0.05 | 0.00 |
| Pb-Ba without Na | /                   | 23.10 | 3.40 | 0.60 | 8.10  | 9.10  |      |      | 0.70 | 39.30 | 1.30 |  |      | 14.40 |      |      | 0.10 | 0.00 |
| Pb-Ba without Na | 42-1-95             | 9.14  | 2.02 | 0.66 | 12.71 | 10.14 |      |      | 0.83 | 42.26 | 1.34 |  | 0.20 | 19.76 |      |      | 0.95 | 0.00 |
| Pb-Ba without Na | C/18202             | 26.87 | 3.71 | 1.17 | 5.41  | 4.57  |      |      | 0.79 | 46.75 | 1.26 |  | 0.05 | 9.42  |      |      |      | 0.00 |
| Pb-Ba without Na | /                   | 26.90 | 3.70 | 1.20 | 5.40  | 4.60  |      |      | 0.80 | 46.80 | 1.30 |  | 0.10 | 9.40  |      |      |      | 0.00 |
| Pb-Ba without Na | 44-18-36D           | 30.86 | 4.60 | 0.69 | 3.11  | 1.12  |      |      | 1.18 | 57.06 | 0.24 |  | 0.12 | 1.03  |      |      |      | 0.00 |
| Pb-Ba without Na | /                   | 30.90 | 4.60 | 0.70 | 3.10  | 1.10  |      |      | 1.20 | 57.10 | 0.20 |  | 0.10 | 1.00  |      |      |      | 0.00 |
| Pb-Ba with Na    | XJ-42B(black)       | 56.98 | 2.39 | 4.44 | 1.13  | 1.34  | 0.16 | 3.36 | 0.44 | 23.70 | 2.86 |  |      | 0.54  |      |      |      |      |
| Pb-Ba without Na | /                   | 57.04 | 6.94 | 0.84 | 3.41  | 5.42  |      |      | 0.51 | 23.77 | 1.08 |  |      |       |      |      |      | 0.01 |
| Pb-Ba without Na | XJ-42B(white)       | 68.46 | 2.07 | 0.65 | 0.78  | 1.10  |      |      | 0.68 | 25.38 | 0.11 |  | 0.03 | 0.01  | 0.74 |      |      |      |
| Pb-Ba without Na | XJ-42B(black)       | 43.52 | 3.65 | 9.96 | 1.49  | 1.43  |      |      | 0.76 | 31.28 | 5.28 |  | 0.06 | 0.03  | 2.51 |      |      |      |
| Pb-Ba without Na | XJ-42B(green)       | 49.35 | 3.19 | 0.82 | 2.25  | 7.78  |      |      | 0.37 | 34.24 | 0.64 |  |      | 0.01  | 0.97 |      |      |      |
| Pb-Ba with Na    | srz-12-green        | 39.89 | 1.15 | 0.33 | 0.80  | 4.92  | 0.39 | 6.32 | 0.00 | 44.80 | 1.07 |  | 0.02 | 0.00  | 0.09 | 0.00 | 0.05 |      |
| Pb-Ba with Na    | srz-13-blue1        | 33.43 | 0.61 | 0.08 | 0.39  | 9.82  | 0.17 | 6.00 | 0.00 | 48.27 | 0.91 |  | 0.01 | 0.00  | 0.02 | 0.00 | 0.10 |      |



|                  |              |       |       |      |      |       |      |      |      |       |      |      |      |      |      |      |
|------------------|--------------|-------|-------|------|------|-------|------|------|------|-------|------|------|------|------|------|------|
| Pb-Ba with Na    | srz-12-black | 32.89 | 2.18  | 4.53 | 0.72 | 2.40  | 0.44 | 4.32 | 0.11 | 48.48 | 3.56 | 0.04 | 0.02 | 0.18 | 0.00 | 0.05 |
| Pb-Ba with Na    | srz-13-blue2 | 32.40 | 0.62  | 0.19 | 0.42 | 10.28 | 0.18 | 5.46 | 0.00 | 49.30 | 0.94 | 0.01 | 0.00 | 0.02 | 0.00 | 0.10 |
| Pb-Ba with Na    | srz-14       | 32.79 | 0.73  | 0.18 | 0.70 | 6.25  | 0.99 | 6.43 | 0.00 | 51.11 | 0.56 | 0.01 | 0.00 | 0.02 | 0.00 | 0.06 |
| Pb-Ba with Na    | srz-12-white | 31.33 | 0.65  | 0.30 | 0.87 | 11.11 | 0.39 | 3.55 | 0.00 | 51.44 | 0.03 | 0.03 | 0.01 | 0.08 | 0.00 | 0.06 |
| Pb-Ba with Na    | srz-15       | 28.57 | 0.71  | 0.15 | 0.69 | 8.71  | 0.79 | 5.52 | 0.00 | 54.01 | 0.54 | 0.01 | 0.00 | 0.02 | 0.00 | 0.04 |
| Pb-Ba with Na    | /            | 55.04 | 1.99  | 0.35 | 2.67 | 8.16  | 2.24 | 5.10 | 0.27 | 22.28 |      |      |      |      |      |      |
| Pb-Ba without Na | /            | 51.70 | 4.60  | 0.30 | 0.90 | 16.10 |      |      | 0.10 | 23.20 | 0.20 | 0.00 | 0.10 | 0.70 |      | 0.00 |
| Pb-Ba with Na    | /            | 39.87 |       |      | 0.29 | 17.40 |      | 7.20 |      | 34.40 | 0.81 |      |      |      |      |      |
| Pb-Ba with Na    | /            | 78.23 | 11.09 | 0.85 | 0.66 | 1.16  |      | 0.46 | 0.71 | 6.34  | 0.04 | 0.20 | 0.01 | 0.24 | 0.01 |      |
| Pb-Ba with Na    | /            | 68.98 | 11.43 | 0.41 | 0.87 | 5.11  | 0.08 | 0.83 | 1.16 | 9.10  | 0.04 | 0.09 | 0.04 | 0.94 |      |      |
| Pb-Ba with Na    | /            | 73.57 | 8.96  | 0.55 | 0.83 | 3.45  |      | 0.95 | 0.83 | 9.91  | 0.04 | 0.20 | 0.03 | 0.65 |      |      |
| Pb-Ba with Na    | /            | 76.34 | 5.66  | 0.31 | 0.87 | 3.41  |      | 0.97 | 0.43 | 10.46 | 0.05 | 0.08 | 0.02 | 1.40 |      |      |
| Pb-Ba with Na    | /            | 78.48 | 4.58  | 0.48 | 0.62 | 3.22  |      | 0.33 | 0.58 | 10.63 | 0.11 | 0.11 | 0.03 | 0.80 |      |      |
| Pb-Ba with Na    | 3345         | 50.80 | 6.29  | 0.74 | 2.56 | 17.80 | 0.58 | 1.49 | 4.75 | 12.31 | 1.31 | 0.24 |      |      |      |      |
| Pb-Ba with Na    | /            | 72.24 | 5.49  | 1.67 | 0.82 | 1.51  | 0.37 | 0.97 | 0.91 | 12.76 | 0.19 | 0.10 | 0.02 | 2.90 |      |      |
| Pb-Ba with Na    | /            | 73.99 | 2.26  | 0.24 | 0.60 | 4.51  |      | 1.94 | 1.20 | 13.29 | 0.45 | 0.18 | 0.04 | 1.31 |      |      |
| Pb-Ba with Na    | /            | 70.44 | 8.08  | 0.56 | 1.32 | 1.62  |      | 0.45 | 0.64 | 13.43 | 1.51 | 0.09 | 0.01 | 1.85 |      |      |
| Pb-Ba with Na    | /            | 70.15 | 7.75  | 0.26 | 0.69 | 3.35  |      | 1.13 | 1.28 | 13.47 | 0.15 | 0.14 | 0.03 | 1.60 |      |      |
| Pb-Ba with Na    | /            | 64.90 | 7.09  | 0.58 | 2.15 | 4.39  | 0.67 | 1.43 | 0.76 | 13.55 | 0.07 | 0.25 | 0.03 | 4.14 |      |      |
| Pb-Ba with Na    | /            | 74.69 | 0.45  | 0.75 | 0.31 | 4.30  |      | 1.70 | 0.45 | 14.00 | 0.04 | 0.12 | 0.03 | 3.15 |      |      |
| Pb-Ba with Na    | /            | 71.67 | 7.24  | 0.11 | 0.68 | 2.96  |      | 0.58 | 0.87 | 14.26 | 0.24 | 0.13 | 0.02 | 1.22 |      |      |
| Pb-Ba with Na    | /            | 69.81 | 6.25  | 0.74 | 0.66 | 3.17  | 0.03 | 1.08 | 3.34 | 14.99 | 0.07 | 0.12 | 0.02 | 1.04 |      |      |
| Pb-Ba with Na    | 50           | 55.00 | 2.13  | 0.62 | 2.95 | 9.74  | 1.27 | 7.53 | 4.05 | 15.00 | 0.31 | 0.08 | 0.01 |      | 0.02 | 0.06 |
| Pb-Ba with Na    | /            | 55.96 | 12.93 | 2.79 | 1.77 | 1.56  | 0.49 | 0.70 | 1.34 | 15.39 | 0.06 | 0.33 | 0.01 | 6.65 |      |      |
| Pb-Ba with Na    | /            | 64.97 | 5.98  | 0.06 | 0.50 | 7.65  |      | 2.53 | 0.98 | 15.53 | 0.04 | 0.02 | 0.05 | 1.53 |      |      |
| Pb-Ba with Na    | /            | 48.60 | 4.46  | 0.55 | 1.41 | 18.07 | 1.18 | 1.09 | 0.76 | 15.74 | 4.66 | 0.83 | 0.12 | 2.53 |      |      |
| Pb-Ba with Na    | /            | 59.52 | 3.21  | 2.77 | 0.77 | 3.84  |      | 8.13 | 0.64 | 15.78 | 0.54 | 0.20 | 0.03 | 1.58 |      |      |
| Pb-Ba with Na    | /            | 74.40 | 3.51  | 0.11 | 0.39 | 2.41  | 1.10 | 0.50 | 0.25 | 15.89 | 0.28 | 0.06 | 0.02 | 1.08 |      |      |
| Pb-Ba without Na | /            | 62.54 | 10.25 | 0.71 | 2.09 | 1.93  | 0.23 |      | 0.73 | 16.02 | 0.13 | 0.05 | 0.02 | 5.27 |      |      |
| Pb-Ba with Na    | /            | 63.01 | 10.21 | 0.26 | 1.53 | 1.76  | 0.66 | 0.79 | 0.72 | 16.16 | 0.33 | 0.08 | 0.01 | 4.47 |      |      |
| Pb-Ba with Na    | /            | 71.18 | 0.18  | 0.15 | 0.60 | 4.20  |      | 3.82 | 1.04 | 16.71 | 0.49 | 0.17 | 0.03 | 1.43 |      |      |
| Pb-Ba with Na    | /            | 69.64 | 0.42  | 0.07 | 0.62 | 7.21  |      | 2.79 | 0.59 | 16.74 | 0.05 | 0.30 | 0.05 | 1.52 |      |      |
| Pb-Ba with Na    | /            | 61.28 | 12.06 | 0.62 | 1.38 | 2.86  | 1.08 | 0.05 | 0.71 | 17.24 | 0.07 | 0.10 | 0.03 | 2.52 |      |      |
| Pb-Ba with Na    | /            | 63.52 | 3.48  | 0.40 | 1.83 | 5.74  |      | 4.75 | 0.87 | 17.29 | 0.25 | 0.32 | 0.05 | 1.49 |      |      |

|                  |     |       |       |      |      |       |      |       |      |       |      |      |      |      |
|------------------|-----|-------|-------|------|------|-------|------|-------|------|-------|------|------|------|------|
| Pb-Ba with Na    | /   | 59.23 | 4.47  | 1.97 | 1.47 | 5.87  | 0.43 | 0.99  | 0.64 | 17.43 | 2.06 | 0.27 |      | 5.13 |
| Pb-Ba with Na    | /   | 59.32 | 7.01  | 0.38 | 1.94 | 6.31  | 2.44 | 1.43  | 0.93 | 17.48 | 0.07 | 0.28 | 0.04 | 2.36 |
| Pb-Ba with Na    | /   | 66.92 | 5.02  | 0.21 | 0.81 | 4.58  |      | 2.06  | 0.44 | 17.59 | 0.39 | 0.22 | 0.04 | 1.37 |
| Pb-Ba with Na    | /   | 65.19 | 2.35  | 0.39 | 1.54 | 6.92  |      | 2.64  | 0.57 | 18.04 | 0.16 | 0.31 | 0.05 | 1.82 |
| Pb-Ba with Na    | /   | 66.95 | 2.18  | 0.49 | 1.44 | 3.89  | 0.58 | 3.63  | 0.74 | 18.11 | 0.06 | 0.27 | 0.03 | 1.63 |
| Pb-Ba with Na    | /   | 70.41 | 2.63  | 0.06 | 0.76 | 2.60  |      | 2.77  | 0.44 | 18.31 | 0.33 | 0.06 | 0.02 | 1.62 |
| Pb-Ba with Na    | /   | 63.07 | 1.40  | 2.71 | 0.57 | 6.20  |      | 4.00  | 0.47 | 18.43 | 0.45 | 0.29 | 0.04 | 2.39 |
| Pb-Ba with Na    | /   | 63.49 | 5.25  | 0.34 | 1.58 | 3.68  |      | 0.38  | 0.67 | 18.58 | 0.09 | 0.16 | 0.03 | 5.75 |
| Pb-Ba with Na    | /   | 66.13 | 2.65  | 0.14 | 0.97 | 4.65  |      | 4.05  | 0.67 | 18.96 | 0.05 | 0.24 | 0.03 | 1.45 |
| Pb-Ba with Na    | 91  | 52.40 | 2.62  | 0.28 | 1.48 | 11.10 | 2.62 | 10.10 | 0.16 | 19.20 | 1.31 | 0.03 | 0.00 | 0.01 |
| Pb-Ba with Na    | /   | 49.67 | 18.41 | 2.64 | 1.00 | 2.24  | 0.79 | 1.65  | 1.57 | 19.96 |      | 0.35 | 0.04 | 1.53 |
| Pb-Ba with Na    | /   | 63.04 | 3.82  | 0.12 | 0.50 | 6.15  | 0.59 | 2.72  | 0.40 | 20.31 | 0.46 | 0.13 | 0.04 | 1.74 |
| Pb-Ba with Na    | /   | 61.13 | 8.44  | 0.29 | 1.10 | 3.95  |      | 1.40  | 0.51 | 20.59 | 0.70 | 0.15 | 0.03 | 1.70 |
| Pb-Ba with Na    | /   | 65.04 | 0.18  | 0.13 | 0.72 | 4.58  |      | 4.67  | 0.50 | 20.67 | 1.43 | 0.22 | 0.03 | 1.85 |
| Pb-Ba with Na    | /   | 71.97 |       | 0.07 | 0.43 | 4.00  |      | 0.09  | 0.27 | 20.77 | 0.05 | 0.10 | 0.03 | 2.22 |
| Pb-Ba with Na    | /   | 63.06 | 2.04  | 0.39 | 1.57 | 4.49  | 0.52 | 4.06  | 0.64 | 20.97 | 0.09 | 0.28 | 0.04 | 1.85 |
| Pb-Ba with Na    | 89  | 51.50 | 0.98  | 3.54 | 1.00 | 14.50 | 0.75 | 5.39  | 0.21 | 21.00 | 0.60 | 0.03 | 0.01 |      |
| Pb-Ba with Na    | G21 | 56.53 | 0.69  | 0.14 | 0.70 | 10.95 | 1.67 | 7.42  | 0.06 | 21.30 | 0.20 | 0.01 | 0.01 |      |
| Pb-Ba with Na    | /   | 59.00 | 8.61  | 0.58 | 0.68 | 3.63  |      | 3.36  | 0.90 | 21.40 | 0.27 | 0.35 | 0.03 | 1.20 |
| Pb-Ba with Na    | /   | 50.88 | 14.96 | 1.18 | 1.70 | 1.18  | 2.08 | 0.83  | 0.74 | 21.89 | 0.12 | 0.20 | 0.01 | 4.23 |
| Pb-Ba with Na    | /   | 67.08 |       | 0.06 | 0.48 | 3.98  |      | 1.88  | 0.39 | 22.22 | 0.05 | 0.17 | 0.03 | 3.67 |
| Pb-Ba without Na | /   | 59.71 | 2.07  | 0.24 | 1.83 | 3.20  |      |       | 0.53 | 22.24 | 0.05 | 0.18 | 0.02 | 9.91 |
| Pb-Ba with Na    | /   | 67.98 | 2.78  | 0.12 | 0.59 | 2.70  | 0.00 | 1.49  | 0.62 | 22.47 | 0.06 | 0.15 | 0.02 | 1.02 |
| Pb-Ba with Na    | /   | 64.81 | 1.61  | 0.10 | 0.41 | 4.93  |      | 2.75  | 0.53 | 22.63 | 0.07 | 0.25 | 0.04 | 1.81 |
| Pb-Ba with Na    | /   | 66.57 |       | 0.08 | 0.44 | 5.90  |      | 0.52  | 0.48 | 22.65 | 0.34 | 0.20 | 0.04 | 2.77 |
| Pb-Ba with Na    | /   | 60.16 | 8.86  | 1.06 | 0.52 | 1.42  |      | 1.36  | 1.63 | 22.80 | 0.06 | 0.19 | 0.01 | 1.94 |
| Pb-Ba without Na | /   | 59.64 | 6.65  | 0.38 | 1.64 | 1.75  | 0.61 |       | 0.54 | 23.35 | 0.78 | 0.11 | 0.02 | 4.54 |
| Pb-Ba with Na    | /   | 60.77 | 0.33  | 0.13 | 0.68 | 7.40  |      | 1.19  | 0.48 | 23.89 | 0.38 | 0.29 | 0.04 | 4.41 |
| Pb-Ba with Na    | /   | 47.06 | 5.91  | 1.13 | 1.78 | 3.22  | 0.62 | 0.01  | 0.86 | 23.95 | 6.55 | 0.24 | 0.04 | 8.57 |
| Pb-Ba with Na    | /   | 56.52 | 2.36  | 1.00 | 0.91 | 2.37  | 0.71 | 4.51  | 1.02 | 24.52 | 0.21 | 0.18 | 0.02 | 5.68 |
| Pb-Ba with Na    | /   | 65.99 | 1.28  | 0.07 | 0.62 | 3.27  |      | 1.49  | 0.60 | 24.62 | 0.06 | 0.15 | 0.02 | 1.82 |
| Pb-Ba with Na    | /   | 48.57 | 6.82  | 1.98 | 1.17 | 6.59  | 5.38 | 1.24  | 1.25 | 24.63 | 0.15 | 0.53 | 0.06 | 1.61 |
| Pb-Ba with Na    | /   | 47.67 | 8.55  | 0.96 | 3.43 | 4.98  | 0.20 | 0.74  | 1.10 | 24.67 | 0.33 | 0.20 | 0.03 | 7.13 |
| Pb-Ba with Na    | /   | 54.46 | 3.87  | 0.62 | 1.54 | 10.05 |      | 1.35  | 0.78 | 24.78 | 0.10 | 0.38 | 0.06 | 1.97 |

|                  |     |       |      |      |      |       |      |      |      |       |      |      |      |       |      |      |
|------------------|-----|-------|------|------|------|-------|------|------|------|-------|------|------|------|-------|------|------|
| Pb-Ba with Na    | /   | 61.29 | 4.01 | 0.49 | 1.17 | 2.53  |      | 0.58 | 0.55 | 24.98 | 0.18 | 0.08 | 0.03 | 4.12  |      |      |
| Pb-Ba with Na    | /   | 63.95 | 1.29 | 0.13 | 0.58 | 3.50  |      | 2.49 | 0.45 | 25.09 | 0.56 | 0.18 | 0.03 | 1.74  |      |      |
| Pb-Ba with Na    | /   | 60.16 | 2.63 | 0.17 | 0.75 | 3.42  | 0.07 | 2.88 | 0.68 | 25.57 | 0.27 | 0.17 | 0.03 | 3.20  |      |      |
| Pb-Ba with Na    | /   | 53.65 | 6.66 | 0.46 | 1.26 | 5.37  | 1.13 | 2.03 | 0.70 | 25.71 | 0.70 | 0.30 | 0.04 | 2.00  |      |      |
| Pb-Ba with Na    | /   | 54.86 | 6.80 | 0.23 | 1.21 | 1.48  |      | 0.60 | 1.01 | 26.51 | 0.67 | 0.04 | 0.02 | 6.57  |      |      |
| Pb-Ba with Na    | /   | 56.50 |      | 0.06 | 0.54 | 9.29  | 0.08 | 3.59 | 0.44 | 26.66 | 0.07 | 0.49 | 0.06 | 2.23  |      |      |
| Pb-Ba with Na    | /   | 59.63 | 0.43 | 0.07 | 1.07 | 5.61  |      | 1.91 | 0.68 | 26.94 | 0.07 | 0.19 | 0.04 | 6.06  |      |      |
| Pb-Ba with Na    | /   | 58.84 |      | 0.04 | 0.47 | 6.54  | 0.06 | 3.56 | 0.44 | 27.30 | 0.22 | 0.27 | 0.04 | 2.27  |      |      |
| Pb-Ba with Na    | /   | 55.09 | 1.29 | 0.16 | 1.65 | 3.23  | 0.73 | 1.07 | 0.50 | 27.33 | 0.31 | 0.18 | 0.03 | 8.41  |      |      |
| Pb-Ba with Na    | /   | 53.89 | 7.02 | 0.25 | 1.49 | 2.85  | 0.15 | 3.09 | 0.98 | 27.39 | 0.72 | 0.06 | 0.02 | 2.07  |      |      |
| Pb-Ba with Na    | /   | 59.39 | 3.58 | 0.09 | 0.83 | 4.63  | 0.00 | 1.17 | 0.55 | 27.47 | 0.08 | 0.20 | 0.04 | 1.98  |      |      |
| Pb-Ba with Na    | /   | 51.39 | 6.50 | 2.02 | 2.44 | 1.27  | 0.19 | 0.49 | 0.59 | 27.87 | 1.60 | 0.20 | 0.01 | 5.42  |      |      |
| Pb-Ba with Na    | 95  | 51.30 | 0.46 | 0.10 | 0.37 | 11.40 | 1.52 | 6.12 | 0.08 | 28.30 | 0.01 | 0.01 | 0.00 |       | 0.05 |      |
| Pb-Ba with Na    | /   | 57.15 | 5.20 | 0.18 | 0.58 | 4.28  | 0.00 | 1.17 | 0.55 | 28.79 | 0.08 | 0.26 | 0.03 | 1.73  |      |      |
| Pb-Ba with Na    | /   | 58.54 | 0.82 | 0.10 | 1.28 | 2.02  |      | 0.08 | 0.44 | 29.30 | 0.21 | 0.06 | 0.02 | 7.11  |      |      |
| Pb-Ba with Na    | /   | 52.65 | 0.93 | 0.09 | 0.79 | 5.70  | 0.98 | 1.75 | 0.65 | 29.37 | 0.06 | 0.22 | 0.04 | 6.77  |      |      |
| Pb-Ba with Na    | 52  | 42.00 | 2.12 | 0.63 | 1.92 | 19.20 | 0.18 | 1.58 | 0.17 | 31.60 | 0.10 | 0.08 | 0.00 |       | 0.02 |      |
| Pb-Ba with Na    | 73  | 40.30 | 1.82 | 0.65 | 3.67 | 17.40 | 0.61 | 3.17 | 0.57 | 32.20 | 0.13 |      |      |       |      |      |
| Pb-Ba without Na | /   | 26.56 | 3.25 | 0.83 | 3.14 | 15.51 |      |      | 0.76 | 32.25 | 3.61 | 0.35 | 0.11 | 12.61 |      |      |
| Pb-Ba with Na    | /   | 54.25 |      | 0.06 | 1.41 | 5.36  |      | 1.59 | 0.77 | 33.35 | 0.48 | 0.36 | 0.04 | 2.33  |      |      |
| Pb-Ba with Na    | /   | 48.68 | 1.52 | 0.19 | 2.74 | 3.82  | 0.83 | 0.99 | 0.81 | 33.47 | 0.50 | 0.18 | 0.03 | 6.23  |      |      |
| Pb-Ba with Na    | /   | 38.77 | 2.30 | 0.26 | 0.56 | 20.05 | 0.11 | 1.75 | 0.22 | 33.92 | 0.05 | 0.01 | 0.00 |       |      |      |
| Pb-Ba with Na    | /   | 50.32 | 0.12 | 0.06 | 0.54 | 7.24  |      | 2.90 | 0.57 | 34.09 | 0.34 | 0.32 | 0.05 | 3.43  |      |      |
| Pb-Ba with Na    | /   | 41.70 | 1.90 | 5.04 | 0.63 | 10.10 | 0.53 | 2.02 | 0.63 | 34.50 | 0.35 |      |      |       |      |      |
| Pb-Ba with Na    | 94  | 41.70 | 1.90 | 5.04 | 2.92 | 10.10 | 0.53 | 2.02 | 0.63 | 34.50 | 0.35 | 0.10 | 0.04 |       |      |      |
| Pb-Ba with Na    | 69  | 46.90 | 1.93 | 4.63 | 2.67 | 3.09  | 0.73 | 3.01 | 0.66 | 35.20 | 0.50 | 0.12 | 0.02 |       | 0.08 | 0.05 |
| Pb-Ba with Na    | 83  | 40.50 | 0.18 | 0.24 | 0.96 | 19.70 | 0.04 | 2.72 | 0.22 | 35.20 | 0.01 | 0.01 | 0.00 |       |      |      |
| Pb-Ba with Na    | /   | 53.06 | 0.72 | 0.15 | 0.93 | 3.06  | 0.19 | 1.72 | 0.64 | 35.44 | 0.73 | 0.20 | 0.02 | 3.16  |      |      |
| Pb-Ba with Na    | /   | 44.12 | 6.00 | 0.15 | 0.76 | 5.71  |      | 2.11 | 0.96 | 36.21 | 0.41 | 0.02 | 0.05 | 3.48  |      |      |
| Pb-Ba without Na | /   | 34.69 | 1.16 |      |      | 10.36 | 9.62 |      | 0.54 | 37.24 | 5.20 |      |      |       |      |      |
| Pb-Ba with Na    | 92  | 41.40 | 0.89 | 0.27 | 1.37 | 9.71  | 0.58 | 5.94 | 0.16 | 37.40 | 2.07 | 0.01 | 0.00 |       |      |      |
| Pb-Ba with Na    | /   | 37.30 | 1.19 | 7.35 | 0.37 | 9.40  | 0.61 | 3.75 | 0.37 | 37.50 | 0.42 |      |      |       |      |      |
| Pb-Ba with Na    | G53 | 36.15 | 0.04 |      | 0.25 | 20.10 | 0.02 | 2.11 | 0.05 | 39.11 | 2.96 | 0.01 | 0.01 |       |      |      |
| Pb-Ba with Na    | /   | 38.04 | 3.89 | 0.16 | 1.08 | 7.35  |      | 3.72 | 0.73 | 39.50 | 0.69 | 0.18 | 0.06 | 4.59  |      |      |

|                  |      |       |      |      |      |       |      |      |      |       |      |       |        |       |
|------------------|------|-------|------|------|------|-------|------|------|------|-------|------|-------|--------|-------|
| Pb-Ba with Na    | 3382 | 36.30 | 0.37 | 0.19 | 0.16 | 19.90 | 0.00 | 2.18 | 0.13 | 39.90 | 0.05 | 0.13  |        |       |
| Pb-Ba with Na    | /    | 23.43 | 3.68 | 1.83 | 3.45 | 8.38  | 0.33 | 0.22 | 0.65 | 40.13 | 1.88 | 0.34  | 0.07   | 14.70 |
| Pb-Ba with Na    | /    | 33.87 | 3.90 | 0.33 | 2.74 | 3.21  | 0.99 | 3.09 | 1.17 | 40.30 | 0.11 | 0.10  |        | 10.20 |
| Pb-Ba with Na    | /    | 36.03 | 0.02 | 0.07 | 0.22 | 21.49 | 0.08 | 2.27 | 0.04 | 40.37 |      |       |        |       |
| Pb-Ba with Na    | 51   | 37.20 | 0.15 | 0.01 | 1.01 | 14.60 | 1.17 | 3.94 | 0.02 | 41.40 | 3.30 | <0.01 | <0.005 | 0.01  |
| Pb-Ba with Na    | 3383 | 39.30 | 1.67 | 0.32 | 2.75 | 10.37 | 0.41 | 3.07 | 0.34 | 41.53 | 0.73 |       |        |       |
| Pb-Ba without Na | /    | 29.14 | 3.57 | 0.22 | 4.69 | 1.14  | 0.75 |      | 0.54 | 41.64 | 0.73 | 0.01  | 0.02   | 17.50 |
| Pb-Ba with Na    | G41* | 38.80 | 1.28 | 0.17 | 0.71 | 10.70 | 0.14 | 3.34 | 0.20 | 42.40 | 0.05 | 0.08  |        |       |
| Pb-Ba with Na    | /    | 46.77 |      | 0.05 | 0.64 | 2.46  |      | 4.21 | 0.45 | 42.47 | 0.07 | 0.08  | 0.02   | 2.79  |
| Pb-Ba with Na    | 80   | 36.80 | 0.28 | 0.14 | 0.46 | 17.40 | 0.15 | 1.87 | 0.16 | 42.60 | 0.02 | nf    | 0.00   |       |
| Pb-Ba with Na    | G52* | 34.83 | 0.18 |      | 0.36 | 17.38 | 0.01 | 2.16 | 0.08 | 42.98 | 0.03 | 0.01  | 0.01   |       |
| Pb-Ba with Na    | /    | 34.42 | 0.76 | 0.16 | 0.12 | 12.58 | 0.35 | 4.32 | 1.02 | 43.20 |      |       |        |       |
| Pb-Ba with Na    | 5892 | 34.95 | 0.21 | 0.05 | 0.10 | 17.22 | 0.00 | 2.82 | 0.06 | 43.95 | 0.04 | 0.43  |        |       |
| Pb-Ba with Na    | /    | 39.78 | 0.43 | 0.07 | 0.81 | 3.71  | 4.36 | 2.37 | 0.57 | 44.08 | 0.10 | 0.08  | 0.03   | 3.61  |
| Pb-Ba with Na    | /    | 36.54 | 0.58 | 0.08 | 0.72 | 10.33 |      | 1.74 | 0.62 | 45.32 | 0.13 | 0.41  | 0.08   | 3.43  |
| Pb-Ba with Na    | /    | 22.19 | 2.37 | 0.97 | 3.97 | 3.55  |      | 0.68 | 0.75 | 47.70 | 0.47 | 0.14  | 0.05   | 17.10 |
| Pb-Ba with Na    | /    | 30.37 | 1.35 | 0.74 | 2.05 | 1.85  |      | 0.79 | 0.55 | 50.44 | 0.62 | 0.08  | 0.02   | 10.90 |
| Pb-Ba with Na    | /    | 27.77 | 3.66 | 0.46 | 1.72 | 6.78  | 0.69 | 1.88 | 0.82 | 52.35 | 0.69 |       | 0.05   | 3.12  |
| Pb-Ba with Na    | /    | 34.59 | 0.93 | 0.17 | 1.11 | 5.99  |      | 0.17 | 0.85 | 54.72 | 0.12 | 0.34  | 0.05   | 0.94  |
| Pb-Ba with Na    | /    | 39.00 | 0.43 | 0.16 | 3.35 | 14.12 | 3.69 | 0.06 | 0.06 | 37.50 | 0.84 |       |        |       |
| Pb-Ba without Na | /    | 34.94 |      |      | 1.96 | 8.49  |      |      |      | 54.61 |      |       |        |       |
| Pb-Ba with Na    | /    | 44.28 | 3.37 |      |      | 14.72 | 1.24 | 5.85 | 0.24 | 29.38 |      |       |        |       |
| Pb-Ba with Na    | /    | 29.13 | 0.55 |      |      | 18.06 |      | 3.67 |      | 48.77 |      |       |        |       |
| Pb-Ba with Na    | /    | 41.20 | 0.46 | 0.06 | 0.42 | 11.43 | 0.27 | 6.82 | 0.25 | 35.72 |      |       |        |       |
| Pb-Ba with Na    | /    | 38.00 | 0.35 | 0.29 | 1.10 | 14.00 | 0.15 | 3.90 | 0.19 | 38.50 | 0.78 |       |        |       |
| Pb-Ba with Na    | /    | 38.00 | 0.35 | 0.29 | 1.10 | 14.00 | 0.51 | 3.90 | 0.20 | 38.50 | 0.78 |       |        |       |
| Pb-Ba with Na    | /    | 37.00 | 0.52 | 0.14 | 0.50 | 16.00 | 0.20 | 2.68 | 0.50 | 40.80 | 0.76 |       |        |       |
| Pb-Ba with Na    | /    | 38.90 | 0.56 | 0.30 | 2.83 | 7.59  | 0.95 | 4.68 | 0.21 | 43.50 | 0.42 |       |        |       |
| Pb-Ba with Na    | /    | 36.00 | 0.13 | 0.07 | 0.01 | 13.00 | 0.08 | 1.96 | 0.17 | 48.50 | 0.84 |       |        |       |

**Continue to Table 1**

| Inventory number | Glass Type | Reference | Location  | Colour            | Method | Site                                                   |
|------------------|------------|-----------|-----------|-------------------|--------|--------------------------------------------------------|
| 24022011         | Eye bead   | Gan 2009  | Chongqing | green             | PIXE   | Dongsun Dam of Ba County                               |
| 24022012         | Eye bead   | Gan 2009  | Chongqing | white transparent | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| 24022002         | Bi disk    | Gan 2009  | Chongqing | white transparent | PIXE   | Southern part of Baocheng Railway                      |

|          |          |                       |           |                   |        |                                                        |
|----------|----------|-----------------------|-----------|-------------------|--------|--------------------------------------------------------|
| 24022014 | Eye bead | Gan 2009              | Chongqing | dark blue         | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| 24022010 | Eye bead | Gan 2009              | Chongqing | black             | PIXE   | Dongsun Dam of Ba County                               |
| 24022015 | Eye bead | Gan 2009              | Chongqing | blue              | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| 24022013 | Eye bead | Gan 2009              | Chongqing | blue              | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| 24022042 | Bead     | Gan 2009              | Chongqing | green             | PIXE   | Maliuwan in Wanzhou                                    |
|          | Eye bead | Gan 2009              | Chongqing | dark blue         | PIXE   | Dongsun Dam of Ba County                               |
| /        | Eye bead | Gan 2005              | Chongqing | blue              | Unkown | Dongsun Dam of Ba County                               |
| CQ-19    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | blue              | PIXE   | unknown                                                |
| /        | Eye bead | Gan 2009              | Chongqing | white opaque      | PIXE   | Ba County, Dong Sun Ba                                 |
| /        | Eye bead | Gan 2009              | Chongqing | /                 | PIXE   | Ba County, Dong Sun Ba                                 |
| /        | Eye bead | Gan 2005              | Chongqing | black             | Unkown | Dongsun Dam of Ba County                               |
| CQ-10    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | green             | PIXE   | Dongsun Dam of Ba County                               |
| /        | Eye bead | Gan 2009              | Chongqing | black             | PIXE   | Ba County, Dong Sun Ba                                 |
| 24022037 | Bead     | Gan 2009              | Chongqing | white translucent | PIXE   | R. F. Luo's tomb in Wanzhou                            |
| 24022038 | Bead     | Gan 2009              | Chongqing | blue              | PIXE   | R. F. Luo's tomb in Wanzhou                            |
| CQ-01    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | light green       | PIXE   | Southern part of Baocheng Railway                      |
| /        | Eye bead | Gan 2009              | Chongqing | green             | PIXE   | Ba County, Dong Sun Ba                                 |
| /        | Eye bead | Gan 2005              | Chongqing | black             | Unkown | Dongsun Dam of Ba County                               |
| CQ-11    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | white opaque      | PIXE   | Dongsun Dam of Ba County                               |
| 24022036 | Bead     | Gan 2009              | Chongqing | green             | PIXE   | R. F. Luo's tomb in Wanzhou                            |
| 24022029 | Bead     | Gan 2009              | Chongqing | black             | PIXE   | M12 tomb at Changshan, Zhangming                       |
| /        | Bi disk  | Gan 2009              | Chongqing | pale green        | PIXE   | South Bao Cheng Road                                   |
| CQ-09    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | black             | PIXE   | Dongsun Dam of Ba County                               |
| /        | Eye bead | Gan 2005              | Chongqing | /                 | Unkown | unknown                                                |
| /        | Eye bead | Gan 2005              | Chongqing | dark blue         | Unkown | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| SX-13    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | dark blue         | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| /        | Bead     | Gan 2009              | Chongqing | green             | PIXE   | Bao Cheng Road, Zhaohua city, Bao Lun Yuan M8          |
| /        | Eye bead | Gan 2005              | Chongqing | dark blue         | Unkown | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| SX-12    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | light blue        | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| /        | Bead     | Gan 2009              | Chongqing | black             | PIXE   | Bao Cheng Road, Zhaohua city, Bao Lun Yuan M7          |
| /        | Bead     | Gan 2009              | Chongqing | yellow            | PIXE   | Bao Cheng Road, Zhaohua city, Bao Lun Yuan M10         |
| /        | Eye bead | Gan 2005              | Chongqing | dark blue         | Unkown | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| SX-15    | Eye bead | Li <i>et al.</i> 2006 | Chongqing | blue              | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| /        | Eye bead | Gan 2005              | Chongqing | dark blue         | Unkown | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |

|                 |                |                          |           |              |        |                                                        |
|-----------------|----------------|--------------------------|-----------|--------------|--------|--------------------------------------------------------|
| SX-14           | Eye bead       | Gan 2009                 | Chongqing | dark blue    | PIXE   | Yujia Dam, Three Gorges Reservoir Area, Kaixian County |
| /               | Bead           | Gan 2009                 | Chongqing | black        | PIXE   | Bao Cheng Road, Zhaozhua city, Bao Lun Yuan M9         |
| MJY-M4-6-1      | Bead           | Huang <i>et al.</i> 2015 | Gansu     | blue         | EDXRF  | Tomb M4, MaJiayuan                                     |
| MJY-M4-23-1     | Eye bead       | Huang <i>et al.</i> 2015 | Gansu     | blue         | EDXRF  | Tomb M4, MaJiayuan                                     |
| /               | Ear pendant    | Gan 2005                 | Gansu     | dark blue    | Unkown | unknown                                                |
| MJY-M4-23       | Eye bead       | Huang <i>et al.</i> 2015 | Gansu     | blue         | EDXRF  | Tomb M4, MaJiayuan                                     |
| MJY-M4-23-2     | Eye bead       | Huang <i>et al.</i> 2015 | Gansu     | brown        | EDXRF  | Tomb M4, MaJiayuan                                     |
| /               | Ear pendant    | Gan 2005                 | Gansu     | green        | Unkown | Han Tomb M4 of Shangsunjiazhai, Datong, Qinghai        |
| MJY-M4-6-2      | Bead           | Huang <i>et al.</i> 2015 | Gansu     | purple       | EDXRF  | Tomb M4, MaJiayuan                                     |
| /               | Bead           | Gan 2005                 | Gansu     | green        | Unkown | M2, Dabaozi Mountain, Li County                        |
| GD01(white eye) | Eye bead       | Li <i>et al.</i> 2005    | Guangdong | white opaque | PIXE   | Songshan tomb, Zhaoqing                                |
| GD01            | Eye bead       | Gan 2009                 | Guangdong | blue         | PIXE   | Songshan tomb, Zhaoqing                                |
| /               | Bead           | Gan 2005                 | Guangdong | /            | Unkown | Kele Town, Haozhang County                             |
| GD01(blue eye)  | Eye bead       | Li <i>et al.</i> 2005    | Guangdong | blue         | PIXE   | Songshan tomb, Zhaoqing                                |
| /               | Glass plaque   | Gan 2005                 | Guangdong | light green  | Unkown | Nanyue King Tomb                                       |
| /               | Glass plaque   | Gan 2005                 | Guangdong | light green  | Unkown | Nanyue King Tomb                                       |
| /               | Glass plaque   | Gan 2005                 | Guangdong | light green  | Unkown | Nanyue King Tomb                                       |
| /               | Ear pendant    | Gan 2009                 | Guizhou   | green        | PIXE   | Qingzhen, Ludi village M56                             |
| GZH-5           | Ornament glass | Gan 2016                 | Guizhou   | green        | PIXE   | Luohuo Village, Qing County M56                        |
| /               | Bead           | Gan 2009                 | Guizhou   | /            | PIXE   | Hezhang, Kele M87                                      |
| GZH-9           | Ear pendant    | Gan 2016                 | Guizhou   | /            | PIXE   | Pingba, Jin-jia-ba M12                                 |
| /               | Ear pendant    | Gan 2009                 | Guizhou   | /            | PIXE   | Pingba, Jin-jia-ba M12                                 |
| GZH-4B          | Bead           | Gan 2016                 | Guizhou   | blue         | PIXE   | Liuqing, Zhonghou Village, Qing County M101            |
| /               | Bead           | Gan 2009                 | Guizhou   | blue         | PIXE   | Qingzhen, Zhonghou village M100                        |
| /               | Bead           | Gan 2009                 | Guizhou   | white opaque | PIXE   | Qingzhen, Zhonghou village M100                        |
| GZH-4A          | Bead           | Gan 2016                 | Guizhou   | white opaque | PIXE   | Liuqing, Zhonghou Village, Qing County M100            |
| /               | Ear pendant    | Gan 2009                 | Guizhou   | /            | PIXE   | Qianxi M13                                             |
| GZH-11          | Ear pendant    | Gan 2016                 | Guizhou   | /            | PIXE   | Qianxi M13                                             |
| GZH-16          | Ear pendant    | Gan 2016                 | Guizhou   | /            | PIXE   | Weining, Zhong-shui-li M24                             |
| /               | Ear pendant    | Gan 2009                 | Guizhou   | /            | PIXE   | Weining, Zhong-shui-li M24                             |
| GZH-4C          | Bead           | Gan 2016                 | Guizhou   | green        | PIXE   | Liuqing, Zhonghou Village, Qing County M101            |
| /               | Bead           | Gan 2009                 | Guizhou   | green        | PIXE   | Qingzhen, Zhonghou village M100                        |
| GZH-14          | Ear pendant    | Gan 2016                 | Guizhou   | /            | PIXE   | Xingren, Jiaole M2                                     |
| /               | Bead           | Gan 2009                 | Guizhou   | green        | PIXE   | Qingzhen, Ya-long-ba M14                               |

|              |                |                         |         |              |        |                                         |
|--------------|----------------|-------------------------|---------|--------------|--------|-----------------------------------------|
| GZH-6B       | Bead           | Gan 2016                | Guizhou | green        | PIXE   | Yalong Dam, Qing County M14             |
| /            | Ear pendant    | Gan 2009                | Guizhou | blue         | PIXE   | Qianxi Gantang M18                      |
| GZH-12       | Ornament glass | Gan 2016                | Guizhou | blue         | PIXE   | Qianxi Gantang M18                      |
| IINWK-V-63   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | light green  | pXRF   | Xin zheng                               |
| IINWK-V-69   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| IINWK-V-69   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | dark blue    | pXRF   | Xin zheng                               |
| HNLY-17c     | Eye bead       | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Ren-wei-lou at Luoyang city             |
| IINWK-V-66   | Bead           | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| IINWK-V-83   | Bead           | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Baofeng Liaoqiying                      |
| IINWK-V-84   | Bead           | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Baofeng Liaoqiying                      |
| NYWKI-5-1a   | Bead           | Dong <i>et al.</i> 2012 | Henan   | green opaque | PIXE   | Wan-jia-yuan at Nanyang                 |
| IINWK-V-82   | Bead           | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Baofeng Liaoqiying                      |
| NYWKI-5-2a   | Bead           | Dong <i>et al.</i> 2012 | Henan   | green opaque | PIXE   | Wan-jia-yuan at Nanyang                 |
| HNLY-03b     | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | green opaque | PIXE   | Shao-gou at Luoyang city                |
| IINWK-V-68   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| HNLY-20      | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | /            | PIXE   | M401 excavating area of at Luoyang city |
| HNWKII-88    | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Xue village site at Xing county         |
| /            | Bead           | Gan 1984                | Henan   | white opaque | Unkown | Luoyang                                 |
| /            | Bead           | Gan 2005                | Henan   | /            | Unkown | Luoyang                                 |
| /            | Eye bead       | Gan 2005                | Henan   | /            | Unkown | Tomb M2 of Guwei Village, Hui County    |
| HNWKII-84d*a | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Xue village site at Xing county         |
| NYWKI-5-2b   | Bead           | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Wan-jia-yuan at Nanyang                 |
| IINWK-V-71   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| IINWK-V-74   | Ear pendant    | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Baofeng Liaoqiying                      |
| /            | Eye bead       | Gan 2005                | Henan   | /            | Unkown | M1 Tomb of Guwei Village, Hui County    |
| NYWKI-5-1c   | Bead           | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Wan-jia-yuan at Nanyang                 |
| IINWK-V-63   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| HNWKII-87c   | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Xue village site at Xing county         |
| IINWK-V-65   | Bead           | Fu <i>et al.</i> 2014   | Henan   | white opaque | pXRF   | Xin zheng                               |
| HNLY-17b     | Eye bead       | Dong <i>et al.</i> 2012 | Henan   | blue         | PIXE   | Ren-wei-lou at Luoyang city             |
| IINWK-V-72   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | blue         | pXRF   | Xin zheng                               |
| IINWK-V-77   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | white opaque | pXRF   | Baofeng Liaoqiying                      |
| IINWK-V-71   | Eye bead       | Fu <i>et al.</i> 2014   | Henan   | white opaque | pXRF   | Xin zheng                               |
| HNWKII-87a   | Ornament glass | Dong <i>et al.</i> 2012 | Henan   | white opaque | PIXE   | Xue village site at Xing county         |

|                |                |                         |       |              |                         |                                      |
|----------------|----------------|-------------------------|-------|--------------|-------------------------|--------------------------------------|
| NYWKI-5-1b     | Bead           | Dong <i>et al.</i> 2012 | Henan | black        | PIXE                    | Wan-jia-yuan at Nanyang              |
| IINWK-V-71     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | blue         | pXRF                    | Xin zheng                            |
| IINWK-V-72     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | blue         | pXRF                    | Xin zheng                            |
| HNWKII-84d*c   | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| IINWK-V-80     | Bead           | Fu <i>et al.</i> 2014   | Henan | colourless   | pXRF                    | Baofeng Liaoqiying                   |
| HNWKII-85a     | Bead           | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| HNWKII-84d*d   | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| IINWK-V-79     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | black        | pXRF                    | Baofeng Liaoqiying                   |
| /              | Bead           | Gan 1984                | Henan | colourless   | Unkown                  | Jin Village, Luoyang                 |
| IINWK-V-77     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | black        | pXRF                    | Baofeng Liaoqiying                   |
| HNWKII-84d*b   | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| IINWK-V-78     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | black        | pXRF                    | Baofeng Liaoqiying                   |
| IINWK-V-76     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | black        | pXRF                    | Baofeng Liaoqiying                   |
| IINWK-V-72     | Eye bead       | Fu <i>et al.</i> 2014   | Henan | yellow       | pXRF                    | Xin zheng                            |
| HNWKII-85b     | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| HNWKII-86b     | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| HNWKII-86a     | Ornament glass | Dong <i>et al.</i> 2012 | Henan | white opaque | PIXE                    | Xue village site at Xing county      |
| /              | Eye bead       | Gan 2005                | Henan | /            | Unkown                  | M2 Tomb of Guwei Village, Hui County |
| 5: 7053        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | blue         | pXRF                    | Jingzhou Chu tomb                    |
| 5: 6855        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | blue         | pXRF                    | Jingzhou Chu tomb                    |
| 5: 2271        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | turquoise    | pXRF                    | Jingzhou Chu tomb                    |
| 5: 7053        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | green        | pXRF                    | Jingzhou Chu tomb                    |
| 5: 3491        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | blue         | pXRF                    | Jingzhou Chu tomb                    |
| 5: 3491        | Eye bead       | Li <i>et al.</i> 2013   | Hubei | yellow       | pXRF                    | Jingzhou Chu tomb                    |
| GHD-G-13-Blue1 | Eye bead       | Cui <i>et al.</i> 2009  | Hunan | white opaque | LA-ICP-AES              | Yuan Shui                            |
| GHD-G-13-Red1  | Eye bead       | Cui <i>et al.</i> 2009  | Hunan | white opaque | LA-ICP-AES              | Yuan Shui                            |
| GHD-G-12-White | Eye bead       | Cui <i>et al.</i> 2009  | Hunan | white opaque | LA-ICP-AES              | Yuan Shui                            |
| /              | Bi disk        | Gan 1984                | Hunan | white opaque | Unkown                  | Changsha City                        |
| /              | Bi disk        | Gan 1984                | Hunan | light green  | Laser Spectrum Analysis | Changsha City                        |
| /              | Bi disk        | Gan 1984                | Hunan | light green  | Laser Spectrum Analysis | Changsha City                        |
| /              | Bi disk        | Gan 1984                | Hunan | white opaque | Laser Spectrum Analysis | Hengyang                             |
| /              | Bi disk        | Gan 1984                | Hunan | dark green   | AAS                     | Unknown                              |
| GHD-G-11       | Bi disk        | Cui <i>et al.</i> 2009  | Hunan | white opaque | LA-ICP-AES              | Yuan Shui                            |
| GHD-G-10       | Bi disk        | Cui <i>et al.</i> 2009  | Hunan | white opaque | LA-ICP-AES              | Yuan Shui                            |



|             |               |                        |         |              |            |                                                         |
|-------------|---------------|------------------------|---------|--------------|------------|---------------------------------------------------------|
| GHD-G-01    | Bi disk       | Cui <i>et al.</i> 2009 | Hunan   | white opaque | LA-ICP-AES | Yuan Shui                                               |
| HSB 147-1   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | blue         | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-5   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | green        | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-1   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | blue         | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-2   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | blue         | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-5   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | blue         | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-1   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | white opaque | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-2   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | white opaque | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-5   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | white opaque | pXRF       | Yue Cemetery, Hongshan                                  |
| HSB 147-2   | Eye bead      | Xia <i>et al.</i> 2013 | Jiangsu | white opaque | pXRF       | Yue Cemetery, Hongshan                                  |
| ML: 3918-10 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| /           | Glass block   | Gan 2005               | Jiangsu | dark blue    | Unkown     | unknown                                                 |
| ML: 3918-9  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-4  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-20 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-15 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-3  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-7  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-21 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-6  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-11 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-13 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-5  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-2  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-15 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-14 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-17 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-16 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-9  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
|             | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-8  | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| ML: 3918-18 | Chime         | Gan 2016               | Jiangsu | pale green   | pXRF       | Dayun Mountain, Xuyi County                             |
| /           | Glass Garment | Gan 2005               | Jiangsu | white opaque | Unkown     | Tomb of "Concubine Moshu" in Guangling King's Mausoleum |
| /           | Glass vessel  | Gan 2005               | Jiangsu | /            | Unkown     | unknown                                                 |

|             |                |                         |         |              |         |                                                                        |
|-------------|----------------|-------------------------|---------|--------------|---------|------------------------------------------------------------------------|
| /           | Bi disk        | Gan 2005                | Jiangsu | green        | Unkown  | unknown                                                                |
| /           | Glass Garment  | Gan 2005                | Jiangsu | white opaque | Unkown  | unknown                                                                |
| /           | Ornament glass | Gan 2005                | Jiangsu | white opaque | Unkown  | unknown                                                                |
| MI: 3918-22 | Chime          | Gan 2016                | Jiangsu | pale green   | pXRF    | Dayun Mountain, Xuyi County                                            |
| MI: 3918-19 | Chime          | Gan 2016                | Jiangsu | pale green   | pXRF    | Dayun Mountain, Xuyi County                                            |
| /           | Ear pendant    | Gan 2009                | Qinghai | blue         | ICP-AES | Han Tomb M7 of Shangsunjiazhai, Datong, Qinghai                        |
| /           | Ear pendant    | Gan 2009                | Qinghai | blue         | EDX     | Han Tomb M6 of Shangsunjiazhai, Datong, Qinghai                        |
| /           | Ear pendant    | Gan 2009                | Qinghai | blue         | EDX     | Han Tomb M5 of Shangsunjiazhai, Datong, Qinghai                        |
| /           | Ear pendant    | Gan 2009                | Qinghai | green        | ICP-AES | Han Tomb M4 of Shangsunjiazhai, Datong, Qinghai                        |
| /           | Ear pendant    | Gan 2005                | Qinghai | green        | Unkown  | Han Tomb M4 of Shangsunjiazhai, Datong, Qinghai                        |
| Xi'an-16C   | Eye bead       | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Guanghua Rubber Shoes Factory M15:5                                    |
| Xi'an-6b    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Shijiaxingcheng Community M196                                         |
| Xi'an-4     | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Yidong 2000 M93: 12                                                    |
| Xi'an-9     | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | blue         | pXRF    | Qujiang Yanhu Community M16                                            |
| Xi'an-14    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Yahe City Garden Community, 91XY, M13                                  |
| Xi'an-12    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | blue         | pXRF    | Shijiaxingcheng Community M141: 29                                     |
| Xi'an-15b   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-9b    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | blue         | pXRF    | Qujiang Yanhu Community M16                                            |
| Xi'an-13    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | National Cotton Plant No. 5 M17: 40                                    |
| Xi'an-15    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-5     | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Ronghai Community M1                                                   |
| Xi'an-11    | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Yanxi Community M19                                                    |
| Xi'an-15f   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-1     | Eye bead       | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | South District of Xi'an University of Posts & Telecommunications M3: 4 |
| Xi'an-15c   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-16    | Eye bead       | Zhao <i>et al.</i> 2015 | Shaanxi | green        | pXRF    | Guanghua Rubber Shoes Factory M15:4                                    |
| Xi'an-6     | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Shijiaxingcheng Community M196                                         |
| Xi'an-14b   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Yahe City Garden Community, 91XY, M13                                  |
| Xi'an-15d   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-11b   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | dark blue    | pXRF    | Yanxi Community M19                                                    |
| Xi'an-15e   | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | turquoise    | pXRF    | Shijiaxingcheng Community M97                                          |
| Xi'an-8     | Ear pendant    | Zhao <i>et al.</i> 2015 | Shaanxi | blue         | pXRF    | China Century City Community M15: 35                                   |
| /           | Eye bead       | Gan 2009                | Sichuan | yellow       | PIXE    | unknown                                                                |
| /           | Bead           | Gan 2009                | Sichuan | green        | PIXE    | unknown                                                                |

|                      |             |                       |         |              |        |                                           |
|----------------------|-------------|-----------------------|---------|--------------|--------|-------------------------------------------|
| 44-18-36A            | Eye bead    | Gan 2016              | Sichuan | yellow       | PIXE   | unknown                                   |
| 44-18-36C            | Eye bead    | Gan 2016              | Sichuan | black        | PIXE   | unknown                                   |
| /                    | Bead        | Gan 2009              | Sichuan | yellow       | PIXE   | unknown                                   |
| /                    | Ear pendant | Gan 2009              | Sichuan | dark blue    | PIXE   | South Nanchong Station M27:2              |
| M27:2                | Ear pendant | Gan 2016              | Sichuan | blue         | PIXE   | Nanchong City East Railway Station M27: 2 |
| /                    | Ear pendant | Gan 2005              | Sichuan | light blue   | Unkown | Nanchong City East Railway Station        |
| /                    | Ear pendant | Gan 2009              | Sichuan | light blue   | PIXE   | South Nanchong Station M27:4              |
| /                    | Eye bead    | Gan 2009              | Sichuan | white opaque | PIXE   | unknown                                   |
| M40:1                | Ear pendant | Gan 2016              | Sichuan | blue         | PIXE   | Nanchong City East Railway Station M40: 1 |
| /                    | Ear pendant | Gan 2009              | Sichuan | dark blue    | PIXE   | South Nanchong Station M40:1              |
| M13-15               | Eye bead    | Gan 2009              | Sichuan | /            | PIXE   | Haojiaping, Qingchuan                     |
| /                    | Eye bead    | Gan 2009              | Sichuan | black        | PIXE   | Qingchuan Haojiaping M13:15               |
| /                    | Eye bead    | Gan 2005              | Sichuan | black        | Unkown | Dongsun Dam of Ba County                  |
| /                    | Eye bead    | Gan 2009              | Sichuan | black        | PIXE   | Qingchuan Haojiaping M13:16               |
| /                    | Eye bead    | Gan 2005              | Sichuan | black        | Unkown | M17, Haojiaping, Qingchuan County         |
| /                    | Eye bead    | Gan 2009              | Sichuan | blue         | PIXE   | unknown                                   |
| 44-18-36D            | Eye bead    | Gan 2016              | Sichuan | green        | PIXE   | unknown                                   |
| /                    | Eye bead    | Gan 2009              | Sichuan | black        | PIXE   | unknown                                   |
| 44-18-36C            | Eye bead    | Gan 2016              | Sichuan | green        | PIXE   | unknown                                   |
| /                    | Eye bead    | Gan 2009              | Sichuan | /            | PIXE   | Qingchuan Haojiaping M13:15               |
| /                    | Eye bead    | Gan 2009              | Sichuan | green        | PIXE   | Qingchuan Haojiaping M13:16               |
| /                    | Eye bead    | Gan 2005              | Sichuan | green        | Unkown | M14, Haojiaping, Qingchuan County         |
| /                    | Eye bead    | Gan 2009              | Sichuan | green        | PIXE   | Qingchuan Haojiaping M13:15               |
| M13:15(green eye)    | Eye bead    | Li <i>et al.</i> 2005 | Sichuan | green        | PIXE   | Qingchuan Haojiaping M13:15               |
| 44-18-36A            | Eye bead    | Gan 2016              | Sichuan | blue         | PIXE   | unknown                                   |
| /                    | Eye bead    | Gan 2009              | Sichuan | blue         | PIXE   | unknown                                   |
| 44-18-36C            | Eye bead    | Gan 2016              | Sichuan | white opaque | PIXE   | unknown                                   |
| /                    | Eye bead    | Gan 2009              | Sichuan | green        | PIXE   | unknown                                   |
| /                    | Eye bead    | Gan 2009              | Sichuan | yellow       | PIXE   | Qingchuan Haojiaping M13:16               |
| M13:16 ((yellow eye) | Eye bead    | Li <i>et al.</i> 2005 | Sichuan | yellow       | PIXE   | Qingchuan Haojiaping M13:16               |
| /                    | Bead        | Gan 2009              | Sichuan | green        | PIXE   | unknown                                   |
| 42-1-94              | Bead        | Gan 2016              | Sichuan | green        | PIXE   | unknown                                   |

|                     |                |                        |          |                   |                      |                                     |
|---------------------|----------------|------------------------|----------|-------------------|----------------------|-------------------------------------|
| M13:15 (yellow eye) | Eye bead       | Li <i>et al.</i> 2005  | Sichuan  | yellow            | PIXE                 | Qingchuan Haojiaping M13:15         |
| /                   | Eye bead       | Gan 2009               | Sichuan  | yellow            | PIXE                 | Qingchuan Haojiaping M13:15         |
| M13:16(yellow eye)  | Eye bead       | Li <i>et al.</i> 2005  | Sichuan  | yellow            | PIXE                 | Qingchuan Haojiaping M13:16         |
| /                   | Eye bead       | Gan 2009               | Sichuan  | yellow            | PIXE                 | Qingchuan Haojiaping M13:16         |
| 42-1-95             | Tubular bead   | Gan 2016               | Sichuan  | green             | PIXE                 | unknown                             |
| /                   | Bead           | Gan 2009               | Sichuan  | green             | PIXE                 | unknown                             |
| 42-1-95             | Tubular bead   | Gan 2016               | Sichuan  | green             | PIXE                 | unknown                             |
| C/18202             | Bead           | Gan 2016               | Sichuan  | green             | PIXE                 | unknown                             |
| /                   | Eye bead       | Gan 2009               | Sichuan  | black             | PIXE                 | unknown                             |
| 44-18-36D           | Eye bead       | Gan 2016               | Sichuan  | white opaque      | PIXE                 | unknown                             |
| /                   | Eye bead       | Gan 2009               | Sichuan  | green             | PIXE                 | unknown                             |
| XJ-42B(black)       | Eye bead       | Li <i>et al.</i> 2005  | Xinjiang | black             | PIXE                 | Ancient City of Akspiri             |
| /                   | Eye bead       | Gan 2005               | Xinjiang | black             | Unkown               | Ancient City of Akspil              |
| XJ-42B(white)       | Eye bead       | Li <i>et al.</i> 2005  | Xinjiang | white opaque      | PIXE                 | Ancient City of Akspiri             |
| XJ-42B(black)       | Eye bead       | Li <i>et al.</i> 2005  | Xinjiang | black             | PIXE                 | Ancient City of Akspiri             |
| XJ-42B(green)       | Eye bead       | Li <i>et al.</i> 2005  | Xinjiang | green             | PIXE                 | Ancient City of Akspiri             |
| srz-12-green        | Eye bead       | Wen <i>et al.</i> 2016 | Xinjiang | green             | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-13-blue1        | Eye bead       | Wen <i>et al.</i> 2016 | Xinjiang | blue              | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-12-black        | Eye bead       | Wen <i>et al.</i> 2016 | Xinjiang | black             | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-13-blue2        | Eye bead       | Wen <i>et al.</i> 2016 | Xinjiang | blue              | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-14              | Bead           | Wen <i>et al.</i> 2016 | Xinjiang | blue              | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-12-white        | Eye bead       | Wen <i>et al.</i> 2016 | Xinjiang | white opaque      | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| srz-15              | Bead           | Wen <i>et al.</i> 2016 | Xinjiang | blue              | LA-ICP-AES           | Shirenzigou Sites in Balikun County |
| /                   | Ear pendant    | Gan 1984               | Guangxi  | dark green        | Unkown               | Shaopingfeng M5                     |
| /                   | Ornament glass | Gan 2009               | Guangxi  | /                 | PIXE                 | Heguan M10                          |
| /                   | Ornament glass | Gan 2005               | Guangxi  | turquoise         | Unkown               | unknown                             |
| /                   | Eye bead       | Gan 2005               | unknown  | blue              | Unkown               | unknown                             |
| /                   | Eye bead       | Gan 2005               | unknown  | blue              | Unkown               | unknown                             |
| /                   | Eye bead       | Gan 2005               | unknown  | blue              | Unkown               | unknown                             |
| /                   | Eye bead       | Gan 2005               | unknown  | blue              | Unkown               | unknown                             |
| /                   | Ornament glass | Gan 2005               | unknown  | dark blue         | Unkown               | unknown                             |
| 3345                | Glass vessel   | Brill 1992             | unknown  | light blue opaque | Wet Chemistry Method | Unknown                             |

|    |                |            |         |              |                      |         |
|----|----------------|------------|---------|--------------|----------------------|---------|
| /  | Eye bead       | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Tubular bead   | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Tubular bead   | Gan 2005   | unknown | light blue   | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Ear pendant    | Gan 2005   | unknown | /            | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | yellow       | Unkown               | unknown |
| 50 | Bead           | Brill 1992 | unknown | dark blue    | Wet Chemistry Method | Unknown |
| /  | Tubular bead   | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Ear pendant    | Gan 2005   | unknown | /            | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | purple       | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | brown        | Unkown               | unknown |
| /  | Bi disk        | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | white opaque | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Tubular bead   | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | white opaque | Unkown               | unknown |
| /  | Bi disk        | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | brown        | Unkown               | unknown |
| /  | Tubular bead   | Gan 2005   | unknown | dark blue    | Unkown               | unknown |
| /  | Ornament glass | Gan 2005   | unknown | white opaque | Unkown               | unknown |
| 91 | Bead           | Brill 1992 | unknown | medium blue  | Wet Chemistry Method | Unknown |
| /  | Bi disk        | Gan 2005   | unknown | white opaque | Unkown               | unknown |
| /  | Bi disk        | Gan 2005   | unknown | green        | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |
| /  | Eye bead       | Gan 2005   | unknown | blue         | Unkown               | unknown |

|     |                |            |         |                 |                      |         |
|-----|----------------|------------|---------|-----------------|----------------------|---------|
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | blue            | Unkown               | unknown |
| 89  | Bead           | Brill 1992 | unknown | black           | Wet Chemistry Method | Unknown |
| G21 | Tubular bead   | Brill 1992 | unknown | greenish opaque | Wet Chemistry Method | Unknown |
| /   | Eye bead       | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | dark blue       | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Tubular bead   | Gan 2005   | unknown | turquoise       | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | dark blue       | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Bead           | Gan 2005   | unknown | turquoise       | Unkown               | unknown |
| /   | Ear pendant    | Gan 2005   | unknown | dark blue       | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Bi disk        | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | yellow          | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Bi disk        | Gan 2005   | unknown | dark green      | Unkown               | unknown |
| /   | Tubular bead   | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | green           | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Eye bead       | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | blue            | Unkown               | unknown |
| /   | Bead           | Gan 2005   | unknown | turquoise       | Unkown               | unknown |
| /   | Bi disk        | Gan 2005   | unknown | green           | Unkown               | unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |
| /   | Tubular bead   | Gan 2005   | unknown | dark blue       | Unkown               | unknown |
| 95  | Bead           | Brill 1992 | unknown | colourless      | Wet Chemistry Method | Unknown |
| /   | Ornament glass | Gan 2005   | unknown | white opaque    | Unkown               | unknown |

|      |                |            |         |                    |                      |         |
|------|----------------|------------|---------|--------------------|----------------------|---------|
| /    | Ornament glass | Gan 2005   | unknown | white opaque       | Unkown               | unknown |
| /    | Ornament glass | Gan 2005   | unknown | white opaque       | Unkown               | unknown |
| 52   | bead           | Brill 1992 | unknown | dark blue          | Wet Chemistry Method | Unknown |
| 73   | Ornament glass | Brill 1992 | unknown | /                  | Wet Chemistry Method | Unknown |
| /    | Ornament glass | Gan 2005   | unknown | purple             | Unkown               | unknown |
| /    | Bi disk        | Gan 2005   | unknown | dark green         | Unkown               | unknown |
| /    | Glass seal     | Gan 2005   | unknown | green              | Unkown               | unknown |
| /    | Eye bead       | Brill 1992 | unknown | dark blue          | Wet Chemistry Method | Unknown |
| /    | Glass seal     | Gan 2005   | unknown | green              | Unkown               | unknown |
| /    | Black bead     | Gan 2009   | unknown | black              | EMPA                 | unknown |
| 94   | Bead           | Brill 1992 | unknown | black              | Wet Chemistry Method | Unknown |
| 69   | Bead           | Brill 1992 | unknown | black              | Wet Chemistry Method | Unknown |
| 83   | Glass plaque   | Brill 1992 | unknown | colourless         | Wet Chemistry Method | Unknown |
| /    | Eye bead       | Gan 2005   | unknown | brown              | Unkown               | unknown |
| /    | Bi disk        | Gan 2005   | unknown | blue               | Unkown               | unknown |
| /    | Bi disk        | Brill 1992 | unknown | white opaque       | Wet Chemistry Method | Unknown |
| 92   | Bead           | Brill 1992 | unknown | turquoise          | Wet Chemistry Method | Unknown |
| /    | Black bead     | Gan 2009   | unknown | black              | EMPA                 | unknown |
| G53  | Glass Garment  | Brill 1992 | unknown | green opaque       | Wet Chemistry Method | Unknown |
| /    | Tubular bead   | Gan 2005   | unknown | green              | Unkown               | unknown |
| 3382 | Glass vessel   | Brill 1992 | unknown | light green turbid | Wet Chemistry Method | Unknown |
| /    | Tubular bead   | Gan 2005   | unknown | dark blue          | Unkown               | unknown |
| /    | Ornament glass | Gan 2005   | unknown | white opaque       | Unkown               | unknown |
| /    | Glass Garment  | Brill 1992 | unknown | white opaque       | Wet Chemistry Method | Unknown |
| 51   | Bead           | Brill 1992 | unknown | light blue         | Wet Chemistry Method | Unknown |
| 3383 | Bi disk        | Brill 1992 | unknown | dark green         | Wet Chemistry Method | Unknown |
| /    | Eye bead       | Gan 2005   | unknown | blue               | Unkown               | unknown |
| G41* | Ornament glass | Brill 1992 | unknown | white opaque       | Wet Chemistry Method | Unknown |
| /    | Bi disk        | Gan 2005   | unknown | white opaque       | Unkown               | unknown |
| 80   | Bi disk        | Brill 1992 | unknown | colourless         | Wet Chemistry Method | Unknown |
| G52* | Glass Garment  | Brill 1992 | unknown | white opaque       | Wet Chemistry Method | Unknown |
| /    | Ornament glass | Brill 1992 | unknown | white opaque       | Wet Chemistry Method | Unknown |
| 5892 | Glass plaque   | Brill 1992 | unknown | white turbid       | Wet Chemistry Method | Unknown |
| /    | Bead           | Gan 2005   | unknown | white opaque       | Unkown               | unknown |

|   |                |          |         |              |                      |                          |
|---|----------------|----------|---------|--------------|----------------------|--------------------------|
| / | Ornament glass | Gan 2005 | unknown | light blue   | Unkown               | unknown                  |
| / | Tubular bead   | Gan 2005 | unknown | blue         | Unkown               | unknown                  |
| / | Bead           | Gan 2005 | unknown | light blue   | Unkown               | unknown                  |
| / | Ornament glass | Gan 2005 | unknown | blue         | Unkown               | unknown                  |
| / | Bi disk        | Gan 2005 | unknown | white opaque | Unkown               | unknown                  |
| / | Bead           | Gan 2005 | Korea   | green        | Unkown               | unknown                  |
| / | Bi disk        | Gan 2005 | Anhui   | dark green   | Unkown               | unknown                  |
| / | Tubular bead   | Gan 2005 | Hebei   | green        | Unkown               | Zhongshan King, Pingshan |
| / | Tubular bead   | Gan 2005 | Hebei   | green        | Unkown               | Zhongshan King, Pingshan |
| / | Tubular bead   | Gan 2009 | Japan   | dark green   | Unknown              | unknown                  |
| / | Tubular bead   | Gan 1984 | Japan   | dark green   | AAS                  | Suku Okamoto             |
| / | Tubular bead   | Gan 2005 | Japan   | dark green   | Unkown               | unknown                  |
| / | Tubular bead   | Gan 1984 | Japan   | dark green   | AAS                  | Tateiwa                  |
| / | Tubular bead   | Gan 1984 | Japan   | dark green   | Wet Chemistry Method | Uki Kuda                 |
| / | Bi disk        | Gan 1984 | Japan   | dark green   | AAS                  | Unknown                  |

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## Data file S2

**Table 1 LA-ICP-MS analysis of glass chemical composition (major elements%)**

|             | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | MnO  | FeO  | Type         |
|-------------|-------------------|------|--------------------------------|------------------|-------------------------------|------------------|------|------------------|------|------|--------------|
| 08XYXM18-11 | 18.19             | 0.65 | 3.48                           | 68.96            | 0.24                          | 0.94             | 2.65 | 0.65             | 0.11 | 1.21 | Natron glass |
| LM1285-1-J  | 15.21             | 0.42 | 2.89                           | 70.01            | 0.03                          | 0.84             | 7.66 | 0.05             | 0.01 | 0.33 | Natron glass |
| LM1285-1-W  | 13.01             | 0.35 | 2.19                           | 51.40            | 0.02                          | 1.12             | 5.68 | 0.04             | 0.01 | 0.72 | Natron glass |
| LM1285-1-Y  | 14.05             | 0.51 | 2.38                           | 74.93            | 0.13                          | 1.00             | 6.36 | 0.06             | 0.01 | 0.29 | Natron glass |
| LM1285-1-B  | 17.38             | 0.59 | 2.75                           | 67.84            | 0.02                          | 1.02             | 7.62 | 0.07             | 0.01 | 1.89 | Natron glass |
| 5.772       | 20.10             | 1.20 | 2.73                           | 66.50            | 0.11                          | 0.53             | 6.05 | 0.22             | 0.65 | 0.98 | Natron glass |
| 5.43632-B   | 16.22             | 0.47 | 2.71                           | 67.09            | 0.07                          | 1.20             | 8.10 | 0.06             | 0.02 | 2.37 | Natron glass |
| 5.43632-W   | 14.40             | 0.48 | 2.55                           | 62.70            | 0.12                          | 0.98             | 7.83 | 0.07             | 0.01 | 0.46 | Natron glass |
| 5.43632-J   | 12.84             | 0.56 | 2.77                           | 72.18            | 0.14                          | 0.85             | 8.45 | 0.08             | 0.03 | 0.53 | Natron glass |
| 5.43633-B   | 16.48             | 0.48 | 2.69                           | 66.48            | 0.08                          | 1.02             | 8.63 | 0.06             | 0.02 | 2.42 | Natron glass |
| 5.43633-W   | 14.51             | 0.50 | 2.64                           | 62.11            | 0.07                          | 0.86             | 8.33 | 0.07             | 0.02 | 0.55 | Natron glass |
| 5.43633-J   | 14.77             | 0.49 | 2.95                           | 69.28            | 0.07                          | 0.77             | 8.54 | 0.06             | 0.11 | 0.43 | Natron glass |
| 5.43621-J   | 15.48             | 0.33 | 1.63                           | 67.65            | 0.16                          | 0.91             | 8.41 | 0.06             | 0.25 | 0.65 | Natron glass |
| 5.43621-W   | 12.08             | 0.22 | 1.29                           | 54.17            | 0.08                          | 1.23             | 4.86 | 0.06             | 0.01 | 0.59 | Natron glass |
| 5.43561-J   | 16.01             | 0.52 | 3.06                           | 68.31            | 0.10                          | 0.47             | 8.05 | 0.06             | 0.01 | 0.57 | Natron glass |
| 5.43561-W   | 12.96             | 0.38 | 2.24                           | 59.22            | 0.07                          | 0.42             | 7.50 | 0.06             | 0.01 | 0.38 | Natron glass |
| 5.43561-B   | 15.14             | 0.59 | 2.85                           | 64.42            | 0.11                          | 0.48             | 9.17 | 0.06             | 0.02 | 2.37 | Natron glass |
| LM1285-2-J  | 18.89             | 0.53 | 2.63                           | 66.18            | 0.13                          | 0.33             | 7.42 | 0.07             | 0.01 | 0.39 | Natron glass |
| LM1285-2-W  | 14.13             | 0.53 | 2.32                           | 60.38            | 0.12                          | 0.45             | 8.82 | 0.06             | 0.01 | 0.47 | Natron glass |
| LM1285-2-B  | 14.89             | 0.55 | 2.89                           | 65.08            | 0.08                          | 0.70             | 9.33 | 0.05             | 0.02 | 3.16 | Natron glass |
| 5.39178-J   | 14.46             | 0.72 | 2.56                           | 65.20            | 0.12                          | 0.99             | 8.53 | 0.07             | 0.02 | 0.48 | Natron glass |
| 5.39178-B   | 16.45             | 0.52 | 2.60                           | 67.37            | 0.11                          | 0.71             | 9.30 | 0.07             | 0.01 | 1.17 | Natron glass |
| 5.39178-W   | 10.32             | 0.31 | 1.53                           | 44.43            | 0.05                          | 0.60             | 5.08 | 0.04             | 0.01 | 0.44 | Natron glass |

|                 |       |      |       |       |      |      |       |      |      |       |               |
|-----------------|-------|------|-------|-------|------|------|-------|------|------|-------|---------------|
| 5.39178-G       | 16.54 | 0.58 | 2.30  | 68.90 | 0.12 | 0.63 | 9.63  | 0.08 | 0.37 | 0.67  | Natron glass  |
| 5.39205-W       | 10.81 | 0.59 | 2.83  | 70.93 | 0.09 | 1.30 | 8.21  | 0.06 | 0.01 | 0.35  | Natron glass  |
| 5.43621-B       | 15.59 | 0.31 | 1.91  | 66.07 | 0.08 | 1.81 | 5.68  | 0.09 | 0.01 | 2.63  | Natron glass  |
| 5.39205-J       | 15.69 | 0.57 | 2.81  | 66.90 | 0.15 | 1.89 | 9.01  | 0.07 | 0.04 | 1.66  | Natron glass  |
| 5.39205-B       | 16.12 | 0.71 | 2.93  | 68.05 | 0.11 | 1.63 | 8.52  | 0.08 | 0.02 | 1.14  | Natron glass  |
| SJM1S-2         | 19.68 | 3.92 | 0.68  | 64.83 | 0.30 | 1.07 | 6.00  | 0.02 | 0.01 | 0.43  | Natron glass  |
| M1ZC-4          | 18.61 | 3.65 | 1.63  | 65.83 | 0.22 | 1.14 | 5.16  | 0.04 | 0.01 | 0.40  | Natron glass  |
| 2018ZHCM226-7-R | 2.54  | 0.38 | 1.74  | 35.14 | 1.36 | 2.06 | 2.17  | 0.07 | 0.01 | 15.28 | Pb-Ba faience |
| 2018ZHCM226-7-W | 0.22  | 0.20 | 8.87  | 38.13 | 0.08 | 1.37 | 1.69  | 0.11 | 0.00 | 0.19  | Pb-Ba faience |
| 2018ZHCM226-7-B | 4.04  | 0.36 | 4.19  | 61.84 | 0.07 | 1.83 | 1.06  | 0.08 | 0.01 | 0.26  | Pb-Ba faience |
| 20102XHM4-2-1-R | 0.60  | 0.40 | 3.43  | 26.60 | 1.75 | 0.42 | 2.04  | 0.18 | 0.01 | 39.04 | Pb-Ba faience |
| 20102XHM4-2-1-W | 0.55  | 7.90 | 2.43  | 48.75 | 9.58 | 0.88 | 14.31 | 0.16 | 0.02 | 0.91  | Pb-Ba faience |
| 20102XHM4-2-1-Y | 0.48  | 0.30 | 15.28 | 31.21 | 0.74 | 0.58 | 1.50  | 0.68 | 0.00 | 9.09  | Pb-Ba faience |
| 20102XHM4-2-2-J | 0.34  | 1.29 | 13.56 | 38.94 | 0.41 | 1.24 | 4.48  | 0.72 | 0.04 | 5.58  | Pb-Ba faience |
| 20102XHM4-2-3-B | 0.64  | 0.22 | 4.88  | 56.53 | 0.50 | 0.26 | 1.69  | 0.24 | 0.01 | 1.11  | Pb-Ba faience |
| 20102XHM4-2-3-J | 0.17  | 6.36 | 3.55  | 64.13 | 5.48 | 0.46 | 10.52 | 0.26 | 0.03 | 2.07  | Pb-Ba faience |
| 20102XHM4-2-3-R | 1.65  | 0.33 | 2.61  | 31.45 | 1.19 | 0.71 | 2.41  | 0.09 | 0.00 | 23.09 | Pb-Ba faience |
| 20102XHM4-2-3-W | 0.52  | 0.51 | 13.87 | 38.86 | 0.50 | 0.95 | 6.02  | 0.35 | 0.00 | 0.57  | Pb-Ba faience |
| 20102XHM4-2-3-Y | 0.36  | 0.27 | 15.06 | 32.86 | 0.90 | 0.40 | 1.32  | 0.69 | 0.00 | 7.54  | Pb-Ba faience |
| 20102XHM4-2-4-B | 0.49  | 0.27 | 5.59  | 64.86 | 0.53 | 0.26 | 1.79  | 0.32 | 0.01 | 0.97  | Pb-Ba faience |
| 20102XHM4-2-4-R | 0.47  | 0.33 | 4.19  | 33.54 | 1.07 | 0.47 | 2.60  | 0.09 | 0.00 | 19.55 | Pb-Ba faience |
| 20102XHM4-2-4-W | 0.23  | 0.14 | 5.22  | 18.39 | 0.22 | 0.38 | 2.96  | 0.14 | 0.00 | 0.29  | Pb-Ba faience |
| 20102XHM4-2-4-Y | 0.27  | 0.37 | 14.55 | 31.23 | 0.71 | 0.36 | 1.63  | 0.74 | 0.00 | 7.08  | Pb-Ba faience |
| 20102XHM4-2-5-B | 0.68  | 0.55 | 4.88  | 66.49 | 0.45 | 0.23 | 2.21  | 0.19 | 0.01 | 1.37  | Pb-Ba faience |
| 20102XHM4-2-5-R | 1.98  | 0.22 | 1.28  | 36.73 | 0.09 | 0.83 | 1.16  | 0.06 | 0.00 | 14.19 | Pb-Ba faience |
| 20102XHM4-2-5-W | 1.09  | 0.42 | 12.09 | 57.80 | 0.30 | 0.89 | 4.42  | 0.32 | 0.00 | 0.60  | Pb-Ba faience |
| 20102XHM4-2-5-Y | 0.22  | 0.42 | 15.30 | 39.53 | 0.54 | 0.58 | 1.95  | 0.68 | 0.00 | 6.59  | Pb-Ba faience |
| 20102XHM4-2-6-B | 4.91  | 0.39 | 4.37  | 52.08 | 0.11 | 0.64 | 1.79  | 0.11 | 0.02 | 0.48  | Pb-Ba faience |

|                   |      |       |       |       |       |      |       |      |      |       |               |
|-------------------|------|-------|-------|-------|-------|------|-------|------|------|-------|---------------|
| 20102XHM4-2-6-R   | 1.32 | 0.56  | 2.78  | 36.92 | 0.98  | 0.33 | 2.59  | 0.12 | 0.01 | 18.01 | Pb-Ba faience |
| 20102XHM4-2-6-Y   | 0.63 | 1.77  | 11.98 | 37.65 | 0.64  | 0.63 | 3.55  | 0.62 | 0.02 | 5.75  | Pb-Ba faience |
| 20102XHM4-2-7-B   | 2.84 | 0.54  | 2.77  | 50.97 | 0.09  | 0.88 | 2.25  | 0.11 | 0.02 | 0.74  | Pb-Ba faience |
| 20102XHM4-2-7-R   | 0.68 | 0.19  | 1.80  | 35.12 | 0.30  | 0.96 | 2.10  | 0.09 | 0.01 | 28.51 | Pb-Ba faience |
| 20102XHM4-2-7-Y   | 0.20 | 0.32  | 14.42 | 35.22 | 0.79  | 1.10 | 1.27  | 0.74 | 0.00 | 7.08  | Pb-Ba faience |
| 2018ZHCM398-3-1-B | 3.98 | 0.22  | 4.53  | 54.54 | 0.28  | 1.64 | 0.95  | 0.08 | 0.03 | 0.50  | Pb-Ba faience |
| 2018ZHCM398-3-1-R | 0.13 | 0.23  | 1.92  | 22.20 | 5.48  | 0.07 | 4.00  | 0.09 | 0.00 | 39.89 | Pb-Ba faience |
| 2018ZHCM398-3-1-W | 2.39 | 0.26  | 8.56  | 59.12 | 0.09  | 0.89 | 2.16  | 0.14 | 0.00 | 0.28  | Pb-Ba faience |
| 2018ZHCM398-3-2-B | 3.77 | 0.24  | 4.79  | 52.25 | 0.07  | 1.28 | 0.75  | 0.10 | 0.01 | 0.33  | Pb-Ba faience |
| 2018ZHCM398-3-2-R | 0.19 | 0.24  | 2.03  | 18.69 | 6.38  | 0.25 | 3.37  | 0.09 | 0.00 | 39.76 | Pb-Ba faience |
| 2018ZHCM398-3-2-W | 1.74 | 0.41  | 13.83 | 47.59 | 1.63  | 0.78 | 5.74  | 0.23 | 0.01 | 0.47  | Pb-Ba faience |
| M19-3-R           | 0.77 | 0.65  | 4.16  | 33.92 | 0.27  | 1.62 | 4.59  | 0.21 | 0.04 | 6.40  | Pb-Ba faience |
| M19-3-W           | 1.67 | 0.19  | 6.33  | 50.15 | 0.06  | 1.44 | 3.68  | 0.03 | 0.01 | 0.31  | Pb-Ba faience |
| M657-1-J          | 0.66 | 7.24  | 3.43  | 48.45 | 10.78 | 4.19 | 20.37 | 0.15 | 0.08 | 0.75  | Pb-Ba faience |
| M657-1-P          | 0.38 | 0.48  | 11.23 | 41.49 | 0.57  | 1.65 | 2.38  | 0.21 | 0.00 | 0.86  | Pb-Ba faience |
| M657-1-R          | 3.26 | 0.27  | 1.86  | 42.95 | 0.07  | 1.72 | 1.31  | 0.06 | 0.01 | 16.02 | Pb-Ba faience |
| M657-1-W          | 3.34 | 0.29  | 6.46  | 55.08 | 0.06  | 2.13 | 1.22  | 0.10 | 0.01 | 0.15  | Pb-Ba faience |
| M657-3-B          | 1.48 | 0.34  | 1.99  | 46.63 | 0.34  | 0.41 | 1.52  | 0.10 | 0.01 | 0.72  | Pb-Ba faience |
| M657-3-J          | 0.70 | 10.23 | 4.77  | 54.13 | 3.58  | 0.94 | 17.17 | 1.15 | 0.04 | 1.81  | Pb-Ba faience |
| M657-3-R          | 1.43 | 0.22  | 0.34  | 31.18 | 0.08  | 0.76 | 0.95  | 0.01 | 0.00 | 13.65 | Pb-Ba faience |
| M657-3-W          | 2.60 | 0.20  | 4.44  | 52.47 | 0.12  | 0.85 | 1.24  | 0.14 | 0.00 | 0.23  | Pb-Ba faience |
| M657-3-Y          | 0.09 | 0.45  | 11.35 | 26.02 | 0.86  | 0.27 | 2.20  | 0.66 | 0.01 | 4.93  | Pb-Ba faience |
| 20102XHM4-2-1-J   | 0.43 | 7.55  | 6.98  | 59.02 | 4.26  | 1.37 | 16.47 | 0.27 | 0.06 | 2.25  | Pb-Ba faience |
| 20102XHM4-2-1-B   | 0.79 | 0.17  | 2.17  | 47.07 | 0.43  | 0.11 | 1.46  | 0.19 | 0.01 | 0.80  | Pb-Ba faience |
| M-4-YD            | 5.78 | 0.17  | 0.49  | 37.65 | 0.09  | 0.06 | 0.58  | 0.02 | 0.00 | 0.26  | Pb-Ba glass   |
| 5.29754-B         | 8.45 | 0.78  | 0.93  | 44.31 | 0.06  | 0.04 | 0.63  | 0.02 | 0.00 | 0.18  | Pb-Ba glass   |
| 5.29754-W         | 7.81 | 0.61  | 0.32  | 43.36 | 0.03  | 0.07 | 0.56  | 0.01 | 0.00 | 0.12  | Pb-Ba glass   |
| 5.29754-J         | 8.84 | 0.81  | 0.93  | 47.64 | 0.03  | 0.04 | 0.43  | 0.02 | 0.00 | 0.13  | Pb-Ba glass   |

|           |      |      |      |       |      |      |      |      |      |      |             |
|-----------|------|------|------|-------|------|------|------|------|------|------|-------------|
| 1301Bi    | 2.81 | 0.33 | 0.94 | 32.35 | 0.05 | 0.13 | 0.66 | 0.01 | 0.01 | 0.07 | Pb-Ba glass |
| TSS-43-4  | 4.89 | 0.11 | 0.22 | 28.38 | 0.01 | 0.10 | 0.21 | 0.00 | 0.00 | 0.07 | Pb-Ba glass |
| TSS-43-3  | 3.86 | 0.09 | 0.24 | 27.93 | 0.01 | 0.16 | 0.25 | 0.01 | 0.00 | 0.08 | Pb-Ba glass |
| TSS-43-2  | 2.91 | 0.24 | 0.78 | 30.22 | 0.09 | 0.25 | 2.00 | 0.03 | 0.02 | 0.64 | Pb-Ba glass |
| TSS-33-1  | 6.03 | 1.90 | 0.72 | 40.66 | 0.06 | 0.03 | 3.63 | 0.04 | 0.02 | 0.66 | Pb-Ba glass |
| TSS-33-2  | 5.12 | 1.02 | 0.28 | 39.15 | 0.02 | 0.07 | 1.58 | 0.01 | 0.01 | 0.16 | Pb-Ba glass |
| TSS-33-3  | 3.20 | 0.21 | 0.69 | 28.47 | 0.07 | 0.23 | 1.46 | 0.03 | 0.01 | 0.28 | Pb-Ba glass |
| TSS-33-4  | 6.96 | 0.84 | 0.47 | 39.53 | 0.03 | 0.02 | 1.76 | 0.02 | 0.01 | 0.35 | Pb-Ba glass |
| TSS-33-5  | 6.01 | 1.84 | 0.72 | 41.16 | 0.06 | 0.02 | 3.55 | 0.03 | 0.02 | 0.61 | Pb-Ba glass |
| TSS-33-6  | 2.18 | 0.30 | 0.32 | 28.65 | 0.08 | 0.21 | 1.37 | 0.02 | 0.01 | 0.17 | Pb-Ba glass |
| TSS-43-G  | 2.63 | 0.19 | 0.61 | 29.06 | 0.02 | 0.15 | 0.59 | 0.02 | 0.00 | 0.12 | Pb-Ba glass |
| TSS-43-BL | 2.64 | 0.19 | 0.64 | 28.77 | 0.02 | 0.15 | 0.58 | 0.02 | 0.00 | 0.11 | Pb-Ba glass |
| TSS-43-1  | 2.94 | 0.23 | 0.86 | 29.62 | 0.10 | 0.26 | 1.79 | 0.03 | 0.01 | 0.54 | Pb-Ba glass |
| TSS-43-5  | 2.83 | 0.23 | 0.72 | 27.44 | 0.09 | 0.23 | 1.92 | 0.03 | 0.02 | 0.41 | Pb-Ba glass |
| SJM1S-4   | 5.18 | 0.43 | 0.45 | 37.87 | 0.02 | 0.12 | 1.12 | 0.01 | 0.00 | 0.09 | Pb-Ba glass |
| C3-3      | 4.80 | 0.32 | 0.97 | 41.66 | 0.02 | 0.37 | 1.16 | 0.02 | 0.01 | 0.33 | Pb-Ba glass |
| SR15-12   | 5.93 | 0.50 | 0.49 | 39.51 | 0.01 | 0.05 | 1.30 | 0.01 | 0.00 | 0.14 | Pb-Ba glass |
| SJM16     | 5.35 | 0.41 | 0.44 | 37.91 | 0.03 | 0.14 | 1.27 | 0.01 | 0.00 | 0.16 | Pb-Ba glass |
| S13-370-1 | 8.03 | 1.14 | 1.05 | 48.05 | 0.00 | 0.10 | 0.99 | 0.02 | 0.00 | 0.18 | Pb-Ba glass |
| S12-97-2  | 4.34 | 0.39 | 0.22 | 29.48 | 0.02 | 0.04 | 0.99 | 0.01 | 0.00 | 0.09 | Pb-Ba glass |
| S22-60-1  | 4.23 | 0.40 | 0.24 | 31.51 | 0.01 | 0.05 | 1.09 | 0.01 | 0.00 | 0.10 | Pb-Ba glass |
| S6-148A-J | 8.87 | 1.04 | 1.09 | 47.52 | 0.02 | 0.06 | 0.90 | 0.01 | 0.00 | 0.19 | Pb-Ba glass |
| S6-148A-G | 9.61 | 1.04 | 1.00 | 49.21 | 0.00 | 0.06 | 0.83 | 0.03 | 0.00 | 0.13 | Pb-Ba glass |
| S6-148A-W | 9.02 | 1.05 | 1.01 | 48.55 | 0.01 | 0.07 | 0.81 | 0.05 | 0.00 | 0.14 | Pb-Ba glass |
| SJMIS-1   | 7.39 | 0.80 | 0.83 | 45.43 | 0.01 | 0.03 | 0.66 | 0.14 | 0.00 | 0.33 | Pb-Ba glass |

**Table 2 LA-ICP-MS analysis of glass chemical composition (trace elements ppm)**

|             | Sc   | V     | Cr    | Co      | Ni    | Cu       | Zn     | Ga    | Ge   | Rb    | Sr     | Y     | Zr      | Nb    | Mo   | Ag   | Cd   | Sn      | Sb        | Cs   | Ba     | La    |
|-------------|------|-------|-------|---------|-------|----------|--------|-------|------|-------|--------|-------|---------|-------|------|------|------|---------|-----------|------|--------|-------|
| 08XYXM18-11 | 8.58 | 65.66 | 69.57 | 13.18   | 40.37 | 15649.75 | 81.00  | 4.25  | 0.18 | 32.02 | 188.15 | 15.75 | 1284.86 | 10.04 | 2.24 | 7.85 | 0.03 | 2903.41 | 21.39     | 0.65 | 324.56 | 26.99 |
| LM1285-1-J  | 4.56 | 6.89  | 8.90  | 38.45   | 6.31  | 8293.54  | 22.16  | 3.90  | 0.00 | 10.27 | 463.10 | 7.76  | 37.27   | 1.03  | 0.24 | 0.21 | 0.05 | 10.44   | 10417.95  | 0.46 | 213.41 | 5.44  |
| LM1285-1-W  | 2.71 | 5.39  | 3.13  | 1.61    | 2.95  | 78.06    | 16.72  | 2.37  | 0.18 | 10.93 | 344.33 | 5.83  | 30.40   | 0.98  | 0.29 | 0.40 | 0.04 | 3.76    | 190701.37 | 0.00 | 153.47 | 6.45  |
| LM1285-1-Y  | 4.03 | 6.69  | 14.69 | 1.20    | 1.29  | 28.99    | 25.29  | 1.01  | 1.30 | 10.46 | 433.49 | 6.93  | 47.92   | 1.53  | 0.29 | 0.43 | 0.00 | 3.61    | 1088.75   | 0.70 | 165.83 | 6.58  |
| LM1285-1-B  | 4.48 | 6.87  | 9.91  | 1705.03 | 11.27 | 1577.77  | 989.51 | 30.47 | 1.52 | 9.76  | 431.22 | 7.47  | 46.52   | 1.06  | 0.53 | 0.14 | 0.05 | 4.25    | 543.79    | 0.21 | 195.36 | 6.13  |
| 5.772       | 5.45 | 25.54 | 14.88 | 5.80    | 6.24  | 196.68   | 34.05  | 2.76  | 0.14 | 5.12  | 512.26 | 8.35  | 111.10  | 3.18  | 2.26 | 0.21 | 0.13 | 9.18    | 5278.29   | 0.04 | 245.65 | 7.37  |
| 5.43632-B   | 4.56 | 5.60  | 8.12  | 1005.78 | 7.93  | 4495.02  | 202.98 | 13.64 | 0.64 | 12.41 | 480.29 | 7.14  | 34.18   | 0.90  | 0.87 | 0.17 | 0.10 | 2.83    | 5786.50   | 0.38 | 215.07 | 6.31  |
| 5.43632-W   | 3.42 | 6.21  | 10.43 | 17.39   | 2.16  | 898.43   | 29.41  | 2.75  | 0.58 | 11.96 | 427.51 | 7.52  | 36.36   | 1.29  | 0.28 | 0.22 | 0.12 | 4.01    | 76129.27  | 0.30 | 183.79 | 6.85  |
| 5.43632-J   | 3.92 | 7.44  | 4.20  | 24.36   | 7.19  | 10385.97 | 25.58  | 2.24  | 0.70 | 11.15 | 424.20 | 7.77  | 42.61   | 1.50  | 0.75 | 0.51 | 0.04 | 21.00   | 497.76    | 0.32 | 202.16 | 6.12  |
| 5.43633-B   | 3.19 | 5.44  | 3.88  | 931.41  | 7.04  | 3711.71  | 197.06 | 13.04 | 0.63 | 12.55 | 483.99 | 7.69  | 35.39   | 1.56  | 0.81 | 0.11 | 0.13 | 3.47    | 5995.91   | 0.43 | 210.55 | 6.18  |
| 5.43633-W   | 3.33 | 6.75  | 7.82  | 17.27   | 2.89  | 621.69   | 25.89  | 3.01  | 0.01 | 11.15 | 447.80 | 7.88  | 42.19   | 1.58  | 0.46 | 0.11 | 0.00 | 3.11    | 75962.00  | 0.12 | 179.21 | 7.09  |
| 5.43633-J   | 3.90 | 7.17  | 7.33  | 3.52    | 5.53  | 11080.97 | 17.19  | 2.69  | 0.59 | 10.79 | 478.22 | 7.32  | 34.72   | 1.27  | 0.31 | 0.60 | 0.02 | 271.62  | 7232.75   | 0.19 | 215.48 | 6.56  |
| 5.43621-J   | 4.52 | 7.27  | 9.70  | 199.01  | 8.86  | 16327.52 | 82.74  | 4.77  | 0.27 | 8.00  | 299.11 | 5.60  | 31.69   | 1.22  | 0.38 | 0.69 | 0.14 | 22.27   | 15339.32  | 0.39 | 417.35 | 4.33  |
| 5.43621-W   | 3.20 | 5.03  | 5.29  | 433.02  | 5.97  | 871.48   | 130.91 | 6.81  | 0.39 | 10.39 | 223.18 | 3.78  | 30.01   | 1.33  | 0.16 | 0.25 | 0.08 | 2.57    | 189060.75 | 0.11 | 123.80 | 4.11  |
| 5.43561-J   | 3.86 | 6.78  | 10.95 | 5.47    | 7.02  | 8019.14  | 13.33  | 2.72  | 0.40 | 7.29  | 459.07 | 6.91  | 36.06   | 1.25  | 0.40 | 3.03 | 0.22 | 404.89  | 10914.86  | 0.54 | 194.26 | 6.19  |
| 5.43561-W   | 3.56 | 5.82  | 8.01  | 18.99   | 3.77  | 52.48    | 21.08  | 2.14  | 0.17 | 6.01  | 375.77 | 6.27  | 43.86   | 1.10  | 0.20 | 0.62 | 0.06 | 1.98    | 125205.19 | 0.33 | 149.39 | 5.33  |
| 5.43561-B   | 4.54 | 4.61  | 10.81 | 2689.87 | 13.60 | 2553.49  | 506.87 | 26.28 | 1.62 | 7.37  | 471.45 | 7.75  | 38.81   | 1.60  | 0.73 | 0.60 | 0.44 | 52.69   | 28588.79  | 0.34 | 184.35 | 6.23  |
| LM1285-2-J  | 1.12 | 7.08  | 7.86  | 12.28   | 4.91  | 7760.11  | 9.17   | 2.07  | 0.00 | 5.58  | 413.35 | 5.56  | 35.61   | 1.42  | 0.00 | 1.11 | 0.00 | 385.42  | 16674.93  | 0.00 | 178.94 | 5.44  |
| LM1285-2-W  | 4.63 | 5.18  | 8.45  | 38.60   | 5.34  | 119.50   | 40.63  | 2.13  | 0.53 | 5.57  | 408.55 | 0.00  | 35.79   | 1.45  | 0.17 | 0.17 | 0.00 | 4.44    | 94459.56  | 0.04 | 192.20 | 5.73  |
| LM1285-2-B  | 3.74 | 7.07  | 10.53 | 2560.48 | 13.57 | 2855.54  | 506.70 | 30.33 | 2.39 | 9.02  | 482.40 | 7.01  | 34.72   | 1.24  | 0.69 | 0.13 | 0.20 | 10.08   | 17031.13  | 0.23 | 190.61 | 6.18  |
| 5.39178-J   | 3.87 | 8.00  | 5.97  | 2.97    | 6.13  | 6060.38  | 53.68  | 2.05  | 0.30 | 14.58 | 458.34 | 7.01  | 51.24   | 1.53  | 0.11 | 0.80 | 0.08 | 37.76   | 44315.58  | 0.43 | 173.00 | 5.26  |
| 5.39178-B   | 3.52 | 7.95  | 11.13 | 959.50  | 9.35  | 2187.87  | 29.58  | 6.63  | 0.37 | 10.53 | 517.64 | 7.89  | 45.32   | 1.18  | 0.74 | 0.64 | 0.19 | 4.26    | 8390.96   | 0.00 | 177.50 | 6.81  |
| 5.39178-W   | 2.44 | 3.79  | 2.31  | 2.02    | 2.34  | 117.09   | 18.82  | 1.20  | 0.05 | 7.85  | 282.40 | 4.72  | 35.83   | 1.19  | 0.22 | 0.23 | 0.06 | 2.19    | 279051.13 | 0.13 | 93.75  | 5.06  |
| 5.39178-G   | 4.17 | 12.13 | 6.49  | 3.08    | 7.49  | 67.20    | 14.07  | 2.45  | 0.47 | 7.73  | 453.82 | 6.82  | 56.75   | 1.40  | 0.52 | 1.58 | 0.09 | 1.93    | 116.89    | 0.26 | 335.04 | 6.24  |

|                 |       |        |        |         |        |          |        |       |       |       |         |       |        |       |       |        |      |         |          |      |           |        |
|-----------------|-------|--------|--------|---------|--------|----------|--------|-------|-------|-------|---------|-------|--------|-------|-------|--------|------|---------|----------|------|-----------|--------|
| 5.39205-W       | 3.52  | 6.21   | 10.67  | 1.99    | 7.55   | 39.66    | 15.90  | 3.23  | 0.37  | 10.08 | 453.40  | 7.58  | 40.69  | 1.72  | 0.21  | 0.64   | 0.00 | 1.23    | 35113.93 | 0.32 | 209.85    | 7.70   |
| 5.43621-B       | 4.91  | 9.40   | 0.86   | 3135.59 | 16.61  | 3096.66  | 549.27 | 33.82 | 1.09  | 14.63 | 251.46  | 5.30  | 48.62  | 1.52  | 1.29  | 0.10   | 0.43 | 7.85    | 35664.58 | 0.86 | 137.16    | 5.79   |
| 5.39205-J       | 4.28  | 9.44   | 12.20  | 2331.12 | 147.22 | 4651.24  | 462.62 | 18.01 | 15.64 | 10.49 | 451.88  | 7.69  | 39.26  | 1.40  | 1.35  | 0.32   | 0.00 | 182.93  | 7.47     | 0.05 | 229.83    | 7.39   |
| 5.39205-B       | 4.12  | 8.64   | 11.64  | 1219.57 | 77.16  | 2315.72  | 240.62 | 10.76 | 7.83  | 9.96  | 483.20  | 7.98  | 49.44  | 1.92  | 0.80  | 0.53   | 0.00 | 120.27  | 4.80     | 0.17 | 213.76    | 7.52   |
| SJM1S-2         | 2.83  | 2.83   | 12.03  | 4.27    | 4.76   | 8276.47  | 11.57  | 1.06  | 0.13  | 12.48 | 244.53  | 2.51  | 20.89  | 1.19  | 1.72  | 0.92   | 0.00 | 26.69   | 9843.03  | 0.14 | 41.36     | 2.56   |
| M1ZC-4          | 3.87  | 4.62   | 9.16   | 1.53    | 7.49   | 10016.67 | 12.28  | 2.29  | 0.10  | 18.80 | 219.34  | 2.85  | 32.52  | 2.65  | 0.95  | 0.95   | 0.21 | 214.98  | 10911.29 | 0.20 | 40.67     | 2.51   |
| 2018ZHCM226-7-R | 3.03  | 122.88 | 15.57  | 2.92    | 23.78  | 5375.41  | 70.05  | 2.72  | 2.11  | 24.75 | 725.71  | 2.96  | 25.62  | 2.06  | 11.06 | 12.57  | 0.00 | 80.76   | 180.54   | 0.85 | 20107.51  | 137.91 |
| 2018ZHCM226-7-W | 2.81  | 5.01   | 2.91   | 0.26    | 3.24   | 603.80   | 26.01  | 9.12  | 0.17  | 7.28  | 3319.50 | 3.13  | 59.46  | 3.90  | 0.36  | 8.32   | 0.34 | 1.32    | 181.34   | 0.10 | 97802.84  | 19.24  |
| 2018ZHCM226-7-B | 4.61  | 5.53   | 3.53   | 3.07    | 12.40  | 35140.43 | 112.29 | 4.73  | 0.16  | 24.63 | 2213.06 | 8.53  | 25.31  | 2.79  | 0.57  | 11.93  | 0.24 | 1.01    | 51.04    | 0.48 | 85568.51  | 12.46  |
| 20102XHM4-2-1-R | 3.59  | 210.20 | 39.01  | 3.94    | 24.30  | 8443.59  | 40.33  | 2.45  | 4.33  | 10.08 | 348.38  | 8.82  | 76.25  | 6.69  | 2.27  | 7.63   | 0.42 | 609.89  | 176.94   | 0.59 | 14101.67  | 9.04   |
| 20102XHM4-2-1-W | 5.01  | 81.26  | 30.19  | 1.22    | 6.76   | 1128.80  | 49.86  | 2.52  | 0.00  | 10.67 | 1452.06 | 12.20 | 21.75  | 3.19  | 1.36  | 61.73  | 0.00 | 1382.71 | 10.73    | 1.81 | 16464.62  | 34.14  |
| 20102XHM4-2-1-Y | 7.27  | 168.47 | 57.86  | 0.71    | 4.72   | 2009.51  | 42.76  | 12.63 | 0.62  | 10.86 | 1483.86 | 9.00  | 199.53 | 21.46 | 0.12  | 1.01   | 0.05 | 352.64  | 286.48   | 0.62 | 183080.75 | 8.00   |
| 20102XHM4-2-2-J | 11.52 | 51.20  | 95.99  | 4.08    | 5.96   | 2731.93  | 64.09  | 12.06 | 0.27  | 37.43 | 3532.91 | 14.74 | 224.13 | 13.69 | 0.30  | 111.07 | 0.00 | 7.75    | 29.30    | 2.66 | 224293.35 | 17.15  |
| 20102XHM4-2-3-B | 6.67  | 13.62  | 29.15  | 1.22    | 1.79   | 59864.11 | 55.57  | 2.98  | 0.09  | 4.51  | 2033.55 | 9.39  | 60.20  | 7.03  | 1.49  | 11.54  | 0.26 | 172.02  | 51.48    | 0.41 | 185645.76 | 9.92   |
| 20102XHM4-2-3-J | 7.85  | 28.57  | 31.06  | 1.83    | 5.22   | 4208.58  | 42.10  | 0.88  | 0.29  | 9.16  | 556.36  | 12.96 | 37.93  | 3.66  | 1.29  | 12.48  | 0.00 | 6.67    | 13.06    | 0.00 | 2047.83   | 23.77  |
| 20102XHM4-2-3-R | 2.99  | 176.03 | 28.53  | 3.01    | 15.57  | 6117.85  | 71.92  | 4.72  | 2.96  | 11.86 | 1322.96 | 7.59  | 28.23  | 4.20  | 4.23  | 28.56  | 0.10 | 45.66   | 405.12   | 0.50 | 62886.79  | 6.52   |
| 20102XHM4-2-3-W | 4.21  | 25.89  | 25.25  | 0.37    | 0.83   | 1571.86  | 39.69  | 10.25 | 0.14  | 9.15  | 4401.58 | 14.33 | 106.62 | 12.41 | 0.51  | 6.06   | 0.55 | 26.80   | 257.76   | 0.00 | 150043.85 | 43.97  |
| 20102XHM4-2-3-Y | 9.73  | 138.93 | 55.92  | 0.97    | 4.28   | 3645.99  | 48.03  | 12.82 | 0.77  | 7.01  | 1076.41 | 13.00 | 200.05 | 22.37 | 0.47  | 3.40   | 0.07 | 80.64   | 1149.37  | 0.37 | 172752.95 | 11.63  |
| 20102XHM4-2-4-B | 4.95  | 35.03  | 38.33  | 1.06    | 1.91   | 29122.98 | 40.76  | 2.83  | 0.33  | 6.06  | 1302.44 | 7.82  | 53.59  | 8.30  | 6.78  | 4.89   | 0.15 | 160.11  | 92.19    | 0.28 | 120886.65 | 8.08   |
| 20102XHM4-2-4-R | 3.47  | 272.91 | 194.73 | 1.12    | 10.26  | 1857.67  | 25.50  | 6.45  | 2.17  | 7.69  | 705.87  | 14.81 | 40.68  | 5.09  | 5.95  | 10.01  | 0.00 | 14.88   | 379.89   | 0.30 | 33695.30  | 8.52   |
| 20102XHM4-2-4-W | 2.12  | 18.85  | 22.23  | 0.13    | 1.05   | 136.62   | 14.82  | 3.95  | 0.06  | 2.42  | 3704.33 | 4.20  | 44.84  | 4.14  | 0.75  | 4.85   | 0.05 | 8.86    | 129.47   | 0.19 | 81266.89  | 20.25  |
| 20102XHM4-2-4-Y | 10.32 | 165.69 | 119.02 | 1.72    | 10.94  | 990.83   | 51.55  | 12.14 | 0.72  | 8.30  | 1164.48 | 13.28 | 181.12 | 23.43 | 1.19  | 24.17  | 0.33 | 112.98  | 693.55   | 0.31 | 166551.88 | 14.92  |
| 20102XHM4-2-5-B | 5.24  | 20.08  | 19.60  | 2.51    | 2.27   | 66932.81 | 43.62  | 1.60  | 0.05  | 3.98  | 3143.67 | 5.27  | 49.84  | 8.22  | 1.30  | 4.95   | 0.08 | 5.45    | 32.32    | 0.24 | 72944.29  | 5.88   |
| 20102XHM4-2-5-R | 2.61  | 107.11 | 6.48   | 3.15    | 9.86   | 561.93   | 87.82  | 2.87  | 2.60  | 13.23 | 179.61  | 1.35  | 12.86  | 2.03  | 6.33  | 33.37  | 0.04 | 1.66    | 421.38   | 0.56 | 854.84    | 2.29   |
| 20102XHM4-2-5-W | 4.23  | 15.85  | 28.60  | 0.42    | 1.17   | 549.79   | 24.02  | 7.56  | 0.35  | 6.00  | 1892.18 | 5.26  | 65.75  | 9.84  | 0.58  | 12.53  | 0.55 | 7.16    | 13.50    | 0.06 | 24063.49  | 29.47  |
| 20102XHM4-2-5-Y | 10.91 | 120.96 | 76.08  | 1.05    | 3.99   | 1916.03  | 53.35  | 11.52 | 0.76  | 13.54 | 871.84  | 12.35 | 179.26 | 21.53 | 0.32  | 2.39   | 0.21 | 8.07    | 203.96   | 0.51 | 110134.56 | 13.76  |

|                   |       |        |        |       |       |          |        |       |      |       |         |       |        |       |       |        |      |         |         |      |           |        |
|-------------------|-------|--------|--------|-------|-------|----------|--------|-------|------|-------|---------|-------|--------|-------|-------|--------|------|---------|---------|------|-----------|--------|
| 20102XHM4-2-6-B   | 4.13  | 9.18   | 5.70   | 3.99  | 12.67 | 55607.53 | 98.50  | 5.06  | 0.13 | 13.21 | 3728.54 | 9.81  | 33.90  | 3.53  | 1.39  | 90.06  | 0.19 | 40.59   | 17.02   | 0.38 | 141324.78 | 16.55  |
| 20102XHM4-2-6-R   | 3.52  | 160.53 | 36.19  | 4.38  | 33.99 | 11188.27 | 51.47  | 5.60  | 3.00 | 8.91  | 1009.78 | 6.59  | 27.23  | 3.71  | 5.18  | 66.88  | 0.18 | 4.29    | 292.91  | 0.29 | 45041.48  | 5.83   |
| 20102XHM4-2-6-Y   | 14.58 | 92.07  | 76.69  | 4.02  | 40.95 | 5847.34  | 42.71  | 11.22 | 0.80 | 21.73 | 921.08  | 13.44 | 138.01 | 11.28 | 0.36  | 21.86  | 0.30 | 20.76   | 4810.13 | 0.28 | 114411.86 | 13.66  |
| 20102XHM4-2-7-B   | 4.37  | 10.42  | 14.55  | 8.39  | 11.55 | 74454.41 | 149.55 | 3.36  | 0.13 | 10.84 | 5380.30 | 14.32 | 41.27  | 3.09  | 0.82  | 29.00  | 0.33 | 808.29  | 49.79   | 0.23 | 223331.45 | 14.48  |
| 20102XHM4-2-7-R   | 3.20  | 184.22 | 13.03  | 5.56  | 20.84 | 874.87   | 91.31  | 4.33  | 4.04 | 17.34 | 1419.38 | 3.72  | 24.44  | 3.50  | 6.20  | 40.42  | 0.04 | 253.55  | 276.56  | 0.61 | 48521.29  | 4.19   |
| 20102XHM4-2-7-Y   | 11.39 | 177.92 | 57.88  | 1.06  | 7.29  | 2165.95  | 41.71  | 18.42 | 1.03 | 40.44 | 771.11  | 12.93 | 178.21 | 22.00 | 0.38  | 3.48   | 0.09 | 342.91  | 111.87  | 0.33 | 161701.25 | 15.77  |
| 2018ZHCM398-3-1-B | 5.75  | 7.19   | 4.31   | 10.85 | 5.57  | 38927.50 | 103.11 | 5.97  | 0.15 | 30.86 | 2982.78 | 5.39  | 32.24  | 3.19  | 1.74  | 282.08 | 0.23 | 4.48    | 256.10  | 0.87 | 114164.57 | 15.81  |
| 2018ZHCM398-3-1-R | 3.17  | 363.99 | 154.84 | 2.20  | 18.11 | 914.75   | 27.21  | 2.45  | 4.43 | 1.57  | 335.80  | 4.87  | 27.33  | 3.75  | 3.98  | 40.41  | 0.06 | 12.93   | 563.82  | 0.07 | 14233.26  | 6.10   |
| 2018ZHCM398-3-1-W | 6.41  | 7.34   | 12.36  | 0.40  | 1.78  | 731.30   | 21.75  | 7.67  | 0.16 | 17.20 | 2495.84 | 2.60  | 42.44  | 5.18  | 0.89  | 130.35 | 0.00 | 3.52    | 284.69  | 0.57 | 106344.90 | 12.60  |
| 2018ZHCM398-3-2-B | 5.10  | 6.06   | 6.23   | 3.89  | 8.70  | 49219.35 | 73.47  | 4.87  | 0.13 | 23.43 | 2909.86 | 7.02  | 45.77  | 3.56  | 0.50  | 21.72  | 0.03 | 2.41    | 67.07   | 1.08 | 110588.97 | 13.96  |
| 2018ZHCM398-3-2-R | 2.57  | 320.58 | 51.07  | 3.68  | 43.53 | 1391.25  | 41.41  | 4.04  | 4.09 | 3.33  | 337.19  | 4.41  | 26.51  | 3.32  | 6.78  | 2.39   | 0.18 | 121.18  | 63.73   | 0.30 | 15441.27  | 5.39   |
| 2018ZHCM398-3-2-W | 5.80  | 132.40 | 29.37  | 0.52  | 4.39  | 397.52   | 61.29  | 12.03 | 0.17 | 11.01 | 912.46  | 8.87  | 66.88  | 5.94  | 1.62  | 2.48   | 0.00 | 13.66   | 10.00   | 0.29 | 94969.34  | 51.33  |
| M19-3-R           | 5.94  | 71.25  | 27.37  | 6.25  | 17.10 | 42419.13 | 170.47 | 7.23  | 0.92 | 37.17 | 412.22  | 20.71 | 64.58  | 5.51  | 2.25  | 180.13 | 0.38 | 894.54  | 287.32  | 1.51 | 10353.34  | 20.77  |
| M19-3-W           | 4.84  | 8.15   | 4.93   | 0.55  | 2.16  | 473.32   | 24.73  | 7.67  | 0.37 | 35.23 | 290.95  | 4.33  | 32.67  | 2.42  | 0.19  | 96.16  | 0.11 | 7.68    | 184.63  | 0.94 | 1691.34   | 4.53   |
| M657-1-J          | 5.56  | 15.43  | 23.88  | 7.98  | 17.46 | 6665.58  | 28.98  | 3.41  | 0.32 | 32.94 | 914.28  | 6.08  | 22.37  | 3.51  | 10.26 | 44.93  | 0.19 | 6.79    | 9.78    | 0.62 | 1600.60   | 13.74  |
| M657-1-P          | 6.11  | 21.13  | 20.83  | 8.93  | 4.74  | 62702.71 | 53.61  | 7.86  | 1.31 | 17.86 | 1560.80 | 9.20  | 63.00  | 5.76  | 12.21 | 5.02   | 0.00 | 23.10   | 36.59   | 0.00 | 213696.20 | 622.04 |
| M657-1-R          | 3.29  | 87.09  | 8.54   | 3.95  | 15.32 | 4004.42  | 46.14  | 3.61  | 2.49 | 32.87 | 478.36  | 2.89  | 21.36  | 4.16  | 4.92  | 96.86  | 0.00 | 5.61    | 843.72  | 0.58 | 17431.41  | 3.90   |
| M657-1-W          | 3.38  | 5.08   | 9.18   | 0.79  | 16.01 | 8968.67  | 24.73  | 7.16  | 0.29 | 27.90 | 3193.18 | 3.75  | 34.17  | 3.69  | 1.37  | 47.46  | 0.00 | 1.25    | 18.82   | 0.35 | 110903.33 | 14.01  |
| M657-3-B          | 3.50  | 26.47  | 16.34  | 6.32  | 13.92 | 49968.29 | 60.85  | 2.35  | 0.42 | 7.04  | 3827.95 | 7.19  | 14.59  | 2.57  | 1.09  | 77.52  | 0.56 | 14.32   | 264.18  | 0.27 | 195897.07 | 7.62   |
| M657-3-J          | 7.48  | 58.16  | 50.08  | 17.31 | 28.11 | 8315.26  | 45.06  | 4.58  | 0.57 | 32.80 | 659.00  | 17.98 | 34.70  | 15.06 | 1.35  | 56.72  | 2.01 | 35.39   | 22.67   | 4.03 | 430.43    | 13.45  |
| M657-3-R          | 1.97  | 34.11  | 5.00   | 1.42  | 11.18 | 1095.43  | 78.52  | 5.36  | 2.14 | 10.30 | 3193.15 | 5.44  | 3.25   | 0.35  | 3.97  | 112.34 | 0.17 | 12.70   | 207.99  | 0.19 | 165480.83 | 3.99   |
| M657-3-W          | 3.34  | 13.10  | 7.55   | 2.72  | 5.54  | 2290.55  | 29.39  | 5.66  | 0.07 | 10.42 | 2510.54 | 5.32  | 36.97  | 4.73  | 0.36  | 107.21 | 0.19 | 12.17   | 207.27  | 0.00 | 114690.30 | 10.03  |
| M657-3-Y          | 11.09 | 109.42 | 45.36  | 12.35 | 16.46 | 23410.38 | 64.50  | 11.44 | 0.59 | 7.12  | 2216.42 | 16.16 | 153.24 | 16.13 | 1.03  | 9.56   | 0.28 | 38.76   | 236.67  | 0.23 | 136740.31 | 19.53  |
| 20102XHM4-2-1-J   | 10.08 | 43.54  | 26.14  | 6.62  | 21.32 | 702.32   | 28.14  | 8.24  | 0.18 | 11.67 | 1072.57 | 12.19 | 42.41  | 3.77  | 2.17  | 6.93   | 0.00 | 90.22   | 2.35    | 1.58 | 606.11    | 20.04  |
| 20102XHM4-2-1-B   | 4.86  | 18.52  | 11.70  | 0.94  | 3.21  | 96289.30 | 77.98  | 0.22  | 0.07 | 1.54  | 2811.38 | 6.31  | 34.39  | 4.00  | 0.66  | 2.65   | 0.28 | 2962.15 | 10.87   | 0.17 | 259846.50 | 6.40   |
| M-4-YD            | 3.28  | 4.92   | 2.22   | 0.48  | 2.87  | 185.70   | 33.74  | 0.82  | 0.13 | 1.54  | 4384.37 | 2.34  | 7.18   | 0.43  | 0.18  | 17.78  | 0.10 | 3.05    | 416.66  | 0.17 | 165030.92 | 3.30   |



|           |      |      |      |        |       |         |        |      |      |      |         |      |       |      |      |        |      |         |         |      |           |      |
|-----------|------|------|------|--------|-------|---------|--------|------|------|------|---------|------|-------|------|------|--------|------|---------|---------|------|-----------|------|
| 5.29754-B | 3.03 | 1.79 | 0.00 | 0.83   | 1.69  | 5509.62 | 122.11 | 0.53 | 2.70 | 0.75 | 2385.17 | 3.30 | 8.49  | 0.83 | 0.14 | 2.51   | 1.01 | 8.13    | 104.79  | 0.06 | 108986.13 | 2.70 |
| 5.29754-W | 2.28 | 1.55 | 4.44 | 0.50   | 0.82  | 161.47  | 27.27  | 0.00 | 1.49 | 1.23 | 2419.98 | 4.02 | 3.95  | 0.40 | 0.00 | 2.09   | 0.00 | 10.80   | 75.87   | 0.14 | 121836.44 | 1.99 |
| 5.29754-J | 2.33 | 1.28 | 3.47 | 0.50   | 0.00  | 5546.88 | 133.81 | 0.50 | 1.61 | 0.96 | 2345.26 | 3.39 | 7.97  | 0.78 | 0.05 | 2.99   | 1.15 | 7.82    | 106.94  | 0.52 | 104838.70 | 2.46 |
| 1301Bi    | 1.50 | 2.04 | 1.53 | 0.43   | 2.83  | 54.14   | 17.04  | 0.96 | 0.38 | 2.94 | 1594.93 | 1.93 | 4.92  | 0.50 | 0.15 | 1.32   | 0.15 | 2.58    | 2.97    | 0.11 | 89956.44  | 1.03 |
| TSS-43-4  | 1.51 | 0.62 | 1.23 | 0.90   | 6.73  | 1927.70 | 22.14  | 0.25 | 0.11 | 1.15 | 1715.25 | 1.29 | 2.37  | 0.18 | 0.03 | 223.47 | 0.06 | 0.63    | 610.77  | 0.09 | 118952.80 | 1.65 |
| TSS-43-3  | 1.37 | 0.93 | 0.38 | 0.71   | 2.71  | 2077.54 | 17.56  | 0.24 | 0.05 | 1.78 | 1296.93 | 1.19 | 2.64  | 0.18 | 0.28 | 464.34 | 0.03 | 0.69    | 1019.12 | 0.21 | 91648.39  | 1.70 |
| TSS-43-2  | 2.04 | 4.54 | 4.02 | 304.45 | 11.94 | 773.33  | 25.83  | 3.04 | 0.24 | 4.08 | 1549.06 | 2.58 | 12.05 | 0.79 | 0.34 | 474.60 | 0.04 | 507.89  | 708.70  | 0.28 | 115562.32 | 3.01 |
| TSS-33-1  | 2.79 | 4.01 | 3.60 | 407.14 | 8.70  | 187.81  | 18.62  | 2.76 | 0.36 | 0.88 | 741.20  | 3.43 | 16.32 | 0.91 | 0.46 | 1.43   | 0.02 | 1027.11 | 513.36  | 0.07 | 87764.73  | 2.94 |
| TSS-33-2  | 1.93 | 1.25 | 0.21 | 296.39 | 16.16 | 404.77  | 24.25  | 0.77 | 0.32 | 1.20 | 2299.96 | 2.14 | 7.94  | 0.28 | 0.04 | 1.35   | 0.01 | 1486.61 | 128.50  | 0.25 | 121378.45 | 1.69 |
| TSS-33-3  | 1.97 | 3.95 | 2.62 | 284.96 | 7.07  | 543.03  | 22.69  | 1.48 | 0.17 | 3.86 | 1655.61 | 2.54 | 11.17 | 0.75 | 0.37 | 340.23 | 0.02 | 542.12  | 1627.83 | 0.13 | 128215.95 | 3.14 |
| TSS-33-4  | 2.42 | 2.64 | 2.19 | 347.47 | 12.79 | 198.13  | 31.92  | 1.26 | 0.75 | 0.90 | 1938.30 | 1.92 | 13.67 | 0.56 | 0.54 | 2.32   | 0.00 | 1482.41 | 172.65  | 0.29 | 75299.16  | 3.02 |
| TSS-33-5  | 2.10 | 3.66 | 1.34 | 402.68 | 8.38  | 187.97  | 19.08  | 2.90 | 0.27 | 0.62 | 737.91  | 3.40 | 16.41 | 0.86 | 0.29 | 1.56   | 0.13 | 1024.43 | 495.45  | 0.21 | 81577.95  | 3.10 |
| TSS-33-6  | 1.54 | 3.11 | 2.50 | 314.14 | 15.55 | 1337.05 | 24.45  | 0.87 | 0.23 | 2.81 | 1830.11 | 2.69 | 10.81 | 0.41 | 0.81 | 114.39 | 0.00 | 1761.14 | 158.87  | 0.26 | 124280.25 | 2.13 |
| TSS-43-G  | 1.55 | 2.59 | 0.08 | 1.59   | 9.26  | 3458.86 | 41.55  | 0.77 | 0.06 | 2.37 | 1160.08 | 2.18 | 9.29  | 0.48 | 0.20 | 123.35 | 0.06 | 2.43    | 320.50  | 0.24 | 91006.89  | 2.43 |
| TSS-43-BL | 1.50 | 2.48 | 0.77 | 1.88   | 8.64  | 3513.10 | 37.50  | 0.81 | 0.13 | 2.50 | 1171.05 | 2.06 | 9.42  | 0.46 | 0.12 | 124.84 | 0.37 | 2.40    | 308.33  | 0.17 | 92752.01  | 2.46 |
| TSS-43-1  | 1.82 | 4.06 | 2.88 | 328.73 | 7.90  | 402.99  | 23.62  | 3.12 | 0.11 | 4.80 | 1534.18 | 2.68 | 12.39 | 0.68 | 0.33 | 512.92 | 0.00 | 451.70  | 927.00  | 0.20 | 112993.88 | 3.10 |
| TSS-43-5  | 2.21 | 3.66 | 3.62 | 298.14 | 10.22 | 753.30  | 23.29  | 2.74 | 0.29 | 3.82 | 1515.59 | 2.52 | 11.34 | 0.73 | 0.45 | 505.23 | 0.12 | 513.90  | 696.60  | 0.22 | 117765.13 | 2.95 |
| SJM1S-4   | 2.79 | 1.95 | 0.24 | 14.72  | 3.86  | 3040.41 | 44.31  | 0.73 | 0.40 | 1.68 | 924.77  | 3.33 | 5.45  | 0.45 | 0.02 | 49.99  | 0.07 | 23.64   | 497.23  | 0.00 | 86090.64  | 1.41 |
| C3-3      | 2.99 | 2.33 | 1.32 | 91.04  | 5.32  | 4328.24 | 30.50  | 1.37 | 0.81 | 5.24 | 1760.33 | 4.30 | 9.93  | 0.87 | 0.07 | 40.60  | 0.11 | 115.78  | 600.52  | 0.34 | 97739.52  | 2.70 |
| SR15-12   | 2.13 | 2.87 | 1.24 | 12.51  | 4.84  | 3995.53 | 57.69  | 0.34 | 0.03 | 1.14 | 844.70  | 3.16 | 6.18  | 0.44 | 0.19 | 71.47  | 0.09 | 23.93   | 739.11  | 0.10 | 77729.87  | 1.28 |
| SJM16     | 2.91 | 2.30 | 1.22 | 13.79  | 3.93  | 3250.23 | 44.29  | 0.97 | 0.18 | 2.00 | 913.71  | 3.49 | 5.35  | 0.46 | 0.40 | 56.30  | 0.22 | 21.05   | 515.76  | 0.23 | 87436.36  | 1.31 |
| S13-370-1 | 2.89 | 2.37 | 2.11 | 0.29   | 2.08  | 5283.70 | 134.83 | 1.14 | 0.62 | 1.68 | 1446.22 | 2.46 | 9.91  | 0.71 | 0.00 | 2.91   | 0.01 | 4387.46 | 223.37  | 0.49 | 48909.53  | 2.50 |
| S12-97-2  | 1.10 | 2.17 | 0.96 | 25.92  | 4.00  | 2541.99 | 22.13  | 0.42 | 0.04 | 0.60 | 1854.01 | 2.40 | 4.21  | 0.41 | 0.39 | 4.27   | 0.01 | 63.26   | 79.09   | 0.05 | 151801.28 | 2.40 |
| S22-60-1  | 1.43 | 2.35 | 0.71 | 27.03  | 4.07  | 2607.49 | 22.93  | 0.60 | 0.09 | 0.77 | 1880.11 | 2.60 | 4.80  | 0.35 | 0.35 | 4.83   | 0.07 | 67.65   | 73.36   | 0.10 | 152735.98 | 2.44 |
| S6-148A-J | 2.17 | 1.63 | 1.03 | 0.55   | 1.48  | 4129.34 | 115.07 | 0.89 | 0.02 | 1.28 | 1468.50 | 1.42 | 11.07 | 0.90 | 0.05 | 3.92   | 0.21 | 4576.60 | 119.93  | 0.04 | 42942.49  | 2.88 |
| S6-148A-G | 1.79 | 1.02 | 1.38 | 0.39   | 0.67  | 3395.04 | 110.94 | 0.76 | 0.34 | 0.84 | 1470.85 | 1.45 | 10.04 | 0.95 | 0.02 | 1.32   | 0.12 | 4640.16 | 122.28  | 0.07 | 36707.13  | 2.34 |

|           |      |      |      |      |      |         |        |      |      |      |         |      |      |      |      |      |      |         |        |      |          |      |
|-----------|------|------|------|------|------|---------|--------|------|------|------|---------|------|------|------|------|------|------|---------|--------|------|----------|------|
| S6-148A-W | 2.26 | 1.03 | 0.77 | 0.44 | 2.29 | 3508.68 | 101.93 | 0.88 | 0.00 | 1.81 | 1515.55 | 1.57 | 9.92 | 0.75 | 0.03 | 1.63 | 0.16 | 4396.48 | 117.83 | 0.05 | 42604.12 | 2.51 |
| SJMIS-1   | 2.26 | 2.07 | 1.51 | 0.45 | 2.96 | 5390.21 | 100.42 | 0.54 | 0.11 | 1.03 | 2155.50 | 1.63 | 8.43 | 0.78 | 0.01 | 8.22 | 0.38 | 44.30   | 140.33 | 0.10 | 88902.63 | 2.13 |

**Continued to Table 2**

|             | Ce    | Pr   | Nd    | Sm   | Eu   | Gd   | Tb   | Dy   | Ho   | Er   | Tm   | Yb   | Lu   | Hf    | Ta   | W    | Au   | Hg   | Pb      | Bi   | Th   | U     |
|-------------|-------|------|-------|------|------|------|------|------|------|------|------|------|------|-------|------|------|------|------|---------|------|------|-------|
| 08XYXM18-11 | 38.13 | 5.54 | 20.74 | 3.31 | 0.85 | 3.46 | 0.45 | 2.41 | 0.51 | 1.57 | 0.27 | 1.66 | 0.31 | 29.00 | 0.70 | 0.51 | 0.00 | 0.00 | 1676.24 | 0.76 | 8.90 | 12.60 |
| LM1285-1-J  | 11.87 | 1.24 | 6.95  | 1.67 | 0.63 | 1.17 | 0.35 | 0.79 | 0.20 | 0.41 | 0.10 | 0.71 | 0.06 | 0.78  | 0.11 | 0.13 | 0.00 | 0.00 | 28.37   | 0.01 | 0.82 | 2.34  |
| LM1285-1-W  | 9.33  | 1.21 | 5.59  | 1.34 | 0.39 | 1.36 | 0.16 | 1.19 | 0.26 | 0.60 | 0.07 | 0.60 | 0.07 | 0.92  | 0.15 | 0.04 | 0.00 | 0.00 | 165.15  | 0.03 | 0.56 | 2.32  |
| LM1285-1-Y  | 11.13 | 1.74 | 8.26  | 2.12 | 0.72 | 2.30 | 0.10 | 1.24 | 0.27 | 0.47 | 0.03 | 1.07 | 0.09 | 1.44  | 0.00 | 0.11 | 0.00 | 0.00 | 10.58   | 0.00 | 0.77 | 2.91  |
| LM1285-1-B  | 11.89 | 1.57 | 8.32  | 1.80 | 0.26 | 1.82 | 0.18 | 1.87 | 0.24 | 1.11 | 0.11 | 0.65 | 0.09 | 1.18  | 0.07 | 0.02 | 0.00 | 0.00 | 23.03   | 0.03 | 0.72 | 3.36  |
| 5.772       | 16.17 | 1.85 | 9.38  | 1.90 | 0.42 | 1.47 | 0.42 | 1.96 | 0.25 | 0.97 | 0.07 | 1.04 | 0.15 | 3.56  | 0.22 | 0.14 | 0.00 | 0.00 | 158.27  | 0.07 | 1.77 | 1.27  |
| 5.43632-B   | 12.06 | 1.62 | 7.89  | 1.94 | 0.40 | 1.30 | 0.23 | 1.32 | 0.25 | 0.61 | 0.09 | 0.51 | 0.06 | 0.93  | 0.11 | 0.03 | 0.00 | 0.00 | 153.48  | 0.06 | 0.84 | 1.59  |
| 5.43632-W   | 10.99 | 1.61 | 6.27  | 1.61 | 0.47 | 1.20 | 0.18 | 1.77 | 0.29 | 0.58 | 0.07 | 0.72 | 0.06 | 1.01  | 0.11 | 0.02 | 0.00 | 0.00 | 430.69  | 0.03 | 0.80 | 1.76  |
| 5.43632-J   | 11.92 | 1.70 | 6.94  | 1.40 | 0.48 | 1.51 | 0.32 | 1.92 | 0.21 | 0.59 | 0.14 | 0.32 | 0.09 | 0.99  | 0.19 | 0.02 | 0.00 | 0.00 | 687.39  | 0.10 | 1.04 | 2.48  |
| 5.43633-B   | 11.86 | 1.32 | 7.98  | 1.63 | 0.54 | 1.61 | 0.23 | 1.31 | 0.29 | 0.83 | 0.08 | 0.73 | 0.05 | 0.43  | 0.12 | 0.01 | 0.00 | 0.00 | 418.72  | 0.02 | 0.86 | 1.74  |
| 5.43633-W   | 12.38 | 1.54 | 6.22  | 1.74 | 0.65 | 1.59 | 0.26 | 1.27 | 0.28 | 0.92 | 0.11 | 0.68 | 0.07 | 0.78  | 0.12 | 0.06 | 0.00 | 0.00 | 458.72  | 0.01 | 0.88 | 1.87  |
| 5.43633-J   | 12.13 | 1.60 | 6.68  | 2.35 | 0.29 | 1.57 | 0.21 | 1.99 | 0.24 | 0.61 | 0.09 | 0.42 | 0.06 | 0.88  | 0.11 | 0.00 | 0.00 | 0.00 | 307.55  | 0.10 | 0.66 | 1.78  |
| 5.43621-J   | 7.31  | 1.03 | 3.53  | 1.14 | 0.30 | 1.00 | 0.27 | 1.35 | 0.24 | 0.42 | 0.13 | 0.51 | 0.11 | 0.87  | 0.14 | 0.01 | 0.00 | 0.00 | 1874.23 | 0.48 | 0.62 | 0.70  |
| 5.43621-W   | 6.59  | 0.91 | 2.99  | 0.67 | 0.22 | 1.12 | 0.11 | 1.02 | 0.11 | 0.25 | 0.05 | 0.44 | 0.06 | 0.64  | 0.10 | 0.00 | 0.00 | 0.00 | 67.37   | 0.05 | 0.45 | 0.60  |
| 5.43561-J   | 11.21 | 1.72 | 7.54  | 1.69 | 0.51 | 1.77 | 0.12 | 1.56 | 0.19 | 0.60 | 0.20 | 0.79 | 0.11 | 0.87  | 0.16 | 0.12 | 0.00 | 0.00 | 1509.96 | 4.11 | 0.98 | 1.85  |
| 5.43561-W   | 8.94  | 1.34 | 6.05  | 1.07 | 0.34 | 1.27 | 0.24 | 1.00 | 0.31 | 0.34 | 0.11 | 0.82 | 0.02 | 0.89  | 0.19 | 0.04 | 0.00 | 0.00 | 68.48   | 0.03 | 0.70 | 1.34  |
| 5.43561-B   | 11.22 | 1.56 | 6.27  | 1.58 | 0.45 | 1.22 | 0.25 | 1.28 | 0.32 | 0.94 | 0.13 | 0.79 | 0.07 | 1.17  | 0.10 | 0.01 | 0.00 | 0.00 | 519.80  | 0.71 | 0.75 | 1.68  |
| LM1285-2-J  | 10.91 | 2.07 | 3.87  | 1.44 | 0.31 | 1.35 | 0.56 | 1.21 | 0.25 | 1.10 | 0.21 | 0.61 | 0.14 | 1.08  | 0.43 | 0.28 | 0.00 | 0.00 | 383.29  | 2.39 | 1.09 | 4.79  |
| LM1285-2-W  | 9.61  | 1.49 | 6.80  | 1.27 | 0.44 | 0.84 | 0.31 | 0.70 | 0.32 | 0.44 | 0.09 | 0.29 | 0.09 | 1.01  | 0.17 | 0.02 | 0.00 | 0.00 | 160.95  | 0.08 | 0.72 | 2.71  |
| LM1285-2-B  | 11.62 | 1.70 | 5.17  | 0.93 | 0.51 | 1.64 | 0.28 | 1.57 | 0.43 | 0.97 | 0.08 | 0.71 | 0.06 | 0.83  | 0.16 | 0.06 | 0.00 | 0.00 | 21.34   | 0.05 | 0.81 | 1.65  |
| 5.39178-J   | 11.32 | 1.51 | 5.41  | 0.76 | 0.47 | 0.73 | 0.23 | 1.00 | 0.22 | 0.79 | 0.06 | 0.77 | 0.09 | 0.97  | 0.10 | 0.09 | 0.00 | 0.00 | 569.48  | 0.10 | 0.93 | 3.22  |
| 5.39178-B   | 11.55 | 1.78 | 6.57  | 1.29 | 0.46 | 1.76 | 0.27 | 1.56 | 0.26 | 0.70 | 0.08 | 0.54 | 0.03 | 0.67  | 0.16 | 0.12 | 0.00 | 0.00 | 74.64   | 0.00 | 0.73 | 3.95  |
| 5.39178-W   | 7.21  | 0.87 | 3.57  | 0.67 | 0.31 | 0.89 | 0.16 | 0.71 | 0.17 | 0.26 | 0.06 | 0.44 | 0.03 | 0.62  | 0.06 | 0.00 | 0.00 | 0.00 | 125.99  | 0.02 | 0.50 | 2.38  |

|                 |       |       |       |      |      |      |      |      |      |      |      |      |      |      |      |        |      |      |           |       |       |      |
|-----------------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|--------|------|------|-----------|-------|-------|------|
| 5.39178-G       | 10.73 | 1.34  | 6.40  | 1.17 | 0.44 | 0.64 | 0.25 | 1.09 | 0.31 | 0.87 | 0.09 | 0.53 | 0.02 | 1.48 | 0.20 | 0.05   | 0.00 | 0.00 | 67.18     | 0.03  | 0.90  | 3.95 |
| 5.39205-W       | 12.25 | 1.70  | 6.62  | 1.16 | 0.51 | 1.22 | 0.21 | 1.32 | 0.23 | 1.11 | 0.07 | 1.19 | 0.13 | 0.79 | 0.17 | 0.00   | 0.00 | 0.00 | 26.20     | 0.01  | 1.10  | 3.11 |
| 5.43621-B       | 8.09  | 1.25  | 2.57  | 0.45 | 0.09 | 0.87 | 0.22 | 1.08 | 0.10 | 0.30 | 0.06 | 0.39 | 0.10 | 2.07 | 0.16 | 0.13   | 0.00 | 0.00 | 39.62     | 0.02  | 0.91  | 0.69 |
| 5.39205-J       | 11.94 | 1.78  | 7.76  | 1.44 | 0.58 | 1.62 | 0.27 | 1.30 | 0.30 | 0.84 | 0.07 | 1.10 | 0.08 | 1.01 | 0.09 | 0.02   | 0.00 | 0.00 | 96.51     | 0.02  | 1.00  | 2.01 |
| 5.39205-B       | 13.37 | 1.95  | 8.21  | 1.55 | 0.50 | 2.05 | 0.29 | 1.64 | 0.27 | 0.96 | 0.13 | 1.13 | 0.08 | 1.30 | 0.23 | 0.04   | 0.00 | 0.00 | 63.64     | 0.02  | 1.20  | 3.88 |
| SJM1S-2         | 5.38  | 0.58  | 1.96  | 0.46 | 0.07 | 0.45 | 0.06 | 0.58 | 0.09 | 0.32 | 0.07 | 0.17 | 0.05 | 0.41 | 0.13 | 1.45   | 0.00 | 0.00 | 51.36     | 0.12  | 0.74  | 1.82 |
| M1ZC-4          | 5.25  | 0.73  | 2.49  | 0.51 | 0.04 | 0.49 | 0.08 | 0.61 | 0.17 | 0.55 | 0.07 | 0.34 | 0.16 | 0.73 | 0.40 | 1.11   | 0.00 | 0.00 | 55.09     | 0.14  | 2.11  | 1.33 |
| 2018ZHCM226-7-R | 6.70  | 0.83  | 2.76  | 1.09 | 0.31 | 0.59 | 0.09 | 0.60 | 0.13 | 0.33 | 0.03 | 0.34 | 0.04 | 0.63 | 0.10 | 17.500 | 0.00 | 0.00 | 308715.43 | 0.61  | 1.43  | 1.21 |
| 2018ZHCM226-7-W | 34.28 | 3.65  | 11.96 | 1.97 | 1.30 | 1.02 | 0.15 | 0.51 | 0.09 | 0.21 | 0.02 | 0.13 | 0.03 | 1.46 | 0.29 | 0.07   | 0.00 | 0.00 | 325903.98 | 0.12  | 1.93  | 0.36 |
| 2018ZHCM226-7-B | 25.97 | 2.82  | 11.14 | 1.56 | 1.10 | 1.31 | 0.18 | 1.26 | 0.28 | 0.87 | 0.15 | 0.68 | 0.15 | 0.66 | 0.20 | 0.05   | 0.00 | 0.00 | 103577.81 | 0.11  | 2.13  | 0.77 |
| 20102XHM4-2-1-R | 10.15 | 2.88  | 10.93 | 2.35 | 0.80 | 2.23 | 0.28 | 2.14 | 0.33 | 1.29 | 0.13 | 1.11 | 0.17 | 4.16 | 0.31 | 9.90   | 0.00 | 0.00 | 186567.94 | 55.41 | 5.14  | 1.33 |
| 20102XHM4-2-1-W | 62.55 | 7.94  | 26.06 | 3.91 | 1.06 | 3.12 | 0.34 | 2.10 | 0.41 | 0.54 | 0.15 | 1.13 | 0.12 | 0.78 | 0.28 | 0.26   | 0.00 | 0.00 | 104555.73 | 9.61  | 4.45  | 1.56 |
| 20102XHM4-2-1-Y | 15.16 | 2.11  | 6.76  | 1.46 | 2.40 | 2.11 | 0.21 | 1.30 | 0.29 | 0.52 | 0.21 | 1.12 | 0.13 | 5.06 | 1.45 | 2.93   | 0.00 | 0.00 | 162823.21 | 8.67  | 18.97 | 1.23 |
| 20102XHM4-2-2-J | 32.38 | 4.67  | 16.48 | 3.41 | 2.73 | 3.26 | 0.37 | 2.29 | 0.44 | 1.50 | 0.25 | 1.10 | 0.12 | 6.48 | 1.09 | 1.57   | 0.00 | 0.00 | 63451.69  | 0.14  | 14.85 | 1.69 |
| 20102XHM4-2-3-B | 19.56 | 2.75  | 7.87  | 1.32 | 2.79 | 1.10 | 0.16 | 0.94 | 0.33 | 0.81 | 0.15 | 0.92 | 0.12 | 2.31 | 0.67 | 0.60   | 0.00 | 0.00 | 46337.93  | 15.47 | 6.56  | 0.48 |
| 20102XHM4-2-3-J | 29.99 | 4.56  | 20.40 | 3.08 | 0.55 | 4.27 | 0.29 | 4.09 | 0.73 | 1.34 | 0.19 | 1.01 | 0.26 | 0.55 | 0.43 | 0.45   | 0.00 | 0.00 | 52202.16  | 0.21  | 3.37  | 1.08 |
| 20102XHM4-2-3-R | 8.84  | 2.07  | 7.75  | 2.02 | 1.02 | 1.33 | 0.23 | 1.34 | 0.23 | 0.39 | 0.10 | 0.48 | 0.10 | 0.53 | 0.17 | 13.790 | 0.00 | 0.00 | 239786.32 | 2.98  | 2.39  | 2.85 |
| 20102XHM4-2-3-W | 84.11 | 10.35 | 37.83 | 4.94 | 2.92 | 2.78 | 0.49 | 1.97 | 0.40 | 1.19 | 0.10 | 0.53 | 0.13 | 3.01 | 1.18 | 0.32   | 0.00 | 0.00 | 175225.47 | 2.44  | 12.28 | 1.27 |
| 20102XHM4-2-3-Y | 44.06 | 4.00  | 15.40 | 2.86 | 2.16 | 2.71 | 0.48 | 2.55 | 0.44 | 1.48 | 0.27 | 1.58 | 0.38 | 5.39 | 1.50 | 4.57   | 0.00 | 0.00 | 175141.49 | 1.70  | 17.42 | 1.37 |
| 20102XHM4-2-4-B | 13.65 | 2.31  | 8.37  | 1.65 | 1.73 | 1.28 | 0.18 | 1.34 | 0.24 | 0.72 | 0.06 | 0.71 | 0.14 | 1.57 | 0.75 | 1.10   | 0.00 | 0.00 | 64996.93  | 22.39 | 5.49  | 0.37 |
| 20102XHM4-2-4-R | 13.51 | 2.21  | 9.03  | 2.00 | 0.89 | 2.59 | 0.35 | 2.01 | 0.40 | 1.59 | 0.14 | 1.32 | 0.31 | 0.77 | 0.16 | 12.040 | 0.00 | 0.00 | 284500.95 | 4.99  | 2.88  | 2.06 |
| 20102XHM4-2-4-W | 49.40 | 4.55  | 13.91 | 2.62 | 1.27 | 1.37 | 0.12 | 0.74 | 0.16 | 0.29 | 0.05 | 0.34 | 0.04 | 1.32 | 0.36 | 0.12   | 0.00 | 0.00 | 539587.31 | 1.16  | 3.56  | 1.53 |
| 20102XHM4-2-4-Y | 46.60 | 4.30  | 18.69 | 3.52 | 2.57 | 2.51 | 0.51 | 3.28 | 0.56 | 1.77 | 0.30 | 1.37 | 0.23 | 4.81 | 1.54 | 5.11   | 0.00 | 0.00 | 205521.31 | 1.68  | 17.61 | 1.43 |
| 20102XHM4-2-5-B | 9.12  | 1.32  | 5.33  | 0.97 | 2.47 | 0.85 | 0.07 | 0.41 | 0.09 | 0.29 | 0.06 | 0.30 | 0.06 | 1.41 | 0.66 | 0.32   | 0.00 | 0.00 | 51722.21  | 4.48  | 7.00  | 0.56 |
| 20102XHM4-2-5-R | 5.11  | 0.51  | 2.42  | 0.68 | 0.23 | 0.41 | 0.07 | 0.28 | 0.08 | 0.19 | 0.02 | 0.20 | 0.02 | 0.39 | 0.08 | 16.770 | 0.00 | 0.00 | 369672.16 | 6.69  | 1.61  | 1.07 |
| 20102XHM4-2-5-W | 58.44 | 7.34  | 22.92 | 5.00 | 1.94 | 2.73 | 0.18 | 0.82 | 0.20 | 0.45 | 0.02 | 0.13 | 0.07 | 2.42 | 1.00 | 0.27   | 0.00 | 0.00 | 164488.62 | 4.93  | 9.69  | 0.67 |

|                   |        |       |       |      |      |      |      |      |      |      |      |      |      |      |      |       |      |      |           |       |       |      |
|-------------------|--------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|-------|------|------|-----------|-------|-------|------|
| 20102XHM4-2-5-Y   | 37.53  | 3.98  | 13.91 | 3.87 | 2.69 | 2.83 | 0.47 | 3.29 | 0.50 | 1.51 | 0.21 | 1.20 | 0.28 | 4.74 | 1.49 | 2.62  | 0.00 | 0.00 | 183728.19 | 9.39  | 18.50 | 1.42 |
| 20102XHM4-2-6-B   | 34.92  | 4.44  | 14.85 | 2.24 | 2.17 | 1.65 | 0.24 | 1.80 | 0.28 | 1.04 | 0.17 | 0.98 | 0.17 | 1.01 | 0.18 | 0.13  | 0.00 | 0.00 | 102486.37 | 0.74  | 3.13  | 0.71 |
| 20102XHM4-2-6-R   | 11.73  | 1.59  | 7.50  | 1.09 | 0.75 | 1.11 | 0.13 | 1.41 | 0.24 | 0.49 | 0.08 | 0.58 | 0.15 | 0.46 | 0.14 | 20.04 | 0.00 | 0.00 | 252556.68 | 0.83  | 2.47  | 1.34 |
| 20102XHM4-2-6-Y   | 46.18  | 4.09  | 15.51 | 3.77 | 1.93 | 3.69 | 0.52 | 3.16 | 0.50 | 1.78 | 0.15 | 1.25 | 0.23 | 3.24 | 0.83 | 3.42  | 0.00 | 0.00 | 192245.19 | 3.96  | 13.20 | 0.83 |
| 20102XHM4-2-7-B   | 25.14  | 3.35  | 11.43 | 1.88 | 2.64 | 2.15 | 0.27 | 1.77 | 0.46 | 1.30 | 0.18 | 1.38 | 0.17 | 1.01 | 0.33 | 0.29  | 0.00 | 0.00 | 32227.03  | 2.11  | 3.22  | 1.22 |
| 20102XHM4-2-7-R   | 6.65   | 1.07  | 4.92  | 1.01 | 0.70 | 0.78 | 0.13 | 0.71 | 0.09 | 0.36 | 0.05 | 0.36 | 0.03 | 0.58 | 0.12 | 19.99 | 0.00 | 0.00 | 204073.29 | 16.80 | 2.16  | 1.72 |
| 20102XHM4-2-7-Y   | 69.60  | 5.35  | 18.51 | 4.68 | 2.68 | 3.54 | 0.58 | 3.54 | 0.61 | 1.86 | 0.39 | 1.55 | 0.30 | 4.30 | 1.38 | 3.06  | 0.00 | 0.00 | 173613.07 | 22.51 | 16.63 | 1.83 |
| 2018ZHCM398-3-1-B | 29.44  | 3.51  | 11.45 | 1.46 | 1.79 | 1.42 | 0.17 | 0.79 | 0.18 | 0.51 | 0.07 | 0.50 | 0.09 | 0.89 | 0.16 | 0.60  | 0.00 | 0.00 | 131062.19 | 1.24  | 2.88  | 0.65 |
| 2018ZHCM398-3-1-R | 7.72   | 1.56  | 5.09  | 0.87 | 0.39 | 0.90 | 0.18 | 1.00 | 0.14 | 0.43 | 0.08 | 0.40 | 0.09 | 0.46 | 0.13 | 8.55  | 0.00 | 0.00 | 198349.89 | 0.55  | 2.29  | 2.06 |
| 2018ZHCM398-3-1-W | 27.47  | 3.35  | 11.25 | 1.97 | 1.49 | 1.17 | 0.09 | 0.47 | 0.08 | 0.22 | 0.03 | 0.16 | 0.04 | 1.30 | 0.42 | 0.28  | 0.00 | 0.00 | 118906.33 | 0.08  | 5.02  | 0.62 |
| 2018ZHCM398-3-2-B | 30.66  | 3.48  | 12.17 | 1.85 | 1.41 | 1.61 | 0.22 | 1.19 | 0.20 | 0.66 | 0.09 | 0.74 | 0.11 | 1.19 | 0.32 | 0.23  | 0.00 | 0.00 | 151079.67 | 0.15  | 2.52  | 0.63 |
| 2018ZHCM398-3-2-R | 8.21   | 1.20  | 4.54  | 0.94 | 0.38 | 0.79 | 0.11 | 1.02 | 0.15 | 0.37 | 0.08 | 0.27 | 0.05 | 0.60 | 0.18 | 12.25 | 0.00 | 0.00 | 223284.30 | 0.92  | 1.94  | 2.14 |
| 2018ZHCM398-3-2-W | 122.82 | 16.24 | 49.88 | 6.93 | 2.72 | 4.27 | 0.46 | 2.30 | 0.32 | 0.71 | 0.11 | 0.49 | 0.09 | 1.82 | 0.57 | 0.41  | 0.00 | 0.00 | 144434.91 | 0.32  | 9.62  | 1.29 |
| M19-3-R           | 41.86  | 4.31  | 16.49 | 3.45 | 0.91 | 3.73 | 0.48 | 3.33 | 0.68 | 1.82 | 0.23 | 1.76 | 0.26 | 1.77 | 0.64 | 11.36 | 0.00 | 0.00 | 349290.87 | 50.87 | 4.45  | 2.73 |
| M19-3-W           | 6.83   | 1.18  | 4.75  | 0.92 | 0.33 | 0.86 | 0.12 | 0.57 | 0.13 | 0.48 | 0.04 | 0.55 | 0.08 | 0.86 | 0.75 | 0.23  | 0.00 | 0.00 | 309330.51 | 50.65 | 1.25  | 0.73 |
| M657-1-J          | 29.68  | 3.58  | 11.84 | 1.77 | 0.49 | 1.69 | 0.16 | 0.84 | 0.16 | 0.82 | 0.09 | 0.53 | 0.06 | 0.83 | 0.29 | 0.51  | 0.00 | 0.00 | 23354.20  | 1.17  | 2.40  | 0.53 |
| M657-1-P          | 22.86  | 3.71  | 15.27 | 6.28 | 2.17 | 1.73 | 0.09 | 1.09 | 0.26 | 0.79 | 0.05 | 0.54 | 0.07 | 1.83 | 0.55 | 0.56  | 0.00 | 0.00 | 75274.31  | 5.44  | 3.70  | 0.23 |
| M657-1-R          | 8.71   | 1.01  | 3.15  | 1.33 | 0.33 | 0.79 | 0.14 | 0.57 | 0.05 | 0.42 | 0.05 | 0.17 | 0.03 | 0.58 | 0.21 | 12.97 | 0.00 | 0.00 | 253593.48 | 1.81  | 2.77  | 1.29 |
| M657-1-W          | 24.18  | 2.94  | 9.66  | 1.57 | 0.96 | 0.96 | 0.06 | 0.39 | 0.07 | 0.21 | 0.03 | 0.18 | 0.02 | 0.80 | 0.29 | 0.36  | 0.00 | 0.00 | 148989.79 | 0.92  | 1.34  | 0.39 |
| M657-3-B          | 13.57  | 1.61  | 6.14  | 1.66 | 1.83 | 1.26 | 0.15 | 0.71 | 0.25 | 0.41 | 0.07 | 0.40 | 0.07 | 0.53 | 0.13 | 0.31  | 0.00 | 0.00 | 153583.98 | 61.76 | 2.70  | 0.87 |
| M657-3-J          | 28.86  | 2.86  | 8.70  | 3.57 | 0.39 | 2.96 | 0.52 | 3.04 | 1.01 | 2.84 | 0.29 | 1.66 | 0.29 | 1.61 | 1.91 | 0.27  | 0.00 | 0.00 | 35886.44  | 1.79  | 4.88  | 1.00 |
| M657-3-R          | 4.13   | 0.91  | 4.29  | 0.82 | 1.45 | 0.79 | 0.09 | 0.46 | 0.10 | 0.41 | 0.02 | 0.26 | 0.04 | 0.28 | 0.05 | 56.78 | 0.00 | 0.00 | 275963.87 | 12.29 | 0.46  | 2.80 |
| M657-3-W          | 20.01  | 2.52  | 9.70  | 1.39 | 1.24 | 1.04 | 0.07 | 0.60 | 0.18 | 0.46 | 0.08 | 0.28 | 0.06 | 0.86 | 0.24 | 0.11  | 0.00 | 0.00 | 209571.38 | 40.93 | 2.67  | 1.21 |
| M657-3-Y          | 37.31  | 4.87  | 17.09 | 4.05 | 1.99 | 3.42 | 0.42 | 2.96 | 0.57 | 1.84 | 0.28 | 1.52 | 0.28 | 3.92 | 1.20 | 4.35  | 0.00 | 0.00 | 297658.01 | 10.85 | 12.96 | 3.15 |
| 20102XHM4-2-1-J   | 33.75  | 4.48  | 16.70 | 5.27 | 0.69 | 2.59 | 0.29 | 2.52 | 0.63 | 1.60 | 0.41 | 1.51 | 0.34 | 1.14 | 0.54 | 0.75  | 0.00 | 0.00 | 8031.91   | 0.30  | 6.47  | 1.31 |
| 20102XHM4-2-1-B   | 7.62   | 1.64  | 6.32  | 1.92 | 2.54 | 0.61 | 0.13 | 0.25 | 0.07 | 0.25 | 0.19 | 0.63 | 0.01 | 1.20 | 0.25 | 0.01  | 0.00 | 0.00 | 42907.82  | 35.12 | 2.92  | 0.21 |

|           |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |           |        |      |      |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----------|--------|------|------|
| M-4-YD    | 3.78 | 0.56 | 1.81 | 0.42 | 2.41 | 0.58 | 0.04 | 0.24 | 0.02 | 0.11 | 0.02 | 0.10 | 0.01 | 0.22 | 0.07 | 0.38 | 0.00 | 0.00 | 309773.92 | 110.42 | 0.70 | 0.87 |
| 5.29754-B | 3.70 | 0.58 | 1.77 | 0.31 | 1.19 | 0.42 | 0.01 | 0.34 | 0.02 | 0.10 | 0.11 | 0.50 | 0.02 | 0.13 | 0.09 | 0.45 | 0.00 | 0.00 | 271581.09 | 17.94  | 0.49 | 0.33 |
| 5.29754-W | 3.07 | 0.84 | 2.07 | 0.32 | 1.84 | 0.96 | 0.09 | 0.37 | 0.11 | 0.33 | 0.20 | 0.00 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 286636.98 | 3.93   | 0.30 | 0.07 |
| 5.29754-J | 2.33 | 0.48 | 1.86 | 0.44 | 0.97 | 0.63 | 0.06 | 0.00 | 0.03 | 0.06 | 0.00 | 0.08 | 0.01 | 0.24 | 0.03 | 0.21 | 0.00 | 0.00 | 245633.04 | 16.40  | 0.34 | 0.42 |
| 1301Bi    | 2.49 | 0.31 | 1.08 | 0.40 | 0.84 | 0.20 | 0.02 | 0.19 | 0.04 | 0.10 | 0.11 | 0.18 | 0.03 | 0.08 | 0.04 | 0.01 | 0.00 | 0.00 | 452913.17 | 0.58   | 0.24 | 0.58 |
| TSS-43-4  | 2.20 | 0.30 | 1.12 | 0.41 | 0.92 | 0.16 | 0.02 | 0.05 | 0.01 | 0.05 | 0.00 | 0.14 | 0.01 | 0.05 | 0.02 | 0.01 | 0.00 | 0.00 | 450925.20 | 0.40   | 0.19 | 0.19 |
| TSS-43-3  | 2.44 | 0.29 | 1.55 | 0.28 | 0.82 | 0.26 | 0.02 | 0.07 | 0.02 | 0.08 | 0.00 | 0.04 | 0.01 | 0.09 | 0.03 | 0.11 | 0.00 | 0.00 | 488696.55 | 46.64  | 0.39 | 0.29 |
| TSS-43-2  | 4.60 | 0.70 | 2.45 | 0.40 | 1.07 | 0.58 | 0.07 | 0.33 | 0.04 | 0.19 | 0.01 | 0.25 | 0.01 | 0.26 | 0.09 | 6.84 | 0.00 | 0.00 | 426534.81 | 24.46  | 0.74 | 0.38 |
| TSS-33-1  | 5.34 | 0.57 | 2.12 | 0.52 | 0.91 | 0.54 | 0.08 | 0.49 | 0.10 | 0.23 | 0.04 | 0.33 | 0.03 | 0.49 | 0.08 | 2.21 | 0.00 | 0.00 | 311478.89 | 1.05   | 0.83 | 0.68 |
| TSS-33-2  | 3.51 | 0.60 | 2.04 | 0.39 | 1.04 | 0.38 | 0.02 | 0.17 | 0.04 | 0.06 | 0.01 | 0.20 | 0.02 | 0.23 | 0.05 | 0.28 | 0.00 | 0.00 | 332280.87 | 0.44   | 0.28 | 0.42 |
| TSS-33-3  | 4.68 | 0.65 | 3.11 | 0.30 | 1.16 | 0.46 | 0.05 | 0.28 | 0.05 | 0.18 | 0.02 | 0.24 | 0.02 | 0.40 | 0.10 | 6.24 | 0.00 | 0.00 | 435383.19 | 3.17   | 0.64 | 0.48 |
| TSS-33-4  | 4.62 | 0.58 | 3.10 | 0.51 | 0.60 | 0.49 | 0.04 | 0.29 | 0.06 | 0.15 | 0.02 | 0.15 | 0.02 | 0.25 | 0.05 | 0.82 | 0.00 | 0.00 | 354846.66 | 0.41   | 0.50 | 0.51 |
| TSS-33-5  | 5.44 | 0.59 | 2.62 | 0.64 | 0.80 | 0.54 | 0.07 | 0.28 | 0.10 | 0.31 | 0.03 | 0.40 | 0.05 | 0.42 | 0.10 | 2.14 | 0.00 | 0.00 | 315193.04 | 1.08   | 0.77 | 0.71 |
| TSS-33-6  | 3.10 | 0.40 | 2.46 | 0.50 | 1.13 | 0.47 | 0.03 | 0.19 | 0.03 | 0.24 | 0.03 | 0.19 | 0.02 | 0.22 | 0.03 | 1.22 | 0.00 | 0.00 | 450539.97 | 0.91   | 0.36 | 0.37 |
| TSS-43-G  | 4.31 | 0.49 | 2.69 | 0.25 | 0.85 | 0.27 | 0.03 | 0.25 | 0.04 | 0.12 | 0.02 | 0.06 | 0.02 | 0.22 | 0.05 | 0.06 | 0.00 | 0.00 | 482389.21 | 1.38   | 0.46 | 0.51 |
| TSS-43-BL | 4.40 | 0.57 | 2.00 | 0.35 | 0.83 | 0.40 | 0.04 | 0.15 | 0.07 | 0.16 | 0.01 | 0.18 | 0.02 | 0.22 | 0.03 | 0.07 | 0.00 | 0.00 | 482887.40 | 1.37   | 0.46 | 0.51 |
| TSS-43-1  | 5.20 | 0.64 | 2.76 | 0.44 | 0.84 | 0.48 | 0.04 | 0.25 | 0.04 | 0.28 | 0.02 | 0.22 | 0.02 | 0.27 | 0.06 | 2.76 | 0.00 | 0.00 | 436040.40 | 35.19  | 0.79 | 0.41 |
| TSS-43-5  | 4.78 | 0.64 | 3.22 | 0.63 | 0.97 | 0.35 | 0.07 | 0.23 | 0.06 | 0.19 | 0.04 | 0.11 | 0.02 | 0.29 | 0.09 | 7.19 | 0.00 | 0.00 | 452904.60 | 26.67  | 0.80 | 0.39 |
| SJM1S-4   | 1.18 | 0.18 | 0.89 | 0.16 | 1.54 | 0.38 | 0.05 | 0.34 | 0.04 | 0.14 | 0.03 | 0.09 | 0.00 | 0.15 | 0.02 | 0.14 | 0.00 | 0.00 | 384114.38 | 591.05 | 0.21 | 0.36 |
| C3-3      | 4.52 | 0.61 | 2.53 | 0.45 | 1.25 | 0.40 | 0.04 | 0.49 | 0.09 | 0.12 | 0.02 | 0.42 | 0.01 | 0.38 | 0.08 | 1.04 | 0.00 | 0.00 | 333086.05 | 30.39  | 0.60 | 0.44 |
| SR15-12   | 1.32 | 0.23 | 1.28 | 0.31 | 1.03 | 0.32 | 0.02 | 0.19 | 0.04 | 0.25 | 0.02 | 0.16 | 0.02 | 0.27 | 0.02 | 0.33 | 0.00 | 0.00 | 368112.35 | 498.74 | 0.31 | 0.38 |
| SJM16     | 1.37 | 0.24 | 0.91 | 0.61 | 1.12 | 0.56 | 0.02 | 0.33 | 0.01 | 0.03 | 0.03 | 0.17 | 0.01 | 0.31 | 0.01 | 0.67 | 0.00 | 0.00 | 378916.76 | 622.50 | 0.39 | 0.31 |
| S13-370-1 | 4.10 | 0.35 | 2.10 | 1.19 | 0.89 | 0.33 | 0.00 | 0.61 | 0.10 | 0.29 | 0.05 | 0.00 | 0.03 | 0.35 | 0.04 | 0.41 | 0.00 | 0.00 | 289719.46 | 33.56  | 0.48 | 0.50 |
| S12-97-2  | 3.46 | 0.49 | 1.95 | 0.29 | 1.46 | 0.38 | 0.05 | 0.29 | 0.05 | 0.12 | 0.01 | 0.26 | 0.04 | 0.21 | 0.03 | 0.31 | 0.00 | 0.00 | 405462.50 | 16.32  | 0.53 | 0.72 |
| S22-60-1  | 3.47 | 0.47 | 1.74 | 0.40 | 1.51 | 0.56 | 0.04 | 0.27 | 0.05 | 0.16 | 0.03 | 0.13 | 0.05 | 0.08 | 0.04 | 0.23 | 0.00 | 0.00 | 386397.01 | 17.78  | 0.51 | 0.71 |
| S6-148A-J | 5.33 | 0.79 | 2.90 | 0.65 | 0.48 | 0.44 | 0.07 | 0.14 | 0.06 | 0.10 | 0.01 | 0.27 | 0.04 | 0.33 | 0.06 | 0.33 | 0.00 | 0.00 | 295353.80 | 29.89  | 0.59 | 0.37 |

|           |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |      |      |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|------|------|
| S6-148A-G | 4.11 | 0.59 | 1.79 | 0.36 | 0.47 | 0.25 | 0.01 | 0.16 | 0.05 | 0.12 | 0.02 | 0.23 | 0.04 | 0.25 | 0.03 | 0.29 | 0.00 | 0.00 | 2832 | 26.15 | 30.14 | 0.41 | 0.34 |
| S6-148A-W | 3.93 | 0.54 | 3.02 | 0.32 | 0.52 | 0.35 | 0.05 | 0.16 | 0.04 | 0.13 | 0.02 | 0.21 | 0.05 | 0.38 | 0.06 | 0.22 | 0.00 | 0.00 | 2880 | 22.82 | 29.39 | 0.41 | 0.39 |
| SJMIS-1   | 3.76 | 0.61 | 2.27 | 1.03 | 0.90 | 0.38 | 0.05 | 0.16 | 0.03 | 0.13 | 0.02 | 0.12 | 0.01 | 0.15 | 0.05 | 0.14 | 0.00 | 0.00 | 2892 | 55.93 | 38.50 | 0.39 | 1.34 |

## Data file S3

**Table 1 Blomme *et al.* (2017)**

| Type                 | Sample         | Colour  | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | P <sub>2</sub> O <sub>5</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | TiO <sub>2</sub><br>wt% | MnO<br>wt% | Fe <sub>2</sub> O <sub>3</sub><br>wt% | CoO<br>wt% | CuO<br>wt% | SnO <sub>2</sub><br>wt% |
|----------------------|----------------|---------|--------------------------|------------|---------------------------------------|-------------------------|--------------------------------------|------------------------|-----------|-------------------------|------------|-------------------------|------------|---------------------------------------|------------|------------|-------------------------|
| Type II Natron glass | 2-Py 945/T25a  | Wh.Op   | 17,50                    | 0,45       | 2,47                                  | 64,56                   | 0,06                                 | 0,31                   | 0,99      | 0,43                    | 7,29       | 0,05                    | 0,12       | 0,35                                  | b.d.       | 0,05       | b.d.                    |
| Type II Natron glass | 4-Py 133       | C.less  | 19,06                    | 0,57       | 2,66                                  | 66,31                   | 0,06                                 | 0,35                   | 1,08      | 0,53                    | 6,70       | 0,06                    | b.d.       | 0,34                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 5-Py 3543B     | Blue    | 16,32                    | 0,51       | 2,38                                  | 67,20                   | 0,06                                 | 0,17                   | 1,26      | 0,52                    | 7,13       | 0,06                    | 0,36       | 0,89                                  | 0,09       | 0,16       | b.d.                    |
| Type II Natron glass | 6-Py 3543      | C.less  | 19,32                    | 0,57       | 2,48                                  | 63,72                   | 0,07                                 | 0,39                   | 1,05      | 0,67                    | 7,33       | 0,06                    | b.d.       | 0,34                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 7-Py 369a      | Yellow  | 12,41                    | 0,32       | 2,22                                  | 61,92                   | 0,05                                 | 0,05                   | 1,33      | 0,39                    | 5,63       | 0,05                    | b.d.       | 0,77                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 7-Py 369b      | Green   | 16,07                    | 0,37       | 2,60                                  | 69,13                   | 0,05                                 | 0,09                   | 1,36      | 0,48                    | 6,40       | 0,05                    | b.d.       | 1,08                                  | b.d.       | 0,11       | b.d.                    |
| Type II Natron glass | 8-Py 371       | Cyan    | 15,31                    | 0,58       | 2,51                                  | 65,50                   | 0,12                                 | 0,15                   | 1,38      | 0,60                    | 9,66       | 0,07                    | 0,07       | 2,96                                  | b.d.       | 0,08       | b.d.                    |
| Type II Natron glass | 10-Py519/521a  | Dk blue | 18,32                    | 0,64       | 2,51                                  | 63,60                   | 0,09                                 | 0,20                   | 1,45      | 0,56                    | 7,82       | 0,06                    | 0,04       | 3,72                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 10-Py 519/521b | C.less  | 17,73                    | 0,59       | 2,53                                  | 66,71                   | 0,10                                 | 0,12                   | 1,07      | 1,17                    | 6,76       | 0,07                    | b.d.       | 0,35                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 11-Py 6245     | Green   | 14,82                    | 0,57       | 2,83                                  | 61,63                   | 0,14                                 | 0,16                   | 1,16      | 0,55                    | 11,96      | 0,10                    | 0,10       | 2,50                                  | 0,04       | 0,84       | b.d.                    |
| Type II Natron glass | 12-Py 6245     | Yellow  | 11,67                    | 0,33       | 2,05                                  | 58,96                   | 0,06                                 | 0,11                   | 1,02      | 0,37                    | 6,04       | 0,05                    | b.d.       | 0,96                                  | b.d.       | 0,13       | b.d.                    |
| Type II Natron glass | 13-Py 6253     | Dp cy   | 15,75                    | 0,54       | 2,66                                  | 67,38                   | 0,10                                 | 0,14                   | 1,42      | 0,59                    | 8,71       | 0,08                    | 0,02       | 1,94                                  | b.d.       | 0,23       | b.d.                    |
| Type II Natron glass | 14-Py 6267b    | Turqu   | 16,72                    | 0,49       | 2,16                                  | 66,95                   | 0,09                                 | 0,16                   | 1,43      | 0,50                    | 7,62       | 0,06                    | b.d.       | 1,48                                  | 0,04       | 0,31       | b.d.                    |
| Type II Natron glass | 15-Py 6273     | Cyan    | 17,31                    | 0,87       | 2,62                                  | 67,04                   | 0,07                                 | 0,28                   | 0,83      | 0,66                    | 8,28       | 0,08                    | 0,27       | 0,69                                  | 0,09       | 0,17       | b.d.                    |
| Type II Natron glass | 18-Py 6299     | Aqua M  | 17,40                    | 0,59       | 2,64                                  | 66,81                   | 0,08                                 | 0,22                   | 1,11      | 0,58                    | 8,55       | 0,06                    | b.d.       | 0,79                                  | b.d.       | 0,13       | b.d.                    |
| Type II Natron glass | 20-Py 6405     | Dp cyan | 16,12                    | 0,59       | 2,14                                  | 60,62                   | 0,12                                 | 0,17                   | 1,16      | 0,51                    | 6,22       | 0,08                    | 0,33       | 11,58                                 | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 21-Py 6435     | C.less  | 18,27                    | 0,70       | 2,18                                  | 66,73                   | 0,16                                 | 0,16                   | 0,60      | 1,27                    | 7,57       | 0,06                    | b.d.       | 0,48                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 22-Py 6436     | C.less  | 18,20                    | 0,70       | 2,16                                  | 66,41                   | 0,16                                 | 0,16                   | 0,69      | 1,25                    | 7,61       | 0,05                    | b.d.       | 0,47                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 27-Py 8372 T   | C.less  | 17,64                    | 0,77       | 2,63                                  | 65,60                   | 0,08                                 | 0,19                   | 1,33      | 1,18                    | 7,36       | 0,07                    | b.d.       | 0,44                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 29-Py 8382     | Honey   | 18,59                    | 0,57       | 1,89                                  | 68,04                   | 0,05                                 | 0,27                   | 1,21      | 0,33                    | 6,68       | 0,06                    | b.d.       | 0,84                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 37-Py 8483     | Cyan    | 17,07                    | 0,46       | 2,63                                  | 69,42                   | 0,09                                 | 0,16                   | 1,20      | 0,84                    | 6,66       | 0,06                    | 0,50       | 0,92                                  | 0,18       | 0,44       | b.d.                    |
| Type II Natron glass | 39-Py 872      | C.less  | 18,69                    | 0,67       | 2,48                                  | 67,20                   | 0,08                                 | 0,37                   | 0,78      | 0,72                    | 6,84       | 0,06                    | b.d.       | 0,38                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 54-Mth 1309    | Bluish  | 20,23                    | 0,64       | 2,46                                  | 67,96                   | 0,06                                 | 0,21                   | 0,94      | 0,45                    | 8,74       | 0,06                    | 0,02       | 0,38                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 55-Mth 2898    | Bluish  | 20,18                    | 0,55       | 1,62                                  | 67,94                   | 0,09                                 | 0,21                   | 1,44      | 0,36                    | 8,51       | 0,07                    | 0,17       | 1,20                                  | 0,03       | 0,20       | b.d.                    |
| Type I Natron glass  | 60-Mth 338     | Cyan    | 17,55                    | 0,42       | 0,93                                  | 71,02                   | 0,04                                 | 0,11                   | 1,45      | 0,21                    | 5,74       | 0,13                    | b.d.       | 0,87                                  | 0,11       | 0,15       | b.d.                    |
| Type II Natron glass | 61-Mth 822     | Honey   | 20,50                    | 0,64       | 0,47                                  | 68,68                   | 0,07                                 | 0,25                   | 1,49      | 0,11                    | 9,81       | 0,07                    | b.d.       | 0,25                                  | b.d.       | b.d.       | b.d.                    |
| Type II Natron glass | 62-Mth 824     | Bluish  | 17,78                    | 0,52       | 2,72                                  | 68,25                   | 0,07                                 | 0,09                   | 1,55      | 0,32                    | 9,53       | 0,06                    | 0,04       | 0,36                                  | b.d.       | b.d.       | b.d.                    |

| Type                 | Sample         | Colour  | Sb <sub>2</sub> O <sub>5</sub><br>wt% | BaO<br>wt% | TiO <sub>2</sub><br>wt% | Cr<br>ppm | Y<br>ppm  | Zr<br>ppm | Li<br>ppm | B<br>ppm  | V<br>ppm  | Cr<br>ppm | Co<br>ppm | Ni<br>ppm | Cu<br>ppm | Zn<br>ppm | As<br>ppm |
|----------------------|----------------|---------|---------------------------------------|------------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Type II Natron glass | 2-Py 945/T25a  | Wh.Op   | 2,15                                  | b.d.       | 0.05                    | 8         | 6.2       | 32.2      | 3.3       | 97        | 6.8       | 8         | 5.5       | 3.4       | 367       | 7.5       | 4.3       |
| Type II Natron glass | 4-Py 133       | C.less  | 1,14                                  | b.d.       | 0.06                    | 8.3       | 6.3       | 36.2      | 2.8       | 159       | 6         | 8.3       | i.i       | 6.8       | 6         | 8.7       | 5.6       |
| Type II Natron glass | 5-Py 3543B     | Blue    | b.d.                                  | 0,02       | 0.06                    | 8.1       | 7         | 36.5      | 3         | 77        | 15.7      | 8.1       | 800.8     | 143.8     | 1243      | 124.3     | 9.9       |
| Type II Natron glass | 6-Py 3543      | C.less  | 1,34                                  | b.d.       | 0.06                    | 7.6       | 6.5       | 36.7      | 3.2       | 111       | 6.9       | 7.6       | 12.1      | 4.9       | 53        | 7.7       | 5.5       |
| Type II Natron glass | 7-Py 369a      | Yellow  | 1,28                                  | b.d.       | 0.05                    | 7         | 5.3       | 28.8      | 2.6       | 130       | 6.6       | 7         | 1.5       | 4.2       | 173       | 6.5       | 10.1      |
| Type II Natron glass | 7-Py 369b      | Green   | b.d.                                  | b.d.       | 0.05                    | 7.7       | 6.1       | 31.2      | 3.3       | 139       | 6.8       | 7.7       | 88.8      | 4.4       | 868       | 148.1     | 4.2       |
| Type II Natron glass | 8-Py 371       | Cyan    | 0,04                                  | 0,03       | 0.07                    | 15.8      | 7.3       | 36.7      | 3.7       | 133       | 9.6       | 15.8      | 37.6      | 9.7       | 642       | 28.2      | 7         |
| Type II Natron glass | 10-Py519/521a  | Dk blue | 0,03                                  | b.d.       | 0.06                    | 17.1      | 6.3       | 31.2      | 3.1       | 357       | 7.4       | 17.1      | 18.4      | 9.3       | 100       | 8.7       | 8.9       |
| Type II Natron glass | 10-Py 519/521b | C.less  | 0,97                                  | b.d.       | 0.07                    | 11.6      | 6.3       | 42.2      | 3.8       | 81        | 7         | 11.6      | i.i       | 4.3       | 26        | 10        | 11.5      |
| Type II Natron glass | 11-Py 6245     | Green   | 0,69                                  | b.d.       | 0.1                     | 41.6      | 9.2       | 43.6      | 5.3       | 107       | 15.8      | 41.6      | 308       | 11.6      | 6636      | 113.4     | 21.7      |
| Type II Natron glass | 12-Py 6245     | Yellow  | 2,10                                  | b.d.       | 0.05                    | 8.7       | 4.6       | 24.4      | 2.8       | 69        | 6.3       | 8.7       | 10.5      | 4.4       | 1646      | 10.9      | 96.5      |
| Type II Natron glass | 13-Py 6253     | Dp cy   | 0,03                                  | 0,02       | 0.08                    | n.i       | 7.3       | 37.6      | 4.2       | 121       | 10.2      | 11.1      | 118.3     | 6.2       | 1702      | 136.4     | 9.3       |
| Type II Natron glass | 14-Py 6267b    | Turqu   | 0,62                                  | b.d.       | 0.06                    | 9.3       | 7.3       | 45.5      | 4.8       | 138       | 5.9       | 7.5       | 342.1     | 5.4       | 2612      | 339.4     | 11.7      |
| Type II Natron glass | 15-Py 6273     | Cyan    | b.d.                                  | b.d.       | 0.08                    | 8.3       | 7.1       | 38.9      | 3.9       | 143       | 16.7      | 9.3       | 778.2     | 100.1     | 1500      | 85        | 15.1      |
| Type II Natron glass | 18-Py 6299     | Aqua M  | 0,10                                  | 0,02       | 0.06                    | 13.3      | 6         | 43        | 3.9       | 53        | 7.8       | 8.3       | 160.4     | 4.4       | 961       | 28.1      | 3.1       |
| Type II Natron glass | 20-Py 6405     | Dp cyan | 0,39                                  | b.d.       | 0.08                    | 88.9      | 5.8       | 36.2      | 8.3       | 119       | 22.3      | 13.3      | 24.3      | 24.4      | 151       | 33.2      | 18.1      |
| Type II Natron glass | 21-Py 6435     | C.less  | 2,16                                  | b.d.       | 0.06                    | 86.5      | 5.7       | 35.7      | 4.8       | 424       | 6.9       | 88.9      | 3.1       | 26.1      | 12        | 21.1      | 31.6      |
| Type II Natron glass | 22-Py 6436     | C.less  | 2,14                                  | b.d.       | 0.05                    | 16.2      | 5.8       | 40.7      | 5         | 486       | 6.3       | 86.5      | 2.8       | 23.9      | 11        | 17.2      | 34.9      |
| Type II Natron glass | 27-Py 8372 T   | C.less  | 1,71                                  | b.d.       | 0.07                    | 8.2       | 5.7       | 38.7      | 4.9       | 198       | 8.4       | 16.2      | 1.4       | 6         | 14        | 12.2      | 5.2       |
| Type II Natron glass | 29-Py 8382     | Honey   | b.d.                                  | b.d.       | 0.06                    | 7         | 6.1       | 35.4      | 3         | 224       | 7.4       | 7.7       | 30.7      | 5.1       | 77        | 7.7       | 2.3       |
| Type II Natron glass | 37-Py 8483     | Cyan    | 0,03                                  | 0,03       | 0.06                    | 4.1       | 3         | 25.3      | 3.5       | 90        | 24.6      | 7         | 1671.6    | 146.3     | 3505      | 223.1     | 24.7      |
| Type II Natron glass | 39-Py 872      | C.less  | 1,74                                  | b.d.       | 0.06                    | 11.6      | 6.6       | 32.3      | 3.3       | 91        | 8.5       | 7.9       | 1.5       | 3.2       | 12        | 8.1       | 9.2       |
| Type II Natron glass | 54-Mth 1309    | Bluish  | 0,52                                  | b.d.       | 0.06                    | 8         | 5.6       | 68.8      | 3.3       | 123       | 5.5       | 11.6      | 2.4       | 2.7       | 6         | 10        | 1.6       |
| Type II Natron glass | 55-Mth 2898    | Bluish  | 0,88                                  | b.d.       | 0.07                    | 13.6      | 5.1       | 174.1     | 3.2       | 128       | 8.5       | 8         | 207.3     | 9.4       | 1541      | 79.1      | 6.8       |
| Type I Natron glass  | 60-Mth 338     | Cyan    | 0,49                                  | b.d.       | 0.13                    | 6.3       | 5.9       | 61        | 3.7       | 79        | 7.8       | 13.6      | 900.1     | 5.4       | 1310      | 113.4     | 6.6       |
| Type II Natron glass | 61-Mth 822     | Honey   | b.d.                                  | b.d.       | 0.07                    | 8.1       | 8         | 38.6      | 3.3       | 108       | 4.9       | 6.3       | i.i       | 2.2       | 2         | 3.2       | 0.9       |
| Type II Natron glass | 62-Mth 824     | Bluish  | 1,31                                  | b.d.       | 0.06                    |           |           |           | 2.8       | 78        | 5.6       | 8.1       | 1.8       | 2.9       | 10        | 5.9       | 4.7       |
| Type                 | Sample         | Colour  | Rb<br>ppm                             | Sr<br>ppm  | Y<br>ppm                | Zr<br>ppm | Nb<br>ppm | Mo<br>ppm | Ag<br>ppm | Sn<br>ppm | Sb<br>ppm | Cs<br>ppm | Ba<br>ppm | La<br>ppm | Ce<br>ppm | Pr<br>ppm | Nd<br>ppm |
| Type II Natron glass | 2-Py 945/T25a  | Wh.Op   | 6.9                                   | 392.5      | 6.2                     | 32.2      | i.i       | 0.3       | 0.2       | 2.7       | 15315     | 0.08      | 200       | 5.5       | 10.05     | 1.32      | 5.59      |
| Type II Natron glass | 4-Py 133       | C.less  | 8.6                                   | 403.7      | 6.3                     | 36.2      | 1.3       | 0.2       | b.d.      | 0.3       | 8937      | 0.09      | 196       | 5.61      | 10.4      | 1.3       | 5.43      |
| Type II Natron glass | 5-Py 3543B     | Blue    | 8.4                                   | 501.9      | 7                       | 36.5      | 1.3       | 0.7       | 0.1       | 54.2      | 5         | 0.09      | 219       | 5.87      | 10.9      | 1.48      | 6.18      |



|                      |                |         |      |       |      |       |      |      |      |      |       |      |      |        |       |      |      |
|----------------------|----------------|---------|------|-------|------|-------|------|------|------|------|-------|------|------|--------|-------|------|------|
| Type II Natron glass | 6-Py 3543      | C.less  | 9    | 472.7 | 6.5  | 36.7  | 1.2  | 0.4  | 0.1  | 1.5  | 8631  | 0.09 | 192  | 5.79   | 10.61 | 1.38 | 5.86 |
| Type II Natron glass | 7-Py 369a      | Yellow  | 6.2  | 326.7 | 5.3  | 28.8  | 1.1  | 0.6  | 14.2 | 0.7  | 10337 | 0.08 | 167  | 4.81   | 8.88  | 1.15 | 4.71 |
| Type II Natron glass | 7-Py 369b      | Green   | 6.9  | 389   | 6.1  | 31.2  | 1.2  | 0.6  | 0.1  | 0.9  | 42    | 0.09 | 196  | 5.56   | 10.28 | 1.35 | 5.75 |
| Type II Natron glass | 8-Py 371       | Cyan    | 7.8  | 424.9 | 7.3  | 36.7  | 1.7  | 0.8  | 0.3  | 98.9 | 315   | 0.09 | 213  | 6.48   | 11.54 | 1.51 | 6.25 |
| Type II Natron glass | 10-Py519/521a  | Dk blue | 6.5  | 460.1 | 6.3  | 31.2  | 1.1  | 0.5  | 0.3  | 10.2 | 296   | 0.1  | 188  | 5.58   | 10.18 | 1.33 | 5.6  |
| Type II Natron glass | 10-Py 519/521b | C.less  | 15.5 | 408.4 | 6.3  | 42.2  | 1.3  | 0.6  | 0.6  | 0.6  | 8197  | 0.15 | 213  | 5.65   | 10.44 | 1.4  | 5.45 |
| Type II Natron glass | 11-Py 6245     | Green   | 8.4  | 432.1 | 9.2  | 43.6  | 2.3  | 0.8  | 2.1  | 63.2 | 7743  | 0.19 | 237  | 8.21   | 14.57 | 1.89 | 7.64 |
| Type II Natron glass | 12-Py 6245     | Yellow  | 5.3  | 271.3 | 4.6  | 24.4  | 0.9  | 0.2  | 14.5 | 2.8  | 24604 | 0.08 | 135  | 4.2    | 7.53  | 0.99 | 4.1  |
| Type II Natron glass | 13-Py 6253     | Dp cy   | 8.5  | 439.6 | 7.3  | 37.6  | 1.6  | 2.4  | 0.6  | 84.7 | 280   | 0.1  | 209  | 6.57   | 12.02 | 1.47 | 6.5  |
| Type II Natron glass | 14-Py 6267b    | Turqu   | 8.1  | 382.5 | 5.8  | 26.4  | 1.2  | 0.4  | i.i  | 19   | 4899  | 0.1  | 168  | 5.36   | 9.86  | 1.15 | 5.31 |
| Type II Natron glass | 15-Py 6273     | Cyan    | 8.7  | 520.6 | 7.3  | 45.5  | 1.5  | 0.9  | 0.2  | 57.6 | 86    | 0.08 | 208  | 6.24   | 11.58 | 1.47 | 6.36 |
| Type II Natron glass | 18-Py 6299     | Aqua M  | 8.5  | 480.1 | 7.1  | 38.9  | 1.3  | 0.5  | 0.5  | 0.6  | 627   | 0.11 | 214  | 6.34   | 11.62 | 1.49 | 6.42 |
| Type II Natron glass | 20-Py 6405     | Dp cyan | 8    | 428.9 | 6    | 43    | 1.6  | 1.4  | 0.3  | 13.7 | 2750  | 0.16 | 217  | 5.98   | 10.64 | 1.35 | 5.71 |
| Type II Natron glass | 21-Py 6435     | C.less  | 8.6  | 376.3 | 5.8  | 36.2  | 1.2  | 0.2  | 0.1  | 0.3  | 19691 | 0.07 | 127  | 5.45   | 8.84  | U3   | 5.03 |
| Type II Natron glass | 22-Py 6436     | C.less  | 8    | 319   | 5.7  | 35.7  | 1.2  | 0.2  | 0.1  | 0.4  | 21686 | 0.06 | 120  | 5.46   | 8.45  | 1.1  | 4.86 |
| Type II Natron glass | 27-Py 8372 T   | C.less  | 15.2 | 367.6 | 5.8  | 40.7  | 1.4  | 0.8  | 0.1  | 0.4  | 15223 | 0.08 | 189  | 5.13   | 8.5   | 1.06 | 4.6  |
| Type II Natron glass | 29-Py 8382     | Honey   | 4.9  | 395.3 | 5.8  | 35.1  | 1.4  | 0.5  | b.d. | 0.3  | 4     | 0.05 | 136  | 5.41   | 9.73  | 1.26 | 5.5  |
| Type II Natron glass | 37-Py 8483     | Cyan    | 12.5 | 405   | 6.1  | 35.4  | 1.2  | 1.7  | 0.4  | 62.1 | 476   | 0.13 | 241  | 5.33   | 9.79  | 1.23 | 5.91 |
| Type II Natron glass | 39-Py 872      | C.less  | 8.9  | 378.6 | 6.1  | 41.1  | 1.2  | 0.3  | o.l  | 0.7  | 10492 | 0.08 | 172  | 5.18   | 9.69  | 1.23 | 5.52 |
| Type II Natron glass | 54-Mth 1309    | Bluish  | 6.2  | 447.3 | 6.6  | 32.3  | 1.2  | 0.3  | 0.1  | 0.4  | 2550  | 0.06 | 180  | 5.65   | 10.17 | 1.37 | 5.84 |
| Type II Natron glass | 55-Mth 2898    | Bluish  | 4.9  | 352.7 | 5.6  | 68.8  | 1.3  | 0.6  | 0.1  | 93.5 | 4117  | 0.05 | 121  | 5.08   | 7.91  | 1.17 | 4.92 |
| Type I Natron glass  | 60-Mth 338     | Cyan    | 2.9  | 248.2 | 5.1  | 174.1 | 2.7  | 0.2  | 0.2  | 0.8  | 4097  | 0.06 | 71   | 4.55   | 7.67  | 0.99 | 4.14 |
| Type II Natron glass | 61-Mth 822     | Honey   | 1.2  | 335.3 | 5.9  | 61    | 1.1  | 0.1  | b.d. | 0.3  | 5     | 0.02 | 38   | 5.94   | 6.76  | 1.27 | 5.54 |
| Type II Natron glass | 62-Mth 824     | Bluish  | 5.8  | 519.2 | 8    | 38.6  | 1.3  | 0.2  | 0.4  | 0.5  | 6883  | 0.07 | 215  | 6.54   | 11.48 | 1.51 | 6.57 |
| Type                 | Sample         | Colour  | Sm   | Eu    | Gd   | Tb    | Dy   | Ho   | Er   | Tm   | Yb    | Lu   | Hf   | Pb     | Bi    | Th   | U    |
|                      |                |         | ppm  | ppm   | ppm  | ppm   | ppm  | ppm  | ppm  | ppm  | ppm   | ppm  | ppm  | ppm    | ppm   | ppm  | ppm  |
| Type II Natron glass | 2-Py 945/T25a  | Wh.Op   | 1.17 | 0.34  | 1.09 | 0.16  | 1.06 | 0.21 | 0.62 | 0.08 | 0.53  | 0.08 | 0.82 | 302    | 0.03  | 0.8  | 4.33 |
| Type II Natron glass | 4-Py 133       | C.less  | 1.18 | 0.33  | 1.12 | 0.15  | 1    | 0.2  | 0.59 | 0.08 | 0.52  | 0.08 | 0.92 | 12     | 0.03  | 0.7  | 3.31 |
| Type II Natron glass | 5-Py 3543B     | Blue    | 1.24 | 0.36  | 1.24 | 0.18  | 1.2  | 0.24 | 0.69 | 0.08 | 0.58  | 0.09 | 0.94 | 26     | 0.02  | 0.9  | 1.48 |
| Type II Natron glass | 6-Py 3543      | C.less  | 1.25 | 0.34  | 1.19 | 0.16  | 1.12 | 0.21 | 0.66 | 0.08 | 0.5   | 0.07 | 0.96 | 68     | 0.01  | 0.82 | 1.47 |
| Type II Natron glass | 7-Py 369a      | Yellow  | 1    | 0.28  | 1.02 | 0.13  | 0.89 | 0.17 | 0.55 | 0.07 | 0.47  | 0.07 | 0.76 | 108255 | 8.89  | 0.76 | 1.49 |
| Type II Natron glass | 7-Py 369b      | Green   | 1.17 | 0.33  | 1.13 | 0.15  | 1.05 | 0.19 | 0.6  | 0.08 | 0.51  | 0.08 | 0.82 | 178    | 0.04  | 0.87 | 1.68 |
| Type II Natron glass | 8-Py 371       | Cyan    | 1.39 | 0.35  | 1.34 | 0.2   | 1.16 | 0.22 | 0.68 | 0.09 | 0.6   | 0.09 | 0.92 | 1301   | 0.06  | 0.9  | 1.37 |
| Type II Natron glass | 10-Py519/521a  | Dk blue | 1.18 | 0.34  | 1.09 | 0.17  | 0.97 | 0.22 | 0.59 | 0.09 | 0.5   | 0.08 | 0.81 | 8801   | 0.22  | 0.73 | 1.05 |

|                      |                |         |      |      |      |      |      |      |      |      |      |      |      |        |      |      |      |
|----------------------|----------------|---------|------|------|------|------|------|------|------|------|------|------|------|--------|------|------|------|
| Type II Natron glass | 10-Py 519/52lb | C.less  | 1.18 | 0.34 | 1.06 | 0.16 | 1.06 | 0.2  | 0.62 | 0.08 | 0.55 | 0.07 | 1.1  | 8239   | 0.08 | 0.76 | 1.23 |
| Type II Natron glass | 11-Py 6245     | Green   | 1.8  | 0.48 | 1.66 | 0.22 | 1.65 | 0.31 | 0.92 | 0.12 | 0.75 | 0.11 | 1.15 | 13022  | 0.34 | 1.32 | 2.48 |
| Type II Natron glass | 12-Py 6245     | Yellow  | 0.81 | 0.25 | 0.8  | 0.11 | 0.75 | 0.14 | 0.45 | 0.08 | 0.37 | 0.06 | 0.61 | 266497 | 6.17 | 0.56 | 1.6  |
| Type II Natron glass | 13-Py 6253     | Dp cy   | 1.32 | 0.37 | 1.3○ | 0.18 | 1.22 | 0.22 | 0.69 | 0.09 | 0.61 | 0.08 | 0.98 | 623    | 0.13 | 0.94 | 1.94 |
| Type II Natron glass | 14-Py 6267b    | Turqu   | 1.12 | 0.32 | 1    | 0.14 | 1.01 | 0.17 | 0.57 |      |      |      |      |        |      |      |      |
| Type II Natron glass | 15-Py 6273     | Cyan    | 1.34 | 0.36 | 1.31 | 0.18 | 1.19 | 0.22 | 0.74 | 0.09 | 0.61 | 0.09 | 1.12 | 80     | 0.02 | 0.83 | 1.5  |
| Type II Natron glass | 18-Py 6299     | Aqua M  | 1.31 | 0.35 | 1.31 | 0.18 | 1.19 | 0.23 | 0.68 | 0.09 | 0.61 | 0.09 | 0.91 | 4258   | 0.23 | 0.94 | 4.03 |
| Type II Natron glass | 20-Py 6405     | Dp cyan | 1.17 | 0.29 | 1.12 | 0.15 | 1.05 | 0.2  | 0.6  | 0.08 | 0.51 | 0.07 | 1.12 | 369    | 0.1  | 1.46 | 1.06 |
| Type II Natron glass | 21-Py 6435     | C.less  | 1.03 | 0.27 | 0.98 | 0.13 | 0.89 | 0.16 | 0.52 | 0.06 | 0.46 | 0.06 | 0.86 | 199    | 0.03 | 0.77 | 0.87 |
| Type II Natron glass | 22-Py 6436     | C.less  | 1.03 | 0.27 | 0.99 | 0.13 | 0.86 | 0.17 | 0.49 | 0.06 | 0.45 | 0.06 | 0.85 | 169    | 0.04 | 0.79 | 0.84 |
| Type II Natron glass | 27-Py 8372 T   | C.less  | 0.88 | 0.26 | 0.85 | 0.12 | 0.8  | 0.15 | 0.44 | 0.06 | 0.42 | 0.06 | 0.93 | 6      | 0.01 | 0.69 | 1.06 |
| Type II Natron glass | 29-Py 8382     | Honey   | 1.09 | 0.31 | 1.07 | 0.15 | 1.02 | 0.2  | 0.53 | 0.07 | 0.49 | 0.07 | 0.87 | 7      | 0    | 0.7  | 2.07 |
| Type II Natron glass | 37-Py 8483     | Cyan    | 1.23 | 0.32 | 1.22 | 0.17 | 1.1  | 0.2  | 0.66 | 0.08 | 0.58 | 0.08 | 0.99 | 963    | 0.04 | 0.82 | 1.05 |
| Type II Natron glass | 39-Py 872      | C.less  | 1.05 | 0.31 | i.n  | 0.15 | 1.02 | 0.19 | 0.58 | 0.08 | 0.57 | 0.08 | 1.1  | 25     | 0.01 | 0.79 | 4    |
| Type II Natron glass | 54-Mth 1309    | Bluish  | 1.27 | 0.34 | 1.18 | 0.16 | ui   | 0.21 | 0.62 | 0.08 | 0.64 | 0.09 | 0.88 | 204    | 0.12 | 0.74 | 4.86 |
| Type II Natron glass | 55-Mth 2898    | Bluish  | 1    | 0.25 | 0.99 | 0.13 | 0.96 | 0.17 | 0.56 | 0.06 | 0.47 | 0.07 | 1.7  | 78     | 0.06 | 0.69 | 0.68 |
| Type I Natron glass  | 60-Mth 338     | Cyan    | 0.82 | 0.22 | 0.81 | 0.11 | 0.75 | 0.16 | 0.5  | 0.07 | 0.44 | 0.07 | 3.96 | 1259   | 0.51 | 0.72 | 1.69 |
| Type II Natron glass | 61-Mth 822     | Honey   | 1.09 | 0.24 | 1.03 | 0.14 | 0.78 | 0.15 | 0.49 | 0.06 | 0.37 | 0.05 | 1.53 | 3      | 0.01 | 0.6  | 0.83 |
| Type II Natron glass | 62-Mth 824     | Bluish  | 1.43 | 0.42 | 1.42 | 0.2  | 1.28 | 0.25 | 0.79 | 0.1  | 0.65 | 0.09 | 0.98 | 1606   | 1.15 | 0.79 | i.ii |

**Table 2 Tzankova & Mihaylov (2019)**

| Type                 | Lab. code       | SiO <sub>2</sub><br>wt% | TiO <sub>2</sub><br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | FeO<br>wt% | Mn<br>O<br>wt% | Mg<br>O<br>wt% | CaO<br>wt% | Na <sub>2</sub><br>O<br>wt% | K <sub>2</sub> O<br>wt% | P <sub>2</sub> O <sub>5</sub><br>wt% | SO <sub>3</sub><br>wt% | Cu<br>ppm | Zn<br>ppm | Co<br>ppm | Sn<br>ppm | Sb<br>ppm | Pb<br>ppm |
|----------------------|-----------------|-------------------------|-------------------------|---------------------------------------|------------|----------------|----------------|------------|-----------------------------|-------------------------|--------------------------------------|------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Type II Natron glass | Dark orange     | 69.75                   | 0.05                    | 2.24                                  | 0.22       | 0.01           | 0.46           | 8.4        | 17.48                       | 0.4                     | 0.04                                 | 0.01                   | 5.84      | 8.76      | 5.65      | 1.42      | 34.58     | 18.14     |
| Type II Natron glass | 1168 light-blue | 67.21                   | 0.07                    | 2.27                                  | 0.26       | 0.02           | 0.58           | 11.13      | 17.23                       | 0.43                    | 0.05                                 | 0.36                   | 10.57     | 7.4       | 1.1       | 175.06    | 4904.4    | 30.09     |
| Type II Natron glass | 1219 dark-blue  | 69.5                    | 0.06                    | 2.59                                  | 0.43       | 0.01           | 0.44           | 8.54       | 15.77                       | 0.45                    | 0.04                                 | 0.28                   | 358.18    | 70.25     | 747.54    | 1.56      | 2754.4    | 519.21    |
| Type II Natron glass | 1181 yellow     | 62.06                   | 0.05                    | 1.23                                  | 0.86       | 0.01           | 0.38           | 5.37       | 13.88                       | 0.48                    | 0.03                                 | 0.05                   | 149.13    | 10.02     | 4.47      | 73.88     | 8999.09   | 138488    |
| Type II Natron glass | 1181 blue       | 70.17                   | 0.05                    | 2.2                                   | 2.17       | 0.01           | 0.34           | 6.29       | 15.63                       | 1.02                    | 0.05                                 | 0.05                   | 2183.1    | 752.99    | 1157.9    | 435       | 4250.1    | 7971.3    |
| Type II Natron glass | 1181 white      | 68.74                   | 0.06                    | 2.01                                  | 0.4        | 0.01           | 0.39           | 7.49       | 16.32                       | 0.96                    | 0.06                                 | 0.01                   | 678.81    | 22.31     | 8.16      | 8.33      | 34942.1   | 70703.4   |
| Type II Natron glass | 1198 light-blue | 70.81                   | 0.05                    | 2.26                                  | 0.28       | 0.01           | 0.39           | 6.94       | 16.75                       | 0.64                    | 0.03                                 | 0.69                   | 9723.1    | 143.73    | 15.93     | 241.21    | 13914     | 132.01    |
| Type II Natron glass | 1198 white      | 69.7                    | 0.06                    | 2.09                                  | 0.37       | 0.01           | 0.51           | 8.71       | 16.56                       | 0.84                    | 0.04                                 | 0.1                    | 194.66    | 53.51     | 10.26     | 13.36     | 83062.8   | 452.79    |
| Type II Natron glass | 1198 dark-blue  | 70.59                   | 0.06                    | 2.42                                  | 0.79       | 0.01           | 0.41           | 7.38       | 15.88                       | 0.73                    | 0.03                                 | 0.29                   | 2106.6    | 194.87    | 3939.1    | 6.18      | 5249.9    | 176.86    |
| Type II Natron glass | 1247 white      | 68.8                    | 0.06                    | 0.5                                   | 0.32       | 0.01           | 0.59           | 9.69       | 17.87                       | 0.25                    | 0.08                                 | 0.42                   | 28.91     | 14.3      | 1.76      | 2.43      | 68751     | 142.26    |
| Type II Natron glass | White           | 67.28                   | 0.06                    | 1.46                                  | 0.25       | 0.08           | 0.61           | 12.18      | 18.33                       | 0.25                    | 0.05                                 | 0.22                   | 47.51     | 8.74      | 1.21      | 2.82      | 30515.32  | 1967.82   |
| Type II Natron glass | EB3 dark-green  | 65.15                   | 0.06                    | 3.02                                  | 1.23       | 0.35           | 0.5            | 9.16       | 17.52                       | 0.56                    | 0.05                                 | 0.05                   | 7618.1    | 556.64    | 208.53    | 172.14    | 3880.4    | 1748      |
| Type II Natron glass | EB3 blue        | 66.61                   | 0.06                    | 3.15                                  | 0.6        | 0.02           | 0.54           | 8.57       | 17.62                       | 0.72                    | 0.06                                 | 0.92                   | 522.61    | 93.98     | 679.37    | 3.16      | 9586.2    | 14836     |
| Type II Natron glass | EB3 white       | 66.79                   | 0.05                    | 3.25                                  | 0.25       | 0.01           | 0.42           | 8.44       | 17.07                       | 0.6                     | 0.05                                 | 0.01                   | 57.68     | 15.52     | 2.03      | 1.44      | 35958     | 1652.5    |
| Type I0 Natron glass | EB3 yellow      | 66                      | 0.05                    | 3.03                                  | 0.3        | 0.01           | 0.47           | 9.6        | 17.08                       | 0.52                    | 0.03                                 | 0.53                   | 380.5     | 14.31     | 1.55      | 2.24      | 7679.95   | 19865.1   |

| Type                 | Lab. code       | Ba<br>ppm  | Sr<br>ppm   | Ni<br>ppm | Sc<br>ppm | V<br>ppm  | Cr<br>ppm | Ga<br>ppm | As<br>ppm | Rb<br>ppm | Zr<br>ppm | Mo<br>ppm | Ag<br>ppm | Cs<br>ppm | La<br>ppm | Ce<br>ppm | Pr<br>ppm | Nd<br>ppm |
|----------------------|-----------------|------------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Type II Natron glass | Dark orange     | 190        | 514.3       | 9.43      | 4.34      | 4.43      | 21.3<br>5 | 2.74      | 3.92      | 6.9       | 35.9<br>7 | 3.97      | <0.50     | <0.13     | 6.35      | 10.84     | 1.56      | 6.29      |
| Type II Natron glass | 1168 light-blue | 194.4<br>6 | 594.75      | 9.09      | 3.97      | 7.23      | 17.3<br>3 | 2.55      | 10.1<br>4 | 6.74      | 66.7<br>9 | <2.7<br>5 | 31.94     | 0.13      | 7.76      | 12.29     | 1.7       | 7.05      |
| Type II Natron glass | 1219 dark-blue  | 216.7<br>2 | 495.85      | 10.5<br>8 | 4.07      | 5.72      | 19.5<br>9 | 5.32      | 6.39      | 9.33      | 30.9<br>1 | 2.89      | <0.37     | <0.14     | 6.73      | 11.64     | 1.47      | 6.26      |
| Type II Natron glass | 1181 yellow     | 108.6      | 249.67      | 9.01      | 3.3       | 5.36      | 15.4<br>1 | 1.81      | 28.6      | 5.21      | 33.8<br>9 | 2.25      | 10.89     | <0.09     | 5.3       | 7.12      | 0.93      | 3.48      |
| Type II Natron glass | 1181 blue       | 195.3<br>4 | 356.08      | 22.6<br>8 | 2.94      | 6.97      | 14.8<br>6 | 15.5<br>1 | 19.6<br>9 | 11.6<br>7 | 34.3<br>6 | 2.78      | 1.53      | 0.11      | 5.66      | 9.59      | 1.26      | 5.19      |
| Type II Natron glass | 1181 white      | 232.6<br>5 | 400.17      | 8.64      | 3.45      | 5.78      | 15.7<br>3 | 2.05      | 24.1<br>3 | 11.7<br>4 | 36.5<br>7 | 3.1       | 4.26      | 0.14      | 9.97      | 10.78     | 1.48      | 4.37      |
| Type II Natron glass | 1198 light-blue | 229.7<br>8 | 439.65      | 39        | 4.25      | 4.67      | 17.7      | 2.4       | 36.5<br>7 | 13.3<br>8 | 33.4      | 3.21      | 1.64      | 0.53      | 7.83      | 11.24     | 1.6       | 5.81      |
| Type II Natron glass | 1198 white      | 292.6<br>6 | 534.64      | 8.74      | 3.92      | 5.79      | 17.3      | 2.65      | 15.3<br>9 | 12.9      | 49.7<br>1 | 3.31      | 0.64      | 0.27      | 15.93     | 11.28     | 1.54      | 6.55      |
| Type II Natron glass | 1198 dark-blue  | 212.2<br>7 | 444.68      | 15.4<br>8 | 3.74      | 5.52      | 18.0<br>5 | 7.18      | 13.6<br>7 | 12.1<br>1 | 35.1      | 3.4       | 0.75      | 0.4       | 6.64      | 10.77     | 1.41      | 6         |
| Type II Natron glass | 1247 white      | 125.4<br>9 | 404.92      | 9.89      | 4         | 6.08      | 18.1<br>2 | 2.04      | 20.8<br>9 | 2.73      | 70.2<br>2 | 3.03      | <0.46     | <0.10     | 13.52     | 7.22      | 1.3       | 5.41      |
| Type II Natron glass | White           | 165.0<br>8 | 568.41      | 8.48      | 3.3       | 6.99      | 16.5<br>6 | 2.04      | 12.9<br>1 | 3.93      | 62.2<br>2 | 2.91      | 0.47      | 0.09      | 9.41      | 9.62      | 1.49      | 5.6       |
| Type II Natron glass | EB3 dark-green  | 191.9<br>5 | 474.7       | 39.0<br>8 | 3.98      | 12.7      | 21.6<br>9 | 3.38      | 59.5<br>4 | 8.48      | 45.5<br>6 | 2.95      | 5.16      | 0.13      | 6.7       | 10.22     | 1.53      | 5.9       |
| Type II Natron glass | EB3 blue        | 250.5<br>4 | 540.95      | 9.31      | 3.7       | 5.83      | 17.5<br>1 | 4.36      | 14.0<br>2 | 9.69      | 40.6<br>4 | 2.65      | 5.18      | <0.12     | 7.9       | 12.52     | 1.7       | 7.36      |
| Type II Natron glass | EB3 white       | 252.6<br>1 | 492.15      | 9.7       | 4.2       | 4.58      | 19.6<br>6 | 2.86      | 15.5<br>8 | 9.47      | 29.9<br>4 | 3.09      | 0.96      | <0.12     | 10.02     | 10.96     | 1.42      | 5.98      |
| Type I0 Natron glass | EB3 yellow      | 224.1<br>6 | 533.00<br>% | 29.5<br>5 | 10.8<br>4 | 3.44      | 53.3<br>6 | 6.18      | 19.9<br>9 | 9.59      | 37.5<br>1 | 7.12      | 68.46     | <0.33     | 6.9       | 10.58     | 1.44      | 7.34      |
| Type                 | Lab. code       | Sm<br>ppm  | Eu<br>ppm   | Gd<br>ppm | Tb<br>ppm | Dy<br>ppm | Ho<br>ppm | Er<br>ppm | Tm<br>ppm | Yb<br>ppm | Lu<br>ppm | Hf<br>ppm | Ta<br>ppm | Pt<br>ppm | Au<br>ppm | Bi<br>ppm | Th<br>ppm | U<br>ppm  |

|                      |                 |      |       |      |      |      |      |      |           |           |           |      |       |       |       |       |       |      |
|----------------------|-----------------|------|-------|------|------|------|------|------|-----------|-----------|-----------|------|-------|-------|-------|-------|-------|------|
| Type II Natron glass | Dark orange     | 1.32 | 0.4   | 0.92 | 0.22 | 1.12 | 0.23 | 0.52 | 0.11      | 0.73      | <0.1<br>1 | 0.86 | <0.14 | 0.34  | 0.4   | <0.14 | 0.62  | 1.13 |
| Type II Natron glass | 1168 light-blue | 1.46 | 0.41  | 1.66 | 0.24 | 1.38 | 0.31 | 0.72 | 0.1       | 0.66      | 0.1       | 1.62 | <0.12 | <0.34 | <0.29 | <0.23 | 0.76  | 1.64 |
| Type II Natron glass | 1219 dark-blue  | 1.35 | 0.41  | 1.42 | 0.16 | 1.14 | 0.27 | 0.64 | <0.0<br>9 | 0.74      | 0.08      | 0.73 | <0.10 | <0.35 | <0.29 | 0.38  | 0.75  | 1.56 |
| Type II Natron glass | 1181 yellow     | 0.83 | <0.17 | 1    | 0.08 | 0.48 | 0.17 | 0.45 | <0.0<br>6 | 0.54      | <0.0<br>6 | 0.94 | <0.07 | <0.19 | <0.25 | 9.23  | 0.65  | 3.09 |
| Type II Natron glass | 1181 blue       | 1.05 | 0.35  | 1.09 | 0.14 | 0.87 | 0.2  | 0.39 | 0.08      | 0.53      | <0.0<br>7 | 0.9  | <0.09 | <0.24 | <0.26 | 0.32  | 0.76  | 0.92 |
| Type II Natron glass | 1181 white      | 0.73 | 0.33  | 1.15 | 0.19 | 1.07 | 0.24 | 0.48 | <0.0<br>9 | <0.4<br>3 | 0.13      | 0.74 | 0.1   | <0.28 | <0.37 | 4.92  | 0.72  | 2.24 |
| Type II Natron glass | 1198 light-blue | 1.4  | 0.34  | 1.07 | 0.17 | 1.12 | 0.2  | 0.61 | 0.09      | 0.64      | <0.1<br>0 | 1.1  | <0.10 | 0.35  | 0.33  | 0.26  | 0.83  | 0.93 |
| Type II Natron glass | 1198 white      | 1.46 | 0.4   | 1.09 | 0.19 | 1.31 | 0.26 | 0.8  | <0.1<br>0 | 0.65      | 0.12      | 1.18 | <0.11 | <0.15 | 0.38  | 0.3   | 0.81  | 1.26 |
| Type II Natron glass | 1198 dark-blue  | 1.27 | 0.35  | 1.25 | 0.18 | 1.16 | 0.19 | 0.5  | 0.1       | 0.59      | <0.1<br>0 | 0.93 | <0.11 | <0.30 | <0.33 | <0.31 | 0.82  | 0.93 |
| Type II Natron glass | 1247 white      | 0.76 | 0.24  | 0.95 | 0.14 | 1.12 | 0.15 | 0.52 | <0.0<br>6 | 0.55      | <0.0<br>9 | 1.67 | <0.11 | 0.26  | <0.36 | 0.1   | 0.61  | 0.88 |
| Type II Natron glass | White           | 1.08 | 0.26  | 1.26 | 0.17 | 0.99 | 0.22 | 0.72 | 0.11      | 0.56      | <0.0<br>9 | 1.59 | 0.1   | <0.24 | <0.32 | 1.45  | 0.73  | 1.14 |
| Type II Natron glass | EB3 dark-green  | 1.32 | 0.44  | 1.07 | 0.2  | 1.1  | 0.23 | 0.58 | <0.0<br>9 | 0.68      | 0.1       | 1.05 | <0.11 | 0.22  | 0.47  | 1.13  | 0.76  | 0.87 |
| Type II Natron glass | EB3 blue        | 1.15 | 0.3   | 1.73 | 0.15 | 1.41 | 0.26 | 0.47 | 0.11      | <0.5<br>8 | 0.08      | 0.98 | <0.11 | <0.30 | <0.21 | 1.2   | 0.79  | 1.03 |
| Type II Natron glass | EB3 white       | 1.41 | 0.39  | 1.09 | 0.18 | 1.11 | 0.28 | 0.66 | <0.1<br>2 | 0.6       | <0.0<br>8 | 0.61 | 0.12  | <0.26 | 0.31  | 0.47  | 0.75  | 0.72 |
| Type IO Natron glass | EB3 yellow      | 1.53 | 0.5   | 2.03 | 0.21 | 1.11 | 0.27 | 1.04 | <0.2<br>3 | 1.28      | <0.1<br>5 | 1.25 | <0.26 | 0.78  | 1.15  | 3.74  | 0.00% | 0.63 |

**Table 3 Conte *et al.* (2016)**

| Type                 | Sample  | Colour          | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | P <sub>2</sub> O <sub>5</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | TiO <sub>2</sub><br>wt% | Cr <sub>2</sub> O <sub>3</sub><br>wt% | MnO<br>wt% | FeO<br>wt% | CoO<br>wt% | CuO<br>wt% | B*<br>ppm |
|----------------------|---------|-----------------|--------------------------|------------|---------------------------------------|-------------------------|--------------------------------------|------------------------|-----------|-------------------------|------------|-------------------------|---------------------------------------|------------|------------|------------|------------|-----------|
| Type I Natron glass  | SN37t   | turquoise       | 18.83                    | 0.49       | 0.4                                   | 69.25                   | bdl                                  | 0.24                   | 1.38      | 0.18                    | 8.51       | 0.08                    | bdl                                   | 0.31       | 1.05       | bdl        | bdl        | 123       |
| Type I0 Natron glass | SN25b   | blue            | 17.73                    | 0.58       | 0.32                                  | 72.41                   | bdl                                  | 0.17                   | 1.43      | 0.33                    | 5.52       | 0.03                    | bdl                                   | 0.76       | 0.17       | bdl        | 1.45       | 102       |
| Type I Natron glass  | SN34b   | blue            | 17.98                    | 0.85       | 0.66                                  | 69.1                    | bdl                                  | 0.15                   | 1.6       | 0.21                    | 8.14       | 0.19                    | bdl                                   | bdl        | 0.61       | 0.11       | 1.79       | 132       |
| Type I Natron glass  | SN35t   | turquoise       | 19.33                    | 0.43       | 0.3                                   | 69.18                   | bdl                                  | 0.29                   | 1.56      | 0.15                    | 6.83       | 0.07                    | bdl                                   | bdl        | 0.48       | 0.04       | 1.25       | 95        |
| Type I Natron glass  | SN32g   | light-green     | 18.39                    | 0.55       | 0.39                                  | 70.48                   | bdl                                  | 0.14                   | 1.85      | 0.09                    | 8.54       | 0.08                    | bdl                                   | bdl        | 0.25       | bdl        | bdl        | 78.5      |
| Type I Natron glass  | SN4t    | light-turquoise | 19.28                    | 0.51       | 0.42                                  | 68.92                   | bdl                                  | 0.3                    | 1.55      | 0.16                    | 8.24       | 0.09                    | bdl                                   | 0.31       | 0.96       | bdl        | bdl        | 123       |
| Type I Natron glass  | SN7t    | turquoise       | 18.27                    | 0.54       | 0.56                                  | 69.58                   | bdl                                  | 0.31                   | 1.45      | 0.32                    | 7.51       | 0.11                    | bdl                                   | 0.45       | 0.37       | bdl        | 1.48       | 195       |
| Type I Natron glass  | SN9g    | green           | 21.64                    | 0.48       | 0.44                                  | 67.75                   | bdl                                  | 0.6                    | 1.2       | 0.12                    | 6.57       | 0.1                     | bdl                                   | 0.3        | 0.44       | bdl        | bdl        | <0.1      |
| Type I Natron glass  | SN33a   | amber           | 17.71                    | 1.01       | 0.81                                  | 68.58                   | bdl                                  | 0.16                   | 1.61      | 0.16                    | 10.05      | 0.11                    | bdl                                   | bdl        | 0.49       | bdl        | bdl        | 163       |
| Type I Natron glass  | SN52g   | green           | 19.07                    | 0.54       | 0.48                                  | 73.9                    | bdl                                  | 0.44                   | 0.9       | 0.12                    | 4.32       | 0.12                    | bdl                                   | 0.73       | 0.29       | bdl        | 0.85       | 115       |
| Type I0 Natron glass | CA13inc | colourless      | 17.78                    | 0.92       | 0.37                                  | 74.44                   | bdl                                  | 0.33                   | 1.06      | 0.36                    | 6.01       | 0.05                    | bdl                                   | bdl        | 0.23       | bdl        | bdl        | 106       |
| Type                 | Sample  | Colour          | Ti<br>ppm                | V<br>ppm   | Cr<br>ppm                             | Co<br>ppm               | Ni<br>ppm                            | Cu<br>ppm              | Zn<br>ppm | Ga<br>ppm               | Rb<br>ppm  | Sr<br>ppm               | Y<br>ppm                              | Zr<br>ppm  | Nb<br>ppm  | Sn<br>ppm  | Sb<br>ppm  | Ba<br>ppm |
| Type I Natron glass  | SN37t   | turquoise       | 376                      | 9.5        | 9.8                                   | 2.9                     | 6.6                                  | 65.29                  | 9.1       | 0.7                     | 2.3        | 295                     | 4.4                                   | 87.6       | 1          | 1          | 1.1        | 58.2      |
| Type I0 Natron glass | SN25b   | blue            | 175                      | 11.6       | 3.9                                   | 3.8                     | 21.8                                 | 9255                   | 40.6      | 0.6                     | 4.1        | 159                     | 2                                     | 19         | 0.5        | 105        | 11         | 58.1      |
| Type I Natron glass  | SN34b   | blue            | 817                      | 7.9        | 16.7                                  | 6%                      | 383                                  | 10459                  | 112       | 1.9                     | 9.9        | 276                     | 4.5                                   | 253        | 2.1        | 14.3       | 6.2        | 40.4      |
| Type I Natron glass  | SN35t   | turquoise       | 352                      | 3.6        | 7.6                                   | 192                     | 53.5                                 | 7350                   | 54.8      | 2                       | 3.9        | 191                     | 4.3                                   | 75.6       | 0.9        | 34.3       | 4.8        | 27.8      |
| Type I Natron glass  | SN32g   | light-green     | 317                      | 3.8        | 10.1                                  | 1.1                     | 6.7                                  | 2.9                    | 4.3       | 0.6                     | 0.6        | 235                     | 3.9                                   | 82.1       | 0.9        | 6.2        | <0.1       | 21.7      |
| Type I Natron glass  | SN4t    | light-turquoise | 450                      | 9.6        | 8.8                                   | 2.8                     | 5.5                                  | 58.1                   | 9         | 0.6                     | 1.6        | 275                     | 4                                     | 104        | 1.1        | 1.1        | 1.8        | 48.7      |
| Type I Natron glass  | SN7t    | turquoise       | 620                      | 14.9       | 11.7                                  | 3.5                     | 10                                   | 10005                  | 15.4      | 0.8                     | 14.1       | 265                     | 4.1                                   | 122        | 1.5        | 22.4       | 36.2       | 69.9      |
| Type I Natron glass  | SN9g    | green           | 430                      | 6.7        | 9.7                                   | 1.4                     | 3.1                                  | 33.8                   | 8.1       | 0.6                     | 0.9        | 205                     | 3.9                                   | 75.7       | 1          | 0.6        | 2          | 54.8      |
| Type I Natron glass  | SN33a   | amber           | 504                      | 9.7        | 12.5                                  | 1.3                     | 3.8                                  | 9.2                    | 13.3      | 1.0                     | 1.7        | 344                     | 4.5                                   | 87.5       | 1.3        | 2.5        | 1.4        | 48        |
| Type I Natron glass  | SN52g   | green           | 533                      | 12.9       | 13.9                                  | 4.3                     | 11.5                                 | 5644                   | 7         | 1.2                     | 1          | 118                     | 3.5                                   | 125        | 1.5        | 66.8       | 44.4       | 56.5      |
| Type I0 Natron glass | CA13inc | colourless      | 279                      | 4.8        | n.a.                                  | 1.1                     | 3.6                                  | 21                     | 9.7       | 0.7                     | 2.4        | 171                     | 1.6                                   | 35.4       | 0.8        | 2.5        | 22.2       | 29.7      |

**Table 4 Panighello *et al.* (2012)**

| Type                  | Sample | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | CaO   | TiO <sub>2</sub> | MnO   | Fe <sub>2</sub> O <sub>3</sub> | CoO   | CuO  | Sb <sub>2</sub> O <sub>3</sub> | PbO   | Li  | Be   | B   | Sc  |
|-----------------------|--------|-------------------|------|--------------------------------|------------------|-------------------------------|------------------|-------|------------------|-------|--------------------------------|-------|------|--------------------------------|-------|-----|------|-----|-----|
|                       |        | wt%               | wt%  | wt%                            | wt%              | wt%                           | wt%              | wt%   | wt%              | wt%   | wt%                            | wt%   | wt%  | wt%                            | wt%   | ppm | ppm  | ppm | ppm |
| Type II Natron glass  | 51b    | 17.9              | 0.54 | 2.43                           | 68.6             | 0.04                          | 0.43             | 7.51  | 0.06             | 0.013 | 1.67                           | 0.118 | 0.4  | 0.02                           | 0.07  | 3   | 0.26 | 64  | 1.6 |
| Type II Natron glass  | 52b    | 18                | 0.54 | 2.43                           | 68.2             | 0.04                          | 0.42             | 7.44  | 0.06             | 0.013 | 1.65                           | 0.114 | 0.41 | 0.01                           | 0.05  | 2.9 | 0.24 | 64  | 1.6 |
| Type II Natron glass  | 53b    | 16.9              | 0.41 | 2.38                           | 69.5             | 0.06                          | 0.61             | 7.05  | 0.06             | 0.013 | 2                              | 0.086 | 0.29 | 0.16                           | 0.29  | 3   | 0.21 | 72  | 1.4 |
| Type II Natron glass  | 54b    | 17.4              | 0.53 | 2.41                           | 68.9             | 0.04                          | 0.42             | 7.35  | 0.06             | 0.013 | 1.87                           | 0.135 | 0.46 | 0.04                           | 0.16  | 2.4 | 0.22 | 63  | 1.8 |
| Type II Natron glass  | 52t    | 16.4              | 0.46 | 2.19                           | 63.3             | 0.05                          | 0.47             | 6.81  | 0.06             | 0.012 | 0.57                           | 0.004 | 2.98 | 3.5                            | 2.21  | 2.7 | 0.22 | 49  | 1.5 |
| Type II Natron glass  | 51t    | 16.8              | 0.47 | 2.42                           | 62.9             | 0.05                          | 0.45             | 7.04  | 0.06             | 0.012 | 0.54                           | 0.004 | 2.69 | 4.15                           | 2.1   | 2.6 | 0.26 | 50  | 1.5 |
| Type II Natron glass  | 53t    | 17.1              | 0.4  | 2.13                           | 64.2             | 0.07                          | 0.53             | 6.79  | 0.05             | 0.011 | 0.39                           | 0.002 | 3.58 | 2.98                           | 1.86  | 2.9 | 0.23 | 82  | 1.3 |
| Type II Natron glass  | 54t    | 16.5              | 0.48 | 2.18                           | 64.2             | 0.05                          | 0.44             | 6.88  | 0.06             | 0.012 | 0.54                           | 0.005 | 2.49 | 3.33                           | 1.85  | 2.4 | 0.21 | 51  | 1.5 |
| Type II Natron glass  | 51y    | 10.7              | 0.31 | 1.6                            | 48.1             | 0.04                          | 0.29             | 4.39  | 0.06             | 0.011 | 1.8                            | 0.003 | 0.12 | 4.05                           | 28.89 | 1.9 | 0.18 | 38  | 1.5 |
| Type II Natron glass  | 52y    | 10.4              | 0.21 | 1.56                           | 47.3             | 0.04                          | 0.28             | 4.3   | 0.06             | 0.011 | 1.86                           | 0.003 | 0.1  | 3.58                           | 29.61 | 1.8 | 0.18 | 37  | 1.4 |
| Type II Natron glass  | 53y    | 13.8              | 0.3  | 1.85                           | 59.4             | 0.04                          | 0.44             | 4.48  | 0.06             | 0.009 | 1.41                           | 0.001 | 0.14 | 1.52                           | 16.17 | 2.3 | 0.21 | 67  | 2.3 |
| Type III Natron glass | 3b     | 15.1              | 1.04 | 1.99                           | 66.7             | 0.1                           | 0.71             | 10.63 | 0.18             | 0.036 | 2.27                           | 0.258 | 0.54 | 0.04                           | 0.19  | 8.9 | 0.31 | 200 | 3.1 |
| Type III Natron glass | 3w     | 17.5              | 0.7  | 1.42                           | 64.4             | 0.07                          | 0.46             | 7.63  | 0.12             | 0.017 | 0.94                           | 0.029 | 0.08 | 6.46                           | 0.04  | 8.8 | 0.22 | 184 | 2.3 |
| Type III Natron glass | 2bl    | 15.3              | 0.53 | 1.57                           | 73.6             | 0.16                          | 1.2              | 5.27  | 0.14             | 0.021 | 1.61                           | 0.077 | 0.24 | 0.01                           | 0.02  | 5.8 | 0.22 | 308 | 2.7 |
| Type III Natron glass | 2b2    | 16.4              | 0.5  | 1.59                           | 70.6             | 0.16                          | 1.2              | 5.26  | 0.14             | 0.022 | 1.61                           | 0.078 | 0.24 | 0.01                           | 0.02  | 5.8 | 0.25 | 306 | 2.7 |
| Type III Natron glass | 21ya   | 10.2              | 0.23 | 1.74                           | 50.9             | 0.08                          | 0.64             | 3.1   | 0.11             | 0.013 | 4.07                           | 0.008 | 0.11 | 3.42                           | 25.21 | 3.2 | 0.35 | 133 | 2.5 |
| Type III Natron glass | 21yb   | 11                | 0.29 | 1.55                           | 55.8             | 0.1                           | 0.69             | 3.6   | 0.11             | 0.015 | 3.44                           | 0.024 | 0.12 | 2.67                           | 20.51 | 3.7 | 0.31 | 174 | 2.4 |
| Type III Natron glass | 22ya   | 10.2              | 0.21 | 0.91                           | 51               | 0.08                          | 0.61             | 3.32  | 0.09             | 0.013 | 3.76                           | 0.001 | 0.09 | 3.43                           | 26.19 | 3.5 | 0.26 | 134 | 1.9 |
| Type III Natron glass | 22yb   | 10.3              | 0.21 | 0.88                           | 48.9             | 0.08                          | 0.66             | 3.13  | 0.09             | 0.013 | 4.02                           | 0.006 | 0.1  | 3.82                           | 27.69 | 3.1 | 0.31 | 125 | 1.8 |
| Type III Natron glass | 21w    | 15.5              | 0.53 | 1.22                           | 70.5             | 0.12                          | 1.29             | 5.81  | 0.17             | 0.014 | 0.77                           | 0.001 | 0.05 | 3.77                           | 0.04  | 6.3 | 0.19 | 314 | 2.3 |
| Type                  | Sample | V                 | Cr   | Ni                             | Zn               | Ga                            | As               | Se    | Rb               | Sr    | Y                              | Zr    | Nb   | Mo                             | Ag    | Cd  | In   | Sn  | Ba  |
|                       |        | ppm               | ppm  | ppm                            | ppm              | ppm                           | ppm              | ppm   | ppm              | ppm   | ppm                            | ppm   | ppm  | ppm                            | ppm   | ppm | ppm  | ppm | ppm |
| Type II Natron glass  | 51b    | 7                 | 8.7  | 8.5                            | 449              | 14.8                          | 15               | 10.5  | 7.22             | 385   | 7.1                            | 37    | 1.2  | 0.7                            | 4     | 0.2 | 1.1  | 3   | 181 |
| Type II Natron glass  | 52b    | 7                 | 8.3  | 8.4                            | 427              | 14.6                          | 15               | 9.9   | 7.23             | 401   | 7                              | 37    | 1.2  | 0.6                            | 4     | 0.2 | 1.1  | 3   | 180 |

|                       |        |      |      |      |     |      |     |      |      |     |     |     |     |     |     |     |     |      |     |
|-----------------------|--------|------|------|------|-----|------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|
| Type II Natron glass  | 53b    | 6    | 8.1  | 6.7  | 316 | 13.3 | 12  | 8.5  | 9.69 | 376 | 6.5 | 34  | 1.2 | 0.9 | 1   | 0.2 | 0.9 | 10   | 199 |
| Type II Natron glass  | 54b    | 7    | 8    | 9.4  | 472 | 15.4 | 16  | 8.4  | 7.09 | 397 | 7.1 | 37  | 1.2 | 0.7 | 2   | 0.2 | 1.2 | 10   | 176 |
| Type II Natron glass  | 52t    | 6.4  | 8.2  | 14.9 | 23  | 4.2  | 88  | 10.2 | 8.19 | 363 | 6.7 | 33  | 1.2 | 0.5 | 30  | 0.3 | 4.4 | 1199 | 172 |
| Type II Natron glass  | 51t    | 6.6  | 8.3  | 15.3 | 25  | 4.3  | 87  | 9.3  | 8.17 | 381 | 7   | 35  | 1.2 | 0.6 | 30  | 0.4 | 5.2 | 1587 | 179 |
| Type II Natron glass  | 53t    | 6.3  | 7.8  | 11   | 17  | 4.1  | 63  | 8.3  | 9.03 | 341 | 6.2 | 33  | 1.1 | 0.1 | 11  | 0.3 | 1.5 | 1216 | 192 |
| Type II Natron glass  | 54t    | 8.1  | 7.9  | 14.2 | 27  | 4.2  | 127 | 6.8  | 7.49 | 224 | 4.8 | 34  | 1.1 | 0.3 | 53  | 0.2 | 4.9 | 1242 | 167 |
| Type II Natron glass  | 51y    | 8.1  | 7.7  | 7.1  | 21  | 3.2  | 70  | 7    | 4.99 | 227 | 4.9 | 34  | 1.1 | 0.3 | 50  | 0.4 | 0.1 | 16   | 118 |
| Type II Natron glass  | 52y    | 5.3  | 7.4  | 10.5 | 21  | 4.1  | 72  | 6.8  | 4.83 | 336 | 6   | 33  | 1.1 | 0.3 | 11  | 0.4 | 0.1 | 264  | 118 |
| Type II Natron glass  | 53y    | 10.9 | 10.7 | 4.9  | 13  | 3.6  | 33  | 11.2 | 7.17 | 186 | 5.9 | 32  | 3   | 0.1 | 2   | 0.4 | 0   | 1    | 147 |
| Type III Natron glass | 3b     | 20.6 | 15   | 288  | 189 | 8.8  | 29  | 7    | 7.07 | 243 | 5.5 | 81  | 2.9 | 1   | 1   | 0.2 | 9.6 | 31   | 85  |
| Type III Natron glass | 3w     | 12.2 | 11.7 | 38.8 | 41  | 3    | 18  | 7.2  | 6.6  | 234 | 5.1 | 87  | 2.2 | 0.4 | 1   | 0.4 | 1.2 | 5    | 81  |
| Type III Natron glass | 2bl    | 12.2 | 11.1 | 20.7 | 75  | 5.3  | 42  | 11.7 | 9.51 | 164 | 6.4 | 204 | 2.6 | 2   | 1   | 0.2 | 1.1 | 7    | 139 |
| Type III Natron glass | 2b2    | 12.2 | 10.9 | 19.1 | 76  | 4.3  | 47  | 11.5 | 9.45 | 165 | 6.4 | 205 | 2.6 | 2   | 1   | 0.2 | 1.1 | 6    | 130 |
| Type III Natron glass | 21ya   | 10.7 | 11.9 | 8.7  | 40  | 3    | 90  | 8.5  | 5.85 | 89  | 6.4 | 107 | 3   | 0.4 | 50  | 0.6 | 0.3 | 43   | 79  |
| Type III Natron glass | 21yb   | 10.6 | 10.8 | 11   | 52  | 3.3  | 76  | 8.9  | 6.39 | 105 | 6.3 | 128 | 2.5 | 0.7 | 50  | 0.7 | 0.5 | 34   | 91  |
| Type III Natron glass | 22ya   | 8.6  | 7.2  | 6.6  | 32  | 1.8  | 82  | 8.6  | 5.71 | 92  | 5.6 | 95  | 1.6 | 0.2 | 65  | 0.5 | 0.2 | 43   | 81  |
| Type III Natron glass | 22yb   | 8.5  | 6.8  | 6.8  | 33  | 1.9  | 89  | 8.1  | 5.52 | 86  | 5.8 | 98  | 1.6 | 0.3 | 46  | 0.5 | 0.2 | 46   | 76  |
| Type III Natron glass | 21w    | 10.9 | 10.8 | 4.9  | 36  | 2.8  | 33  | 11.2 | 9.07 | 186 | 5.9 | 276 | 3   | 0.7 | 2   | 0.2 | 0   | 1    | 125 |
| Type                  | Sample | La   | Ce   | Pr   | Nd  | Sm   | Eu  | Gd   | Tb   | Dy  | Ho  | Er  | Tm  | Y   | Lu  | Au  | Bi  | Th   | U   |
|                       |        | ppm  | ppm  | ppm  | ppm | ppm  | ppm | ppm  | ppm  | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm  | ppm |
| Type II Natron glass  | 51b    | 6.4  | 11.3 | 1.5  | 6.5 | 1.3  | 0.4 | 1.2  | 0.2  | 1.2 | 0.2 | 0.7 | 0.1 | 0.6 | 0.1 | 0   | 0.1 | 0.9  | 12  |
| Type II Natron glass  | 52b    | 6.4  | 11.2 | 1.5  | 6.4 | 1.3  | 0.4 | 1.2  | 0.2  | 1.2 | 0.2 | 0.6 | 0.1 | 0.6 | 0.1 | 0   | 0.1 | 0.9  | 12  |
| Type II Natron glass  | 53b    | 5.8  | 10.3 | 1.3  | 5.9 | 1.2  | 0.3 | 1.1  | 0.2  | 1.1 | 0.2 | 0.6 | 0.1 | 0.6 | 0.1 | 0   | 0.2 | 0.8  | 1.4 |
| Type II Natron glass  | 54b    | 6.2  | 10.9 | 1.4  | 6.3 | 1.3  | 0.4 | 1.2  | 0.2  | 1.2 | 0.2 | 0.6 | 0.1 | 0.6 | 0.2 | 0.6 | 0.3 | 0.9  | 12  |
| Type II Natron glass  | 52t    | 6.1  | 10.7 | 1.4  | 6.1 | 1.2  | 0.4 | 1.2  | 0.2  | 1.1 | 0.2 | 0.6 | 0.1 | 0.6 | 0.1 | 0.7 | 31  | 0.8  | 7.1 |
| Type II Natron glass  | 51t    | 6.4  | 11.2 | 1.5  | 6.3 | 1.3  | 0.4 | 1.3  | 0.2  | 1.2 | 0.2 | 0.7 | 0.1 | 0.6 | 0.1 | 0.6 | 34  | 0.9  | 7.4 |
| Type II Natron glass  | 53t    | 5.6  | 9.4  | 1.3  | 5.5 | 1.1  | 0.3 | 1    | 0.2  | 1   | 0.2 | 0.6 | 0.1 | 0.5 | 0.1 | 0.5 | 1.1 | 0.8  | 1.4 |



|                       |      |     |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-----------------------|------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Type II Natron glass  | 54t  | 5.9 | 10.5 | 1.4 | 5.9 | 1.2 | 0.4 | 1.1 | 0.2 | 1.1 | 0.2 | 0.6 | 0.1 | 0.5 | 0.1 | 0.6 | 32  | 0.8 | 7.4 |
| Type II Natron glass  | 51y  | 7.2 | 14.1 | 1.4 | 5   | 0.9 | 0.3 | 0.9 | 0.1 | 0.8 | 2   | 0.5 | 0.1 | 0.4 | 0.1 | 0.1 | 3.3 | 0.9 | 5.3 |
| Type II Natron glass  | 52y  | 5.4 | 9    | 1.2 | 5.5 | 1.2 | 0.3 | 1   | 0.2 | 1   | 0.2 | 0.4 | 0.1 | 0.5 | 0.1 | 0.1 | 3.4 | 0.8 | 1.3 |
| Type II Natron glass  | 53y  | 7.6 | 14.5 | 1.6 | 6.7 | 1.3 | 0.3 | 1.1 | 0.2 | 1   | 0.2 | 0.6 | 0.1 | 0.7 | 0.1 | 0   | 0   | 2   | 1.4 |
| Type III Natron glass | 3b   | 7.8 | 15.1 | 1.7 | 7.1 | 1.4 | 0.3 | 1.1 | 0.2 | 1   | 0.2 | 0.5 | 0.1 | 0.5 | 0.1 | 0   | 0.2 | 1.7 | 1.8 |
| Type III Natron glass | 3w   | 7   | 13.2 | 1.6 | 6.3 | 1.3 | 0.3 | 1   | 0.2 | 0.9 | 0.2 | 0.5 | 0.1 | 0.5 | 0.1 | 0   | 0.1 | 1.6 | 2.1 |
| Type III Natron glass | 2bl  | 7.5 | 14.8 | 1.7 | 7.1 | 1.4 | 0.3 | 1.2 | 0.2 | 1.1 | 0.2 | 0.6 | 0.1 | 0.7 | 0.1 | 0   | 0.1 | 1.8 | 1.3 |
| Type III Natron glass | 2b2  | 7.6 | 14.5 | 1.7 | 7.2 | 1.4 | 0.3 | 1.2 | 0.2 | 1.1 | 0.2 | 0.6 | 0.1 | 0.6 | 0.1 | 0   | 0.1 | 1.9 | 1.4 |
| Type III Natron glass | 21ya | 6.4 | 14.1 | 1.6 | 6.5 | 1.4 | 0.3 | 1.3 | 0.2 | 1.1 | 0.2 | 0.6 | 0.1 | 0.6 | 0.1 | 0.1 | 5.6 | 1.7 | 0.9 |
| Type III Natron glass | 21yb | 6.2 | 13.4 | 1.5 | 6.3 | 1.4 | 0.3 | 1.3 | 0.2 | 1.1 | 0.2 | 0.6 | 0.1 | 0.5 | 0.1 | 0.1 | 4.4 | 1.7 | 1   |
| Type III Natron glass | 22ya | 5   | 10.2 | 1.2 | 5.4 | 1.2 | 0.3 | 1.1 | 0.2 | 1   | 0.2 | 0.5 | 0.1 | 0.5 | 0.1 | 0.1 | 5.4 | 1.3 | 0.8 |
| Type III Natron glass | 22yb | 4.9 | 10.1 | 1.2 | 5.3 | 1.2 | 0.3 | 1.2 | 0.2 | 1   | 0.2 | 0.5 | 0.1 | 0.5 | 0.1 | 0.1 | 6   | 1.3 | 0.8 |
| Type III Natron glass | 21w  | 7.6 | 14.5 | 1.6 | 6.7 | 1.3 | 0.3 | 1.1 | 0.2 | 1   | 0.2 | 0.6 | 0.1 | 0.7 | 0.1 | 0   | 0   | 2   | 1.4 |

**Table 5 Conte *et al.* (2019)**

| Type                 | Sample | Na <sub>2</sub> O<br>wt% | MgO<br>wt%              | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | P <sub>2</sub> O <sub>5</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | TiO <sub>2</sub><br>wt% | MnO<br>wt% | FeO<br>wt% | CoO<br>wt% |
|----------------------|--------|--------------------------|-------------------------|---------------------------------------|-------------------------|--------------------------------------|------------------------|-----------|-------------------------|------------|-------------------------|------------|------------|------------|
| Type I0 Natron glass | FM5a   | 17.76                    | 0.44                    | 0.19                                  | 74.33                   | 0.05                                 | 0.08                   | 0.78      | 0.23                    | 6.47       | bdl                     | bdl        | 0.14       | bdl        |
| Type I0 Natron glass | FMlOa  | 18.57                    | 0.43                    | 0.24                                  | 74.53                   | 0.08                                 | 0.08                   | 0.79      | 0.2                     | 6.64       | bdl                     | bdl        | 0.14       | bdl        |
| Type I0 Natron glass | FMlla  | 19.69                    | 0.39                    | 0.14                                  | 75.25                   | 0.06                                 | 0.07                   | 0.81      | 0.2                     | 5.2        | bdl                     | bdl        | 0.09       | bdl        |
| Type I Natron glass  | AMI g  | 17.38                    | 0.63                    | 0.33                                  | 68.51                   | 0.06                                 | 0.25                   | 1.19      | 0.06                    | 10.53      | 0.13                    | bdl        | 0.28       | bdl        |
| Type                 | Sample | Cu <sub>2</sub> O<br>wt% | SnO <sub>2</sub><br>wt% | Sb <sub>2</sub> O <sub>3</sub><br>wt% | PbO<br>wt%              | Ti<br>ppm                            | V<br>ppm               | Cr<br>ppm | Co<br>ppm               | Ni<br>ppm  | Cu<br>ppm               | Zn<br>ppm  | Ga<br>ppm  | As<br>ppm  |
| Type I0 Natron glass | FM5a   | 0.11                     | bdl                     | bdl                                   | bdl                     | 104                                  | 2.94                   | n.r.      | 0.97                    | 5.21       | 44.44                   | 28.46      | 0.31       | 0.69       |
| Type I0 Natron glass | FMlOa  | bdl                      | bdl                     | bdl                                   | bdl                     | 114                                  | 3.01                   | 1.82      | 0.44                    | 3.18       | 9.03                    | 13.14      | 0.6        | n.d        |
| Type I0 Natron glass | FMlla  | bdl                      | bdl                     | bdl                                   | bdl                     | 78                                   | 2.34                   | 2.73      | 0.48                    | 1.79       | 5.68                    | 5.65       | 0.24       | 0.1        |
| Type I Natron glass  | AMI g  | bdl                      | bdl                     | bdl                                   | bdl                     | 627                                  | 5.07                   | n.r.      | 1.24                    | 6.97       | 5.09                    | 13.62      | 0.81       | 1.15       |
| Type                 | Sample | Rb<br>ppm                | Sr<br>ppm               | Y<br>ppm                              | Zr<br>ppm               | Nb<br>ppm                            | Sn<br>ppm              | Sb<br>ppm | Ba<br>ppm               | Hf<br>ppm  | Ta<br>ppm               | Th<br>ppm  | U<br>ppm   |            |
| Type I0 Natron glass | FM5a   | 1.97                     | 168                     | 0.97                                  | 7.26                    | 0.28                                 | 12.26                  | 3.52      | 35                      | 0.16       | 0.01                    | 0.14       | 0.35       |            |
| Type I0 Natron glass | FMlOa  | 1.71                     | 174                     | 1.12                                  | 8.04                    | 0.31                                 | 5.67                   | 2.31      | 32                      | 0.18       | 0.01                    | 0.18       | 0.35       |            |
| Type I0 Natron glass | FMlla  | 1.93                     | 164                     | 0.98                                  | 7.19                    | 0.22                                 | 5.47                   | 4.48      | 32                      | 0.15       | 0.01                    | 0.12       | 0.46       |            |
| Type I Natron glass  | AMI g  | 0.56                     | 2%                      | 4.25                                  | 201.64                  | 1.66                                 | 6.1                    | 0.3       | 22                      | 4.16       | 0.1                     | 0.5        | 0.99       |            |

**Table 6 Strydonck *et al.* (2018)**

| Type                  | Sample       | Na <sub>2</sub> O<br>wt%              | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt%              | P <sub>2</sub> O <sub>5</sub><br>wt% | Cl<br>wt%                             | K <sub>2</sub> O<br>wt% | CaO<br>wt% | TiO <sub>2</sub><br>wt%               | MnO<br>wt%               | Fe <sub>2</sub> O <sub>3</sub><br>wt% | CoO<br>wt%                           | CuO<br>wt%              |
|-----------------------|--------------|---------------------------------------|------------|---------------------------------------|--------------------------------------|--------------------------------------|---------------------------------------|-------------------------|------------|---------------------------------------|--------------------------|---------------------------------------|--------------------------------------|-------------------------|
| Type III Natron glass | S.M. n° 1 b  | 13.3                                  | 0.46       | 1.17                                  | 71.6                                 | 0.12                                 | 1.01                                  | 0.77                    | 9.23       | 0.086                                 | 0.013                    | 1.48                                  | 0.28                                 | 0.22                    |
| Type III Natron glass | S.M. n° 1 w  | 12.5                                  | 0.36       | 0.9                                   | 70.3                                 | 0.083                                | 0.74                                  | 0.58                    | 9.37       | 0.075                                 | 0.0086                   | 0.76                                  | 0.0049                               | 0.0087                  |
| Type III Natron glass | S.M. n° 2 b  | 12.9                                  | 0.56       | 1.22                                  | 70.3                                 | 0.11                                 | 1.2                                   | 0.65                    | 9.5        | 0.15                                  | 0.019                    | 1.83                                  | 0.58                                 | 0.45                    |
| Type III Natron glass | S.M. n° 2 w  | 14.4                                  | 0.49       | 0.95                                  | 63.6                                 | 0.087                                | 1.19                                  | 0.57                    | 10.04      | 0.1                                   | 0.015                    | 0.89                                  | 0.0018                               | 0.042                   |
| Type III Natron glass | S.M. n° 4 b  | 13.4                                  | 0.46       | 1.69                                  | 69.5                                 | 0.094                                | 1.03                                  | 0.58                    | 10.91      | 0.14                                  | 0.033                    | 1.33                                  | 0.29                                 | 0.35                    |
| Type III Natron glass | S.M. n° 4 w  | 12                                    | 0.35       | 1.15                                  | 66.9                                 | 0.036                                | 0.61                                  | 0.55                    | 10.56      | 0.098                                 | 0.011                    | 0.9                                   | 0.0012                               | 0.0054                  |
| Type III Natron glass | S.M. n° 7 a  | 17.7                                  | 0.62       | 1.19                                  | 63.3                                 | 0.073                                | 1.21                                  | 0.34                    | 6.21       | 0.095                                 | 0.043                    | 9.04                                  | 0.0047                               | 0.035                   |
| Type III Natron glass | S.M. n° 7 y  | 16.4                                  | 0.41       | 0.71                                  | 59.7                                 | 0.017                                | 0.62                                  | 0.24                    | 3.24       | 0.082                                 | 0.0089                   | 1.39                                  | 0.0004                               | 0.04                    |
| Type III Natron glass | S.M. n° 12 b | 15.3                                  | 0.35       | 0.79                                  | 69.9                                 | 0.07                                 | 0.76                                  | 0.34                    | 9.06       | 0.09                                  | 0.011                    | 0.91                                  | 0.32                                 | 0.23                    |
| Type III Natron glass | S.M. n° 12 w | 12.8                                  | 0.37       | 0.95                                  | 64.4                                 | 0.06                                 | 0.48                                  | 0.36                    | 8.81       | 0.092                                 | 0.011                    | 1.27                                  | 0.0012                               | 0.012                   |
| Type III Natron glass | S.M. n° 3 b1 | 14.7                                  | 0.39       | 1.02                                  | 72.4                                 | 0.12                                 | 0.75                                  | 0.49                    | 8.34       | 0.085                                 | 0.029                    | 0.97                                  | 0.27                                 | 0.2                     |
| Type III Natron glass | S.M. n° 3 b2 | 13.7                                  | 0.38       | 1.35                                  | 72.4                                 | 0.11                                 | 0.75                                  | 0.94                    | 8.23       | 0.072                                 | 0.11                     | 1.27                                  | 0.22                                 | 0.2                     |
| Type II Natron glass  | S.M. n° 3 w  | 14.3                                  | 0.39       | 2.35                                  | 69.4                                 | 0.11                                 | 0.76                                  | 1.31                    | 7.88       | 0.048                                 | 0.015                    | 0.89                                  | 0.0057                               | 0.0357                  |
| Type II Natron glass  | S.M. n° 5 b  | 16.6                                  | 0.36       | 2.33                                  | 68.7                                 | 0.044                                | 1.11                                  | 0.62                    | 5.89       | 0.051                                 | 0.046                    | 2.3                                   | 0.47                                 | 0.38                    |
| Type II Natron glass  | S.M. n° 5 w  | 15.6                                  | 0.27       | 1.48                                  | 70.4                                 | 0.017                                | 0.98                                  | 0.43                    | 5.98       | 0.045                                 | 0.0093                   | 0.34                                  | 0.0006                               | 0.0053                  |
| Type II Natron glass  | S.M. n° 6 b  | 14.6                                  | 0.3        | 2.45                                  | 73.1                                 | 0.032                                | 1                                     | 0.42                    | 6.29       | 0.05                                  | 0.11                     | 0.97                                  | 0.19                                 | 0.24                    |
| Type II Natron glass  | S.M. n° 6 w  | 15.4                                  | 0.25       | 1.31                                  | 70.8                                 | 0                                    | 1.01                                  | 0.37                    | 5.57       | 0.043                                 | 0.0082                   | 0.49                                  | 0.0006                               | 0.0042                  |
| Type II Natron glass  | S.M. n° 10 b | 16.4                                  | 0.38       | 2.34                                  | 69.5                                 | 0.052                                | 0.96                                  | 0.62                    | 7.99       | 0.049                                 | 0.017                    | 1.14                                  | 0.18                                 | 0.18                    |
| Type II Natron glass  | S.M. n° 10 w | 17.6                                  | 0.37       | 2.24                                  | 64.6                                 | 0.019                                | 0.8                                   | 0.56                    | 7.66       | 0.044                                 | 0.012                    | 0.63                                  | 0.0002                               | 0.053                   |
| Type                  | Sample       | Sb <sub>2</sub> O <sub>3</sub><br>wt% | PbO<br>wt% | Li <sub>2</sub> O<br>ppm              | B <sub>2</sub> O <sub>3</sub><br>ppm | V <sub>2</sub> O <sub>5</sub><br>ppm | Cr <sub>2</sub> O <sub>3</sub><br>ppm | NiO<br>ppm              | ZnO<br>ppm | As <sub>2</sub> O <sub>3</sub><br>ppm | Rb <sub>2</sub> O<br>ppm | SrO<br>ppm                            | Y <sub>2</sub> O <sub>3</sub><br>ppm | ZrO <sub>2</sub><br>ppm |
| Type III Natron glass | S.M. n° 1 b  | 0.027                                 | 0.046      | 19.3                                  | 413                                  | 14.9                                 | 10.8                                  | 296                     | 163        | 91.8                                  | 6.83                     | 257                                   | 5.74                                 | 139                     |
| Type III Natron glass | S.M. n° 1 w  | 4.12                                  | 0.031      | 25.8                                  | 393                                  | 12.9                                 | 2.11                                  | 8.15                    | 34         | 23.5                                  | 6.28                     | 259                                   | 5.45                                 | 124                     |

|                       |              |                                |        |                  |     |                                |                  |                  |                                |                  |                                |                  |                 |      |
|-----------------------|--------------|--------------------------------|--------|------------------|-----|--------------------------------|------------------|------------------|--------------------------------|------------------|--------------------------------|------------------|-----------------|------|
| Type III Natron glass | S.M. n° 2 b  | 0.076                          | 0.24   | 24.2             | 612 | 20.2                           | 16.6             | 195              | 145                            | 43.7             | 6.92                           | 258              | 6.63            | 183  |
| Type III Natron glass | S.M. n° 2 w  | 7.43                           | 0.07   | 29.6             | 590 | 16.1                           | 9.4              | 5.98             | 34                             | 126              | 6.97                           | 259              | 5.96            | 145  |
| Type III Natron glass | S.M. n° 4 b  | 0.047                          | 0.046  | 25.3             | 290 | 28.4                           | 19.1             | 50               | 57.1                           | 11.2             | 6.98                           | 331              | 7.6             | 185  |
| Type III Natron glass | S.M. n° 4 w  | 5.36                           | 1.31   | 40.4             | 312 | 16.5                           | 8.4              | 9.3              | 38.2                           | 63.9             | 7.17                           | 249              | 6.19            | 150  |
| Type III Natron glass | S.M. n° 7 a  | 0.019                          | 0.027  | 20               | 461 | 17.2                           | 15.4             | 10.3             | 37.7                           | 8.79             | 5.04                           | 232              | 5.18            | 110  |
| Type III Natron glass | S.M. n° 7 y  | 1.82                           | 15.3   | 16.5             | 343 | 15.3                           | 9.73             | 9.14             | 21.6                           | 3.93             | 4.74                           | 176              | 4.64            | 96.8 |
| Type III Natron glass | S.M. n° 12 b | 0.56                           | 1.14   | 18.3             | 526 | 13.1                           | 11.9             | 79.7             | 93.6                           | 35.4             | 5.13                           | 215              | 5.39            | 148  |
| Type III Natron glass | S.M. n° 12 w | 6.06                           | 4.12   | 23.4             | 556 | 14.5                           | 9.63             | 6.73             | 51.5                           | 109              | 5.43                           | 203              | 5.93            | 161  |
| Type III Natron glass | S.M. n° 3 b1 | 0.007                          | 0.023  | 19.6             | 527 | 15.6                           | 11.4             | 86.1             | 79.6                           | 13.2             | 6.11                           | 259              | 5.36            | 155  |
| Type III Natron glass | S.M. n° 3 b2 | 0.024                          | 0.049  | 26.6             | 565 | 15.9                           | 11.9             | 71.2             | 87                             | 27               | 12                             | 324              | 6.2             | 114  |
| Type II Natron glass  | S.M. n° 3 w  | 2.28                           | 0.075  | 29.1             | 209 | 11.6                           | 10.8             | 6.82             | 38.2                           | 39.4             | 18.9                           | 476              | 8.31            | 42.4 |
| Type II Natron glass  | S.M. n° 5 b  | 0.25                           | 0.59   | 13.7             | 641 | 12.5                           | 11.3             | 176              | 355                            | 39.3             | 9.88                           | 386              | 7.59            | 44.8 |
| Type II Natron glass  | S.M. n° 5 w  | 2.98                           | 1.42   | 23               | 316 | 10.3                           | 6.09             | 4.08             | 11.9                           | 23.5             | 6.31                           | 370              | 7.55            | 44.4 |
| Type II Natron glass  | S.M. n° 6 b  | 0.037                          | 0.021  | 13.7             | 219 | 13.1                           | 11               | 73.2             | 135                            | 18.9             | 7.16                           | 410              | 8.39            | 47.1 |
| Type II Natron glass  | S.M. n° 6 w  | 3.32                           | 1.32   | 39.5             | 306 | 9.89                           | 2.04             | 4.24             | 10.3                           | 27.7             | 5.76                           | 343              | 6.71            | 41   |
| Type II Natron glass  | S.M. n° 10 b | 0.019                          | 0.016  | 11.3             | 520 | 11.5                           | 10.9             | 68.3             | 134                            | 10.3             | 10.5                           | 548              | 9.45            | 45   |
| Type II Natron glass  | S.M. n° 10 w | 5.29                           | 0.0094 | 18.1             | 572 | 9.62                           | 6.78             | 3.4              | 12.4                           | 26.6             | 9.52                           | 530              | 8.87            | 41.6 |
| Type                  | Sample       | Nb <sub>2</sub> O <sub>3</sub> | In     | SnO <sub>2</sub> | BaO | La <sub>2</sub> O <sub>3</sub> | CeO <sub>2</sub> | PrO <sub>2</sub> | Nd <sub>2</sub> O <sub>3</sub> | HfO <sub>2</sub> | Ta <sub>2</sub> O <sub>3</sub> | ThO <sub>2</sub> | UO <sub>2</sub> |      |
|                       |              | ppm                            | ppm    | ppm              | ppm | ppm                            | ppm              | ppm              | ppm                            | ppm              | ppm                            | ppm              | ppm             |      |
| Type III Natron glass | S.M. n° 1 b  | 2.38                           | 7.49   | 64.7             | 122 | 8.03                           | 16.1             | 1.77             | 7.03                           | 3.01             | 0.14                           | 1.75             | 1.06            |      |
| Type III Natron glass | S.M. n° 1 w  | 1.84                           | 0.16   | 1.42             | 118 | 7.6                            | 14.9             | 1.7              | 6.15                           | 2.43             | 0.09                           | 1.46             | 1.23            |      |
| Type III Natron glass | S.M. n° 2 b  | 3.36                           | 13.6   | 154              | 110 | 9.39                           | 18.3             | 2.01             | 7.55                           | 3.78             | 0.19                           | 2.09             | 0.88            |      |
| Type III Natron glass | S.M. n° 2 w  | 2.47                           | 0.04   | 1.89             | 150 | 8.38                           | 15.2             | 1.71             | 6.38                           | 3.05             | 0.13                           | 1.66             | 1.35            |      |
| Type III Natron glass | S.M. n° 4 b  | 3.28                           | 2.26   | 158              | 169 | 10.6                           | 20.8             | 2.3              | 8.86                           | 3.89             | 0.18                           | 2.51             | 1.67            |      |
| Type III Natron glass | S.M. n° 4 w  | 2.18                           | 0.03   | 0.93             | 95  | 7.97                           | 15.3             | 1.73             | 6.55                           | 2.95             | 0.11                           | 1.9              | 2               |      |
| Type III Natron glass | S.M. n° 7 a  | 2.42                           | 0.03   | 28.9             | 64  | 7.06                           | 13.3             | 1.5              | 5.84                           | 2.3              | 0.18                           | 1.55             | 2.37            |      |

|                       |              |      |      |      |     |      |      |      |      |      |      |      |      |
|-----------------------|--------------|------|------|------|-----|------|------|------|------|------|------|------|------|
| Type III Natron glass | S.M. n° 7 y  | 1.93 | 0.01 | 0.49 | 49  | 5.31 | 9.8  | 1.16 | 4.6  | 2.05 | 0.11 | 1.21 | 1.87 |
| Type III Natron glass | S.M. n° 12 b | 2.12 | 7.83 | 65.3 | 80  | 7.58 | 14.9 | 1.68 | 6.54 | 3.09 | 0.12 | 1.65 | 1.96 |
| Type III Natron glass | S.M. n° 12 w | 2.18 | 0.16 | 1.34 | 117 | 7.76 | 14.9 | 1.68 | 6.37 | 3.28 | 0.12 | 1.68 | 1.95 |
| Type III Natron glass | S.M. n° 3 b1 | 2.01 | 3.13 | 163  | 111 | 7.5  | 15   | 1.63 | 6.25 | 3.24 | 0.11 | 1.49 | 1.81 |
| Type III Natron glass | S.M. n° 3 b2 | 1.76 | 2.84 | 154  | 203 | 7.47 | 14.5 | 1.63 | 6.33 | 2.33 | 0.1  | 1.26 | 1.6  |
| Type II Natron glass  | S.M. n° 3 w  | 1.38 | 0.07 | 5.58 | 249 | 7.71 | 13.3 | 1.7  | 7.11 | 0.94 | 0.07 | 0.88 | 0.77 |
| Type II Natron glass  | S.M. n° 5 b  | 1.37 | 30   | 424  | 210 | 7.05 | 12.5 | 1.6  | 6.6  | 1.03 | 0.08 | 1.04 | 0.99 |
| Type II Natron glass  | S.M. n° 5 w  | 1.13 | 0.01 | 2.33 | 133 | 6.74 | 11.4 | 1.51 | 6.23 | 1.03 | 0.06 | 1.04 | 1.93 |
| Type II Natron glass  | S.M. n° 6 b  | 1.31 | 10.6 | 139  | 215 | 7.16 | 12.6 | 1.61 | 6.64 | 1.14 | 0.08 | 1.26 | 1.18 |
| Type II Natron glass  | S.M. n° 6 w  | 1.09 | 0    | 2.17 | 119 | 6.2  | 10.4 | 1.37 | 5.65 | 0.88 | 0.05 | 0.91 | 1.77 |
| Type II Natron glass  | S.M. n° 10 b | 1.39 | 4.25 | 76.9 | 224 | 8.2  | 14.4 | 1.86 | 7.65 | 1.02 | 0.09 | 0.97 | 1.83 |
| Type II Natron glass  | S.M. n° 10 w | 1.28 | 0.01 | 0.81 | 207 | 7.47 | 13   | 1.67 | 6.88 | 0.98 | 0.07 | 0.87 | 1.89 |

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**Table 7 Oikonomou *et al.* (2018)**

| Type                 | Sample | Inventory No. | Colour    | Type        | Group | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | Fe <sub>2</sub> O <sub>3</sub><br>wt% | Li<br>ppm | B<br>ppm |
|----------------------|--------|---------------|-----------|-------------|-------|--------------------------|------------|---------------------------------------|-------------------------|------------------------|-----------|-------------------------|------------|---------------------------------------|-----------|----------|
| Type II Natron glass | Sa.1   | CAT.1         | Dark blue | Alabastron  | B     | 16.45                    | 0.32       | 1.79                                  | 73.47                   | 0.37                   | 1.05      | 0.62                    | 5.05       | 0.95                                  | 4.82      | 164      |
| Type II Natron glass | Sa.2   | CAT.4         | Dark blue | Alabastron  | B     | 16.21                    | 0.44       | 2                                     | 70.6                    | 0.36                   | 1.23      | 0.48                    | 7.95       | 0.75                                  | 3.023     | 171      |
| Type II Natron glass | Sa.3   | CAT.5         | Dark blue | Alabastron  | B     | 16.62                    | 0.63       | 2.47                                  | 70.07                   | 0.14                   | 1.21      | 0.39                    | 7.65       | 0.84                                  | 3.587     | 173      |
| Type II Natron glass | Sa.6   | CAT. 11       | Dark blue | Alabastron  | B     | 19.16                    | 0.73       | 2.25                                  | 69.68                   | 0.27                   | 1.17      | 0.29                    | 6.07       | 0.57                                  | 3.477     | 175      |
| Type II Natron glass | Sa.7   | CAT. 13       | Dark blue | Alabastron  | B     | 17.47                    | 0.53       | 2.13                                  | 69.6                    | 0.2                    | 1.33      | 0.5                     | 7.43       | 0.81                                  | 3.397     | 212      |
| Type II Natron glass | Sa.8   | CAT. 15       | Dark blue | Alabastron  | B     | 17.71                    | 0.58       | 2.24                                  | 69.49                   | 0.24                   | 1.42      | 0.48                    | 7.19       | 0.77                                  | 4.144     | 202      |
| Type II Natron glass | Sa.9   | CAT. 16       | Dark blue | Alabastron  | B     | 17.83                    | 0.64       | 2.28                                  | 69.13                   | 0.26                   | 1.36      | 0.53                    | 7.32       | 0.72                                  | 3.893     | 222      |
| Type II Natron glass | Sa.10  | CAT.36        | Dark blue | Alabastron  | B     | 17.1                     | 0.36       | 2.35                                  | 71.28                   | 0.39                   | 0.96      | 0.56                    | 6.27       | 0.73                                  | 6.277     | 255      |
| Type II Natron glass | Sa.11  | CAT.40        | Dark blue | Alabastron  | B     | 15.91                    | 0.67       | 2.42                                  | 70.78                   | 0.16                   | 1.27      | 0.44                    | 7.54       | 0.83                                  | 3.647     | 185      |
| Type II Natron glass | Sa.12  | CAT.42        | Dark blue | Alabastron  | B     | 16.94                    | 0.53       | 2.31                                  | 70.31                   | 0.22                   | 1.17      | 0.44                    | 7.18       | 0.9                                   | 3.86      | 176      |
| Type II Natron glass | Sa.13  | CAT.44        | Dark blue | Alabastron  | B     | 17.01                    | 0.6        | 2.37                                  | 70.19                   | 0.29                   | 1.15      | 0.4                     | 7.23       | 0.76                                  | 4.76      | 171      |
| Type II Natron glass | Sa.14  | CAT.45        | Dark blue | Alabastron  | B     | 17.22                    | 0.93       | 2.21                                  | 70.91                   | 0.29                   | 1.01      | 0.62                    | 6.01       | 0.8                                   | 5.95      | 324      |
| Type II Natron glass | Sa.15  | CAT.50        | Dark blue | Alabastron  | B     | 16.7                     | 0.42       | 2.01                                  | 70.3                    | 0.17                   | 1.19      | 0.48                    | 8.16       | 0.61                                  | 4.447     | 178      |
| Type II Natron glass | Sa.17  | CAT.54        | Dark blue | Alabastron  | B     | 16.6                     | 0.38       | 1.94                                  | 73.49                   | 0.4                    | 0.91      | 0.59                    | 4.79       | 0.82                                  | 3.433     | 161      |
| Type II Natron glass | Sa.18  | CAT.55        | Dark blue | Alabastron  | B     | 16.83                    | 0.59       | 2.15                                  | 70.08                   | 0.27                   | 1.27      | 0.45                    | 7.64       | 0.77                                  | 3.493     | 201      |
| Type II Natron glass | Sa.19  | CAT.57        | Dark blue | Alabastron  | B     | 19.43                    | 0.69       | 2.35                                  | 69.22                   | 0.15                   | 1.17      | 0.36                    | 6.12       | 0.53                                  | 3.34      | 195      |
| Type II Natron glass | Sa.20  | CAT.58        | Dark blue | Alabastron  | B     | 19.52                    | 0.66       | 2.34                                  | 68.96                   | 0.22                   | 1.25      | 0.42                    | 6.08       | 0.57                                  | 3.433     | 194      |
| Type II Natron glass | Sa.22  | CAT.66        | Dark blue | Alabastron  | B     | 21.53                    | 0.76       | 2.37                                  | 68.64                   | 0.24                   | 0.99      | 0.51                    | 4.7        | 0.26                                  | 4.91      | 183      |
| Type II Natron glass | Sa.23  | CAT.68        | Dark blue | Alabastron  | B     | 16.53                    | 0.3        | 2.01                                  | 74.01                   | 0.47                   | 0.77      | 0.49                    | 4.84       | 0.58                                  | 3.65      | 153      |
| Type II Natron glass | Sa.24  | CAT.72        | Dark blue | Alabastron  | B     | 17.74                    | 0.58       | 2.17                                  | 70.17                   | 0.19                   | 1.13      | 0.46                    | 7.16       | 0.44                                  | 3.25      | 183      |
| Type II Natron glass | Sa.25  | CAT.76        | Dark blue | Amphoriskos | B     | 20.17                    | 0.65       | 2.24                                  | 68.81                   | 0.21                   | 1.22      | 0.51                    | 5.86       | 0.34                                  | 4.847     | 319      |
| Type II Natron glass | Sa.26  | CAT.78        | Dark blue | Amphoriskos | B     | 17.63                    | 0.66       | 2.27                                  | 69.46                   | 0.25                   | 1.28      | 0.46                    | 7.24       | 0.76                                  | 3.27      | 197      |
| Type II Natron glass | Sa.27  | CAT.79        | Dark blue | Amphoriskos | B     | 17.57                    | 0.54       | 2.22                                  | 69.37                   | 0.26                   | 1.33      | 0.45                    | 7.26       | 0.79                                  | 4.233     | 185      |
| Type II Natron glass | Sa.28  | CAT.81        | Brown     | Amphoriskos | B     | 18.58                    | 0.5        | 2.1                                   | 68.61                   | 0.3                    | 1.47      | 0.55                    | 7.55       | 0.34                                  | 6.797     | 346      |
| Type II Natron glass | Sa.29  | CAT.82        | Brown     | Amphoriskos | B     | 17.61                    | 0.55       | 2.17                                  | 69.39                   | 0.22                   | 1.43      | 0.63                    | 7.72       | 0.27                                  | 10.64     | 363      |
| Type II Natron glass | Sa.30  | CAT.83        | Brown     | Amphoriskos | B     | 18.22                    | 0.56       | 2.02                                  | 68.81                   | 0.33                   | 1.54      | 0.54                    | 7.74       | 0.24                                  | 3.173     | 372      |
| Type II Natron glass | Sa.31  | CAT.85        | Dark blue | Hydriskos   | B     | 17.72                    | 0.61       | 2.21                                  | 69.49                   | 0.11                   | 1.42      | 0.42                    | 7.24       | 0.84                                  | 3.133     | 180      |

| Type II Natron glass  | Sa.32  | CAT.87         | Dark blue | Hydriskos    | B     | 18.57     | 0.68     | 1.64      | 71.2      | 0.23      | 1.2       | 0.36      | 5.57      | 0.55      | 3.553     | 184       |
|-----------------------|--------|----------------|-----------|--------------|-------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Type II Natron glass  | Sa.33  | CAT.89         | Dark blue | Hydriskos    | B     | 17.74     | 0.54     | 2.14      | 69.97     | 0.21      | 1.41      | 0.54      | 6.69      | 0.76      | 7.893     | 339       |
| Type II Natron glass  | Sa.34  | CAT.92         | Dark blue | Hydriskos    | B     | 17.03     | 0.5      | 2.21      | 71.14     | 0.3       | 1.15      | 0.47      | 6.54      | 0.66      | 3.08      | 192       |
| Type II Natron glass  | Sa.36  | CAT.98         | Dark blue | Oinochoe     | B     | 16.99     | 0.76     | 2.56      | 70.41     | 0.49      | 0.83      | 0.54      | 6.88      | 0.53      | 4.033     | 139       |
| Type II Natron glass  | Sa.37  | CAT.99         | Dark blue | Oinochoe     | B     | 17.99     | 0.72     | 2.17      | 69.63     | 0.49      | 1.05      | 0.58      | 6.64      | 0.73      | 5.073     | 110       |
| Type III Natron glass | Sa.38  | CAT. 101       | Dark blue | Oinochoe     | B     | 18.16     | 0.6      | 2.08      | 69.91     | 0.57      | 0.97      | 0.59      | 6.46      | 0.64      | 5.537     | 123       |
| Type II Natron glass  | Sa.39  | CAT. 102       | Dark blue | Oinochoe     | B     | 16.85     | 0.72     | 2.62      | 70.51     | 0.45      | 0.73      | 0.53      | 6.95      | 0.65      | 5.223     | 136       |
| Type II Natron glass  | Sa.41  | CAT. 105       | Dark blue | Oinochoe     | B     | 16.1      | 0.33     | 2.43      | 71.8      | 0.45      | 1.04      | 0.5       | 6.91      | 0.45      | 2.76      | 46.7      |
| Type II Natron glass  | Sa.42  | CAT. 107       | Dark blue | Oinochoe     | B     | 16.44     | 0.44     | 2.23      | 72.55     | 0.36      | 1.03      | 0.51      | 6.17      | 0.35      | 2.917     | 48.4      |
| Type II Natron glass  | Sa.43  | V1091          | Dark blue | Bead         | B     | 17.23     | 0.56     | 2.68      | 71.69     | 0.19      | 1.02      | 0.33      | 5.23      | 1.09      | 2.68      | 149       |
| Type II Natron glass  | Sa.44  | Tomb 29a (V75) | Dark blue | Bead         | B     | 18.66     | 0.52     | 2.22      | 69.47     | 0.38      | 1.31      | 0.4       | 6.74      | 0.3       | 3.703     | 135       |
| Type II Natron glass  | Sa.45  | Tomb 19(V71)   | Dark blue | Bead         | B     | 17.79     | 0.59     | 2.24      | 70.55     | 0.41      | 0.89      | 0.58      | 5.42      | 1.53      | 3.727     | 81.2      |
| Type III Natron glass | Sa.4   | CAT.7          | Dark blue | Unidentified | A     | 19.11     | 0.63     | 1.25      | 72.45     | 0.18      | 1.08      | 0.29      | 4.66      | 0.35      | 8.723     | 135       |
| Type III Natron glass | Sa.5   | CAT.9          | turquoise | Alabastron   | A     | 18.23     | 0.57     | 1.25      | 70.26     | 0.51      | 1.05      | 0.33      | 7.13      | 0.67      | 6.883     | 191       |
| Type III Natron glass | Sa.16  | CAT.52         | Dark blue | Alabastron   | A     | 16.69     | 0.57     | 1.15      | 73.74     | 0.18      | 1.17      | 0.29      | 5.67      | 0.55      | 7.747     | 126       |
| Type III Natron glass | Sa.21  | CAT.64         | turquoise | Alabastron   | A     | 17.92     | 0.48     | 1.22      | 70.38     | 0.46      | 1.06      | 0.27      | 7.48      | 0.72      | 6.733     | 201       |
| Type III Natron glass | Sa.40  | CAT. 104       | Brown     | Oinochoe     | A     | 17.91     | 0.62     | 0.78      | 71.77     | 0.46      | 1.35      | 0.27      | 6.51      | 0.34      | 4.383     | 374       |
| Type                  | Sample | Inventory No.  | Colour    | Type         | Group | Ti<br>ppm | V<br>ppm | Cr<br>ppm | Mn<br>ppm | Co<br>ppm | Ni<br>ppm | Cu<br>ppm | Zn<br>ppm | As<br>ppm | Rb<br>ppm | Sr<br>ppm |
| Type II Natron glass  | Sa.1   | CAT.1          | Dark blue | Alabastron   | B     | 336       | 10.4     | 8.753     | 1369      | 1633      | 66.4      | 1968      | 112       | 14.1      | 9.84      | 303       |
| Type II Natron glass  | Sa.2   | CAT.4          | Dark blue | Alabastron   | B     | 342       | 6.083    | 8         | 114       | 1480      | 41        | 1467      | 132       | 8.933     | 7.193     | 524       |
| Type II Natron glass  | Sa.3   | CAT.5          | Dark blue | Alabastron   | B     | 329       | 10       | 8.493     | 1272      | 1532      | 42.5      | 1807      | 116       | 12.1      | 6.5       | 518       |
| Type II Natron glass  | Sa.6   | CAT. 11        | Dark blue | Alabastron   | B     | 312       | 10.1     | 8.833     | 1350      | 1613      | 43.6      | 1940      | 109       | 15.8      | 6.073     | 495       |
| Type II Natron glass  | Sa.7   | CAT. 13        | Dark blue | Alabastron   | B     | 313       | 10.4     | 7.893     | 1349      | 1119      | 30.4      | 1236      | 106       | 12.2      | 7.183     | 494       |
| Type II Natron glass  | Sa.8   | CAT. 15        | Dark blue | Alabastron   | B     | 330       | 10.5     | 8.56      | 1423      | 1236      | 33.1      | 1366      | 116       | 11.2      | 7.987     | 490       |
| Type II Natron glass  | Sa.9   | CAT. 16        | Dark blue | Alabastron   | B     | 316       | 11       | 8.72      | 1586      | 1288      | 34.5      | 1400      | 129       | 12.3      | 8.07      | 502       |
| Type II Natron glass  | Sa.10  | CAT.36         | Dark blue | Alabastron   | B     | 314       | 7.963    | 7.337     | 1644      | 1629      | 54.8      | 2119      | 54.8      | 16.1      | 9.043     | 415       |
| Type II Natron glass  | Sa.11  | CAT.40         | Dark blue | Alabastron   | B     | 326       | 10.4     | 8.83      | 1380      | 1614      | 42.8      | 1963      | 129       | 14.5      | 7.317     | 506       |
| Type II Natron glass  | Sa.12  | CAT.42         | Dark blue | Alabastron   | B     | 307       | 9.943    | 8.15      | 1189      | 1456      | 39.8      | 1778      | 108       | 14.8      | 6.32      | 491       |
| Type II Natron glass  | Sa.13  | CAT.44         | Dark blue | Alabastron   | B     | 331       | 10.1     | 8.277     | 1213      | 1551      | 42.4      | 1814      | 113       | 14.7      | 8.077     | 517       |

|                       |       |                |           |              |   |     |       |       |      |       |       |       |       |       |       |     |
|-----------------------|-------|----------------|-----------|--------------|---|-----|-------|-------|------|-------|-------|-------|-------|-------|-------|-----|
| Type II Natron glass  | Sa.14 | CAT.45         | Dark blue | Alabastron   | B | 458 | 9.7   | 49.7  | 212  | 702   | 44.9  | 1762  | 83    | 21.1  | 8.577 | 371 |
| Type II Natron glass  | Sa.15 | CAT.50         | Dark blue | Alabastron   | B | 340 | 6.643 | 8.86  | 107  | 1538  | 43.7  | 1549  | 134   | 12.4  | 6.553 | 551 |
| Type II Natron glass  | Sa.17 | CAT.54         | Dark blue | Alabastron   | B | 347 | 11    | 9.87  | 1296 | 1583  | 63.1  | 1850  | 97.1  | 14.3  | 9.06  | 293 |
| Type II Natron glass  | Sa.18 | CAT.55         | Dark blue | Alabastron   | B | 330 | 10.7  | 7.887 | 1441 | 1265  | 34.6  | 1500  | 113   | 11.5  | 7.52  | 519 |
| Type II Natron glass  | Sa.19 | CAT.57         | Dark blue | Alabastron   | B | 320 | 10.3  | 8.38  | 1411 | 1225  | 32.2  | 1429  | 114   | 10.9  | 7.347 | 517 |
| Type II Natron glass  | Sa.20 | CAT.58         | Dark blue | Alabastron   | B | 325 | 10.3  | 7.237 | 1368 | 1303  | 34.2  | 1381  | 120   | 12.3  | 7.69  | 504 |
| Type II Natron glass  | Sa.22 | CAT.66         | Dark blue | Alabastron   | B | 332 | 5.947 | 8.393 | 105  | 1346  | 37    | 1298  | 106   | 9     | 6.753 | 471 |
| Type II Natron glass  | Sa.23 | CAT.68         | Dark blue | Alabastron   | B | 365 | 7.017 | 9.39  | 171  | 964   | 48.6  | 1175  | 89.9  | 10.3  | 7.81  | 270 |
| Type II Natron glass  | Sa.24 | CAT.72         | Dark blue | Alabastron   | B | 328 | 6.067 | 8.537 | 110  | 1534  | 42.1  | 1379  | 130   | 10.2  | 6.82  | 512 |
| Type II Natron glass  | Sa.25 | CAT.76         | Dark blue | Amphoriskos  | B | 314 | 11.5  | 7.9   | 1693 | 1144  | 28.8  | 1433  | 77.6  | 13.6  | 8.177 | 434 |
| Type II Natron glass  | Sa.26 | CAT.78         | Dark blue | Amphoriskos  | B | 357 | 9.677 | 7.633 | 1119 | 1513  | 43.2  | 1543  | 134   | 13.2  | 7.147 | 493 |
| Type II Natron glass  | Sa.27 | CAT.79         | Dark blue | Amphoriskos  | B | 357 | 9.177 | 8.603 | 1096 | 1709  | 46.9  | 1784  | 149   | 16    | 7.67  | 539 |
| Type II Natron glass  | Sa.28 | CAT.81         | Brown     | Amphoriskos  | B | 294 | 5.18  | 6.743 | 105  | 6.083 | 2.933 | 25    | 4.703 | 1.137 | 8.487 | 546 |
| Type II Natron glass  | Sa.29 | CAT.82         | Brown     | Amphoriskos  | B | 291 | 5.157 | 8.157 | 109  | 2.89  | 2.983 | 47.4  | 5.357 | 1.287 | 11.2  | 562 |
| Type II Natron glass  | Sa.30 | CAT.83         | Brown     | Amphoriskos  | B | 291 | 5.213 | 7.54  | 110  | 2.3   | 2.79  | 5.613 | 6.123 | 0.587 | 8.587 | 545 |
| Type II Natron glass  | Sa.31 | CAT.85         | Dark blue | Hydriskos    | B | 333 | 9.84  | 8.79  | 1186 | 1774  | 46.4  | 1882  | 155   | 14.9  | 7.513 | 528 |
| Type II Natron glass  | Sa.32 | CAT.87         | Dark blue | Hydriskos    | B | 325 | 10.1  | 8.597 | 1273 | 1923  | 48.7  | 2077  | 167   | 17.4  | 7.81  | 551 |
| Type II Natron glass  | Sa.33 | CAT.89         | Dark blue | Hydriskos    | B | 346 | 11.3  | 8.713 | 1772 | 1193  | 28.7  | 1541  | 70.8  | 11.4  | 8.267 | 479 |
| Type II Natron glass  | Sa.34 | CAT.92         | Dark blue | Hydriskos    | B | 321 | 6.157 | 9.05  | 204  | 1648  | 52.5  | 1572  | 69.3  | 10.2  | 8.22  | 480 |
| Type II Natron glass  | Sa.36 | CAT.98         | Dark blue | Oinochoe     | B | 605 | 22.3  | 12.9  | 2463 | 513   | 40.5  | 2400  | 64.3  | 17.3  | 8.563 | 542 |
| Type II Natron glass  | Sa.37 | CAT.99         | Dark blue | Oinochoe     | B | 562 | 18.9  | 11    | 2253 | 772   | 57    | 2200  | 70.5  | 10.2  | 8.93  | 413 |
| Type III Natron glass | Sa.38 | CAT. 101       | Dark blue | Oinochoe     | B | 585 | 15.7  | 10.4  | 1423 | 746   | 40.1  | 2577  | 66.7  | 9.55  | 9.4   | 441 |
| Type II Natron glass  | Sa.39 | CAT. 102       | Dark blue | Oinochoe     | B | 577 | 20.5  | 12.1  | 2376 | 557   | 44.4  | 1951  | 70.6  | 12.5  | 8.763 | 513 |
| Type II Natron glass  | Sa.41 | CAT. 105       | Dark blue | Oinochoe     | B | 312 | 12.3  | 7.133 | 2495 | 327   | 28.6  | 684   | 102   | 7.423 | 8.047 | 397 |
| Type II Natron glass  | Sa.42 | CAT. 107       | Dark blue | Oinochoe     | B | 325 | 12    | 7.14  | 2630 | 385   | 30.7  | 786   | 121   | 7.707 | 7.903 | 397 |
| Type II Natron glass  | Sa.43 | V1091          | Dark blue | Bead         | B | 295 | 5.01  | 10    | 102  | 1397  | 148   | 3150  | 85.7  | 9.507 | 7.1   | 407 |
| Type II Natron glass  | Sa.44 | Tomb 29a (V75) | Dark blue | Bead         | B | 364 | 9.367 | 8.903 | 2341 | 2683  | 94.9  | 4495  | 315   | 25.6  | 8.947 | 345 |
| Type II Natron glass  | Sa.45 | Tomb 19(V71)   | Dark blue | Bead         | B | 380 | 6.477 | 13.9  | 131  | 1141  | 15.1  | 838   | 109   | 22.6  | 12.02 | 420 |
| Type III Natron glass | Sa.4  | CAT.7          | Dark blue | Unidentified | A | 737 | 24.9  | 11.3  | 3623 | 1294  | 207   | 695   | 47.6  | 3.013 | 6.373 | 233 |
| Type III Natron glass | Sa.5  | CAT.9          | turquoise | Alabastron   | A | 729 | 14.4  | 10.5  | 500  | 91.4  | 13.8  | 5542  | 40.6  | 11.3  | 5.24  | 274 |



| Type III Natron glass | Sa.16  | CAT.52        | Dark blue | Alabastron  | A     | 754      | 24.7      | 10.8      | 3540      | 1271      | 201       | 646       | 48.9      | 2.463     | 5.463     | 229      |
|-----------------------|--------|---------------|-----------|-------------|-------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|
| Type III Natron glass | Sa.21  | CAT.64        | turquoise | Alabastron  | A     | 715      | 13.7      | 10.3      | 504       | 86.1      | 13.1      | 5307      | 37.2      | 11.4      | 5.39      | 273      |
| Type III Natron glass | Sa.40  | CAT. 104      | Brown     | Oinochoe    | A     | 470      | 5.497     | 6.983     | 72        | 1.29      | 1.947     | 14.1      | 9.367     | 0.663     | 3.24      | 228      |
| Type                  | Sample | Inventory No. | Colour    | Type        | Group | Y<br>ppm | Zr<br>ppm | Sn<br>ppm | Sb<br>ppm | Ba<br>ppm | La<br>ppm | Ce<br>ppm | Nd<br>ppm | Pb<br>ppm | Th<br>ppm | U<br>ppm |
| Type II Natron glass  | Sa.1   | CAT.1         | Dark blue | Alabastron  | B     | 5.113    | 32.1      | 333       | 447       | 191       | 5.207     | 9.8       | 4.683     | 789       | 0.805     | 1.608    |
| Type II Natron glass  | Sa.2   | CAT.4         | Dark blue | Alabastron  | B     | 7.5      | 35.7      | 56        | 359       | 181       | 6.347     | 11.4      | 5.777     | 231       | 0.863     | 0.758    |
| Type II Natron glass  | Sa.3   | CAT.5         | Dark blue | Alabastron  | B     | 7.537    | 33.5      | 47.4      | 234       | 221       | 6.043     | 11.3      | 6.057     | 314       | 0.849     | 0.814    |
| Type II Natron glass  | Sa.6   | CAT. 11       | Dark blue | Alabastron  | B     | 7.003    | 35.1      | 43.8      | 194       | 213       | 5.677     | 11.1      | 6.2       | 273       | 0.693     | 0.737    |
| Type II Natron glass  | Sa.7   | CAT. 13       | Dark blue | Alabastron  | B     | 7.147    | 33.2      | 44.9      | 335       | 235       | 6.52      | 11.7      | 6.167     | 376       | 0.829     | 0.809    |
| Type II Natron glass  | Sa.8   | CAT. 15       | Dark blue | Alabastron  | B     | 7.763    | 38.8      | 45.9      | 386       | 229       | 5.99      | 11.8      | 6.713     | 330       | 0.793     | 0.784    |
| Type II Natron glass  | Sa.9   | CAT. 16       | Dark blue | Alabastron  | B     | 7.77     | 38.9      | 46.3      | 337       | 245       | 6.517     | 13.6      | 7.07      | 359       | 0.82      | 0.806    |
| Type II Natron glass  | Sa.10  | CAT.36        | Dark blue | Alabastron  | B     | 7.023    | 39        | 52.8      | 416       | 239       | 6.273     | 12.3      | 6.3       | 257       | 0.795     | 1.201    |
| Type II Natron glass  | Sa.11  | CAT.40        | Dark blue | Alabastron  | B     | 7.547    | 37.5      | 47.2      | 273       | 232       | 6.32      | 12.6      | 6.74      | 497       | 0.79      | 0.809    |
| Type II Natron glass  | Sa.12  | CAT.42        | Dark blue | Alabastron  | B     | 7.833    | 37.4      | 45.7      | 243       | 230       | 7.01      | 12.2      | 7.13      | 288       | 0.911     | 0.798    |
| Type II Natron glass  | Sa.13  | CAT.44        | Dark blue | Alabastron  | B     | 7.437    | 34.4      | 45.5      | 420       | 215       | 6.4       | 11.6      | 6.293     | 421       | 0.768     | 0.836    |
| Type II Natron glass  | Sa.14  | CAT.45        | Dark blue | Alabastron  | B     | 6.337    | 41.8      | 75.5      | 3513      | 171       | 6.227     | 11        | 5.8       | 3120      | 1.023     | 1.053    |
| Type II Natron glass  | Sa.15  | CAT.50        | Dark blue | Alabastron  | B     | 8.83     | 40.1      | 58.8      | 433       | 181       | 7.33      | 12.7      | 7.463     | 421       | 0.878     | 0.811    |
| Type II Natron glass  | Sa.17  | CAT.54        | Dark blue | Alabastron  | B     | 5.597    | 36.2      | 301       | 345       | 179       | 5.44      | 8.997     | 4.993     | 645       | 0.782     | 1.39     |
| Type II Natron glass  | Sa.18  | CAT.55        | Dark blue | Alabastron  | B     | 7.907    | 38.3      | 46.3      | 210       | 222       | 6.43      | 11        | 6.37      | 376       | 0.831     | 0.784    |
| Type II Natron glass  | Sa.19  | CAT.57        | Dark blue | Alabastron  | B     | 8.257    | 37.3      | 47.4      | 208       | 221       | 6.47      | 11        | 6.177     | 311       | 0.867     | 0.815    |
| Type II Natron glass  | Sa.20  | CAT.58        | Dark blue | Alabastron  | B     | 7.25     | 34.5      | 47.8      | 294       | 216       | 5.987     | 10.7      | 5.977     | 625       | 0.823     | 0.764    |
| Type II Natron glass  | Sa.22  | CAT.66        | Dark blue | Alabastron  | B     | 7.433    | 35.4      | 47.6      | 275       | 183       | 6.513     | 11.5      | 6.013     | 23.2      | 0.753     | 0.652    |
| Type II Natron glass  | Sa.23  | CAT.68        | Dark blue | Alabastron  | B     | 5.78     | 38.9      | 140       | 644       | 185       | 5.8       | 9.913     | 5.94      | 1117      | 0.805     | 1.349    |
| Type II Natron glass  | Sa.24  | CAT.72        | Dark blue | Alabastron  | B     | 8.743    | 39        | 57.2      | 245       | 190       | 7.223     | 12.5      | 6.817     | 151       | 0.858     | 0.787    |
| Type II Natron glass  | Sa.25  | CAT.76        | Dark blue | Amphoriskos | B     | 6.85     | 35.4      | 53.4      | 945       | 224       | 6.423     | 11.1      | 6.327     | 2231      | 0.783     | 0.71     |
| Type II Natron glass  | Sa.26  | CAT.78        | Dark blue | Amphoriskos | B     | 7.313    | 35.3      | 55.8      | 201       | 214       | 6.067     | 10.6      | 5.787     | 263       | 0.863     | 0.827    |
| Type II Natron glass  | Sa.27  | CAT.79        | Dark blue | Amphoriskos | B     | 8.783    | 39        | 66.1      | 176       | 238       | 6.95      | 12.1      | 7.307     | 287       | 1.06      | 0.907    |
| Type II Natron glass  | Sa.28  | CAT.81        | Brown     | Amphoriskos | B     | 8.493    | 35.2      | 3.177     | 8.19      | 211       | 6.397     | 11.4      | 7.027     | 10.9      | 0.839     | 0.784    |
| Type II Natron glass  | Sa.29  | CAT.82        | Brown     | Amphoriskos | B     | 7.52     | 32        | 2.35      | 10.3      | 224       | 6.193     | 11.8      | 6.413     | 11.8      | 0.802     | 0.8      |

|                       |       |                |           |              |   |       |      |       |       |      |       |       |       |       |       |       |
|-----------------------|-------|----------------|-----------|--------------|---|-------|------|-------|-------|------|-------|-------|-------|-------|-------|-------|
| Type II Natron glass  | Sa.30 | CAT.83         | Brown     | Amphoriskos  | B | 8.037 | 33.5 | 2.01  | 3.613 | 222  | 6.687 | 12.3  | 7.303 | 6.457 | 0.858 | 0.815 |
| Type II Natron glass  | Sa.31 | CAT.85         | Dark blue | Hydriskos    | B | 8.653 | 38.9 | 67.1  | 172   | 239  | 6.793 | 12.3  | 7.16  | 302   | 0.994 | 0.896 |
| Type II Natron glass  | Sa.32 | CAT.87         | Dark blue | Hydriskos    | B | 8.12  | 35.9 | 70.7  | 199   | 237  | 6.503 | 11.9  | 6.523 | 317   | 0.897 | 0.898 |
| Type II Natron glass  | Sa.33 | CAT.89         | Dark blue | Hydriskos    | B | 7.853 | 38   | 51.6  | 512   | 232  | 6.623 | 11.6  | 6.703 | 1414  | 0.94  | 0.847 |
| Type II Natron glass  | Sa.34 | CAT.92         | Dark blue | Hydriskos    | B | 7.607 | 35   | 65    | 509   | 205  | 6.51  | 11.5  | 6.52  | 655   | 0.99  | 1     |
| Type II Natron glass  | Sa.36 | CAT.98         | Dark blue | Oinochoe     | B | 7.153 | 49   | 43.2  | 2679  | 218  | 6.817 | 13.4  | 6.54  | 2060  | 0.91  | 4.43  |
| Type II Natron glass  | Sa.37 | CAT.99         | Dark blue | Oinochoe     | B | 7.04  | 58.4 | 59.5  | 887   | 187  | 6.67  | 12.8  | 5.893 | 3973  | 1.038 | 2.693 |
| Type III Natron glass | Sa.38 | CAT. 101       | Dark blue | Oinochoe     | B | 6.653 | 69.4 | 42.9  | 1246  | 184  | 7.403 | 14.4  | 6.31  | 5353  | 1.168 | 1.868 |
| Type II Natron glass  | Sa.39 | CAT. 102       | Dark blue | Oinochoe     | B | 7.413 | 51.1 | 49.3  | 328   | 224  | 6.77  | 12.7  | 6.2   | 1097  | 0.916 | 4.403 |
| Type II Natron glass  | Sa.41 | CAT. 105       | Dark blue | Oinochoe     | B | 6.637 | 34.5 | 39.8  | 6.247 | 223  | 5.563 | 10.1  | 5.297 | 27.9  | 0.826 | 1.092 |
| Type II Natron glass  | Sa.42 | CAT. 107       | Dark blue | Oinochoe     | B | 6.35  | 31.8 | 46.1  | 7.363 | 224  | 5.623 | 10.5  | 5.43  | 31.8  | 0.889 | 1.161 |
| Type II Natron glass  | Sa.43 | V1091          | Dark blue | Bead         | B | 6.133 | 28.8 | 5.28  | 360   | 185  | 5.767 | 10.3  | 5.657 | 16.2  | 0.682 | 1.341 |
| Type II Natron glass  | Sa.44 | Tomb 29a (V75) | Dark blue | Bead         | B | 5.877 | 30   | 78.6  | 2282  | 196  | 5.467 | 9.657 | 5.23  | 76.1  | 0.696 | 3.473 |
| Type II Natron glass  | Sa.45 | Tomb 19(V71)   | Dark blue | Bead         | B | 6.507 | 30.8 | 88.9  | 1294  | 199  | 6.29  | 10.9  | 5.69  | 12247 | 0.83  | 1.49  |
| Type III Natron glass | Sa.4  | CAT.7          | Dark blue | Unidentified | A | 4.813 | 76.8 | 28.4  | 15.2  | 133  | 6.233 | 12.2  | 5.193 | 206   | 1.183 | 1.397 |
| Type III Natron glass | Sa.5  | CAT.9          | turquoise | Albastron    | A | 5.017 | 120  | 10.5  | 52.6  | 146  | 6.957 | 14.6  | 6.493 | 935   | 1.564 | 1.967 |
| Type III Natron glass | Sa.16 | CAT.52         | Dark blue | Alabastron   | A | 4.853 | 75.7 | 26.4  | 7.63  | 131  | 6.217 | 12    | 6.073 | 63.7  | 1.279 | 1.28  |
| Type III Natron glass | Sa.21 | CAT.64         | turquoise | Albastron    | A | 4.75  | 123  | 10.6  | 49.1  | 150  | 7.317 | 15.3  | 6.787 | 957   | 1.563 | 1.933 |
| Type III Natron glass | Sa.40 | CAT. 104       | Brown     | Oinochoe     | A | 3.697 | 54.4 | 2.063 | 0     | 74.8 | 5.153 | 10.4  | 4.193 | 41.9  | 1.071 | 1.811 |

**Table 8 Oikonomou and Triantafyllidis (2018)**

| Type               | Sample |              | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | Fe <sub>2</sub> O <sub>3</sub><br>wt% | P<br>ppm  | Ti<br>ppm | Cr<br>ppm |
|--------------------|--------|--------------|--------------------------|------------|---------------------------------------|-------------------------|------------------------|-----------|-------------------------|------------|---------------------------------------|-----------|-----------|-----------|
| Mesopotamian glass | R.17   | Green        | 16.88                    | 3.01       | 0.84                                  | 69.72                   | 0.51                   | 0.69      | 1.32                    | 5.9        | 0.46                                  | 741       | 243       | 12        |
| Mesopotamian glass | R.19   | Green        | 15.33                    | 2.63       | 1.06                                  | 72.89                   | 0.71                   | 0.91      | 1.09                    | 5.32       | 0.43                                  | 745       | 256       | 14        |
| Mesopotamian glass | R.28   | Green        | 21.32                    | 6.76       | 1.26                                  | 61.29                   | 0.89                   | 0.85      | 2.11                    | 4.82       | 0.31                                  | 1077      | 387       | 12        |
| Mesopotamian glass | R.33   | Green        | 17.57                    | 2.62       | 0.73                                  | 70.62                   | 0.7                    | 0.98      | 1.03                    | 5.3        | 0.47                                  | 820       | 231       | 10        |
| Mesopotamian glass | R.34   | Green        | 16.9                     | 0.88       | 3.09                                  | 68.48                   | 0.96                   | 0.98      | 1.13                    | 6.25       | 0.8                                   | 485       | 304       | 8         |
| Mesopotamian glass | R.38   | Green        | 20.87                    | 0.63       | 0.87                                  | 70.38                   | 0.39                   | 0.85      | 0.14                    | 5.56       | 0.32                                  | 203       | 410       | 8         |
| Mesopotamian glass | R.39   | Green        | 15.97                    | 2.75       | 1.15                                  | 69.2                    | 0.51                   | 0.89      | 1.35                    | 7.62       | 0.55                                  | 681       | 381       | 14        |
| Mesopotamian glass | R.42   | Yellow       | 16.59                    | 3.71       | 1.09                                  | 66.96                   | 1.25                   | 1.14      | 1.65                    | 6.93       | 0.67                                  | 820       | 357       | 13        |
| Mesopotamian glass | R.50   | Green        | 20.7                     | 4.35       | 1.31                                  | 66.41                   | 0.55                   | 0.67      | 1.48                    | 4.16       | 0.37                                  | 722       | 327       | 14        |
| Mesopotamian glass | R.51   | Green yellow | 19.48                    | 3.93       | 1.06                                  | 66.38                   | 0.51                   | 0.77      | 1.19                    | 6.36       | 0.33                                  | 900       | 356       | 14        |
| Mesopotamian glass | R.52   | Green yellow | 20.19                    | 5.84       | 1.19                                  | 68.14                   | 0.34                   | 0.66      | 0.68                    | 2.74       | 0.17                                  | 838       | 343       | 16        |
| Mesopotamian glass | R.55   | Green yellow | 18                       | 2.84       | 0.97                                  | 69.35                   | 0.78                   | 0.72      | 1.26                    | 5.66       | 0.43                                  | 623       | 298       | 13        |
| Mesopotamian glass | R.57   | Green        | 17.73                    | 3.18       | 1.41                                  | 67.66                   | 0.74                   | 0.85      | 1.53                    | 6.4        | 0.71                                  | 694       | 381       | 14        |
| Mesopotamian glass | R.60   | Green        | 18.46                    | 1          | 1.2                                   | 72.59                   | 0.67                   | 0.85      | 0.25                    | 4.56       | 0.42                                  | 191       | 509       | 12        |
| Mesopotamian glass | R.61   | Green        | 20.19                    | 2.88       | 1.15                                  | 67.82                   | 0.35                   | 0.44      | 1.02                    | 5.79       | 0.36                                  | 691       | 472       | 11        |
| Mesopotamian glass | R.76   | Green yellow | 20.36                    | 6.92       | 0.93                                  | 63.94                   | 0.44                   | 0.75      | 1.45                    | 4.92       | 0.29                                  | 945       | 335       | 13        |
| Mesopotamian glass | R.77   | Green yellow | 20.15                    | 3.2        | 0.76                                  | 68.51                   | 0.47                   | 0.92      | 0.96                    | 4.75       | 0.28                                  | 747       | 290       | 9         |
| Mesopotamian glass | R.81   | Green        | 20.28                    | 3.61       | 0.96                                  | 67.94                   | 0.65                   | 0.64      | 0.79                    | 4.83       | 0.33                                  | 645       | 296       | 10        |
| Mesopotamian glass | R.84   | Green        | 20.03                    | 2.3        | 0.89                                  | 69.35                   | 0.64                   | 0.61      | 0.77                    | 4.76       | 0.41                                  | 400       | 243       | 9         |
| Mesopotamian glass | R.85   | Green        | 20.08                    | 3.93       | 0.88                                  | 67.35                   | 0.49                   | 0.84      | 1.39                    | 4.78       | 0.26                                  | 871       | 285       | 13        |
| Type               | Sample |              | Mn<br>ppm                | Ni<br>ppm  | Zn<br>ppm                             | Rb<br>ppm               | Sr<br>ppm              | Y<br>ppm  | Zr<br>ppm               | Sb<br>ppm  | Ba<br>ppm                             | La<br>ppm | Nd<br>ppm | Pb<br>ppm |
| Mesopotamian glass | R.17   | Green        | 5783                     | 13         | 41                                    | 8                       | 353                    | 2         | 12                      | 587        | 409                                   | 2         | 2         | 13        |
| Mesopotamian glass | R.19   | Green        | 193                      | 8          | 24                                    | 7                       | 443                    | 2         | 12                      | 11         | 75                                    | 3         | 3         | 1         |
| Mesopotamian glass | R.28   | Green        | 3552                     | 10         | 25                                    | 10                      | 403                    | 3         | 16                      | 1616       | 61                                    | 4         | 4         | 7         |
| Mesopotamian glass | R.33   | Green        | 1287                     | 9          | 30                                    | 7                       | 325                    | 2         | 12                      | 1822       | 45                                    | 2         | 2         | 2         |
| Mesopotamian glass | R.34   | Green        | 4803                     | 9          | 15                                    | 10                      | 528                    | 6         | 32                      | 1529       | 207                                   | 5         | 6         | 7         |
| Mesopotamian glass | R.38   | Green        | 99                       | 3          | 8                                     | 1                       | 198                    | 5         | 52                      | 3          | 26                                    | 5         | 4         | 2         |
| Mesopotamian glass | R.39   | Green        | 522                      | 10         | 27                                    | 6                       | 447                    | 3         | 18                      | 814        | 104                                   | 3         | 3         | 7         |
| Mesopotamian glass | R.42   | Yellow       | 909                      | 9          | 34                                    | 7                       | 390                    | 3         | 20                      | 2216       | 88                                    | 4         | 3         | 4         |
| Mesopotamian glass | R.50   | Green        | 204                      | 9          | 29                                    | 6                       | 324                    | 2         | 19                      | 2804       | 67                                    | 3         | 4         | 6         |

|                    |      |              |      |    |    |   |     |   |    |      |    |   |   |    |
|--------------------|------|--------------|------|----|----|---|-----|---|----|------|----|---|---|----|
| Mesopotamian glass | R.51 | Green yellow | 217  | 9  | 32 | 8 | 422 | 3 | 20 | 3745 | 96 | 3 | 3 | 3  |
| Mesopotamian glass | R.52 | Green yellow | 1386 | 12 | 36 | 6 | 347 | 3 | 16 | 3948 | 71 | 4 | 3 | 3  |
| Mesopotamian glass | R.55 | Green yellow | 178  | 8  | 25 | 5 | 376 | 3 | 14 | 3003 | 66 | 4 | 4 | 2  |
| Mesopotamian glass | R.57 | Green        | 526  | 10 | 27 | 6 | 437 | 3 | 19 | 785  | 99 | 3 | 3 | 7  |
| Mesopotamian glass | R.60 | Green        | 95   | 5  | 12 | 2 | 213 | 5 | 78 | 2    | 47 | 5 | 4 | 3  |
| Mesopotamian glass | R.61 | Green        | 116  | 8  | 32 | 7 | 215 | 2 | 20 | 5435 | 31 | 3 | 3 | 3  |
| Mesopotamian glass | R.76 | Green yellow | 164  | 10 | 30 | 7 | 428 | 2 | 15 | 2843 | 50 | 3 | 3 | 10 |
| Mesopotamian glass | R.77 | Green yellow | 156  | 6  | 30 | 6 | 327 | 2 | 19 | 1274 | 70 | 2 | 2 | 3  |
| Mesopotamian glass | R.81 | Green        | 206  | 7  | 25 | 7 | 338 | 2 | 16 | 2610 | 64 | 2 | 2 | 10 |
| Mesopotamian glass | R.84 | Green        | 1617 | 7  | 21 | 5 | 237 | 2 | 14 | -    | 41 | 3 | 3 | 1  |
| Mesopotamian glass | R.85 | Green        | 225  | 9  | 22 | 6 | 454 | 2 | 16 | 3    | 82 | 3 | 3 | 2  |

**Table 9 Oikonomou (2018)**

| Region     | Sample | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | SO <sub>3</sub><br>wt% | Cl<br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | Fe <sub>2</sub> O <sub>3</sub><br>wt% | Li<br>ppm | Ti<br>ppm | Cr<br>ppm | Mn<br>ppm | Co<br>ppm |
|------------|--------|--------------------------|------------|---------------------------------------|-------------------------|------------------------|-----------|-------------------------|------------|---------------------------------------|-----------|-----------|-----------|-----------|-----------|
| Dodona     | Do3    | 15.14                    | 0.41       | 2.1                                   | 71.75                   | 0.42                   | 1.15      | 0.63                    | 7.75       | 0.65                                  | 3.4       | 319       | 6.9       | 117       | 170       |
|            | Do5    | 15.01                    | 0.44       | 2.22                                  | 72.21                   | 0.31                   | 1.18      | 0.56                    | 7.39       | 0.69                                  | 2.9       | 299       | 6.2       | 105       | 191       |
|            | Do6    | 14.37                    | 0.44       | 2.1                                   | 72.25                   | 0.26                   | 1.32      | 0.46                    | 7.71       | 1.09                                  | 3         | 344       | 7         | 102       | 292       |
|            | Do8    | 15.98                    | 0.31       | 2.53                                  | 71.71                   | 0.01                   | 1.69      | 0.36                    | 6.56       | 0.83                                  | 3.1       | 315       | 6.5       | 92        | 1531      |
| Ambracia   | Arl3a  | 18.14                    | 0.54       | 2.32                                  | 71.63                   | 0.23                   | 0.85      | 0.71                    | 5.2        | 0.37                                  | 4.9       | 321       | 9.3       | 1213      | 813       |
|            | Arl3b  | 16.81                    | 0.63       | 2.65                                  | 71.75                   | 0.24                   | 0.89      | 0.84                    | 5.64       | 0.55                                  | 3.9       | 345       | 9.6       | 1666      | 1162      |
|            | Ar36a  | 13.83                    | 0.52       | 2.18                                  | 71                      | 0.5                    | 0.89      | 1.36                    | 7.86       | 1.19                                  | 4.2       | 391       | 8.8       | 4035      | 1027      |
|            | Ar36b  | 13.75                    | 0.61       | 2.22                                  | 71.06                   | 0.56                   | 0.93      | 1.27                    | 7.71       | 0.92                                  | 3.8       | 443       | 9.8       | 3631      | 934       |
| Cassope    | Cas1   | 20.46                    | 0.7        | 2.31                                  | 70.68                   | 0.29                   | 0.77      | 0.5                     | 4.01       | 0.19                                  | 3.3       | 304       | 7.4       | 1631      | 872       |
|            | Cas2   | 17.83                    | 0.5        | 2.04                                  | 70.77                   | 0.33                   | 0.94      | 0.34                    | 6.58       | 0.68                                  | 2.5       | 311       | 7.9       | 103       | 1458      |
|            | Cas3   | 18.32                    | 0.57       | 1.8                                   | 68.89                   | 0.42                   | 0.99      | 0.52                    | 6.91       | 0.86                                  | 7.6       | 685       | 11        | 1592      | 1235      |
|            | Cas4   | 16.76                    | 0.61       | 1.18                                  | 73.04                   | 0.32                   | 1.13      | 0.23                    | 5.64       | 0.59                                  | 4.9       | 802       | 10.5      | 2016      | 1073      |
|            | Cas5   | 19.22                    | 0.63       | 1.53                                  | 69.7                    | 0.4                    | 0.89      | 0.45                    | 6.4        | 0.76                                  | 8.1       | 683       | 10.6      | 1829      | 1392      |
|            | Cas6   | 19.72                    | 0.8        | 2.24                                  | 68.43                   | 0.15                   | 0.9       | 0.84                    | 5.88       | 0.44                                  | 4.1       | 400       | 9.2       | 6796      | 442       |
|            | Cas20  | 17.25                    | 0.9        | 1.5                                   | 73.63                   | 0.34                   | 1.07      | 0.57                    | 3.33       | 1.4                                   | 5.2       | 1367      | 15        | 3369      | 1314      |
| Elea       | E12    | 18.05                    | 0.7        | 2.34                                  | 71.42                   | 0.25                   | 0.88      | 0.64                    | 5.19       | 0.53                                  | 3.1       | 328       | 7.5       | 611       | 783       |
|            | E13    | 16.64                    | 0.69       | 2.23                                  | 72.4                    | 0.12                   | 0.9       | 0.67                    | 5.77       | 0.58                                  | 3.1       | 332       | 7.9       | 846       | 1100      |
| Dymokastro | Dyl    | 17.86                    | 0.63       | 2.28                                  | 70.75                   | 0.27                   | 0.92      | 0.74                    | 6.07       | 0.46                                  | 4.9       | 463       | 14.4      | 15,497    | 345       |
|            | Dyl9   | 20.16                    | 1.02       | 2.64                                  | 69.69                   | 0.18                   | 0.67      | 1.07                    | 4.25       | 0.32                                  | 4.4       | 436       | 14.6      | 5850      | 763       |
|            | Dy38   | 17.22                    | 0.51       | 2.26                                  | 72.96                   | 0.29                   | 0.79      | 0.49                    | 5.25       | 0.28                                  | 3         | 328       | 7.9       | 1231      | 898       |
|            | Dy39   | 16.55                    | 0.54       | 2.3                                   | 72.41                   | 0.12                   | 1.04      | 0.58                    | 6.12       | 0.34                                  | 3         | 326       | 8.1       | 146       | 198       |
|            | Dy40   | 17.9                     | 0.4        | 2.17                                  | 69.35                   | 0.48                   | 1.13      | 0.73                    | 6.5        | 0.38                                  | 3.7       | 290       | 6.8       | 6353      | 1567      |
|            | Dy41   | 18.48                    | 0.44       | 2                                     | 68.95                   | 0.28                   | 1.36      | 0.66                    | 6.68       | 0.45                                  | 3.4       | 281       | 6.5       | 6277      | 1577      |
|            | Dy42   | 18.84                    | 0.83       | 2.41                                  | 68.03                   | 0.28                   | 0.59      | 0.96                    | 6.7        | 0.46                                  | 4.3       | 486       | 13.7      | 13,233    | 1707      |
|            | Dy43   | 16.22                    | 0.43       | 2.32                                  | 72.65                   | 0.24                   | 0.94      | 0.73                    | 5.92       | 0.54                                  | 3.4       | 371       | 8.2       | 147       | 437       |
|            | Dy44   | 16.71                    | 0.58       | 2.22                                  | 71.53                   | 0.34                   | 0.87      | 0.75                    | 6.64       | 0.4                                   | 3.2       | 351       | 7.6       | 963       | 1048      |
|            | Dy45   | 16.25                    | 0.59       | 2.29                                  | 72.54                   | 0.32                   | 0.96      | 0.55                    | 5.97       | 0.6                                   | 3.2       | 410       | 8.3       | 158       | 737       |
|            | Gt1a   | 18.98                    | 0.84       | 2.22                                  | 69.2                    | 0.26                   | 0.85      | 1.11                    | 5.75       | 0.31                                  | 5.1       | 383       | 9.7       | 6954      | 448       |
| Git ana    | Gt1b   | 18.06                    | 0.97       | 1.88                                  | 72.15                   | 0.18                   | 0.48      | 0.61                    | 3.87       | 0.17                                  | 5.4       | 418       | 10.6      | 6990      | 444       |
|            | Gt2    | 18.24                    | 0.55       | 2.21                                  | 69.29                   | 0.45                   | 1         | 0.81                    | 5.92       | 0.58                                  | 3.6       | 363       | 9         | 9373      | 282       |
|            | Gt3    | 19.6                     | 0.58       | 2.27                                  | 68.1                    | 0.49                   | 0.66      | 0.65                    | 5.67       | 1.97                                  | 4.2       | 369       | 12.2      | 667       | 885       |

|            | Gt4    | 19.4  | 0.71 | 2.48 | 70.19 | 0.24 | 0.8  | 0.6  | 5.29 | 0.29 | 2.9 | 348 | 8.4  | 2089 | 952  |
|------------|--------|-------|------|------|-------|------|------|------|------|------|-----|-----|------|------|------|
|            | Gt5    | 18.33 | 0.65 | 2.33 | 69.06 | 0.24 | 1.12 | 0.74 | 6.98 | 0.54 | 4   | 431 | 18.9 | 2169 | 281  |
|            | Gt9    | 18.87 | 0.89 | 2.24 | 69.03 | 0.29 | 0.78 | 0.93 | 6.02 | 0.42 | 4.5 | 428 | 9.6  | 8166 | 426  |
|            | Gt20   | 17.25 | 0.57 | 2.37 | 69.71 | 0.39 | 1.08 | 0.54 | 6.55 | 0.79 | 5.4 | 492 | 10.3 | 7207 | 1091 |
|            | Gt21   | 17.95 | 0.35 | 2.21 | 70.75 | 0.48 | 0.68 | 0.56 | 5.61 | 0.68 | 2.3 | 303 | 7    | 7863 | 1423 |
|            | Gt22   | 18.15 | 0.63 | 2.36 | 70.2  | 0.35 | 0.72 | 0.77 | 5.89 | 0.61 | 3.3 | 354 | 8.1  | 3518 | 2082 |
|            | Gt23   | 21.72 | 1.01 | 2.84 | 58.75 | 0.65 | n.m. | 0.58 | 2.67 | 0.08 | 4.7 | 549 | 13   | 3194 | 697  |
| Region     | Sample | Ni    | Cu   | Zn   | As    | Rb   | Sr   | Y    | Zr   | Sn   | Ba  | La  | Nd   | Hf   |      |
|            |        | ppm   | ppm  | ppm  | ppm   | ppm  | ppm  | ppm  | ppm  | ppm  | ppm | ppm | ppm  | ppm  |      |
| Dodona     | Do3    | 4     | 817  | 39   | 4     | 11   | 485  | 7.1  | 38   | 13   | 215 | 6.1 | 6.3  | 0.8  |      |
|            | Do5    | 4     | 551  | 30   | 2     | 10   | 496  | 8.6  | 45   | 11   | 212 | 6.7 | 6.8  | 0.9  |      |
|            | Do6    | 5     | 873  | 222  | 5     | 8    | 475  | 9.1  | 39   | 27   | 200 | 6.7 | 6.4  | 1.1  |      |
|            | Do8    | 6     | 716  | 276  | 6     | 7    | 445  | 7.4  | 31   | 18   | 196 | 6.1 | 5.9  | 0.8  |      |
| Ambracia   | Arl3a  | 36    | 1428 | 36   | 11    | 12   | 451  | 6.3  | 33   | 54   | 227 | 6   | 6    | 0.9  |      |
|            | Arl3b  | 55    | 1567 | 50   | 18    | 15   | 458  | 6.3  | 33   | 72   | 221 | 5.9 | 5.7  | 0.8  |      |
|            | Ar36a  | 44    | 5890 | 108  | 34    | 13   | 465  | 7    | 38   | 63   | 231 | 6   | 5.9  | 0.9  |      |
|            | Ar36b  | 39    | 4416 | 70   | 32    | 13   | 496  | 8.7  | 47   | 88   | 244 | 7.2 | 7    | 1.1  |      |
| Cassope    | Cas1   | 37    | 973  | 34   | 11    | 10   | 441  | 6.1  | 33   | 57   | 212 | 5.6 | 5.9  | 0.8  |      |
|            | Cas2   | 9     | 1449 | 151  | 6     | 7    | 496  | 7    | 30   | 9    | 186 | 6.2 | 6.2  | 0.7  |      |
|            | Cas3   | 85    | 4875 | 115  | 14    | 8    | 309  | 5.2  | 102  | 296  | 164 | 6.9 | 6.5  | 2.5  |      |
|            | Cas4   | 77    | 989  | 66   | 4     | 4    | 230  | 5    | 73   | 38   | 117 | 6.6 | 6.4  | 1.8  |      |
|            | Cas5   | 93    | 4762 | 116  | 14    | 8    | 306  | 5.4  | 99   | 351  | 166 | 7   | 6.8  | 2.4  |      |
|            | Cas6   | 14    | 557  | 31   | 10    | 14   | 576  | 6.7  | 34   | 244  | 237 | 6.1 | 6    | 0.9  |      |
|            | Cas20  | 118   | 3762 | 326  | 47    | 4    | 215  | 5.4  | 134  | 56   | 171 | 7.1 | 6.2  | 3.3  |      |
| Elea       | E12    | 31    | 1707 | 71   | 17    | 10   | 428  | 5.5  | 27   | 38   | 215 | 5.4 | 5.4  | 0.7  |      |
|            | E13    | 42    | 2823 | 77   | 24    | 10   | 446  | 6.7  | 34   | 51   | 214 | 5.8 | 6.3  | 1    |      |
| Dymokastro | Dyl    | 40    | 3704 | 87   | 19    | 11   | 735  | 7.4  | 40   | 557  | 426 | 7.3 | 6.7  | 1.1  |      |
|            | Dyl9   | 45    | 3276 | 128  | 36    | 12   | 516  | 7.5  | 38   | 71   | 260 | 6.6 | 6.2  | 1    |      |
|            | Dy38   | 27    | 1190 | 45   | 12    | 10   | 460  | 6.5  | 35   | 18   | 206 | 5.8 | 6    | 0.9  |      |
|            | Dy39   | 8     | 1377 | 115  | 9     | 9    | 431  | 7.1  | 35   | 8    | 233 | 5.8 | 6    | 1    |      |
|            | Dy40   | 79    | 1302 | 51   | 12    | 10   | 562  | 7.7  | 35   | 58   | 236 | 5.9 | 5.9  | 0.9  |      |
|            | Dy41   | 77    | 1397 | 51   | 12    | 10   | 552  | 7.4  | 35   | 56   | 238 | 6   | 6.1  | 0.8  |      |
|            | Dy42   | 66    | 2560 | 54   | 16    | 12   | 675  | 7.8  | 44   | 111  | 389 | 7.1 | 7    | 1    |      |
|            | Dy43   | 15    | 1631 | 204  | 30    | 13   | 447  | 7.2  | 37   | 15   | 222 | 6.2 | 6.2  | 0.9  |      |

|         |      |     |      |     |    |    |     |     |    |     |     |     |     |     |
|---------|------|-----|------|-----|----|----|-----|-----|----|-----|-----|-----|-----|-----|
| Git ana | Dy44 | 46  | 1273 | 34  | 12 | 10 | 466 | 7.1 | 36 | 53  | 206 | 5.9 | 5.8 | 1   |
|         | Dy45 | 15  | 2019 | 278 | 21 | 9  | 438 | 7.6 | 41 | 20  | 222 | 6.6 | 6.4 | 1.1 |
|         | Gt1a | 22  | 1209 | 42  | 9  | 12 | 557 | 7.1 | 35 | 30  | 232 | 6.1 | 6.2 | 0.9 |
|         | Gt1b | 24  | 3295 | 47  | 12 | 13 | 576 | 7.3 | 37 | 29  | 238 | 6.7 | 6.4 | 0.9 |
|         | Gt2  | 21  | 998  | 35  | 13 | 13 | 529 | 5.7 | 33 | 107 | 246 | 5.6 | 5.6 | 0.7 |
|         | Gt3  | 23  | 3328 | 152 | 10 | 11 | 407 | 7.2 | 34 | 10  | 201 | 6.4 | 6.3 | 0.8 |
|         | Gt4  | 30  | 1780 | 50  | 15 | 9  | 445 | 6.7 | 34 | 34  | 228 | 5.8 | 5.7 | 0.8 |
|         | Gt5  | 15  | 603  | 32  | 11 | 10 | 445 | 6.8 | 41 | 17  | 225 | 6.1 | 5.9 | 1.1 |
|         | Gt9  | 17  | 480  | 32  | 9  | 15 | 580 | 7.1 | 36 | 196 | 244 | 6.1 | 5.9 | 0.9 |
|         | Gt20 | 128 | 4322 | 157 | 26 | 9  | 467 | 7.1 | 41 | 135 | 259 | 6.2 | 6.3 | 1.1 |
|         | Gt21 | 46  | 1655 | 20  | 14 | 9  | 425 | 6.1 | 31 | 43  | 832 | 5.4 | 5.4 | 0.8 |
|         | Gt22 | 65  | 3138 | 20  | 19 | 11 | 422 | 7.4 | 44 | 134 | 454 | 6   | 5.9 | 1.1 |
|         | Gt23 | 26  | 2172 | 293 | 44 | 9  | 506 | 9   | 54 | 115 | 217 | 7.8 | 7.3 | 1.5 |

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**Table 10 Varberg *et al.* (2015)**

| Sample        | Na <sub>2</sub> O<br>wt%             | MgO<br>wt%                           | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt%               | P <sub>2</sub> O <sub>5</sub><br>wt% | Cl<br>wt%  | K <sub>2</sub> O<br>wt%              | CaO<br>wt%              | Fe <sub>2</sub> O <sub>3</sub><br>wt% | TiO <sub>2</sub><br>ppm | MnO<br>ppm                            | CoO<br>ppm | CuO<br>ppm                            | NiO<br>ppm              | ZnO<br>ppm                            | Li <sub>2</sub> O<br>ppm |
|---------------|--------------------------------------|--------------------------------------|---------------------------------------|---------------------------------------|--------------------------------------|------------|--------------------------------------|-------------------------|---------------------------------------|-------------------------|---------------------------------------|------------|---------------------------------------|-------------------------|---------------------------------------|--------------------------|
| Ke299/B 2209  | 18.1                                 | 3.79                                 | 1.39                                  | 64.9                                  | 0.25                                 | 1.64       | 1.68                                 | 7.07                    | 0.58                                  | 1041                    | 2738                                  | 396        | 138                                   | 382                     | 463                                   | 8                        |
| Ke2014A/ D115 | 17.7                                 | 3.38                                 | 1.97                                  | 65.4                                  | 0.1                                  | 1.04       | 0.47                                 | 8.74                    | 0.65                                  | 1143                    | 1240                                  | 770        | 75                                    | 511                     | 784                                   | nd                       |
| DANMK 7410 1  | 14.1                                 | 3.77                                 | 2.63                                  | 66.6                                  | 0.12                                 | 0.83       | 1.14                                 | 9.04                    | 0.82                                  | 1686                    | 1231                                  | 1022       | 1926                                  | 540                     | 1404                                  | 8.3                      |
| DANMK 7411 2  | 17.4                                 | 4.12                                 | 2.19                                  | 60.6                                  | 0.15                                 | 0.92       | 1.25                                 | 9.31                    | 0.57                                  | 1003                    | 2396                                  | 1021       | 18545                                 | 569                     | 1509                                  | 16                       |
| DANMK 7411 3  | 14.9                                 | 4.35                                 | 2.38                                  | 68                                    | 0.09                                 | 1.08       | 0.79                                 | 7.04                    | 0.6                                   | 1173                    | 1973                                  | 895        | 367                                   | 391                     | 993                                   | 8.5                      |
| DANMK 7411 4  | 17.9                                 | 4.04                                 | 1.78                                  | 62.6                                  | 0.13                                 | 1.1        | 1.17                                 | 9.67                    | 0.51                                  | 940                     | 1148                                  | 606        | 2794                                  | 311                     | 858                                   | 16                       |
| Sample        | B <sub>2</sub> O <sub>3</sub><br>ppm | V <sub>2</sub> O <sub>5</sub><br>ppm | Cr <sub>2</sub> O <sub>3</sub><br>ppm | As <sub>2</sub> O <sub>3</sub><br>ppm | Rb <sub>2</sub> O<br>ppm             | SrO<br>ppm | Y <sub>2</sub> O <sub>3</sub><br>ppm | ZrO <sub>2</sub><br>ppm | Nb <sub>2</sub> O <sub>3</sub><br>ppm | SnO <sub>2</sub><br>ppm | Sb <sub>2</sub> O <sub>3</sub><br>ppm | BaO<br>ppm | La <sub>2</sub> O <sub>3</sub><br>ppm | CeO <sub>2</sub><br>ppm | Nd <sub>2</sub> O <sub>3</sub><br>ppm | PbO<br>ppm               |
| Ke299/B 2209  | 322                                  | 22                                   | 12                                    | 3.5                                   | 10                                   | 670        | 7                                    | 67                      | 2.3                                   | 13                      | 72                                    | 64         | 4.4                                   | 10                      | 5.3                                   | 3.1                      |
| Ke2014A/ D115 | 386                                  | 18                                   | 14                                    | 2                                     | 4.2                                  | 560        | 8                                    | 52                      | 2.4                                   | 10                      | 12                                    | 48         | 4.3                                   | 11                      | 5.5                                   | 3.4                      |
| DANMK 7410 1  | 395                                  | 22                                   | 7                                     | 7.5                                   | 7.7                                  | 467        | 10                                   | 117                     | 3.8                                   | 116                     | 620                                   | 73         | 7.9                                   | 17                      | 10                                    | 66                       |
| DANMK 7411 2  | 351                                  | 17                                   | 10                                    | 75                                    | 6.5                                  | 803        | 10                                   | 81                      | 2.1                                   | 1468                    | 4816                                  | 69         | 5.3                                   | 11                      | 6.5                                   | 2778                     |
| DANMK 7411 3  | 426                                  | 18                                   | 11                                    | 2.5                                   | 3.4                                  | 440        | 11                                   | 81                      | 2.4                                   | 53                      | 0.3                                   | 50         | 7.1                                   | 16                      | 9                                     | 12                       |
| DANMK 7411 4  | 304                                  | 15                                   | 12                                    | 15                                    | 6.8                                  | 912        | 8.2                                  | 79                      | 2                                     | 151                     | 2891                                  | 46         | 4.9                                   | 10                      | 5.7                                   | 884                      |



**Table 11 Shortland *et al.* (2007)**

| Location |         | Sample | Object type | Colour | Li   | Be    | B    | Al     | P    | Sc   | Ti   | V     | Cr   | Mn   | Fe   | Co   |
|----------|---------|--------|-------------|--------|------|-------|------|--------|------|------|------|-------|------|------|------|------|
|          |         |        |             |        | ppm  | ppm   | ppm  | ppm    | ppm  | ppm  | ppm  | ppm   | ppm  | ppm  | ppm  | ppm  |
| Egyptian | Malkata | UPP30  | rod         | blue   | 6.3  | 0.953 | 113  | 9090   | 260  | 1.47 | 511  | 6     | 4.6  | 565  | 2891 | 589  |
| Egyptian | Malkata | UPP31  | rod         | blue   | 3.9  | 0.66  | 78   | 8287   | 371  | 1.44 | 507  | 6.02  | 4.1  | 845  | 3058 | 624  |
| Egyptian | Malkata | UPP32  | rod         | blue   | 6.8  | 0.913 | 172  | 12,218 | 349  | 1.92 | 726  | 9.01  | 7.8  | 1330 | 2562 | 999  |
| Egyptian | Malkata | UPP33  | rod         | blue   | 5.6  | 0.521 | 103  | 8087   | 313  | 1.49 | 513  | 6.18  | 3.4  | 691  | 3633 | 658  |
| Egyptian | Malkata | UPP34  | rod         | blue   | 5.2  | 0.47  | 100  | 7912   | 319  | 1.49 | 503  | 6.11  | 4.4  | 655  | 3823 | 626  |
| Egyptian | Malkata | UPP35  | rod         | blue   | 9    | 0.95  | 102  | 10,545 | 714  | 1.63 | 442  | 6.93  | 4.6  | 1587 | 2832 | 1539 |
| Egyptian | Malkata | UPP36  | rod         | blue   | 6    | 0.459 | 90   | 8416   | 271  | 1.56 | 455  | 5.9   | 3.3  | 591  | 3035 | 565  |
| Egyptian | Malkata | UPP37  | rod         | blue   | 5.2  | 1.27  | 112  | 13,653 | 313  | 1.65 | 466  | 5.67  | 6.2  | 750  | 2476 | 754  |
| Egyptian | Malkata | UPP38  | rod         | blue   | 5.5  | 0.257 | 56   | 3047   | 434  | 1.27 | 389  | 7.1   | 5.6  | 7576 | 2415 | 22.4 |
| Egyptian | Malkata | UPP39  | rod         | blue   | 5.6  | 0.645 | 165  | 10445  | 191  | 1.88 | 687  | 7.6   | 5.4  | 533  | 3824 | 633  |
| Egyptian | Malkata | UPP40  | rod         | blue   | 6    | 1.07  | 85   | 13,294 | 336  | 1.98 | 775  | 11.72 | 6.4  | 1620 | 5042 | 980  |
| Egyptian | Malkata | UPP41  | rod         | blue   | 3.8  | 0.922 | 74   | 17,973 | 481  | 2.91 | 1205 | 19.76 | 9.7  | 1453 | 7071 | 861  |
| Egyptian | Malkata | UPP42  | rod         | blue   | 5.2  | 1.19  | 83   | 12,285 | 313  | 1.47 | 497  | 5.97  | 2.4  | 1259 | 2939 | 939  |
| Location |         | Sample | Object type | Colour | Ni   | Cu    | Zn   | Ga     | As   | Rb   | Sr   | Y     | Zr   | Ag   | Sn   | Sb   |
|          |         |        |             |        | ppm  | ppm   | ppm  | ppm    | ppm  | ppm  | ppm  | ppm   | ppm  | ppm  | ppm  | ppm  |
| Egyptian | Malkata | UPP30  | rod         | blue   | 375  | 1624  | 880  | 1.93   | 12.8 | 3.9  | 764  | 12.65 | 47.3 | 0.04 | 124  | 1917 |
| Egyptian | Malkata | UPP31  | rod         | blue   | 352  | 268   | 1023 | 2.1    | 4    | 4.9  | 504  | 4.08  | 50.5 | 0.08 | 19.7 | 600  |
| Egyptian | Malkata | UPP32  | rod         | blue   | 667  | 550   | 1171 | 3.59   | 7.9  | 4.9  | 474  | 17.07 | 73.2 | 0.81 | 31.3 | 2238 |
| Egyptian | Malkata | UPP33  | rod         | blue   | 320  | 3467  | 516  | 2.16   | 5    | 3.8  | 725  | 7.49  | 39.5 | 0.1  | 40.9 | 73.3 |
| Egyptian | Malkata | UPP34  | rod         | blue   | 302  | 3609  | 485  | 2.1    | 5.8  | 3.8  | 734  | 7.29  | 41.7 | 0.15 | 68.5 | 77.1 |
| Egyptian | Malkata | UPP35  | rod         | blue   | 1164 | 400   | 2145 | 2.28   | 2    | 4.5  | 573  | 11.91 | 34.7 | 8.53 | 13.3 | 58.9 |

| Egyptian | Malkata | UPP36  | rod         | blue   | 273     | 3071   | 402  | 1    | 4.9     | 3.8  | 692  | 7.21    | 43.5  | 2.8   | 70.7 | 69.4 |
|----------|---------|--------|-------------|--------|---------|--------|------|------|---------|------|------|---------|-------|-------|------|------|
| Egyptian | Malkata | UPP37  | rod         | blue   | 472     | 284    | 945  | 0.92 | 0.9     | 4.3  | 349  | 14.26   | 37.5  | 0.07  | 17.6 | 0.94 |
| Egyptian | Malkata | UPP38  | rod         | blue   | 18.7    | 11,564 | 178  | 0.75 | 28.4    | 9.7  | 900  | 2.95    | 42.3  | 2.27  | 794  | 589  |
| Egyptian | Malkata | UPP39  | rod         | blue   | 414     | 1119   | 681  | 1.55 | 12.9    | 0.3  | 261  | 11.74   | 73.5  | 0.84  | 102  | 2533 |
| Egyptian | Malkata | UPP40  | rod         | blue   | 706     | 90     | 1319 | 1.53 | 11      | 3    | 276  | 12.51   | 47.6  | 0.41  | 13.1 | 3783 |
| Egyptian | Malkata | UPP41  | rod         | blue   | 630     | 90     | 1156 | 2.44 | 8.9     | 2.9  | 255  | 11.53   | 51.4  | 0.55  | 11.1 | 3059 |
| Egyptian | Malkata | UPP42  | rod         | blue   | 531     | 68     | 1044 | 1.01 | 1       | 4.3  | 1253 | 5.33    | 42.5  | 0.07  | 11.3 | 118  |
| Location |         | Sample | Object type | Colour | Cs      | Ba     | La   | Ce   | W       | Au   | Pb   | Bi      | Th    | U     |      |      |
|          |         |        |             |        | ppm     | ppm    | ppm  | ppm  | ppm     | ppm  | ppm  | ppm     | ppm   | ppm   |      |      |
| Egyptian | Malkata | UPP30  | rod         | blue   | 0.036   | 30.9   | 3.41 | 6.81 | <0.0093 | 0.32 | 37.9 | 0.03    | 0.989 | 0.419 |      |      |
| Egyptian | Malkata | UPP31  | rod         | blue   | <0.0055 | 38.3   | 3.24 | 6.32 | 0.02    | 0.23 | 17   | 0.18    | 0.764 | 0.331 |      |      |
| Egyptian | Malkata | UPP32  | rod         | blue   | 0.065   | 56.3   | 5.03 | 10.8 | <0.017  | 0.13 | 39.4 | 0.06    | 1.211 | 1.32  |      |      |
| Egyptian | Malkata | UPP33  | rod         | blue   | 0.041   | 35.7   | 3.47 | 7.33 | <0.032  | 0.06 | 7.6  | 0.26    | 0.877 | 0.393 |      |      |
| Egyptian | Malkata | UPP34  | rod         | blue   | 0.086   | 36.1   | 3.42 | 7.14 | 0.01    | 0.08 | 8.1  | 0.27    | 0.857 | 0.409 |      |      |
| Egyptian | Malkata | UPP35  | rod         | blue   | 0.056   | 42.2   | 3.02 | 7.51 | 0.01    | 0.05 | 31.6 | 0.24    | 0.865 | 0.435 |      |      |
| Egyptian | Malkata | UPP36  | rod         | blue   | 0.039   | 33.3   | 3.49 | 7.24 | 0.02    | 0.06 | 7.8  | 0.26    | 0.897 | 0.424 |      |      |
| Egyptian | Malkata | UPP37  | rod         | blue   | 0.051   | 44.7   | 3.44 | 7.5  | 0.01    | 0.02 | 12   | 0.03    | 0.915 | 0.495 |      |      |
| Egyptian | Malkata | UPP38  | rod         | blue   | 0.114   | 64.2   | 2.67 | 4.84 | 0.04    | 9.72 | 114  | 0.09    | 0.648 | 0.402 |      |      |
| Egyptian | Malkata | UPP39  | rod         | blue   | 0.037   | 56.1   | 5.91 | 12.4 | 0.03    | 1.5  | 49.8 | 0.05    | 1.43  | 0.793 |      |      |
| Egyptian | Malkata | UPP40  | rod         | blue   | 0.034   | 44.2   | 3.79 | 8.44 | 0.02    | 0.35 | 56.2 | 0.02    | 0.878 | 0.479 |      |      |
| Egyptian | Malkata | UPP41  | rod         | blue   | 0.042   | 52.2   | 4.4  | 9.76 | 0.06    | 0.28 | 49.7 | <0.0100 | 0.98  | 0.486 |      |      |
| Egyptian | Malkata | UPP42  | rod         | blue   | 0.038   | 40     | 3.81 | 7.47 | <0.0038 | 0.12 | 93.8 | 0.03    | 0.93  | 0.427 |      |      |

**Table 12 Walton *et al.* (2009)**

|                      | Sample    | Na <sub>2</sub> O<br>wt% | MgO<br>wt% | Al <sub>2</sub> O <sub>3</sub><br>wt% | SiO <sub>2</sub><br>wt% | K <sub>2</sub> O<br>wt% | CaO<br>wt% | TiO <sub>2</sub><br>wt% | Fe <sub>2</sub> O <sub>3</sub><br>wt% | Cu<br>ppm | Mn<br>ppm | Sc<br>ppm | V<br>ppm  | Cr<br>ppm | Co<br>ppm | Ni<br>ppm |
|----------------------|-----------|--------------------------|------------|---------------------------------------|-------------------------|-------------------------|------------|-------------------------|---------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| J. Paul Getty Museum | 2004.15.1 | 15.55                    | 2.97       | 1.99                                  | 69.57                   | 0.96                    | 7.76       | 0.1                     | 0.62                                  | 7313      | 878.2     | 18.5      | 14.4      | 10.4      | 380.8     | 310.9     |
| J. Paul Getty Museum | 2004.15.2 | 15.24                    | 3.12       | 2.13                                  | 69.51                   | 1.86                    | 6.89       | 0.11                    | 0.58                                  | 766.7     | 912.6     | 15.9      | 16.6      | 11.4      | 393.9     | 317.6     |
| J. Paul Getty Museum | 2004.15.4 | 16.11                    | 3.52       | 2.04                                  | 66.87                   | 2.24                    | 8.15       | 0.08                    | 0.53                                  | 385.2     | 855.7     | 12.2      | 10.6      | 6.4       | 335.6     | 272.6     |
| J. Paul Getty Museum | 2004.15.7 | 16.52                    | 3.52       | 2.09                                  | 65.23                   | 0.89                    | 9.85       | 0.14                    | 0.73                                  | 417.5     | 1664.3    | 16.7      | 15        | 14.4      | 263.5     | 298.1     |
|                      | Sample    | Zn<br>ppm                | Ga<br>ppm  | Ge<br>ppm                             | As<br>ppm               | Se<br>ppm               | Rb<br>ppm  | Sr<br>ppm               | Y<br>ppm                              | Zr<br>ppm | Nb<br>ppm | Mo<br>ppm | Rh<br>ppm | Pd<br>ppm | Ag<br>ppm | Cd<br>ppm |
| J. Paul Getty Museum | 2004.15.1 | 639.6                    | 8.3        | 0.9                                   | 5                       | 0.8                     | 9.9        | 615.7                   | 10.8                                  | 42.3      | 1.8       | 0.6       | 0         | 0         | 3.9       | 3.4       |
| J. Paul Getty Museum | 2004.15.2 | 685                      | 6.7        | 0.9                                   | 6.3                     | 0.1                     | 29.4       | 588.9                   | 11.1                                  | 46.4      | 1.8       | 0.5       | 0         | 0         | 6         | 4.7       |
| J. Paul Getty Museum | 2004.15.4 | 567.4                    | 3.6        | 1                                     | 2.2                     | 0.2                     | 10         | 746.3                   | 9.5                                   | 41.3      | 1.5       | 0.4       | 0         | 0         | 12        | 2.3       |
| J. Paul Getty Museum | 2004.15.7 | 1055.4                   | 6.3        | 0.6                                   | 4.3                     | 5.5                     | 8.4        | 1068.5                  | 14.2                                  | 61        | 2.1       | 0.9       | 0         | 0         | 19        | 8.4       |
|                      | Sample    | In<br>ppm                | Sn<br>ppm  | Sb<br>ppm                             | Cs<br>ppm               | Ba<br>ppm               | La<br>ppm  | Ce<br>ppm               | Pr<br>ppm                             | Nd<br>ppm | Sm<br>ppm | Eu<br>ppm | Gd<br>ppm | Tb<br>ppm | Dy<br>ppm | Ho<br>ppm |
| J. Paul Getty Museum | 2004.15.1 | 0.3                      | 57.5       | 33                                    | 1                       | 72.1                    | 4.7        | 8.8                     | 1.1                                   | 6.1       | 12        | 0.3       | 1.6       | 0.2       | 1.3       | 0.3       |
| J. Paul Getty Museum | 2004.15.2 | 0.4                      | 80.9       | 38                                    | 0.5                     | 70                      | 3.8        | 8.3                     | 1.1                                   | 6.3       | 1.2       | 0.3       | 1.7       | 0.2       | 1.4       | 0.3       |
| J. Paul Getty Museum | 2004.15.4 | 0.2                      | 35.2       | 6.8                                   | 0.4                     | 56.9                    | 3.2        | 7.7                     | 1                                     | 5.6       | 1.2       | 0.3       | 1.5       | 0.2       | 1.2       | 0.3       |
| J. Paul Getty Museum | 2004.15.7 | 0.5                      | 64.2       | 101.5                                 | 0.2                     | 102.7                   | 5.6        | 12.9                    | 1.4                                   | 8.2       | 1.7       | 0.6       | 3.2       | 0.6       | 3.4       | 0.6       |
|                      | Sample    | Er<br>ppm                | Tm<br>ppm  | Yb<br>ppm                             | Lu<br>ppm               | Hf<br>ppm               | Ta<br>ppm  | W<br>ppm                | Re<br>ppm                             | Pt<br>ppm | Au<br>ppm | Tl<br>ppm | Pb<br>ppm | Bi<br>ppm | Th<br>ppm | U<br>ppm  |
| J. Paul Getty Museum | 2004.15.1 | 0.8                      | 0.1        | 0.7                                   | 0.1                     | 1                       | 0.1        | 0.5                     | 0                                     | 0         | 0.8       | 0.2       | 106.2     | 1.9       | 0.9       | 0.7       |
| J. Paul Getty Museum | 2004.15.2 | 0.8                      | 0.1        | 0.7                                   | 0.1                     | 1.1                     | 0.1        | 0.2                     | 0                                     | 0         | 1.3       | 0.4       | 405.1     | 4.2       | 0.9       | 0.6       |
| J. Paul Getty Museum | 2004.15.4 | 0.7                      | 0.1        | 0.6                                   | 0.1                     | 1.1                     | 0.1        | 0.2                     | 0                                     | 0         | 1.3       | 1         | 136.7     | 0.8       | 0.8       | 0.6       |
| J. Paul Getty Museum | 2004.15.7 | 1.5                      | 0.2        | 0.9                                   | 0.1                     | 1.4                     | 0.1        | 0.7                     | 0                                     | 0.1       | 16.8      | 0.7       | 95.3      | 1.2       | 1.4       | 0.6       |

**Table 13 Smirniou and Rehren (2013)**

| No        | Origin     | K <sub>2</sub> O<br>wt% | Al<br>ppm | P<br>ppm  | Ti<br>ppm | Cr<br>ppm | Mn<br>ppm | Fe<br>ppm | Co<br>ppm | Ni<br>ppm | Cu<br>ppm | Sn<br>ppm | Zn<br>ppm |
|-----------|------------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| kaz35372  | Mycenaeae  | 1.54                    | 8615      | 752       | 404       | 16        | 946       | 4329      | 726       | 527       | 8605      | 14        | 1179      |
| kazT5     | Mycenaeae  | 1.91                    | 11021     | 688       | 560       | 12.1      | 1116      | 5714      | 589       | 347       | 2194      | 150       | 844       |
| kaz34649  | Mycenaeae  | 1.66                    | 10898     | 648       | 577       | 10.3      | 1776      | 4980      | 490       | 319       | 1625      | 31        | 560       |
| kazTl     | Mycenaeae  | 1.55                    | 8862      | 641       | 558       | 11        | 991       | 4664      | 523       | 231       | 1433      | 54        | 721       |
| kaz44141  | Mycenaeae  | 1.34                    | 10136     | 670       | 541       | 9.2       | 1591      | 5044      | 632       | 489       | 1215      | 24        | 989       |
| kaz44040  | Mycenaeae  | 1.17                    | 11611     | 720       | 585       | 11.1      | 1267      | 4740      | 614       | 451       | 1124      | 28        | 798       |
| kaz35722  | Mycenaeae  | 1.17                    | 11077     | 671       | 563       | 9.3       | 1674      | 4620      | 653       | 486       | 1105      | 25        | 784       |
| kaz 44039 | Mycenaeae  | 1.12                    | 11109     | 616       | 569       | 7.9       | 1570      | 4814      | 641       | 470       | 1010      | 21        | 766       |
| 15889019b | Mycenaeae  | 0.85                    | 10575     | 508       | 586       | 23.8      | 1239      | 4515      | 535       | 353       | 1580      | 79        | 713       |
| 15889008  | Mycenaeae  | 0.55                    | 10632     | 472       | 608       | 24.8      | 1243      | 4306      | 526       | 348       | 1510      | 79        | 530       |
| 1588906   | Mycenaeae  | 0.49                    | 10710     | 596       | 636       | 36.6      | 1241      | 4869      | 520       | 352       | 1548      | 82        | 707       |
| 29793B    | Mycenaeae  | 0.5                     | 11029     | 1724      | 746       | 57.5      | 1253      | 5251      | 535       | 363       | 1615      | 97        | 665       |
| 29793C    | Mycenaeae  | 0.59                    | 10790     | 947       | 653       | 63.1      | 1262      | 5459      | 519       | 350       | 1575      | 92        | 608       |
| UPP34     | Eg-Malkata | 0.7                     | 7912      | 319       | 503       | 4.4       | 655       | 3823      | 626       | 302       | 3609      | 69        | 485       |
| UPP33     | Eg-Malkata | 0.7                     | 8087      | 313       | 513       | 3.4       | 691       | 3633      | 658       | 320       | 3467      | 41        | 516       |
| UPP36     | Eg-Malkata | 0.7                     | 8416      | 271       | 455       | 3.3       | 591       | 3035      | 565       | 273       | 3071      | 71        | 402       |
| UPP30     | Eg-Malkata | 0.7                     | 9090      | 260       | 511       | 4.6       | 565       | 2891      | 589       | 375       | 1624      | 124       | 880       |
| UPP39     | Eg-Malkata | 1.9                     | 10445     | 191       | 687       | 5.4       | 533       | 3824      | 633       | 414       | 1119      | 102       | 681       |
| Q8        | Eg-Q.antir | 0.44                    | 19633     | 159       | 537       | 2.5       | 4804      | 15529     | 2738      | 2116      | 3261      | 376       | 1261      |
| No        | Origin     | As<br>ppm               | Rb<br>ppm | Sr<br>ppm | Y<br>ppm  | Zr<br>ppm | Ag<br>ppm | Sb<br>ppm | Ba<br>ppm | La<br>ppm | Ce<br>ppm | Au<br>ppm | Pb<br>ppm |
| kaz35372  | Mycenaeae  | 6.8                     | 11.3      | 263       | 5.9       | 32        | 0.2       | 111       | 70        | 3.5       | 7.9       | 0.8       | 18        |
| kazT5     | Mycenaeae  | 6.8                     | 12.7      | 502       | 11.1      | 51        | 1.5       | 211       | 51        | 5.9       | 11.4      | 0.5       | 27        |
| kaz34649  | Mycenaeae  | 5.1                     | 10.4      | 493       | 9.7       | 54        | 0.5       | 124       | 64        | 3.9       | 8.6       | 0.1       | 5         |
| kazTl     | Mycenaeae  | 4.8                     | 13.6      | 447       | 6.7       | 48        | 0.7       | 230       | 47        | 3.9       | 8.3       | 28        | 33        |
| kaz44141  | Mycenaeae  | 5                       | 7.4       | 529       | 11        | 50        | 0.1       | 359       | 49        | 4.5       | 10.7      | 0.1       | 10        |
| kaz44040  | Mycenaeae  | 4.4                     | 6.2       | 662       | 13.7      | 60        | 7.4       | 488       | 50        | 4.2       | 8.9       | 0.6       | 9         |
| kaz35722  | Mycenaeae  | 4.3                     | 6.3       | 597       | 12.8      | 57        | 0.1       | 369       | 46        | 4.1       | 9.3       | 0.1       | 4         |

|           |            |     |      |     |      |    |     |       |    |     |      |     |     |
|-----------|------------|-----|------|-----|------|----|-----|-------|----|-----|------|-----|-----|
| kaz 44039 | Mycenaeae  | 4   | 6    | 608 | 13.3 | 58 | 0.1 | 315   | 47 | 4.4 | 9.9  | 0   | 5   |
| 15889019b | Mycenaeae  | 12  | 10.1 | 446 | 8.1  | 65 | 0.1 | 486   | 52 | 4.5 | 11   | 0.1 | 11  |
| 15889008  | Mycenaeae  | 10  | 8.7  | 480 | 8.7  | 69 | 0.1 | 517   | 54 | 5   | 11   | 0.2 | 13  |
| 1588906   | Mycenaeae  | 8.5 | 8.8  | 472 | 8.9  | 79 | 0   | 505   | 69 | 5   | 11   | 0.1 | 10  |
| 29793B    | Mycenaeae  | 10  | 8.6  | 480 | 9.5  | 76 | 0   | 498   | 59 | 5.3 | 13.4 | 0.1 | 15  |
| 29793C    | Mycenaeae  | 4.1 | 7.7  | 473 | 9.2  | 72 | 0.2 | 526   | 55 | 5.4 | 13.3 | 0.3 | 13  |
| UPP34     | Eg-Malkata | 5.8 | 3.8  | 734 | 7.3  | 42 | 0.2 | 77    | 36 | 3.4 | 7.1  | 0.1 | 8   |
| UPP33     | Eg-Malkata | 5   | 3.8  | 725 | 7.5  | 40 | 0.1 | 73    | 36 | 3.5 | 7.3  | 0.1 | 8   |
| UPP36     | Eg-Malkata | 4.9 | 3.8  | 692 | 7.2  | 44 | 2.8 | 69    | 33 | 3.5 | 7.2  | 0.1 | 8   |
| UPP30     | Eg-Malkata | 13  | 3.9  | 764 | 12.7 | 47 | 0   | 1917  | 31 | 3.4 | 6.8  | 0.3 | 38  |
| UPP39     | Eg-Malkata | 13  | 0.3  | 261 | 11.7 | 74 | 0.8 | 2533  | 56 | 5.9 | 12.4 | 1.5 | 50  |
| Q8        | Eg-Q.antir | 0   | 3.4  | 372 | 18.1 | 45 | 0.3 | 10509 | 45 | 6.2 | 16.2 | 0.1 | 114 |

**Table 14 Chen *et al.* (1999)**

|       | Site      |           |           |           |           |           | Material    |           |           |           |           |                  | Typology    |           |           |           |           |          |          |  |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|-------------|-----------|-----------|-----------|-----------|------------------|-------------|-----------|-----------|-----------|-----------|----------|----------|--|
|       | Al<br>wt% | As<br>ppm | Ba<br>wt% | Ca<br>wt% | Co<br>ppm | Cr<br>ppm | Cs<br>ppm   | Eu<br>ppm | Fe<br>wt% | La<br>ppm | Mn<br>ppm | Na<br>wt%        | Rb<br>ppm   | Sc<br>ppm | Sm<br>ppm | Ti<br>wt% | Th<br>ppm | U<br>ppm | V<br>ppm |  |
| 001JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | ?           |           |           |           |           |          |          |  |
|       | 7         | 10        | 0.099     | 6.6       | 9.7       | 110       | 13          | 1.6       | 3.4       | 42        | 190       | 0.3              | 99          | 14        | 6.7       | 0.52      | 18        | 3.8      | 84       |  |
| 002JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 6.1       | 10        | 0.12      | 9.6       | 10        | 110       | 12          | 2.4       | 5.7       | 52        | 370       | 0.83             | 120         | 14        | 94        | 0.4       | 16        | 3.5      | 130      |  |
| 003JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 5.2       | 8.1       | 0.18      | 9.8       | 6.1       | 110       | 7.3         | 1.7       | 2.6       | 38        | 130       | 0.52             | 62          | 11        | 6.7       | 0.3       | 12        | 2.4      | 78       |  |
| 004JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 61        | 10        | 0.81      | 11        | 11        | 100       | 11          | 1.9       | 4.8       | 46        | 530       | 0.85             | 130         | 14        | 8.3       | 0.47      | 17        | 3.8      | 100      |  |
| 019JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           | <i>Dakougang</i> |             |           |           |           |           |          |          |  |
|       | 7.6       | 6.5       | 0.1       | 12        | 4.3       | 94        | 9.6         | 1.5       | 1.6       | 45        | 310       | 0.19             | 110         | 16        | 6.3       | 0.76      | 15        | 3.2      | 89       |  |
| 021JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 7.3       | 14        | 0.17      | 9         | 14        | 87        | 7.9         | 1.8       | 3.7       | 47        | 580       | 0.76             | 130         | 14        | 7.1       | 0.56      | 16        | 3.3      | 98       |  |
| 027JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 7.3       | 10        | 0.15      | 12        | 6.8       | 83        | 6.4         | 1.7       | 3.7       | 44        | 270       | 0.83             | 120         | 14        | 7.1       | 0.4       | 15        | 2.4      | 90       |  |
| 046JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 1.2       | 9         | 0.18      | 15        | 9.8       | 95        | 6.4         | 1.5       | 3.7       | 45        | 430       | 0.94             | 120         | 14        | 7         | 0.44      | 16        | 2.9      | 69       |  |
| 048JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 6.9       | 9.6       | 0.072     | 9.7       | 8.5       | 61        | 7.6         | 1.2       | 3.4       | 37        | 440       | 0.75             | 130         | 12        | 5.7       | 0.42      | 14        | 2.6      | 98       |  |
| 059JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | ?           |           |           |           |           |          |          |  |
|       | 5.9       | 7.9       | 0.084     | 6.9       | 3.8       | 58        | 6.8         | 1.3       | 3.2       | 55        | 160       | 0.9              | 120         | 11        | 8.2       | 0.46      | 16        | 3.1      | 54       |  |
| 065JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 7.1       | 9         | 0.11      | 10        | 91        | 60        | 4.7         | 1.2       | 3         | 32        | 420       | 0.43             | 93          | 11        | 5.1       | 0.38      | 11        | 3.6      | 90       |  |
| 066JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Fu</i>   |           |           |           |           |          |          |  |
|       | 8.3       | 15        | 0.14      | 9.3       | 9.9       | 81        | 9.3         | 1.4       | 3.8       | 43        | 360       | 0.65             | 190         | 15        | 6.8       | 0.44      | 14        | 2.4      | 99       |  |
| 073JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Gang</i> |           |           |           |           |          |          |  |
|       | 7.9       | 6.4       | 0.17      | 5.4       | 4.2       | 78        | 11          | 11        | 2.7       | 44        | 220       | 0.18             | 150         | 16        | 6.9       | 0.51      | 14        | 34       | 88       |  |
| F01JJ |           |           | Jingnansi |           |           |           | earthenware |           |           |           |           |                  | <i>Gang</i> |           |           |           |           |          |          |  |

|       |     |     |              |     |     |     |             |      |     |    |     |      |      |    |     |      |    |     |     |
|-------|-----|-----|--------------|-----|-----|-----|-------------|------|-----|----|-----|------|------|----|-----|------|----|-----|-----|
| F02JJ | 5.7 | 17  | 0.097        | 5.5 | 8.6 | 76  | 9.4         | 1.4  | 3.4 | 46 | 140 | 0.27 | 100  | 15 | 65  | 0.31 | 18 | 31  | 72  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Gang |    |     |      |    |     |     |
| F03JJ | 5.8 | 19  | 0.1          | 6.4 | 9.2 | 77  | 9.5         | 1.2  | 3.4 | 44 | 210 | 0.3  | 110  | 14 | 6.2 | 0.33 | 17 | 3.1 | 70  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Gang |    |     |      |    |     |     |
| F04JJ | 5.9 | 16  | 0.12         | 5.9 | 8   | 88  | 11          | 1    | 3.3 | 47 | 140 | 0.28 | 91   | 15 | 6.3 | 0.35 | 18 | 3.3 | 63  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Gang |    |     |      |    |     |     |
| F05JJ | 5.8 | 17  | 0.1          | 6.5 | 8.8 | 79  | 10          | 0.92 | 3.4 | 41 | 210 | 0.27 | 100  | 14 | 5.7 | 0.33 | 17 | 3.3 | 72  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Gang |    |     |      |    |     |     |
| F07JJ | 61  | 7.6 | 0.07         | 7.4 | 51  | 73  | 15          | 11   | 2.4 | 45 | 160 | 0.37 | 150  | 14 | 61  | 0.32 | 16 | 3.3 | 57  |
|       |     |     | Jingnansi    |     | 7.5 |     | earthenware |      |     |    |     |      | Gui  |    |     |      |    |     |     |
| F17JJ | 5.4 | 9   | 0.15         | 8.4 |     | 77  | 6.2         | 1.4  | 2.6 | 44 | 190 | 0.45 | 100  | 14 | 6.5 | 0.37 | 17 | 3.2 | 56  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Fu   |    |     |      |    |     |     |
| F18JJ | 4.4 | 8.1 | 0.18         | 7.1 | 4.8 | 85  | 6.2         | 0.64 | 2.7 | 39 | 100 | 0.53 | 69   | 11 | 5.8 | 0.21 | 11 | 1.7 | 62  |
|       |     |     | Jingnansi    |     |     |     | earthenware |      |     |    |     |      | Fu   |    |     |      |    |     |     |
| F63PZ | 5.9 | 9.4 | 0.17         | 7.8 | 12  | 96  | 10          | 1.4  | 3.8 | 42 | 170 | 0.83 | 170  | 16 | 6.5 | 0.31 | 16 | 21  | 79  |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     |      | Guan |    |     |      |    |     |     |
| F65PZ | 8.4 | 16  | 0.079        | 2.7 | 10  | 79  | 10          | 1.8  | 4   | 48 | 150 | 0.48 | 99   | 17 | 7.3 | 0.5  | 16 | 4.3 | 110 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     |      | Li   |    |     |      |    |     |     |
| F68PZ | 8.3 | 12  | 0.012        | 2.9 | 6.4 | 49  | 4.6         | 0.64 | 3.3 | 22 | 340 | 0.87 | 110  | 10 | 6.6 | 0.34 | 12 | 1.5 | 56  |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Gang |      |    |     |      |    |     |     |
| F69PZ | 11  | 15  | 0.078        | 31  | 7.9 | 66  | 16          | 1.2  | 4   | 43 | 210 | 0.67 | 160  | 15 | 5.9 | 0.52 | 23 | 4.9 | 110 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Li   |      |    |     |      |    |     |     |
| F71PZ | 7.3 | 16  | 0.11         | 2.7 | 12  | 84  | 5.2         | 1.6  | 4.1 | 50 | 270 | 0.62 | 84   | 15 | 7.7 | 0.54 | 17 | 41  | 100 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Gang |      |    |     |      |    |     |     |
| F72PZ | 10  | 20  | 0.11         | 4.3 | 13  | 100 | 12          | 1.5  | 3.3 | 53 | 330 | 0.23 | 140  | 20 | 8   | 0.61 | 19 | 3.3 | 120 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Gang |      |    |     |      |    |     |     |
| F73PZ | 7.6 | 15  | 0.073        | 3.7 | 7.4 | 99  | 10          | 1.3  | 4.2 | 38 | 130 | 0.64 | 150  | 15 | 5.7 | 0.47 | 16 | 3.3 | 120 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Li-1 |      |    |     |      |    |     |     |
| F74PZ | 8.3 | 26  | 0.094        | 4.5 | 18  | 100 | 5.3         | 1.6  | 5   | 48 | 340 | 0.61 | 88   | 15 | 7.2 | 0.51 | 15 | 2.9 | 130 |
|       |     |     | Panlongcheng |     |     |     | earthenware |      |     |    |     | Li-2 |      |    |     |      |    |     |     |
|       | 9.5 | 12  | 0.081        | 3.5 | 13  | 100 | 6.2         | 1.7  | 4.8 | 46 | 460 | 0.52 | 77   | 17 | 8.1 | 0.59 | 17 | 3.3 | 120 |

|       |     |     |            |     |     |     |             |      |     |    |     |       |     |    |     |      |    |     |     |  |  |
|-------|-----|-----|------------|-----|-----|-----|-------------|------|-----|----|-----|-------|-----|----|-----|------|----|-----|-----|--|--|
| F83TL |     |     | Tonggushan |     |     |     | earthenware |      |     |    |     | Gum   |     |    |     |      |    |     |     |  |  |
|       | 1.6 | 5.5 | 0.098      | 9.2 | 4.1 | 71  | 6.2         | 1.2  | 2   | 36 | 200 | 0.66  | 98  | 12 | 5.5 | 0.47 | 13 | 3.4 | 72  |  |  |
| F85TL |     |     | Tonggushan |     |     |     | earthenware |      |     |    |     | Hu    |     |    |     |      |    |     |     |  |  |
|       | 8.7 | 23  | 0.14       | 7.9 | 6.7 | 110 | 8.8         | 1.3  | 3   | 42 | 80  | 0.59  | 110 | 16 | 6.8 | 0.44 | 16 | 3.5 | 120 |  |  |
| F87TL |     |     | Tonggushan |     |     |     | earthenware |      |     |    |     | Hu    |     |    |     |      |    |     |     |  |  |
|       | 8.2 | 18  | 0.13       | 8.3 | 5.5 | 92  | 7.2         | 0.96 | 3.3 | 34 | 140 | 0.48  | 95  | 14 | 5.3 | 0.5  | 16 | 3.8 | 100 |  |  |
| F88TZ |     |     | Tonggushan |     |     |     | earthenware |      |     |    |     | ?     |     |    |     |      |    |     |     |  |  |
|       | 11  | 15  | 0.078      | 6.4 | 1.6 | 96  | 6.7         | 0.79 | 4.4 | 33 | 130 | 0.12  | 70  | 17 | 5.1 | 0.44 | 18 | 3.9 | 120 |  |  |
| 032WT |     |     | Wucheng    |     |     |     | earthenware |      |     |    |     | ?     |     |    |     |      |    |     |     |  |  |
|       | 7   | 2.6 | 0.046      | 11  | 4.8 | 160 | 6.6         | 1    | 2.4 | 33 | 50  | 0.3   | 83  | 14 | 4.3 | 0.61 | 17 | 8.4 | 120 |  |  |
| 039WT |     |     | Wucheng    |     |     |     | earthenware |      |     |    |     | Gum   |     |    |     |      |    |     |     |  |  |
|       | 9.5 | 3.5 | 0.05       | 1.2 | 4.1 | 60  | 61          | 1    | 1.3 | 55 | 140 | 0.17  | 210 | 14 | 6.7 | 0.6  | 23 | 4.5 | 76  |  |  |
| 049WT |     |     | Wucheng    |     |     |     | earthenware |      |     |    |     | Li    |     |    |     |      |    |     |     |  |  |
|       | 10  | 26  | 0.039      | 2.4 | 8.2 | 130 | 24          | 0.98 | 5.9 | 44 | 110 | 0.057 | 150 | 18 | 5.7 | 0.56 | 26 | 5   | 100 |  |  |
| 052WT |     |     | Wucheng    |     |     |     | earthenware |      |     |    |     | Gum   |     |    |     |      |    |     |     |  |  |
|       | 11  | 2.8 | 0.024      | 1.2 | 11  | 160 | 5.2         | 1.2  | 1.6 | 51 | 74  | 0.073 | 42  | 20 | 1.6 | 1.1  | 28 | 6.5 | 100 |  |  |
| 075WT |     |     | Wucheng    |     |     |     | earthenware |      |     |    |     | Zun   |     |    |     |      |    |     |     |  |  |
|       | 10  | 9.9 | 0.038      | 3.5 | 11  | 110 | 17          | 1.2  | 4.3 | 54 | 98  | 0.19  | 82  | 18 | 8   | 0.74 | 24 | 5.8 | 110 |  |  |
| 006ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Peng  |     |    |     |      |    |     |     |  |  |
|       | 5.5 | 10  | 0.071      | 11  | 17  | 100 | 13          | 1.8  | 4.3 | 43 | 570 | 1.1   | 130 | 16 | 8.1 | 0.34 | 17 | 2.7 | 75  |  |  |
| 008ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Gui   |     |    |     |      |    |     |     |  |  |
|       | 5.5 | 15  | 0.073      | 17  | 18  | 110 | 14          | 2.5  | 4.4 | 45 | 610 | 1.1   | 140 | 16 | 84  | 0.39 | 18 | 2.7 | 77  |  |  |
| 014ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Li    |     |    |     |      |    |     |     |  |  |
|       | 7.9 | 16  | 0.052      | 10  | 14  | 86  | 7.7         | 0.97 | 3.8 | 36 | 550 | 0.53  | 120 | 13 | 5.6 | 0.5  | 16 | 3   | 110 |  |  |
| 015ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Gang  |     |    |     |      |    |     |     |  |  |
|       | 11  | 11  | 0.056      | 7.4 | 15  | 100 | 11          | 1.4  | 3.3 | 49 | 210 | 0.33  | 160 | 16 | 7.6 | 0.6  | 19 | 4.5 | 110 |  |  |
| 016ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Peng  |     |    |     |      |    |     |     |  |  |
|       | 9   | 15  | 0.066      | 22  | 17  | 87  | 11          | 1.4  | 4.7 | 45 | 950 | 0.95  | 180 | 17 | 1.2 | 0.49 | 18 | 2.6 | 130 |  |  |
| 042ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Weng  |     |    |     |      |    |     |     |  |  |
|       | 8.1 | 11  | 0.07       | 27  | 16  | 78  | 11          | 1.3  | 4.3 | 44 | 950 | 1     | 150 | 16 | 1.2 | 0.49 | 17 | 2.6 | 100 |  |  |
| 044ZZ |     |     | Zhengzhou  |     |     |     | earthenware |      |     |    |     | Ding  |     |    |     |      |    |     |     |  |  |



|       |     |     |           |     |     |    |                |     |     |    |      |          |     |    |     |      |    |     |     |
|-------|-----|-----|-----------|-----|-----|----|----------------|-----|-----|----|------|----------|-----|----|-----|------|----|-----|-----|
|       | 7.7 | 19  | 0.071     | 19  | 16  | 72 | 8.4            | 1.3 | 3.8 | 41 | 710  | 1.1      | 140 | 15 | 6.6 | 0.41 | 15 | 1.1 | 95  |
| F51ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 9.6 | 15  | 0.067     | 19  | 20  | 84 | 12             | 1.5 | 5.1 | 48 | 820  | 0.85     | 180 | 19 | 7.3 | 0.46 | 19 | 2.3 | 130 |
| F52ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 8.1 | 26  | 0.068     | 12  | 17  | 71 | 9.4            | 1.4 | 4.3 | 44 | 1000 | 1.1      | 150 | 15 | 6.8 | 0.46 | 16 | 2.3 | 99  |
| F53ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 8.1 | 28  | 0.092     | 20  | 18  | 76 | 8.9            | 1.5 | 4.7 | 42 | 870  | 0.97     | 140 | 16 | 6.6 | 0.37 | 16 | 2.1 | 120 |
| F54ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Li       |     |    |     |      |    |     |     |
|       | 8.8 | 8.1 | 0.07      | 15  | 17  | 74 | 9.5            | 1.4 | 4.3 | 43 | 660  | 1.2      | 160 | 15 | 6.5 | 0.44 | 16 | 2.2 | 100 |
| F55ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 9.4 | 14  | 0.071     | 20  | 18  | 82 | 11             | 1.3 | 4.8 | 44 | 950  | 0.98     | 160 | 17 | 6.9 | 0.46 | 17 | 2.4 | 120 |
| F56ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Gufupan  |     |    |     |      |    |     |     |
|       | 8.6 | 14  | 0.069     | 13  | 18  | 86 | 11             | 1.3 | 4.8 | 45 | 720  | 0.99     | 150 | 17 | 7.1 | 0.41 | 17 | 2.5 | 110 |
| F57ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Jiafudou |     |    |     |      |    |     |     |
|       | 7.7 | 17  | 0.071     | 21  | 16  | 76 | 9.8            | 1.5 | 4.4 | 42 | 650  | 1.1      | 150 | 16 | 6.7 | 0.43 | 15 | 3.6 | 110 |
| F58ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Ymnfugmn |     |    |     |      |    |     |     |
|       | 8.1 | 11  | 0.07      | 19  | 17  | 71 | 10             | 1.4 | 4.3 | 41 | 690  | 43467    | 140 | 15 | 6.6 | 0.46 | 15 | 3.2 | 100 |
| F59ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | ?        |     |    |     |      |    |     |     |
|       | 9.1 | 23  | 0.069     | 21  | 18  | 76 | 12             | 1.5 | 4.7 | 41 | 600  | 0.91     | 180 | 17 | 6.4 | 0.39 | 16 | 3.1 | 120 |
| F61ZZ |     |     | Zhengzhou |     |     |    | earthenware    |     |     |    |      | Weng     |     |    |     |      |    |     |     |
|       | 8   | 23  | 0.082     | 26  | 16  | 68 | 9.4            | 1.3 | 4.3 | 40 | 630  | 0.91     | 160 | 15 | 6.2 | 0.5  | 15 | 2.5 | 120 |
| 082JY |     |     | Jingnansi |     |     |    | protoporcelain |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 8.8 | 3.6 | 0.052     | 2.9 | 4.6 | 79 | 10             | 1.4 | 1.5 | 47 | 95   | 0.41     | 140 | 15 | 7.1 | 0.93 | 16 | 3.9 | 86  |
| 083JY |     |     | Jingnansi |     |     |    | protoporcelain |     |     |    |      | Zun      |     |    |     |      |    |     |     |
|       | 10  | 2.8 | 0.072     | 11  | 12  | 87 | 10             | 1.6 | 1.1 | 53 | 170  | 0.21     | 120 | 19 | 8.8 | 0.78 | 18 | 4.4 | 110 |
| 090JY |     |     | Jingnansi |     |     |    | protoporcelain |     |     |    |      | Hu       |     |    |     |      |    |     |     |
|       | 9.6 | 3.1 | 0.058     | 7   | 8.2 | 80 | 18             | 1.7 | 2.6 | 56 | 140  | 0.3      | 130 | 19 | 9.2 | 0.54 | 18 | 4.4 | 110 |
| F45JY |     |     | Jingnansi |     |     |    | protoporcelain |     |     |    |      | ?        |     |    |     |      |    |     |     |
|       | 8.9 | 4.8 | 0.061     | 1.9 | 14  | 74 | 11             | 1.6 | 3.5 | 41 | 240  | 0.41     | 150 | 16 | 6.7 | 0.39 | 16 | 4.3 | 110 |
| F46JY |     |     | Jingnansi |     |     |    | protoporcelain |     |     |    |      | ?        |     |    |     |      |    |     |     |
|       | 8.9 | 4.1 | 0.058     | 2.9 | 11  | 68 | 13             | 1.9 | 21  | 46 | 180  | 0.75     | 130 | 17 | 7.7 | 0.39 | 15 | 4.2 | 90  |

|       |     |     |              |      |     |     |                |     |     |    |     |        |     |     |     |      |    |     |     |
|-------|-----|-----|--------------|------|-----|-----|----------------|-----|-----|----|-----|--------|-----|-----|-----|------|----|-----|-----|
| F47JY |     |     | Jingnansi    |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 7.7 | 4.6 | 0.063        | 2.8  | 10  | 86  | 9.4            | 1.4 | 2.5 | 48 | 180 | 0.21   | 82  | 13  | 6.6 | 0.59 | 15 | 4.7 | 80  |
| F48JY |     |     | Jingnansi    |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 9.6 | 3.5 | 0.057        | 0.72 | 9   | 79  | 17             | 1.9 | 2.6 | 53 | 130 | 0.3    | 130 | 19  | 8.9 | 0.48 | 17 | 4.5 | 110 |
| F49JY |     |     | Jingnansi    |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 10  | 2.9 | 0.055        | 1.7  | 8.5 | 78  | 16             | 1.9 | 2.5 | 54 | 130 | 0.3    | 150 | 19  | 8.7 | 0.55 | 17 | 3.5 | 120 |
| F50JY |     |     | Jingnansi    |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 8.4 | 2.5 | 0.053        | 1.5  | 8.9 | 74  | 16             | 1.6 | 2.5 | 54 | 120 | 0.3    | 140 | 19  | 8.6 | 0.53 | 17 | 3.7 | 110 |
| 091PY |     |     | Panlongcheng |      |     |     | protoporcelain |     |     |    |     | Weng   |     |     |     |      |    |     |     |
|       | 12  | 5.2 | 0.082        | 1.3  | 21  | 110 | 18             | 2   | 31  | 61 | 480 | 0.51   | 150 | 22  | 10  | 0.55 | 22 | 4.6 | 140 |
| F66PY |     |     | Panlongcheng |      |     |     | protoporcelain |     |     |    |     | Zun    |     |     |     |      |    |     |     |
|       | 8.7 | 6.1 | 0.046        | 0.89 | 3.9 | 110 | 5.2            | 1   | 2.3 | 37 | 60  | 13     | 45  | 16  | 5.2 | 0.81 | 18 | 3.8 | 110 |
| F67PY |     |     | Panlongcheng |      |     |     | protoporcelain |     |     |    |     | Weng   |     |     |     |      |    |     |     |
|       | 8.5 | 3.8 | 0.06         | 1.4  | 9.8 | 78  | 13             | 1.5 | 2.4 | 46 | 400 | 0.38   | 150 | 17  | 7.5 | 0.51 | 16 | 3.8 | 100 |
| F70PY |     |     | Panlongcheng |      |     |     | protoporcelain |     |     |    |     | Weng   |     |     |     |      |    |     |     |
|       | 12  | 3.8 | 0.054        | 2.3  | 13  | 120 | 12             | 1.5 | 4.5 | 51 | 440 | 0.2    | 140 | 22  | 7.7 | 0.58 | 20 | 3.7 | 140 |
| F84TY |     |     | Tonggushan   |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 9.7 | 3.8 | 0.056        | 1.9  | 4.9 | 87  | 10             | 1.6 | 2   | 52 | 80  | 1.7    | 110 | 17  | 8   | 0.63 | 18 | 3.7 | 84  |
| F89TY |     |     | Tonggushan   |      |     |     | protoporcelain |     |     |    |     | LI     |     |     |     |      |    |     |     |
|       | 10  | 2.3 | 0.087        | 5.5  | 6.2 | 25  | 15             | 1.2 | 2   | 48 | 220 | 0.48   | 130 | 7.9 | 5.5 | 0.36 | 20 | 3.8 | 67  |
| F90TY |     |     | Tonggushan   |      |     |     | protoporcelain |     |     |    |     | Zun    |     |     |     |      |    |     |     |
|       | 7.9 | 1.2 | 0.059        | 0.79 | 3.9 | 70  | 61             | 1.2 | 1.2 | 51 | 60  | 18     | 63  | 14  | 6.6 | 0.6  | 24 | 4.9 | 56  |
| 029WY |     |     | Wucheng      |      |     |     | protoporcelain |     |     |    |     | Yu     |     |     |     |      |    |     |     |
|       | 11  | 2.6 | 0.045        | 2.7  | 7.8 | 96  | 11             | 1.7 | 2.6 | 60 | 240 | 0.095  | 110 | 20  | 6.6 | 0.57 | 25 | 6.3 | 110 |
| 030WY |     |     | Wucheng      |      |     |     | protoporcelain |     |     |    |     | Xiaobo |     |     |     |      |    |     |     |
|       | 8.1 | 2.6 | 0.042        | 11   | 9.1 | 170 | 8.1            | 1.5 | 21  | 46 | 130 | 0.44   | 77  | 17  | 7.1 | 0.66 | 19 | 4.1 | 110 |
| 035WY |     |     | Wucheng      |      |     |     | protoporcelain |     |     |    |     | Guan   |     |     |     |      |    |     |     |
|       | 7.9 | 2.6 | 0.024        | 2    | 5.9 | 94  | 43592          | 11  | 1.5 | 45 | 77  | 13     | 62  | 15  | 6.4 | 1    | 20 | 3.5 | 110 |
| 040WY |     |     | Wucheng      |      |     |     | protoporcelain |     |     |    |     | ?      |     |     |     |      |    |     |     |
|       | 11  | 4.3 | 0.062        | 3.3  | 18  | 74  | 18             | 1.4 | 3.9 | 55 | 380 | 0.18   | 230 | 16  | 7.8 | 0.65 | 25 | 5   | 120 |
| 050WY |     |     | Wucheng      |      |     |     | protoporcelain |     |     |    |     | Guan   |     |     |     |      |    |     |     |

|       |     |     |           |      |     |     |                |      |     |     |     |       |     |     |      |      |    |     |     |
|-------|-----|-----|-----------|------|-----|-----|----------------|------|-----|-----|-----|-------|-----|-----|------|------|----|-----|-----|
| 051WY | 8.5 | 4.8 | 0.027     | 1    | 41  | 90  | 13             | 1.2  | 1.7 | 48  | 120 | 0.081 | 97  | 15  | 6.3  | 0.77 | 23 | 5.2 | 83  |
|       |     |     | Wucheng   |      |     |     | protoporcelain |      |     |     |     | Guan  |     |     |      |      |    |     |     |
| 080WY | 8.6 | 7.1 | 0.015     | 1.6  | 9.8 | 130 | 4.5            | 0.55 | 4   | 22  | 130 | 0-23  | 93  | 16  | 3.6  | 0.69 | 21 | 4.1 | 120 |
|       |     |     | Wucheng   |      |     |     | protoporcelain |      |     |     |     | Qigai |     |     |      |      |    |     |     |
| 084WY | 11  | 3.2 | 0.055     | 21   | 7.5 | 61  | 11             | 2.2  | 5.4 | 140 | 12  | 0.09  | 15  | 7.4 | 0.66 | 2.2  | 4  | 7.6 |     |
|       |     |     | Wucheng   |      |     |     | protoporcelain |      |     |     |     | Guan  |     |     |      |      |    |     |     |
| 085WY | 12  | 6.9 | 0.041     | 0.96 | 8.9 | 170 | 11             | 1.7  | 2.6 | 63  | 160 | 0.31  | 94  | 20  | 7.8  | 1    | 24 | 6.7 | 130 |
|       |     |     | Wucheng   |      |     |     | protoporcelain |      |     |     |     | Guan  |     |     |      |      |    |     |     |
| 089WY | 9   | 2.7 | 0.034     | 1.2  | 6.8 | 97  | 9.3            | 11   | 1.9 | 36  | 100 | 0.088 | 87  | 16  | 5.6  | 1.2  | 24 | 4.4 | 53  |
|       |     |     | Wucheng   |      |     |     | protoporcelain |      |     |     |     | Zun   |     |     |      |      |    |     |     |
| 007ZY | 11  | 6.6 | 0.059     | 3.6  | 8.4 | 110 | 12             | 2    | 2.6 | 63  | 180 | 0.34  | 93  | 22  | 9    | 0.52 | 20 | 4.7 | 100 |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | ?     |     |     |      |      |    |     |     |
| 013ZY | 5   | 4.1 | 0.045     | 0.96 | 5   | 73  | 14             | 1.7  | 1.1 | 51  | 57  | 0.16  | 110 | 12  | 7    | 0.41 | 21 | 4.4 | 52  |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | ?     |     |     |      |      |    |     |     |
| 041ZY | 8.1 | 3.5 | 0.031     | 2.7  | 3.7 | 63  | 11             | 11   | 1.8 | 48  | 160 | 0.17  | 110 | 11  | 6.8  | 0.65 | 14 | 3.5 | 95  |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | Zun   |     |     |      |      |    |     |     |
| 043ZY | 7.6 | 3.6 | 0.043     | 2.3  | 6.2 | 73  | 18             | 1.2  | 1.8 | 45  | 140 | 0.28  | 180 | 15  | 6.3  | 0.46 | 16 | 3.5 | 87  |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | Zun   |     |     |      |      |    |     |     |
| 088ZY | 7.3 | 2.6 | 0.051     | 2.5  | 5.4 | 62  | 21             | 1.2  | 1.5 | 43  | 120 | 0.17  | 190 | 13  | 6.3  | 0.41 | 14 | 3.2 | 68  |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | Zun   |     |     |      |      |    |     |     |
| F62ZY | 8.9 | 3.5 | 0.036     | 2.6  | 51  | 89  | 12             | 1.2  | 2.3 | 44  | 110 | 0.095 | 92  | 15  | 6.2  | 1.1  | 17 | 3.7 | 120 |
|       |     |     | Zhengzhou |      |     |     | protoporcelain |      |     |     |     | ?     |     |     |      |      |    |     |     |
|       | 7.9 | 2.7 | 0.036     | 1.5  | 61  | 77  | 13             | 1.2  | 2.2 | 43  | 90  | 0.094 | 98  | 15  | 5.9  | 0.56 | 17 | 4.6 | 110 |

## Data file S4

**Table 1 LA-ICP-MS analysis of the glass chemical composition (major elements %)**

| Type      |              | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | CaO  | TiO <sub>2</sub> | MnO  | FeO  |
|-----------|--------------|-------------------|------|--------------------------------|------------------|-------------------------------|------------------|------|------------------|------|------|
| weathered | GMG-19       | 0.16              | 0.18 | 3.41                           | 87.82            | 0.17                          | 3.31             | 0.57 | 0.11             | 0.02 | 0.38 |
| m-K       | 2011M5GMG-26 | 2.20              | 3.53 | 2.77                           | 60.60            | 1.20                          | 15.81            | 5.85 | 0.62             | 0.19 | 3.51 |
| weathered | GMG-18       | 0.12              | 0.25 | 3.82                           | 87.45            | 0.18                          | 3.02             | 1.30 | 0.03             | 0.04 | 0.31 |
| m-K       | GMG-21       | 1.46              | 3.73 | 3.06                           | 59.60            | 1.38                          | 17.30            | 6.88 | 0.59             | 0.16 | 2.20 |
| m-K       | 5.29548-J    | 0.75              | 0.77 | 2.86                           | 70.95            | 0.26                          | 13.66            | 5.78 | 0.19             | 0.13 | 0.98 |
| m-K       | GMG-22       | 1.44              | 3.64 | 2.98                           | 59.20            | 1.42                          | 18.30            | 6.69 | 0.59             | 0.16 | 2.12 |
| weathered | GMG-23       | 0.02              | 0.39 | 2.93                           | 88.86            | 0.29                          | 1.82             | 1.96 | 0.11             | 0.09 | 0.52 |
| m-K       | 5.39316-B    | 0.99              | 0.79 | 2.07                           | 69.75            | 0.28                          | 14.52            | 3.52 | 0.12             | 0.11 | 0.64 |
| m-K       | 5.39316-J    | 1.49              | 0.76 | 2.02                           | 68.44            | 0.39                          | 13.88            | 5.03 | 0.13             | 0.11 | 0.73 |
| m-K       | GMG-10       | 0.75              | 0.24 | 3.33                           | 78.85            | 0.14                          | 12.65            | 1.09 | 0.04             | 0.03 | 0.28 |
| weathered | GMG-20       | 0.02              | 0.21 | 2.08                           | 91.03            | 0.30                          | 1.69             | 0.76 | 0.05             | 0.90 | 0.38 |
| m-K       | GMG-13       | 0.51              | 0.20 | 2.92                           | 77.90            | 0.18                          | 14.47            | 1.03 | 0.03             | 0.02 | 0.22 |
| m-K       | GMG-14       | 0.60              | 0.23 | 3.13                           | 74.35            | 0.16                          | 17.43            | 1.16 | 0.04             | 0.03 | 0.36 |
| weathered | GMG-11       | 0.10              | 0.38 | 1.55                           | 86.65            | 0.17                          | 6.59             | 1.61 | 0.07             | 0.07 | 0.37 |
| m-K       | 5.29461-J    | 0.61              | 0.97 | 2.66                           | 69.67            | 0.70                          | 16.08            | 5.27 | 0.18             | 0.11 | 0.91 |
| m-K       | 5.29340-2    | 0.57              | 0.99 | 2.50                           | 72.08            | 0.44                          | 15.68            | 3.87 | 0.18             | 0.11 | 0.83 |
| m-K       | GMG-12       | 0.25              | 0.23 | 3.41                           | 76.19            | 0.12                          | 15.29            | 0.94 | 0.10             | 0.78 | 0.42 |
| m-K       | GMG-16       | 0.29              | 0.21 | 3.16                           | 70.05            | 0.13                          | 21.76            | 0.87 | 0.10             | 0.74 | 0.43 |
| m-K       | GMG-15       | 0.36              | 0.24 | 3.52                           | 72.20            | 0.13                          | 19.38            | 1.10 | 0.09             | 0.13 | 0.46 |
| m-K       | 5.29340-1    | 0.46              | 0.92 | 2.20                           | 72.04            | 0.31                          | 15.17            | 5.28 | 0.16             | 0.12 | 0.91 |

|           |              |      |      |      |       |      |       |      |      |      |      |
|-----------|--------------|------|------|------|-------|------|-------|------|------|------|------|
| m-K       | GMG-17       | 0.31 | 0.31 | 3.85 | 73.18 | 0.13 | 17.97 | 1.33 | 0.11 | 0.13 | 0.56 |
| m-K       | 5.29340-3    | 0.56 | 1.17 | 2.79 | 66.81 | 0.78 | 17.89 | 6.15 | 0.21 | 0.12 | 0.95 |
| m-K       | 5.29548-W    | 2.55 | 0.93 | 2.49 | 73.82 | 0.30 | 11.34 | 5.55 | 0.15 | 0.10 | 0.74 |
| weathered | GMG-25       | 0.02 | 0.46 | 1.76 | 86.96 | 0.72 | 1.84  | 2.19 | 0.13 | 3.40 | 0.68 |
| m-K       | GMG-1        | 0.05 | 0.31 | 0.76 | 73.65 | 0.80 | 17.00 | 2.67 | 0.04 | 2.21 | 0.26 |
| m-K       | GMG-5        | 0.14 | 0.25 | 0.77 | 74.91 | 0.28 | 16.62 | 2.71 | 0.06 | 1.83 | 0.49 |
| m-K       | GMG-6        | 0.25 | 0.17 | 1.13 | 73.23 | 0.58 | 16.95 | 3.33 | 0.07 | 1.93 | 0.40 |
| m-K       | 2011M5GMG-33 | 0.18 | 0.22 | 1.08 | 70.17 | 0.75 | 18.91 | 1.73 | 0.06 | 3.76 | 0.82 |
| m-K       | 2011M5GMG-35 | 0.21 | 0.25 | 1.08 | 69.80 | 0.90 | 18.73 | 2.27 | 0.06 | 3.79 | 0.65 |
| m-K       | 2011M5GMG-34 | 0.17 | 0.22 | 1.08 | 70.58 | 0.70 | 18.45 | 1.97 | 0.06 | 3.74 | 0.79 |
| m-K       | 2011M5GMG-28 | 0.16 | 0.20 | 1.07 | 69.67 | 0.68 | 19.36 | 2.08 | 0.06 | 3.73 | 0.84 |
| m-K       | 2011M5GMG-37 | 0.16 | 0.22 | 1.08 | 70.87 | 0.66 | 18.37 | 2.01 | 0.06 | 3.71 | 0.69 |
| m-K       | 2011M5GMG-27 | 0.16 | 0.20 | 1.04 | 69.09 | 0.66 | 19.91 | 2.16 | 0.06 | 3.68 | 0.88 |
| m-K       | jzl-08       | 0.20 | 0.21 | 5.41 | 74.99 | 0.10 | 14.68 | 0.27 | 0.25 | 1.49 | 1.45 |
| m-K       | GMG-9        | 0.08 | 0.19 | 1.27 | 76.35 | 0.31 | 13.58 | 1.70 | 0.08 | 4.54 | 0.60 |
| m-K       | 2011M5GMG-36 | 0.11 | 0.18 | 1.03 | 74.63 | 0.38 | 15.74 | 1.65 | 0.06 | 4.35 | 0.62 |
| m-K       | 2011M5GMG-29 | 0.07 | 0.17 | 1.20 | 70.95 | 0.68 | 18.07 | 1.54 | 0.08 | 4.69 | 1.27 |
| m-K       | 2011M5GMG-30 | 0.08 | 0.16 | 1.12 | 71.21 | 0.74 | 17.92 | 1.43 | 0.06 | 4.57 | 1.46 |
| m-K       | 2011M5GMG-38 | 0.20 | 0.12 | 0.91 | 75.32 | 0.23 | 15.99 | 1.43 | 0.04 | 4.27 | 0.40 |
| m-K       | GMG-7        | 0.06 | 0.14 | 0.98 | 77.54 | 0.43 | 13.84 | 1.56 | 0.05 | 4.00 | 0.30 |
| m-K       | GMG-2        | 0.07 | 0.15 | 0.96 | 75.93 | 0.51 | 15.42 | 1.64 | 0.05 | 3.85 | 0.35 |
| m-K       | 2011M5GMG-32 | 0.65 | 0.16 | 0.85 | 74.42 | 0.32 | 17.04 | 1.71 | 0.05 | 3.38 | 0.42 |
| m-K       | 2011M5GMG-31 | 0.08 | 0.12 | 0.88 | 74.62 | 0.32 | 17.46 | 1.04 | 0.04 | 3.87 | 0.47 |
| weathered | GMG-24       | 0.03 | 0.46 | 3.39 | 86.31 | 0.28 | 2.21  | 2.03 | 0.14 | 0.43 | 0.73 |
| m-K       | 2016M1GMG-43 | 0.21 | 0.17 | 2.80 | 50.44 | 0.11 | 12.21 | 0.54 | 0.11 | 0.05 | 0.94 |

|           |              |      |      |      |       |      |       |      |      |      |      |
|-----------|--------------|------|------|------|-------|------|-------|------|------|------|------|
| m-K       | 2016M1GMG-44 | 0.18 | 0.15 | 1.89 | 49.52 | 0.10 | 10.44 | 0.47 | 0.07 | 0.02 | 1.35 |
| m-K       | 2016M1GMG-46 | 0.21 | 0.16 | 1.90 | 53.11 | 0.08 | 11.40 | 0.51 | 0.07 | 0.01 | 1.17 |
| m-K       | 2016M1GMG-47 | 0.16 | 0.13 | 1.66 | 48.31 | 0.07 | 11.55 | 0.48 | 0.06 | 0.01 | 1.27 |
| m-K       | 2016M1GMG-45 | 0.18 | 0.14 | 1.74 | 47.90 | 0.07 | 10.88 | 0.52 | 0.07 | 0.01 | 1.27 |
| weathered | M1ZC-2       | 0.02 | 0.41 | 1.30 | 89.87 | 0.46 | 1.58  | 3.13 | 0.05 | 0.04 | 0.96 |
| weathered | GMG-3        | 0.07 | 0.53 | 2.31 | 89.02 | 0.35 | 1.63  | 2.60 | 0.15 | 0.13 | 1.35 |
| weathered | M1ZC-1       | 0.17 | 0.24 | 2.16 | 80.80 | 0.29 | 12.15 | 1.43 | 0.04 | 0.01 | 0.97 |
| weathered | SJM1S-3      | 0.02 | 0.49 | 2.59 | 89.78 | 0.40 | 2.13  | 2.09 | 0.13 | 0.02 | 0.86 |
| weathered | GMG-8        | 0.08 | 0.68 | 3.82 | 86.94 | 0.41 | 1.66  | 3.26 | 0.22 | 0.26 | 1.35 |
| m-K       | SM24-11-1    | 0.12 | 0.22 | 1.74 | 77.25 | 0.24 | 16.22 | 1.75 | 0.07 | 0.02 | 1.09 |
| weathered | SJM6-31-2    | 0.02 | 0.51 | 2.38 | 90.34 | 0.57 | 1.28  | 3.06 | 0.09 | 0.02 | 0.82 |
| m-K       | GMG-4        | 2.04 | 0.62 | 3.98 | 75.66 | 0.33 | 12.36 | 2.38 | 0.23 | 0.15 | 1.30 |
| m-K       | jzl-15       | 0.46 | 0.37 | 3.50 | 75.65 | 0.12 | 15.87 | 0.82 | 0.10 | 1.43 | 0.64 |
| m-K       | jzl-04       | 0.43 | 0.37 | 3.53 | 76.20 | 0.12 | 15.02 | 0.94 | 0.10 | 1.44 | 0.77 |
| m-K       | 1445         | 0.40 | 0.27 | 4.41 | 75.34 | 0.23 | 15.48 | 0.87 | 0.18 | 1.28 | 0.98 |
| m-K       | jzl-16       | 0.49 | 0.15 | 4.99 | 75.20 | 0.10 | 15.98 | 0.26 | 0.22 | 1.15 | 0.91 |
| m-K       | jzl-26       | 0.16 | 0.48 | 2.67 | 73.37 | 0.41 | 15.66 | 2.24 | 0.27 | 2.41 | 1.62 |
| m-K       | jzl-14       | 0.20 | 0.51 | 2.65 | 70.78 | 0.42 | 17.82 | 2.61 | 0.25 | 2.29 | 1.78 |
| m-K       | jzl-12       | 0.76 | 0.46 | 1.97 | 73.70 | 0.12 | 16.01 | 1.60 | 0.18 | 2.68 | 1.72 |
| m-K       | jzl-11       | 0.55 | 0.15 | 5.13 | 74.46 | 0.09 | 16.65 | 0.23 | 0.22 | 1.02 | 0.98 |
| m-K       | jzl-19       | 0.53 | 0.16 | 5.16 | 74.68 | 0.08 | 16.40 | 0.26 | 0.23 | 1.00 | 1.01 |
| m-K       | jzl-02       | 0.58 | 0.14 | 5.07 | 74.28 | 0.09 | 16.98 | 0.22 | 0.22 | 0.99 | 0.93 |
| m-K       | jzl-18       | 0.58 | 0.14 | 4.92 | 73.91 | 0.11 | 17.52 | 0.26 | 0.22 | 0.97 | 0.88 |
| m-K       | jzl-05       | 0.49 | 0.15 | 5.11 | 74.88 | 0.10 | 16.40 | 0.25 | 0.23 | 1.01 | 0.90 |
| m-K       | jzl-25       | 0.28 | 0.20 | 4.19 | 78.92 | 0.26 | 12.84 | 0.49 | 0.19 | 1.51 | 0.55 |

|           |              |       |      |       |       |      |       |      |      |      |      |
|-----------|--------------|-------|------|-------|-------|------|-------|------|------|------|------|
| m-K       | jzl-13       | 0.17  | 0.62 | 2.92  | 75.56 | 0.19 | 15.31 | 1.86 | 0.13 | 1.53 | 1.24 |
| m-K       | jzl-28       | 0.17  | 0.65 | 2.88  | 75.99 | 0.19 | 15.07 | 2.01 | 0.14 | 1.43 | 1.02 |
| m-K       | 08XYXM18-14  | 0.26  | 0.15 | 4.53  | 76.51 | 0.24 | 15.70 | 0.34 | 0.18 | 0.97 | 0.63 |
| m-K       | jzl-23       | 0.11  | 0.40 | 2.85  | 74.28 | 0.60 | 14.49 | 2.70 | 0.28 | 2.33 | 1.35 |
| m-K       | 2005ZHM3-1   | 0.35  | 0.34 | 2.53  | 76.00 | 0.18 | 13.83 | 2.44 | 0.17 | 1.97 | 1.60 |
| m-K       | 2005ZHM3-2   | 0.36  | 0.30 | 2.50  | 75.90 | 0.20 | 13.97 | 2.27 | 0.17 | 2.07 | 1.71 |
| m-K       | jzl-03       | 0.46  | 0.15 | 4.46  | 76.53 | 0.20 | 15.36 | 0.43 | 0.17 | 0.96 | 0.87 |
| m-K       | jzl-01       | 0.27  | 0.23 | 4.34  | 76.88 | 0.18 | 15.46 | 0.42 | 0.17 | 0.94 | 0.71 |
| m-K       | 2016M1GMG-42 | 0.14  | 0.23 | 5.00  | 77.63 | 0.15 | 13.57 | 0.83 | 0.19 | 0.04 | 1.69 |
| m-K       | 2016M1GMG-39 | 1.24  | 0.16 | 6.17  | 75.98 | 0.08 | 14.47 | 0.80 | 0.04 | 0.02 | 0.74 |
| m-K       | 2016M1GMG-40 | 0.28  | 0.42 | 1.54  | 77.10 | 0.22 | 16.84 | 2.58 | 0.13 | 0.02 | 0.75 |
| m-K       | 2016M1GMG-41 | 0.28  | 0.42 | 1.49  | 77.06 | 0.24 | 16.90 | 2.55 | 0.12 | 0.02 | 0.80 |
| weathered | S13-370-2    | 0.54  | 0.33 | 1.19  | 81.30 | 0.09 | 12.52 | 2.99 | 0.07 | 0.06 | 0.76 |
| m-Na-Al   | 08XYXM18-1   | 14.91 | 1.43 | 6.49  | 69.74 | 0.14 | 1.82  | 1.84 | 0.80 | 0.22 | 2.08 |
| m-Na-Al   | 08XYXM18-10  | 17.71 | 0.30 | 12.92 | 61.99 | 0.05 | 1.37  | 2.87 | 0.39 | 0.03 | 0.87 |
| m-Na-Al   | 08XYXM18-12  | 18.31 | 0.26 | 11.45 | 62.07 | 0.06 | 1.82  | 2.22 | 0.61 | 0.04 | 1.02 |
| m-Na-Al   | 08XYXM18-13  | 18.98 | 0.36 | 13.48 | 59.48 | 0.06 | 1.59  | 2.71 | 0.47 | 0.05 | 1.05 |
| m-Na-Al   | 08XYXM18-15  | 22.13 | 0.26 | 10.74 | 58.79 | 0.09 | 1.62  | 2.28 | 0.50 | 0.04 | 0.99 |
| m-Na-Al   | 08XYXM18-16  | 18.23 | 0.46 | 12.96 | 60.26 | 0.10 | 1.54  | 2.98 | 0.51 | 0.05 | 1.02 |
| m-Na-Al   | 08XYXM18-17  | 16.29 | 0.39 | 12.64 | 61.08 | 0.14 | 2.88  | 2.35 | 0.46 | 0.04 | 0.84 |
| m-Na-Al   | 08XYXM18-18  | 19.01 | 0.31 | 13.43 | 59.53 | 0.10 | 1.63  | 2.79 | 0.32 | 0.04 | 0.93 |
| m-Na-Al   | 08XYXM18-19  | 20.82 | 0.25 | 12.30 | 58.39 | 0.06 | 2.00  | 2.45 | 0.56 | 0.04 | 0.95 |
| m-Na-Al   | 08XYXM18-2   | 16.42 | 0.22 | 10.27 | 67.92 | 0.04 | 1.07  | 1.79 | 0.39 | 0.03 | 0.73 |
| m-Na-Al   | 08XYXM18-20  | 18.33 | 0.45 | 12.20 | 59.61 | 0.13 | 2.22  | 2.54 | 0.48 | 0.06 | 1.07 |
| m-Na-Al   | 08XYXM18-21  | 17.04 | 0.35 | 13.56 | 61.66 | 0.06 | 1.72  | 2.60 | 0.53 | 0.04 | 1.14 |

|         |            |       |      |       |       |      |      |      |      |      |      |
|---------|------------|-------|------|-------|-------|------|------|------|------|------|------|
| m-Na-Al | 08XYXM18-3 | 17.16 | 0.26 | 7.93  | 67.99 | 0.06 | 0.93 | 2.03 | 1.00 | 0.05 | 1.18 |
| m-Na-Al | 08XYXM18-4 | 19.01 | 0.29 | 13.52 | 60.34 | 0.06 | 1.62 | 2.57 | 0.33 | 0.03 | 0.85 |
| m-Na-Al | 08XYXM18-5 | 17.96 | 0.40 | 13.42 | 56.93 | 0.14 | 1.76 | 2.68 | 0.49 | 0.04 | 1.14 |
| m-Na-Al | 08XYXM18-6 | 16.73 | 0.31 | 12.29 | 60.64 | 0.10 | 1.65 | 2.50 | 0.77 | 0.04 | 1.03 |
| m-Na-Al | 08XYXM18-7 | 17.05 | 0.33 | 13.95 | 61.49 | 0.05 | 1.76 | 2.46 | 0.53 | 0.04 | 1.02 |
| m-Na-Al | 08XYXM18-8 | 13.45 | 1.48 | 10.92 | 64.82 | 0.13 | 2.24 | 2.99 | 0.74 | 0.14 | 2.03 |
| m-Na-Al | 08XYXM18-9 | 17.45 | 0.28 | 8.88  | 66.51 | 0.06 | 0.95 | 2.15 | 0.86 | 0.05 | 1.06 |
| m-Na-Al | jzl-09     | 14.96 | 1.58 | 4.63  | 65.18 | 0.67 | 2.65 | 3.63 | 0.24 | 0.08 | 1.09 |
| m-Na-Al | jzl-10     | 15.44 | 1.57 | 4.81  | 66.22 | 0.73 | 2.62 | 3.63 | 0.24 | 0.08 | 1.09 |
| m-Na-Al | jzl-20     | 12.95 | 1.59 | 5.90  | 66.41 | 0.77 | 2.73 | 3.94 | 0.25 | 0.08 | 1.27 |
| m-Na-Al | jzl-21     | 15.25 | 1.53 | 4.40  | 67.49 | 0.83 | 2.58 | 3.60 | 0.24 | 0.08 | 0.98 |
| m-Na-Al | jzl-22     | 14.90 | 1.50 | 4.66  | 67.38 | 0.77 | 2.76 | 3.46 | 0.24 | 0.08 | 1.05 |
| m-Na-Al | jzl-27     | 15.45 | 1.59 | 4.81  | 64.82 | 0.69 | 2.69 | 3.75 | 0.25 | 0.08 | 1.05 |
| m-Na-Al | jzl-29     | 16.48 | 1.62 | 4.76  | 65.22 | 0.75 | 2.37 | 3.59 | 0.24 | 0.08 | 1.03 |
| m-Na-Al | jzl-30     | 15.82 | 1.55 | 4.92  | 66.05 | 0.68 | 2.57 | 3.57 | 0.25 | 0.08 | 1.04 |



**Table 2 LA-ICP-MS analysis of the glass chemical composition (trace elements ppm)**

|              | Sc   | V      | Cr    | Co    | Ni     | Cu       | Zn      | Ga    | Ge   | Rb     | Sr     | Y     | Zr     | Nb    | Mo   | Ag   | Cd   | Sn     | Sb    | Cs   | Ba       |
|--------------|------|--------|-------|-------|--------|----------|---------|-------|------|--------|--------|-------|--------|-------|------|------|------|--------|-------|------|----------|
| GMG-19       | 4.11 | 11.30  | 7.98  | 0.93  | 4.83   | 29741.79 | 27.64   | 2.88  | 0.11 | 442.48 | 17.09  | 6.60  | 114.92 | 3.15  | 0.51 | 2.04 | 0.13 | 7.34   | 1.79  | 5.18 | 44.24    |
| 2011M5GMG-26 | 6.07 | 36.36  | 21.87 | 72.95 | 161.66 | 27073.35 | 83.10   | 3.96  | 0.44 | 104.53 | 198.19 | 8.88  | 222.34 | 9.27  | 3.33 | 0.87 | 0.14 | 14.35  | 1.00  | 0.61 | 901.00   |
| GMG-18       | 5.58 | 13.20  | 3.42  | 1.22  | 6.78   | 26622.35 | 27.11   | 7.38  | 0.23 | 416.32 | 45.85  | 9.79  | 16.86  | 11.69 | 0.87 | 7.78 | 0.14 | 7.21   | 0.39  | 4.79 | 75.68    |
| GMG-21       | 7.19 | 38.74  | 25.63 | 51.54 | 170.56 | 26451.45 | 121.59  | 3.97  | 0.36 | 136.01 | 210.30 | 10.29 | 172.85 | 8.76  | 6.94 | 0.97 | 0.04 | 3.87   | 0.18  | 0.65 | 1008.32  |
| 5.29548-J    | 7.09 | 525.77 | 35.05 | 4.96  | 46.90  | 25750.93 | 499.09  | 43.01 | 8.86 | 136.33 | 273.20 | 32.96 | 70.28  | 3.68  | 2.98 | 2.18 | 0.65 | 179.46 | 2.86  | 2.99 | 977.42   |
| GMG-22       | 6.08 | 39.37  | 22.01 | 53.94 | 179.45 | 24981.24 | 130.29  | 4.09  | 0.56 | 135.02 | 203.95 | 9.90  | 158.37 | 10.01 | 6.88 | 0.78 | 0.00 | 3.14   | 0.09  | 0.27 | 1003.79  |
| GMG-23       | 3.11 | 16.65  | 9.48  | 1.73  | 8.80   | 22831.91 | 41.01   | 3.37  | 0.19 | 287.47 | 56.28  | 6.60  | 85.51  | 3.21  | 0.67 | 4.82 | 0.00 | 48.38  | 2.05  | 5.09 | 81.62    |
| 5.39316-B    | 5.17 | 339.42 | 19.58 | 5.43  | 47.20  | 21995.49 | 1089.98 | 32.07 | 3.71 | 154.54 | 752.94 | 18.16 | 69.83  | 3.04  | 1.56 | 1.81 | 0.84 | 622.02 | 2.49  | 2.70 | 35581.48 |
| 5.39316-J    | 4.71 | 330.37 | 27.38 | 5.58  | 44.54  | 21297.09 | 1051.17 | 30.84 | 4.82 | 153.21 | 736.71 | 18.18 | 71.44  | 2.79  | 2.32 | 3.12 | 0.44 | 627.71 | 2.14  | 3.49 | 34621.78 |
| GMG-10       | 4.80 | 13.51  | 3.25  | 1.06  | 4.96   | 19864.64 | 19.32   | 5.48  | 0.00 | 374.51 | 35.03  | 7.06  | 20.37  | 11.57 | 0.18 | 7.44 | 0.00 | 10.03  | 10.87 | 3.71 | 66.96    |
| GMG-20       | 4.50 | 12.14  | 3.69  | 11.37 | 8.53   | 19483.35 | 47.42   | 2.08  | 0.44 | 286.94 | 30.58  | 3.43  | 23.17  | 1.14  | 1.19 | 0.58 | 0.12 | 28.84  | 0.69  | 2.49 | 401.12   |
| GMG-13       | 3.70 | 11.10  | 3.21  | 0.48  | 6.33   | 19338.21 | 27.58   | 4.97  | 0.51 | 335.22 | 25.91  | 5.07  | 15.96  | 9.91  | 0.15 | 7.98 | 0.00 | 8.68   | 8.49  | 3.42 | 45.24    |
| GMG-14       | 5.29 | 14.74  | 5.70  | 0.92  | 5.41   | 19230.88 | 23.49   | 4.92  | 0.26 | 375.34 | 35.02  | 5.93  | 22.38  | 10.47 | 0.32 | 7.76 | 0.00 | 13.28  | 6.73  | 3.95 | 65.57    |
| GMG-11       | 4.24 | 18.16  | 5.59  | 1.64  | 4.93   | 18452.85 | 26.49   | 2.14  | 0.00 | 345.20 | 45.97  | 3.08  | 40.25  | 2.12  | 0.31 | 4.14 | 0.20 | 66.20  | 1.75  | 1.90 | 90.11    |
| 5.29461-J    | 6.58 | 399.00 | 35.33 | 6.41  | 43.29  | 17377.65 | 2062.33 | 36.99 | 4.06 | 154.47 | 228.13 | 22.25 | 78.85  | 4.44  | 6.43 | 3.51 | 1.10 | 371.32 | 2.70  | 3.11 | 1298.63  |
| 5.29340-2    | 3.11 | 388.41 | 5.01  | 4.66  | 42.51  | 16943.52 | 401.59  | 23.51 | 2.72 | 141.91 | 176.88 | 20.46 | 85.02  | 3.95  | 0.79 | 8.17 | 0.00 | 264.57 | 1.68  | 2.47 | 1248.33  |
| GMG-12       | 4.86 | 16.16  | 11.19 | 10.28 | 13.20  | 16503.79 | 28.52   | 2.33  | 0.14 | 346.49 | 34.32  | 6.41  | 92.65  | 3.13  | 0.32 | 1.57 | 0.09 | 129.59 | 3.93  | 2.43 | 373.38   |
| GMG-16       | 4.13 | 15.37  | 8.35  | 9.93  | 10.75  | 16359.29 | 23.24   | 3.17  | 0.29 | 361.41 | 32.12  | 6.95  | 86.09  | 3.00  | 0.18 | 1.56 | 0.00 | 154.17 | 2.92  | 2.82 | 369.77   |
| GMG-15       | 4.33 | 14.18  | 4.37  | 4.83  | 7.23   | 16061.84 | 25.45   | 3.68  | 0.01 | 368.73 | 33.29  | 5.81  | 71.59  | 3.87  | 0.33 | 7.30 | 0.00 | 362.53 | 50.53 | 3.46 | 237.20   |
| 5.29340-1    | 5.96 | 441.77 | 31.85 | 4.40  | 40.91  | 15086.82 | 393.10  | 11.10 | 0.00 | 136.58 | 180.15 | 24.57 | 75.07  | 3.44  | 3.56 | 5.55 | 0.01 | 187.70 | 3.72  | 2.98 | 1009.68  |
| GMG-17       | 3.99 | 16.05  | 13.18 | 4.72  | 10.89  | 14125.56 | 30.82   | 4.20  | 0.10 | 367.64 | 41.97  | 7.03  | 86.39  | 4.99  | 0.40 | 5.95 | 0.04 | 339.18 | 44.80 | 3.33 | 228.99   |
| 5.29340-3    | 5.67 | 453.64 | 36.93 | 5.87  | 52.69  | 12557.69 | 2275.89 | 41.59 | 3.93 | 184.35 | 250.61 | 24.49 | 84.67  | 4.66  | 5.71 | 2.67 | 0.00 | 979.82 | 6.52  | 3.42 | 862.90   |
| 5.29548-W    | 6.48 | 377.92 | 28.54 | 3.73  | 39.18  | 12234.24 | 922.43  | 31.93 | 1.44 | 116.38 | 286.07 | 19.89 | 78.47  | 3.36  | 2.80 | 1.83 | 0.33 | 410.29 | 1.47  | 2.30 | 1096.18  |

|              |       |       |        |        |       |          |       |      |      |        |        |       |        |      |       |       |      |          |       |      |          |
|--------------|-------|-------|--------|--------|-------|----------|-------|------|------|--------|--------|-------|--------|------|-------|-------|------|----------|-------|------|----------|
| GMG-25       | 5.52  | 13.19 | 25.88  | 37.26  | 20.82 | 11153.07 | 63.06 | 3.83 | 0.09 | 164.25 | 102.65 | 11.15 | 146.06 | 2.11 | 0.62  | 0.33  | 0.03 | 60.40    | 3.01  | 1.56 | 2976.92  |
| GMG-1        | 3.61  | 10.27 | 4.54   | 115.52 | 25.82 | 12849.38 | 37.53 | 1.68 | 0.15 | 55.28  | 75.20  | 2.95  | 30.02  | 0.98 | 9.06  | 1.57  | 0.20 | 144.15   | 6.87  | 0.37 | 4803.53  |
| GMG-5        | 4.73  | 14.21 | 6.47   | 72.84  | 24.21 | 10933.11 | 29.01 | 3.01 | 0.37 | 71.77  | 70.12  | 3.29  | 31.08  | 2.81 | 9.31  | 0.76  | 0.01 | 23.91    | 6.06  | 0.00 | 4263.77  |
| GMG-6        | 5.59  | 10.08 | 9.11   | 81.91  | 23.06 | 9659.89  | 23.77 | 2.52 | 0.12 | 86.53  | 106.36 | 3.32  | 27.91  | 1.82 | 9.77  | 2.00  | 0.02 | 895.53   | 5.04  | 0.47 | 4801.32  |
| 2011M5GMG-33 | 5.10  | 24.71 | 5.41   | 162.02 | 14.83 | 9458.57  | 39.65 | 2.56 | 0.31 | 65.49  | 61.06  | 4.20  | 27.63  | 1.08 | 18.15 | 1.49  | 0.00 | 5.95     | 8.68  | 0.69 | 9070.14  |
| 2011M5GMG-35 | 5.73  | 19.09 | 4.73   | 162.83 | 18.90 | 9347.38  | 34.36 | 3.36 | 0.11 | 63.18  | 64.03  | 3.80  | 24.44  | 0.93 | 26.20 | 1.57  | 0.08 | 5.75     | 4.77  | 0.12 | 8808.09  |
| 2011M5GMG-34 | 5.16  | 23.31 | 2.84   | 167.95 | 16.65 | 9199.71  | 33.53 | 2.99 | 0.39 | 62.62  | 58.82  | 3.62  | 27.96  | 1.06 | 18.03 | 1.52  | 0.23 | 4.82     | 8.89  | 0.73 | 8773.76  |
| 2011M5GMG-28 | 5.15  | 23.74 | 2.94   | 161.87 | 16.78 | 8939.50  | 34.02 | 3.74 | 0.61 | 61.28  | 59.85  | 3.79  | 26.75  | 0.99 | 14.83 | 1.29  | 0.58 | 5.50     | 8.73  | 0.96 | 8122.26  |
| 2011M5GMG-37 | 4.24  | 24.92 | 5.91   | 161.55 | 17.34 | 8933.55  | 36.60 | 2.54 | 0.47 | 58.93  | 59.27  | 4.54  | 26.04  | 1.15 | 18.68 | 1.53  | 0.00 | 5.86     | 9.93  | 0.83 | 8370.02  |
| 2011M5GMG-27 | 5.09  | 23.16 | 3.21   | 162.05 | 15.46 | 8842.56  | 26.39 | 3.47 | 0.20 | 59.22  | 59.21  | 3.77  | 25.48  | 1.10 | 13.05 | 1.58  | 0.36 | 5.77     | 7.87  | 0.48 | 8338.73  |
| jzl-08       | 11.41 | 46.21 | 178.72 | 190.86 | 80.79 | 4408.71  | 15.11 | 6.25 | 1.10 | 396.86 | 17.14  | 13.75 | 247.50 | 6.44 | 1.01  | 0.21  | 0.38 | 1.92     | 3.79  | 3.62 | 1923.23  |
| GMG-9        | 5.65  | 22.85 | 8.57   | 199.40 | 19.46 | 657.55   | 48.08 | 3.14 | 0.79 | 64.90  | 48.57  | 6.62  | 30.21  | 1.78 | 6.18  | 0.18  | 0.02 | 3.24     | 0.17  | 0.42 | 10037.10 |
| 2011M5GMG-36 | 5.89  | 22.93 | 11.07  | 196.15 | 18.57 | 540.87   | 45.72 | 2.22 | 0.91 | 69.57  | 49.76  | 5.41  | 30.57  | 1.13 | 10.15 | 0.01  | 0.53 | 4.75     | 0.14  | 0.29 | 9652.85  |
| 2011M5GMG-29 | 5.61  | 23.49 | 9.31   | 210.57 | 26.80 | 252.72   | 55.63 | 2.81 | 0.26 | 66.47  | 52.75  | 4.88  | 35.43  | 1.79 | 7.95  | 0.15  | 0.13 | 8.97     | 0.12  | 0.83 | 9944.93  |
| 2011M5GMG-30 | 5.46  | 20.43 | 9.08   | 202.87 | 26.07 | 199.77   | 42.79 | 3.14 | 0.14 | 65.70  | 46.74  | 6.36  | 29.39  | 1.80 | 7.43  | 0.16  | 0.20 | 2.61     | 0.55  | 0.14 | 9750.32  |
| 2011M5GMG-38 | 4.67  | 20.20 | 1.60   | 200.08 | 12.00 | 115.45   | 46.74 | 1.93 | 0.49 | 54.14  | 40.48  | 3.99  | 12.77  | 0.74 | 17.87 | 0.00  | 0.09 | 0.76     | 0.27  | 0.56 | 8758.30  |
| GMG-7        | 4.88  | 11.88 | 6.28   | 151.35 | 20.10 | 115.38   | 39.74 | 2.66 | 0.34 | 61.80  | 47.14  | 3.81  | 27.40  | 1.43 | 5.39  | 0.00  | 0.45 | 1.64     | 0.47  | 0.09 | 9020.50  |
| GMG-2        | 4.48  | 11.75 | 3.71   | 148.29 | 15.99 | 98.75    | 33.03 | 2.42 | 0.50 | 62.46  | 44.10  | 3.38  | 27.87  | 1.18 | 5.29  | 0.04  | 0.25 | 1.16     | 0.00  | 0.38 | 8817.37  |
| 2011M5GMG-32 | 5.56  | 14.45 | 4.65   | 139.60 | 7.96  | 95.44    | 29.30 | 2.38 | 0.59 | 54.65  | 45.19  | 3.25  | 23.83  | 0.75 | 23.13 | 0.10  | 0.06 | 0.59     | 0.26  | 0.55 | 8289.85  |
| 2011M5GMG-31 | 5.16  | 16.03 | 7.24   | 189.76 | 16.66 | 65.24    | 42.70 | 1.80 | 0.08 | 61.75  | 32.93  | 3.91  | 24.98  | 1.67 | 11.44 | 0.15  | 0.13 | 0.34     | 0.23  | 0.78 | 8853.64  |
| GMG-24       | 4.53  | 23.68 | 7.51   | 8.27   | 11.32 | 27495.22 | 48.90 | 4.35 | 0.33 | 393.59 | 66.59  | 7.34  | 88.55  | 3.83 | 0.84  | 7.18  | 0.09 | 624.01   | 11.17 | 5.48 | 357.57   |
| 2016M1GMG-43 | 3.11  | 25.43 | 6.70   | 3.36   | 7.39  | 266.70   | 7.16  | 3.20 | 0.01 | 244.50 | 26.27  | 4.94  | 71.38  | 3.32 | 0.57  | 29.91 | 0.20 | 21844.32 | 0.52  | 2.76 | 94.21    |
| 2016M1GMG-44 | 3.34  | 21.77 | 7.97   | 1.34   | 8.09  | 107.77   | 11.85 | 2.02 | 0.19 | 222.01 | 24.65  | 3.22  | 69.94  | 1.99 | 0.64  | 22.68 | 0.50 | 29781.17 | 0.89  | 2.90 | 40.30    |
| 2016M1GMG-46 | 3.96  | 17.93 | 3.30   | 0.87   | 3.00  | 95.62    | 10.27 | 1.74 | 0.03 | 233.90 | 26.32  | 3.44  | 63.60  | 1.97 | 0.57  | 23.97 | 0.11 | 3953.92  | 0.82  | 3.57 | 46.10    |
| 2016M1GMG-47 | 2.24  | 15.70 | 5.14   | 0.71   | 11.55 | 89.40    | 6.34  | 1.92 | 0.09 | 214.64 | 24.55  | 3.45  | 61.74  | 1.99 | 0.44  | 22.64 | 0.00 | 23586.62 | 0.96  | 3.71 | 39.11    |

|              |       |        |        |         |        |          |       |      |      |        |        |       |        |      |       |       |      |          |        |      |         |
|--------------|-------|--------|--------|---------|--------|----------|-------|------|------|--------|--------|-------|--------|------|-------|-------|------|----------|--------|------|---------|
| 2016M1GMG-45 | 2.40  | 15.74  | 5.96   | 1.30    | 8.83   | 82.98    | 5.70  | 1.81 | 0.30 | 216.36 | 23.41  | 3.06  | 57.90  | 1.45 | 0.62  | 19.15 | 0.00 | 18453.12 | 0.88   | 3.93 | 44.10   |
| M1ZC-2       | 3.51  | 10.59  | 9.13   | 615.54  | 240.09 | 14681.36 | 29.61 | 1.98 | 0.10 | 96.31  | 109.02 | 7.82  | 85.49  | 1.79 | 48.04 | 0.97  | 0.00 | 435.55   | 10.67  | 0.66 | 143.57  |
| GMG-3        | 6.34  | 21.44  | 11.19  | 763.63  | 224.64 | 12280.94 | 38.91 | 2.96 | 0.90 | 88.94  | 99.25  | 10.63 | 114.95 | 3.66 | 40.05 | 0.36  | 0.00 | 42.89    | 15.36  | 1.08 | 237.23  |
| M1ZC-1       | 4.04  | 7.89   | 6.12   | 1957.17 | 382.91 | 10108.84 | 7.38  | 2.08 | 0.04 | 86.19  | 107.32 | 6.51  | 73.40  | 1.68 | 70.74 | 0.05  | 0.00 | 10.62    | 1.22   | 0.92 | 184.87  |
| SJM1S-3      | 7.02  | 13.10  | 0.00   | 320.24  | 199.20 | 10087.43 | 28.99 | 3.34 | 0.86 | 90.04  | 51.39  | 8.81  | 108.14 | 3.74 | 27.78 | 0.54  | 0.05 | 13.75    | 11.98  | 0.93 | 208.72  |
| GMG-8        | 7.35  | 30.38  | 16.29  | 682.36  | 222.69 | 7587.54  | 49.30 | 5.70 | 0.75 | 97.81  | 107.77 | 12.91 | 140.32 | 5.11 | 62.87 | 0.69  | 0.28 | 28.54    | 204.79 | 2.47 | 454.37  |
| SM24-11-1    | 3.45  | 10.21  | 6.96   | 1236.21 | 295.47 | 7377.38  | 17.91 | 2.12 | 0.53 | 172.84 | 38.24  | 7.25  | 69.75  | 2.81 | 32.53 | 0.40  | 0.00 | 138.64   | 1.88   | 0.50 | 222.59  |
| SJM6-31-2    | 3.99  | 12.60  | 14.12  | 245.98  | 86.20  | 5646.80  | 20.03 | 2.23 | 0.38 | 78.85  | 75.05  | 9.56  | 126.34 | 3.19 | 47.19 | 0.22  | 0.24 | 6.43     | 7.37   | 1.13 | 251.08  |
| GMG-4        | 4.84  | 27.69  | 24.31  | 609.30  | 36.57  | 5371.48  | 43.03 | 5.78 | 0.38 | 145.04 | 79.82  | 19.97 | 130.72 | 5.15 | 46.60 | 0.26  | 0.00 | 21.45    | 13.36  | 2.25 | 274.24  |
| jzl-15       | 5.01  | 28.39  | 98.74  | 171.93  | 118.97 | 1784.29  | 29.99 | 3.80 | 0.51 | 475.54 | 34.71  | 7.29  | 77.61  | 2.39 | 6.27  | 0.59  | 0.18 | 614.87   | 0.57   | 3.70 | 1731.96 |
| jzl-04       | 5.71  | 28.42  | 86.33  | 179.57  | 115.08 | 1540.77  | 33.09 | 3.88 | 1.74 | 451.02 | 36.85  | 7.02  | 75.69  | 2.56 | 6.94  | 0.43  | 1.94 | 606.46   | 0.54   | 3.97 | 1867.93 |
| 1445         | 7.42  | 32.99  | 128.58 | 230.21  | 153.87 | 977.99   | 26.70 | 4.86 | 0.89 | 449.97 | 29.80  | 11.43 | 155.18 | 4.90 | 22.87 | 0.20  | 0.36 | 51.05    | 3.39   | 3.20 | 1926.71 |
| jzl-16       | 7.19  | 39.82  | 135.68 | 192.29  | 125.80 | 898.12   | 17.90 | 5.21 | 1.30 | 614.51 | 17.99  | 13.12 | 186.14 | 6.05 | 25.83 | 0.37  | 0.56 | 42.09    | 4.23   | 3.55 | 1778.63 |
| jzl-26       | 10.45 | 74.99  | 191.31 | 766.27  | 465.41 | 837.03   | 37.36 | 4.65 | 1.26 | 79.69  | 134.76 | 13.75 | 150.91 | 3.12 | 3.72  | 0.58  | 0.42 | 21.36    | 0.09   | 0.50 | 2280.97 |
| jzl-14       | 9.23  | 71.66  | 196.48 | 724.62  | 436.60 | 802.57   | 35.39 | 4.14 | 1.40 | 75.53  | 150.07 | 13.46 | 145.54 | 2.92 | 4.11  | 0.80  | 0.36 | 17.17    | 0.14   | 0.54 | 2264.11 |
| jzl-12       | 10.83 | 112.49 | 177.44 | 1114.66 | 584.47 | 777.73   | 33.86 | 4.27 | 1.32 | 233.03 | 108.80 | 14.75 | 26.12  | 1.44 | 4.49  | 2.14  | 0.93 | 3.05     | 0.10   | 0.94 | 2681.79 |
| jzl-11       | 7.06  | 37.34  | 166.87 | 176.55  | 112.66 | 724.09   | 13.64 | 5.36 | 1.09 | 635.98 | 16.25  | 12.72 | 187.39 | 5.84 | 31.76 | 0.31  | 0.00 | 26.02    | 3.81   | 3.67 | 1785.41 |
| jzl-19       | 6.96  | 37.42  | 150.33 | 170.03  | 120.85 | 705.44   | 15.40 | 4.95 | 1.51 | 627.19 | 16.67  | 12.58 | 188.68 | 6.19 | 26.53 | 0.20  | 0.49 | 24.22    | 4.16   | 3.41 | 1696.30 |
| jzl-02       | 7.21  | 36.41  | 131.56 | 170.57  | 113.22 | 698.64   | 15.67 | 5.43 | 1.82 | 638.79 | 15.17  | 12.14 | 188.98 | 5.80 | 25.26 | 0.41  | 0.49 | 22.40    | 4.21   | 3.50 | 1730.64 |
| jzl-18       | 6.85  | 35.74  | 162.56 | 162.93  | 109.02 | 634.37   | 13.97 | 5.23 | 1.41 | 654.76 | 14.64  | 12.24 | 183.33 | 5.68 | 26.08 | 0.32  | 0.77 | 20.28    | 4.06   | 3.42 | 1669.55 |
| jzl-05       | 7.18  | 36.34  | 155.90 | 173.19  | 114.91 | 633.81   | 12.07 | 4.59 | 1.59 | 612.52 | 16.85  | 12.10 | 187.17 | 5.73 | 27.59 | 0.27  | 0.65 | 21.37    | 4.19   | 3.26 | 1650.83 |
| jzl-25       | 8.85  | 38.48  | 18.33  | 207.18  | 24.96  | 628.94   | 25.51 | 4.37 | 0.00 | 428.85 | 28.77  | 11.78 | 128.30 | 4.06 | 11.62 | 0.16  | 0.96 | 144.11   | 0.38   | 2.20 | 2270.64 |
| jzl-13       | 8.04  | 44.77  | 80.41  | 484.57  | 238.32 | 511.71   | 22.71 | 3.72 | 1.01 | 282.49 | 68.02  | 10.18 | 123.77 | 3.08 | 0.72  | 0.16  | 0.31 | 7.40     | 2.17   | 2.22 | 1525.85 |
| jzl-28       | 8.70  | 42.91  | 78.32  | 459.45  | 231.85 | 493.74   | 22.20 | 3.73 | 1.10 | 291.79 | 73.39  | 10.07 | 129.82 | 3.01 | 0.65  | 0.34  | 0.34 | 8.11     | 1.95   | 2.37 | 1416.31 |
| 08XYXM18-14  | 8.92  | 33.57  | 12.29  | 164.27  | 19.92  | 439.39   | 14.72 | 5.85 | 0.40 | 522.18 | 21.74  | 12.07 | 152.68 | 4.87 | 4.22  | 2.83  | 0.38 | 16.88    | 0.58   | 4.08 | 1487.07 |

|              |       |       |        |        |        |          |        |       |      |        |        |       |         |       |       |       |      |         |       |      |         |
|--------------|-------|-------|--------|--------|--------|----------|--------|-------|------|--------|--------|-------|---------|-------|-------|-------|------|---------|-------|------|---------|
| jzl-23       | 10.92 | 72.83 | 25.94  | 719.05 | 104.08 | 429.51   | 37.21  | 5.13  | 4.33 | 81.24  | 164.44 | 15.34 | 173.62  | 3.07  | 3.81  | 0.43  | 0.44 | 19.22   | 0.01  | 0.70 | 2256.99 |
| 2005ZHM3-1   | 12.34 | 93.55 | 12.99  | 652.00 | 75.21  | 412.67   | 32.28  | 4.13  | 0.34 | 82.40  | 108.25 | 9.43  | 57.55   | 2.29  | 10.33 | 0.59  | 0.20 | 6.25    | 0.41  | 0.49 | 2531.18 |
| 2005ZHM3-2   | 11.53 | 90.27 | 15.88  | 660.61 | 73.61  | 335.17   | 34.92  | 3.97  | 0.35 | 76.60  | 101.39 | 9.24  | 57.33   | 2.37  | 10.94 | 0.57  | 0.18 | 6.23    | 0.16  | 0.39 | 2215.38 |
| jzl-03       | 6.74  | 29.21 | 132.85 | 241.21 | 175.99 | 243.16   | 13.19  | 4.19  | 1.26 | 442.46 | 21.43  | 11.88 | 167.50  | 4.55  | 30.27 | 0.57  | 0.32 | 4.26    | 3.46  | 2.89 | 1539.76 |
| jzl-01       | 6.41  | 33.32 | 126.46 | 246.49 | 139.65 | 233.02   | 16.28  | 4.54  | 0.89 | 425.99 | 23.02  | 11.85 | 137.02  | 4.00  | 1.44  | 0.29  | 0.49 | 2.06    | 0.34  | 3.38 | 1490.24 |
| 2016M1GMG-42 | 5.93  | 34.58 | 19.39  | 1.60   | 9.90   | 2804.43  | 19.71  | 5.38  | 0.37 | 324.19 | 24.61  | 6.98  | 129.64  | 4.73  | 0.25  | 3.62  | 0.00 | 38.46   | 23.49 | 3.33 | 122.97  |
| 2016M1GMG-39 | 4.64  | 16.51 | 8.31   | 0.67   | 2.43   | 1223.04  | 13.24  | 7.77  | 0.60 | 346.57 | 36.00  | 10.44 | 25.11   | 2.97  | 0.72  | 0.61  | 0.42 | 13.77   | 0.35  | 3.69 | 164.19  |
| 2016M1GMG-40 | 5.10  | 12.56 | 11.58  | 3.37   | 11.50  | 47.27    | 11.79  | 2.03  | 0.23 | 105.84 | 212.21 | 6.68  | 64.51   | 1.80  | 2.37  | 0.06  | 0.29 | 0.35    | 0.11  | 0.13 | 112.68  |
| 2016M1GMG-41 | 3.54  | 9.97  | 8.61   | 2.85   | 13.63  | 42.25    | 14.20  | 2.15  | 0.00 | 104.53 | 213.21 | 5.66  | 55.49   | 1.64  | 3.36  | 0.05  | 0.00 | 0.70    | 0.34  | 0.16 | 118.75  |
| S13-370-2    | 4.54  | 21.99 | 1.37   | 17.21  | 4.74   | 18.75    | 4.55   | 1.30  | 0.16 | 153.24 | 75.92  | 2.29  | 18.54   | 0.97  | 35.18 | 0.08  | 0.22 | 1.51    | 0.04  | 0.65 | 163.49  |
| 08XYXM18-1   | 12.22 | 71.92 | 102.49 | 12.48  | 25.13  | 499.82   | 126.69 | 8.26  | 0.37 | 65.76  | 163.99 | 25.21 | 1198.65 | 12.65 | 2.44  | 2.11  | 0.41 | 31.85   | 0.62  | 1.58 | 437.59  |
| 08XYXM18-10  | 7.60  | 45.22 | 24.32  | 11.38  | 35.89  | 7690.65  | 93.23  | 13.91 | 0.38 | 25.34  | 570.18 | 12.48 | 393.45  | 7.04  | 1.39  | 5.81  | 0.17 | 808.11  | 25.01 | 0.43 | 720.18  |
| 08XYXM18-12  | 6.69  | 83.56 | 13.92  | 8.71   | 32.27  | 10142.06 | 45.87  | 12.02 | 0.34 | 33.10  | 540.36 | 11.41 | 810.61  | 10.12 | 0.44  | 5.96  | 0.17 | 1276.12 | 18.76 | 0.34 | 1167.16 |
| 08XYXM18-13  | 6.98  | 78.09 | 13.53  | 6.32   | 17.14  | 7698.43  | 28.93  | 15.11 | 0.23 | 29.94  | 636.77 | 12.00 | 329.25  | 8.59  | 0.37  | 5.07  | 0.18 | 871.74  | 13.90 | 0.58 | 1001.71 |
| 08XYXM18-15  | 6.59  | 69.43 | 17.10  | 7.48   | 29.85  | 11895.75 | 34.84  | 11.03 | 0.19 | 29.39  | 581.63 | 10.78 | 726.52  | 8.64  | 0.39  | 12.44 | 0.11 | 1632.64 | 20.96 | 0.54 | 1219.27 |
| 08XYXM18-16  | 7.80  | 75.81 | 18.62  | 9.43   | 23.54  | 8492.04  | 34.82  | 15.47 | 0.33 | 32.03  | 683.71 | 11.27 | 256.55  | 7.91  | 0.28  | 3.86  | 0.26 | 966.67  | 13.48 | 0.64 | 1041.68 |
| 08XYXM18-17  | 6.05  | 52.43 | 10.70  | 11.94  | 60.02  | 15415.66 | 44.42  | 14.38 | 0.22 | 65.97  | 453.07 | 14.75 | 568.56  | 9.42  | 0.78  | 14.47 | 0.10 | 1639.89 | 28.36 | 0.51 | 1259.88 |
| 08XYXM18-18  | 7.20  | 52.16 | 15.97  | 8.01   | 29.14  | 10487.75 | 32.60  | 14.42 | 0.20 | 31.28  | 650.81 | 8.24  | 237.92  | 6.28  | 0.31  | 5.11  | 0.07 | 709.33  | 11.88 | 0.39 | 877.81  |
| 08XYXM18-19  | 6.71  | 64.82 | 15.42  | 8.07   | 28.27  | 9810.69  | 26.53  | 11.81 | 0.37 | 34.06  | 744.74 | 8.28  | 387.00  | 8.40  | 0.48  | 5.27  | 0.08 | 1224.73 | 20.64 | 0.34 | 1736.49 |
| 08XYXM18-2   | 7.20  | 34.41 | 17.13  | 5.80   | 22.50  | 5423.05  | 30.44  | 10.58 | 0.32 | 17.67  | 399.01 | 11.19 | 385.86  | 7.43  | 0.62  | 7.57  | 0.00 | 679.63  | 21.52 | 0.18 | 549.15  |
| 08XYXM18-20  | 6.63  | 63.94 | 18.34  | 17.77  | 63.21  | 14697.20 | 59.59  | 12.86 | 0.26 | 44.12  | 504.36 | 11.60 | 551.99  | 9.17  | 0.90  | 31.46 | 0.27 | 1862.40 | 23.97 | 0.36 | 1103.63 |
| 08XYXM18-21  | 6.49  | 43.25 | 29.13  | 8.03   | 11.34  | 5500.50  | 28.80  | 14.13 | 0.28 | 32.20  | 665.77 | 12.34 | 457.50  | 8.88  | 0.21  | 4.41  | 0.12 | 773.15  | 12.59 | 0.18 | 1229.67 |
| 08XYXM18-3   | 8.35  | 47.20 | 27.13  | 7.20   | 24.09  | 6544.31  | 121.70 | 8.53  | 0.39 | 20.74  | 384.61 | 9.99  | 644.19  | 13.38 | 0.49  | 3.56  | 0.01 | 675.18  | 18.96 | 0.30 | 553.88  |
| 08XYXM18-4   | 6.17  | 50.73 | 10.28  | 8.77   | 31.29  | 6542.08  | 22.90  | 14.93 | 0.19 | 30.33  | 604.89 | 8.55  | 165.54  | 5.94  | 0.41  | 1.25  | 0.00 | 675.47  | 11.96 | 0.46 | 782.41  |
| 08XYXM18-5   | 6.77  | 74.88 | 22.44  | 14.51  | 50.75  | 33763.03 | 49.04  | 15.34 | 0.16 | 28.90  | 589.02 | 11.17 | 296.28  | 8.66  | 0.18  | 5.48  | 0.23 | 924.64  | 15.42 | 0.80 | 937.45  |

|            |       |       |        |       |        |          |         |       |      |       |        |       |        |       |      |      |      |          |       |      |         |
|------------|-------|-------|--------|-------|--------|----------|---------|-------|------|-------|--------|-------|--------|-------|------|------|------|----------|-------|------|---------|
| 08XYXM18-6 | 6.73  | 45.97 | 36.16  | 16.26 | 67.74  | 21295.37 | 48.68   | 13.03 | 0.30 | 30.50 | 500.32 | 13.81 | 573.69 | 15.38 | 0.39 | 6.29 | 0.11 | 1329.38  | 14.32 | 0.49 | 816.68  |
| 08XYXM18-7 | 7.16  | 42.68 | 19.71  | 8.96  | 13.42  | 5749.57  | 29.04   | 14.63 | 0.28 | 29.51 | 668.87 | 11.43 | 402.12 | 8.52  | 0.17 | 6.51 | 0.08 | 865.52   | 25.57 | 0.45 | 1226.16 |
| 08XYXM18-8 | 10.00 | 60.04 | 73.22  | 9.33  | 12.60  | 4896.33  | 42.39   | 11.91 | 0.32 | 53.29 | 426.40 | 18.03 | 522.87 | 10.16 | 1.61 | 3.97 | 0.00 | 142.07   | 0.89  | 0.86 | 903.84  |
| 08XYXM18-9 | 7.69  | 47.48 | 27.11  | 16.91 | 54.42  | 8155.83  | 24.55   | 9.22  | 0.27 | 18.73 | 402.06 | 10.14 | 667.25 | 12.11 | 0.38 | 2.00 | 0.00 | 860.11   | 17.19 | 0.08 | 554.49  |
| jzl-09     | 5.35  | 33.91 | 123.28 | 19.67 | 222.01 | 21802.35 | 847.34  | 5.37  | 1.72 | 63.61 | 114.14 | 16.68 | 189.99 | 5.49  | 5.21 | 2.58 | 0.00 | 15663.70 | 6.35  | 1.88 | 275.63  |
| jzl-10     | 5.32  | 35.11 | 135.90 | 20.57 | 222.44 | 23287.52 | 811.85  | 5.52  | 1.82 | 63.78 | 117.97 | 17.49 | 210.09 | 5.78  | 6.59 | 2.19 | 0.35 | 1581.23  | 4.62  | 2.15 | 290.31  |
| jzl-20     | 5.16  | 35.92 | 166.58 | 20.12 | 236.68 | 21467.43 | 939.19  | 6.35  | 1.23 | 67.94 | 119.37 | 17.50 | 202.03 | 5.94  | 6.00 | 4.00 | 0.18 | 7264.53  | 8.27  | 2.64 | 288.57  |
| jzl-21     | 5.42  | 33.92 | 113.16 | 21.18 | 236.08 | 18208.22 | 1208.81 | 5.25  | 1.72 | 64.38 | 116.70 | 16.83 | 209.02 | 5.68  | 6.44 | 2.71 | 0.81 | 1614.74  | 6.17  | 2.11 | 300.10  |
| jzl-22     | 5.67  | 33.93 | 134.76 | 20.11 | 214.10 | 18096.45 | 985.87  | 5.57  | 1.61 | 65.86 | 114.93 | 15.67 | 197.46 | 5.33  | 5.87 | 4.04 | 0.10 | 2222.33  | 5.17  | 1.99 | 295.44  |
| jzl-27     | 5.99  | 33.29 | 139.83 | 20.46 | 218.12 | 24238.06 | 961.53  | 5.82  | 1.33 | 65.42 | 117.40 | 17.65 | 198.49 | 6.01  | 5.21 | 2.74 | 0.08 | 2569.11  | 6.71  | 2.22 | 295.94  |
| jzl-29     | 6.49  | 33.30 | 129.46 | 19.45 | 213.02 | 20565.82 | 905.23  | 5.43  | 1.57 | 58.56 | 111.21 | 16.97 | 187.99 | 5.61  | 5.16 | 1.93 | 0.26 | 4988.84  | 5.09  | 1.94 | 274.68  |
| jzl-30     | 6.09  | 35.55 | 146.27 | 19.74 | 214.12 | 22624.42 | 740.36  | 5.66  | 1.39 | 62.64 | 117.53 | 18.26 | 210.10 | 5.92  | 5.93 | 2.73 | 0.30 | 1160.90  | 4.94  | 2.22 | 291.16  |

**Continued to Table 2**

|              | La    | Ce    | Pr   | Nd    | Sm   | Eu   | Gd   | Tb   | Dy   | Ho   | Er   | Tm   | Yb   | Lu   | Hf   | Ta   | W    | Au   | Hg   | Pb     | Bi   | Th   | U    |
|--------------|-------|-------|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|--------|------|------|------|
| GMG-19       | 9.32  | 18.70 | 2.17 | 8.54  | 1.64 | 0.16 | 0.61 | 0.12 | 0.68 | 0.18 | 0.58 | 0.08 | 0.94 | 0.11 | 3.03 | 0.25 | 0.87 | 0.00 | 0.00 | 14.71  | 0.04 | 3.64 | 0.93 |
| 2011M5GMG-26 | 12.36 | 20.88 | 2.73 | 10.80 | 1.28 | 0.50 | 2.16 | 0.19 | 2.28 | 0.40 | 1.05 | 0.18 | 1.08 | 0.08 | 6.03 | 0.62 | 0.48 | 0.00 | 0.00 | 10.34  | 0.08 | 4.77 | 0.57 |
| GMG-18       | 3.62  | 7.63  | 0.85 | 3.91  | 1.07 | 0.12 | 0.49 | 0.27 | 1.42 | 0.20 | 0.98 | 0.15 | 1.64 | 0.22 | 0.65 | 4.17 | 1.32 | 0.00 | 0.00 | 14.29  | 2.22 | 2.57 | 2.35 |
| GMG-21       | 12.45 | 24.46 | 3.45 | 12.92 | 2.22 | 0.42 | 3.10 | 0.30 | 1.47 | 0.42 | 1.27 | 0.09 | 1.09 | 0.13 | 4.94 | 0.64 | 0.67 | 0.00 | 0.00 | 4.94   | 0.01 | 3.90 | 0.81 |
| 5.29548-J    | 12.15 | 21.57 | 2.95 | 10.29 | 3.44 | 0.86 | 3.77 | 0.49 | 3.52 | 0.66 | 3.12 | 1.80 | 2.20 | 0.54 | 1.85 | 0.28 | 0.55 | 0.00 | 0.00 | 79.65  | 0.07 | 2.96 | 5.81 |
| GMG-22       | 12.67 | 24.72 | 3.06 | 13.56 | 1.79 | 0.35 | 2.36 | 0.35 | 1.99 | 0.37 | 0.79 | 0.14 | 1.19 | 0.17 | 4.36 | 0.67 | 0.56 | 0.00 | 0.00 | 4.38   | 0.02 | 3.82 | 0.83 |
| GMG-23       | 10.65 | 21.10 | 2.43 | 8.40  | 1.22 | 0.24 | 1.24 | 0.23 | 1.50 | 0.21 | 0.83 | 0.11 | 0.89 | 0.12 | 2.22 | 0.24 | 1.03 | 0.00 | 0.00 | 123.20 | 0.11 | 3.63 | 0.81 |
| 5.39316-B    | 9.56  | 16.85 | 2.18 | 8.61  | 1.67 | 0.43 | 2.43 | 0.28 | 2.41 | 0.53 | 1.55 | 1.34 | 1.54 | 0.39 | 1.65 | 0.16 | 0.57 | 0.00 | 0.00 | 346.83 | 0.23 | 2.53 | 5.35 |
| 5.39316-J    | 9.62  | 16.47 | 1.97 | 8.17  | 2.34 | 0.86 | 2.48 | 0.24 | 1.84 | 0.69 | 2.06 | 1.62 | 1.76 | 0.28 | 1.20 | 0.19 | 0.48 | 0.00 | 0.00 | 347.14 | 0.19 | 2.31 | 4.92 |
| GMG-10       | 3.27  | 6.41  | 0.88 | 3.55  | 0.42 | 0.16 | 1.17 | 0.08 | 1.23 | 0.10 | 0.46 | 0.09 | 0.82 | 0.24 | 1.02 | 3.27 | 0.84 | 0.00 | 0.00 | 12.08  | 0.07 | 2.26 | 2.03 |
| GMG-20       | 3.76  | 8.29  | 0.89 | 2.72  | 0.39 | 0.19 | 1.01 | 0.09 | 1.23 | 0.17 | 0.42 | 0.04 | 0.38 | 0.05 | 0.30 | 0.08 | 0.20 | 0.00 | 0.00 | 16.87  | 0.21 | 1.27 | 0.75 |

|              |       |       |      |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |         |        |      |      |
|--------------|-------|-------|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------|--------|------|------|
| GMG-13       | 2.98  | 5.86  | 0.59 | 2.06  | 0.70 | 0.06 | 0.22 | 0.14 | 0.69 | 0.13 | 0.42 | 0.03 | 1.02 | 0.15 | 0.40 | 2.14 | 0.29 | 0.00 | 0.00 | 9.37    | 0.04   | 1.62 | 1.07 |
| GMG-14       | 3.98  | 8.23  | 1.15 | 4.38  | 1.42 | 0.02 | 0.92 | 0.13 | 0.98 | 0.23 | 0.72 | 0.12 | 1.17 | 0.15 | 0.77 | 2.79 | 1.02 | 0.00 | 0.00 | 12.62   | 0.09   | 1.40 | 2.17 |
| GMG-11       | 3.50  | 8.97  | 0.76 | 2.64  | 0.24 | 0.29 | 0.73 | 0.06 | 0.65 | 0.13 | 0.29 | 0.08 | 0.90 | 0.08 | 0.54 | 0.24 | 2.02 | 0.00 | 0.00 | 243.20  | 0.19   | 1.28 | 0.49 |
| 5.29461-J    | 17.08 | 27.31 | 3.45 | 16.00 | 1.81 | 0.34 | 2.53 | 0.55 | 3.68 | 0.58 | 1.97 | 2.37 | 1.58 | 0.40 | 1.54 | 0.34 | 0.42 | 0.00 | 0.00 | 75.31   | 0.07   | 3.38 | 7.50 |
| 5.29340-2    | 16.45 | 22.50 | 3.39 | 15.44 | 3.09 | 0.74 | 1.86 | 0.54 | 3.05 | 0.86 | 1.80 | 1.12 | 1.98 | 0.76 | 2.34 | 0.53 | 0.20 | 0.00 | 0.00 | 1846.58 | 0.04   | 2.74 | 4.98 |
| GMG-12       | 7.94  | 16.65 | 1.94 | 6.76  | 1.76 | 0.27 | 1.27 | 0.21 | 1.13 | 0.28 | 0.88 | 0.09 | 1.22 | 0.11 | 2.31 | 0.42 | 0.59 | 0.00 | 0.00 | 297.08  | 0.04   | 2.66 | 0.74 |
| GMG-16       | 8.39  | 18.30 | 2.08 | 6.37  | 1.54 | 0.25 | 1.61 | 0.23 | 1.44 | 0.24 | 0.95 | 0.08 | 0.98 | 0.13 | 2.31 | 0.24 | 0.47 | 0.00 | 0.00 | 353.82  | 0.10   | 2.73 | 0.80 |
| GMG-15       | 7.51  | 16.92 | 1.90 | 5.61  | 0.78 | 0.29 | 1.08 | 0.14 | 0.92 | 0.24 | 0.95 | 0.17 | 0.62 | 0.14 | 2.06 | 0.54 | 2.10 | 0.00 | 0.00 | 1720.27 | 1.84   | 2.83 | 0.79 |
| 5.29340-1    | 14.36 | 23.65 | 3.11 | 12.21 | 3.00 | 0.38 | 3.54 | 0.45 | 2.40 | 0.66 | 1.66 | 1.41 | 2.37 | 0.19 | 1.36 | 0.20 | 0.36 | 0.00 | 0.00 | 1409.48 | 0.02   | 3.31 | 6.03 |
| GMG-17       | 8.90  | 19.02 | 1.99 | 7.70  | 1.39 | 0.22 | 0.99 | 0.20 | 1.11 | 0.29 | 0.83 | 0.12 | 1.03 | 0.11 | 2.85 | 0.66 | 2.07 | 0.00 | 0.00 | 1409.40 | 1.70   | 3.22 | 0.86 |
| 5.29340-3    | 15.73 | 24.63 | 2.72 | 13.23 | 2.80 | 0.48 | 3.09 | 0.44 | 2.32 | 0.70 | 1.83 | 1.91 | 1.95 | 0.34 | 1.48 | 0.27 | 0.57 | 0.00 | 0.00 | 2397.88 | 0.13   | 3.12 | 7.98 |
| 5.29548-W    | 10.83 | 18.28 | 2.31 | 9.78  | 1.99 | 0.79 | 2.58 | 0.39 | 2.29 | 0.46 | 1.83 | 0.93 | 1.44 | 0.29 | 1.75 | 0.14 | 0.41 | 0.00 | 0.00 | 145.83  | 0.02   | 2.94 | 5.96 |
| GMG-25       | 15.95 | 35.45 | 3.61 | 15.25 | 2.53 | 0.56 | 3.59 | 0.48 | 2.71 | 0.54 | 1.28 | 0.16 | 1.42 | 0.18 | 5.04 | 0.36 | 0.47 | 0.00 | 0.00 | 20.65   | 0.06   | 8.33 | 2.40 |
| GMG-1        | 3.81  | 18.99 | 0.73 | 3.20  | 0.73 | 0.38 | 0.81 | 0.10 | 0.61 | 0.11 | 0.43 | 0.06 | 0.56 | 0.06 | 0.59 | 0.10 | 0.32 | 0.00 | 0.00 | 154.41  | 0.45   | 1.57 | 0.53 |
| GMG-5        | 4.87  | 15.57 | 1.73 | 7.39  | 0.94 | 0.48 | 0.71 | 0.25 | 0.93 | 0.13 | 0.51 | 0.08 | 0.20 | 0.14 | 1.63 | 0.53 | 0.60 | 0.00 | 0.00 | 111.59  | 38.54  | 4.14 | 0.49 |
| GMG-6        | 4.59  | 15.59 | 1.13 | 4.47  | 1.46 | 0.18 | 0.81 | 0.15 | 0.65 | 0.16 | 0.21 | 0.03 | 0.57 | 0.04 | 0.89 | 0.15 | 0.14 | 0.00 | 0.00 | 380.20  | 19.02  | 2.12 | 0.63 |
| 2011M5GMG-33 | 4.21  | 32.05 | 1.49 | 5.37  | 1.08 | 0.37 | 1.34 | 0.24 | 1.49 | 0.20 | 0.96 | 0.21 | 0.84 | 0.08 | 0.66 | 0.13 | 0.41 | 0.00 | 0.00 | 51.86   | 63.56  | 1.89 | 0.40 |
| 2011M5GMG-35 | 4.78  | 29.24 | 1.25 | 6.08  | 1.29 | 0.06 | 1.34 | 0.30 | 1.45 | 0.17 | 0.39 | 0.04 | 0.21 | 0.11 | 0.62 | 0.09 | 0.58 | 0.00 | 0.00 | 65.70   | 110.38 | 1.31 | 0.31 |
| 2011M5GMG-34 | 4.62  | 32.40 | 1.30 | 7.16  | 0.99 | 0.39 | 1.55 | 0.25 | 1.85 | 0.22 | 0.48 | 0.15 | 0.10 | 0.11 | 0.75 | 0.10 | 1.28 | 0.00 | 0.00 | 48.77   | 62.83  | 1.79 | 0.44 |
| 2011M5GMG-28 | 4.82  | 30.84 | 1.21 | 7.82  | 1.24 | 0.59 | 1.30 | 0.12 | 0.88 | 0.30 | 0.61 | 0.13 | 0.80 | 0.08 | 0.53 | 0.11 | 0.85 | 0.00 | 0.00 | 49.50   | 62.99  | 1.40 | 0.26 |
| 2011M5GMG-37 | 4.57  | 31.16 | 1.34 | 6.36  | 0.97 | 0.34 | 1.44 | 0.19 | 1.07 | 0.20 | 0.44 | 0.09 | 0.26 | 0.09 | 0.49 | 0.09 | 0.61 | 0.00 | 0.00 | 46.95   | 59.47  | 1.63 | 0.68 |
| 2011M5GMG-27 | 4.85  | 31.22 | 1.39 | 4.66  | 1.48 | 0.38 | 0.97 | 0.24 | 1.62 | 0.21 | 0.12 | 0.09 | 0.53 | 0.02 | 0.58 | 0.07 | 0.12 | 0.00 | 0.00 | 47.56   | 59.00  | 1.45 | 0.40 |
| jzl-08       | 13.29 | 83.14 | 2.95 | 12.32 | 2.38 | 0.55 | 2.07 | 0.41 | 2.53 | 0.51 | 1.40 | 0.23 | 1.59 | 0.27 | 5.70 | 0.47 | 0.22 | 0.00 | 0.00 | 0.03    | 12.05  | 5.21 | 1.46 |
| GMG-9        | 3.48  | 45.43 | 1.88 | 7.51  | 3.38 | 0.40 | 2.33 | 0.34 | 1.45 | 0.29 | 0.76 | 0.09 | 1.09 | 0.15 | 1.08 | 0.06 | 0.51 | 0.00 | 0.00 | 30.18   | 0.01   | 2.13 | 0.51 |
| 2011M5GMG-36 | 6.26  | 47.42 | 1.87 | 8.44  | 1.87 | 0.34 | 1.79 | 0.22 | 2.46 | 0.27 | 0.81 | 0.08 | 1.08 | 0.11 | 1.08 | 0.19 | 0.26 | 0.00 | 0.00 | 38.41   | 0.03   | 2.04 | 0.31 |

|              |       |       |      |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |               |             |      |       |
|--------------|-------|-------|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------------|-------------|------|-------|
| 2011M5GMG-29 | 7.15  | 39.86 | 2.11 | 10.29 | 1.65 | 0.24 | 2.59 | 0.34 | 2.28 | 0.41 | 0.87 | 0.15 | 0.33 | 0.07 | 0.96 | 0.17 | 0.17 | 0.00 | 0.00 | 51.89         | 0.02        | 2.95 | 0.60  |
| 2011M5GMG-30 | 5.92  | 40.48 | 1.86 | 9.10  | 2.29 | 0.69 | 2.39 | 0.26 | 2.12 | 0.32 | 1.14 | 0.14 | 1.09 | 0.05 | 0.63 | 0.20 | 0.29 | 0.00 | 0.00 | 38.79         | 0.01        | 2.35 | 0.60  |
| 2011M5GMG-38 | 4.52  | 31.42 | 1.19 | 4.79  | 0.91 | 0.37 | 2.31 | 0.24 | 1.64 | 0.19 | 0.63 | 0.04 | 0.56 | 0.05 | 0.40 | 0.13 | 0.54 | 0.00 | 0.00 | 11.76         | 0.01        | 1.31 | 0.32  |
| GMG-7        | 1.82  | 25.90 | 0.94 | 4.48  | 0.79 | 0.32 | 0.77 | 0.22 | 0.73 | 0.22 | 0.48 | 0.08 | 0.49 | 0.09 | 0.50 | 0.17 | 0.24 | 0.00 | 0.00 | 19.66         | 0.31        | 1.73 | 0.38  |
| GMG-2        | 4.11  | 25.49 | 1.00 | 3.74  | 0.87 | 0.33 | 0.91 | 0.17 | 0.77 | 0.19 | 0.54 | 0.09 | 0.81 | 0.05 | 0.62 | 0.23 | 0.32 | 0.00 | 0.00 | 18.78         | 0.24        | 1.83 | 0.44  |
| 2011M5GMG-32 | 3.55  | 21.42 | 0.95 | 3.55  | 0.89 | 0.29 | 0.68 | 0.16 | 0.93 | 0.14 | 0.38 | 0.08 | 0.75 | 0.09 | 0.59 | 0.04 | 0.86 | 0.00 | 0.00 | 8.22          | 0.13        | 1.12 | 0.23  |
| 2011M5GMG-31 | 4.05  | 27.46 | 1.21 | 4.36  | 1.14 | 0.31 | 1.47 | 0.16 | 1.09 | 0.21 | 0.69 | 0.14 | 0.41 | 0.07 | 0.89 | 0.72 | 0.40 | 0.00 | 0.00 | 14.38         | 0.03        | 2.20 | 0.47  |
| GMG-24       | 10.71 | 21.12 | 2.31 | 10.29 | 1.89 | 0.29 | 1.71 | 0.23 | 1.53 | 0.21 | 0.85 | 0.11 | 1.04 | 0.12 | 2.96 | 0.32 | 6.83 | 0.00 | 0.00 | 2429.99       | 0.42        | 4.39 | 1.32  |
| 2016M1GMG-43 | 9.08  | 17.71 | 1.87 | 7.79  | 1.39 | 0.22 | 1.34 | 0.13 | 1.17 | 0.27 | 0.50 | 0.13 | 0.10 | 0.07 | 2.23 | 0.27 | 0.34 | 0.00 | 0.00 | 254771.390.06 | 3.05        | 0.57 |       |
| 2016M1GMG-44 | 6.67  | 11.44 | 1.28 | 5.41  | 0.96 | 0.20 | 0.86 | 0.13 | 1.26 | 0.13 | 0.48 | 0.11 | 0.29 | 0.01 | 1.68 | 0.13 | 0.16 | 0.00 | 0.00 | 275753.480.17 | 2.47        | 0.32 |       |
| 2016M1GMG-46 | 7.74  | 11.60 | 1.82 | 6.08  | 0.15 | 0.40 | 1.38 | 0.19 | 0.74 | 0.20 | 0.41 | 0.00 | 0.65 | 0.04 | 1.50 | 0.22 | 0.50 | 0.00 | 0.00 | 265599.730.17 | 2.48        | 0.42 |       |
| 2016M1GMG-47 | 5.71  | 12.15 | 1.44 | 4.39  | 0.67 | 0.14 | 0.19 | 0.11 | 1.00 | 0.04 | 0.37 | 0.14 | 0.13 | 0.03 | 1.62 | 0.13 | 0.16 | 0.00 | 0.00 | 286741.390.19 | 2.15        | 0.41 |       |
| 2016M1GMG-45 | 7.30  | 11.54 | 1.28 | 5.00  | 0.50 | 0.21 | 1.23 | 0.14 | 0.67 | 0.25 | 0.43 | 0.06 | 0.22 | 0.09 | 1.99 | 0.11 | 0.16 | 0.00 | 0.00 | 300336.220.21 | 2.51        | 0.40 |       |
| M1ZC-2       | 12.51 | 25.05 | 3.16 | 10.18 | 1.73 | 0.35 | 1.67 | 0.28 | 1.62 | 0.26 | 0.63 | 0.11 | 0.82 | 0.17 | 2.35 | 0.23 | 2.56 | 0.00 | 0.00 | 362.35        | 2.72        | 3.59 | 1.45  |
| GMG-3        | 14.45 | 29.10 | 3.16 | 11.85 | 2.93 | 0.30 | 2.19 | 0.43 | 1.94 | 0.39 | 1.36 | 0.17 | 1.44 | 0.21 | 3.02 | 0.26 | 2.61 | 0.00 | 0.00 | 48.96         | 1.02        | 6.36 | 8.68  |
| M1ZC-1       | 9.08  | 19.31 | 2.24 | 7.41  | 2.13 | 0.33 | 1.62 | 0.19 | 1.35 | 0.29 | 0.42 | 0.12 | 1.16 | 0.23 | 2.01 | 0.19 | 4.13 | 0.00 | 0.00 | 16.58         | 0.57        | 3.17 | 0.78  |
| SJM1S-3      | 12.29 | 22.04 | 2.75 | 10.64 | 2.03 | 0.93 | 1.27 | 0.38 | 1.76 | 0.35 | 1.10 | 0.22 | 1.04 | 0.10 | 2.59 | 0.19 | 1.26 | 0.00 | 0.00 | 8.40          | 3.17        | 5.61 | 1.34  |
| GMG-8        | 18.62 | 38.75 | 4.17 | 15.28 | 4.88 | 0.62 | 2.82 | 0.34 | 2.69 | 0.65 | 1.45 | 0.15 | 2.57 | 0.23 | 3.45 | 0.40 | 3.32 | 0.00 | 0.00 | 69.01         | 1.89        | 7.29 | 13.05 |
| SM24-11-1    | 11.95 | 22.47 | 2.53 | 11.01 | 1.95 | 0.57 | 1.44 | 0.21 | 1.61 | 0.19 | 0.38 | 0.14 | 0.56 | 0.08 | 1.51 | 0.17 | 1.15 | 0.00 | 0.00 | 29.39         | 0.69        | 5.20 | 0.54  |
| SJM6-31-2    | 14.98 | 27.50 | 3.41 | 11.39 | 3.00 | 0.51 | 2.31 | 0.34 | 2.11 | 0.40 | 0.95 | 0.06 | 0.70 | 0.16 | 2.79 | 0.37 | 2.08 | 0.00 | 0.00 | 8.52          | 0.43        | 5.60 | 0.83  |
| GMG-4        | 21.06 | 39.22 | 5.29 | 19.96 | 6.78 | 0.39 | 3.43 | 0.69 | 3.76 | 0.88 | 2.20 | 0.14 | 1.10 | 0.43 | 4.40 | 0.80 | 2.93 | 0.00 | 0.00 | 50.82         | 0.12        | 8.28 | 27.58 |
| jzl-15       | 10.97 | 46.40 | 2.35 | 9.37  | 1.75 | 0.43 | 1.39 | 0.21 | 1.36 | 0.28 | 0.80 | 0.11 | 0.78 | 0.11 | 1.85 | 0.17 | 0.22 | 0.00 | 0.00 | 0.14          | 3288.912.72 | 0.65 |       |
| jzl-04       | 10.45 | 46.31 | 2.17 | 9.88  | 1.92 | 0.52 | 1.87 | 0.23 | 1.65 | 0.34 | 0.93 | 0.12 | 0.77 | 0.14 | 1.76 | 0.14 | 0.25 | 0.00 | 0.00 | 0.19          | 3713.472.85 | 0.71 |       |
| 1445         | 13.35 | 54.55 | 3.16 | 11.89 | 2.75 | 0.59 | 2.08 | 0.36 | 2.31 | 0.48 | 1.37 | 0.18 | 1.40 | 0.23 | 3.75 | 0.34 | 0.87 | 0.00 | 0.00 | 0.08          | 196.22      | 3.61 | 0.77  |
| jzl-16       | 13.08 | 47.40 | 2.96 | 11.32 | 2.34 | 0.54 | 2.16 | 0.36 | 2.58 | 0.48 | 1.43 | 0.25 | 1.64 | 0.25 | 4.41 | 0.48 | 0.85 | 0.00 | 0.00 | 0.87          | 96.92       | 4.22 | 0.82  |

|              |       |        |      |       |      |      |      |      |      |      |      |      |      |      |       |      |      |      |      |         |       |       |       |
|--------------|-------|--------|------|-------|------|------|------|------|------|------|------|------|------|------|-------|------|------|------|------|---------|-------|-------|-------|
| jzl-26       | 30.86 | 217.94 | 7.29 | 28.94 | 5.85 | 1.33 | 4.51 | 0.71 | 4.37 | 0.78 | 2.20 | 0.32 | 2.31 | 0.30 | 3.57  | 0.18 | 0.18 | 0.00 | 0.00 | 0.02    | 94.14 | 14.15 | 1.16  |
| jzl-14       | 29.20 | 207.11 | 7.06 | 27.47 | 6.04 | 1.24 | 4.07 | 0.64 | 4.19 | 0.78 | 2.17 | 0.29 | 2.06 | 0.29 | 3.30  | 0.18 | 0.14 | 0.00 | 0.00 | 0.05    | 81.05 | 13.42 | 1.04  |
| jzl-12       | 13.24 | 294.68 | 4.73 | 20.25 | 5.75 | 1.50 | 4.64 | 0.80 | 4.81 | 0.88 | 2.34 | 0.37 | 2.20 | 0.31 | 0.63  | 0.14 | 0.11 | 0.00 | 0.00 | 0.06    | 8.94  | 1.34  | 0.39  |
| jzl-11       | 13.08 | 45.19  | 2.92 | 10.80 | 2.30 | 0.65 | 2.33 | 0.36 | 2.46 | 0.50 | 1.56 | 0.24 | 1.88 | 0.26 | 4.45  | 0.44 | 0.92 | 0.00 | 0.00 | 0.60    | 72.21 | 4.19  | 0.70  |
| jzl-19       | 12.99 | 44.60  | 2.84 | 10.98 | 2.36 | 0.49 | 1.89 | 0.38 | 2.41 | 0.49 | 1.57 | 0.22 | 1.73 | 0.23 | 4.46  | 0.45 | 0.97 | 0.00 | 0.00 | 0.46    | 61.49 | 4.21  | 0.73  |
| jzl-02       | 13.22 | 44.83  | 2.91 | 12.24 | 2.14 | 0.55 | 2.19 | 0.36 | 2.49 | 0.44 | 1.20 | 0.24 | 1.56 | 0.25 | 4.10  | 0.46 | 1.03 | 0.00 | 0.00 | 0.46    | 76.88 | 4.11  | 0.78  |
| jzl-18       | 12.82 | 43.00  | 2.71 | 11.49 | 2.30 | 0.51 | 2.11 | 0.37 | 2.61 | 0.52 | 1.50 | 0.19 | 1.52 | 0.29 | 4.37  | 0.46 | 0.85 | 0.00 | 0.00 | 0.41    | 66.61 | 4.22  | 0.73  |
| jzl-05       | 12.91 | 45.05  | 2.94 | 11.12 | 2.15 | 0.64 | 2.22 | 0.41 | 2.34 | 0.51 | 1.63 | 0.25 | 1.62 | 0.23 | 4.36  | 0.48 | 0.82 | 0.00 | 0.00 | 0.44    | 60.66 | 4.12  | 0.82  |
| jzl-25       | 15.08 | 63.68  | 1.61 | 12.59 | 3.17 | 0.74 | 3.60 | 0.35 | 1.91 | 0.55 | 1.60 | 1.08 | 1.74 | 0.34 | 2.78  | 0.17 | 0.24 | 0.00 | 0.00 | 439.31  | 0.03  | 4.46  | 0.73  |
| jzl-13       | 14.05 | 96.58  | 3.65 | 15.67 | 3.44 | 0.77 | 2.67 | 0.42 | 2.74 | 0.50 | 1.40 | 0.19 | 1.39 | 0.23 | 2.94  | 0.26 | 0.25 | 0.00 | 0.00 | 0.02    | 48.25 | 3.24  | 0.80  |
| jzl-28       | 13.73 | 90.69  | 3.50 | 14.38 | 3.39 | 0.74 | 2.66 | 0.41 | 2.61 | 0.47 | 1.40 | 0.21 | 1.39 | 0.20 | 2.99  | 0.24 | 0.28 | 0.00 | 0.00 | 0.02    | 35.10 | 3.31  | 0.79  |
| 08XYXM18-14  | 15.45 | 56.71  | 3.52 | 13.59 | 2.80 | 0.61 | 2.26 | 0.35 | 2.78 | 0.45 | 1.45 | 0.23 | 1.44 | 0.16 | 3.70  | 0.36 | 0.23 | 0.00 | 0.00 | 441.95  | 0.13  | 4.31  | 0.86  |
| jzl-23       | 35.93 | 217.47 | 9.04 | 31.87 | 9.26 | 1.42 | 3.97 | 0.84 | 4.00 | 0.98 | 1.79 | 2.31 | 2.46 | 0.33 | 5.27  | 0.13 | 0.00 | 0.00 | 0.00 | 63.65   | 0.03  | 16.90 | 1.22  |
| 2005ZHM3-1   | 14.42 | 205.05 | 3.73 | 13.63 | 3.26 | 1.16 | 3.51 | 0.53 | 3.36 | 0.52 | 1.54 | 0.27 | 1.38 | 0.21 | 1.57  | 0.17 | 0.44 | 0.00 | 0.00 | 21.92   | 0.05  | 5.56  | 1.25  |
| 2005ZHM3-2   | 13.16 | 205.37 | 3.44 | 13.07 | 3.73 | 1.00 | 3.32 | 0.55 | 3.11 | 0.57 | 1.66 | 0.24 | 1.59 | 0.23 | 1.43  | 0.24 | 0.42 | 0.00 | 0.00 | 22.75   | 0.03  | 5.30  | 1.19  |
| jzl-03       | 13.46 | 65.17  | 3.09 | 12.91 | 2.89 | 0.60 | 2.20 | 0.37 | 2.10 | 0.52 | 1.48 | 0.26 | 1.39 | 0.18 | 3.86  | 0.33 | 0.94 | 0.00 | 0.00 | 0.02    | 27.18 | 3.59  | 0.63  |
| jzl-01       | 14.34 | 72.86  | 3.21 | 12.52 | 2.71 | 0.60 | 2.06 | 0.40 | 2.42 | 0.49 | 1.36 | 0.28 | 1.76 | 0.24 | 3.09  | 0.32 | 0.25 | 0.00 | 0.00 | 0.02    | 13.62 | 4.08  | 1.03  |
| 2016M1GMG-42 | 15.07 | 29.29  | 2.62 | 7.20  | 2.42 | 0.09 | 2.57 | 0.27 | 2.58 | 0.38 | 0.87 | 0.13 | 0.54 | 0.01 | 4.00  | 0.56 | 0.71 | 0.00 | 0.00 | 58.27   | 0.07  | 5.75  | 0.71  |
| 2016M1GMG-39 | 4.96  | 10.58  | 1.30 | 5.85  | 0.40 | 0.17 | 1.19 | 0.37 | 2.41 | 0.41 | 1.02 | 0.22 | 2.10 | 0.33 | 1.13  | 1.05 | 0.46 | 0.00 | 0.00 | 22.84   | 0.11  | 4.73  | 2.24  |
| 2016M1GMG-40 | 16.12 | 29.30  | 3.33 | 13.72 | 2.00 | 0.33 | 2.52 | 0.22 | 1.48 | 0.21 | 0.70 | 0.14 | 0.17 | 0.08 | 1.67  | 0.09 | 0.85 | 0.00 | 0.00 | 2.56    | 0.03  | 11.35 | 0.71  |
| 2016M1GMG-41 | 16.18 | 28.83  | 3.07 | 13.84 | 2.25 | 0.33 | 1.44 | 0.29 | 0.93 | 0.18 | 0.43 | 0.13 | 0.61 | 0.10 | 1.48  | 0.11 | 0.98 | 0.00 | 0.00 | 3.11    | 0.01  | 12.05 | 0.91  |
| S13-370-2    | 3.59  | 9.33   | 0.89 | 3.46  | 0.69 | 0.03 | 0.62 | 0.05 | 0.53 | 0.16 | 0.76 | 0.09 | 0.28 | 0.05 | 0.61  | 0.24 | 0.29 | 0.00 | 0.00 | 5.20    | 0.14  | 1.69  | 0.58  |
| 08XYXM18-1   | 41.05 | 66.17  | 8.66 | 35.24 | 5.87 | 1.56 | 5.58 | 0.74 | 4.40 | 0.80 | 2.67 | 0.43 | 2.23 | 0.36 | 26.55 | 0.74 | 0.94 | 0.00 | 0.00 | 49.74   | 0.01  | 11.48 | 11.92 |
| 08XYXM18-10  | 21.90 | 54.79  | 4.73 | 18.26 | 3.67 | 1.14 | 2.52 | 0.44 | 2.29 | 0.43 | 1.51 | 0.25 | 1.47 | 0.26 | 8.94  | 0.55 | 0.28 | 0.00 | 0.00 | 1028.74 | 0.56  | 7.46  | 11.54 |
| 08XYXM18-12  | 21.31 | 49.03  | 4.57 | 18.39 | 3.21 | 1.06 | 2.64 | 0.35 | 1.79 | 0.35 | 1.35 | 0.24 | 1.44 | 0.21 | 17.73 | 0.59 | 0.14 | 0.00 | 0.00 | 2664.06 | 0.54  | 11.18 | 24.27 |



|             |       |       |      |       |      |      |      |      |      |      |      |      |      |      |       |      |      |      |      |         |         |       |       |
|-------------|-------|-------|------|-------|------|------|------|------|------|------|------|------|------|------|-------|------|------|------|------|---------|---------|-------|-------|
| 08XYXM18-13 | 25.90 | 57.01 | 5.78 | 20.74 | 3.56 | 1.29 | 3.00 | 0.41 | 2.30 | 0.34 | 1.11 | 0.19 | 1.31 | 0.20 | 8.19  | 0.58 | 0.27 | 0.00 | 0.00 | 2954.71 | 0.47    | 7.96  | 11.02 |
| 08XYXM18-15 | 21.35 | 48.34 | 4.44 | 18.09 | 2.69 | 1.05 | 2.35 | 0.34 | 1.90 | 0.42 | 1.15 | 0.15 | 1.15 | 0.24 | 16.17 | 0.57 | 0.12 | 0.00 | 0.00 | 4040.56 | 0.54    | 9.20  | 23.31 |
| 08XYXM18-16 | 26.89 | 72.28 | 6.20 | 22.59 | 4.17 | 1.32 | 3.28 | 0.46 | 2.34 | 0.36 | 1.03 | 0.20 | 0.78 | 0.19 | 6.37  | 0.64 | 0.10 | 0.00 | 0.00 | 3091.97 | 0.72    | 10.90 | 10.69 |
| 08XYXM18-17 | 17.09 | 52.95 | 3.74 | 15.24 | 2.89 | 0.95 | 2.72 | 0.41 | 2.57 | 0.47 | 1.69 | 0.27 | 1.65 | 0.30 | 13.35 | 0.52 | 0.09 | 0.00 | 0.00 | 3207.52 | 0.70    | 9.44  | 35.94 |
| 08XYXM18-18 | 20.50 | 48.32 | 4.44 | 16.57 | 2.98 | 1.29 | 2.25 | 0.28 | 1.48 | 0.29 | 0.98 | 0.16 | 0.91 | 0.16 | 4.99  | 0.40 | 0.09 | 0.00 | 0.00 | 1772.99 | 0.76    | 6.99  | 13.59 |
| 08XYXM18-19 | 20.84 | 45.17 | 3.89 | 16.24 | 2.13 | 1.21 | 1.93 | 0.22 | 1.38 | 0.26 | 0.69 | 0.13 | 0.93 | 0.14 | 8.64  | 0.50 | 0.10 | 0.00 | 0.00 | 3122.93 | 0.78    | 8.75  | 19.02 |
| 08XYXM18-2  | 19.71 | 52.52 | 4.31 | 15.10 | 3.05 | 1.04 | 2.58 | 0.29 | 1.81 | 0.35 | 1.15 | 0.20 | 1.60 | 0.20 | 9.20  | 0.58 | 0.12 | 0.00 | 0.00 | 1046.29 | 0.47    | 8.43  | 12.23 |
| 08XYXM18-20 | 19.64 | 51.98 | 4.28 | 17.94 | 2.42 | 1.06 | 2.70 | 0.31 | 1.99 | 0.41 | 1.20 | 0.16 | 1.24 | 0.24 | 12.68 | 0.63 | 0.17 | 0.00 | 0.00 | 4140.12 | 1.04    | 8.79  | 25.42 |
| 08XYXM18-21 | 23.98 | 57.67 | 5.01 | 19.29 | 2.94 | 1.37 | 3.06 | 0.31 | 2.17 | 0.40 | 1.29 | 0.19 | 1.19 | 0.18 | 11.00 | 0.51 | 0.14 | 0.00 | 0.00 | 996.05  | 0.31    | 8.48  | 14.44 |
| 08XYXM18-3  | 17.38 | 47.09 | 4.01 | 14.98 | 2.82 | 0.92 | 2.22 | 0.32 | 1.97 | 0.37 | 1.11 | 0.18 | 1.62 | 0.21 | 13.88 | 0.77 | 0.26 | 0.00 | 0.00 | 1723.24 | 0.78    | 6.97  | 15.17 |
| 08XYXM18-4  | 20.85 | 49.29 | 4.09 | 15.84 | 2.50 | 1.27 | 2.00 | 0.29 | 1.68 | 0.29 | 0.86 | 0.13 | 0.74 | 0.12 | 3.99  | 0.45 | 0.24 | 0.00 | 0.00 | 1682.03 | 0.43    | 6.15  | 13.56 |
| 08XYXM18-5  | 26.29 | 55.85 | 5.80 | 21.00 | 4.30 | 1.04 | 3.01 | 0.39 | 2.26 | 0.46 | 1.08 | 0.15 | 1.27 | 0.25 | 6.99  | 0.56 | 0.28 | 0.00 | 0.00 | 2999.95 | 1.65    | 7.61  | 10.59 |
| 08XYXM18-6  | 24.62 | 59.95 | 5.24 | 19.97 | 3.63 | 1.30 | 3.06 | 0.42 | 2.27 | 0.47 | 1.53 | 0.24 | 1.78 | 0.28 | 13.14 | 1.10 | 0.22 | 0.00 | 0.00 | 6639.77 | 2.49    | 12.65 | 11.43 |
| 08XYXM18-7  | 24.53 | 57.34 | 5.46 | 19.28 | 3.74 | 1.45 | 3.53 | 0.39 | 2.54 | 0.41 | 1.19 | 0.20 | 1.51 | 0.21 | 9.82  | 0.57 | 0.06 | 0.00 | 0.00 | 1056.47 | 0.58    | 8.94  | 14.31 |
| 08XYXM18-8  | 34.21 | 57.91 | 7.27 | 26.69 | 4.47 | 1.22 | 3.99 | 0.60 | 3.34 | 0.61 | 1.68 | 0.29 | 1.64 | 0.32 | 12.48 | 0.53 | 0.55 | 0.00 | 0.00 | 127.81  | 0.18    | 8.85  | 3.99  |
| 08XYXM18-9  | 17.36 | 42.40 | 3.43 | 14.32 | 3.09 | 1.10 | 2.02 | 0.32 | 1.88 | 0.32 | 1.20 | 0.16 | 1.15 | 0.22 | 14.30 | 0.72 | 0.21 | 0.00 | 0.00 | 2766.24 | 0.46    | 6.02  | 11.70 |
| jzl-09      | 25.26 | 54.53 | 5.73 | 20.32 | 3.93 | 0.60 | 3.03 | 0.48 | 3.07 | 0.59 | 1.76 | 0.28 | 1.70 | 0.29 | 4.82  | 0.63 | 1.63 | 0.00 | 0.00 | 7.61    | 2491.47 | 12.06 | 35.55 |
| jzl-10      | 26.67 | 57.67 | 5.90 | 21.15 | 3.99 | 0.57 | 3.62 | 0.50 | 3.05 | 0.57 | 1.81 | 0.27 | 1.93 | 0.29 | 5.00  | 0.63 | 1.76 | 0.00 | 0.00 | 8.28    | 1386.75 | 12.78 | 36.33 |
| jzl-20      | 26.34 | 56.68 | 5.71 | 21.31 | 4.19 | 0.63 | 3.59 | 0.51 | 3.03 | 0.61 | 1.87 | 0.25 | 1.55 | 0.27 | 4.91  | 0.65 | 1.74 | 0.00 | 0.00 | 9.45    | 1660.47 | 12.58 | 36.17 |
| jzl-21      | 24.95 | 55.74 | 5.70 | 22.11 | 4.05 | 0.60 | 3.38 | 0.45 | 2.89 | 0.61 | 1.69 | 0.29 | 1.67 | 0.26 | 5.20  | 0.55 | 1.67 | 0.00 | 0.00 | 9.16    | 1606.02 | 12.10 | 38.84 |
| jzl-22      | 23.89 | 53.19 | 5.32 | 20.26 | 3.94 | 0.58 | 3.34 | 0.44 | 2.81 | 0.56 | 1.64 | 0.24 | 1.50 | 0.21 | 4.57  | 0.60 | 1.89 | 0.00 | 0.00 | 8.51    | 2847.96 | 11.52 | 35.72 |
| jzl-27      | 26.66 | 57.54 | 5.90 | 22.80 | 4.25 | 0.63 | 3.55 | 0.50 | 3.07 | 0.58 | 1.79 | 0.28 | 1.79 | 0.27 | 5.04  | 1.26 | 1.81 | 0.00 | 0.00 | 8.16    | 9969.41 | 12.76 | 37.32 |
| jzl-29      | 24.75 | 53.98 | 5.47 | 20.75 | 4.18 | 0.62 | 3.36 | 0.47 | 3.04 | 0.57 | 1.76 | 0.25 | 1.84 | 0.25 | 4.73  | 0.71 | 1.56 | 0.00 | 0.00 | 7.68    | 3087.37 | 12.19 | 37.20 |
| jzl-30      | 27.13 | 59.27 | 5.78 | 22.93 | 4.46 | 0.59 | 3.68 | 0.53 | 3.24 | 0.62 | 1.85 | 0.28 | 1.75 | 0.25 | 5.11  | 0.60 | 1.62 | 0.00 | 0.00 | 7.59    | 1690.69 | 12.97 | 36.83 |

**Table 3 Lankton and Dussubieux (2006)**

| Sample label               | SiO <sub>2</sub> | Na <sub>2</sub> O | CaO  | K <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | Ti      | Zn   | P <sub>2</sub> O <sub>5</sub> | Ba     | V     | Cr   | from  | Sr     | Zr    | U     | Location |
|----------------------------|------------------|-------------------|------|------------------|------|--------------------------------|--------------------------------|---------|------|-------------------------------|--------|-------|------|-------|--------|-------|-------|----------|
| 3.2.2                      | 60.20            | 17.60             | 2.60 | 2.40             | 0.50 | 11.70                          | 1.10                           | 2341    | 54   | 0.1                           | 1168.3 | 61    | 14   | 61    | 14     | 481   | 19    | KSK      |
| 3J.1                       | 67.70            | 14.20             | 2.10 | 2.30             | 0.30 | 8.00                           | 1.30                           | 2597    | 29   | 0                             | 1278.1 | 44    | 35   | 44    | 35     | 563   | 5     | KSK      |
| 3J.I                       | 68.10            | 14.00             | 1.90 | 2.50             | 0.20 | 8.00                           | 1.20                           | 5xxx    | nd   | nd                            | 3xxx   |       |      |       |        |       |       | KSK      |
| 3J.6                       | 60.70            | 15.50             | 2.50 | 2.60             | 0.70 | 13.30                          | 1.40                           | 6xxx    | nd   | nd                            | 4xxx   |       |      |       |        |       |       | KSK      |
| 3.1.1                      | 62.40            | 15.90             | 2.30 | 2.00             | 0.40 | 13.30                          | 1.20                           | 4xxx    | nd   | nd                            | nd     |       |      |       |        |       |       | KSK      |
| 32.2                       | 60.50            | 16.30             | 2.40 | 2.90             | 0.40 | 11.80                          | 1.10                           | Sxxx    | nd   | nd                            | nd     |       |      |       |        |       |       | KSK      |
| 33.1                       | 63.70            | 18.20             | 1.70 | 1.80             | 0.50 | 8.70                           | 0.80                           | 4xxx    | nd   | 0.2                           | 3xxx   |       |      |       |        |       |       | KSK      |
| GCV4.31b. Pit 4. burial 31 | 66.93            | 19.28             | 1.5  | 2.4              | 1.1  | 6.76                           | 1.127                          | 2029.12 | 65.9 | 0.6                           | 275.6  | 93.1  | 32.3 | 111.8 | 121.1  | 214.2 | 115.8 | Vietnam  |
| VGCVA3                     | 62.44            | 22.28             | 2.11 | 2.34             | 1    | 6.43                           | 2.68                           | 2401    | nd   |                               | 521.1  | 0     | 0    | 114.9 | nd     | 203.3 | 59.5  | Vietnam  |
| VGTA                       | 68.36            | 12.67             | 3.03 | 2.99             | 1.1  | 7                              | 4                              | 2385    | 89.8 | 0.2                           | 401    | 55.8  | 48   | 83.8  | 129.5  | 116.4 | 77.1  | Vietnam  |
| SG11                       | 61               | 18.3              | 2.9  | 4.3              | 0.9  | 6.2                            | 2.9                            | 3xxx    |      | 0.3                           | <lxxx  |       |      |       |        |       |       | Vietnam  |
| SG13                       | 67.3             | 11.3              | 4    | 4.5              | 0.29 | 6.6                            | 3.1                            | 3xxx    |      | 0.6                           | 9xx    |       |      |       |        |       |       | Vietnam  |
| SG14                       | 67.3             | 11.3              | 4.1  | 4.5              | 0.2  | 6.6                            | 3.1                            | 3xxx    |      | 0.5                           | 9xx    |       |      |       |        |       |       | Vietnam  |
| SG15                       | 60.2             | 19.5              | 2.7  | 0.3              | 0.9  | 6.6                            | 3.4                            | 3xxx    |      | 0.3                           |        |       |      |       |        |       |       | Vietnam  |
| VNQC1.6                    | 73.1             | 12.1              | 2.5  | 2.3              | 0.8  | 6.1                            | 1.5                            | 2xxx    | nd   | 0.4                           | nd     |       |      |       |        |       |       | Vietnam  |
| VNQC1.6                    | 73.1             | 12.1              | 2.5  | 2.3              | 0.8  | 6.1                            | 1.5                            | 2xxx    | nd   | 0.4                           | nd     |       |      |       |        |       |       | India    |
| Brill 2006 unpublished     | 70.20            | 15.50             | 2.80 | 3.00             | 1.60 | 5.30                           | 1.70                           |         |      |                               |        |       |      |       |        |       |       | India    |
| Brill 1051                 | 63.60            | 15.20             | 2.40 | 2.40             | 1.00 | 6.10                           | 1.50                           | 2xxx    | 3xxx |                               | 3xx    |       |      |       |        |       |       | India    |
| Brill! 052                 | 67.00            | 13.40             | 3.20 | 3.80             | 2.00 | 7.30                           | 2.20                           | 2xxx    |      |                               | 9xx    |       |      |       |        |       |       | India    |
| Brill 1053                 | 66.10            | 17.10             | 2.40 | 2.70             | 1.70 | 4.40                           | 1.30                           | lxxx    |      |                               | 4xx    |       |      |       |        |       |       | India    |
| Brill 1055                 | 67.00            | 15.80             | 3.20 | 2.80             | 2.00 | 5.00                           | 2.00                           | lxxx    |      |                               | 9xx    |       |      |       |        |       |       | India    |
| Brill 1056                 | 61.70            | 20.30             | 3.00 | 3.00             | 2.50 | 6.30                           | 1.80                           | 2xxx    |      |                               | 9xx    |       |      |       |        |       |       | India    |
| Bril! 1060G                | 66.70            | 14.80             | 1.90 | 3.20             | 1.40 | 4.60                           | 1.40                           | 2xxx    |      |                               |        |       |      |       |        |       |       | India    |
| Brill 2900                 | 57.90            | 17.90             | 5.20 | 3.70             | 3.30 | 8.80                           | 2.80                           | lxxx    |      |                               | 2xx    |       |      |       |        |       |       | India    |
| BrU1 2902                  | 62.00            | 17.80             | 4.70 | 3.80             | 2.70 | 4.40                           | 2.80                           | lxxx    |      |                               |        |       |      |       |        |       |       | India    |
| Brill 430                  | 67.10            | 18.70             | 2.60 | 1.90             | 0.90 | 5.20                           | 2.40                           | Sxxx    |      |                               | 2xxx   |       |      |       |        |       |       | India    |
| Brill 431                  | 69.00            | 17.30             | 2.50 | 1.80             | 0.80 | 5.70                           | 2.00                           | 3xxx    |      |                               | 9xx    |       |      |       |        |       |       | India    |
| IARBN                      | 68.84            | 14.33             | 3.01 | 2.67             | 0.85 | 7.23                           | 1.36                           | 989     | 81.5 | 0.8                           | 352.7  | 40.4  | 26.7 | 83.5  | 126.7  | 253.1 | 24.4  | India    |
| IKIBCl                     | 63.72            | 17.44             | 2.00 | 2.58             | 0.88 | 9.17                           | 2.90                           | 1624    | 58.6 | 0.3                           | 328.7  | 83.8  | 47.5 | 64.4  | ;135.2 | 249.9 | 336.3 | India    |
| RR13P                      | 55.50            | 12.54             | 3.65 | 5.22             | 1.08 | 7.06                           | 3.58                           | 2005    | 86.8 | 0.5                           | 503.4  | 57.7  | 37.1 | 102.4 | 134.4  | 324.3 | 51.3  | India    |
| RID23G                     | 58.98            | 19.95             | 2.27 | 3.74             | 0.37 | 7.57                           | 3.79                           | 2034    | 19.8 | 0.1                           | 505.6  | 181.7 | 21.8 | 102.6 | 203.2  | 470.7 | 214.3 | India    |
| SRH3                       | 52.30            | 11.40             | 5.50 | 3.70             | 2.70 | 9.40                           | 2.70                           | 3xxx    |      | 1.6                           |        |       |      |       |        |       |       | India    |

|            |       |       |      |      |      |       |      |       |       |     |       |      |      |       |       |       |       |  |          |
|------------|-------|-------|------|------|------|-------|------|-------|-------|-----|-------|------|------|-------|-------|-------|-------|--|----------|
| SRII4b     | 65.70 | 12.30 | 2.90 | 2.00 | 0.80 | 11.30 | 2.10 | 4xxx  |       | 0.2 |       |      |      |       |       |       |       |  | India    |
| BGH 265    | 68.6  | 10.4  | 2.8  | 5.1  | 1.5  | 6.6   | 2.3  | 5xxx  |       | 1.1 |       |      |      |       |       |       |       |  | Thailand |
| BGH 3939   | 63.7  | 11.1  | 2.8  | 4.2  | 0.9  | 5.6   | 1.9  | 4xxx  |       | 0.6 |       |      |      |       |       |       |       |  | Thailand |
| BGH 3957   | 66.9  | 11.8  | 3.9  | 4.7  | 1.1  | 5.5   | 2.2  | 5xxx  |       | 0.7 |       |      |      |       |       |       |       |  | Thailand |
| BGH 6114   | 62.9  | 11.3  | 2.6  | 3.4  | 1.4  | 6.7   | 2.4  | 4xxx  |       | 0.6 |       |      |      |       |       |       |       |  | Thailand |
| BGH 6075   | 66    | 12    | 4    | 4.9  | 1.5  | 6.2   | 2.7  | 5xxx  |       | 0.9 |       |      |      |       |       |       |       |  | Thailand |
| TCJ2       | 59.89 | 13.67 | 2.92 | 3.41 | 0.5  | 9.19  | 1.1  | 1130  | 20.6  | 0.1 | 386.7 | 67   | 10.6 | 92.8  | 140.3 | 355.2 | 101.8 |  | Thailand |
| TCJ8       | 61.36 | 14.37 | 3.27 | 3.6  | 0.5  | 9.83  | 1.6  | 1151  | 37.3  | 0.1 | 409.6 | 76.2 | 7.4  | 96.8  | 139.4 | 411.4 | 105.2 |  | Thailand |
| S2.17      | 54.1  | 12.9  | 4.5  | 4.5  | 2.3  | 9.6   | 2.9  | 6xxx  | nd    | 1.2 | 26xx  |      |      |       |       |       |       |  | Thailand |
| 1.2.1      | 69.4  | 17.1  | 1.8  | 1.8  | 0.9  | 5.7   | 1.7  | 2xxx  | nd    | nd  | nd    |      |      |       |       |       |       |  | Thailand |
| SC 36      | 71.9  | 12.1  | 1.9  | 1.7  | 0.6  | 4.3   | 1.3  | <lxxx |       | 0.3 | <lxxx |      |      |       |       |       |       |  | Thailand |
| Brill 1946 | 63.5  | 18.6  | 2.2  | 2.3  | 0.6  | 8.4   | 2    | 3xxx  | 2xx   | 0.1 | 7xx   |      |      |       |       |       |       |  | Thailand |
| KT06.39    | 65.2  | 15    | 2.5  | 3.2  | 1.4  | 6.7   | 3.1  | 1521  | 96    | 0.9 | 952.2 | 55.5 | 28.1 | 83.2  | 135.3 | 170.5 | 46.7  |  | Thailand |
| KT06.39    | 70.6  | 11.5  | 2.7  | 3    | 1.6  | 6.2   | 1.5  | 1576  | 170   | 1   | 331.4 | 55   | 30.8 | 76.9  | 127   | 118.8 | 47.1  |  | Thailand |
| KT1W       | 69.32 | 14.01 | 2.93 | 2.84 | 1.35 | 5.78  | 1.42 | 2080  | 139.8 | 1.1 | 361.5 | 47.7 | 25.9 | 114   | 139.5 | 166.9 | 68.8  |  | Thailand |
| KT1N       | 68.54 | 14.11 | 2.23 | 3.06 | 1.33 | 6.14  | 1.38 | 2063  | 160.5 | 0.8 | 432.5 | 46.6 | 26.6 | 113.7 | 169.3 | 153   | 71%4  |  | Thailand |
| KT1R       | 63.41 | 14.02 | 3.07 | 2.74 | 1.57 | 6.86  | 1.73 | 2258  | 166.2 | 1.2 | 378.8 | 49.5 | 31.6 | 109.3 | 169.3 | 172.8 | 60.3  |  | Thailand |
| KTIB       | 68.5  | 14.6  | 2.7  | 2.7  | 1.3  | 5.5   | 1.4  | 1870  | 126.2 | 0.8 | 381.6 | 42.2 | 23   | 101.6 | 159.8 | 173.5 | 61.3  |  | Thailand |
| T3B1       | 63.8  | 14.6  | 4.1  | 3.1  | 3.4  | 8     | 3    | 9xx   |       |     | 3xxx  |      |      |       |       |       |       |  | Thailand |
| T3B6       | 72.3  | 13.6  | 2.5  | 1.4  | 0.8  | 6.8   | 2.6  | 6xxx  |       |     | 1xxx  |      |      |       |       |       |       |  | Thailand |