Capturing changes: applying the Oxford system to further understand the movement of metal in Shang China



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Abstract

The Bronze Age China presents to us a significant contrast to the rest of Eurasia in two aspects, the great commitment to the complicated bronze ritual vessels and the immense scale of production. Both features reached their zenith in the late Shang period in the late second millennium BC but left a delicate puzzle to archaeologists: through what trajectories was the metal moved and engaged with human societies in China?

The traditional approach is heavily confined to either cultural-historic paradigms or text-oriented researches. Whilst the increasing number of scientific studies in recent decades allows scholars to be more precisely focused on bronze artefacts, their sometimes overwhelming obsession on the provenance of metal provokes criticism in many ways.

Drawing from approximately 3000 alloying analyses, 1000 trace elemental data and 1100 lead isotopes, this thesis delivers a series of systematic comparative studies on copper-based artefacts with the newly developed Oxford system. The waning and waxing of various types of metal in different time and space depict a constantly and unpredictably changing pattern. People inhabited along the borderlands appeared to be greatly dependent on local supply of metal whereas Anyang undoubtedly absorbed metal from a variety of regions. Intriguingly, seen from the current database, very little evidence can be highlighted in support of some large-scale mixing or recycling, particularly for ritual vessels of top elites at Anyang. The newly discovered compositional difference of bronzes between Zhengzhou and Panlongcheng calls into question on the classical model on the relation between the two sites. Striking domination of clean copper in southwestern China shed new light on the issues of local production and local supply of metal.

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In conclusion, the chemical and isotopic analyses of copper-based objects carry a huge amount of information not just on provenance but many others. People living in various parts of China had chosen differing strategies to obtain metal. The elaborate data structures are a result of a highly efficient and dynamic network supplying system. Through combining the changes in metal compositions with other archaeological information, it becomes viable to reveal more subtle knowledge about this remote world and give us better-defined questions.

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Ruiliang Liu unpublished thesis

ABSTRACT ..... **I**

ACKNOWLEDGEMENT ..... **III**

LIST OF FIGURES ..... **X**

LIST OF TABLES ..... **XIX**

CHAPTER ONE INTRODUCTION **1**

1.1 Research objectives **1**

1.2 Why changes in metal chemistry? **4**

1.3 Why China? **6**

1.4 Geographical landscape in China **11**

1.5 Archaeological landscape **17**

1.5.1 Erlitou *20*

1.5.2 Erligang *29*

1.5.3 Anyang *35*

1.5.4 Outside the lineage of the Central Plains *43*

South *43*

Southwest *48*

West *52*

North *55*

East *57*

1.6 Structure of the thesis **59**

CHAPTER TWO METHODOLOGY **62**

Ruiliang Liu unplished thesis

1.1 Overview of recent archaeometallurgical study in China 63

1.2 The 'Oxford system': form and flow 71

1.2.1 Theoretical basis 71

1.2.2 On the basis of changing chemistry 75

Experimental observation 75

Thermodynamics 78

1.2.3 Toolkit 79

Trace elemental patterns 79

Reflections on copper groups 82

Alloying elements 90

Lead isotope ratios 93

2.2 Time, space and scale 96

2.3 Synthesis of legacy data 98

2.4 Summary 101

CHAPTER THREE DATA QUALITY ASSESSMENT: A PRELIMINARY COMPARISON PROJECT 102

3.1 Introduction 102

3.2 Potential inhomogeneity of metal composition 105

3.3 Inter-laboratory comparison 109

3.3.1 Evaluation of different techniques 109

3.3.2 Inter-laboratory comparisons in Western academia 117

3.3.3 New and old data of Bronze Age China: preliminary assessment 124

Evaluation of Oxford SEM-EDS 126

Primary standards 127

Comparison of analytical averages and certified values 134

Minimum detection limit (MDL) 144

Final protocol 149

Assessment of legacy data 153

3.4 Conclusions 169

CHAPTER FOUR A COMPARATIVE PERSPECTIVE: REVISITING PANLONGCHENG METAL ASSEMBLAGE 171

4.1 Introduction 171

4.2 Cross-linking Chronology 182

4.3 Previous scholarship on scientific analyses of bronzes: production and provenance 184

Ruiliang Liu unpublished thesis

4.4 Data Reprocessing 188
4.4.1 Summary of database 188
4.4.2 Alloying profile 191
4.4.3 New presentation of lead isotopes 192

4.5 Discussion 194
4.5.1 Copper flow between Zhengzhou and Panlongcheng 194
4.5.2 Comparison of the profile of tin 202
4.5.3 Combining trace elements and lead isotopes: lead sources and potential evidence of realloying 206
4.5.4 Local production versus importation 209

5. Summary 212

CHAPTER FIVE CHARACTERIZATION OF METAL CHEMISTRY IN SOUTHWEST CHINA 215

5.1 Introduction 215

5.2 Sanxingdui 217
5.2.1 A review of the Sanxingdui metal assemblage 217
5.2.2 A review of scientific analyses of the Sanxingdui metal assemblage 231
5.2.3 Re-characterization the Sanxingdui metal assemblage 233
Copper groups 233
Alloying patterns 235
Lead isotopes 236

5.3 Hanzhong 237
5.3.1 A review of the Hanzhong metal assemblage 237
5.3.2 A review of scientific analyses of the Hanzhong metal assemblage 242
5.3.3 Key caches at Hanzhong 248
Caches 1 and 2: Longtou 249
Cache 3: Xushui 250
Cache 4: Wulangmiao B 250
Cache 5; Fanba 251
Cache 6: Sucun Xiaozhong 252
5.3.4 Re-characterization of the Hanzhong metal assemblage 256
Copper groups 256
Lead isotopes 262
5.3.5 Discussion 263
A narrative of Hanzhong: copper groups and alloying 263
Importation or localisation: Sucun Xiaozhong 269

5.4 Circulation of clean copper in Southwest China 274

5.5 Summary 276

Ruifang Liu unpublished thesis

CHAPTER SIX: A DYNAMIC PICTURE OF METAL PRODUCTION AT ANYANG 278

6.1 Introduction 278

6.2 Characterization of key chemical databases for Anyang metals 280

6.2.1 Yinxu II phase: metal assemblage of Fu Hao 280

Data description 280

Data reprocessing 283

6.2.2 Yinxu III phase: Guojiazhuang M160 290

Data description 290

Data reprocessing 293

6.2.3 Yinxu IV phase: North Liujiazhuang M1046 295

Data description 296

Data reprocessing 298

6.2.4 The Western Area 300

Data description 300

Data reprocessing 303

6.2.5 Reprocessing the data in Zhao (2004) 306

6.2.6 Sackler collection 310

6.2.7 Change in lead isotopes 317

6.3 Comparative analysis 319

6.3.1 A vertical comparison: social status 319

6.3.2 A horizontal comparison: chronology 323

6.3.3 Mixing and recycling 326

6.4 Summary 329

CHAPTER SEVEN OVERVIEW ON METAL MOVEMENTS IN THE LATE SHANG PERIOD: A BIG PICTURE 331

7.1 Introduction 331

7.2 Regional and chronological comparison 332

7.2.1 Copper groups 332

A horizontal view on the distribution of copper groups 332

Models of copper procurement 335

A vertical view: changes in copper supply to central China 341

7.2.2 Distribution of alloy types 343

A horizontal view: comparison of alloy distributions across regions 343

A vertical view: changes in tin and lead in central China 349

7.3 Future work 357

7.3.1 More and better scientific analysis of metal objects 357

7.3.2 Modeling uncertainties 358

Ruiliang Liu unpublished thesis

CHAPTER EIGHT: CONCLUSIONS 361

8.1 From points to networks 362

8.2 From objects to assemblages and scales 368

8.3 The use of legacy data: a stepping stone 371

8.4 Future works: resolution 374

BIBLIOGRAPHY 383

APPENDIX 411

LIST OF PUBLICATIONS 434

Ruiliang Liu unplished thesis

List of Figures

Figure 1 The largest Shang bronze vessel discovered so far, Simuwu *Ding* (鼎), height *c.* 133cm, weight *c.* 832 Kg....7
Figure 2 Key sites in Chapter One....9
Figure 3 Piece-mould casting....10
Figure 4 Three geographical steps in China and its monsoon seasons....15
Figure 5 Copper deposits in China (after Liu and Chen 2009: 38, figure 5)....17
Figure 6 Tin deposits in China (after Liu and Chen 2009: 40, figure 6)....17
Figure 7 Lead deposits in China (after Liu and Chen 2009: 41, figure 7)....17
Figure 8 Remodel radiocarbon dates of Erlitou, Erligang and Anyang....19
Figure 9 Outline of Erlitou, from Liu and Chen (2009: 61, figure 12)....21
Figure 10 Satellite image of Erlitou site (after IA CASS 2014, volume V, colour image II)....22
Figure 11 Palace No.1 at Erlitou, from IA CASS (1999:139, figure 84)....24
Figure 12 Excavation of the palace foundations....24
Figure 13 Erlitou styled pottery and bronzes....26
Figure 14 Outline of the Dongxiafeng site, after Liu and Chen (2001:16, fig. 5)....28
Figure 15 Craft productions at Dongxiafeng, after Liu and Chen (2001:17, fig. 6)....28
Figure 16 Outline of the Yuanqu site, after Liu and Chen (2001:29, fig. 14)....29
Figure 17 Traces of copper ores collected in the Zhongtiao mountains....29
Figure 18 Outline of Zhengzhou, from Liu and Chen (2009: 94, fig.21)....31
Figure 19 Cross-section of the inner walls of Zhengzhou....32
Figure 20 Bronze objects discovered from the cache of Nanshunchengjie at Zhengzhou, from Henan Institute of Archaeology and Zhengzhou Institute of Archaeology (1999: colour picture 2)....34
Figure 21 Plan of Anyang (after IA CASS, 2004)....36
Figure 22 Reconstruction of buildings in Anyang (after IA CASS, 1994: 56, 58&71)....37
Figure 23 King cemeteries in Xibeigang, North Xiaotun (after IA CASS, 1994: 102)....37
Figure 24 King cemeteries and surrounded tombs and ceremonial pits (after Bagley, 1999: 186)....38
Figure 25 Human sacrifices in ceremonial pits (after IA CASS, 1994: 115)....38
Figure 26 Photos of ongoing excavation of Fu Hao tomb and some selected objects from the

Ruiliang Liu unpublished thesis

tomb (after IA CASS, 1980)....39
Figure 27 Moulds found at Xiaomintun, Anyang (after IA CASS, 2006)....41
Figure 28 Bronze objects at Panlongcheng....44
Figure 29 Bronzes at Xin'gan Dayangzhou....46
Figure 30 Ningxiang metal assemblage in Hunan province (pictures from the website of Hunan provincial museum, http://www.hnmuseum.com)....48
Figure 31 Bronze objects at Sanxingdui....50
Figure 32 Bronze tree and standing human figures at Sanxingdui....50
Figure 33 Metal objects at Hanzhong (after Zhao, 2006)....52
Figure 34 Bronze objects at Laoniupo....54
Figure 35 Bronze objects in the north zone, after Cao (2009)....56
Figure 36 Bronzes at Daxinzhuang, after Shandong University and Shandong Institute of Archaeology (2010)....58
Figure 37 Bronzes at Qianzhangda, after IA CASS (2005)....58
Figure 38 Overlapping between Cyprus ores and non-Cyprus artefacts (Stos-Gale and Gale, 2010)....71
Figure 39 Enlarged area....71
Figure 40 Results of simulation experiments in MeKerrell and Tylecote (1972): arsenic loss.....77
Figure 41 Results of simulation experiments in MeKerrell and Tylecote (1972): antimony loss....77
Figure 42 Change of arsenic concentration in oxidizing/reducing atmosphere (MeKerrell and Tylecote, 1972)....78
Figure 43 The Ellingham diagram of selected metals and oxides, after Bray and Pollard (2012)....79
Figure 44 16 copper groups based on presence/absence of arsenic, antimony, silver and nickel (after Bray *et al*., 2015)....82
Figure 45 Copper groups defined in SAM (after Bray 2009, Volume II: 6)....84
Figure 46 copper groups defined in SAM (after Bray 2009, Volume II: 7)....84
Figure 47 copper groups defined by P. Northover (after Bray 2009, Volume II: 29)....84
Figure 48 Linking different regions by ubiquity of copper groups (after Bray *et al*., 2015: Fig. 2)....88
Figure 49 Two theoretical models of alloying distribution indicating different alloying practice (primary or secondary alloying)....91
Figure 50 Ubiquity of along groups in each period of Roman Britain....92
Figure 51 Profile of zinc percentage in alloying groups of different periods....93
Figure 52 New plotting of lead isotopes suggested by Pollard and Bray (2015)....94
Figure 53 New plotting of lead isotopes in Sardinian objects and ingots....96
Figure 54 Lead isotopes of Cyprus copper sources....96
Figure 55 Alloying database for Shang bronzes....99
Figure 56 Trace elemental database for Shang bronzes....99
Figure 57 Lead isotopes database for Shang bronzes....99
Figure 58 Multi-spot analysis (from Slater and Charles, 1970)....107
Figure 59 Schematic drawing of AAS....111

Ruiliang Liu unpublished thesis

Figure 60 Schematic drawing for laser-ablation/solution-based ICP-MS.....114
Figure 61 Summary of minimum detection limit (MDL) for the first groups of instruments (Pollard *et al*., 2007: 61, Figure 3.4). The definition of (MDL) is given below.....114
Figure 62 Sample bombarded by primary electron beam in an electron microscope 116
Figure 63 Comparison of chemical composition of the identical Bulgarian artefacts 120
Figure 64 Comparison of XRF and NAA tin measurements for the Mesopotamian sites 122
Figure 65 Comparison of XRF and NAA Sb measurements for the Mesopotamian sites ..122
Figure 66 Comparison of OES and ICP-MS lead measurements for Susa 122
Figure 67 Comparison of OES and PIXE arsenic measurements for Hissar.....122
Figure 68 Comparison of XRF and NAA Ag measurements for the Mesopotamian sites..122
Figure 69 Analytical results on pure copper.....128
Figure 70 Oxygen in the primary standard.....128
Figure 71 Analytical results on pure cobalt.....129
Figure 72 Analytical results on pure nickel.....129
Figure 73 Analytical results on pure silver.....129
Figure 74 Analytical results on pure zinc.....130
Figure 75 Analytical results on pure iron.....130
Figure 76 Analytical results on pure iron.....131
Figure 77 Analytical results on pure antimony 131
Figure 78 Analytical results on AsIn (expected percentage of As: 39.45%).....131
Figure 79 Analytical results on PbTe (expected percentage of Pb: 61.89%) 132
Figure 80 Analytical results of copper on secondary standards 135
Figure 81 Cu RE on secondary standards 135
Figure 82 Analytical results of Sn on secondary standards.....136
Figure 83 Sn RE on secondary standards.....136
Figure 84 Analytical results of Pb on secondary standards.....137
Figure 85 Pb RE on secondary standards.....137
Figure 86 Analytical results of As on secondary standards.....139
Figure 87 As RE on secondary standards.....139
Figure 88 Analytical results of Sb on secondary standards.....140
Figure 89 Sb RE on secondary standards.....140
Figure 90 Analytical results of Ag on secondary standards 140
Figure 91 Ag RE on secondary standards 140
Figure 92 Analytical results of Ni on secondary standards.....141
Figure 93 Ni RE on secondary standards.....141
Figure 94 Analytical results of Bi on secondary standards 142
Figure 95 Bi RE on secondary standards 142
Figure 96 Analytical results of Fe on secondary standards.....142
Figure 97 Fe RE on secondary standards.....142
Figure 98 Analytical results of Zn on secondary standards.....143
Figure 99 Zn RE on secondary standards.....143
Figure 100 Analytical results of Co on secondary standards 144
Figure 101 Co RE on secondary standards 144

Ruifang Liu unpublished thesis

Figure 102 Calibration line for Sn 147
Figure 103 Calibration line for As 147
Figure 104 Calibration line for Sb 147
Figure 105 Calibration line for Ni 147
Figure 106 Calibration line for Fe 147
Figure 107 Calibration line for Zn 147
Figure 108 Calibration line for Ag 148
Figure 109 Calibration line for Pb 148
Figure 110 Calibration line for Co 148
Figure 111 Final protocol 152
Figure 112 Comparison of tin between SEM-EDS and EPMA 155
Figure 113 Comparison of lead between SEM-EDS and EPMA 155
Figure 114 Comparison of arsenic in Hanzhong objects 158
Figure 115 Comparison of lead in Hanzhong objects 158
Figure 116 Comparison of silver in Hanzhong objects 158
Figure 117 Comparison of nickel in Hanzhong objects 158
Figure 118 Comparison of iron in Hanzhong objects 158
Figure 119 Comparison of bismuth in Hanzhong objects 159
Figure 120 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs 159
Figure 121 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of As (the cut-off for others is 0.1%) 161
Figure 122 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Sb (the cut-off for others is 0.1%) 161
Figure 123 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Ag (the cut-off for others is 0.1%) 161
Figure 124 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Ni (the cut-off for others is 0.1%) 161
Figure 125 Comparison of tin in Sanxingdui objects 164
Figure 126 Comparison of arsenic in Sanxingdui objects 164
Figure 127 Comparison of lead in Sanxingdui objects 164
Figure 128 Comparison of bismuth in Sanxingdui objects 164
Figure 129 Comparison of tin in Panlongcheng objects 166
Figure 130 Comparison of lead in Panlongcheng objects 166
Figure 131 Percentage of tin in Panlongcheng objects reported by different teams 166
Figure 132 Percentage of lead in Panlongcheng objects reported by different teams 166
Figure 133 Selected vessels from the hoard of Xiangyang Huizu Shipinchang at Zhengzhou 173
Figure 134 Outline of the Panlongcheng site 175
Figure 135 Reconstruction of the palaces at Panlongcheng 175
Figure 136 Summary of various finds in Panlongcheng 175
Figure 137 Tomb PLZM2 (after Hubei Institute of Archaeology, 2001:154) 177
Figure 138 Some Bronzes in PLZM2 177
Figure 139 Four groups of pottery in Panlongcheng (after Hubei Institute of Archaeology,

Ruifang Liu unpublished thesis

2001: 495-496) 178
Figure 140 Distribution of metal deposits along the Yangzi river 181
Figure 141 Jinniudong mining site 181
Figure 142 Preservation of a tiny part in Tonglvshan mining site (Eastern Zhou Period) 182
Figure 143 Reconstruction of the mining structure and excavated objects (after Huangshi Museum, 1999: 52, 129) 182
Figure 144 Remodelling radiocarbon dates for Panlongcheng IV 184
Figure 145 PCA analysis for Panlongcheng bronzes (after Chen *et al.*, 2001) 187
Figure 146 Summary of published databases for Panlongcheng metal assemblage (Data appendix) 189
Figure 147 Distribution of copper groups in Panlongcheng and Zhengzhou 190
Figure 148 Copper groups and object typology at Panlongcheng 191
Figure 149 Tin distribution between Zhengzhou and Panlongcheng 192
Figure 150 Lead distribution between Zhengzhou and Panlongcheng 192
Figure 151 Plotting lead isotopes and percentages of Panlongcheng metals 193
Figure 152 Plotting lead isotopes and percentages of Zhengzhou metals 193
Figure 153 Radiocarbon dates for mines along the Yangzi River, remodeled by Oxcal 196
Figure 154 Nickel-bearing objects at Panlongcheng, with reference to those at Zhengzhou 199
Figure 155 Distribution of nickel-bearing objects in pre-Anyang period 199
Figure 156 Distribution of nickel-bearing objects in Anyang period 199
Figure 157 Distribution of nickel deposits in China (After Lightfoot and Evans-Lamswood, 2015) 200
Figure 158 K-S test for tin distributions at Zhengzhou and Panlongcheng 204
Figure 159 Tin mines from modern geological survey (after Chen *et al.*, 2015) 205
Figure 160 Plotting lead isotopes and 1/Pb of CGs1 and 9 (clean copper; As-Ag) in Zhengzhou 207
Figure 161 Plotting lead isotopes and percentages of CGs1 and 9 (clean copper; As-Ag) in Zhengzhou (see Appendix VIII for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$) 207
Figure 162 Lead isotopes distribution in Erlitou, Zhengzhou and Panlongcheng (Jin *et al.* accepted; Appendix IX for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$) 208
Figure 163 Conventional plotting of lead isotopes 209
Figure 164 Location of Hanzhong and Sanxingdui (insert map are caches of Hanzhong, after Chen *et al.*, 2016, and the site of Sanxingdui, after Xu, 2001) 216
Figure 165 The excavation of Pit II, after Bagley (1990) 218
Figure 166 Standing figure at Sanxingdui (after Rawson, 1996: 61-62) 219
Figure 167 Bronze human-like heads and masks at Sanxingdui, ... 221
Figure 168 One bronze tree from the Pit I, picture on the right is modified from Xu (2001: 62) 222
Figure 169 Zun vessels from Sanxingdui and the middle Yangzi (the top left one is from Sanxingdui, after Xu (2001: 140), the top right one is from Funan in Anhui province, after Bagley (1990b, both bottom ones are modified from Rawson (1996: 72-73), the bottom left is from Sanxingdui and the bottom right is from Hunan province) 224
Figure 170 Jade *ge* (戈), *zhang* (璋) and gold objects at Sanxingdui, the picture of tiger after Xu (2001: 132) 225

Ruiliang Liu unpublished thesis

Figure 171 Gold sheath at Sanxingdui (after Xu (2001:71), length 1.42 m, diameter, 0.023 m and weight 463 g).....225
Figure 172 Distribution of the *zhang* (璋) objects, after Rawson (1996: 83).....230
Figure 173 Copper group distribution at Sanxingdui.....234
Figure 174 Copper groups of vessels and weapons at Sanxingdui 234
Figure 175 As and Sb distribution of CGs1&2 at Sanxingdui 234
Figure 176 Plotting tin and lead of the Sanxingdui metal assemblage.....235
Figure 177 Tin profile between vessels and objects in local styles.....236
Figure 178 Lead profile between vessels and objects in local styles 236
Figure 179 Combining alloying with copper groups.....236
Figure 180 Plotting $^{206}Pb/^{204}Pb$ with 1/Pb (see Appendix XI for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$) 236
Figure 181 SH9 burning pit in Hanzhong and the excavated pottery 240
Figure 182 Pottery found in Baoshan.....240
Figure 183 Selected objects from the Longtou caches.....249
Figure 184 Selected objects from the Xushui cache 250
Figure 185 Selected objects from the cache of Wulangmiao B 251
Figure 186 Selected objects from the cache of Fanba.....252
Figure 187 Selected objects from the cache of Sucun Xiaozhong 253
Figure 188 Selected objects from other caches at Hanzhong.....254
Figure 189 Comparison of weight in sickles.....255
Figure 190 Comparison of length in sickles.....255
Figure 191 Chronology for Hanzhong 255
Figure 192 Distribution of copper groups for the key caches at Hanzhong.....257
Figure 193 Variation of As in objects of the key caches at Hanzhong 258
Figure 194 Variation of Sb in objects of the key caches at Hanzhong 258
Figure 195 Variation of Ag in objects of the key caches at Hanzhong.....258
Figure 196 Variation of Ni in objects of the key caches at Hanzhong 258
Figure 197 Plotting $^{206}Pb/^{204}Pb$ with 1/Pb for key caches at Hanzhong.....263
Figure 198 Pb-Ag assessment for Longtou sickles (see also Chen *et al.*, 2009: Fig. 6b) 265
Figure 199 Pb-Ag assessment for Longtou vessels/weapons.....265
Figure 200 masks/discs from Hanzhong and moulds found at Laoniupo (after Chen *et al.*, 2016) 270
Figure 201 Analyses of copper prills 271
Figure 202 Distribution of triangle *ge* (戈) blade across Shang China (the size of circle representing the number of triangle *ge* (戈) blade in the local region) 273
Figure 203 Distribution of long-shaft *ge* (戈) blade across Shang China (the size of circle representing the number of long-shaft *ge* (戈) blade in the local region) 273
Figure 204 Copper group distribution in the late Shang period 276
Figure 205 Selected objects from Fu Hao tomb,.....281
Figure 206 Summary of bronze objects in Fu Hao's tomb 281
Figure 207 Distribution of copper groups of the Fu Hao metal assemblage.....283
Figure 208 Summary of distribution of copper groups in each object class.....284
Figure 209 Summary of distribution of copper groups in each object class.....284

Ruiliang Liu unpublished thesis

Figure 210 Distribution of arsenic and silver of the Fu Hao metal assemblage.....285
Figure 211 Distribution of tin and lead in the Fu Hao metal assemblage 287
Figure 212 Distribution of tin and lead in the Fu Hao metal assemblage 287
Figure 213 Distribution of tin and lead in the Fu Hao metal assemblage 287
Figure 214 Plotting of $^{206}Pb/^{204}Pb$ of the Fu Hao metal assemblage (see Appendix XIII for plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$).....287
Figure 215 Distribution of tin and lead of the helmets in the king cemetery (M1004).....288
Figure 216 Distribution of tin in objects of.....289
Figure 217 Distribution of lead in objects of Huayuanzhuang M54.....289
Figure 218 Number of tombs in each phase in the Guojiazhuang cemetery（IA CASS, 1998: 51）.....292
Figure 219 The plan and contents of Guojiazhuang M160 (after IA CASS, 1998) 292
Figure 220 Summary of objects in Guojiazhuang M160 tomb 293
Figure 221 The distribution of copper groups in Guojiazhuang M160.....293
Figure 222 Distribution of tin in Guojiazhuang M160.....295
Figure 223 Distribution of lead in Guojiazhuang M160 295
Figure 224 The plan and contents of N. Liujiazhuang M1046 (after IA CASS, 2004).....296
Figure 225 Summary of objects in North Liujiazhuang M1046 tomb 297
Figure 226 Alloying distribution of N. Liujiazhuang M1046 metal assemblage 299
Figure 227 Alloying distribution of N. Liujiazhuang M1046 metal assemblage 299
Figure 228 Distribution of copper groups.....300
Figure 229 Distribution of trace elements in N. Liujiazhuang M1046 300
Figure 230 Distribution of trace elements in N. Liujiazhuang M1046 300
Figure 231 Plan of the Western Area (the number 1-8 in the big map represents each of the eight sections in the Western Area and the intersect map is the distribution of tombs in the first section; after IA CASS, 1997) 301
Figure 232 Chronology of tombs in the Western Area (data from Han, 1997) 302
Figure 233 Summary of chemical analysis in the metals of the Western Area 304
Figure 234 Distribution of copper groups in the Western Area.....304
Figure 235 As and Ni in the Western Area.....305
Figure 236 Ni and Ag in the Western Area 305
Figure 237 Ag and Pb in the Western Area 305
Figure 238 Tin distribution in the Western Area 306
Figure 239 Lead distribution in the Western Area.....306
Figure 240 Variation of tin and lead across Yinxu four phases 308
Figure 241 Variation of tin and lead across Yinxu four phases 308
Figure 242 Plotting of silver and lead for Anyang metals (the silver in the objects above the write line are most likely associated with copper than lead).....309
Figure 243 Distribution of copper groups in Sackler Anyang objects 312
Figure 244 Arsenic distribution in the four major copper groups of Sackler Anyang.....312
Figure 245 Distribution in the four major trace elements of Sackler Anyang.....312
Figure 246 Profile analysis of tin for Anyang styled objects in the Shang Sackler collection 313
Figure 247 Profile analysis of lead for Anyang styled objects in the Shang Sackler collection

Ruifang Liu unpublished thesis

.....313
Figure 248 Traditional bi-plot of lead isotopes.....314
Figure 249 Combing trace elements and lead isotopes.....314
Figure 250 New plotting of lead isotopes and lead concentrations (see Appendix XV for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$).....314
Figure 251 Plotting $^{206}Pb/^{204}Pb$ against lead percentage (see Appendix XVI for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$).....314
Figure 252 A sharp decrease of radiogenic lead in the III phase of Anyang (see Jin *et al.*, accepted for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$).....318
Figure 253 Mixing line: copper with common lead is alloyed with radiogenic lead (see Appendix XVII for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$).....319
Figure 254 summary of metal chemistry in different social status 324
Figure 255 summary of metal chemistry in different phases 324
Figure 256 Theoretical model of mixing reflected by lead isotopes.....328
Figure 257 Theoretical model of mixing reflected by lead isotopes.....328
Figure 258 Distribution of copper groups in the Late Shang period (data source: Ma *et al.*, 2012; Chen, 2009; Liu, 2015; Wei *et al.*, 2006; Dong, 2012; Zhao, 2005; Bagley, 1987; Li, 1982; Li *et al.*, 1984; Ji, 1997; Zhao *et al.*, 2008; Chen *et al.*, 2001; RLAHA unpublished data).....335
Figure 259 movement of metal during the late Shang period (LI: lead isotopes; LI A: radiogenic lead; LI B: common lead, regions in dash square needs more data in the future).....339
Figure 260 Summary of copper group distribution of Erlitou, Zhengzhou and Anyang.....342
Figure 261 Tin movement in Alpine region (after Perucchetti *et al.*, 2015; the colours of the points are the average of tin percentages in the overall metal assemblages from one site and the colour of each square represents the percentage of tin bronze in that region).344
Figure 262 Tin movement in Mesopotamia and Iran plateau (after Cuénod *et al.*, 2015; the symmetric distribution of tin (primary alloying) in Luristan suggests a rich tin supply whereas the skewed tin in Mesopotamia (secondary alloying) is indicative of recycling tin from bronze, possible from Luristan) 345
Figure 263 Alloying distribution in the late Shang period (see data appendix in the thesis for the source of data).....346
Figure 264 Alloying distribution before the late Shang period (see data appendix in the thesis for the source of data) 346
Figure 265 Variation of tin in the pre-Anyang period.....347
Figure 266 Cumulative frequency analysis of tin variation in the pre-Anyang period 347
Figure 267 Variation of tin in the Anyang period.....347
Figure 268 Cumulative frequency analysis of tin variation in the Anyang period.....347
Figure 269 Profile of lead in the pre-Anyang period 348
Figure 270 Cumulative frequency analysis of lead variation in the pre-Anyang period.....348
Figure 271 Profile of lead in the Anyang period.....348
Figure 272 Cumulative frequency analysis of lead variation in the Anyang period 348
Figure 273 Profile of tin in objects at Erlitou, Erligang and Anyang.....351
Figure 274 Cumulative frequency analysis of tin in objects at Erlitou, Erligang and Anyang

Ruiliang Liu unpublished thesis

.....351
Figure 275 Profile of lead in objects at Erlitou, Erligang and Anyang 351
Figure 276 Cumulative frequency analysis of lead in objects at Erlitou, Erligang and Anyang 351
Figure 277 Lead isotopes in the Anyang period, data source: Jin *et al.*(1994, 1995, 2006, 2008, 2001), Tian *et al*. (2010), Liu (2015), Wang *et al.* (2006), Peng *et al*. (1997, 1999), Li (2002), Bagley (1987), Chase (1996-97), Takahama *et al*. (2001). 355
Figure 278 Lead isotopes in the Anyang period, data source: Jin *et al*. (1990, 2001, 2006), Wang *et al*. (2006), Sun *et al*. (2001), Peng *et al*. (1997, 1999, 2001), Cui and Wu (2008), Tian (2013).....355
Figure 279 $^{206}Pb/^{204}Pb$ values for vessels from Erlitou, Erligang, Panlongcheng, Yuanqu, Anyang, Western Zhou (after Jin *et al*., accepted) 356
Figure 280 Modeling possible mixtures of copper-based objects from different regions..360
Figure 281 Summary of alloying data for Shang China.....372
Figure 282 Summary of alloying data for Shang China.....372
Figure 283 Summary of trace element data for Shang China 372
Figure 284 Two identical vessels, the same life history (after Bagley, 1987) 382

Ruiliang Liu unplished thesis

List of Tables

Table 1 Chemical analyses of the pou vessel in Sackler collection 104
Table 2 Analytical results for spots in Figure 58 (data from Slater and Charles, 1970)..... 107
Table 3 Compositional variation of a cannon (Gilmour and Northover, 2003)..... 108
Table 4 List of secondary standards with certified values..... 133
Table 5 Estimation of minimum detectable limit 149
Table 6 Number of objects with trace elements above 0.1% with SEM-EDS/EPMA 157
Table 7 Copper group distribution based on different datasets of Sanxingdui..... 164
Table 8 Comparison chemical databases of objects with Shang metropolitan style produced by different laboratories and instruments..... 168
Table 9 Chronological framework of Panlongcheng (Hubei Institute of Archaeology, 2001: 442-446)..... 183
Table 10 Possible distributions of copper groups at Erlitou..... 197
Table 11 Comparison of tin percentages in objects at Zhengzhou and Panlongcheng..... 203
Table 12 Information of tin distribution in modern China (Data from Chen *et al*., 2015).... 205
Table 13 Presence/absence of various types of lead isotope signals 209
Table 14 Summary of objects in Hanzhong caches..... 241
Table 15 Summarization of copper groups, alloying and typology (Colour coding represents copper group, in each bracket, it shows the number of objects catalogued as one copper group, *e.g.* CG1x9, red representing CG1, means nine objects are catalogued to CG1) 260
Table 16 Chemical and isotopic data on the two vessels above (from Bagley, 1987)..... 382

Ruiliang Liu unpublished thesis

Chapter One Introduction

1.1 Research objectives

The study of Bronze Age China is a vast field, contributed by multiple generations of scholars, and with a great number of excavations and specialist studies. These together form a significant diversity of theories and encompass a wide range of materials, all of which hugely contribute to interweaving our understanding of this remote world. Some of them are exemplified by the study of bronzes, [1] technologies, [2] textual records,[3] settlements,[4] craft productions,[5] chronologies,[6] human diets,[7] climatic changes,[8] landscapes,[9] social organizations,[10] political administrations,[11] ritual practice[12] and ultimately, human interactions.[13]

1 Bagley, 1999, 2008; Chang, 1980; Rawson, 1999; Thorp, 2006.
2 Bagley, 2009; Barnard, 1961; Linduff and Mei, 2014; Mei *et al*., 2009, 2015.
3 Keightley, 1978, 1983.
4 Hosner *et al*., 2016; Liu and Chen, 2009; Wagner *et al*., 2013.
5 Chen, 2014; Ledderose, 2000; Li, 2003; Martinon-Torres *et al*., 2014.
6 Li, 2002; Nivison, 1999; Nivison, 2002; Xia-Shang-Zhou Chronological Project, 2000.
7 Fuller and Rowland, 2011; Jones *et al*., 2011; Underhill, 2002; Zhao, 2011.
8 Dong *et al*., 2012; Dong *et al*., 2013; Tarasov *et al*., 2006.
9 Keightley, 1999; Li, 2006.
10 Liu and Chen, 2012; Shelach-Lavi, 2015.
11 Campbell, 2009.
12 Rawson, 1988; Falkenhausen, 2006.
13 Allan, 2007; Anthony, 2007; Barfield, 1989; Di Cosmo, 2002; Mei, 2009; Rawson, 1994, 2015a, b.

Ruiliang Liu unpublished thesis

Benefiting from all of these valuable studies, this thesis chooses to concentrate on the subject of the chemical analysis of bronze objects in order to open up new dialogues. Its major objective is to capture changes in metal chemistry and ask why. These changes are vital to archaeologists because they carry information on the interactions between metal and humanity, including the changes in the provenance of raw metal, its movement (either as raw materials or finished objects), local production versus importation, and the organization of production. Because of various pragmatic difficulties, it is not yet feasible to provide a full and exact picture for all these topics, but the changes captured by this thesis may help archaeologists ask new questions about these topics and sometimes reveal at least parts of the answer.

Because the discussion focuses on comparing chemical compositions of objects on a level of metal *assemblages*, a large database is thus required (Data appendix in the attached CD). Here I would also like to express our best appreciation to scholars who have produced and published these data.[14] This study could not have been achieved without their immense effort and important publications.

The fundamental difficulty rests on the imbalance between the fragmented nature of the current database and the potentially complex network of metal across Shang China. Therefore, this thesis has chosen to apply an open and integrated research system

[14] Mei *et al*., 2009; Chen *et al*., 2009; Chen, 2009; Li, 1982; Li *et al*., 1984; Ji, 1997; Zhao *et al*., 2006, 2008; Zhao, 2004, 2005; Bagley, 1987; Rawson, 1990; Chen *et al*., 2001; Hao and Sun. 2001; Tian, 2013; Tian *et al*., 2010; Wang *et al*., 2008; Sun *et al*., 2001; Ma *et al*., 2012; Jin, 2000, 2008; Liu, 2015; Cao, 2014; Wei, 2007; Wei *et al*., 2006 and many others.

Ruiliang Liu unplished thesis

which accommodates *both* conventional provenance study linking mines to objects and the *possibility* of mixing/recycling. This has become known as the 'Oxford system' (Bray *et al*., 2015; Pollard *et al*., in press-a and b). The reason that this system is open and integrated is clarified in Chapter Two. Although the same system has been applied to many relatively smaller and simpler regions in Eurasia, this thesis chooses to work on Shang China, which is remarkably different because it was a highly centralized and complex society. As proposed by Rawson in the most two recent papers (Pollard *et al*., in press-a and b), during the late second millennium BC, a network of metal supply and exchange, involving both raw metal and cast bronzes, engaged large areas of northern, southern and central China, which is dramatically different from the patterns seen in other parts of the Bronze Age world.

Clearly, this present study has been driven by the availability of scientific analyses of bronze objects. Given the uneven distribution of such scientific analyses, this thesis focuses on a number of selected regions, including the Central Plains, south and southwestern China. Areas such as the Wei River valley, north Shaanxi and northeastern China are also crucial to understanding the entire network and are drawn into the discussion, in spite of their limited number of data. The chronological scope is restricted to the second millennium BC, following the common framework in the literature, namely Erlitou-Erligang-Anyang. In order to present a broader picture, some metal assemblages dated to the Western Zhou period are occasionally taken into consideration.

Ruiliang Liu unplished thesis

1.2 Why changes in metal chemistry?

In the early stage of archaeometallurgical research, chemical compositions were already used as a key to understanding how the metal in antiquity was transformed into objects and manipulated within human societies (Pollard, 2016; Sherratt, 1976). Considerable attention was given to finding out the earliest activities of mining, smelting and manufacturing technology. By plotting these traces against time and space, scholars began to understand the history of the spread of metallurgy across Eurasia (Chernykh, 2008; Roberts *et al*., 2009). Another crucial thread is provenance studies. Mines and smelting sites, as the birthplace for metal, are absolutely vital to understanding the entire network of metal supply, particularly in a large society where a great mass of metal was routinely consumed. By comparing the chemical or isotopic compositions of metal (copper, tin and lead), scholars have suggested that tracing metals to their original sources becomes possible. This work has been a fundamental driving force for many large-scale projects of metal analysis in Europe (Pernicka, 2014). However, archaeology is not only about things. It is about things, humans, and their interactions (Pollard *et al*., 2007: 1). A one-to-one biographic model, as assumed by the traditional provenance school to link objects to ores, represents a life history in which metals were firstly extracted from the ores, cast into objects, came into the general circulation and were finally deposited. This is certainly correct in some cases, but may not reflect more complicated scenarios (Bray *et al*., 2015; Needham, 1998; Pollard *et al*., in press-a and b).

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This thesis follows the argument proposed by the Oxford group that the changes in metal chemistry are a result of the complexity in a series of human interventions with metal. While the initial chemical signatures of objects are constrained by the nature of the mines, all subsequent procedures could in theory bring about changes to the chemical composition of the resulting metal, including mining, ore selecting, beneficiation, roasting, smelting, refining, casting, hammering, polishing, recycling, realloying and mixing. We argue that apart from linking ores to objects, these changes in chemistry contain many hidden lines of information intriguing to archaeologists and yet to be discovered.

One major feature of metal is that it can be moved from one group of people to another in the form of either finished objects or raw materials, with or without mixing/recycling. These groups of people may live in different times and space. For instance, they could live in contemporary times but geographically different sites, or in the same site but belong to different social strata (*e.g.* elites *versus* non-elites). They could even live in the same geographical region but one replaced the other and inherited their metal objects, which were subsequently recycled into new forms, or not. What is of archaeological interests is the complex mechanism embedded underneath these versatile metal movements due to human activities, including exchange, robbery, capture, tribute, gifts, bribes, heirlooms, to name a few. Investigation into these movements of metal can be used as a proxy to advance our understanding of the use of metal in human societies and various underlying human dynamics.

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1.3 Why China?

Although a number of research articles and PhD theses have successfully applied the Oxford system (defined in Chapter Two) to regions characterized by small-scale social organization (Bray and Pollard, 2012; Cuénod *et al*., 2015; Hsu *et al*., 2016; Perucchetti *et al*., 2015), this thesis aims to show that the same system can improve our knowledge of the use of metal in the large and highly centralized social context of Shang China.

The manufacture and manipulation of metals is exceptionally remarkable in the Chinese Bronze Age (Figure 1). The first distinctive feature is the scale of production (Keightley, 2012; Ledderose, 2000; Rawson, 2015 a and b). Though no accurate estimate is yet possible, undoubtedly the output of metal objects in Bronze Age China, especially ritual vessels during the Shang period, was staggering. In the Central Plains, which is famous for its agricultural production, turning agricultural surplus into bronze vessels signifies a critical socio-political determination and economic prosperity (Rawson, in press-b). It also requires a series of stable and sophisticated social organizations in order to maximize the production and monitor the quality of the bronzes (Bagley, 1990a). The assemblage recovered from the tomb of Fu Hao (*ca.* 11th century BC), the consort of King Wu Ding at Anyang (Figure 2), contains a total amount of bronze metal of 1.6 *ton*. Being scaled up certainly distinguishes China from the rest of Eurasia during the Bronze Age (Rawson, in press-a).

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Secondly, ritual vessels account for a critical component of this scale. No other parts of the Eurasia have ever dedicated so much metal and labour into producing such a range of complicated ritual bronze vessels. Therefore, in the use of metal in China, social preference and ceremonial activities played a salient part.



Figure 1 The largest Shang bronze vessel discovered so far, Simuwu *Ding* (鼎), height *c.* 133cm, weight *c.* 832 Kg

The third feature of Chinese bronzes is the use of lead during the very earliest stage of production. It appears rather striking that some of the metal objects cast at Erlitou, one of the earliest sites in the Central Plains using metal (*ca.* 19th – 16th centuries BC), can

contain over 30% lead (IA CASS, 2014: 1515-1518; Figure 2). Leaded tin-bronze was subsequently used to cast the majority of ritual vessels in Central China during the Erligang and Anyang periods of the Shang, and also into the Western Zhou period. Given the astonishing scale of production, the consumption of lead must have been considerable, but its source(s) is however not yet determined. A further interesting question is how the idea of addition of lead entered into central China in the very beginning of the Bronze Age.

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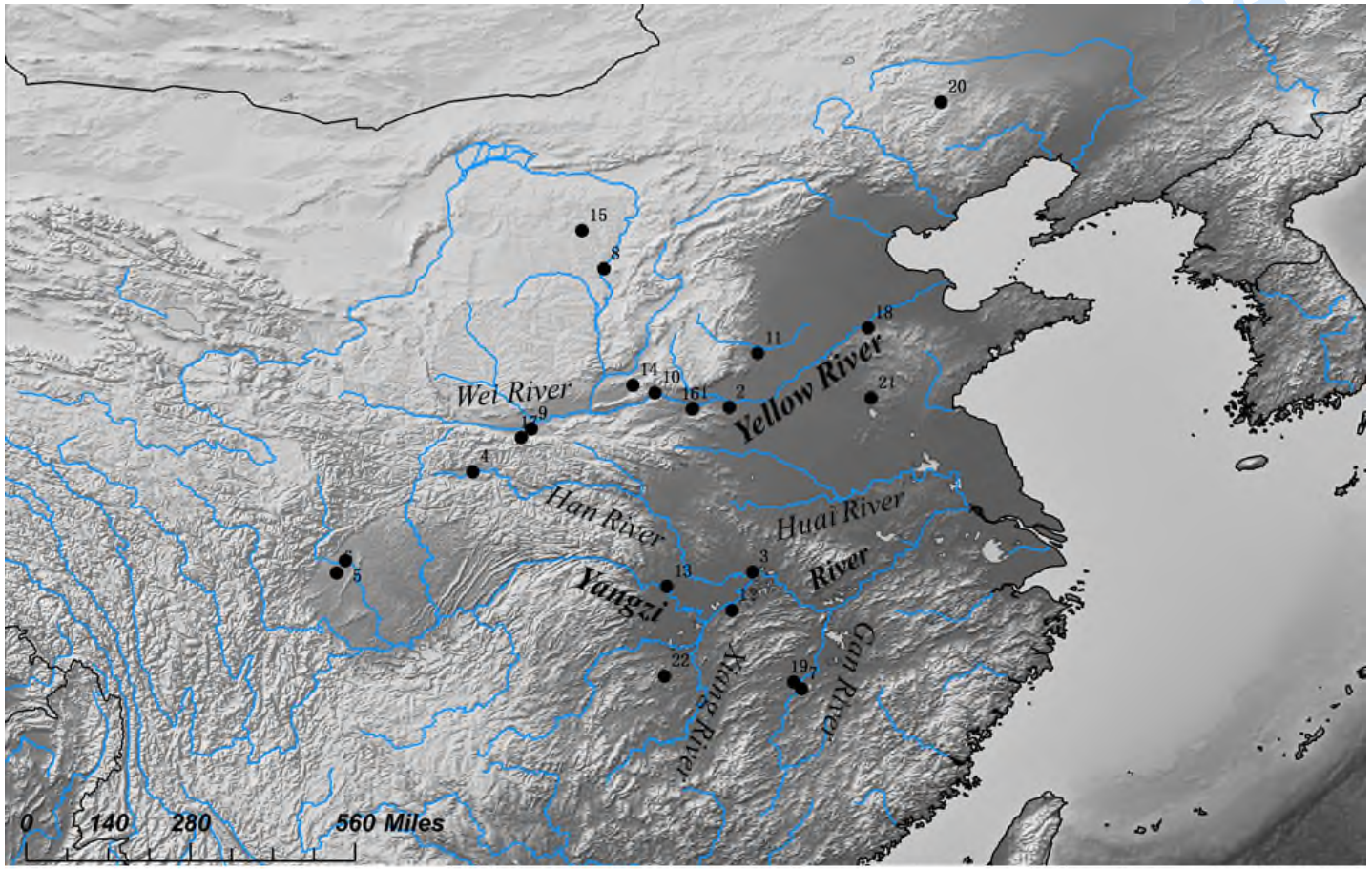

1. Erlitou 2. Erligang 3. Panlongcheng 4. Hanzhong 5. Sanxingdui 5. Jinsha 7. Xin'gan 8. Qingjian 9. Guanzhong 10. Yuanqu 11. Anyang 12. Tonggushan 13. Jingnansi 14. Dongxiafeng 15. Zhukaigou 16. Yanshi 17. Laoniupo 18. Daxinzhuang 19. Wucheng 20. Dadianzi 21. Qianzhangda 22. Tanheli

Figure 2 Key sites in Chapter One

The fourth factor that differentiates China from the rest Eurasia is that its bronze production was deeply rooted in the well-established industry of ceramics (Bagley, 1990a; Liu and Chen, 2009: 63; Rawson, in press-b). In fact, China had built up a highly developed ceramic enterprise long before the arrival of metallurgy. The egg-shell black ceramics found in Shandong represent the pyrotechnology that was already achieved in Neolithic China. Meanwhile, the scale of ceramic production also anticipated a massive production of later bronzes. When we consider the outstanding technology of piece-mould casting for bronzes (Barnard, 1961; Bagley, 1987; Figure 3), it is true to say that the ceramic-based industry formed an indispensable ground for the later bronze production.

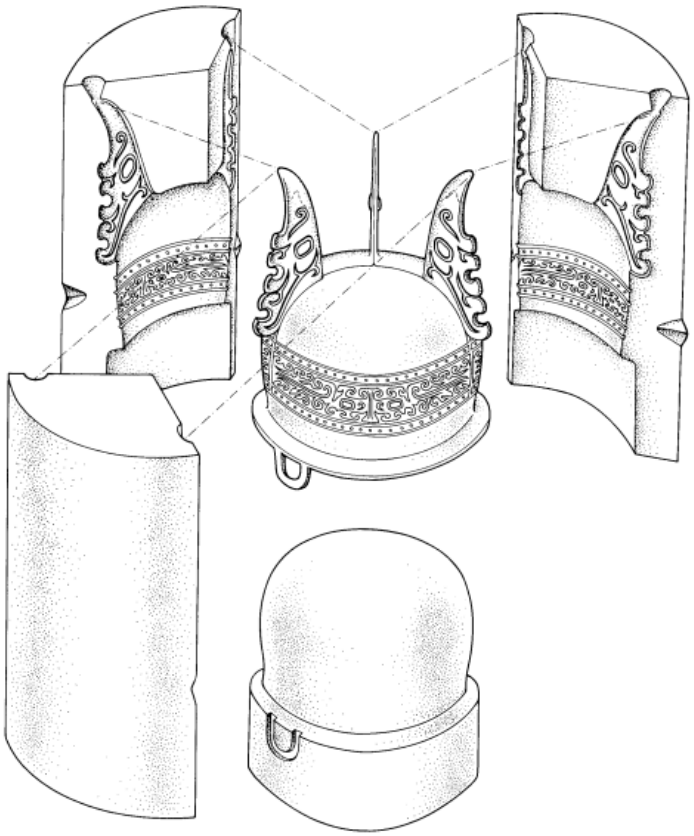

Figure 3 Piece-mould casting

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The archaeological and technological observations summarized above were made in the Slade lectures by Rawson in 2014 at Cambridge (see also Rawson in press-a and b). In the light of these considerations, it is reasonable to argue that, in comparison with many other parts of Eurasia, the metal production in Bronze Age China shows a number of conspicuous features that defined a very different trajectory from the rest of Eurasia. Therefore, an inescapable conclusion must be that though the pattern of metal movement which has been found in other regions might be stimulating, they may not be able to offer some exact analogies to China, which in many ways is worthy of further and independent investigation.

1.4 Geographical landscape in China

A broad overview of modern China reveals many significant geographical characteristics. It can be roughly divided into three regions, which resemble three steps as the height in each part decreases radically from west to east. The western part comprising the Himalayas and the vast Tibetan plateau, where is the result of the collision of the Indo-Australian plate and the Eurasian plate in the Tertiary period. This also accounts for the formation of many formidable chains of mountains in Eurasia and China. The second step includes the landmass between the Tibetan plateau and the line demarcated by a series of north-south mountains, including the Great Xing'an, Taihang, Wu and Xuefeng. Many regions peripheral to Central China are within this step, such as the loess plateau, the Wei River valley, the Hanzhong

Puiliang Liu unplished thesis

basin and the Sichuan basin. The last step lies in the eastern heartland of China, which is comparatively the lowest in height and directly exposed to the Pacific Ocean. The Central Plains lie in the north part of this step and its southern part is mostly valleys and basins situated in mountainous regions.

Two long rivers in China, the Yellow River and Yangzi, originate in the Himalaya. The former flows across the north part of China and the latter flows in the south. Together with the complex tributaries, both rivers have many profound impacts on local landscape and life styles. The Yellow River, when it crosses the loess plateau, becomes saturated with loess and therefore its colour changes to yellow. As it flows further eastwards and slows down, the loess grains start to deposit and raise the river bed. The height of the river bed continues to increase, which finally results in periodic and violent floods which subsequently alter the course of the river. In consequence, people who lived in the lower reaches of the Yellow River frequently had to flee their homeland. The river bed, which is full of fine loess grains, is however extremely fertile and suitable for growing crops. It is also important to mention the main tributary of the Yellow River, the Wei River in the Guanzhong Plain. This develops into another set of rivers of archaeological and historical importance throughout Chinese history. Chang'an (modern Xi'an city), which used to be the capital city of thirteen dynasties, is sited there. Compared with the Yellow River, the Yangzi River in the south is more suitable for transportation. It is less meandering and the channel is much deeper and clearer. It has several important tributaries which connect or flow

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through areas of great archaeological interests. The Han River links the Hanzhong basin and the middle Yangzi River. The Gang and Xiang Rivers, two large branches of the Yangzi River, flow further southwards into the modern province of Jiangxi and Hunan, respectively. Undoubtedly, the river systems provided efficient transportation across different regions and a broad generalization is that the west-east communication seems easier than that of north-south (Shelach-Lavi, 2015: 10).

The landmass of China also provides a huge diversity of climates and vegetation. Putting aside the Tibetan plateau and Xinjiang, the rest of China is still divided into three climatic zones. Each is largely conditioned by the longitude, latitude and the seasonal monsoons. In summer, high pressure forms in the Pacific Ocean and the Indian Ocean and the resultant monsoons bring heavy precipitation into the hinterland of China. The volume of precipitation decreases as they move further north. In winter, the wind that starts in north Siberia blows cold and dry air into the south. The seasonal change of the nature and direction of the monsoon wind greatly affects the local temperature and precipitation. The southern part of China, such as the lower reaches of the Yangzi River, is rather humid and hot in summer, with precipitation around 1300 mm per year. This provides ideal conditions for growing rice. However, the lower reaches of the Yellow River enjoy much less precipitation, which is around 700 mm per year. The major agricultural products are wheat and millet. The catchments of both the Yellow and Yangzi Rivers were well provided with various kinds of animals, such as cattle, pigs, sheep or deer. By virtue of these climatic and

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ecological factors, the reaches of the Yellow River and the Yangzi River offer optimum conditions for communities to settle down and develop an agriculture economy. In contrast, regions beyond the Yan Mountains, which is now formalized by the Great Wall, are more steppe-like. People living there are more mobile and their major economic subsistence is herding animals, such as cattle, sheep and horses, with some agriculture.

Geography matters because it both constrains and empowers (Cunliffe, 2015: 7). Confronting the natural opportunities and challenges, the inhabitants have to develop a great many strategies to make a life. The delicate and complex interrelationship between humanity and the environment generates a wide range of archaeologically intriguing questions. One of the most obvious questions is the communications between different groups of people. Formidable ranges of mountains appear to be huge barriers but passages can be found at the micro level. One example is the Taihang Mountains which isolate the Central Plains from the west. Nevertheless, eight passages (太行八陉) connecting both sides of Taihang have been recorded in the ancient texts.

Ruiliang Liu unplished thesis

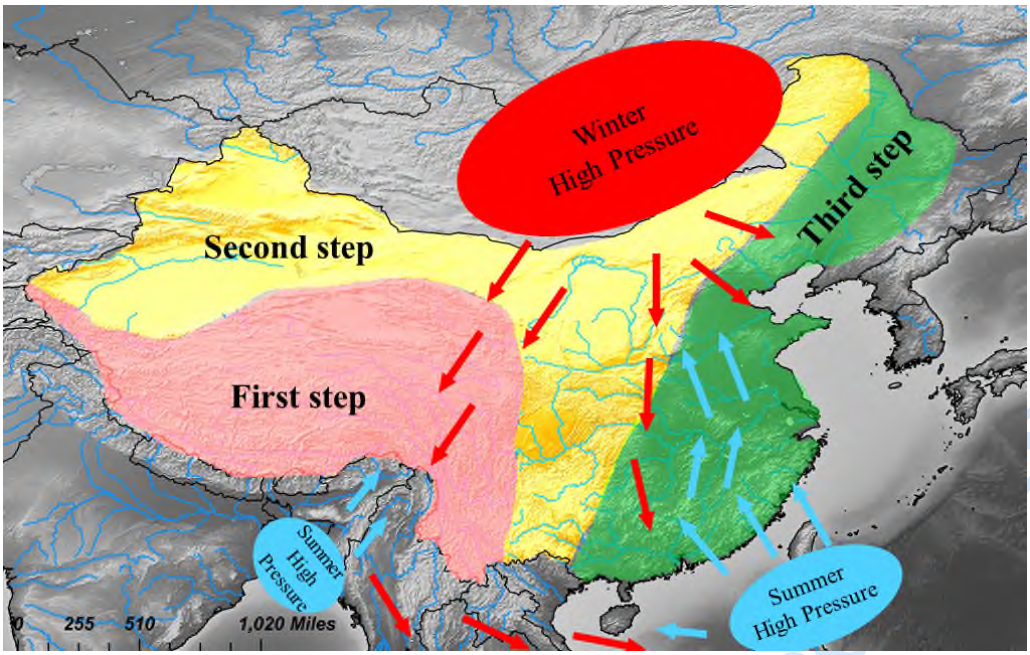

Figure 4 Three geographical steps in China and its monsoon seasons.

Apart from the possible passages through mountains or along rivers, the other factor that affects human life is the acquisition of natural resources, such as highly desired copper, tin and possibly lead. While all these three metals have rich deposits in China, their distributions are extremely uneven. The modern geological investigation shows that the four largest copper-deposited regions in China are on the middle and lower Yangzi River, southwestern China (mainly modern Yunnan province), Gansu and northeastern China. Together these areas possess over two thirds of the entire copper deposits in China. In the Central Plains, which is known for its massive production of metal objects during the Bronze Age, copper deposits can only be found in the Zhongtiao Mountains of southern Shanxi. Compared with copper, the tin deposits are concentrated in far more limited regions. Most of them are in the remote south and southwestern part of modern China, such as Yunnan, Guangxi, Guangdong. Tin mines

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in the northern part of Jiangxi and Hunan province and east Inner Mongolia may lie within the accessible distance of the Central Plains in the Shang period. More detailed discussion on the distribution of tin mines in China can be found in Chapter Four. In contrast to the rarity of copper and tin, lead deposits are significantly more ubiquitous across China. In very broad terms, this difference may indicate that the supply network of lead might be different from that of copper and tin. Similarly, a variety of other kinds of important resources, such as kaolinite, salts or herbs also attracted human attention but may well have been located in some geographically specific areas. The imbalance between the general acquisition of these natural resources and their confined geographical distribution must have caused varying degrees of impact on human movement and interaction. Also, rivers can also provide both connectivity and barriers, depending on the real physical conditions and the water transport technology. As a whole, geography plays a pivotal role in our understanding of the networks of interactions and the socioeconomic basis of different societies.

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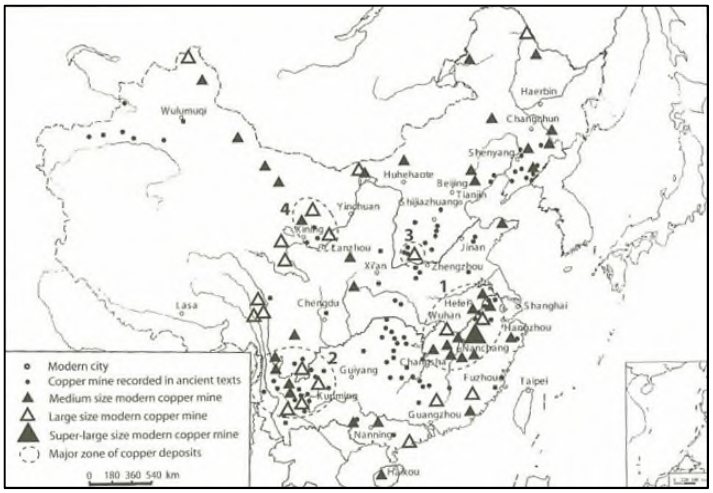

Figure 5 Copper deposits in China (after Liu and Chen 2009: 38, figure 5)

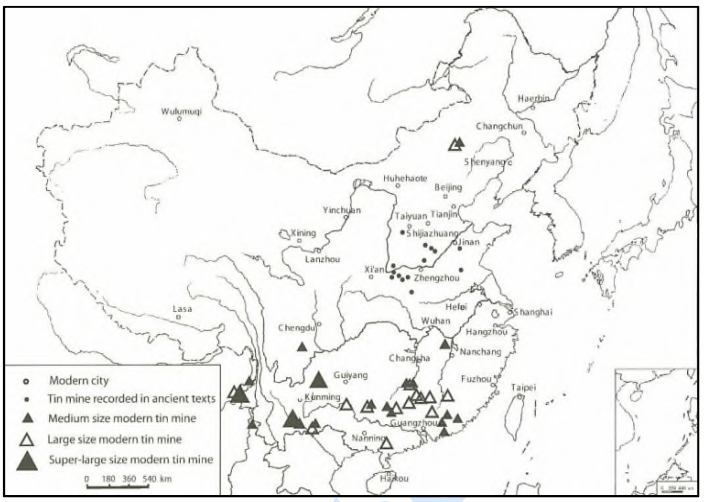

Figure 6 Tin deposits in China (after Liu and Chen 2009: 40, figure 6)



Figure 7 Lead deposits in China (after Liu and Chen 2009: 41, figure 7)

1.5 Archaeological landscape

The period that concerns us is approximately from 19th century BC to 1046 BC. The major chronological framework in this thesis follows the dates proposed in Liu and Chen (2012) (see also Figure 8 and Liu, 2009). By comparison with limited historical records pertinent to this period, the archaeological evidence has become considerably richer as a result of the increasing number of excavations in recent years. Particularly

in the Central Plains, the discovery of the site at Erlitou, Zhengzhou and Anyang, has provided a great deal of complex and continuous material culture for the investigation of the early evolution of China. More importantly, the archaeological cultures that the three sites represent, namely, the Erlitou culture, the Erligang culture and the Yinxu culture, have built up a sequential chronology and convenient nomenclature that have been widely used in publications. Following this framework can give us an easy starting point for the discussion.

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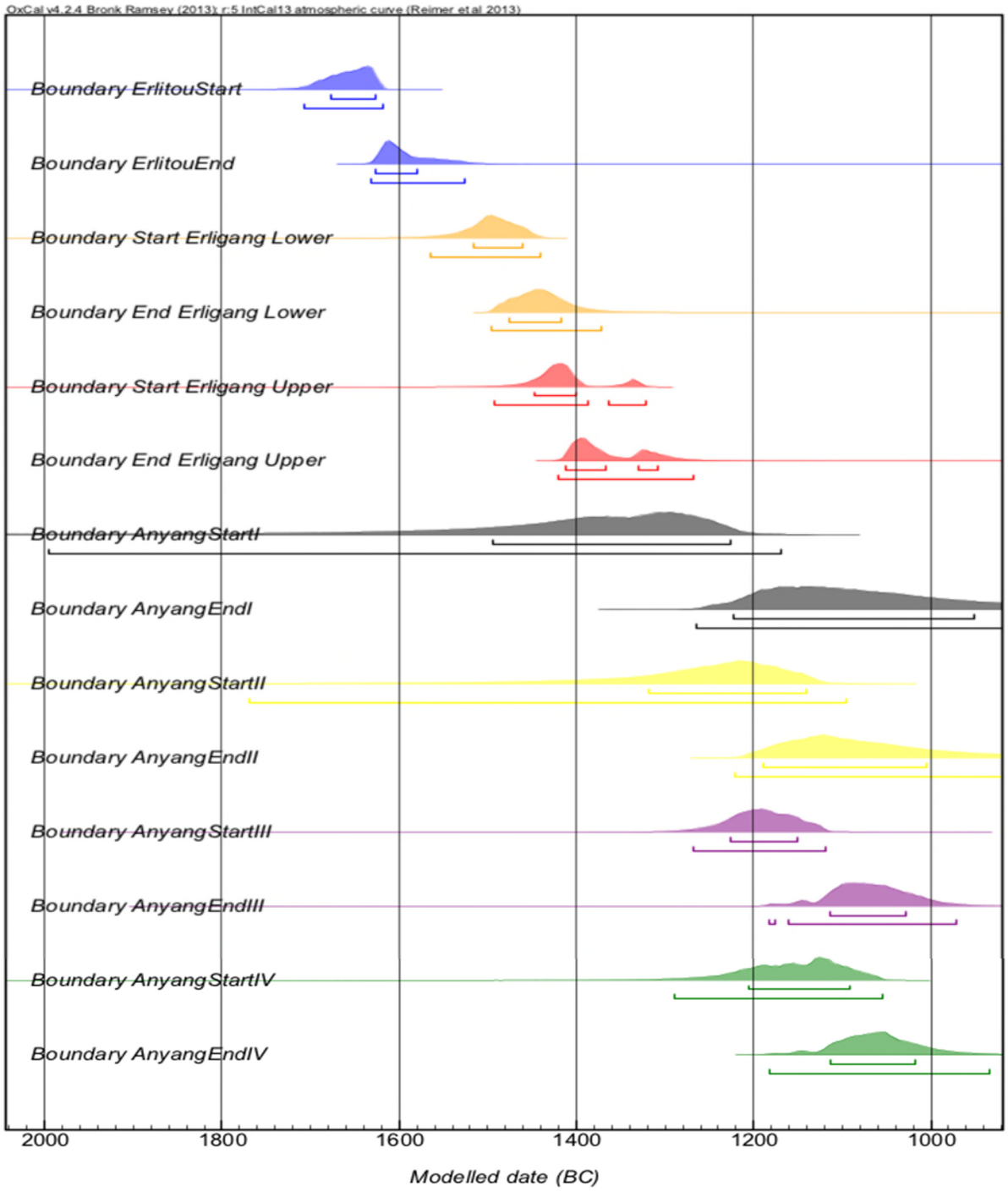

Figure 8 Remodel radiocarbon dates of Erlitou, Erligang and Anyang (data from Xia-Shang-Zhou chronological report)[15]

[15] To our knowledge, applying Bayesian modeling to radiocarbon dates is very rare in the Chinese literature. Figure 8 is probably the first attempt to model the dates of Erlitou, Erligang and Anyang altogether but quite a few interesting results emerge quickly. The start of Erlitou appears not as early as 19th century BC, which has been already confirmed by more dates in the new publication of IA CASS (2014: 1215-1238). A clear gap is visible between the end of Erlitou and the start of Erligang. The reason might be that the samples are not sufficiently representative to draw a clear transition between Erlitou and Zhengzhou but otherwise it would be very archaeologically interesting to ask the meaning of this gap. Likewise, the significant overlap between each phase of Anyang is probably due to the lack of dates (Erlitou: 18 dates; Erligang Lower: 7 dates; Erligang Upper: 8 dates; Anyang I: 3 dates;

1.5.1 Erlitou

The first bronze-casting of ritual vessels in central China was found at the site of Erlitou, located in the present Yanshi city of northwest Henan province (Figure 2). A wealth of materials have been yielded from its excavation since 1959, including various architectural foundations, workshops for bones and bronzes, pottery kilns, burials, and an impressive number of objects, such as bronzes, jades, turquoises, pottery, bones and shells (IA CASS, 1965, 1983, 1984, 1985, 2014). Its major economy was based upon agriculture, with an emphasis on millet. Domestication of animals such as pigs, sheep and cows became increasingly important in the later phases of Erlitou. The strontium analysis on human dental enamel, though in a very limited number, indicates that the percentage of outsiders cannot be neglected (Zhao *et al*., 2011). More discussions on the recent work of Erlitou can be found in IA CASS (2014).

Ruiliang Liu unplished thesis

Anyang II: 3 dates; Anyang III 13 dates; 13 dates; Anyang IV: 5 dates). In this case, I only apply the most straightforward phase-boundary model in Oxcal but in the future when more radiocarbon dates become available, one can use more sophisticated models and perhaps ask questions like on what probability Erlitou, Erligang and Anyang are successive?

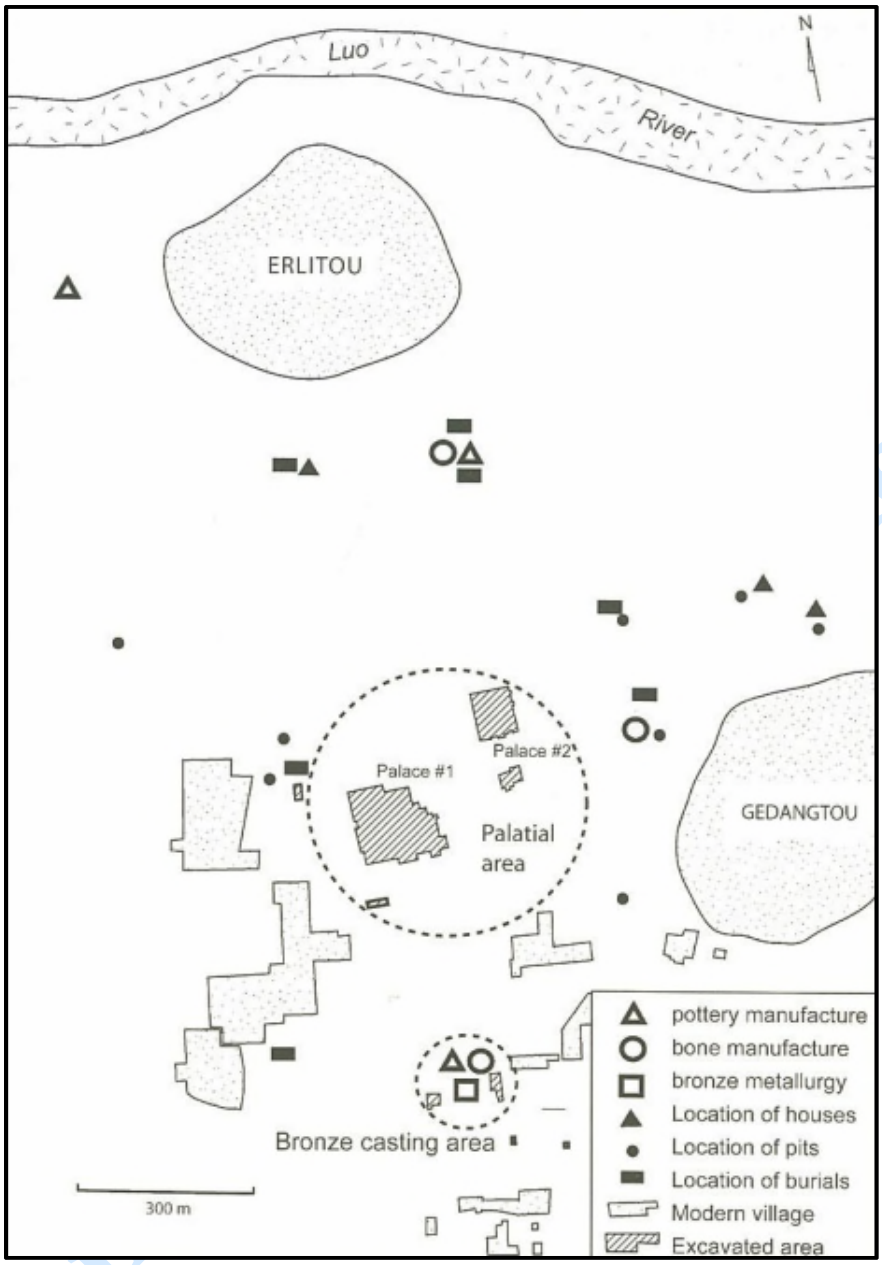

Figure 9 Outline of Erlitou, from Liu and Chen (2009: 61, figure 12)



Figure 10 Satellite image of Erlitou site (after IA CASS 2014, volume V, colour image II)

The site of Erlitou, an area around 400 hectares, was occupied approximately between the 19th and 16th centuries BC (Figure 9). It is usually divided into four chronological phases (IA CASS, 1999, 2014). Initially, it was inhabited by a small group of people before the Erlitou period. The Erlitou I-II phase saw a rapid rise of the local population, a range of craft productions and public works. Liu and Chen (2009: 58) suggested that this might be related to migration from elsewhere rather than a natural population growth. Meanwhile, traces of metalworking have been identified to the II phase of Erlitou, including copper-based objects (knives and chisel), fragments of crucibles and pieces of clay moulds (IA CASS, 1999: 80, 2014: 296). The most recent excavation at Shimao in northern Shaanxi offers a range of materials strongly

Ruliang Liu unpis

resembling those at Erlitou. Rawson suggested that this might imply a wave of immigration from north to south, and the underlying drive could be climate change (Rawson, 2017).

The zenith period of Erlitou was found in phase III. Two “palaces” (Palace No. 1 and No. 2) were constructed upon rammed earth foundations in the third phase (Figure 11). One is around 9585 m^2 and the other is 4200 m^2 (IA CASS, 1999: 138/151). Zou (1979: 28) made an estimate that 20,000 m^3 of earth was necessary to complete the construction of Palace No.1 and this may have required more than 100,000 man/days of work. These two palaces provide a vivid picture of the capability of Erlitou to manipulate and organize a striking amount of human labour in order to achieve public works. The peak of Erlitou continued across its phase III but faded in phase IV, which can be seen by a radical decrease of population and the abandonment of palaces, houses and boundaries.

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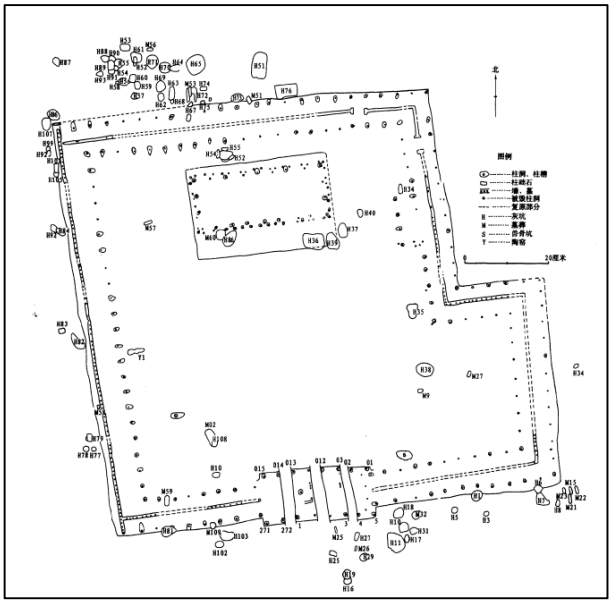

Figure 11 Palace No.1 at Erlitou, from IA CASS (1999:139, figure 84)



Figure 12 Excavation of the palace foundations (after IA CASS, 2004, volume V, colour image V)

In addition to the two so-called palaces, another impressive feature of Erlitou is a variety of craft productions. Their growing importance is well demonstrated by the discovery of many workshops, involving bone processing, pottery firing and metal working, which is in turn strongly suggestive that many objects were made locally at Erlitou. The bronze foundry, dated to Erlitou phase II-IV, was located on the south of the site, roughly with an area of one hectare. It was recognized from the remains of slags, crucibles, clay moulds and casting debris (*e.g.* IA CASS, 1999: 80-82). Most copper-based objects have been dated to the III-IV phase of Erlitou with a few smaller ones to the II phase. They include small tools, weapons, bells and bronze vessels. The appearance of bronze vessels was considered a critical watershed in the understanding of Bronze Age China. As mentioned above, the production of bronze ritual vessels distinguishes China from the rest of Eurasia. Although metallurgy in the northwest of

Ruiliang Liu unplished the

China, such as in the Gansu corridor, was actually earlier, it was completely repurposed by Erlitou through the making of ritual vessels (Bagley, 1999: 141). There are four types of bronze vessels found at Erlitou, *jue* (爵), *jia* (斝), *he* (盉) and *ding* (鼎). Almost every piece has a simple surface with no decoration and imitated the existing forms of pottery, except the *jue* (爵) vessels. It should be also noted that the bronze workshop at Erlitou was in close proximity to the "palatial zone", therefore its production was almost certainly sponsored by the Erlitou elites (Liu and Chen, 2009: 64). The other ceremonial type of objects often encountered at Erlitou is white pottery. Pottery kilns found in the north and northwest of Erlitou and the kaolin resources in the nearby Yiluo region suggest a local production system. Liu and Chen (2009: 62-63) found that, compared with bronze vessels, white pottery was distributed across a much broader area. Following these observations, it can be concluded that the site of Erlitou had become an urban centre around the III phase, based on the agricultural provision and the availability of a large amount of labour working on architectural constructions and craft production.

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Figure 13 Erlitou styled pottery and bronzes

The site of Erlitou was dependent on natural resource from a vast area. A regional survey shows that a great number of Erlitou sites of various sizes were established in the Yiluo River valley of the southern part of Shaanxi (Chen *et al.*, 2003, Ford, 2004, Liu and Chen, 2009: 65-69). They postulated a pattern that smaller sites move resources to the major centres. The Yiluo River valley is very fertile for growing crops, of which millet was the major product (IA CASS, 2014). It also had a developed river system for transportation. Abundant natural resources were essential to the craft productions at Erlitou, including metals, wood, stone and kaolin. Considering its economic importance, the Yiluo valley has been treated as the core region for the site of Erlitou (Liu and Chen, 2009: 65-69). Two regional centres known as Dongxiafeng

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and Yuanqu (Figure 2; Figure 14-16) have been excavated in this area and their establishment were very likely related to the large salt lake and a number of rich metal deposits in the Zhongtiao Mountains, including copper and lead (IA CASS, 1989; IA CASS *et al*., 1988; National Museum of Chinese History *et al*., 1996; Tong, 2012a, b; Wang and Tong, 2005). Abundant trees provided almost infinite fuel for smelting. Though much smaller than Erlitou, the site of Dongxiafeng covered an area of around 25 hectares and was surrounded by a number of smaller sites. A few burials were recovered but with little trace of objects. Liu and Chen (2000, 2001) proposed that Dongxiafeng may have been more related to salt production, as it was situated on the side of the major transportation route of salt offered by the local river system. The other site, Yuanqu, which is also widely known for metal supply in the later Erligang period, was already inhabited at the time of Erlitou and developed into another regional centre (National Museum of Chinese History *et al*., 1996; Tong, 2012a; Wang and Tong, 2005). The Boqing River originates in the Zhongtiao mountains and flows through Yuanqu. Very little evidence of smelting has been found at Yuanqu, indicating that the copper smelting activity may have been carried out in the mountains and then the metal was moved to Yuanqu and further on to Erlitou (see also Liu and Chen, 2009: 65-68). The discovery of pottery in Erlitou styles in modern eastern Shaanxi suggests its far-reaching connection with the further northern area (Zhang, 1998, 2000).

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The period of Erlitou witnessed a series of transitions and transformations. The dramatic increase of the size and population at Erlitou suggests that it evolved into a powerful regional centre. Furthermore, as revealed by the standardization of pottery, stratification of burial practices, various types of craft productions, “palatial zones” versus common residential areas, social polarization at Erlitou became increasingly evident. Expansion of the Erlitou culture is also striking. It is possible to see a cluster structure that small sites contributed resources to major centres. Transportation along rivers and natural resources played an essential role in these interregional networks.

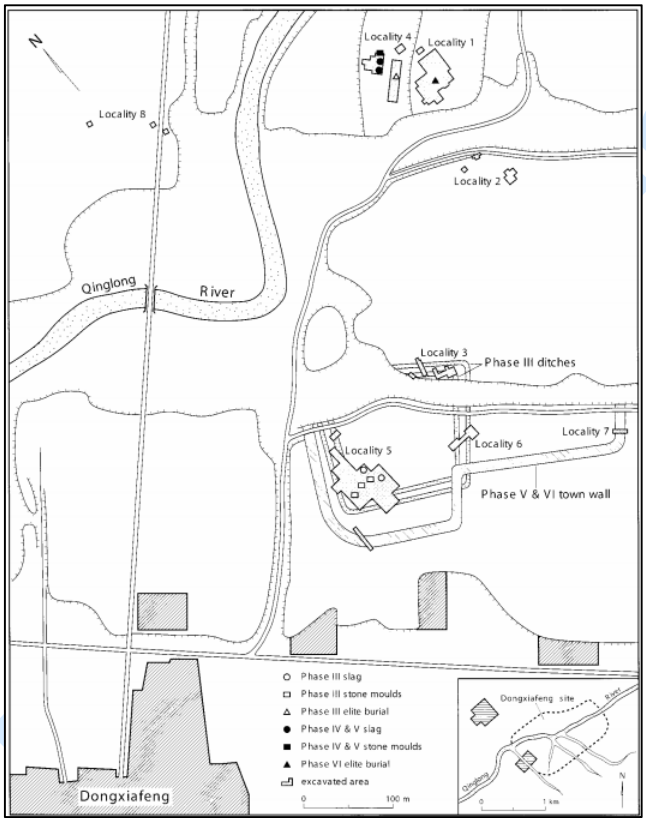

Figure 14 Outline of the Dongxiafeng site, after Liu and Chen (2001:16, fig. 5)

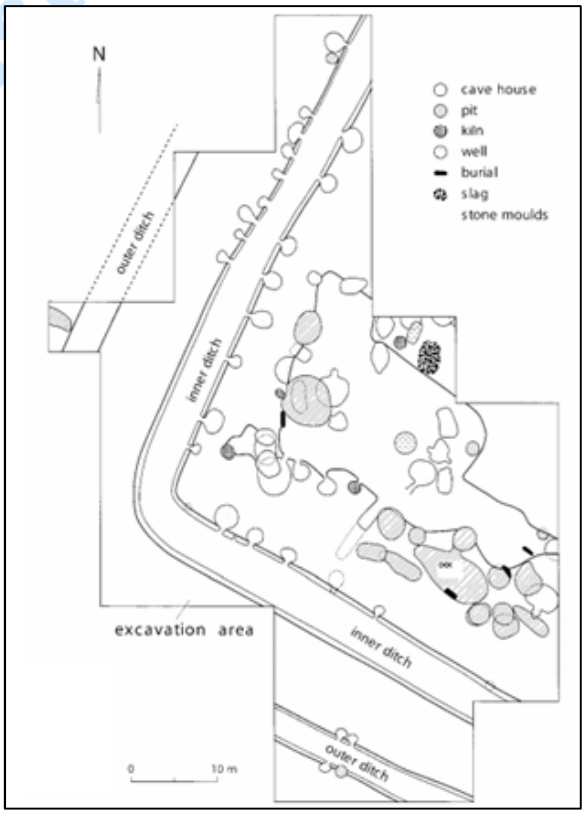

Figure 15 Craft productions at Dongxiafeng, after Liu and Chen (2001:17, fig. 6)

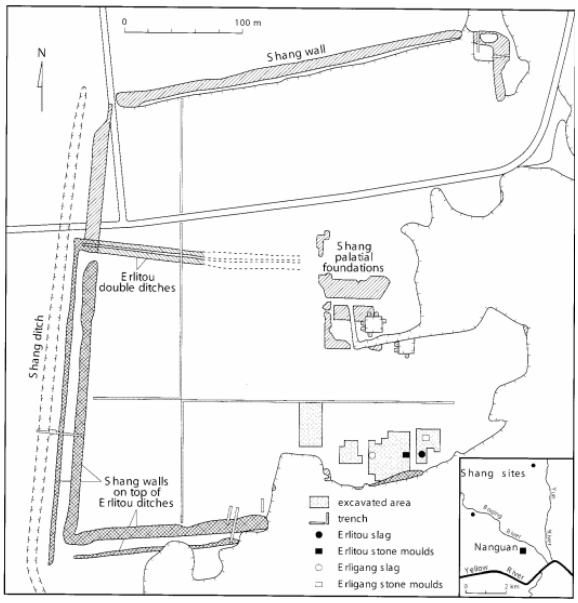

Figure 16 Outline of the Yuanqu site, after Liu and Chen (2001:29, fig. 14)



Figure 17 Traces of copper ores collected in the Zhongtiao mountains

1.5.2 Erligang

The decline of the Erlitou site coincided with the rise of Zhengzhou and many other Shang sites, which are collectively called the Erligang culture (*ca.* 16th -13th centuries BC; Henan Cultural Bureau, 1959, IA CASS, 1984b, Henan Institute of Archaeology, 2001, Bagley, 1999: 158-168, Thorp, 2006: 21-116).

Derived initially from transmitted text, the name Shang is a loosely defined term in publications. It has two common meanings which depend on the context of discussion. Later transmitted texts use Shang to describe people who occupied the Central Plains in the late second millennium BC. It can also refer to this time period. For instance, if an excavation report describes a site located along the Yangzi River as a Shang site, it is more likely that this site is dated to the Shang period, rather than part of Shang

Ruiliang Liu unplished

polity. In order to avoid this potential confusion, I choose to use the actual name of the site in the course of this discussion.

Zhengzhou, one of the most important sites in this period, is located in the present Zhengzhou city. However, as the major part of the site is underneath the modern city, excavations and materials for Zhengzhou are still limited. A number of settlements already occupied this area in the Erlitou period. Subsequent Erligang materials covered a much larger area of around 2500 hectares (Figure 18). With object typology and stratigraphy, archaeologists manage to divide Zhengzhou into four smaller chronological phases, Lower Erligang I/II phase and Upper Erligang I/II phase.

Ruiliang Liu unplished thesis

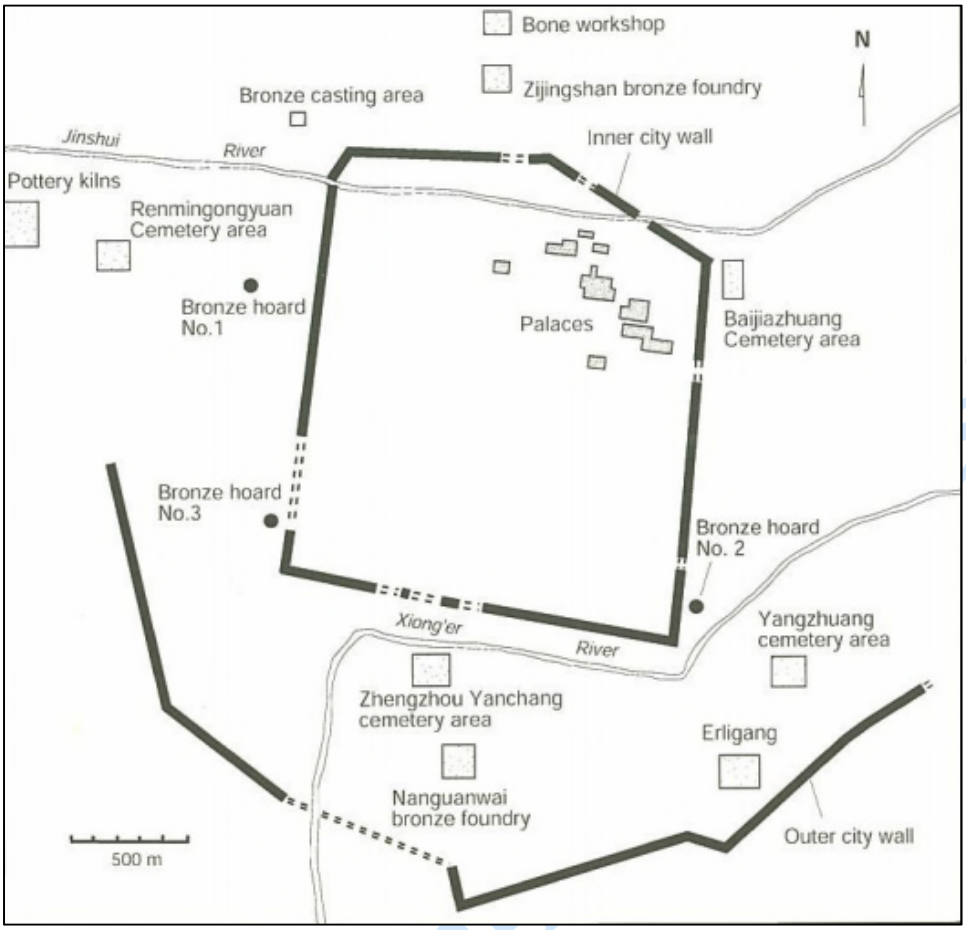

Figure 18 Outline of Zhengzhou, from Liu and Chen (2009: 94, fig.21)

The intrusion of large city walls into these settlements implies that Zhengzhou was a powerful centre (Bagley, 1999; Liu and Chen, 2009: 92-99). Both the inner and outer city walls were constructed with rammed-earth technology. The inner city wall is around 12-25 m wide and its remaining length is over 5000 m. Its walled area is around 300 hectares in extent. The outer one may have enclosed the entire site (Henan Institute of Archaeology, 2001: 180-183; Figure 19), which is radically larger, occupying over some 2, 500 hectares. Both were constructed by the rammed earth technique. The estimation proposed in Shelach-Lavi (2015: 224) suggested that to

Ruiliang Liu ... thesis

construct the inner wall requires around 5, 346, 700 person/days of work.

Within the inner city archaeologists have found many house foundations in varying sizes. The fact that houses of a similar size were segregated in the same part of the inner city implies some degrees of social stratigraphy. Sacrifices of humans and animals show that some structures were also related to ritual activities (Henan Institute of Archaeology, 2001: 175-178).



Figure 19 Cross-section of the inner walls of Zhengzhou

As at Erlitou, the Zhengzhou population engaged in many kinds of craft production. Multiple workshops for making bronzes, pottery and jades have been found in Zhengzhou but all are located outside the inner city. One bronze workshop is named Nanguanwai (2.5 ha), 700 m to the south of the inner city. A range of materials related

to casting and smelting have been recognized, including copper ores, crucibles, furnaces, moulds, slags, casting residues and bronze artefacts. Judging from the remaining clay moulds, the Nanguanwai workshop was capable of producing a many different kinds of metal objects, including tools, weapons and vessels. Another bronze workshop was found at Zijingshan, north of Zhengzhou. Similar materials suggest that its major function was to cast bronzes (Henan Institute of Cultural Relics, 1989). In the workshop of Zijianshan, archaeologists also found around forty fragments of copper ores. Two have been analyzed and show that they are very rich in copper (Cu: 16.08% and 15.9%, Henan Institute of Archaeology, 2001: 378). Interestingly, one of the copper ores contains radiogenic lead (Jin, 2008: 41; for the definition of radiogenic lead see Chapter Two). Meanwhile, four lead blocks were also discovered at Zijinshan. Local excavators found that the starting date of the Zijinshan workshop (Erligang upper I phase) was later than the one at Nanguanwai (Erligang lower II phase to upper I phase). This could suggest that the demand for copper-based objects was increased in the Erligang upper I phase (Henan Institute of Archaeology, 2001: 384).

A ceramic workshop was identified in the western area of Zhengzhou. It covers a large area of 12 hectares with multiple kilns, houses and a significant amount of ceramics. The bone workshop is located further north of the Zijingshan bronze foundry. A variety of remains has been discovered, such as manufacturing tools, raw materials, semi-finished products and bone debris. All of these finds at Zhengzhou

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demonstrate a large-scaled production practice based on various raw materials.



Figure 20 Bronze objects discovered from the cache of Nanshunchengjie at Zhengzhou, from Henan Institute of Archaeology and Zhengzhou Institute of Archaeology (1999: colour picture 2)

In addition to bronze foundries, the bronze objects discovered from three caches can testify to the further development of metal production achieved by the Zhengzhou people (Henan Institute of Archaeology and Zhengzhou Museum, 1983; Henan Museum, 1975). This is firstly demonstrated by the size and the weight of the objects, which clearly surpass the craftsmanship of their Erlitou predecessors. The largest bronze *ding* (鼎) vessels was found in the cache of Nanshunchengjie (南顺城街) and is around 83 cm high and 52.9 kg (Henan Institute of Archaeology and Zhengzhou Institute of Archaeology, 1999: 10). Moreover, many new types of bronze vessels

Ruiliang Liu unpu

were added to the Erlitou repertoire, such as *zun* (尊), *lei* (罍), *yan* (甗), *you* (卣) and *pan* (盘). The inherited forms *jue* (爵) and *jia* (斚) from Erlitou became more standardized at Erligang. The third contribution made by Erligang people was to apply the *tao'tie* to the surface of bronzes. The *tao'tie* is an abstract type of animal decoration which had been continued and developed into the major motif throughout Bronze Age China.

What is more astonishing is that the Erligang culture quickly replaced the preceding Erlitou culture in many regions and expanded further. Its distribution can be found clearly in Shandong, the western part of Shaanxi and further south of the Yangzi River. Bagley suggested that such a wide expansion can be conceptualized as the first empire in China (Bagley 1987, 1999, 2014).

1.5.3 Anyang

The next central polity after the collapse of Zhengzhou was Anyang, or Yinxu (Yin ruins), described in the oracle bones as the last capital of the late Shang (12th to 11th centuries BC; Figure 21). Located in modern Anyang city, Henan province, its entire occupation is roughly 24 km^2. The Huan River passes through and divides it into two parts. Within such a large area were distributed a variety of sites for different functions, including settlements, aggregated royal tombs, ceremonial temples, family or public tombs and workshops (IA CASS, 1994; Li, 1977). Chinese archaeologists

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often divide the occupation period into four chronological phases, collectively called Anyang (Yinxu) I-IV phases (Figure 8).

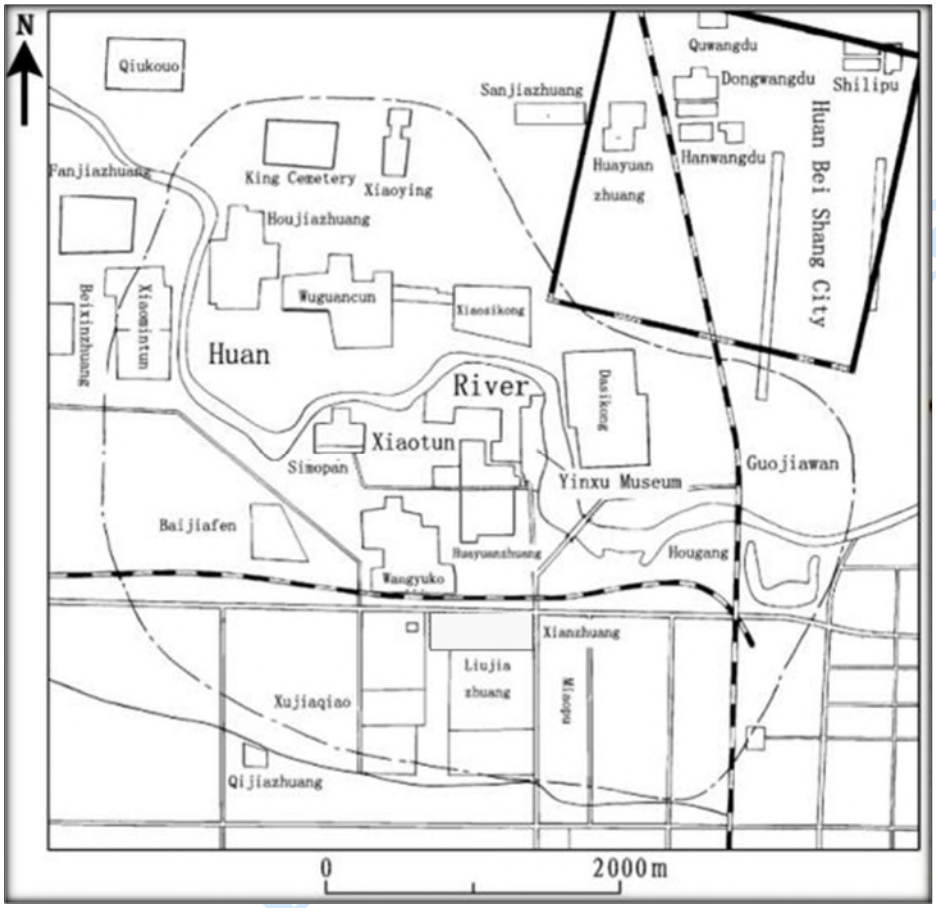

Figure 21 Plan of Anyang (after IA CASS, 2004)

An impressive number of building foundations have been identified as palaces and ceremonial temples in the area of Xiaotun, occupying up to 35,000 m^2 (IA CASS, 1994: 53; Figure 22). The other most general discovery is the astonishing number of cemeteries, which are widespread in the modern village of Anyang. Most of the royal cemeteries were discovered in Xibeigang, north of Anyang, except one huge tomb in Wuguan village, and those found in Xiaotun, including the tomb of Fu Hao, the

consort of the King Wu Ding and a powerful military leader in her own right. Although those in Xibeigang have been severely looted, probably multiple times, through comparison of their sizes relative to that of Fu Hao, the only one found intact in Anyang and buried with 1.6 ton of metal, it is quite clear that the content initially dedicated to those kings must have been enormous.

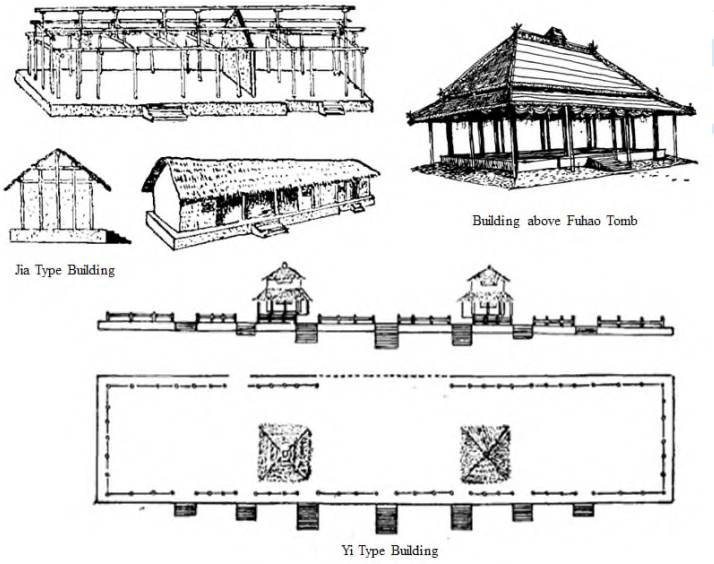

Figure 22 Reconstruction of buildings in Anyang (after IA CASS, 1994: 56, 58&71)

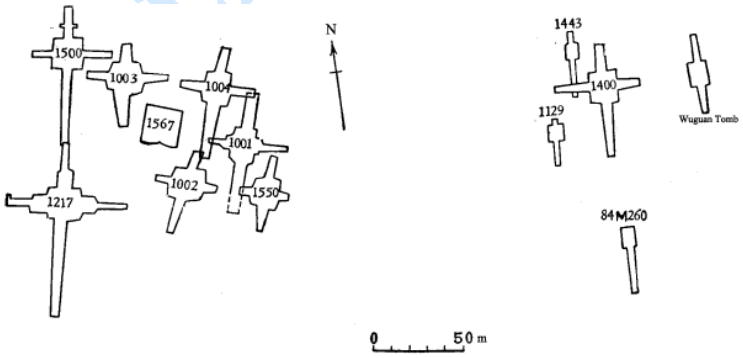

Figure 23 King cemeteries in Xibeigang, North Xiaotun (after IA CASS, 1994: 102)

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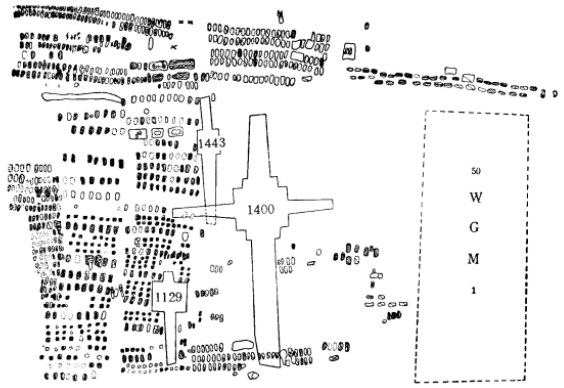

Figure 24 King cemeteries and surrounded tombs and ceremonial pits (after Bagley, 1999: 186)

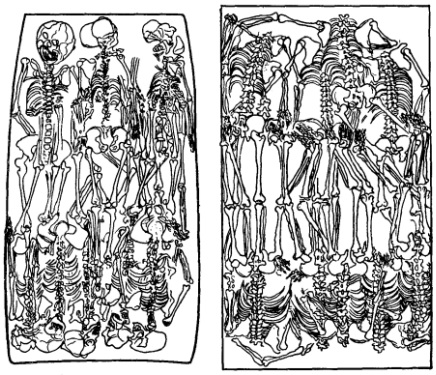

Figure 25 Human sacrifices in ceremonial pits (after IA CASS, 1994: 115)

Burying sets of ritual bronze vessels was one diagnostic feature of the Shang culture. As ritual paraphernalia, these vessels offered food and drink and paid tribute to the ancestors. The number and quality of these bronze vessels were in line with the sociopolitical rankings of their owners (Raswon, 1993). In the tomb of Fu Hao, archaeologists have found over 200 bronze vessels. This significantly contrasts with, for instance, tombs found in the Anyang Western area, which merely contain a few pieces of bronze vessels.

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Figure 26 Photos of ongoing excavation of Fu Hao tomb and some selected objects from the tomb (after IA CASS, 1980)

The discovery of bronze workshops sheds more light on the aspect of metal production at Anyang. So far, they have been found in many places within Anyang, including North Miaopu, Northeast Xiaotun, Xiaomintun, Dasikong and Xuejiazhuang (IA CASS, 1994; Li, 2003). The most convincing evidence for bronze workshops is the discovery of broken moulds, fragmented pieces of crucibles, burnt ground surface and various tools (Figure 27). The largest site is at North Miaopu, which covered an area greater than 10,000 m^2. Some sites were excavated before the Sino-Japanese war and the finds were moved to Taiwan. Those found after the war are kept in the Institute of Archaeology (Academy of Social Science, IA CASS). Li Yung-ti has thoroughly synthesized both old and new material relating to these bronze workshops (Li, 2003). He argued that while the archaeological data is rather fragmented, it is still possible to see two different forms of foundry organization,

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holistic and prescriptive. A holistic form of production indicates special types of objects are manufactured by a small group of individuals who are capable of finishing the entire procedures. By contrast, a prescriptive one requires a more subtle labour division. Those who are specialized in one unit of production may not be skilled in the next, so they have to pass down the semi-finished products for further processing (Li, 2003: 18-22). He meticulously compared the archaeological remains in the bronze foundries in Anyang and argued that the foundry in Xiaotun, which is relatively smaller in size, but has a variety of remains corresponding to a full range of foundry activities and object classes (vessels, weapons and chariots), appears consistent with the holistic form. In contrast, the foundry debris unearthed in Xiaomintun Southeast is ten times larger than those in Xiaotun but overwhelmingly focused on vessels. More importantly, Xiaomintun Southwest seems only capable of casting and finishing bronzes. No clear evidence can be found in situ in favour of the existence of clay processing, mould making or other activities. Therefore, Li suggested a prescriptive form of production was undertaken at Xiaomintun Southwest (Li, 2003: 298). However, considering the fragmented data of these bronze workshops, Li also suggested that a single foundry might change its way of organization during the course of time.

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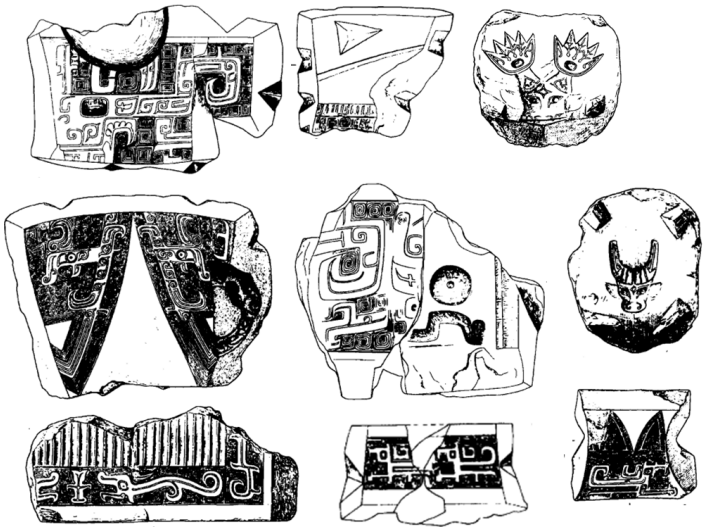

Figure 27 Moulds found at Xiaomintun, Anyang (after IA CASS, 2006)

The mainstream chronological framework is to divide the entire material assemblage at Anyang into four time periods, or four phases (Zou, 1964 a and b). This sort of study can be traced back to 1950-60s. The principal approach is integration of the stratigraphic order and the typological variation. The two major materials include pottery and bronze. Now it becomes the standard framework or language to report and describe old and new excavations. Materials from many well-known excavations are often taken as the criteria to anchor new discoveries into one of the four phases. For instance, materials similar to those from Sanjiazhuang tombs are usually seen as Anyang I phase. Objects, particularly bronzes from Fu Hao tomb, set up golden criteria for the II phase. Objects or sites dated to the III phase are usually based on the comparison with materials interred from M160 at Guojiazhuang. M1046 at north Liujiazhuang is often used to represent the IV phase of Anyang. Scholars can even correlate the lineage of Anyang kings to these four phases (Appendix I).

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The study of oracle bones and radiocarbon dating can also contribute to this four phase chronology. Li (1977) modified the conventional five-phase chronology of oracle bones set up in 1930s and changed it into the four phases. Through the stratigraphic order of the oracle bones and co-occurring pottery, it is possible to link the chronology of the oracle bones to the four main phases. Radiocarbon dates also suggests a chronological progress from the I phase to the IV phase of Anyang (Figure 8). One advantage of using Oxcal is that it can help to estimate the boundary of each phase on a probability level. As in Figure 8, while the overlap between each phase is undeniable and requires more data to reduce, one can see that the I phase starts around 1250 BC and the IV phase ends around 1050 BC.

In terms of relationship outwards, Anyang was situated in a very diverse context with many different local powers. North and West Shaanxi were occupied by local archaeological cultures and the Anyang materials were mostly restricted to the east of Xi'an, such as at Laoniupo. In the south, Panlongcheng was abandoned around the Erligang upper layer and the Anyang I phase. Instead, a regional power named the Wucheng culture, which displayed a range of local characters together with influences of Erligang and Anyang, spring up in the south. Meanwhile, in southwest China, Hanzhong and Sanxingdui became increasingly dominant. Moving across the Qinling mountains, the pre-Zhou culture can be found westwards of modern Xi'an. People living in the further north, such as the loess plateau of Northern Shaanxi and Shanxi, Inner Mongolia and Liaoning, show a strong relationship with the steppe. These local

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powers are further pursued in the next section.

1.5.4 Outside the lineage of the Central Plains

The spread of the traditional lineage of Erlitou-Erligang-Anyang outwards from the Central Plains encountered a great diversity of local powers. These local powers together with the Central Plains created complex networks which play a vital role in our comprehension of the Shang world.

South

The intrusion of the Erlitou culture into the south can be understood by the site of Panlongcheng, which is located on the north bank of the middle Yangzi River. It was an extensive site with a walled palatial area in the middle. The size of the wall is around 260 x 290 m (Hubei Institute of Archaeology, 2001: 14). Dozens of burials have been found outside the walls and some are remarkable in size, with many prestige objects, such as jades, proto-porcelains or bronzes. Its bronzes show a strong relationship with the Erligang culture in the north. Not only are the styles of the bronze vessels very similar to these of Zhengzhou, but also their alloying recipes are similar (Bagley, 1987). More crucially, these ritual vessels were used in a set (Zhang, 2014). More details of these materials are in Chapter Four. Based on the correlation between object typology and stratigraphic sequence, archaeologists have divided Panlongcheng into seven chronological phases. The first four are placed in parallel

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with the Erlitou culture and the rest are in the Erligang culture (Hubei Institute of Archaeology, 2001: 441-446).

In the literature, the importance of Panlongcheng is often emphasized during the period of Erligang (*ca.* 16th -13th centuries BC). Considering the rich natural resources distributed in the south, particularly copper and tin, and its strategic location, the major task of Panlongcheng seems to have been to secure the transportation of raw materials from south to north (Liu and Chen, 2009: 118; Hubei Provincial Museum and Beijing University, 1976; Zhang, 2014; more references see Chapter Four). It is also interesting to mention that due to the virtual absence of traces of bronze foundries, scholars initially suspected that the bronze objects found at Panlongcheng were actually imported from Zhengzhou. Recent excavation however shows that local production was very likely (Zhang, 2014).



Figure 28 Bronze objects at Panlongcheng

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While Panlongcheng was gradually abandoned, in the further southeast, Wucheng, around the Gan River in Jiangxi, quickly developed into a powerful local enterprise (Jiangxi Institute of Archaeology and De'an Museum, 1989; Jiangxi Institute of Archaeology *et al*., 1993; Jiangxi Museum *et al*., 1975; Jiangxi Museum *et al*., 1997). Its chronology can be divided into three phases. The discoveries dated to phase I (the Erligang period) strongly resemble those counterparts at Zhengzhou, but the quantities are on a much smaller scale. It is not very likely that Wucheng in its phase I was a large settlement. However, it rapidly developed into a dominant local power in phase II, equivalent with the Anyang period. Archaeologists have found an extensive settlement of nearly 62 ha enclosed by rammed-earth city walls. Within this settlement, they also found many architectural foundations, roads, ceremonial places, ceramic kilns and bronze workshops. Objects such as stamped wares and proto porcelains are more ubiquitous in the south than the north, indicating a southern local production (Li, 2014; Li *et al*., 1990; Long *et al*., 1992; Peng, 1987; Peng *et al*., 1991; Peng and Peng, 1992). The discovery of stone moulds and bronze foundries are also suggestive of a local metalworking tradition (Jiangxi Museum *et al*., 1975). A number of sites belonging to the Wucheng culture have been found in a close proximity to the well-known copper mine of Tongling and tin mine at De'an (Jiangxi Institute of Archaeology and De'an Museum, 1989; Liu and Lu, 1998). The most impressive discovery related to the Wucheng culture is a huge pit in Xin'gan (Figure 29). It has yielded 75 bronzes, including 48 ritual vessels, three *nao* bells, one *bo* 鎛 bell, 232 weapons, 143 tools and one double-sided mask of a face (Jiangxi Museum *et al*.,

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1997). Chemical analysis shows that most of them are made by leaded bronze (Jiangxi Museum *et al*., 1997: 242). Its metal objects offer a solid example of the metallurgical production of the southern people with the influence from the tradition of the Central Plains.

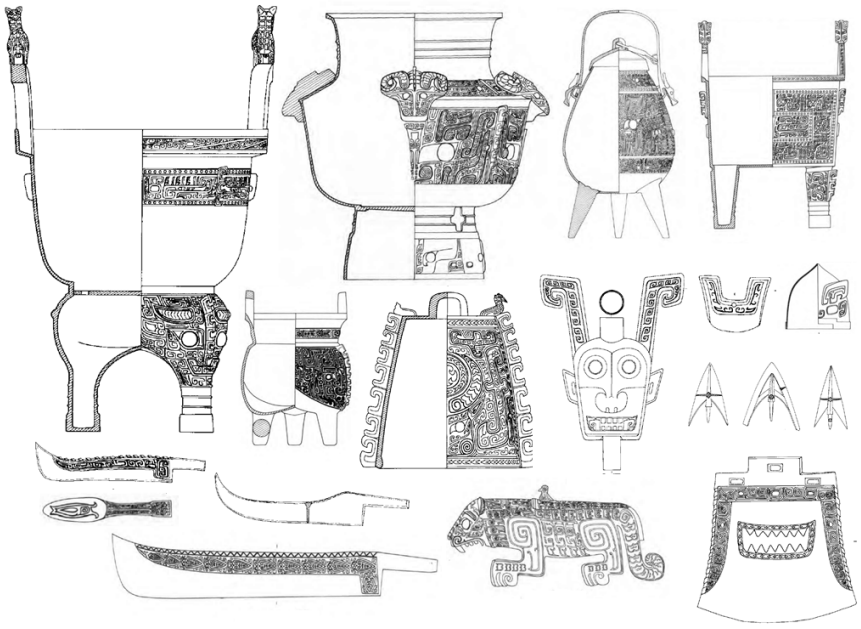

Figure 29 Bronzes at Xin'gan Dayangzhou

In the further south, the present Hunan province, a group of locally discovered metal objects came to light, collectively known as the Ningxiang assemblage (Xiang, 2008; Figure 30). Most of them are chance findings and local archaeologists have not yet found large settlements which are matched with the level of casting of these objects (Figure 30). Regarding this assemblage, three points must be elucidated. Firstly, most of them were buried in various pits along the rivers or on low mounds. Secondly, while some objects might have been made at Anyang, bells are certainly different.

Surprisingly, bells in the Ningxiang metal assemblage even outnumber the total number of bells from all of other regions. Bagley (2000) pointed out that southern bells were developed based on the tiny clapper bells seen at Erlitou, when casting technology was introduced from the north. However, bells witnessed a significant alteration in the south. The clapper was removed and they became radically larger and more lavish. The greater size can produce a greater volume of sound. Due to the limitation of our knowledge on southern practices, it is not easy to tell how these enormous bells were employed but they must have functioned in ritual practices (Bagley, 2005; Bagley, 2000). Thirdly, objects in Hunan were often made in large sizes and thus contain a huge amount of metal. The chronology of these objects is mainly based on typology as their contexts are difficult to date. Scholars tend to believe that they were broadly contemporary with Anyang (Bagley, 1991; Gao, 1993). However, no extensive sites have been discovered in Hunan province claiming the Ningxiang metal assemblage. The site of Shigushan at Yueyang shows strong relation with Panlongcheng but it soon disappeared into local archaeological cultures (Guo, 2001; Xiang, 1993). Other local similar sites to Shigushan include Tanheli, Duimenshan, Feijiahe, Wenjiashan to name only a few (He, 1996; Wang, 1989).

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Figure 30 Ningxiang metal assemblage in Hunan province (pictures from the website of Hunan provincial museum, http://www.hnmuseum.com)

Southwest

In the upper Yangzi River, archaeologists have identified a widely distributed local Bronze Age culture named as Sanxingdui in the Sichuan basin (Bagley, 1988, 1990a and b, 2001; Rawson, 1996; Sichuan Cultural Bureau *et al.*, 1987; Falkenhausen, 2002; Xu, 2003). It covers the edges of the Tibetan plateau. People living in this region could reach Hubei, Hunan or Jiangxi along the Yangzi River. The Jialing River also connects them to the Hanzhong basin. The site of Sanxingdui was excavated in 1980-86 (Sichuan Cultural Bureau *et al.*, 1987). Some surviving parts of walls constructed by rammed earth technology have been found. However, the most extraordinary discovery at Sanxingdui is the two ceremonial pits. The smaller one is around 4.5 m long, 3.4 m wide and 1.6 m deep. It yielded 178 bronzes, 200 jade or

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stone objects, 39 ceramics, 13 elephant tusks, 124 cowries and four thin gold foils. The larger one is around 5 m long, 2 m wide and 1.6 m deep. In this pit archaeologists found an even more striking number of 735 bronzes, 500 jade or stone objects, 67 elephant tusks, 120 ivory beads and 4600 cowries (Sichuan Institute of Archaeology, 1999; Figure 31-32).

From a broad typological point of view, the metal assemblage at the two sacrificial pits of Sanxingdui can be divided into three categories, human-like objects, small-size objects and bronze vessels. The human-like objects are most astonishing (Figure 31). While one can recognize their human features, the design of these objects certainly presents various levels of exaggerations, which can be vividly illustrated by the thick and high-relief eyebrows, elongated and broadened, sometimes even protruding, eyes, big noses, widely stretched mouth and long but angular ears. In fact, these sorts of three dimensional presentations were produced on a large scale at Sanxingdui and must have been highly important to the local people. Meanwhile, some human-like figures are striking by their size and weight (Figure 32). One standing figure from the Pit 2 is 2.62 m tall and 180 kg in weight. The second category of bronzes includes a variety of small objects, such as discs, rings, adzes, axes, drills and knives. Some bronze vessels are also found in these two pits, including *zun* (尊), *lei* (罍) and *bu* (瓿) (Bagley, 2001; Falkenhausen 2002a and b; Ge and Linduff, 1990).

There is no doubt that the Sanxingdui culture represents a powerful group of people in

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the Sichuan basin during the late second millennium BC. The diversity of objects and the capability of collecting such a large amount of metal and jade show that it was part of some efficient communication system. Although little is known about the exact social structures within Sanxingdui, it is possible to conclude that their materials and the underlying social beliefs were rather different from regions such as the Central Plains or the middle and lower Yangzi River (see references above).



Figure 31 Bronze objects at Sanxingdui
(after Sichuan Institute of Archaeology *et al*., 2009)



Figure 32 Bronze tree and standing human figures at Sanxingdui

Another local power can be found in the Hanzhong basin. Although seemingly enclosed by the North Qinling mountains and the south Micang-Daba mountains, the Hanzhong basin is in fact well connected to the outside world. Routes can be plotted across these mountains, and rivers offer convenient transport. The Jialing River connects the Hanzhong and the Sichuan basins and the Han River which derives from

the middle reach of the Yangzi River also flows into the centre of the Hanzhong basins.

This connection between Hanzhong and other regions can be also revealed by the archaeological remains dated to the Shang period. Over 700 metal objects have been uncovered at Hanzhong, mainly from areas around the counties of Chenggu and Yangxian (Zhao, 2006). They include a number of object forms which can be divided into vessels, weapons and 'local styles' (Figure 33). Diversity is the first impression one may get from the copper-based vessels at Hanzhong. Its chronology ranges from Erligang to Anyang. More intriguingly, a large number of vessels at Hanzhong are closely related to many other regions, including Anyang, the middle Yangzi River valley, Guanzhong and Sichuan. Some of them were imported but a few could be local copies (Cao, 2006; Rawson, 2011; Falkenhausen, 2011; Zhao, 1996). In contrast to the vessels which illustrate wide-ranging communications, other types of copper-based objects present a strong localization. For instance, the shape of the Z*hang* (璋, sceptres) are widely distributed across Shang China but most of them were made in jade (see Chapter five). Only at Hanzhong can one find *Zhang* (璋) in copper (Li, 1997). The forms of weapons and masks at Hanzhong were also exceptional (Guo, 2006). The local Baoshan culture is usually believed to be the inhabitants of the Hanzhong basin around the Shang period. Unlike Sanxingdui, the local technology is rather primitive.

Ruiliang Liu unpished thesis

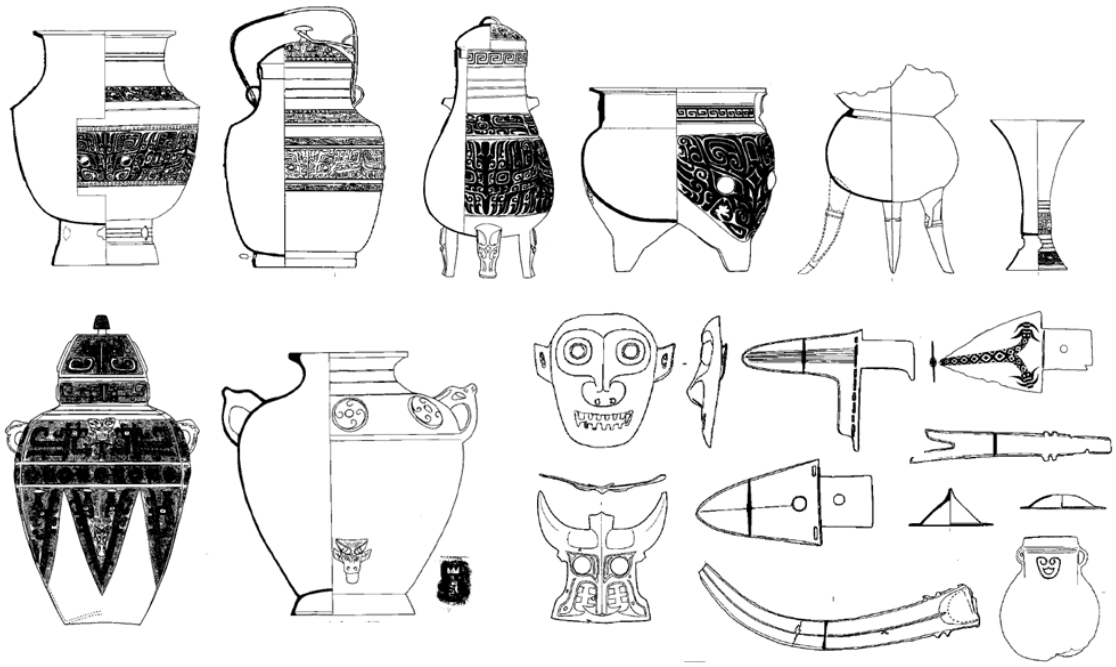

Figure 33 Metal objects at Hanzhong (after Zhao, 2006)

West

Across the Qinling mountains is the well-known Guanzhong plain. Erlitou type remains have been found in the eastern part of Guanzhong. Later in the Erligang period, one can see a strong resemblance between materials found at Guanzhong and Zhengzhou, such as at Laoniupo, Huaizhenfang and Yaoxian Beicun (Zhang, 1998, 2000). This expansion towards the west was also contemporary with the decline of Erligang in the Yiluo valley of southern Shanxi. However, the later Anyang period saw a fall of this Shang resemblance in Guanzhong and the rise of a mixture, with the Laoniupo site as the dominant Shang site, together with a number of local sites (Liu and Chen, 2009: 106).

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The site of Laoniupo was discovered in 1978 and was subsequently excavated during the years 1986-1988 (Liu, 2002; Figure 2). It offers rich material to study the spread of the Shang into the Wei river valley (Figure 34). Its Shang features can be seen in many respects. Most of the tombs are rectangular in shape and are structured with *yaokeng* (腰坑, waist pit) and *ercengtai* (二层台, secondary layer), which are typical of Anyang. Meanwhile, over half of the tombs contain sacrifices of humans and animals, which is a very common ritual activity of the Shang people. While many tombs have been looted, objects left behind are still capable of suggesting a clear image of Shang (Figure 34). A variety of ritual bronze vessels have been found, including *jue* (爵), *jia* (斝) and *ding* (鼎). Many typological features can relate the *jue* (爵) recovered from tomb M44 of Laoniupo to the one of Baijiazhuang at Zhengzhou. This connection can be further reinforced by pottery typology and the use of oracle bones. More interesting discoveries at Laoniupo were chariots. Chariots were imported from the west but became a common way of showing social status at Anyang (Wu, 2013). Whether these chariots of Laoniupo were imported from Anyang or from the west is open to discussion, but these chariot fittings provide another batch of materials to study the link between Laoniupo and the Shang central polity. In addition to Shang, materials of Laoniupo show that it stayed in contact with many local groups of people, such as Zhanzipo, Liujia, Zhengjiapo and Fenghao. The western part of the Guanzhong plains is believed to be the homeland of the Zhou people. Therefore, Shang and Zhou people very likely came into contact with one another here (IA CASS, 2003: (chapter 8) 55-61). In addition, the bronze objects

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found at Laoniupo, especially animal/human masks, are almost exactly the same as those of Hanzhong thus suggesting interregional communication between Guanzhong and Hanzhong.

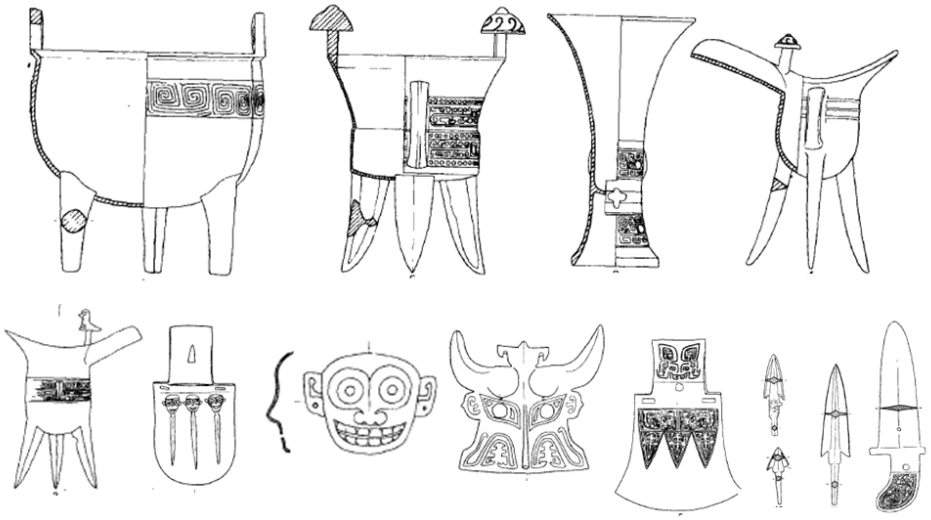

Figure 34 Bronze objects at Laoniupo

Another remarkable finding at Laoniupo is that this is a site where slags of copper smelting and also clay moulds occur together. This means that Laoniupo was able to produce both raw copper and finished objects. Considering the huge consumption of metal in the Central Plains and its strong connection with Guanzhong, it is reasonable to suggest that mines at Laoniupo were critical to the entire supply network of the Shang metal industry.

Ruiliang Liu unp

North

Further north is named the northern zone, the definition of which was firstly proposed by the distinguished Chinese archaeologist, Lin Yun (Lin, 1986). This term describes a massive landmass on the north of the agricultural regions, including the Central Plains and the Wei river valley. The traditional paradigm for the northern zone was established from the transmitted texts in the Han dynasty, suggesting that they were hostile raiders and constantly attacked the Central Plains for subsistence (Di Cosmo, 2002). However, an increasing amount of archaeological evidence shows that the major economy in the northern zone was actually agro-pastoralism. Some groups of people herded animals while other lived by growing crops (Cao, 2014; Lin, 2003; Lv, 1989; Rawson, in press-a). In fact, the entire northern zone shows a strong diversity in terms of micro climate and vegetation, from sandy desert land and loess in North Shaanxi, to steppe-like regions in Inner Mongolia and further northeast. Even in the loess highland of North Shaanxi and Shanxi, people could still find pieces of green land for agricultural production. Therefore, in the northern zone one can encounter various groups of people using many different economic strategies to cope with the local situation. Material culture in the northern zone also shows a great diversity, highlighting the communication with outside regions (So and Bunker, 1995). In the meantime, they were able to establish their own production. A local metal foundry has been recently discovered in North Shaanxi.[16]

[16] This is not yet officially published. See: http://qjzhf.gov.cn/Item/6606.aspx

Ruiliang Liu unplished thesis

In northeastern part of China, scholars are used to dividing local assemblages into the steppe group, the Central Plains group and the hybridized one (Li, 1988; Zhu, 1995b: 655-665; Cao, 2009: 31-43; Figure 35). The communication between the northern zone and the Central Plains was very likely driven by the acquisition of horses by the Shang people and it appears likely that agricultural surplus was traded to the north (Cao, 2014; Rawson, 2017). Meanwhile, the Dajing region is rich in copper and tin, which are possibly another drive for communication with the Central Plains (Li and Han, 1990)



Figure 35 Bronze objects in the north zone, after Cao (2009)

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East

In the east, present-day Shandong was originally occupied by the Yueshi culture in the Erlitou period but was replaced by the Daxinzhuang variant of the Erligang culture from the Lower Erligang phase (Fang, 2004; Fang *et al*., 2004; Gao, 2000; Shandong Relics Bureau, 1959; Xu, 2000; Zhou, 2011). As at Laoniupo, occupation of the site of Daxinzhuang also continued into the Anyang period and the number of its settlements gradually increased. Another important site in Shandong is Qianzhangda, which yields a large number of bronze objects (IA CASS, 2005). Its chronological range is from late Shang to early Western Zhou (Cao, 2015; Fu, 2014; Hu, 1992; Zhang, 2006). The close affiliation of Shandong with Erligang and Anyang can be understood through its bronzes, which are almost identical to those at Zhengzhou (Figure 36-37). In the meantime, as the decline of the Yiluo basin may have led to an insufficient supply of salt, the coastal area of eastern Shandong might have become a new major source of sea salt, which may explain the rise of the Erlitou culture in this area (Liu and Chen, 2009: 115).

Ruiliang Liu unpublished thesis



Figure 36 Bronzes at Daxinzhuang, after Shandong University and Shandong Institute of Archaeology (2010)

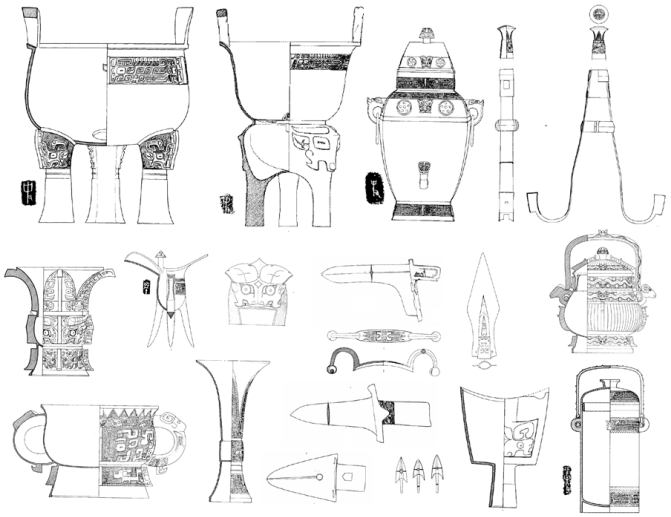

Figure 37 Bronzes at Qianzhangda, after IA CASS (2005)

Owing to limited space, a huge number of local sites have not been described above, but the quick sweep of the principal groups of people in different regions makes several invaluable contributions to this thesis. Firstly, it delivers a basic chronological and geographical framework. On one hand, the time progression for the Bronze Age, as widely adopted in modern studies, is Erlitou-Erligang-Anyang. On the other hand, the metal assemblages discovered in the Central Plains and other surrounding regions offer a number of comparative studies. Secondly, this generalization vividly illustrates a complicated and delicate network. Tributaries of the Yellow River, the Yangzi River and routes across mountains offer physical passages within this network. An enormous number of studies on material cultures demonstrate that people living in this network were in efficient contact with one another. This sets up a basic tone of movement of either people or natural resources, in which metal was only one of many components. These observations keep the discussion in later chapters from existing in

Ruiliang Liu unpublished u

a vacuum. Thirdly, confronting such incredibly large and diverse scales of metal production across different regions and the limited data available at the moment, it is not practical to draw a full and thorough picture. Indeed, conclusions in the end have to be made with great caution and some big error bars. As said in the beginning of this chapter, the study on Bronze Age China is a phenomenally well-established field with a huge volume of scholarship. The overall aim of this thesis is not to revolutionize but contribute one line of research to this rich and ongoing discussion and help archaeologists to ask some new questions based on changes of metal chemistry.

1.6 Structure of the thesis

Unlike the previous research questions being focused on provenance and seeking after a one-to-one correspondence between objects and ores, this thesis attempts to present a series of comparative studies and illustrate the changes of object chemistry between assemblages belonging to different times, space and people. These changes are of archaeological importance as they may provide information on human decisions and interactions. In order to capture and conceptualize these changes systematically, the second chapter clarifies the primary methodology used in this thesis in a stepwise manner. I shall follow the Oxford system in which a series of toolkits are designed to visualize possible changes of chemical and isotopic compositions of metal objects (Pollard *et al.*, in press-a and b; Bray *et al.*, 2015). It is also followed by a set of comments on the pros and cons of this approach.

Ruiliang Liu unplished thesis

The third chapter is mainly focused on the assessment of self-produced SEM-EDS data and of legacy data. This sort of work has not yet been widely conducted in Chinese academia but is frequently seen in the western literature. I argue that the methods employed in those well-known inter-laboratory comparison projects (Chase, 1975, Northover and Rychner, 1998) are also useful to the assessment of Chinese database. By comparing the self-produced data and different sets of published ones, for the first time, we are able to provide a broad assessment on the variation of data quality, which is vital to balance the data quality and the real archaeological interpretation in the following parts of this thesis.

Chapters Four to Seven provide three archaeological case studies. Chapter Four is focused on the comparative works of metal chemistry between Zhengzhou in the Central Plains and Panlongcheng in the southern borderland. This comparative study produces a few archaeologically important implications on local production and exchange of metals between the Central Plains and the middle Yangzi River during the Erligang period. Chapter Five moves to another part of borderland, southwestern China. The metal objects dated to the Anyang period in Sanxingdui and Hanzhong show a strong chemical similarity between one another but significantly contrasts that of Anyang. Combing the chronology and chemical analysis of objects at Hanzhong makes it possible to reveal a life history of local metal production from the birth to the peak. In Chapter Six, the case study breaks down the metal production and use at

Ruiliang Liu unplished thesis

Anyang. I shall characterize all of the major metal assemblages of which chemical analyses are published. A series of comparative works are conducted, mainly following the Anyang chronological framework and social rankings of the objects' owners. The chemical variations captured through these comparative works illustrate the changes of supply and use of metal at Anyang.

Chapter Eight is structured in two parts. The first part presents a big-picture comparative study of the distribution of copper groups, alloying and lead from pre – Anyang, Anyang to the Western Zhou period. Within each period, I also show the geographical profile of these data. This aims to illustrate the changes of metal used in different time periods and various types of metal used in different regions. While no definite answer can be offered, these comparative works provide implications for possible movement of metal and changes of their sources or supply networks. In order to further test and develop these observations, the second part puts forwards a few suggestions for the further work.

Chapter Nine summarizes all the conclusions in each chapter and illustrate some short- and long-term views on future study.

Ruiliang Liu unplished thesis

Chapter Two Methodology

The prime aim of this chapter is to explain the methodology used in this thesis. More crucially, through being presented in a narrative but also in a critical manner, this chapter offers an evaluation of the methodology, particularly based on the tradition of the Chinese archaeometallurgy.

First, an overview on the previous scholarship of interpreting chemical analysis of bronzes in Chinese academia is provided, which can be found in very few publications in English language (Liu *et al.*, 2015). A western perspective is a useful mirror as a number of crucial issues which have been extensively debated for Europe can also be applied to China. The second part presents and explains the methodology of this thesis in a stepwise manner. This method can be supported from a variety of perspectives, including the archaeological theories, fundamental thermodynamics, simulation experiments and real case studies. The argument is that the nature of this method is *a characterization system*, which allows equal importance to chemistry and archaeology. Being different from previous complex statistically based research, this

Ruiliang Liu unplished thesis

creates a set of straightforward tools to reveal the changes of human interactions with metal. The third part is focused on data collection. It synthesizes a large number of legacy data on chemical and lead isotopic analysis of bronzes, which provides an important summary of the databank created for Shang archaeology, which is, again, not easily found in existing literature. This summary enables us to quickly point out extensively studied areas in contrast to those gap areas.

1.1 Overview of recent archaeometallurgical study in China

A more detailed overview has been published in Liu *et al*. (2015). This section is an elaboration of the last period discussed in that paper, 1980s-present. The work in this period involves a number of crucial topics related to archaeometallurgy. These topics include the origins of Chinese metallurgy,[17] smelting technology,[18] piece-mould casting,[19] simulation experiment,[20] sources of metal[21] and special manufacturing technology.[22] It also produces nearly all the major databases of lead isotopes and trace elements used in this thesis (see below). Relative to those large-scale scientific projects in Europe which produced tens of thousands of analyses, the work of using trace elements to characterize and source metals in China is still in her infancy, with only around one thousand analyses. However, the fundamental philosophy is entirely

17 Li, 2005; Linduff and Mei, 2014; Mei, 2009; Mei *et al*., 2015.
18 Li and Han, 1990; Li and Hong, 1995; Wang *et al*., 2013.
19 Chen and Liu, 2011; Li *et al*., 2007; Liu *et al*., 2008.
20 Bai and Yin, 1982; Dong, 2010; Feng *et al*., 1982.
21 Chen, 2012; Hua and Lu, 1996; Jin, 2008; Wei, 2007; Yi, 2013.
22 (Chen *et al*., 2009; Sun *et al*., 2008

Ruiliang Liu unplished thesis

the same. Scholars state that, through comparing concentrations of a group of selected elements in finished objects and copper ores, it is possible to reveal the provenance of these metal objects, or at least rule out some candidates. For instance, on the basis of geological background, partitioning of trace elements in smelting, measurements of copper ores and statistical analyses, the provenance research performed by the University of Science and Technology China (USTC) proposes Au, Ag, As, Sb, Bi, Se, Te, Co, Ni as the proxy for copper source (Qin *et al*., 2004; Qin *et al*., 2006; Wei, 2007: 42; Li, 2010: 67). This is because concentrations of these elements can theoretically characterize and distinguish different copper mines and object assemblages. By comparing the results of copper sources and that of artefacts, the team in USTC asserts that it is theoretically possible to (dis)connect one to another.

The conceptual framework of this approach is what the Oxford group has called 'static chemistry'. Scholars treat these trace elements as unchanging after smelting. However, it is very likely that these so-called "fingerprints" can be heavily altered or even completely rewritten during the process of casting, (re)alloying, recycling and mixing (Bray and Pollard, 2012; Budd *et al*., 1996; Budd *et al*., 1995; Needham, 1998; Pernicka, 1995; Tylecote, 1970). Secondly, the size of the trace element database and associated statistics used appears problematic. Impurity-based provenance studies normally choose to use their own dataset and seem reluctant to integrate with other legacy data. The consequence is that each dataset is rather limited (sometimes merely a few analyses of ores or objects) so that scholars are only able to illustrate a narrow

Ruiliang Liu unplished thesis

and probably unstable pattern. Even though a statistical aid can be added by either cluster analysis or principal components analysis, it is still ambiguous which one should be applied to these real analyses. It is often possible to see that some grouping results suggested by one statistical approach turn out to be random in another (Baxter, 2001, 2006). So applying multiple analyses and focusing on the core structure is more sensible (Pollard, 2009). Thirdly, these trace elements often exist in a certain relation in geology. For instance, more than one element are co-existing in a specific kind of copper ores. For example, tennantite-tetrahedrite in Ross Island is characterized by a high concentration of arsenic and the presence of antimony and silver (Bray 2009: 68-75). Very little attention in the Chinese literature has been devoted to trace elements as a combination. One mainstream way to present trace elemental data is through an x-y scatter plot, which can only include two elements. This is a very tedious approach which results in poor presentations because normally up to eight elements needs plotting one against another (As, Sb, Ag, Ni, Bi, Fe, Co, Zn), which in total produces 28 possible figures. The fourth issue is that some of these publications appear insufficiently analytical, if not critical, of the archaeological foundations. Very often, scholars are only focused on matches of the trace elemental patterning between objects and a specific copper source, but few studies attempt to use other archaeological evidence to test their proposal. It seems that scholars seem to be overly obsessed with provenance and blind to other information embedded in their data. As is discussed below, although in many cases we are not yet able to pinpoint the exact location of the copper source, the variation between datasets is also archaeologically

Ruiliang Liu unplished thesis

meaningful.

Another line of tackling the provenance question is to use lead isotopes. The basic rationale of lead isotope study in archaeology can be found in Pollard and Heron (2008: 302-321). Compared to trace elements, the provenance of lead isotopes in China is more influential and debated. The first lead isotopic study by Chinese scholars can be traced to the 1980s. Jin Zhengyao and his colleagues argued that the lead contained in the ritual vessels of Anyang could have originated in southwest China (Jin, 1987; Jin *et al*., 1995; Jin *et al*., 2004). This discussion was based on their important and now well-known observation that Shang Dynasty bronzes often contain lead which is usually described as 'highly radiogenic' ($^{206}Pb/^{204}Pb > 19\sim20$; $^{207}Pb/^{204}Pb > 15.6\sim15.8$; $^{208}Pb/^{204}Pb > 39$). Moreover, it is also well-known that the Western Zhou generally used lead with a lower ratio of $^{206}Pb/^{204}Pb$ (≈ 17.5), often referred to as 'common lead'. It was argued at the time that northeast Yunnan appeared to be the only region around China capable of yielding radiogenic lead similar to that found in the Anyang bronzes (Jin *et al*., 1987). Furthermore, the predominance of objects containing radiogenic lead at the sites of Sanxingdui (Jin *et al*., 1995), Hanzhong (Wang *et al*., 2008), Jinsha (Jin *et al*., 2004) in the southwest and Panlongcheng and Xin'gan (Jin *et al*., 1994) in the south seemed to reinforce the idea of an external lead supply from somewhere south of the Yangzi River to the Central Plains (Li, 2002; Ma *et al*., 2012; Tian *et al*., 2010). Based on the lead isotopes in archaeological objects, Zhu and Chang (2002) proposed 2.5 Ga as the age

Ruiliang Liu unpublished thesis

of the original lead deposits and limited the likely sources to Northeast Yunnan, the Qinling mountains, Qingchengzi in Northeast China and the Yangzi River valley. Zhu (2010) pointed out that northeast Yunnan was still the most likely candidate, even though the lead isotopes of archaeological objects and the geological ore are not perfectly matched. These suggestions of a lead source in southwest China have raised some difficult questions for specialists in Chinese bronzes – it is very distant, although ivory at least may have been obtained from somewhere towards southwestern China during the Shang period (Huang, 2004). Critically, however, there is as yet insufficient archaeological evidence to allow scholars to ask questions about the nature of any possible contact between Yunnan and the Shang world of the Central Plains.

A different opinion can be found in Saito *et al*. (2002). They recalculated the data based on ratios to ^{204}Pb rather than ^{206}Pb, as had been used previously, and concluded that the southwest region around the border of Yunnan, Sichuan and Guizhou provinces could not have been the source of the radiogenic lead. Importantly, they suggested that the seemingly linear relationship presented by lead isotopes in the Shang objects is in fact a mixing line rather than an isochron, and therefore does not give the true geological age of the deposit. The age they calculate from this line is approximately 5 Ga, which is older than the age of the earth. In addition, they pointed out that no archaeological evidence has yet been found to support this contact, and that Yunnan appears to be too remote from the Central Plains. Saito *et al*. (2002)

Ruiliang Liu unplished thesis

proposed the Qinling mountains as the source of the radiogenic lead, but noted that 'such a high radiogenic lead mine has not been found' in the Qinling mountains. Subsequently, however, Zhu *et al*. (2006) noted that three chalcopyrite samples and the host rock from the Mujiazhuang copper mine in the Qinling mountains have been shown to contain radiogenic lead, renewing the suggestion that radiogenic metal may have come from there.

Peng Zicheng was also one of the earliest scholars who brought lead isotopic analysis into Chinese archaeology (Peng *et al*., 1985), and was particularly interested in the provenance of metals in Bronze Age China. He and his colleagues pointed out three regions in accordance with roughly one hundred lead isotopic analyses of both ore and objects ranging from the Erligang period to the Eastern Zhou (Peng *et al*., 1997, 1999, 2001). Through visual comparison, they suggested that the local source often appeared to be the major supplier of metals for local workshops. Although none of these arguments are absolutely conclusive, one may easily see that the radiogenic lead is often at the centre of the discussion.

More thorough comments and reservations on both Saito *et al.* (2002) and Peng *et al.* (1997) can be found in Jin (2008: 51-54, 43-45). He pointed out that the distance from Yunnan to Anyang does not seem excessive, given the river system and transportation recorded in the later periods (Jin, 2008: 79-81), and using either ^{204}Pb or ^{206}Pb as the base would not change the argument (Jin, 2008: 51-54). In the lecture at Oxford in

Ruiliang Liu unplished thesis

2015, Jin Zhengyao proposed that three economic regions could supply metal to Anyang: Zhongtiao, middle and lower Yangzi River and northeast Yunnan. He argued that metal in the first two regions were directly extracted and moved to Anyang whereas the third one might be more likely to follow an intermittent trade or exchange. He rejected other regions as the potential source of radiogenic lead because their lead isotopic ratios are dramatically higher than have been observed in metal objects.

Instead of focusing on the sources of the radiogenic lead, Cui and Wu (2008) chose to further investigate the sources of the common lead isotopes. In order to address the issue of overlapping sources, they plotted the isotopes as vectors rather than as raw data, based on the methodology proposed by Zhu (1995a). He had published a series of transformations, starting from the raw isotope ratios, which first involved the subtraction of the calculated isotopic ratios in the mantle at the time of formation of the deposit, followed by a series of linear projections to reduce the three dimensional data to two parameters, which he called vectors (V_1 and V_2). He argued that this procedure removed variation caused by the different ages of the deposits, and focused on the varying chemical environments (U/Pb and Th/U ratios) in the six major geochemical provinces identified in China (southern China, Yangzi, northern China, northern Xinjiang, Jiamusi (northeast China) and Tibet). Based on this approach, Cui and Wu made two interesting points. One is that the vectors for most of the objects dated from Erlitou to Western Zhou are associated with Yangzi province, but also lie close to the south China province, as defined by Zhu (Cui and Wu, 2008: 35). The

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other is that Anyang could have exploited two different common lead sources (Cui and Wu, 2008: 37). One of these may have been the same as that exploited during the Erlitou period, which was abandoned during the early Anyang phase and revisited in the later Anyang period (see below).

While no simple agreement has yet been reached between the different schools, there is no doubt that the existence of two sorts of lead ('radiogenic' and 'common') have become the most dominant paradigm and language in publications. Frankly speaking, the critiques of the schools who attempted to use lead isotopes to solve the question of the provenance of metal in English language publications is even more brutal (Barnes *et al*., 1988; Begemann *et al*., 1989; Budd *et al*., 1993; Budd *et al*., 1995; Gale and Stos-Gale, 1982; Gale and Stos-Gale, 1992; Leese, 1992; Pernicka, 1992, 1993; Pernicka, 1995; Pollard, 2009; Reedy and Reedy, 1988; Reedy and Reedy, 1992; Sayre *et al*., 1992a; Sayre *et al*., 1992b; Sayre *et al*., 1993; Tite, 1996; Rehren and Pernicka, 2008). Key issues include the possible anthropogenic fractionation of lead isotopes, defining a source of metal by lead isotopes, overlapping lead isotopes across a variety of metal sources (Figure 38 and 39), and mixing/recycling. As concluded in Jin *et al*. (accepted), lead isotopes alone might not able to solve the issue or provenance but it could illustrate the changes of lead supply and use.

Ruliang Liu unplished thesis

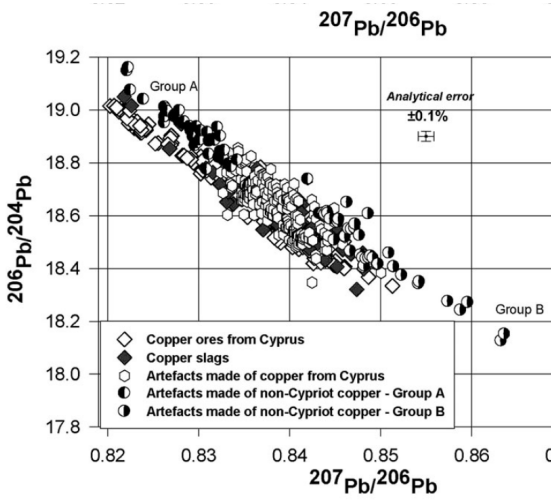

Figure 38 Overlapping between Cyprus ores and non-Cyprus artefacts (Stos-Gale and Gale, 2010)

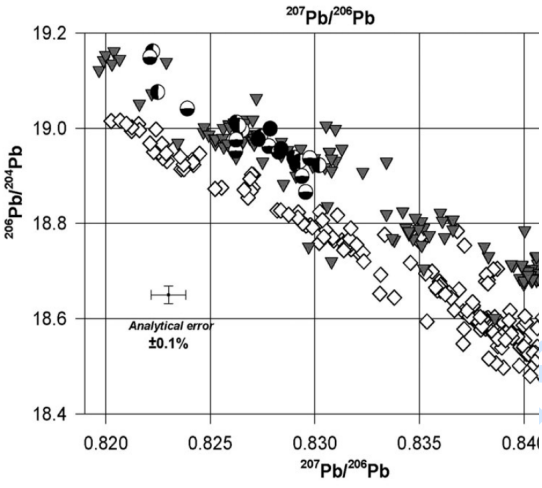

Figure 39 Enlarged area (Stos-Gale and Gale, 2010)

1.2 The 'Oxford system': form and flow

1.2.1 Theoretical basis

One key concept is the life history of the metal. The theory of the life history is exceptionally interesting to anthropologists and archaeologists. As it comprises various kinds of specific biographies (social, political, cultural, economic, technological and so forth), focusing on them can make salient what otherwise remains obscure (Kopytoff, 1986: 67; Gosden and Marshal, l999). If we accept metal as one of the very important materials in the Bronze Age and that its various biographies or life histories are reflective and constitutive to human history, then it is necessary to find a practically feasible solution to approach them.

Form is matter and flow is energy (quoted C. Gosden). As remarked in processual archaeology (Gosden and Malafouris, 2015), the idea of archaeology is centred on the

Ruiliang Liu unplished th

changing flows and forms of people, non-human organisms and things; in short, modes of becoming. Things can be transformed back and forth through times and space. So are human societies. Essentially, these are all about varying degrees of these changes on micro- and macro-scales of negotiation between materials and humans. The word ‘change’ here is of vital importance because it very well captures a set of realistically complicated scenarios between form and flow, or matter and energy. By tracking and summarizing these dynamics one may begin to envision certain parts of biographies in the life history of objects or raw materials. This is particularly true for metals in the Bronze Age.

The question is how to operationalize these changes with real excavated materials. The Oxford group argues that through tracking the chemical variations between different metal assemblages on different scales, it is possible to reconstruct the movement of metal between different groups of people in different times and space (Bray *et al*., 2015; Pollard *et al*., in press-a and b). Two theoretical examples have been suggested in Bray *et al*. (2015), a linear trajectory and a long, complex and branching trajectory. The concept still follows the theory of the life history of object(s). One emperor requires craftsmen using metals from a specific source to cast a sword for him and this sword enters into the burial along with this emperor. This could happen within no more than 30 years and thus can be called a short, linear life history. In stark contrast, an example of a long, complex and branching trajectory might be a batch of weapons made from unknown metal sources that are turned into

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ritual vessels, of which their function shifts completely from practical fighting to ritual ceremonies. These new ritual vessels could be deposited into burials, then looted again and turned into other forms of objects, such as coins and disappear from circulation. One of the fundamental differences between these two models is chemistry. In the first scenario, all of the chemical features are fixed in the primary casting of the sword (also its form). In the second, the chemistry can be altered in each step of becoming into new forms.

What needs to be emphasized in advance is that I have no intention to prioritize one model over the other. In other words, it is unwise to move from extreme provenance thinking to an opposite but equally extreme mode of mixing and recycling. Indeed, it is slightly controversial, as in the beginning Bray *et al*. (2015) proposed a river analogy to visualize the flow of metal, namely several streams merge into one big river, which might have implied a circumstance of constant mixing and recycling of small batches of metal and in the end everything becomes homogeneous. The entire purpose of the river analogy is only to give one example of the potentially complicated relationships between the movement of metal and human societies, rather than an abstracted summary of all possibilities.

Undoubtedly, the issue of mixing and recycling is worthy of careful investigation. In the first Flame conference (03/12/2015), Rawson pointed out that the question of mixing is particularly relevant to China. Her argument derived from four main

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observations. The total weight of the largest *ding* (鼎) vessel in the late Shang period (833 kg) equals the entire metal assemblage in the Early Bronze Age of Britain (quoted P. Bray). There is no hard evidence as yet to rule out the possibility that in order to cast such an astonishingly heavy object, one may need to gather enough metal from a variety of sources and mix them together. The second observation comes from many pieces of bronze inscriptions. These show a likely scenario that weapons of enemies were turned into ritual vessels in memory of victory (Appendix II). The third one is from transmitted texts. One famous one can be found in Shiji (Records of the Grand Historian), which records the first emperor of the Qin dynasty, after unification, collected all the weapons and cast them into twelve large bronze figures. The later Eastern Han texts say that these figures were subsequently turned into coins again. This life history and social impacts are far more comprehensive than the source of metals, which might be even not possible to identify any more in some cases. The fourth one is regarding weapons. Particularly those constantly used in warfare were much likely to be repaired or recycled. All of these observations, which carry many profound social implications, unfortunately cannot comfortably be engaged with in conventional provenance studies.

This thesis argues that as a characterization system, the central objective in the Oxford system is to capture and comprehend changes of metal or copper-based artefacts across times and space. These changes can be informative on at least some parts of the life history of either the same or different assemblages of metal as artefacts or raw

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materials. Taking a step back, even though it might not be possible in the end to draw a complete picture of the life history of one individual assemblage, this comparative work could still show that *people* in different times and space used on the same/different metals and interacted with each other through metals. This result on its own is rather useful because it creates a basis for scholars to discuss movement of metal, local management, agency of raw metal and objects, economic crises and so on, particularly when it accommodates both provenance and mixing/recycling.

1.2.2 On the basis of changing chemistry

Experimental observation

Using chemistry as a fingerprint to source metal artefacts has been constantly questioned for a long time. The reason is that a series of changes can happen to the chemical compositions from extracting, smelting, casting, refining, recycling and mixing. Although clearly complicated alterations occur during the process of smelting, this is not the emphasis in this thesis as in the following chapters these is no intention to compare artefacts against any ores. Instead, the comparison is mostly between artefacts and artefacts. Therefore, I shall focus on a set of possible changes after the smelting process.

The experimental archaeology to explore the changing pattern of arsenic and antimony started at least in McKerrell and Tylecote (1972). Their experiments

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recorded a significant depletion of arsenic and antimony in an oxidizing atmosphere (not observable under a reducing atmosphere). They further showed that hot-working in the air can reduce a substantial amount of arsenic and antimony (Figure 40-42). Similar observations can also be found in other works (Budd and Ottaway, 1991; Charles, 1980; Merkel, 1983) and most recently in Park and Gelegdorj (2015).

Not only arsenic and antimony but also tin, zinc, iron, sulfur are expected to be changed by the high-temperature process (Meeks, 1983; Pollard *et al*., 1991; Budd *et al*., 1992; Pernicka, 1999; Pollard and Heron, 2008: Chapter 7). A loss of tin can be demonstrated in the re-melting experiment carried out in Godfrey (1996). Copper-tin alloy (10% Sn) was placed in a clay-graphite crucible and re-melted in an electric muffle furnace. Every 15 minutes the specimen is cooled down and a small piece taken for chemical analysis. The same procedure was repeated under different temperatures (1100℃, 1200℃ and 1300℃). It is evident that re-melting causes a significant reduction of tin concentration (~2-4%). What deserves more attention is that increasing the re-melting temperature delays the loss of tin. Godfrey (1996: 49) pointed out this might be attributed to the release of an increasing volume of carbon when the temperature goes higher, which results in a reducing atmosphere in the crucible. Further simulations are still necessary to explore to what degree blowing air into the crucible, as can be widely seen in antiquity, can affect the loss of tin (Godfrey, 1996: 50).

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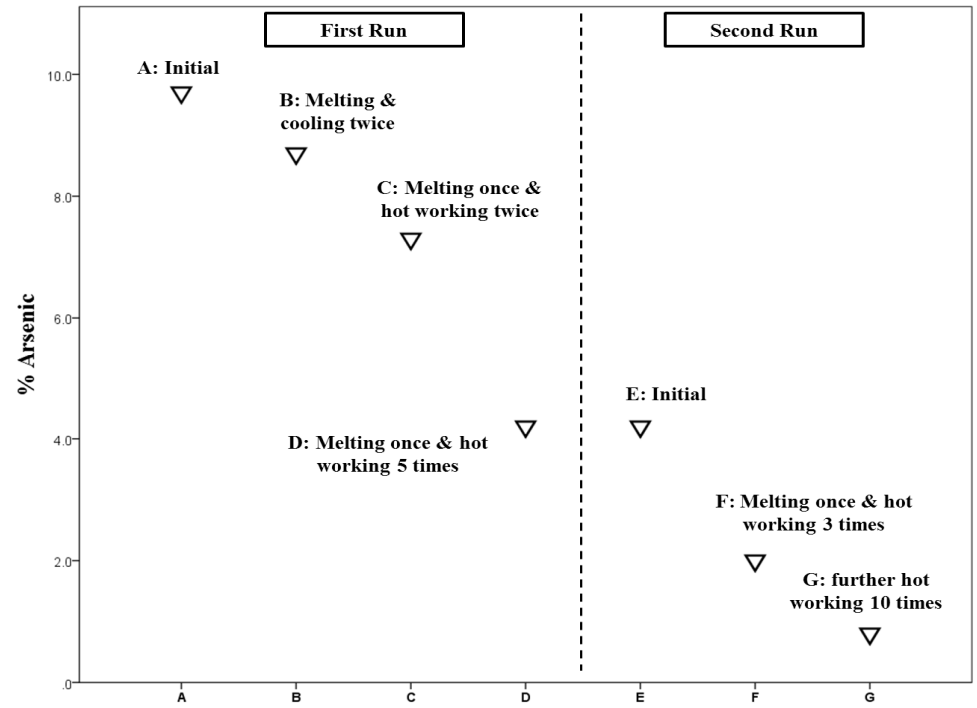

Figure 40 Results of simulation experiments in MeKerrell and Tylecote (1972): arsenic loss.

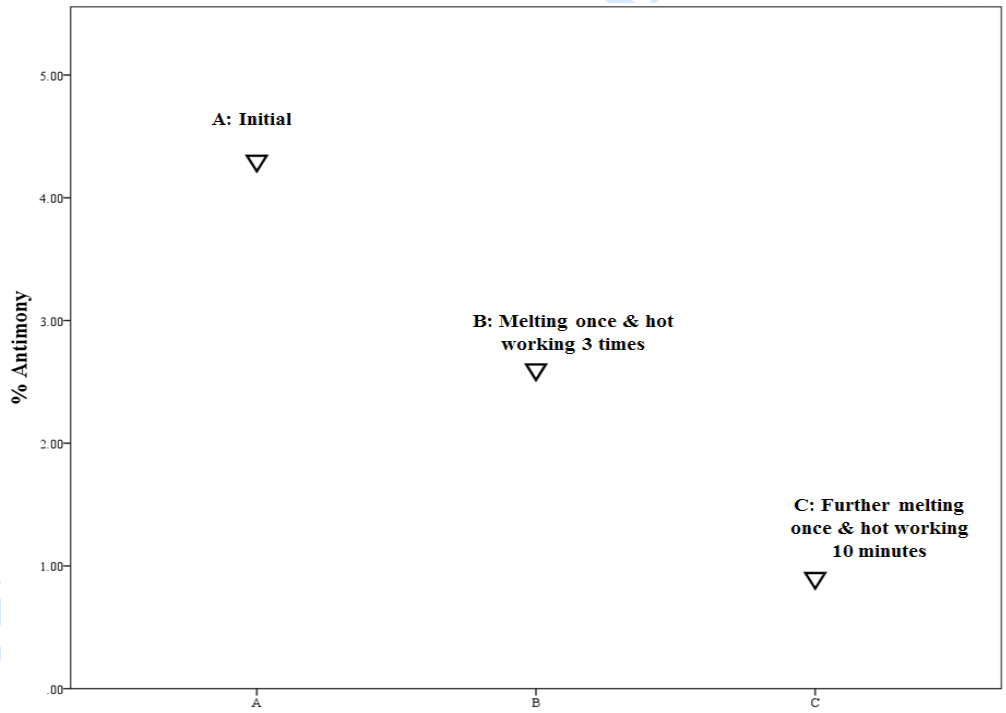

Figure 41 Results of simulation experiments in MeKerrell and Tylecote (1972): antimony loss

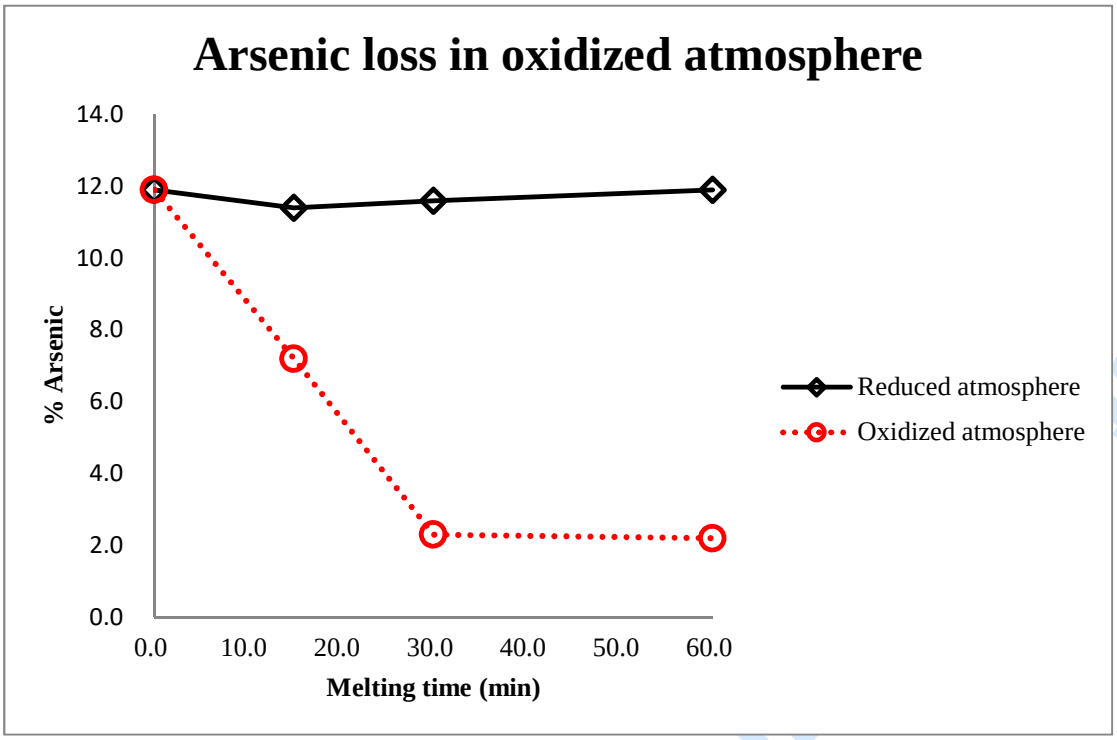

Figure 42 Change of arsenic concentration in oxidizing/reducing atmosphere (MeKerrell and Tylecote, 1972)

Thermodynamics

The fundamental law governing these above-mentioned changes is thermodynamics. High-temperature treatment such as casting and remelting results in varying degrees of the elemental loss through oxidation and volatilisation. It is very useful to consult the Ellingham diagram (Figure 43). This diagram summarizes the loss sequence of various selected elements. The x-axis is the temperature and y-axis is the Gibbs free energy. The more negative the Gibbs free energy is, the more stable affinity is formed between these metal elements and oxygen. For instance, arsenic tends to be oxidized before any other metals due to its higher negative Gibbs free energy (Figure 43). It is also imperative to clarify that this Ellingham diagram is created under perfect

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equilibrium conditions (ideality). While it can help understand what *might* happen, the condition of thermodynamic equilibrium would rarely have been achieved in antiquity, and therefore it should only be treated as a guide to what might actually happen.

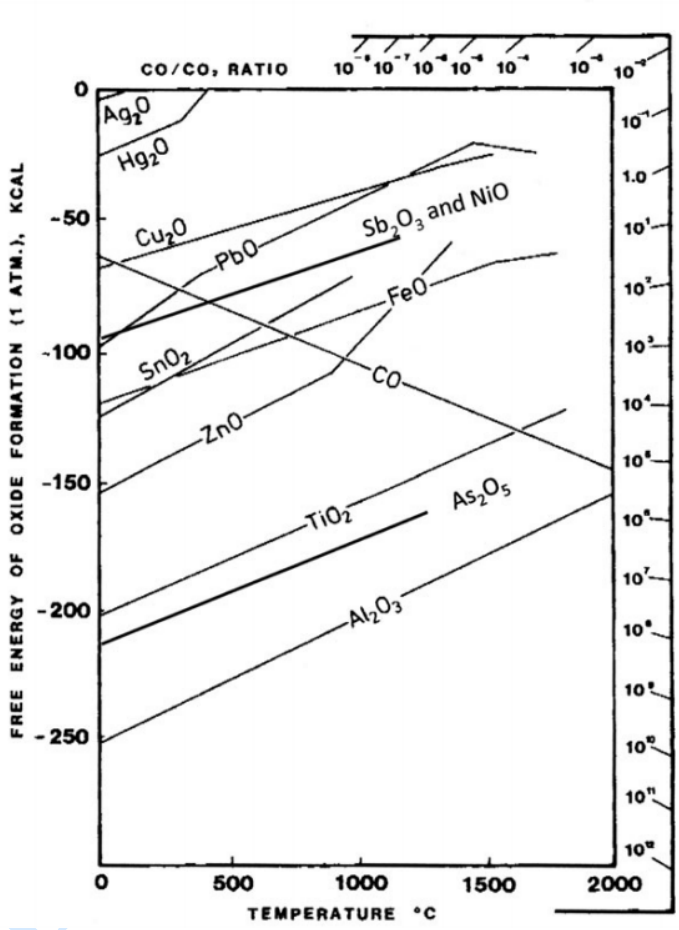

Figure 43 The Ellingham diagram of selected metals and oxides, after Bray and Pollard (2012)

1.2.3 Toolkit

Trace elemental patterns

Four elements (arsenic/antimony/silver/nickel) are selected as diagnostic elements because (1) their concentrations are widely reported and enable me to assemble a

database, which can cover as much time and space as possible (this is the reason that elements such as Bi, Co, Fe or Zn are excluded - they are also potentially helpful but only occasionally reported); (2) their behaviour in high-temperature processes is understood through thermodynamics and simulation experiment (see above). In short, arsenic and antimony are easily lost under oxidizing atmospheres whereas silver and nickel are strongly resistant to removal. Therefore, the commonest way to decrease silver and nickel is by dilution, which means rich-silver/nickel objects are mixed with silver-nickel poor-ones.

It is a two-stage analysis. The first stage is to re-characterize all objects into 16 copper groups based on presence and absence of the four diagnostic elements (Figure 44). The cut-off is tentatively set as 0.1%. It needs pointing out that before classifying objects into 16 copper groups, the concentrations of tin and lead need stripping out as addition of these two alloying elements clearly dilute diagnostic elements (Equation 1). This step is slightly different from what has been previously applied to the database of Europe and Russian where zinc is regarded as an alloying element and is removed as well. So the adjusted concentrations of the four diagnostic elements are copper-based under most circumstances. If not, for instance, some cases in which silver could also be introduced to the copper base through the addition of lead can also be identifiable in the second stage. The selection of 0.1% is essentially a balanced and pragmatic decision. It equals to the minimum detect limit of most instruments in archaeometallurgical research so that any result greater than this value would be

Ruliang Liu unplished thesis

considered statistically valid (Chapter Three). Moreover, we constantly vary this cut-off to test the stability of the data structures. The 0.1% seems reasonable for the database of China. In the following chapter, I have varied this from 0.08-0.12% but the overall distribution of copper groups is quite stable in each metal assemblage. The *exact* choice of cut-off therefore does *not* have a decisive impact on the final interpretation. The third protection comes from the second stage profile analysis. In doing so all the data will be shown in one profile where cut-off is no longer required.

Equation 1 Adjust and normalize the diagnostic elements

$$\%\ \text{of element}_{adjusted} = \%\ \text{of element}_{measured}/(\text{Analytical total-Sn\%}_{measured} - \text{Pb\%}_{measured})*100$$

The second-stage analysis involves two major parts, ubiquity analysis and profile analysis. Ubiquity analysis means to plot the proportion of each copper group geographically and temporally. It infers which copper groups are commonly used in which specific region and period. In addition, a combination of the distribution of copper group and other sorts of information, such as typology, chronology or social context, could also increase our knowledge of the life history of metal. Profile analysis is also known as histograms, which can present the distribution of different elemental concentrations in the entire assemblage. Compared to using one single average value, the overall profile distribution is more transparent, representative and informative. Furthermore, Kolmogorov–Smirnov test is routinely employed to check whether the profiles of two assemblages are statistically distinguishable. Details of

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this method can be found in Pollard *et al.* (submitted). In the end, I also need to emphasize that this methodology is based on an assemblage of objects. In some circumstances, it is potentially feasible to provide information about a single object. If the measurements available are too few, I use x-y scatters instead of profiles, which is equally transparent.

Copper Category	Copper with...	As	Sb	Ag	Ni
1	None	no	no	no	no
2	As	YES	no	no	no
3	Sb	no	YES	no	no
4	Ag	no	no	YES	no
5	Ni	no	no	no	YES
6	As+Sb	YES	YES	no	no
7	Sb+Ag	no	YES	YES	no
8	Ag+Ni	no	no	YES	YES
9	As+Ag	YES	no	YES	no
10	Sb+Ni	no	YES	no	YES
11	As+Ni	YES	no	no	YES
12	As+Sb+Ag	YES	YES	YES	no
13	Sb+Ag+Ni	no	YES	YES	YES
14	As+Sb+Ni	YES	YES	no	YES
15	As+Ag+Ni	YES	no	YES	YES
16	As+Sb+Ag+Ni	YES	YES	YES	YES

Figure 44 16 copper groups based on presence/absence of arsenic, antimony, silver and nickel (after Bray *et al.*, 2015)

Reflections on copper groups

What are these copper groups? Essentially, each copper group is simply a specific set of presences and absences of the four selected elements (arsenic/antimony/silver/nickel; impurity patterns). It is a heuristic characterization system which allows us to summarize all possible combinations in a very quick and straightforward framework. Although the copper groups appear rather alien to

Chinese archaeologists, however, using chemical analysis of trace elements (not necessarily presence/absence) to characterize copper objects has a long tradition in European archaeometallurgy. The example which is widely known is the SAM project (Figure 45 and 46). Each square in the decision trees represents a copper group defined by a specific trace elemental patterning and the authors claimed that they were originated from different sources (Pernicka, 2014). Some different classifications can also be found in Northover (1980), Needham (2002) and Bray (2009). In China, nevertheless, this tool or concept is rarely encountered, or at least not on such a large scale.

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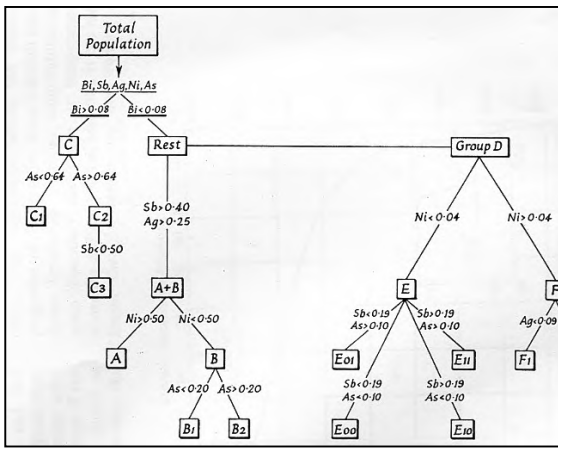

Figure 45 Copper groups defined in SAM (after Bray 2009, Volume II: 6)

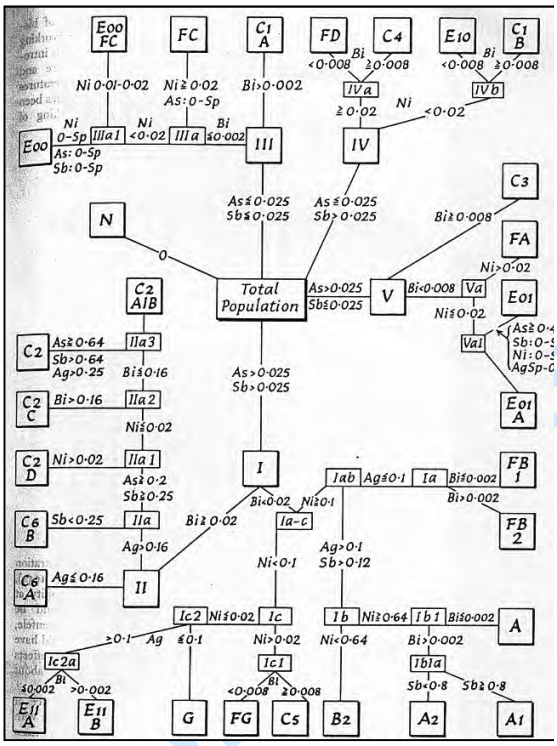

Figure 46 copper groups defined in SAM (after Bray 2009, Volume II: 7)

	Level of Key Element			
	As %	Sb %	Ag %	Ni %
"A" Metal	≥0.24	≥ 0.1	≥0.1	<0.09
Bell Beaker Metal	≥0.24	<0.24	<0.09	>0.09
Clean Metal	<0.09	<0.09	<0.09	<0.09
Arsenic Only Metal	≥0.24	<0.09	<0.09	<0.09
"F" Metal	≥0.1	<0.09	≥0.1	<0.09
Fahl Metal	≥0.1	≥0.1	<0.09	<0.09
Silver/Antimony Metal	<0.09	≥0.1	≥0.1	<0.09
Unclassified/ Recycled Metal	No set characteristics			

Figure 47 copper groups defined by P. Northover (after Bray 2009, Volume II: 29)

A more crucial question might be what makes these copper groups based on presence and absence more pragmatic, if not better? The first advantage has been repeatedly mentioned above. The tool of 16 copper groups is a starting point for a neutral characterization system. It does not preset any hypothesis. It does not presume that any of these copper groups should be related a specific source (although it could be), nor are completely isolated from one another. A variety of processes could introduce chemical changes in copper-based objects, such as smelting, oxidation, volatilisation, alloying, mixing and dilution. All of these could either obscure the original fingerprints or possibly convert one copper group to another. For instance, it is sometimes questioned that since lead often co-occurs with silver, by adding lead into copper it could enhance the concentration of silver so that one object could be turned from a silver-absent copper group to a silver-present one. Can this cause extra ambiguity? My statement is that because I am not expecting one copper group to be linked to one specific source, this is not an issue. Instead, it offers an opportunity to reveal the process of alloying with lead (Chapter Five and Six). What needs emphasizing again is that this tool enables us to *accommodate* these potential changes.

Secondly, the four selected elements are treated in a combination. This has several implications. One geological mine could produce a specific combination of elements. The Ross Island mine of Ireland produces copper of CG12 (As-Sb-Ag), which is high arsenic with the presence of antimony and silver. Thanks to the presence of arsenic,

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antimony and silver, copper from the Ross Island can be distinguished from that of Cwmystwyth and Parys Mountain from around 2000 BC, and the Great Orme (Lewis, 1998), from towards the end of the EBA at around 1600 BC, all of which produce clean copper (Bray, 2009: 95-96). Furthermore, using the combination could help scholars to separate these trace elements more easily. For instance, it is possible to distinguish arsenic from X place to another that of Y because the arsenic from X is associated with antimony whereas in Y it is associated with nickel. This in theory could contribute to disentangling the movement of metal or even mixing in early metallurgy, such as the one seen in the Gansu corridor.

A related issue is the element of arsenic. It has been long debated whether arsenic was deliberately added into copper; if so, when, where and how? There is no doubt that the issue of arsenical copper is extremely complicated and very likely varied case by case (Budd *et al*., 1992; Charles, 1967; Ixer and Pattrick, 2003; Rehren *et al*., 2012; Thornton, 2009). One response here is that we do not exclude the possibility that arsenic was an intentional addition and by plotting its raw data into either scatters or histogram, this possibility may be tested (Hsu, 2016: 154). Therefore, though the Oxford system characterizes arsenic together with antimony, silver and nickel, it does no presume that any of them is intentionally added or natural occurrence with copper. Plus either way can be tested by the subsequent stage of analysis.

The third advantage is attributed to the reliance on presence and absence. Although

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one might criticize that this does not make full use of the measurements, which might contain data recorded to two or three decimal places, this thesis argues that this is a more open and realistic framework (Liversage, 1993). By being open I mean it is not regionally specific. The best example would be the decision tree of the SAM project. It would be very unlikely for an archaeologist in other parts of the world to characterize his/her own data under this complicated grouping system with those exact cut-offs (*e.g.* SAM decision trees). It might be true that the statistical approach behind it is to some degree universal. But the consequence is that in the end each region has its own complicated "decision tree" and no one can easily connect them in a coherent manner. However, a large number of studies based on archaeological records have confirmed interregional metal movements over a large distance. The concepts and methods represented by SAM in this case could severely affect the dialogue between scientific analysis and archaeological studies.

Being completely different, using presence/absence constantly opens one region to another. The example can be found in Bray *et al*. (2015), which maps the distribution of CG2 (As-only) from Britain to continental Europe and further east (Figure 48). This map actually combines two different projects (the postdoc project of Bray, Europe, and the PhD of Cuénod, Iran plateau). Two regions can be clearly identified as "hot spots", where they are dominated by one particular copper group, CG2, with over 50% of the entire local metal assemblage in this case. One flow starts from the Iberia and travels along the Atlantic coast of France and arrives in Britain. The other

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one derives from the western Anatolia/Balkans and enters into Europe. By simply charactering these local metal assemblages and charting their spatial variations, it becomes possible to visualize not only the source of metal but also the movement. This provides two immediate benefits. On one hand, the ubiquity of copper groups (or alloying types) is independent from archaeological surveys therefore could offer some predictions of the potential existence of local sources of metal, such as the tin mines in Assyria (Cuénod *et al.*, 2015). Similar cases can be found in Chinese context (*e.g.* Chapter Five). On the other hand, relying on presence/absence is more pragmatic. It has to be admitted that no single region has high-quality analyses of over 20, 000 objects except Europe. Using this qualitative characterization makes it feasible to integrate more datasets of varying qualities and present important archaeological scenarios.

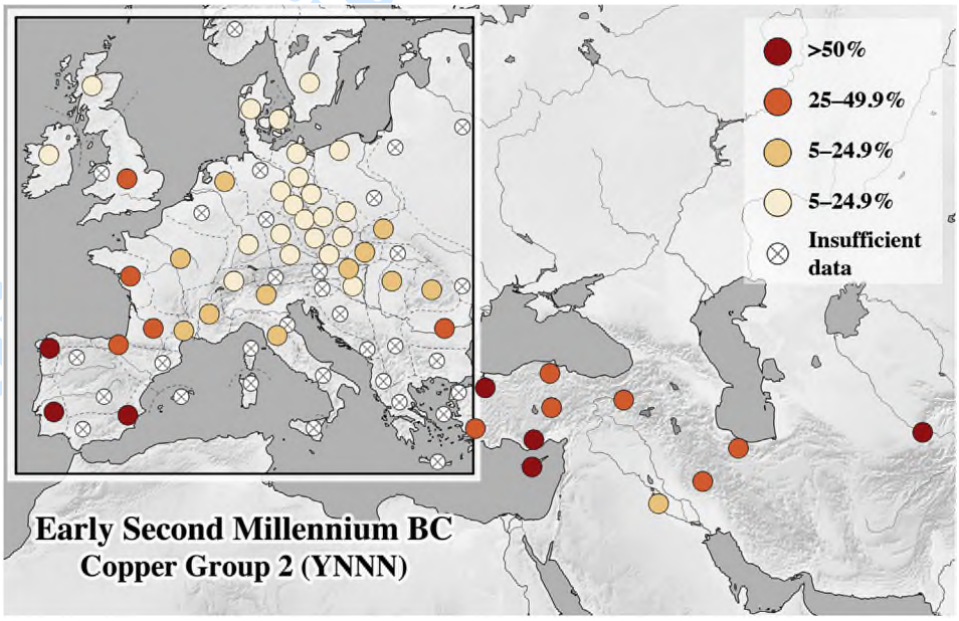

Figure 48 Linking different regions by ubiquity of copper groups (after Bray *et al.*, 2015: Fig. 2)

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Last, but by no means least, this is a simple language. Unlike conventional principal components or cluster analysis which hide the complicated mathematics behind professional software, a basic excel spreadsheet with a few lines of coding can immediately sort out the grouping within the database, however large it is. The procedure is completely transparent so that one can easily see the reasoning from chemical analysis to the final copper group. Because it is so simple, any student with archaeological background can grasp it by themselves with very little training. This implants a seed between science and archaeology in the very early stage for a growing dialogue.

Although a series of positive aspects can be proposed for the framework of copper groups, it needs to be stressed that the observation of arsenic loss might not be applicable in China. In the Chinese database, the concentration of arsenic in a large proportion of As-bearing objects is merely around ~0.2-0.5%. Re-melting under these circumstances might not be able to remove a significant amount of arsenic compared to the analytical error. The same is true for antimony. Therefore, the thermodynamic loss of arsenic and antimony, which appears more obvious in Europe and the Steppe, might not be visible in the Chinese data. This is not a vital issue because one can easily identify this in the second stage of profile analysis of arsenic and antimony.

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Alloying elements

It is also possible to apply the same approach to the alloying practice. The first step is to use presence/absence to produce alloying groups, akin to copper groups. In this case, the arbitrary cut-off is increased to 1%. It is followed by the second stage of profile analysis. Both of them have been frequently encountered in the Chinese language publications. The original contribution lies in the new way of interpretation. Traditionally, alloying elements are normally assumed to be deliberately added to the copper in order to modify certain mechanical properties (primary or designed alloying). However, other possibilities involve mixing, recycling or the use of an object as alloying material, either consciously or unconsciously (secondary or less-designed alloying). All of these possibilities make the picture more complicated and thus require more flexibility. For instance, if the pattern that the percentages of tin/lead in an assemblage is an approximately symmetric distribution (or unimodal), it is more likely that this metal assemblage is alloyed with careful control (primary or designed alloying). On the contrary, instead of a narrow symmetric distribution, under many circumstances, the plotting of tin/lead shows a wide range, concentrating in the low profile of alloying with a long tail towards high profile. Though sometimes a small amount of tin or lead could be added into copper for some symbolic meanings rather than improving their physical properties, this appears more likely that it is a result of mixing and recycling old objects (secondary or less-designed alloying; Figure 49).

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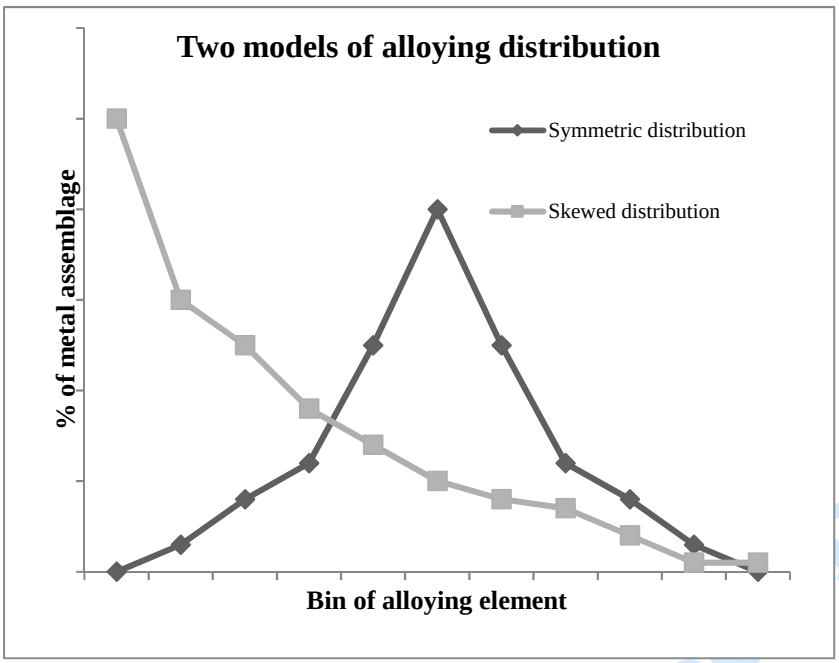

Figure 49 Two theoretical models of alloying distribution indicating different alloying practice (primary or secondary alloying)

Similar to 0.1%, using 1% at the cut-offs to define alloying types is also a balanced and pragmatic choice. In general, elements which are greater than 1% in copper-based artefacts are no longer deemed as impurities. For instance, most chalcopyrites only have a few hundred ppm lead or tin in them, but we can't rule out the possibility of poor sorting of chalcopyrite/galena, resulting in Pb entering the smelted copper, particularly in early metallurgical processes. This is however not a nerve-racking problem because in the second stage of profile analysis we shall put all data together without assuming any cut-off. Particularly, in Bronze Age China, almost all of the objects were either leaded bronze or bronze since the Erlitou period therefore the interpretations in this thesis is largely dependent on the profile analysis.

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One practical application of alloying groups is to track the continuity of metal stocks and quantify the proportion of mixing/recycling in the first millennium AD Britain through their ubiquities across successive periods (Pollard *et al*., 2015). The most dominant alloying group around the 1st century AD is brass (Cu-Zn). This metal stock is subsequently mixed with tin-bronze (Cu-Sn) and changes into gunmetal (Cu-Sn-Zn) in the 2nd century AD. A more diagnostic peak of leaded gunmetal (Cu-Sn-Zn-Pb) can be observed when it comes to the middle Anglo-Saxon period as a result of further mixing and recycling gunmetal with leaded bronze into leaded gunmetal. This can be also supported by profile analysis. Because of constant mixing and recycling, one can observe a decreasing percentage of zinc from the Roman to the early Saxon period and from brass/gunmetal to leaded gunmetal (Figure 50 and 51).

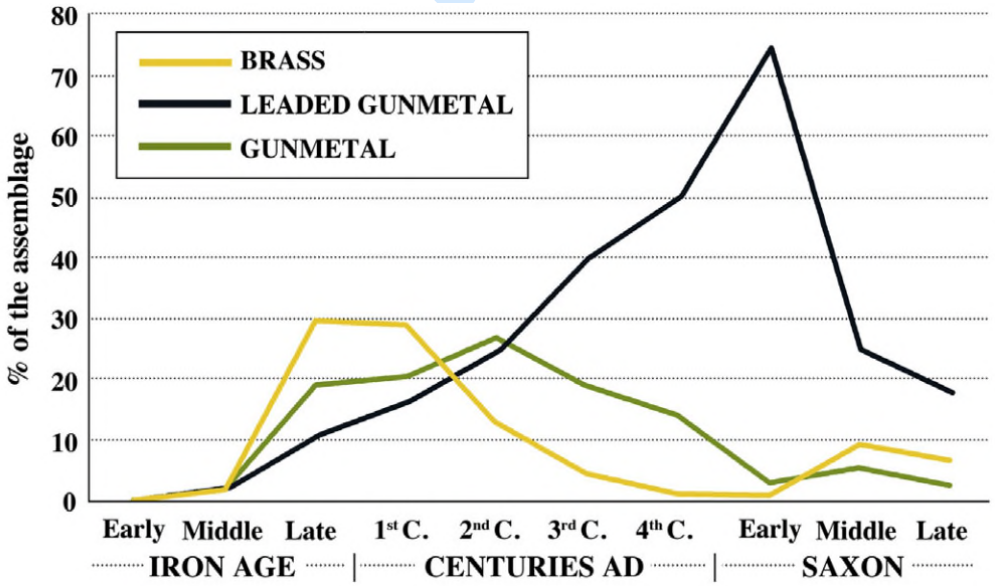

Figure 50 Ubiquity of along groups in each period of Roman Britain
(after Bray *et al*., 2015: Fig.3)

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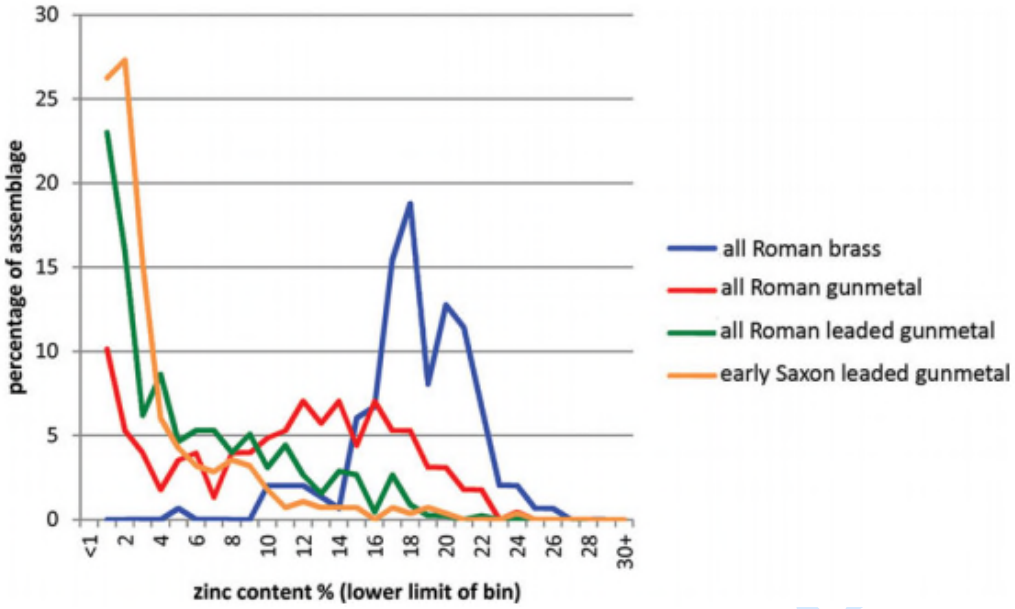

Figure 51 Profile of zinc percentage in alloying groups of different periods
(after Pollard *et al.*, 2015: Fig. 4)

Lead isotope ratios

This DPhil project attempts to employ a new set of diagrams of lead isotopes, which plot reciprocal of lead concentrations against one lead isotopic ratio (Pollard and Bray, 2015). Conventional plotting of two lead isotopic ratios allows geochemists to calculate the age of the deposits. To what extent these plots are helpful to resolve archaeological questions remain to be answered. The new set of graphical methods has several advantages over the traditional diagram which plots lead isotopic ratio against another. First of all, it is more sensitive to recycling and mixing. A mixing line will show up if these plotted objects are made by mixing with different metals. This can be mathematically demonstrated (Appendix III). Secondly, it combines the concentration of lead and its isotopes at the same time. This is of vital importance to

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Chinese bronzes. Since the lead percentage varies from less than 1% to over 30%, it has been long debated that whether lead isotopes are a proxy for copper source or lead source. In the new presentation, it is much clearer that lead isotopes of those points on the right-side of the diagram, which contains less than 1% lead, are more likely associated with copper source whereas those on the left-hand side appear more indicative of lead source (Figure 52). In addition to lead percentages, it is also possible to colour code these dots in accordance with other sorts of information, such as trace elements, typology, sites, chronology and so forth. This allows me to combine lead percentages, lead isotopes and trace elements altogether.

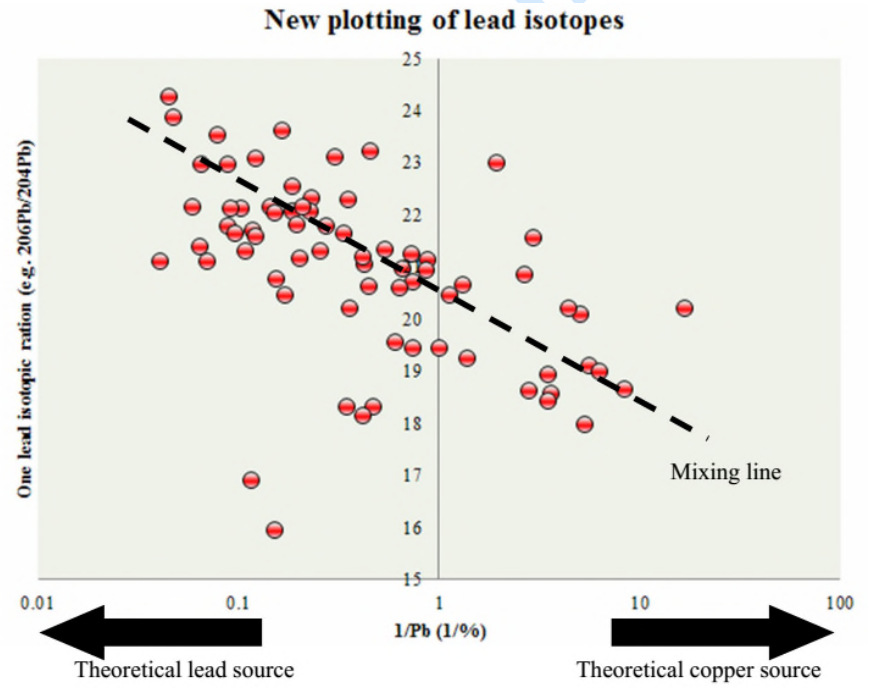

Figure 52 New plotting of lead isotopes suggested by Pollard and Bray (2015)

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The potential danger is that lead percentage cannot be accurately measured (Chapter Three). The reason is explained in the following chapter. This is not a tremendous issue because here I use 1/Pb rather than the absolute value of Pb%. For instance, even if one object actually contains 15% lead but the measured value is only 10%, this does not dramatically affect the final conclusion as the difference reflected on the reciprocal is only 1/10-1/15≈0.03 so cannot obscure the mixing line.

Through reworking the well-known dataset of Sardinian objects and ingots, Pollard and Bray (2015) found that although lead isotopes of most Sardinian ingots are consistent with those of Cyprus ores, as previously suggested, clearly two mixing lines can be observed (Figure 53). One is a mixture between Sardinian ingots (or Cyprus ingots found in Sardinia) and local objects (Line A). The other is between Sardinian ingots (or Cyprus ingot) with an unknown source (Line B). Furthermore, this way of presenting lead isotope data can be varied in accordance with what sort of information is available. As shown in Figure 54, since no data on lead concentrations are published for the Cyprus ore data, Pollard and Bray (2015) simply replace the 1/Pb on the x-axis with sequential sample numbers (Figure 54). This shows that at least one axis can be freed and allow us to combine lead isotopes with a different kind of information. In the later part of thesis, I often use either lead concentrations, sites or chronological sections as the x-axis. This may not directly reveal the source of lead or copper but could show the changes of metal supply during different periods of time.

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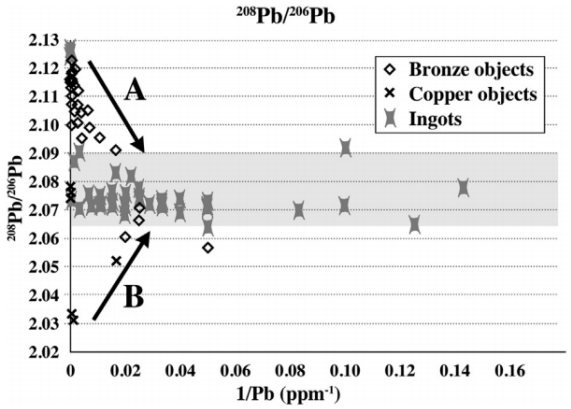

Figure 53 New plotting of lead isotopes in Sardinian objects and ingots

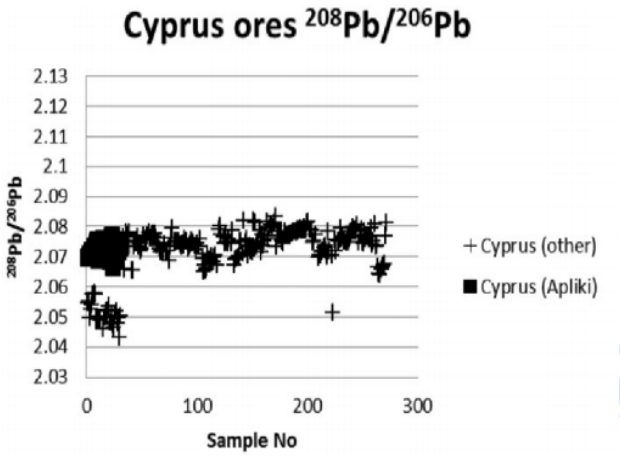

Figure 54 Lead isotopes of Cyprus copper sources

2.2 Time, space and scale

A key aspect of the methodology in this thesis is that it is scalable. As a characterization approach, it allows us to carry out comparative studies on varying scales (Clarke, 2014; Clarke and Chapman, 1978). In archaeology, comparing like with like is not at all innovative. It can be varied from a single object, an assemblage of objects from the same grave up to the overall objects from one continent. However, while they are all archaeological enquiries on human interactions, the scales are dramatically different. The methodology presented here is capable of characterizing from one single object up to an enormous assemblage. This makes it possible to compare objects and explore human interaction on these varying scales through the lens of the scientific analyses of metal.

Two fundamental variables that contribute to or limit the scales of discussion thus need serious consideration. One is the chronological resolution. So far, there is no

Ruiliang Liu unpublished thesis

scientific technique which could directly date the copper-based objects. The chronology of the objects is normally transferred from the date of the archaeological context, such as the burials or hoards, or its own typology. It however plays a critical role in understanding the dynamics of human interactions, or at least metal movement. For example, it has been demonstrated that lead isotopic signatures were radically changed after the Western Zhou took the place of Anyang (Jin *et al*., accepted). But, through dividing the metal assemblage at Anyang into four chronological phases, which is of a finer resolution, it is more striking to see that this change already started during the third phase of Anyang (Jin, 2008: 162-163). With better chronological resolution, the picture of changes can also be refined.

The second one is space. In essence, it is a classical question of local/non-local. If one metal assemblage contains both local products and imported ones and they are separated, the characterization of their chemical analyses as a whole is blurred. Space might not be a large issue provided that there are a large number of analyses and the assumption that the number of objects travelled is in inverse proportion to the distance. It is also useful to check with technology and typology as independent attributes. The argument with space is similar to that of chronology. A better understanding of local/non-local products could improve the resolution of the dynamism in human interaction, or at least reduce some noise when one attempts to summarize the local production system with metal chemistry.

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2.3 Synthesis of legacy data

One of the solid contributions made by this thesis is the delivery of a large legacy database. It has exhausted approximately all of the major datasets available in publications (Figure 55-57). A more comprehensive databank has been published in Liu *et al*. (2015), which includes analyses of bronzes dated to both Shang and Western Zhou. Figure 55-57 present an updated synthesis of Shang bronzes, which lays down the ground work of this thesis.

Ruiliang Liu unplished thesis

Reference	Data number	Instrument
Freer Collection	113	Wet Chemistry
Sun and Han 1981	3	EPMA
Henan Institute of Archaeology and Zhengzhou Museum 1983	4	Wet Chemistry
Li et al. 1984	43	Wet Chmieal for main;AAS for trace
Li 1982	103	Wet Chemistry /AAS
Bagley 1987	122	AAS/NAA
Rawson 1990	176	AAS/NAA
He and Ou 1994	13	SEM-EDS
Fan and Su 1997	37	Wet Chemistry
He 1997	21	Unknown
Peng et al. 1997	44	Wet Chemistry/XRF
Peng et al. 1999	44	Wet Chemmistry/XRF
Hao and Sun 2001	42	SEM-EDS
He 2001	32	SEM-EDS
Sun et al. 2001	39	ICP-MS
Peng et al. 2001	35	Unknown
Chen et al. 2001	58	NAA/SEM-EDS
Takahaman et al. 2001	144	XRF
Yang 2002	42	SEM-EDS
Zhao 2005	233	ICP-AES
Liu et al.2005	53	XRF/ICP-AES
Zhao 2006	18	ICP-AES
Jin et al. 2006	31	ICP-MS
Wang et al. 2008	10	ICP-OES
Zhao 2006	208	AAS
Chen 2007	238	EPMA
Wei 2007	99	ICP-AES
Ji 2007	27	AES
Jin 2008	24	ICP-AES
Zhao 2008	9	ICP-AES
Ma et al. 2012	30	ICO-OES
Tian 2013	32	ICP-OES
Cao 2014	185	XRF
Liu 2015	106	SEM-EDS/ICP-AES
IA CASS 2014	29	SEM-EDS
Collins 1931	10	Unknown
Liang 2004	18	AAS
He 1997	3	Unknown
Henan Institute of Archaeology and Zhengzhou Institute of Arch	4	SEM-EDS
Peng et al 2001	5	Wet chemistry/AAS
Zeng 1989	23	EPMA
Zeng 1991	10	SEM-EDS
Ma 2015	47	SEM-EDS
Wang 2013	19	SEM-EDS
Li and Han 2000	38	SEM-EDS
Neitian et al. 2016	69	EPMA
Liu et al. 2007	53	ICP/XRF
Zhao 2004	208	ICP-AES
Mao et al. 1996	25	XRF
Hsu 2016	39	EPMA
Yang and Ding 1959	1	Unknown
Chen and Mei 2006	21	SEM-EDS
National Tokyo Museum 2005	50	XRF
Liang 1950	8	Unknown
Zhu 1995	4	Unknown
Tian 1981	5	Unknown
Feng et al. 1982	40	SEM-EDS/Wet Chemistry
He and Ou 1994	13	SEM-EDS
Chase and Douglas 1997	108	XRF/AES
Cui et al. 2009	7	SEM-EDS
RLAHA Unpublished data	79	SEM-EDS

Figure 55 Alloying database for Shang bronzes

Reference	Data number	Instrument
Jin 2008	17	ICP-AES
Zhao 2006	208	AAS
Bagley 1987	122	AAS/NAA
Rawson 1990	176	AAS/NAA
Freer Collection	113	Emission Spectrometry
CASS 1985	54	Wet Chemistry /AAS
Chen 2007	238	EPMA
Zhao 2008	9	ICP-AES
Chen et al. 2001	58	NAA
Liu 2015	57	ICP-AES
Zhao 2005	233	ICP-AES
Shang Sackler Collection	123	NAA
Tian 2013	32	ICP-MS
Wei 2007	99	ICP-AES
Fan and Su 1997	37	Wet Chemistry
Li et al. 1984	28	Wet Chmieal for main;AAS for trace
Zhao 2006	18	AAS
Ji 2007	27	AES
Ma et al. 2012	30	ICP-MS
IA CASS 2014	29	ICP-MS
Liang 2004	18	AAS
Cao 2014	185	XRF
Collins 1931	10	Unknown
Zeng 1989	1	EPMA
Zeng 1991	10	SEM-EDS
Wang 2013	6	SEM-EDS
Li and Han 2000	16	SEM-EDS
Neitian et al. 2016	69	EPMA
Zhao 2004	208	ICP-AES
Liu et al. 2007	53	ICP/XRF
Peng et al. 1989	35	Wet Chemmistry for CU and XRF for others
Peng et al. 1999	44	SEM-EDS
Chen and Mei 2006	4	SEM-EDS
Mao et al. 1996	25	XRF
Hsu 2016	39	EPMA
National Tokyo Museum 2005	4	XRF
Liang 1950	8	Unknown
Zhu 1995	4	Unknown
Tian 1981	3	Unknown
Feng et al. 1982	29	SEM-EDS/Wet Chemistry
He and Ou 1994	5	SEM-EDS
Chase and Douglas 1997	108	XRF/AES
Hao and Sun 2001	42	SEM-EDS
RLAHA Unpublished data	79	SEM-EDS
Takahaman et al. 2001	144	XRF

Figure 56 Trace elemental database for Shang bronzes

Lead Isotopes	Data number	Instrument
Cao 2014	182	TIMS
Chase 1996-1997	43	TIMS
Jin 2008	20	ICP-MS
Jin et al. 2006/Unpublished	86	ICP-MS
Sun et al. 2001	40	ICP-MS
Liu 2015	116	ICP-MS
Tian 2013	32	TIMS
Peng et al. 1999	57	ICP-MS
Peng et al. 1997	52	ICP-MS
Cui and Wu 2008	33	TIMS
Jin et al. 2001	62	ICP-MS
Ma 2015	108	TIMS
Jin et al. 1994	11	TIMS
Jin et al. 1995	51	ICP-MS
Bagley 1987	123	TIMS
Rawson 1990	132	TIMS
Takahaman et al. 2001	56	ICP-MS
Cui et al. 2012	13	ICP-MS

Figure 57 Lead isotopes database for Shang bronzes

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As most of these analyses are performed and published independently, there is no way to circumvent their fragmented nature. This can be firstly reflected by a diversity of analytical instruments. The following chapter is devoted to the issue of data quality in these datasets. The fragmented nature is also reflected by the types of reported values. While it has been frequently suggested that alloying, trace elements and lead isotopes should be combined together, there is virtually no publication which manages to put all three types of analysis in a row, with the exception of the Sackler and Freer collections. The first step to realistically combine them requires a laborious cross-referencing of each analysis between different papers based on information like excavation/museum logs. Such a vast database offers a number of overlaps between those publications. For the first time, it is possible to present a pilot study combining alloying, trace elements, lead isotopic data on a nationwide scale. As expected, this combination provides many novel and interesting results, which have been recorded in later chapters. The second benefit is that it reveals major gaps for future research. We can immediately see which site or which region requires what type of analysis. The Guanzhong Plain and the Yangzi River valley deserve a lot more attention (Liu *et al*., 2015). Even though a relatively larger number of alloying analyses is available for Anyang, objects in those important burials, such as Fu Hao or those of the Western Area of Anyang, should have more data on trace elements and lead isotopes, which enable scholars to ask new questions or draw pictures with better resolution (Chapter Six).

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2.4 Summary

Scholars have explicitly presented an integrated system from philosophy to practical tools to characterize metal chemistry in archaeology, which now becomes known as the Oxford system (Pollard *et al*., in press-a and b; Bray *et al*., 2015). This shifts our attention from the static provenance to the concept of life history of metal, which embraces the dynamic reflection on metal movement and human interactions. Although it has been applied to many social systems, such as the British Bronze Age (Bray *et al*., 2015; Bray and Pollard, 2012) and Roman Britain (Pollard *et al*., 2015), Bronze Age Alps (Perucchetti *et al*., 2015), the Iranian plateau (Cuénod *et al*., 2015), and the Eurasian steppe (Hsu, 2016; Hsu *et al*., 2016), it still remains ambiguous as to what outcome would be expected for a highly centralized society, such as Shang China. The long history of archaeometallurgical research in China has accumulated a substantial number of analyses. It is very interesting to carry out a systematic study by applying the Oxford system to Shang data and contributing to the dialogue between scientific analyses and archaeological research, which is presented in later chapters.

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Chapter Three Data quality assessment: a preliminary comparison project

3.1 Introduction

"Would I have gotten a comparable result if I had sampled and analyzed that object by my own techniques?" (Chase, 1975: 148)

This question was posed in the earliest draft of the first large-scale comparative study on the chemical analysis of ancient bronzes (Chase, 1975). Despite being only a few words, this points out a long-standing issue in the archaeometallurgical sphere. While various instruments have been applied to explore the chemical composition of tens of thousands of metal objects in antiquity, the question of which set of data should be selected to support/revise/rewrite the final archaeological interpretation is still open to debate and discussion.

The fundamental aspect of this issue is the very intricate balance between the natural compositional inhomogeneity of metal, instrumental error, and human behaviour embedded underneath the chemical numbers. One example of the former is a *bu* (瓿)

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vessel in the Shang Sackler collection (Bagley, 1987). Atomic absorption spectrometry (AAS) was employed here. Three samples were taken from the ring foot, inside the lid and from a repair of the body from this object. As Table 1 shows, none of them is numerically identical to one another. This difference however emphasizes a considerable theoretical challenge. If we accept the point that the chemical composition of metal objects could further extend our understanding of human behaviour (technology, trade, exchange, warfare or social organization, listed in Chapter Two), one of the elementary questions to ask is which part of the final reported composition is due to natural compositional heterogeneity formed during metal solidification (natural determinism), which is analytical error, and which part could reflect real human behaviour (cultural determinism)? Taking the concentration of tin in the Sackler *bu* (瓿) again as an example, it is quite obvious that the repair contains much less tin than the object itself, either the foot ring or the lid, which is quite possible and is interpretable in many ways. The major question is whether or not it is reasonable to ignore the remaining difference of 4.3% tin and argue that either 10.7% in the foot or 15% in the lid basically leads to the same interpretation? The totals of these analyses are noticeably different. As Chase in the Shang Sackler volume pointed out, the fact that the total is significantly less than 100% could be caused by heavy corrosion. By normalizing this dataset to 100%, tin would increase to 11.9% for the foot ring, therefore only 3.1% less than that in the lid. Probably, the lid and body are made to the same recipe so that the compositional variation only arises from natural inhomogeneity and analytical errors. But no one could completely deny a

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small chance that the difference of tin percentage might indicate a deliberate human choice. Without further information, it is difficult if not impossible to say whether variation of 3-5% tin carries implications of archaeological interest for an individual object.

Table 1 Chemical analyses of the pou vessel in Sackler collection

Analytical Number	Sampling position	Cu	Sn	Pb	Zn	Bi	Ag	Sb	As	Fe	Ni	Co	Au	TOTAL
123V	Foot ring	68.3	10.7	11.2	0	0	0.01	0.014	0.01	0.034	0	0	0	90.27
123S	Ancient repair	88.8	1.49	7.4	0	0	0.02	0.002	0.02	0.02	0	0	0	97.76
123L	Lid inside	76.8	15	7.3	0	0	0.06	0.008	0.07	0.08	0	0	0	99.34

This chapter primarily aims to provide a careful comparison of chemical analyses on the same object produced by different teams. This sort of large and detailed assessment has not yet been seen for Chinese objects in the existing literature. It includes several major legacy databases and fresh measurements generated in RLAHA, Oxford. These legacy data are explored in later chapters so understanding their data quality is vital. The outcome of this chapter is to partly answer the question as to what degree the reported compositional variation is caused by differences in instrumentation and inhomogeneity, and partly to identify analytical disagreements between different teams. Indeed, except for some occasional cases, it is virtually impossible to give any definitive answer on the data quality without full information on what we have called “analytical hygiene” (Pollard *et al*., 2007: 302-321). According to these observations, what can be argued is that by following the

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methodology of data assessment established in western academia, it is equally feasible to identify datasets of unacceptably poor quality, though not very many exist in the Chinese databank. It also reveals a group of excellent datasets which are inter-changeable. This series of data assessments helps to understand the pros and cons of each assemblage of data and keep us from jumping to invalid judgments.

This chapter starts with a discussion of two key aspects, compositional inhomogeneity and instrumental variation. Reviewing the milestone data-comparison projects in western academia is very illuminating for the issue of inter-laboratory data comparison. On the basis of previously published methodologies, the following section of this chapter characterizes and evaluates SEM-EDS in RLAHA Oxford using 16 standards, and compares all series of data banks used in this thesis, element by element, object by object, assemblage by assemblage.

3.2 Potential inhomogeneity of metal composition

Compositional inhomogeneity in archaeological metal objects has been noticed for a long time (*e.g.* Richards and Blin-Stoyle, 1961). As listed by Charles (1973), this inhomogeneity arises from (1) elemental insolubility in the copper base, primarily bismuth and lead (see also Slater and Charles, 1970), (2) non-equilibrium segregation and (3) processing technology. In general, one of the most effective ways to test this theoretical issue is multi-spot analysis. Richards and Blin-Stoyle (1961) published an

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analytical report on the chemical composition of various locations on one Irish arsenical copper axe (Figure 58; Table 2). The largest difference produced in the process of cooling during casting is expected between the tip and centre of the axe because these two differ most in thickness. In the three measured trace elements (Ni, Ag and Sb), the biggest difference observable occurs in antimony (centre 0.247% and tip 0.266%). But this difference is only 0.019 in absolute percentage. One of the most impressive case studies can be found in Northover and Gilmour (2003). They analyzed cannons containing up to several tons of metal with EPMA and conclude that the compositional variation of tin in these giant objects is actually no more than 5% in absolute terms.

Table 3 lists one cannon with 13 analyses by EPMA. These samples are taken by domestic cordless electric drill with a 3mm diameter bit. It shows a very low relative standard deviation for Cu, Sn, Sb, Ni and Ag, indicating little inhomogeneity among these samples. Nevertheless, the relative standard deviations for Fe and Zn are substantial. This might be to do with their low concentrations approaching the minimum detection limit (MDL) of the instrument (see below). The uncertainty of lead is also large and probably due to its insolubility in the copper base. Except for elements of minimal concentrations and lead, a reasonably good agreement can be achieved between these 13 analyses, suggesting that any of them is equally representative of the whole cannon.

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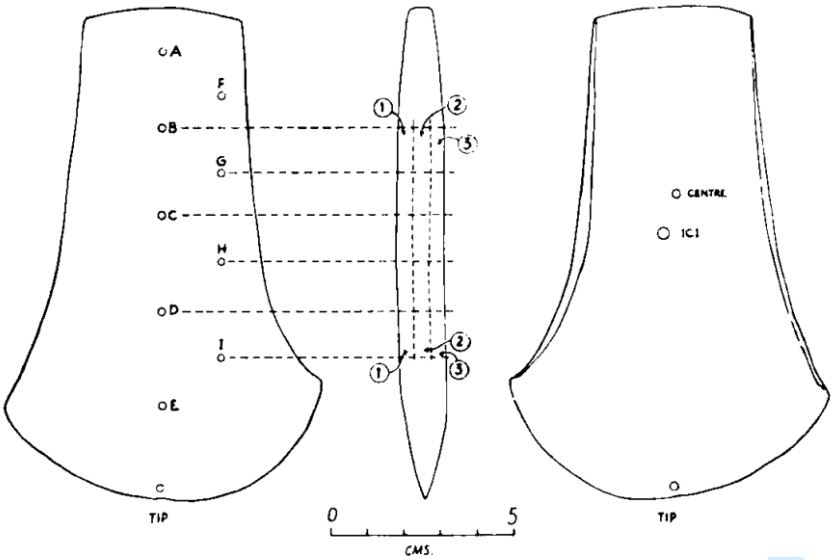

Figure 58 Multi-spot analysis (from Slater and Charles, 1970)

Table 2 Analytical results for spots in Figure 58 (data from Slater and Charles, 1970)

Element	Centre	Tip
Cu	96.4±0.1	96.2±0.2
As	2.89±0.09	3.15±0.11
Ni	0.021±0.001	0.021±0.001
Ag	0.194±0.007	0.207±0.007
Sb	0.247±0.005	0.266±0.013
Pb	0.31±0.01	0.31+0.02
Sn	<0.1	<0.1
Bi	<0.02	<0.02
Fe	<0.02	<0.02
Zn	<0.05	<0.05
Au	<0.01	<0.01

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Table 3 Compositional variation of a cannon (Gilmour and Northover, 2003)

Sample Num	Fe	Co	Ni	Cu	Zn	Sb	Sn	Ag	Pb
1	0.01	0.00	0.11	91.00	0.21	0.17	7.70	0.05	0.30
2	0.01	0.00	0.13	90.00	0.09	0.21	7.90	0.06	0.50
3	0.01	0.00	0.11	91.00	0.07	0.28	8.70	0.06	0.20
4	0.01	0.00	0.13	90.00	0.05	0.17	7.80	0.05	0.40
5	0.00	0.00	0.13	91.00	0.01	0.17	7.90	0.05	0.25
6	0.00	0.00	0.15	89.00	0.01	0.18	8.60	0.05	0.20
7	0.05	0.00	0.09	90.50	0.06	0.18	9.30	0.05	0.20
8	0.01	0.00	0.12	91.00	0.03	0.14	8.10	0.05	0.20
9	0.01	0.00	0.11	91.00	0.04	0.24	8.90	0.05	0.25
10	0.00	0.00	0.15	91.00	0.03	0.27	8.90	0.06	0.50
11	0.01	0.00	0.15	91.00	0.11	0.24	8.70	0.06	0.40
12	0.17	0.00	0.16	90.00	0.01	0.24	9.10	0.06	0.30
13	0.00	0.00	0.15	90.00	0.02	0.33	9.10	0.06	0.50
Average	0.02	0.00	0.13	90.50	0.06	0.22	8.52	0.05	0.32
Std	0.05	0.00	0.02	0.65	0.06	0.06	0.56	0.01	0.12
Relative Std	207.17		16.32	0.71	97.91	25.42	6.59	9.50	37.71
Aver±2std	bdl	bdl	0.09-0.17	89.2-91.8	bdl	0.1-0.34	7.4-9.64	0.03-0.07	0.08-0.56

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In addition, post-depositional processes are likely to contribute to compositional inhomogeneity. Most conservation studies are only focused on the role of major elements. It remains rather ambiguous to what extent it would affect trace elements but processes of such as the corrosion of copper, zinc or destannification do matter (*e.g.* Dussubieux *et al.*, 2008; Wang and Merkel, 2001; Tylecote, 1992). Therefore, it is always suggested that any sample should be free from corrosion. This “soundness checking”, which can be done by metallography or SEM, might be useful to minimize the influence of post-depositional processes.

3.3 Inter-laboratory comparison

3.3.1 Evaluation of different techniques

While detailed analysis of the underlying physics of each technique is beyond the scope of this thesis, it is useful to briefly explain the theoretical principles and the pros/cons of the most commonly used instruments for metal chemistry before any further expansion on the comparison of real analyses. In general, techniques applied to explore metal composition in archaeology can be divided into two groups by the fundamental principles. The first one is based on the quantification of absorption/emission of electromagnetic radiation (a form of energy that is produced by the oscillated magnetic and electronic fields interacting with one another) around the visible region of the spectrum (Pollard *et al*., 2007: 47). Optical emission spectroscopy (OES) is one of the earliest techniques applied to archaeology in the 1930s-1950s, which is now almost obsolete in its original form (Pollard *et al*., 2007: 47). A sample excited by an electronic spark will emit light, which is then dispersed by a quartz prism/diffraction grating into the different wavelength components. The physics behind this is that the energy provided by the electronic spark (high voltage) forces atoms into excited states (electrons on inner shells of low energy escape) and instantly relax back to the ground state (vacancies left are refilled by electrons moving from outer shells of higher energy). This process generates characteristic wavelengths for that particular atom. Each element consisting of the same atoms has a set of specific wavelengths with their own intensities. The overall sample which can contain various kinds of elements in different percentages will all produce characteristic

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wavelengths, which will be further separated by a quartz prism/diffraction grating into different subgroups of waves. All of them are collected and recorded on a single photographic plate. With a scanning densitometer, a device to measure the darkness of each emission line in a spectrum , the presence and intensity of specific emission lines on the photographic plate enables analysts to identify and quantify all the elements present. The quantitative result is obtained through comparing the intensity of a specific wavelength of the unknown sample to that of a standard with known composition. It is important to point out that the advantage of OES is its capability of recording all elements at one time, some of which may be unexpected. The later replacement of the photographic plate by a number of fixed photomultiplier tubes only enables OES to measure a certain number of elements at one time. Its disadvantage can be attributed to the poor reproducibility of excitation conditions and in the development of photographic plates (Pollard *et al*., 2007: 48). The interesting point is that OES is capable of measuring elements in low concentration with much higher accuracy than those in high concentration (Tite, 1972: 263; Hughes, 1979; Pollard, 2015). Quite a few large projects on metal have based their analysis on OES, such as the SAM project, Blin-Stoyle (1959) and Chernykh (1992).

Since the 1980s, OES was gradually replaced by AAS (atomic absorption spectrometry) in archaeology. As can be seen in Figure 59, the structure of AAS is very simple. The sample is dissolved, drawn up by capillary action, aspirated into the burner and turned into the atomized state, which is essentially atomic plasma, a low pressure gas but different from gas, liquid and solid. As a whole, it is not ionized

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(Pollard *et al.*, 2007: 49 and 57). Simultaneously, a beam of light with the exact same frequency as the emission spectrum of the atom being analyzed is generated in a hollow cathode camp and guided into the flame. The mechanism in the lamp is that some of the filler gas (neon/argon) can be ionized by the current applied to the electrodes (tungsten as anode and the targeting element as the cathode). The ionized gas can further sputter off and excite the elements in the cathode. The latter then emits the characteristic wavelength of that element (Pollard *et al.*, 2007: 51). This light then passes through the flame. During this process, providing the targeting element is present in the sample, absorption can happen at this characteristic wavelength and is proportional to the concentration of the element in the sample. The next component in the instrument is a monochromator which has a prism/diffraction grating as the major component to select a single wavelength (Pollard *et al.*, 2007: 54). Following the monochromator is the detector (photomultiplier) which can convert the photon energy into an electronic pulse. The process of quantification in AAS is based on a calibration curve constructed by measuring standards, which is similar to OES.

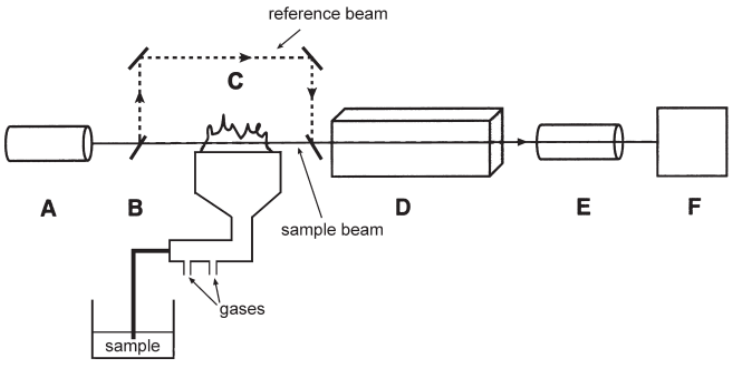

Figure 59 Schematic drawing of AAS

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Some elements are more easily excited than others. At the temperature of the flame they will emit a spectrum, which is called AES (Atomic emission spectrometer, Pollard and Heron, 2008: 24-29). The difficulty is that the temperature achieved in the flame in AAS is not adequately high (normally 2000-3000℃) so very few atoms are exited and give out their characteristic wavelength (Pollard *et al.*, 2007: 56). This can be overcome by connecting the AES to an ICP torch (inductively coupled plasma). The advantage of an ICP torch is that its temperature can rise up to over 10,000℃. This is achieved by an extremely high power radio frequency alternating current applied to copper coils in an ICP, which produces high frequency electromagnetic field. In its centre a few atoms of argon gas are firstly ionized by an electronic spark and then strip off other electrons. Guided by the electromagnetic field, the initially ionized argons cause more argon atoms to be charged and form a high power current, which holds the temperature to 10,000 degrees (Pollard *et al.*, 2007: 57). After the 1980s, the number of multi-elemental analysis conducted by ICP-AES clearly outnumbered AAS (Thompson and Walsh, 2003). Both of them undoubtedly brought about important improvements to archaeometallurgical research. Up to 20 elements can be measured with good detection limits (hundreds of ppm, parts per million, sometimes ppb, parts per billion). However, one of the flaws is the difficulty to preserve tin in a sample solution, which could potentially introduce serious bias into the final result (Hughes *et al.*, 1976). Like many other techniques, the precision of AAS/AES is concentration or matrix-dependent (Gritton and Magalousis, 1978; Harbottle, 1982; Pollard *et al.*, 2007: 55).

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There are some other instruments developed from fundamentally different principles and constantly competing with the first group of techniques in archaeological applications. The 1950s witnessed the rise of neutron activation analysis (NAA) as a standard multi-elemental analysis technique. This lasted until the 1990s when ICP-MS came into wide use in archaeological science and gradually replaced NAA (Pollard *et al*., 2007:123 and 200). Simply speaking, in NAA, elements in the sample are artificially converted into radioactive isotopes by interacting with neutrons. These isotopes then decay and release radiation (α, β, γ particles). The half-life and intensity of the radiation are measured so the presence of an element and its concentration are understood. NAA enables us to analyze up to 48 elements with extremely high sensitivity (down to a few ppm to even ppb). But in the first place, it requires a nuclear reactor, which has become increasingly inaccessible to many archaeometry laboratories. Moreover, lead is completely invisible in conventional NAA (Gritton and Magalousis, 1978; Stos-Gale, 1978). Inductively coupled plasma mass spectrometry (ICP-MS) in the beginning was often employed to analyze lead isotopes but recently many laboratories have chosen it for trace elements as well (Tian, 2013; Puziewicz *et al*., 2015, Oudbashi *et al*., 2015). After being ionized in the hot argon plasma in the ICP field, the sample is guided into a mass spectrometer. Different elemental ions are separated by an electromagnetic field according to the mass-to-charge ratio so identification and quantification can be achieved. Benefiting from the rapidity, isotopic capacity, high sensitivity (ppb, 10^{-9} or even ppt, 10^{-12}), good reproducibility and low interference and matrix effect, ICP-MS has now become almost the gold

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standard in reference for chemical and isotopic analyses (Pollard *et al*., 2007: 197).

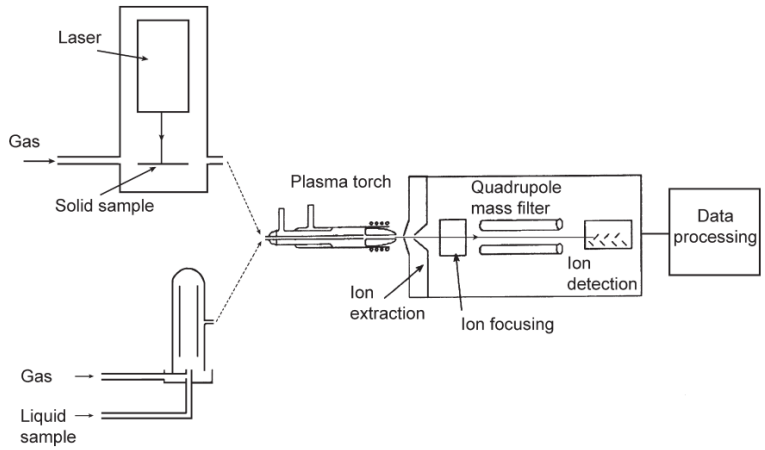

Figure 60 Schematic drawing for laser-ablation/solution-based ICP-MS (after Pollard *et al*., 2007: 198, Figure 9.2)

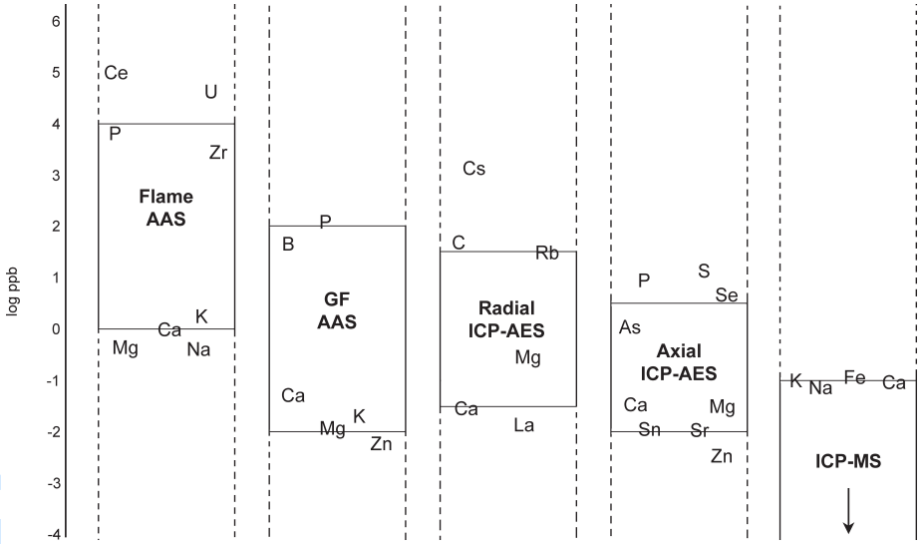

Figure 61 Summary of minimum detection limit (MDL) for the first groups of instruments (Pollard *et al*., 2007: 61, Figure 3.4). The definition of (MDL) is given below.

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The second group of techniques is based on the measurement of characteristic X-rays, including a range of instruments, such as portable XRF, EDXRF, PIXE, SEM-EDS, EPMA. The principle is to remove an inner-shell electron (low energy, E_1) by a specific kind of interaction (*e.g.* primary X-rays for XRF, electrons for SEM-EDS, photons for PIXE). These vacancies are refilled by electrons from the outer shells (high energy, E_2), during which process characteristic X-rays ($\Delta E = E_2 - E_1$) are generated and collected by the detector. In essence, X-rays are also electromagnetic radiation and therefore they are also subject to the theory of particle-wave duality. One can measure either the wavelength or energy, which gives rise to two varieties, wavelength-dispersive spectrometry (*e.g.* electron microscopy or EMPA) and energy-dispersive spectrometry (XRF).

While the X-ray family has witnessed a rapid growth of applications in archaeology, the weakness has to be born in mind. Grinding and polishing to produce a clean surface could introduce the issue of smearing or losing of lead (Northover and Rychner, 1998; Lutz and Pernicka, 1996). Characteristic X-ray lines of some elements of archaeological interests are too heavily overlapped to be resolved by either Si (Li) detector or even SDD (silicon drift detector). Converting counts of characteristic X-ray photons to the real chemical composition involves complicated mathematical modelling with a variety of physical constants (background modelling or filtering, matrix effect correction) and standards with known chemistry. The final accuracy and

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precision of the results are dependent on which calibrating method is selected (Northover and Rychner, 1998; Heginbotham *et al*., 2011). But one tremendous advantage of SEM-EDS is that it combines microstructural images with compositional analysis. This immediately brings huge convenience when examining the manufacturing technology, inclusions in the objects, corrosion effects and chemical compositions. The compositional measurement performed by EPMA is based on the characteristic wavelength of the X-ray rather than the energy. This gives it better resolution and therefore better detection limits (hundreds of ppm or ppm for most elements).

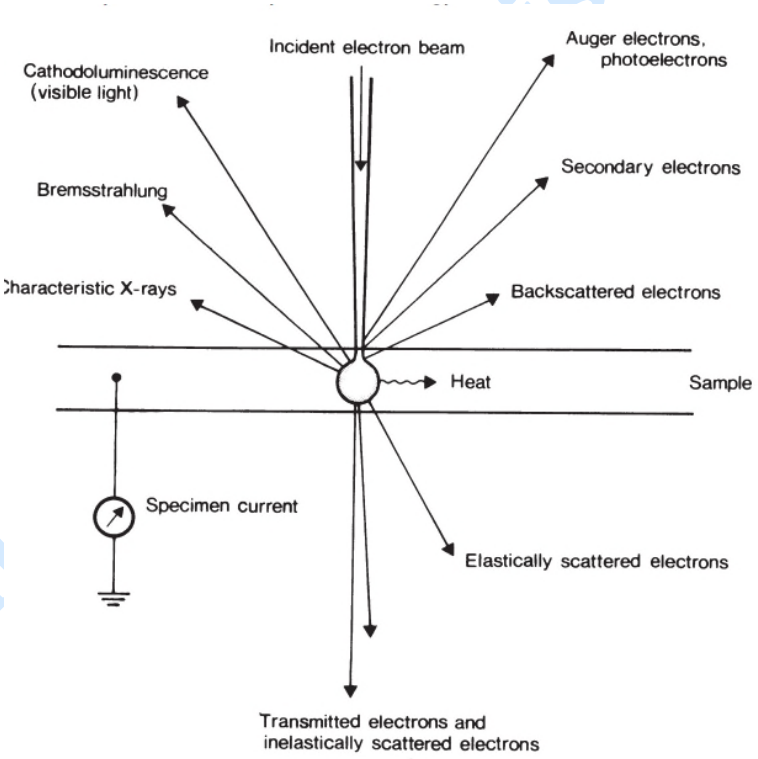

Figure 62 Sample bombarded by primary electron beam in an electron microscope (Pollard *et al*., 2007: 110, Figure 5.6)

Archaeologists have become increasingly aware that every sort of techniques has pros and cons. On one hand, it is no longer allowed to assume that all scientific analyses are flawless. Detailed assessment of data quality is imperative before one enters into real archaeological interpretation. On the other hand, a positive agreement arises from a great number of comparative works which show that interchangeable chemical analysis can be produced by various laboratories with different techniques, as can be seen below.

3.3.2 Inter-laboratory comparisons in Western academia

The question of inter-laboratory consistency has been extensively investigated in the western archaeometallurgical sphere. The first international evaluation on data quality among different laboratories was reported by Chase (1975). Three samples (one Chinese Shang *gu* (觚) vessel, one Luristan bronze spear point and one modern standard) were circulated among twenty one laboratories and analyzed for as many as forty eight elements. It is very frustrating that not all the participating laboratories reported information as required by Chase so the final comparison is merely on the quantification of copper. But the question proposed by Chase is very straightforward and stimulating:

"Now that we have the results, how do they compare? To answer this question fully we have to tabulate a detailed, element-by-element examination of the analytical findings". (Chase, 1975: 149)

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Outliers are more easily identified if the measurements are abundant enough. So is the systematic error. Chase (1975) discovered a clear systematic error on copper. Quite a few laboratories tended to overestimate the percentage of copper. But the real profoundness of this project is a good demonstration of the feasibility to carry out such a wide cooperation between laboratories.

The other important project of inter-laboratory data comparison has been reported in Northover and Rychner (1998). A set of objects was required to be repeatedly analyzed by twenty two laboratories with a variety of instruments. This project, on the one hand, has made remarkable progress in comparing trace elements. One point which was ignored in Chase (1975) is comparing elements on a trace level. The only sample in the project of Chase with known chemistry contained Cu 85%, Sn 5%, Pb 5% and Zn 5%, with no impurities reported at all (Chase, 1975). The objects in the project of Northover and Rychner (1998) contain trace elements from 0.1% to 0.5%, which offer a great opportunity to observe the precision and accuracy when the results approach the detection limit of various instruments. On the other hand, Northover and Rychner (1998) carefully examined the performance of each instrument on a comprehensive list of elements and concluded that:

“we have successfully demonstrated that modern analytical techniques are capable of producing accurate, reproducible data that can, with thorough standardization, be used

Ruiliang Liu unplished thesis

interchangeably with other data and behave similarly in clustering and classification" (Northover and Rychner, 1998: 31).

Apart from these two well-known round-robin experiments, many local assessments show that despite a certain degree of disagreement, analyses by modern techniques are mostly compatible. Hughes (1979) reanalyzed some objects previously reported in Blin-Stoyle (1959) and found that OES and AAS (atomic absorption spectrometer) are comparable for elements of Sb, Ag, Ni, Bi, Fe, As. However, the disagreement in the concentration of lead by these two techniques is huge. Due to self-absorption in OES, lead reported in OES is likely to be underestimated (Hughes, 1979). A large number of objects analyzed by OES in Moscow were compared with the NAA data in Heidelberg (Pernicka *et al.*, 1997). Figure 63 shows that the majority of points fall in the shaded band, indicating that agreement of the respective concentrations within a factor of three (Pernicka *et al.*, 1997: 89). Although one may argue that, strictly speaking, a factor of three is not good enough and plotting the data in logarithm distorts the original distribution into a seemingly linear pattern, by drawing the potential MDL line for NAA (*ca.*10 ppm) and OES (*ca.*500 ppm), actually a large number of outliers are excluded, which reinforces the agreement observed by the author. However, measurement of lead has a large discrepancy between the two teams.

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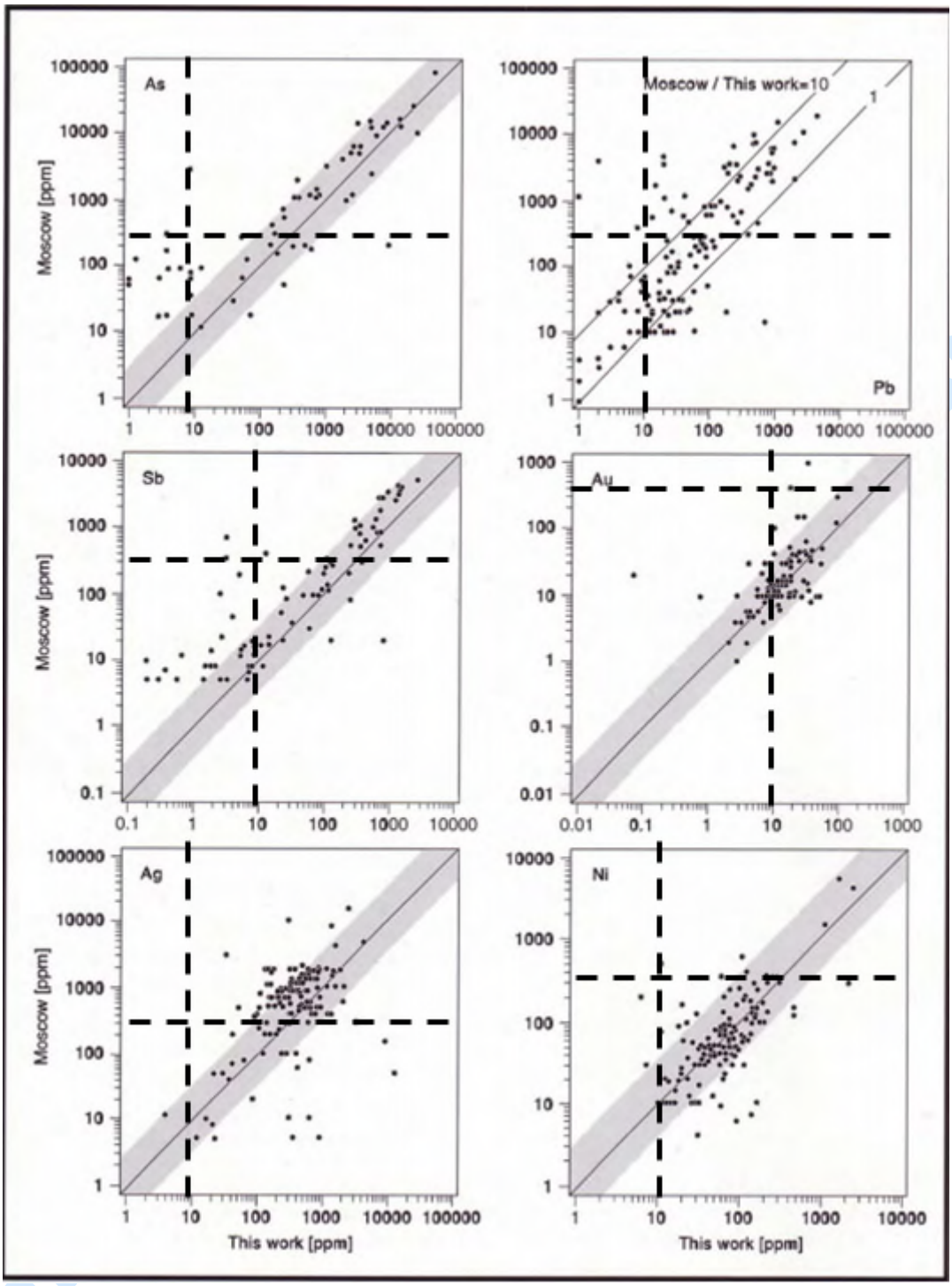

Figure 63 Comparison of chemical composition of the identical Bulgarian artefacts analysed by OES (Moscow, y axis) and NAA (German, x axis, lead measured with isotope dilution mass spectrometry). The shaded band indicates the respective concentrations in agreement within a factor of three. From Pernicka *et al*., (1997, fig. 15). Dashed lines are added by the author to indicate the likely MDL for each element.

A similar comparative project can be found in Cuénod (2012: 126-132) on the Bronze-Iron Age transition in Iran. She collected a large number of samples which have been analyzed by different techniques. Through straightforward plotting of analyses by various techniques, she suggested that in spite of undeniably significant differences in lead, a general agreement can be reached for other elements (Cuénod, 2012: 131).

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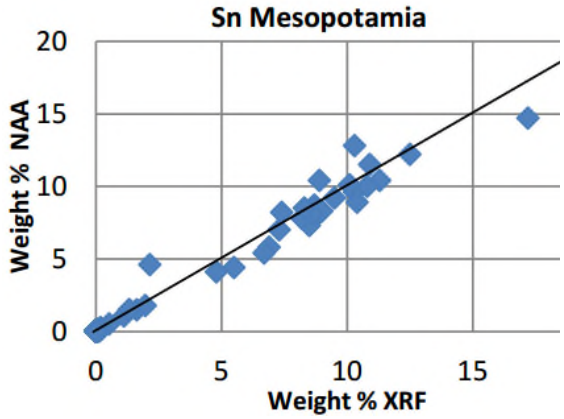

Figure 64 Comparison of XRF and NAA tin measurements for the Mesopotamian sites (from Cuénod, 2012:126, Figure III-10)

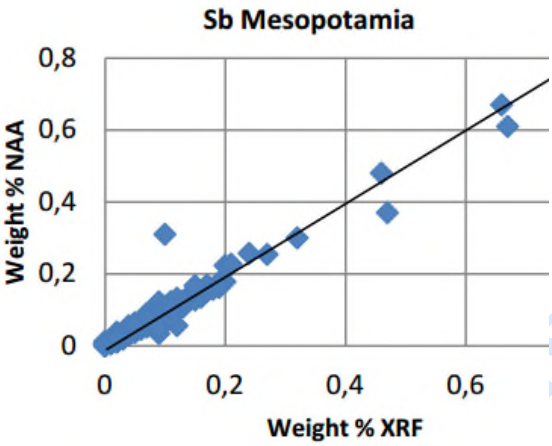

Figure 65 Comparison of XRF and NAA Sb measurements for the Mesopotamian sites (Cuénod, 2012:130, Figure III-18)

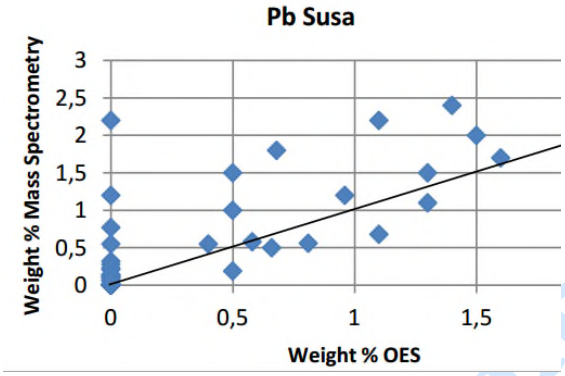

Figure 66 Comparison of OES and ICP-MS lead measurements for Susa (Cuénod, 2012:127, Figure III-10)

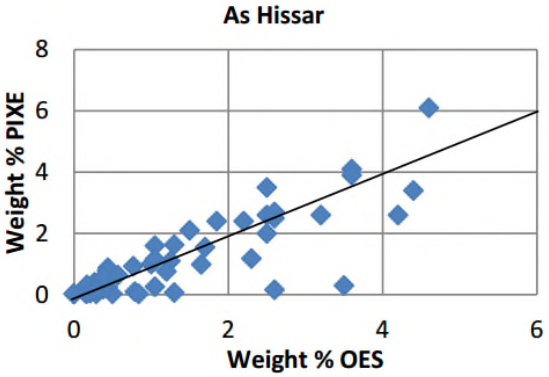

Figure 67 Comparison of OES and PIXE arsenic measurements for Hissar (Cuénod, 2012:127, Figure III-10)

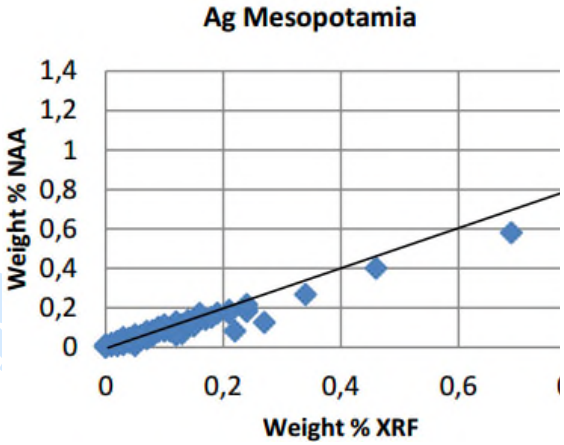

Figure 68 Comparison of XRF and NAA Ag measurements for the Mesopotamian sites (Cuénod, 2012:130, Figure III-18)

The most recent projects are reported in Heginbotham *et al*. (2011 and 2015). Heginbotham *et al*. (2011) was focused on comparing data produced by XRF from different laboratories using different calibration methods and standards. Fourteen museum institutions and a total of 19 XRF instruments were involved in this study. Among all of these participating laboratories, a set of 12 samples (four cuttings obtained from the reference materials, six pieces of historic metal and two small ingots prepared by the lead author) was analyzed in a round-robin process. Not only the final analytical results but also a comprehensive list of parameters (description of the instrument and analytical protocol) have been recorded. The overall design of the assessment is based on ASTM standard E1601 (Standard Practice for Conducting an Interlaboratory Study to Evaluate the Performance of an Analytical Method, following Test Plan A). Most top-ranked laboratories in this project utilize fundamental parameters (FP method) plus correction of standards with known chemical concentration to convert original counts to the elemental percentages. This study is useful in many ways for setting up analytical protocols for data quality control.

However, it is still necessary to bear in mind that all of these round-robin experiments are merely a snapshot of the data quality of these laboratories rather than a routine monitor. Apart from these major projects, a variety of small-scale comparative studies have been conducted by many individual laboratories (*e.g.* Gilmore and Ottaway, 1980; Ottaway, 1982; Carter *et al*., 1983; Lutz and Pernicka, 1996; Northover, 1999;

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Cooper *et al*., 2008; Willett and Sayre, 2000; Young *et al*. 2010). All these abovementioned case studies offer a stimulating picture on the data quality in the other parts of the world, which can be a useful reference to China.

3.3.3 New and old data of Bronze Age China: preliminary assessment

However, although a substantial number of metal objects from Bronze Age China have been analyzed, assessment of data quality has drawn very little consideration. As far as we are aware, there is not yet a program comparable with Chase (1975) or Northover and Rychner (1998) in China. This DPhil project is of course unable to require any Chinese laboratory to analyze the same set of standards with known chemistry and then make comparisons (round-robin experiment). Thanks, however, to collaboration between Oxford and University of Science and Technology China, we have obtained access to some samples which have been previously analyzed and published. Comparing our SEM-EDS data to those legacy data hopefully can lay some groundwork for a discussion of data quality in the future.

The assessment is primarily focused on three parameters: precision, accuracy and minimum detection limit (MDL). Precision is defined by the distribution of random errors. In other words, it is an expression of the reproducibility of measurements under a set of fixed experimental conditions and normally written as the standard deviation (σ). By assuming a normal distribution, one can argue that at the level of 95.4% confidence, the true value lies within ±2σ of the average. But this is not

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commonly reported in publications. Accuracy represents the systematic error, which means how far the reported analysis is from the true value. In many respects, this is more crucial than the precision to this thesis as in most cases we rely on the average of multiple analyses to represent a real object. The following section shows that through cross-referencing our measurements and legacy data it is reasonable to suggest a generally good compatibility in terms of both precision and accuracy.

Minimum detection limit (MDL) is crucial because any reported elemental concentration, if below MDL, should be regarded as statistically meaningless. Therefore, it is a very useful proxy to evaluate the performance of the instrument, particularly for elements in traces. There is indeed a variety of ways to estimate MDL. The most common one is by repeatedly measuring a blank reagent and estimating the average value of analytical signatures from the blank reagent plus three times the standard deviation of the blank measurements. If the measured concentration of one element is above the MDL, it would be fairly confident to argue that this element is really present in the sample, rather than a random result due to the statistical noise in the background. Although MDL is of vital importance to the assessment of the instrument and our presence/absence approach, unfortunately, this has been mentioned in very few publications. Below, it shows the MDL for our SEM-EDS and summarizes published MDL's for other common instruments.

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Evaluation of Oxford SEM-EDS

Any analytical result without a detailed report on the potential error of the instrument has to be considered meaningless. In scientific analysis, an error does not mean a mistake. In essence, it is a measurement of the distance between the result and the true value. Therefore, in the first place, it is imperative to use standards with known chemical composition to calculate the precision and accuracy of SEM-EDS. All of the raw data in this chapter can be found in the Data appendix. The instrument available to this DPhil project is JSM-5910 SEM of JEOL Ltd. The software for EDS is INCA Issue 21 by Oxford Instruments. The EDS detector is Si (Li), 10 mm^2 with resolution of Mn K_α 133 eV (the real resolution could be ~120eV (Doherty pers. comm.). On the basis of the existing literature of not only archaeology but modern metallurgy and analytical chemistry (*e.g.* Armstrong and Buseck, 1975; Newbury, 1999; Schamber, 2009; Henginbotham *et al.*, 2011 for 14 laboratories; Ritchie *et al.*, 2012; Rehren and Pernicka, 2013; Valério *et al.*, 2015), the archaeological questions and the numbers of samples to be analyzed, the analytical conditions we chose are beam energy 20 KeV, beam current 42-48 uA, working distance 10 mm, live time 100 s for collecting characteristic X-rays and process times 5 (a parameter used to differentiate the peak-to-background signals). As a result, the acquisition rate is around 3,200 counts/s and the final acquisition time is about 140 s. For each standard, we keep the sample under the same magnification and analyze 8-10 areas, which cover roughly the entire sample. To pursue a thorough evaluation on data quality produced with this commonly employed protocol, the following section examines a large number of

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standards of either single pure element or multiple elements being repeatedly measured.

Primary standards

Two sets of standards have been analyzed to evaluate the performance of SEM-EDS. The first set includes pure elements (Cu, Co, Ni, Ag, Zn, Fe, Bi, Sb, Figure 69-79) and natural compounds (AsIn and PbTe, Figure 78 and 79). The histogram analysis clearly shows that this SEM-EDS under the analytical conditions mentioned above is able to produce good measurements on pure samples of Cu, Co, Ni, Fe, Ag, Sb and Bi. Zinc is slightly less ideal. The result of arsenic and lead present a relatively wider range than those of others but still obey the Gaussian distribution. As previously discussed, lead is notoriously hard to measure. It can be easily seen that a systematic error occurs in the result of lead, which is up to 6% (Figure 79). This has also been noticed in Northover and Rychner (1998) where 7% systematic error of lead in absolute terms has been reported. In addition, the offsets observed in measurements of all these primary standards are also due to surface oxidation. Taking copper standard as an example, a clear oxygen peak can be seen in every spectrum and its estimation is around 0.5% (Figure 70). Based on the results of the first set of standards (pure elements and natural compound), it seems proper to argue that this SEM-EDS is capable of accurately identifying characteristic peaks for all the elements of interests. Meanwhile, except for lead, quantifications of major elements are fairly reliable.

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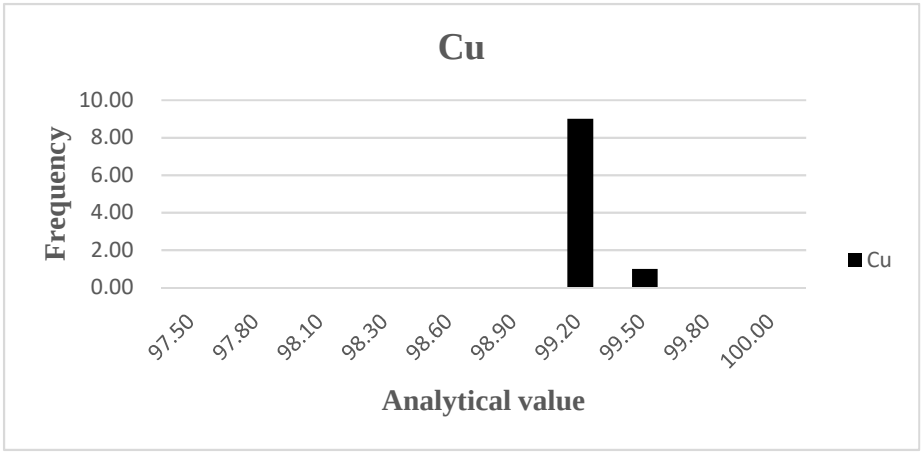

Figure 69 Analytical results on pure copper[23]

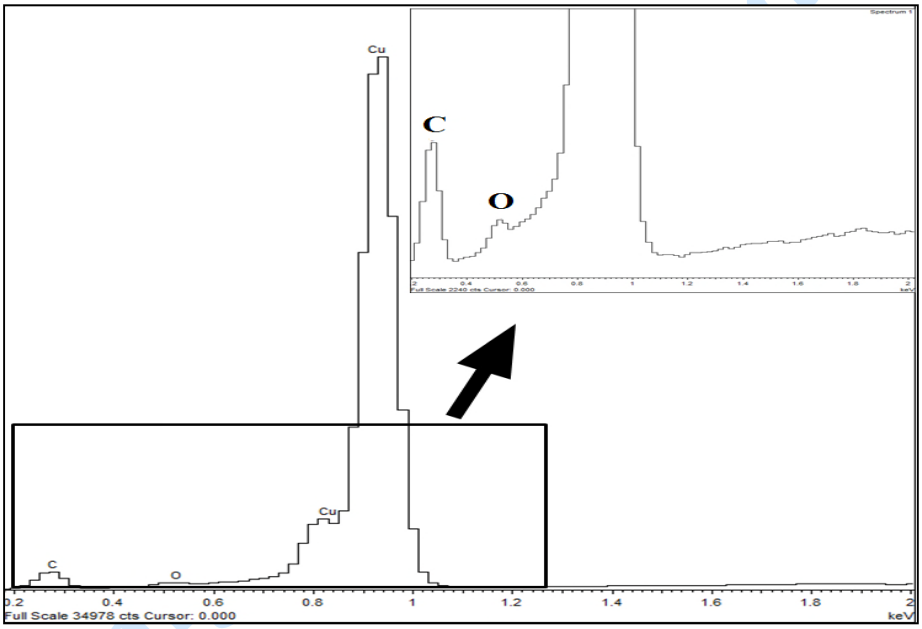

Figure 70 Oxygen in the primary standard

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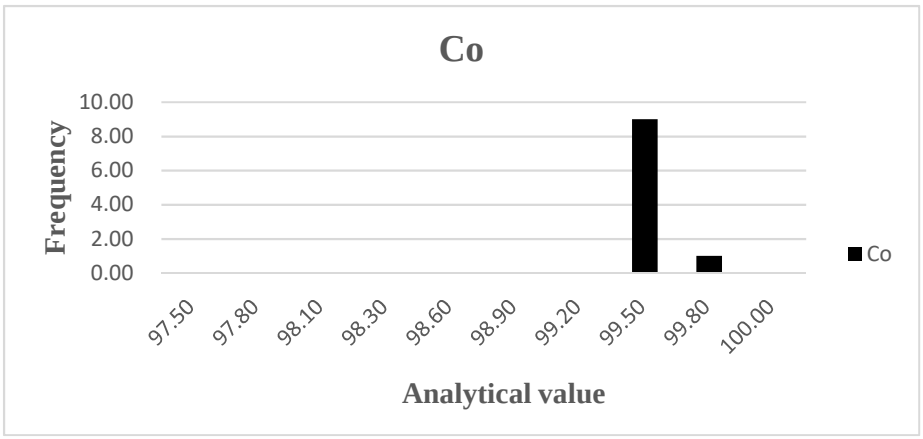

Figure 71 Analytical results on pure cobalt

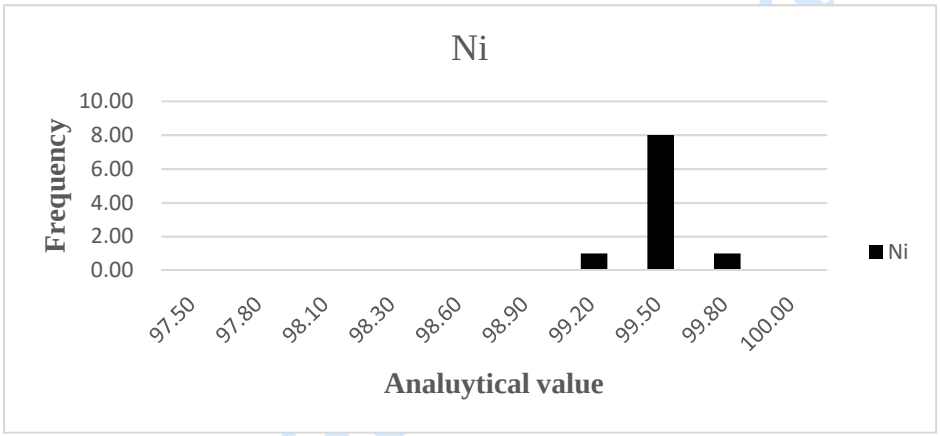

Figure 72 Analytical results on pure nickel

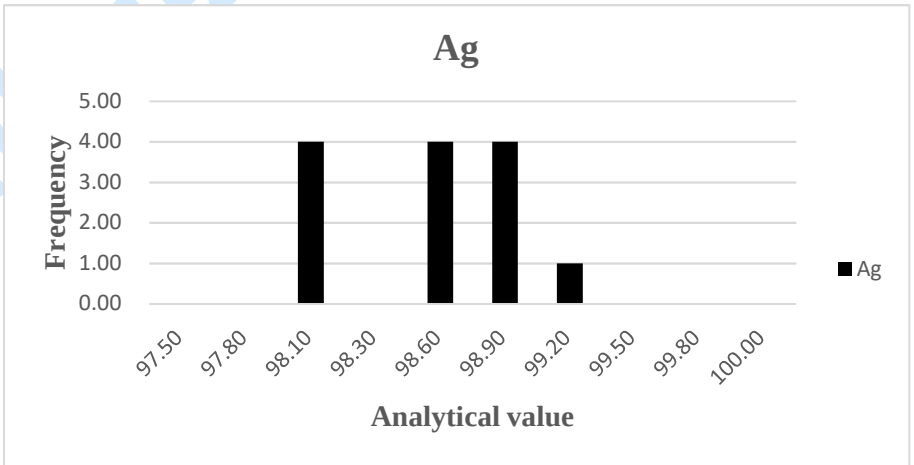

Figure 73 Analytical results on pure silver

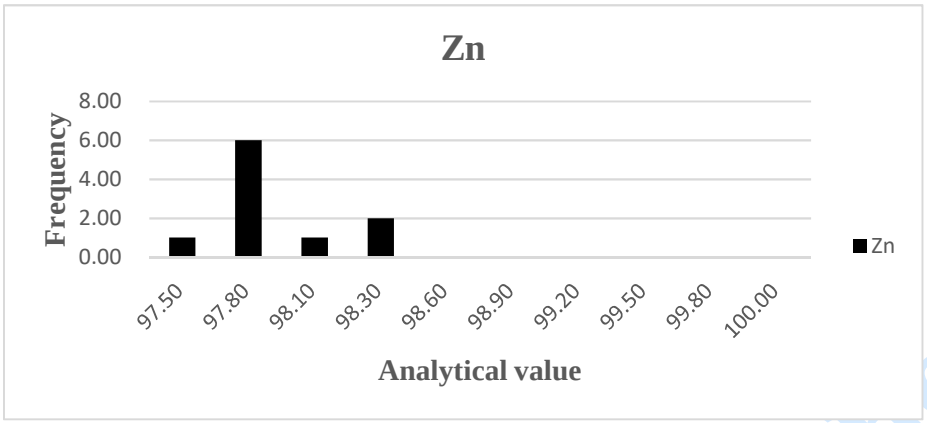

Figure 74 Analytical results on pure zinc

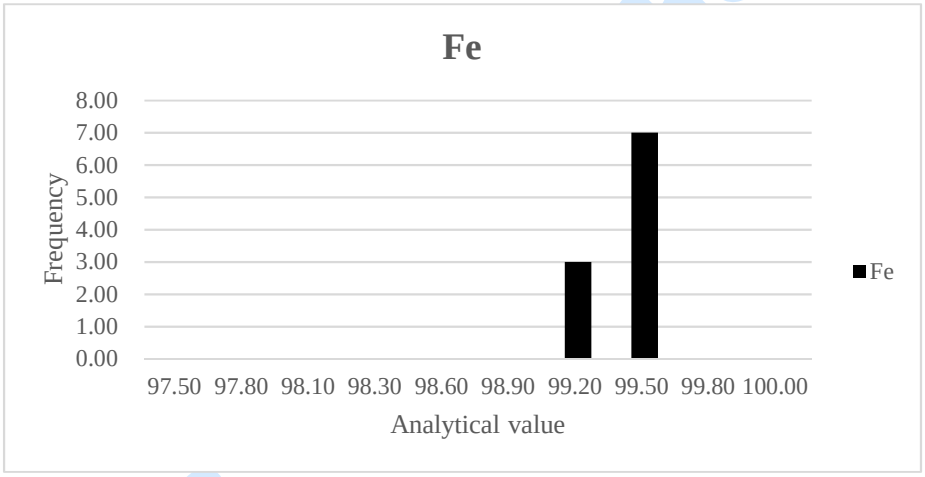

Figure 75 Analytical results on pure iron

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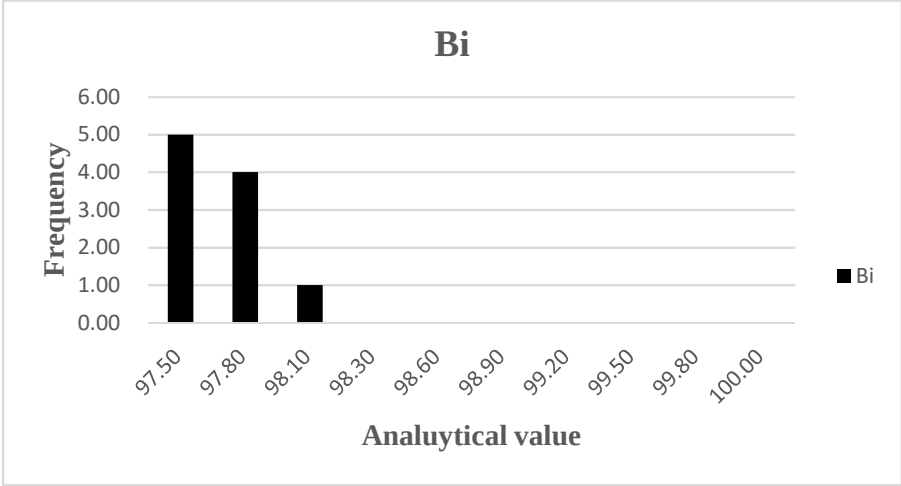

Figure 76 Analytical results on pure iron

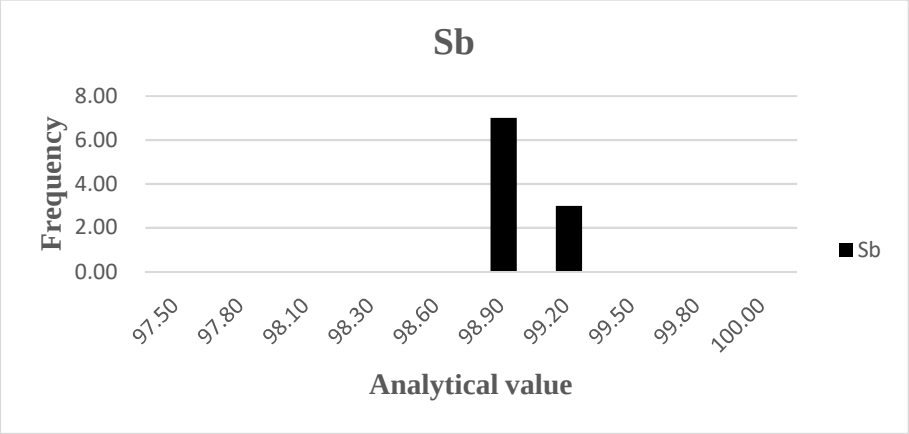

Figure 77 Analytical results on pure antimony

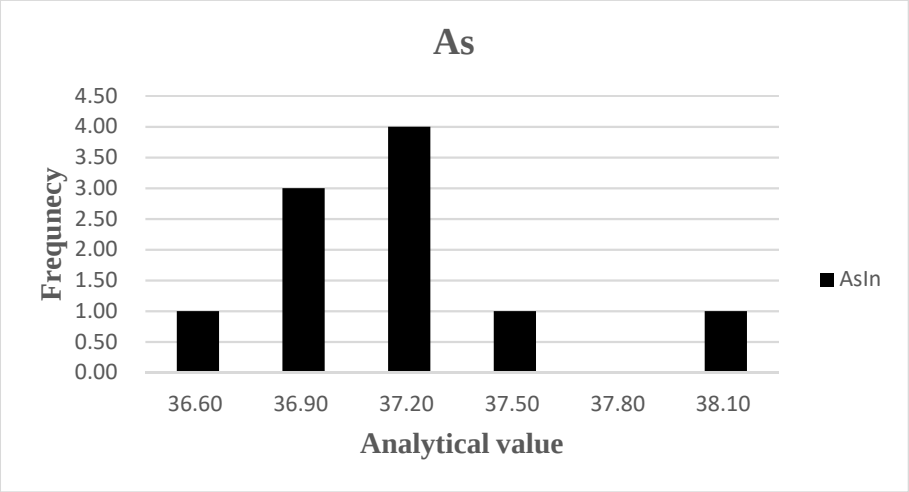

Figure 78 Analytical results on AsIn (expected percentage of As: 39.45%)

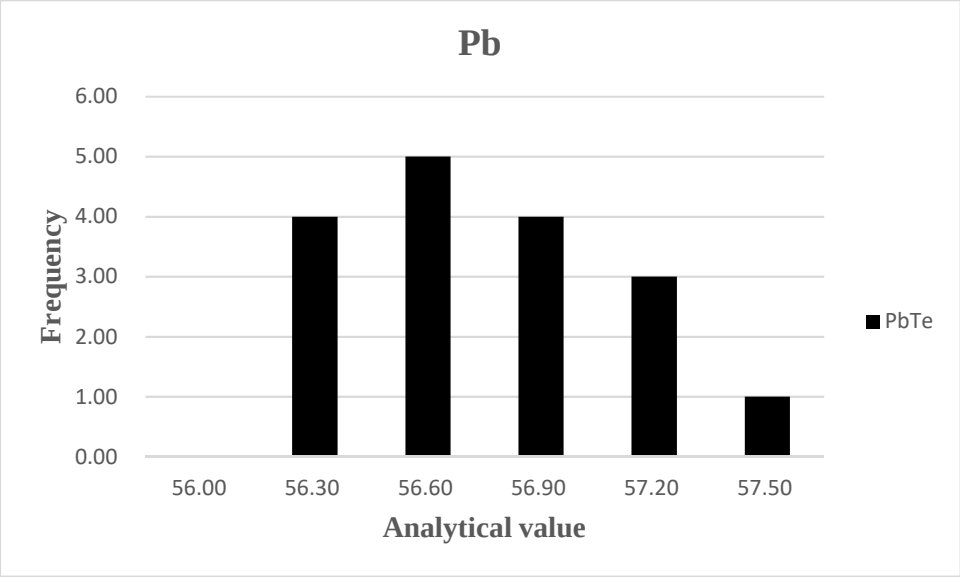

Figure 79 Analytical results on PbTe (expected percentage of Pb: 61.89%)

Secondary standards

The second set of standards gathers together sixteen specimens (Table 4), including bronze (Cu-Sn), leaded bronze (Cu-Sn-Pb), arsenic copper (Cu-As), brass (Cu-Zn) and leaded gunmetal (Cu-Sn-Pb-Zn). These secondary standards come from three sources. One is the most recently produced CHARM standards. Details are in Heginbotham *et al.* (2015). They might be the ideal standards for archaeology as they are produced under supervision of experts in the Getty Museum who deeply understand the need of archaeologists. Certified values (consensus values) are produced by over 13 teams with a variety of techniques. Standard deviations based on each analyses show excellent precision. Two standards (starting from JPN) are inherited from the project of Northover and Rychner (1998), of which the certified values are from atomic absorption spectroscopy (AAS) by the British Museum. The rest are from a collection of German industry standards certified by ICP-AES.

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Table 4 List of secondary standards with certified values

Source	Sample Num	Cu	Sn	Pb	As	Sb	Bi	Ni	Fe	Zn	Ag	Co
Northover and Rychner 1998	JPN337	89.09	7.76	0.21	0.82	0.97	0.02	0.11	0.01		0.71	0.02
Northover and Rychner 1998	JPN334	85.06	10.75	3.09	0.25	0.53	0.03	0.11	0.04	0.01	0.07	0.06
Heginbotham *et al.* 2015	LB17	74.83	5.97	9.83	1.50	4.10	0.22	0.47	0.49	0.63	0.91	0.01
Heginbotham *et al.* 2015	LB14	78.08	5.41	14.62	0.05	0.06	0.97	0.31	0.06	0.04	0.06	0.21
Heginbotham *et al.* 2015	SN7	80.3	12.6	2.6	1.071	0.263	0.052	0.175	0.06	1.96	0.305	0.443
Heginbotham *et al.* 2015	SN6	86.39	7.31	1.56	0.76	0.32	0.16	0.20	0.10	1.17	1.16	0.66
Heginbotham *et al.* 2015	SN5	78.96	16.05	0.26	0.06	0.66	0.10	0.50	1.20	0.49	0.10	0.14
Heginbotham *et al.* 2015	CUAS4	95.76	0.38		3.66							
Heginbotham *et al.* 2015	TB5	55.84	0.11	0.58	0.35	0.17	0.31	0.08	0.18	40.63	0.21	0.02
Heginbotham *et al.* 2015	GM4	82.96	2.56	4.69	0.287	0.0261	0.084	1.795	0.053	7.13	0.0265	0.259
RLAHA standards	GEM D	93.30	2.97	1.02	0.04	0.07	0.01	2.49			0.05	0.20
RLAHA standards	GEM E	93.00	6.14	0.05	0.01	0.02		0.10	0.10		0.50	0.10
RLAHA standards	GEM F	87.50	11.40		0.08	0.15	0.10	0.05	0.00	0.10	0.01	
RLAHA standards	AC33	96.60	3.30									
RLAHA standards	AC36	90.60	9.40									
RLAHA standards	AC13	75.53			0.10					21.61		

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One point to note is that the percentage of trace elements in these standards varies from <0.1% to 1%. Assembling a full list of standards with a continuous compositional gradient is imperative because this makes possible for us to (1) approximate the minimum detection limit by plotting certified values of a specific element against its relative error, which should soar up to an unacceptable degree when an element approaches the minimum detection limit of the instrument; (2) explicitly present the potential variation between the certified values and analytical ones. The relative error (RE) is defined as:

RE = (analytical result - certified value)/certified value*100%

Comparison of analytical averages and certified values

Copper

The analytical results for copper present an excellent agreement with corresponding certified values (Figure 80). The maximum difference between the two sets of values is 2.10% in absolute terms. The standard deviation is around 1%. So on a confidence level of 95%, the true value should fall into the mean ±2%. The percentage of copper in this set of standards ranges from 56% to 97% and covers the copper percentage of most samples we may encounter in the Bronze Age. The other way to express the uncertainty could be RE. In the case of copper, it might be reasonable to say that the analytical results of copper produced by this SEM-EDS is accompanied by ±3% RE

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(Figure 81).

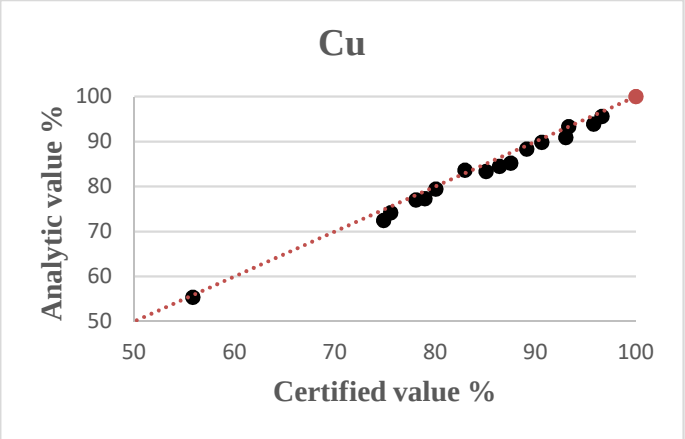

Figure 80 Analytical results of copper on secondary standards

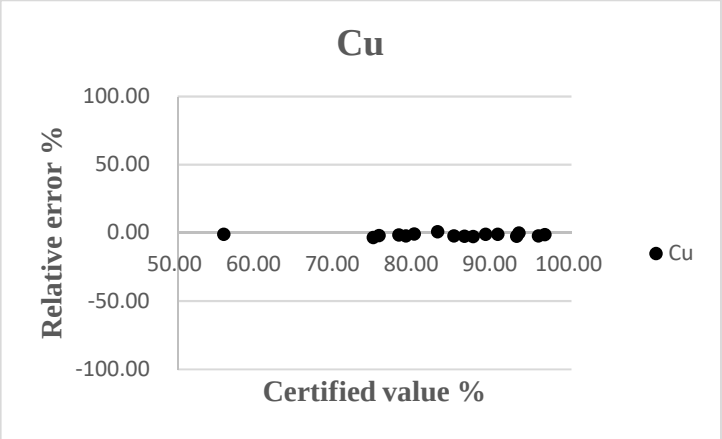

Figure 81 Cu RE on secondary standards

Tin

The percent of tin in this set of standards ranges from 0.11% to 16.05% (Figure 82). Most standards show a relative error around 10% (Figure 83). However, the RE of tin in standards CUAS4 and TB5 climbs up to 31% and 63%, respectively. This can be attributed to their low amounts of tin (CUAS4 with 0.38% and TB5 0.11%). The implication is that the concentrations of tin in these two samples are below the minimum detectable limit (MDL) so the results contain very little statistical significance. As a conclusion for tin, the RE is about 10% if the true value is over 0.4%. Results below 0.4% should be qualitatively reliable but not necessarily quantitatively.

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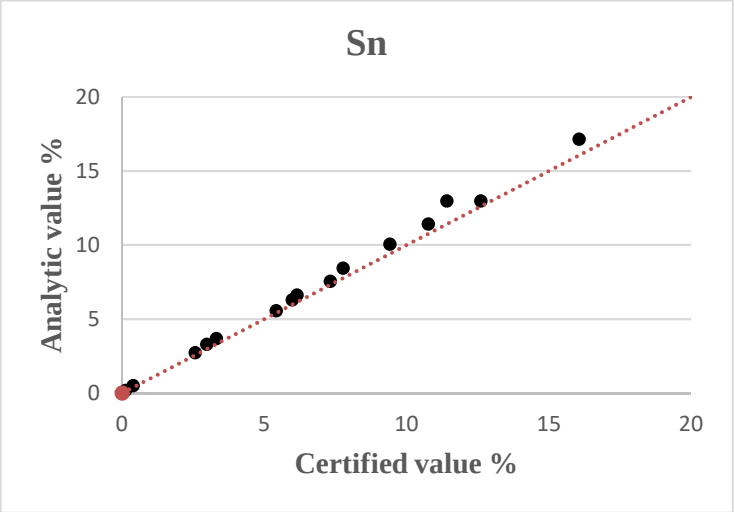

Figure 82 Analytical results of Sn on secondary standards

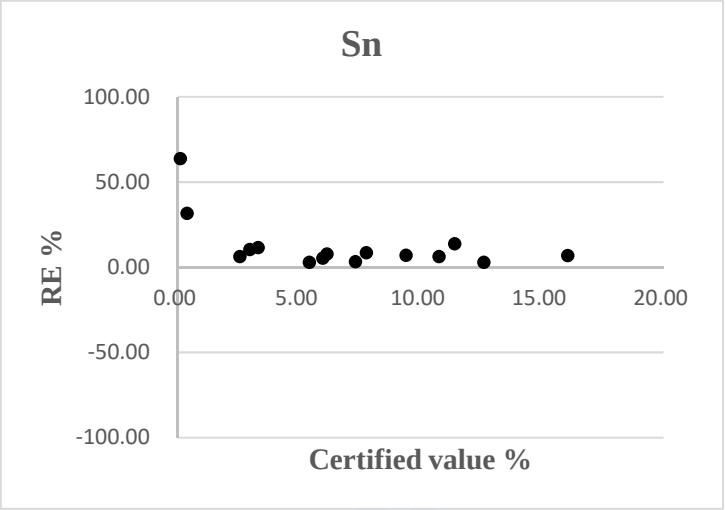

Figure 83 Sn RE on secondary standards

Lead

The RE of lead presents a rather random distribution against the certified values and often drifts beyond 50% in relative terms. This echoes the difficulty of measuring lead with the X-ray family of instruments in a huge number of published studies (see above). Surprisingly, the final results of lead content in the two leaded bronzes are relatively consistent with the certified values (Figure 84-85).

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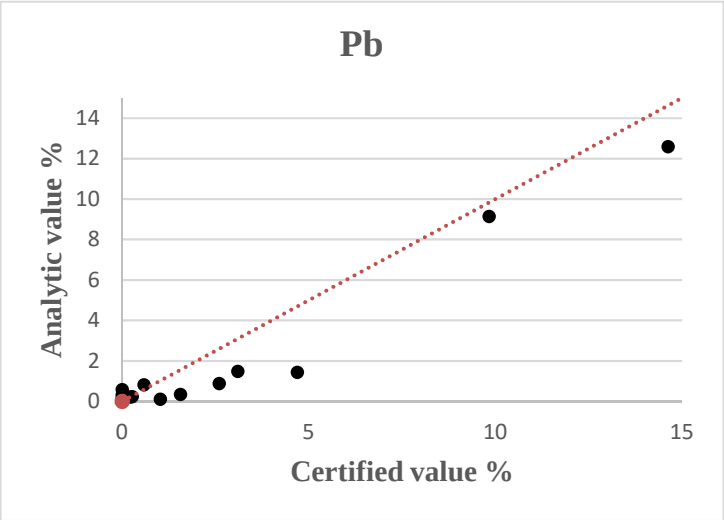

Figure 84 Analytical results of Pb on secondary standards

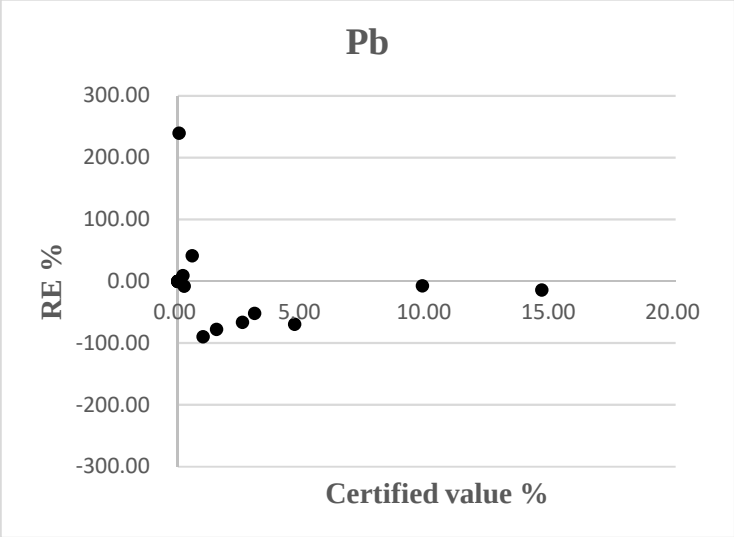

Figure 85 Pb RE on secondary standards

Arsenic

The difficulty in measuring arsenic with SEM-EDS is also associated with lead. As noticed by other scholars, the Pb L_{α} lines ($L_{\alpha1}$=10.55 KeV, $L_{\alpha2}$=10.45 KeV) and the As K_{α} lines ($K_{\alpha1}$=10.54 KeV, $K_{\alpha2}$=10.51 KeV) are severely overlapped. Therefore, it is less likely to have accurate results for trace arsenic if lead is present in a large amount. In fact, a great deal of work has been done to alleviate this problem (*e.g.* Pollard and Heron, 2008: 208). A common solution is to measure the Pb L_{β} lines (Pb $L_{\beta1}$=12.61 KeV, Pb $L_{\beta2}$=12.62 KeV). The ratio of peak area between Pb L_{α} series and Pb L_{β} series is roughly 10:7 so it allows us to calculate Pb L_{α} based on Pb L_{β}, then subtract Pb L_{α} from the overlapped peak area to have relatively more accurate results of As K_{α} series. If luckily lead is not present with arsenic, it is also possible to estimate arsenic directly based on its K_{α}. The other way is to quantify lead directly on L_{β} and arsenic on K_{β}, though much less sensitive because arsenic K_{β} (around 11.79 KeV) is relatively

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weaker than Kα.

However, the INCA software makes these processes entirely impossible. As facing towards not only academic circle but much larger commercial market, it publicizes a "one-button" protocol, making very few original data accessible to users, not mentioned modifying its algorithm. Consequently, what we are able to do is only evaluating how the software works but unlikely further improving it.

In the case of standard AC13, the certified values show 0.1% arsenic with no lead. SEM-EDS analysis gives 0.11% As (RE= 10%). A different case would be, when lead is around 0.82-1.49%, for instance in JPN334, GM4, or TB5, even though they contain higher amounts of arsenic, the corresponding RE can easily rise to 25%. It is also worth noting that the analysis of arsenic above 0.5% seems less affected by the amount of lead. The best example is LB17. In spite of the presence of around 10% lead, the RE of arsenic is so small as 3.33%. Similar cases can also be found in JPN337 and SN7. It is necessary to accept an intertwined relationship between the proportion of lead and the analytical accuracy for arsenic with SEM-EDS. Under the circumstance of no lead, it is likely that the average of arsenic is reasonably accurate (RE 10%). However, the worst situation is when small amounts of arsenic (roughly below 0.5%) co-exist with lead over 1%. The RE, in our experiments, is then up to 25%. When the percentage of arsenic exceeds 0.5%, the issue of overlapping with lead in the spectrum appears much less serious and its estimation becomes more

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meaningful (Figure 86-87).

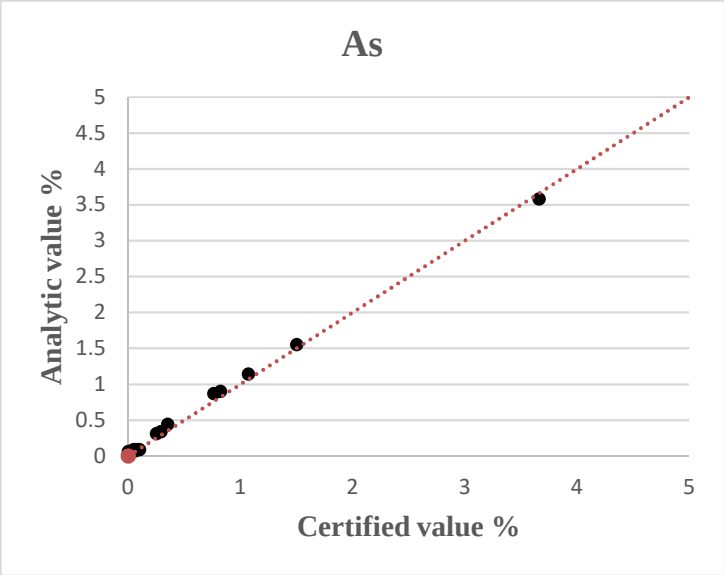

Figure 86 Analytical results of As on secondary standards

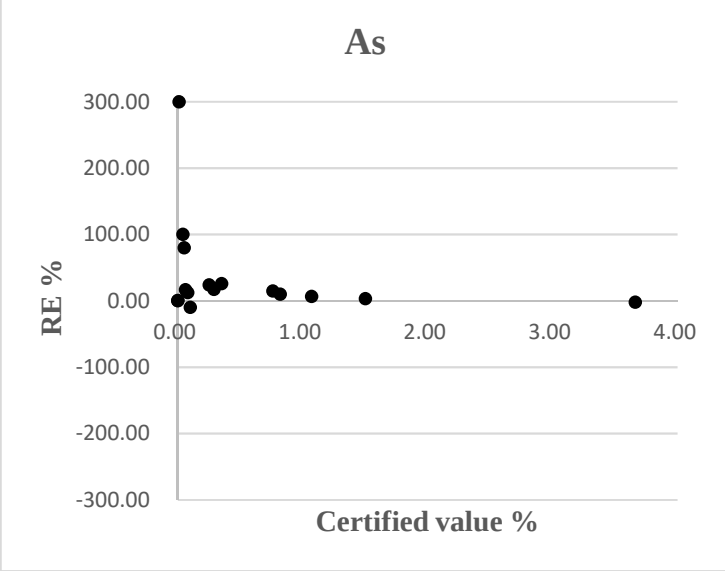

Figure 87 As RE on secondary standards

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Antimony

The analysis of antimony is informative. Whilst none of our standards contain antimony around 0.1%, there are two standards containing antimony at 0.15% (GEM F) and 0.17% (TB5), respectively. The RE for both is around 10-15% (Figure 88-89). However, the RE of GEM D which is supposed to have 0.07% antimony increases to 43%. Theoretically, Sn L_β (3.78 KeV) and Sb L_α (3.66 KeV)/ L_β (3.78 KeV) are also overlapped but much less severely than arsenic and lead (Sn: Lα1=3.44 KeV, Lα2=3.44 KeV, Lβ1=3.66 KeV, Lβ2=3.90 KeV, Lγ1=4.13 KeV; Sb: Lα1=3.60 KeV, Lα2=3.60 KeV, Lβ1=3.66 KeV, Lβ2=3.90 KeV.). A rough relative error 10-20% can be suggested for most of the analytical results.

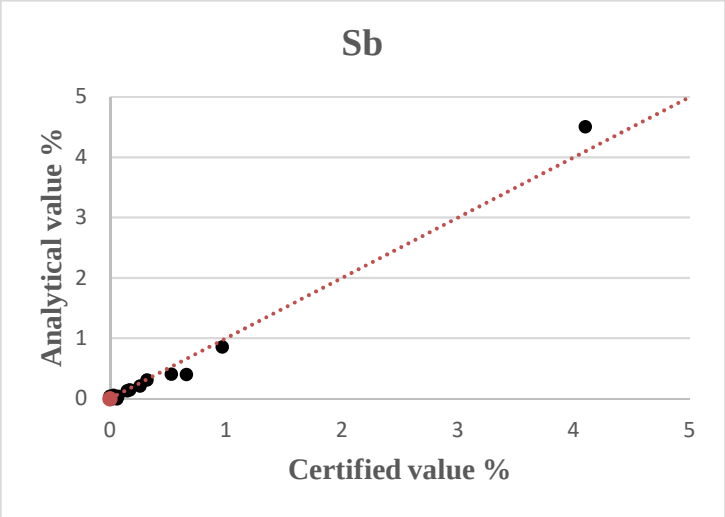

Figure 88 Analytical results of Sb on secondary standards

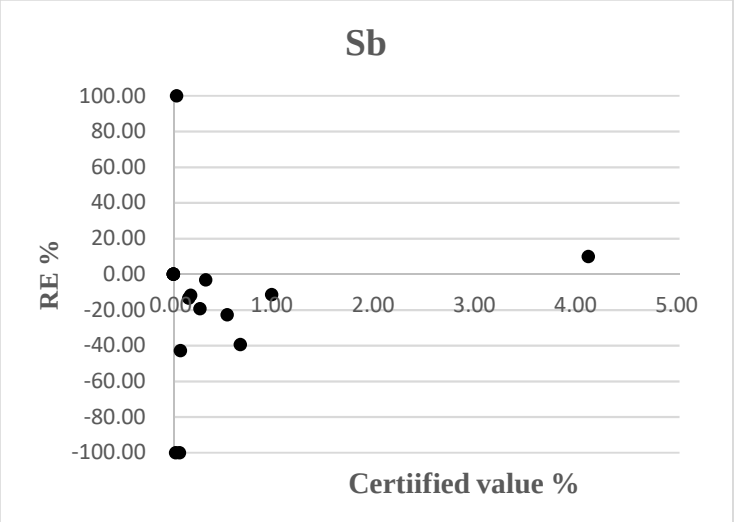

Figure 89 Sb RE on secondary standards

Silver

Analytical result of silver and the certified values are well consistent with one another. All of the results over 0.1% silver present a RE no larger than 10%. It means that this SEM-EDS is able to measure silver as low as 0.1 % with quite high accuracy (Figure 90-91).

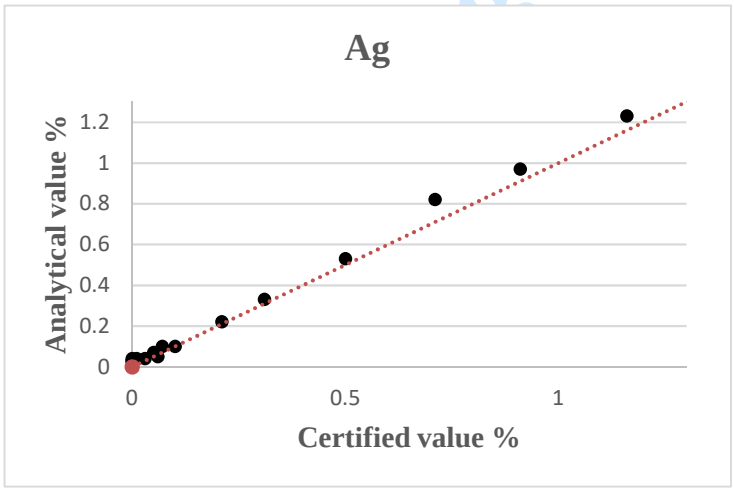

Figure 90 Analytical results of Ag on secondary standards

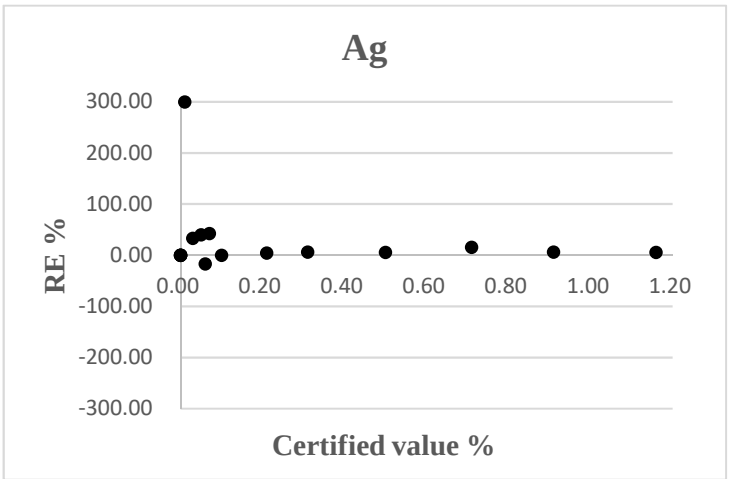

Figure 91 Ag RE on secondary standards

Nickel

The accuracy of nickel in the SEM-EDS is also acceptable (Figure 92-93). All the measurements with over 0.1% nickel fall into 10% RE. It is very fortunate to have four standards of which the percentage of nickel is very close to 0.1% (JPN334 with 0.1% Ni, JPN337 0.1%, GEM E 0.1% and TB5 0.08%). Three of them show that RE is around 10% except JPN337 with that of 27%.

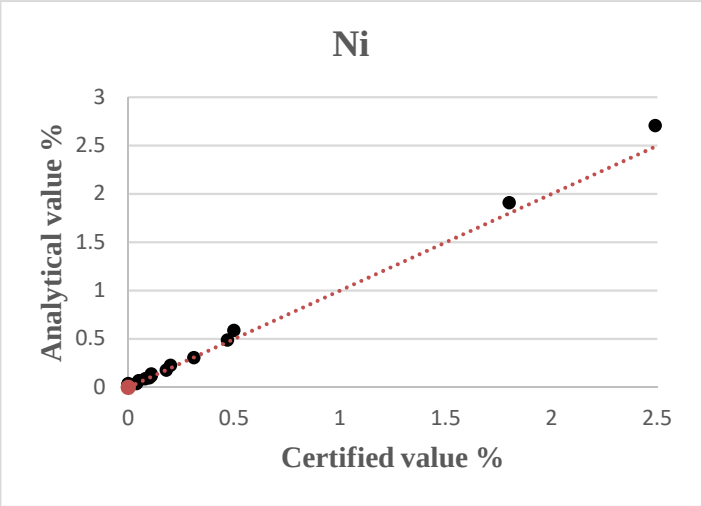

Figure 92 Analytical results of Ni on secondary standards

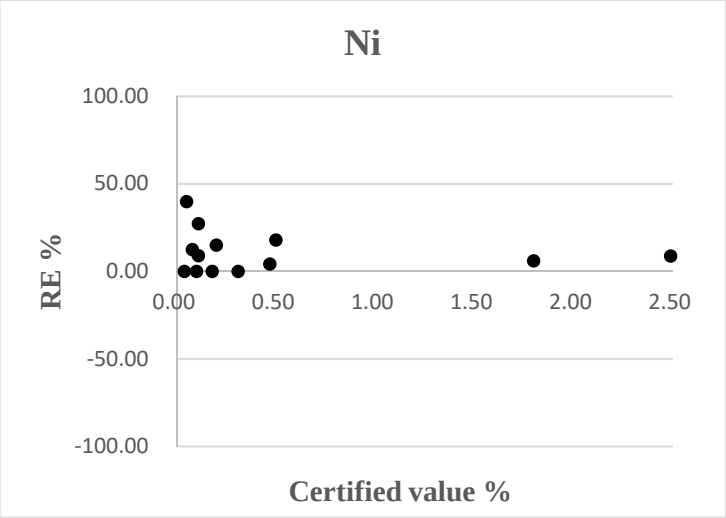

Figure 93 Ni RE on secondary standards

Bismuth

Figure 94-95 indicate that the results of bismuth are not reliable. The RE displays a rather irregular distribution from -80% to +300%, if the certified value is between 0.1 - 0.3%. LB 14 contains the largest concentration of bismuth (1.31%) but reported value is 0.97±0.62% on the level of 95% confidence. It has to be accepted that bismuth here is only qualitatively meaningful.

Ruiliang Liu's Thesis

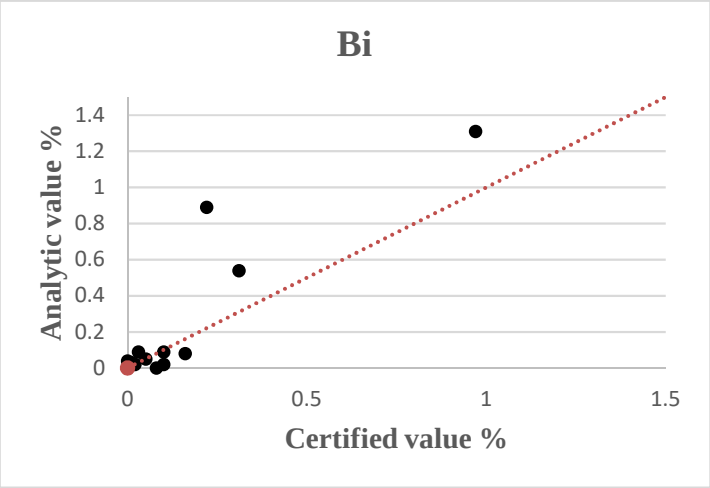

Figure 94 Analytical results of Bi on secondary standards

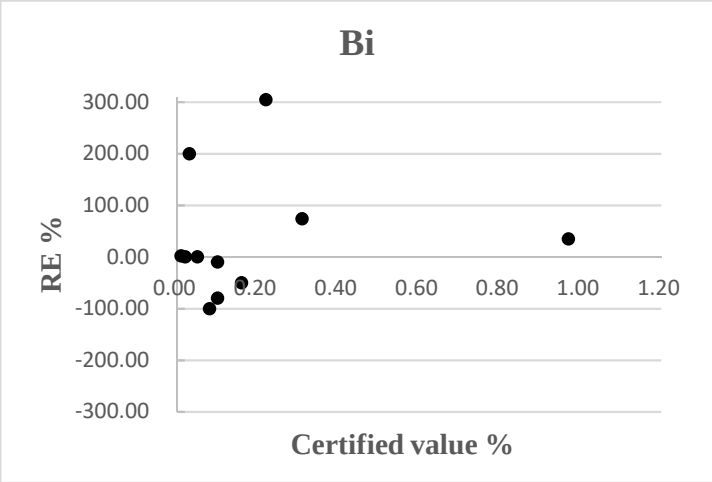

Figure 95 Bi RE on secondary standards

Iron

The performance of SEM-EDS on iron is very stable (Figure 96-97). The RE is constantly below 15% provided the certified value of iron is over 0.1%. Therefore, it can be argued that SEM-EDS under the analytical conditions above is capable of measuring iron with good accuracy.

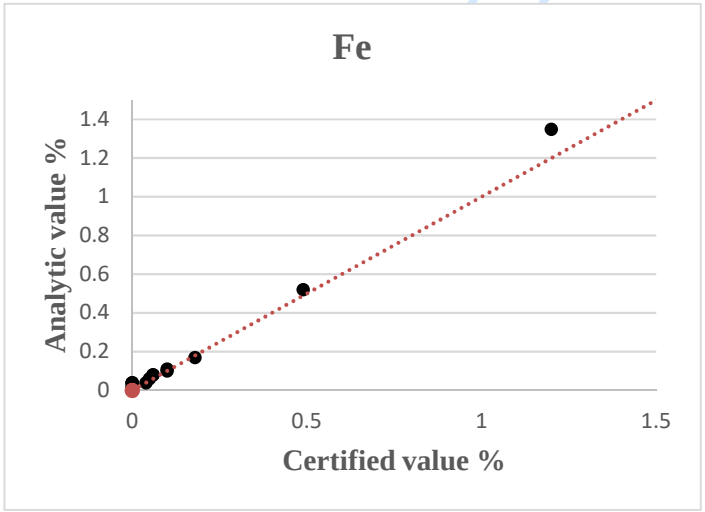

Figure 96 Analytical results of Fe on secondary standards

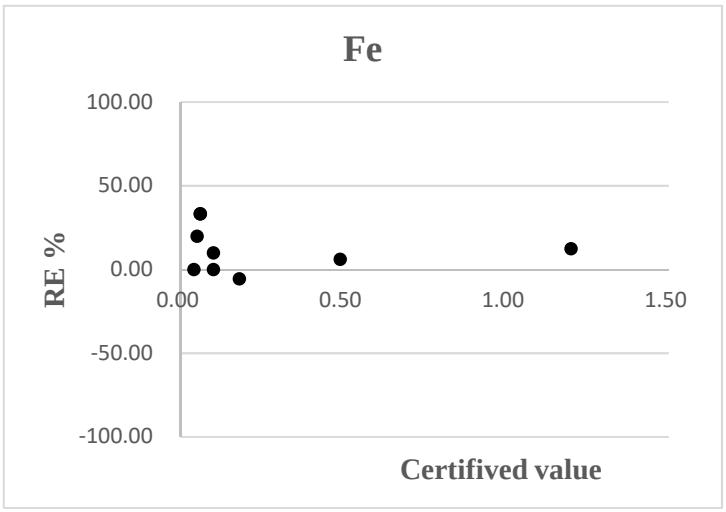

Figure 97 Fe RE on secondary standards

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Zinc

It seems that the analytical quality of zinc is not as good as for other elements. While the precision (standard deviation) and accuracy (relative error) are very small for brass/gunmetal in which zinc is a major component, when its percentage drops at 0.1%, the accuracy is extremely poor. As can be seen in Figure 99, the RE of zinc is almost 25% for the sample with 0.5% zinc and it rises to 40% if the certified value of zinc is 0.1%. One likely reason is that the Zn K_{α} series ($K_{\alpha1}$=8.64 KeV, $K_{\alpha2}$=8.62 KeV) is on the shoulder of Cu $K_{\beta1}$ (8.91 KeV) so that most part of the zinc signal would be affected by copper.

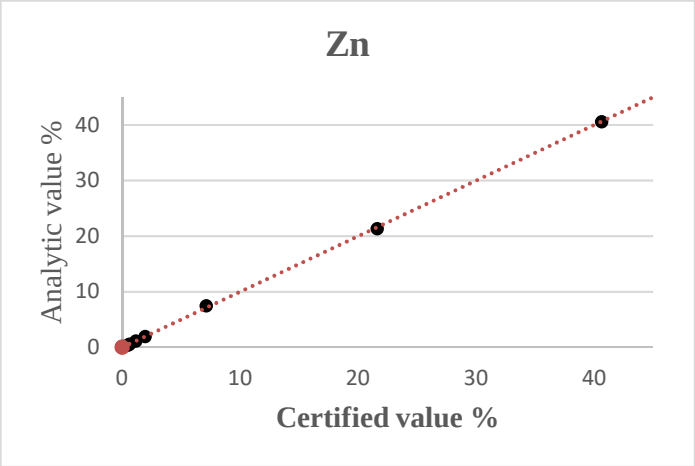

Figure 98 Analytical results of Zn on secondary standards

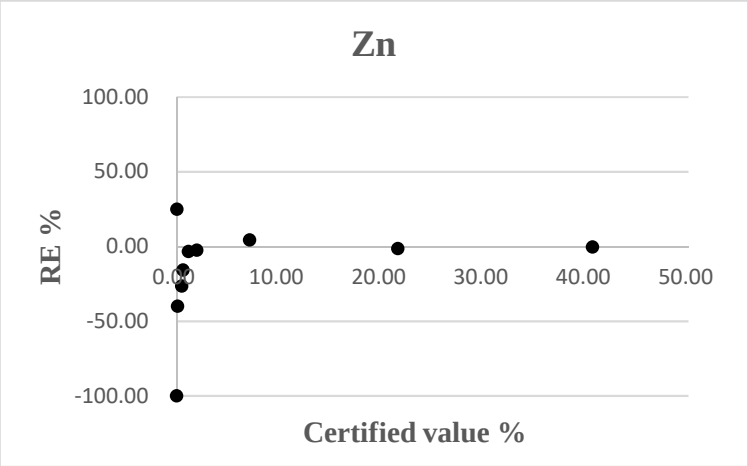

Figure 99 Zn RE on secondary standards

Cobalt

The measurement of cobalt is reasonably good. All of the standards with certified value of cobalt over 0.1% show an RE below 10%. A clear negative relationship between RE and certified value of cobalt can be observed in Figure 101. This gives us

confidence to say that SEM-EDS should be able to measure the amount of cobalt as low as 0.06% with relatively good accuracy (RE around 17%).

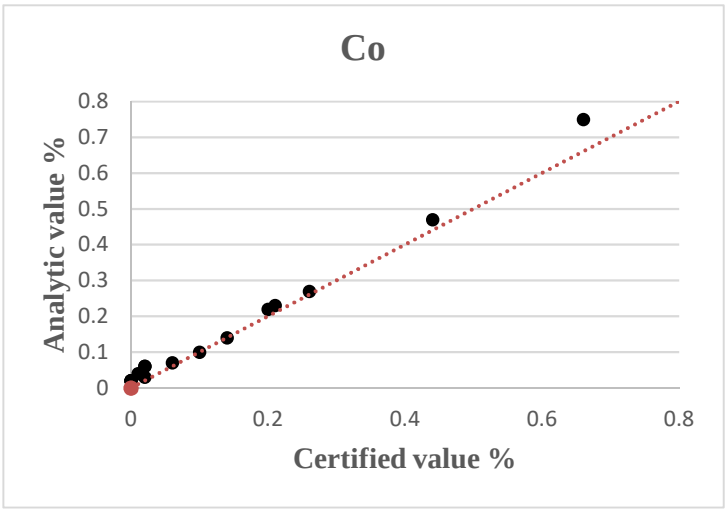

Figure 100 Analytical results of Co on secondary standards

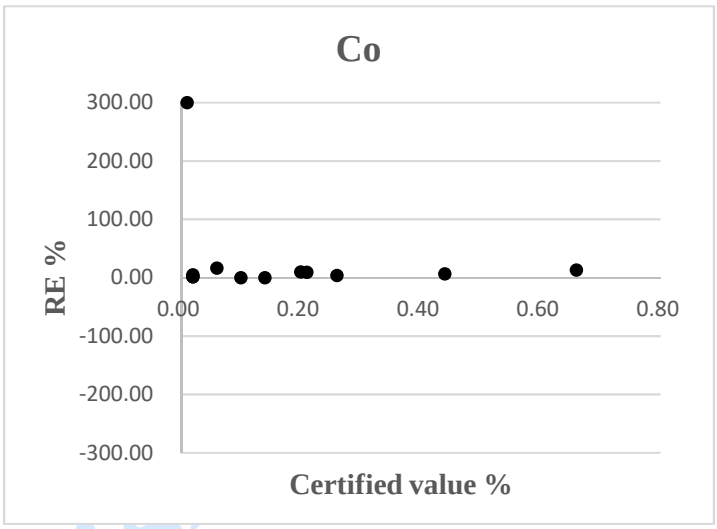

Figure 101 Co RE on secondary standards

Minimum detection limit (MDL)

This study has selected three ways to calculate MDL. The first one is as above, repeatedly analyzing a pure copper tape (blank reagent) with SEM-EDS. Measured X-ray photon counts have been recorded for all the elements (also the standard deviation). Meanwhile, we also independently calculate the calibration lines between X-ray counts and corresponding elemental concentrations based on the data collected for secondary standards (Figure 102-110). This set of calibration lines enables us to project original counts into real elemental percentages. The final MDL is listed in Table 5. This is essentially an empirical way of estimating the potential MDL of the operational instrument. Compared with lower limits reported from other labs

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(Heginbotham *et al*., 2011), the MDL achieved by our SEM-EDS is fairly acceptable.

The second way is to use the RE as a proxy of the MDL. Essentially, the MDL is the boundary below which the analytical value contains little statistical significance to tell the true value. Similarly, the RE is an expression of difference between the analytical value and the true. Therefore, given RE at a certain point becomes considerably large, it might indicate that the MDL is somewhere around that point. This could be furthermore reinforced if we measure one element with a series of concentrations of multiple standards, as achieved in this project.

Essentially, the MDL is a fuzzy demarcation between the real analytical signatures and background noise. The third way is based on the advantage of X-ray techniques that the chemical concentrations and their spectrum can be mutually converted. It means that provided chemical concentrations are known, we can also model the corresponding spectrum. INCA software provides a convenient function called spectrum synthesis, which enables one to model a spectrum based on hypothetical chemical compositions. By visual comparison between the peak and the background of these modeled spectra, most elements are identifiable if its percentage is over 0.1%, except arsenic 0.15%, zinc 0.2% and bismuth 0.15% (Appendix V).

All the three different methods discussed above could help to develop our understanding of the MDL but at the same time they all have potential drawbacks. For

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instance, the first one needs an extremely precise calibration curve. The tricky point for the second one is to which extent RE becomes unacceptable, 20% or 25%? The third one which relies on visual identification of course involves certain degree of subjectivity. However, the nature of chemical analysis is actually about error (Miller and Miller, 1984: 13). There is no “one-button” instrument that can help us to instantly and accurately write down the chemical composition of metal objects. A rigorous and thorough characterization of any instrument as shown above is very helpful to us to make a decent archaeological interpretation based on scientific analyses.

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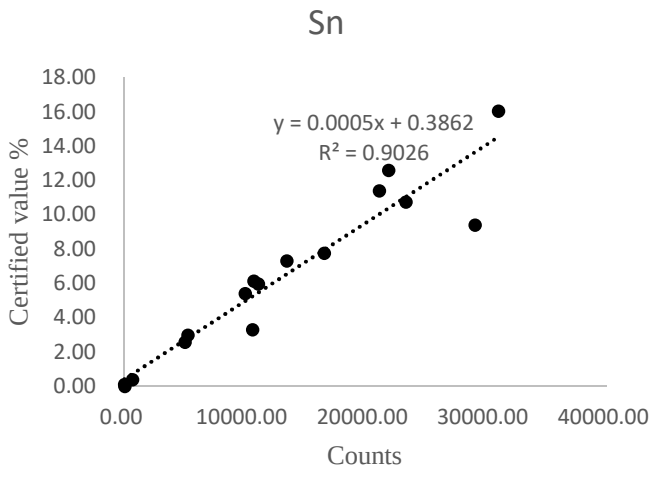

Figure 102 Calibration line for Sn

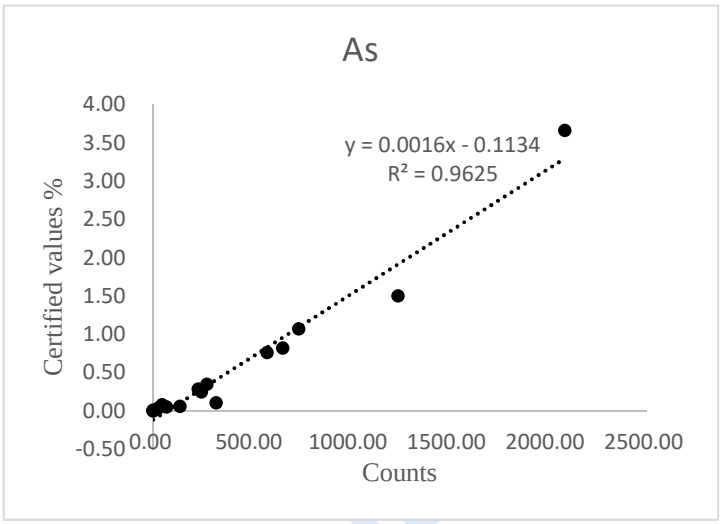

Figure 103 Calibration line for As

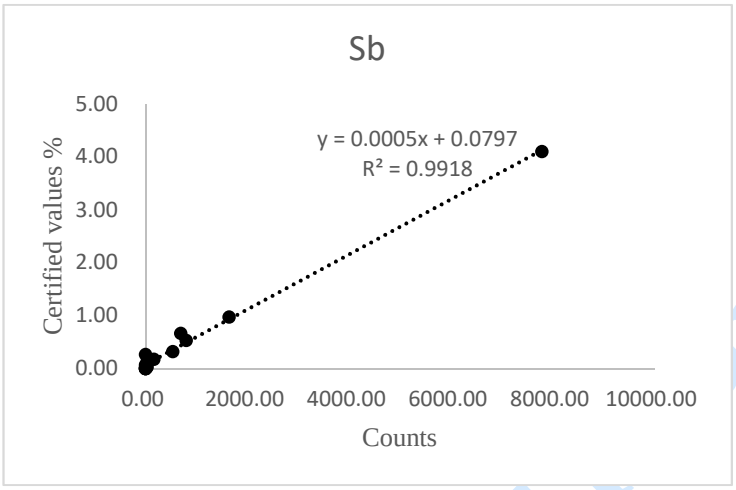

Figure 104 Calibration line for Sb

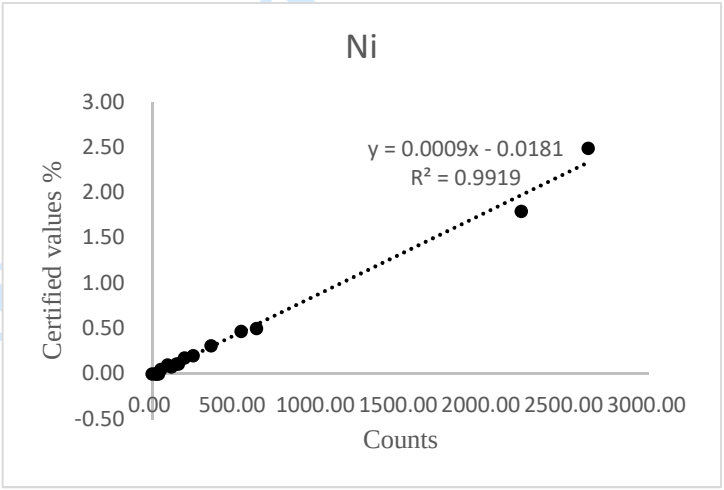

Figure 105 Calibration line for Ni

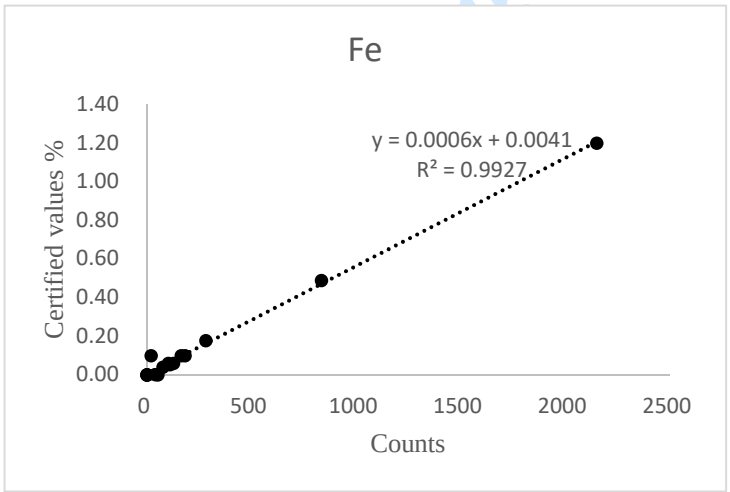

Figure 106 Calibration line for Fe

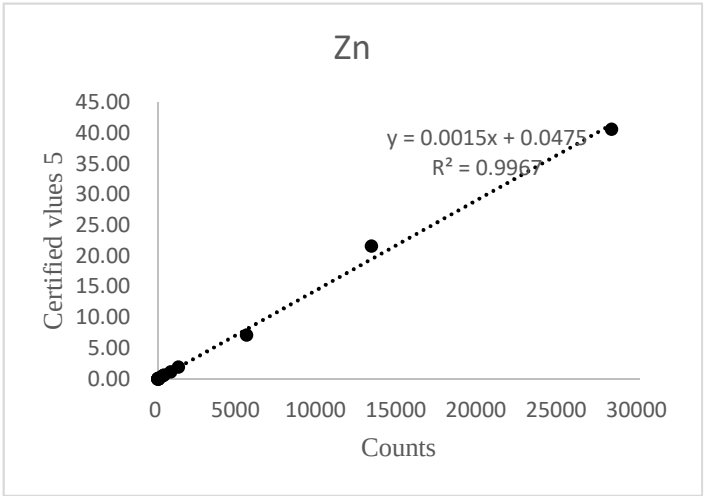

Figure 107 Calibration line for Zn

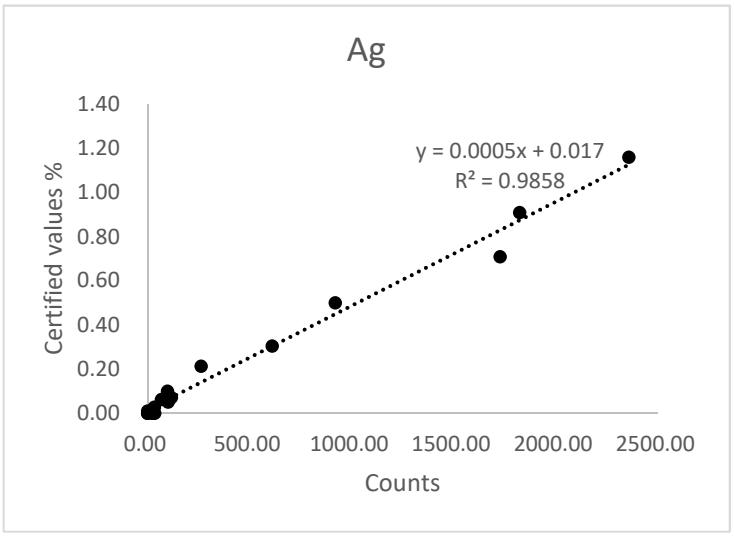

Figure 108 Calibration line for Ag

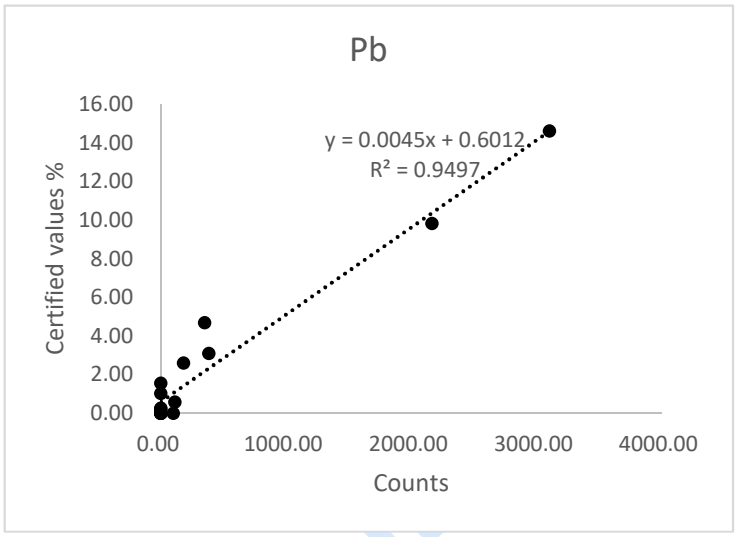

Figure 109 Calibration line for Pb

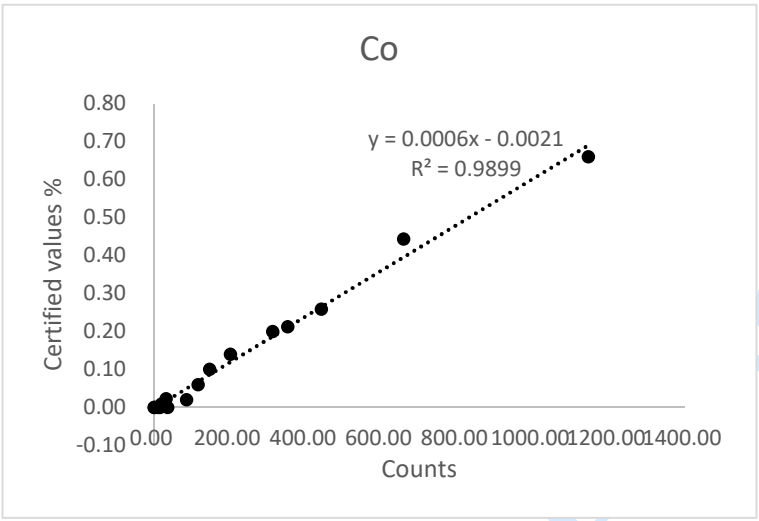

Figure 110 Calibration line for Co

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Table 5 Estimation of minimum detectable limit

MDL/%	Method I	Method II	Method III	Heginbotham *et al*. 2010	FP+ std Heginbotham *et al*. 2010
Sn	0.22	0.4	0.1	0.271	0.121
Pb	2.78	2	0.1	1.217	0.226
As	0.24	0.1	0.15	0.246	0.193
Sb	0.08	0.1	0.1	0.12	0.037
Ag	0.09	0.1	0.1		
Ni	0.09	0.08	0.1	0.354	0.057
Fe	0.11	0.08	0.1	0.168	0.063
Co	0.11	0.05	0.1		
Zn	0.31	0.4	0.2	0.792	0.147
Bi			0.15		

Note: FP means fundamental parameters.

Final protocol

After a rigorous and thorough assessment on the SEM-EDS, a final protocol of using SEM-EDS to analyze metal artefacts is attached here as a reference. Before starting a run of analyses, the instrument should be warmed up for half an hour. Then check the beam efficiency. Charge sample and check the carbon coating. Uneven carbon coating could cause the image drifting under SEM. Next is quantification optimization. This is to monitor the stability of the instrument, particularly beam current. Quantification optimization is a default function installed in the INCA software. Every hour, a high-quality copper tape is required to be measured. The resultant information is collected by the INCA software, which in the subsequent analysis is considered to calibrate the instrument.

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Under the analytical conditions set up above, the whole sample shall be evenly divided into 8-10 sites and then do test-measurement on every of region. This is important because superficial morphology, under the mode of either secondary or backscatter, is not informative enough to tell the degree of corrosion, particularly because the initial X-ray can penetrate a few micrometers below the surface (Goldstein *et al*., 1992: 407). If the region is too corroded inside, it has to be discarded and the whole sample needs re-dividing.

Each of these regions is then independently measured and the mean together with standard deviations are calculated. The more sites we measure, the better the understanding of compositional inhomogeneity that can be obtained from the standard deviation. It is of vital importance to note that the total of every analysis (not only the average) is rigorously kept between 98-102%. The total is the most convenient criteria for quality control. All the negative factors which have to be excluded, such as corrosion, non-flat sample surface drifting of the instrument, are generally reflected by the total. One last point is that although chemical composition is of most interest to this research, the images collected by SEM are really an effective indicator of the stability of the instrument, particularly the primary electron beam. Occasionally, even though quantification optimization is conducted, sometimes the image is moving under high magnification or the brightness/contrast is changing. This is mostly due to bad carbon coating which could potentially affect the final results. These empirical evidences suggest that this measurement should not be included. The consequence of

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using all the precautions described above is that using SEM-EDS is dramatically more time-consuming than previously thought. In addition to calibration of the instrument, every sample, if analyzing 8 regions, takes at least two hours.

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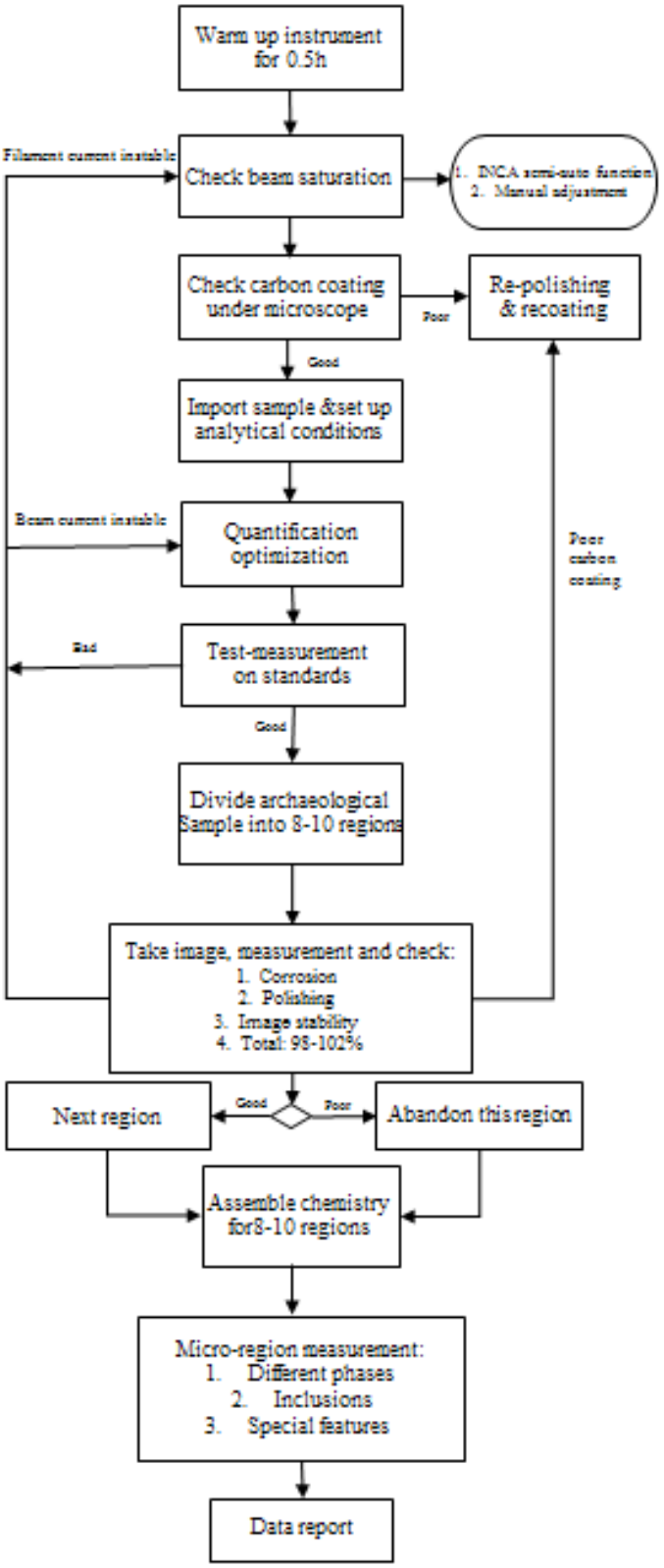

Figure 111 Final protocol

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Assessment of legacy data

Because of strict museum regulations, it is uncommon for the same object to be multiply sampled. At the same time, many samples have been completely consumed (dissolved) in the analysis. Consequently, the compositional information obtained can never be verified by other laboratories or instruments. What makes it even more frustrating is that in quite a few publications a lot of basic information such as detection limits, primary/secondary standards, precision or accuracy has been totally ignored. This makes a thorough evaluation virtually impossible.

What I can offer here is a basic comparative homework comparison of legacy data. The database achieved in this project enables us to quickly identify objects which have been multiply analyzed by different laboratories. Meanwhile, greatly thanks to samples provided by the team of Prof Jin Zhengyao, they provide a great chance to compare our analyses with those published by other laboratories with the same or different instruments (Zhangsun, in prep). I also find a handful of dual analyses for the same object in the legacy database for comparison. The assessment shows that apart from a few outliers, data quality in most publications is generally good and the data are inter-changeable.

Case study: Hanzhong metal assemblage

The metal assemblage found in Hanzhong has been sampled at least by two teams (University of Science and Technology Beijing and University of Science and

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Technology China). 205 objects have been analyzed in Chen (2009) and 62 have been analyzed with SEM-EDS in Oxford. Between them, 33 objects are overlapped. Through a detailed and laborious comparison element by element, it seems proper to argue that the data produced by the two laboratories with two different instruments are interchangeable for a majority of objects.

Major element: Sn and Pb

As demonstrated above, SEM-EDS in RLAHA Oxford is capable of analyzing tin with excellent precision and accuracy. A simple plotting shows a pretty good agreement between the two sets of data produced by SEM-EDS (Oxford) and EPMA (Chen, 2009). This agreement is further confirmed by a quite significant linear relation (Figure 112) close to y=x, which means results of tin by the two instruments are basically identical. Another line of evidence is the comparative work of SEM-EDS and EPMA on the same batch of 205 Hanzhong samples (Chen, 2009, Fig. 3-1). It shows that the maximum difference of tin between SEM-EDS and EPMA is around 2% absolute. The two works combined together give us more confidence in the consistency of tin between SEM-EDS and EPMA. We suggest that both instruments are able to analyze tin with excellent precision and accuracy therefore can be replaceable with each other.

It is interesting to discover that there are three objects of which the difference of tin between SEM-EDS (RLAHA) and EPMA (Chen 2009) is over 3% (1976CHBSXT:16,

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1979YXFT:18 and 1976CHBSXT:325). A quick answer is uneven distribution of tin but ultimately we need to check the basic sampling information and reanalyze them.

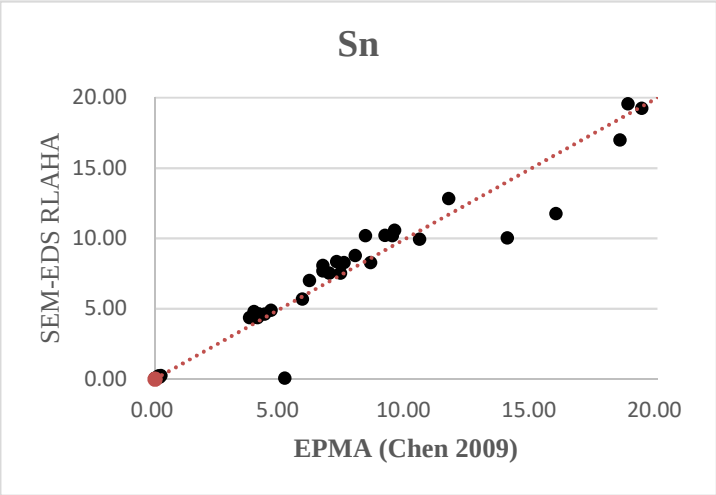

Figure 112 Comparison of tin between SEM-EDS and EPMA

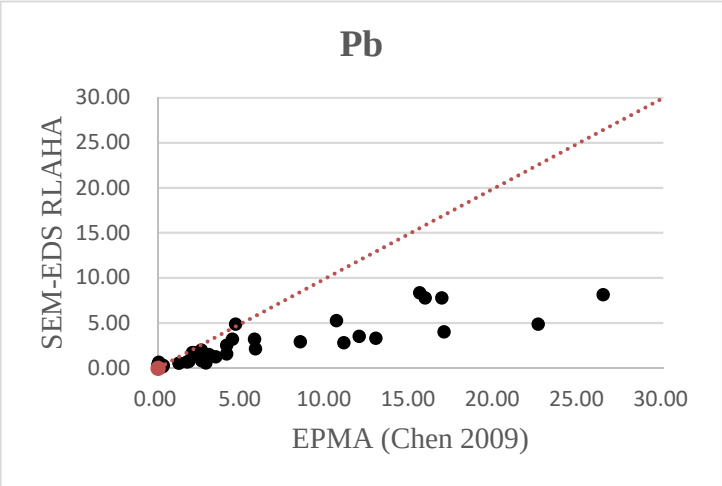

Figure 113 Comparison of lead between SEM-EDS and EPMA

In sharp contract with tin, we see a large systematic error in lead (Figure 113). For the same object, the result of lead by EPMA is constantly higher than that of SEM-EDS. This variation becomes more striking if the lead is over 10% reported as by EPMA. This is however not uncommon. As notified in Chen (2009: 18) as well, the variation of lead between SEM-EDS and EPMA is frequently over 5% in absolute terms. Whilst in a huge number of papers in Chinese SEM-EDS and metallography are routinely used to analyze metal objects, however, this issue has not yet been seriously considered. As shown in Figure 79, the SEM-EDS routinely understates the concentration of lead. Meanwhile, poor polishing might give a negative error to lead. It is not necessarily true as sometimes lead is smeared on the surface of samples by

Ruiliang Liu unpli

polishing thus it tends to be overestimated (Hughes *et al*., 1982; Lutz and Pernicka, 1996; Northover and Rychner, 1998). Scott (1996) proposed that hard pressure must be avoided in the process of grinding and polishing, which could save some lead globules.

Trace elements

There seems no short-cut to compare a variety of trace elements. Characterization of SEM-EDS above based on standards has indicated that the relative error is around 15-20% when the real percentage approaches 0.1-0.2%. Below this, the relative error appears very random and thus has very little statistical meaning. This section aims to explore the variation between SEM-EDS and EPMA for those trace elements of which the amount is above 0.1% (Chapter Two). We would suggest that 0.1% as a reasonably sensitive cut-off for presence and absence of most trace elements for both SEM-EDS and EPMA.

A consensus can be summarized in Table 6. If one instrument shows an element beyond 0.1%, this is highly likely to have a value over 0.1% by the other instrument as well. This dataset, though not very comprehensive, suggests that qualitative estimation of trace elements is in a good agreement between the two instruments, even including measurements of arsenic.

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Table 6 Number of objects with trace elements above 0.1% with SEM-EDS/EPMA

	SEM-EDS>0.1%	**EPMA>0.1%**	**Both >0.1%**
As	13	10	10
Sb	4	2	2
Ag	5	6	5
Ni	11	8	8
Fe	5	4	4
Zn	2	3	0
Bi	9	9	6

Quantitative difference has been illustrated in Figure 114-119. A majority of points plot very close to the reference line (y=x), which means the result of SEM-EDS is nearly identical to that of EPMA. It is slightly frustrating to see that after selecting objects with specific elements of concentration above 0.1%, the size of database shrinks dramatically, particularly for Sb and Zn. Therefore, strictly speaking, this comparison is not very representative. Although most sampling positions are roughly in the same area, the exact sample point is different. This factor might somehow contribute to the final difference in the chemical composition between the two instruments. Cobalt is unfortunately not included in Chen (2009) so we are unable to make any comparison.

Ruiliang Liu unpished thesis

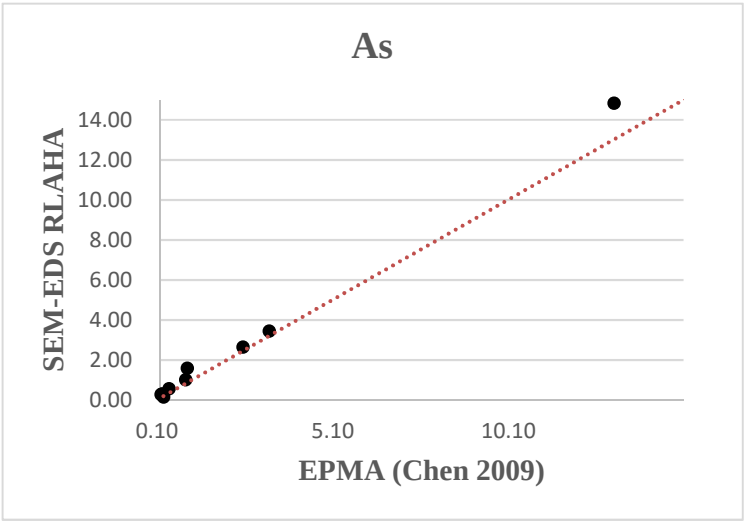

Figure 114 Comparison of arsenic in Hanzhong objects

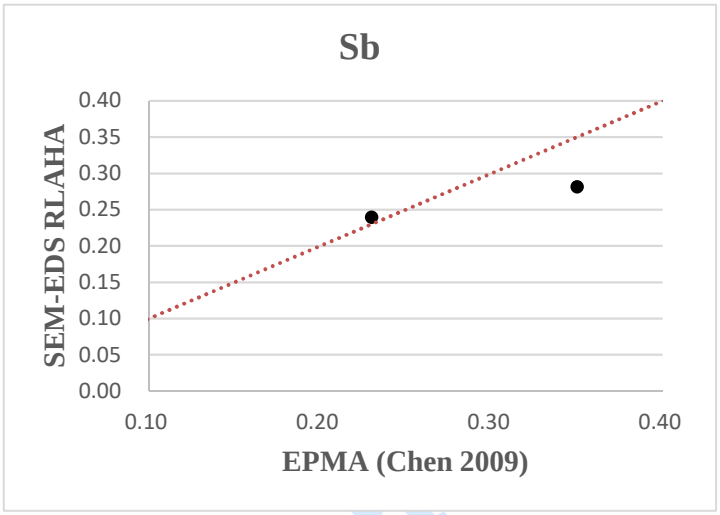

Figure 115 Comparison of lead in Hanzhong objects

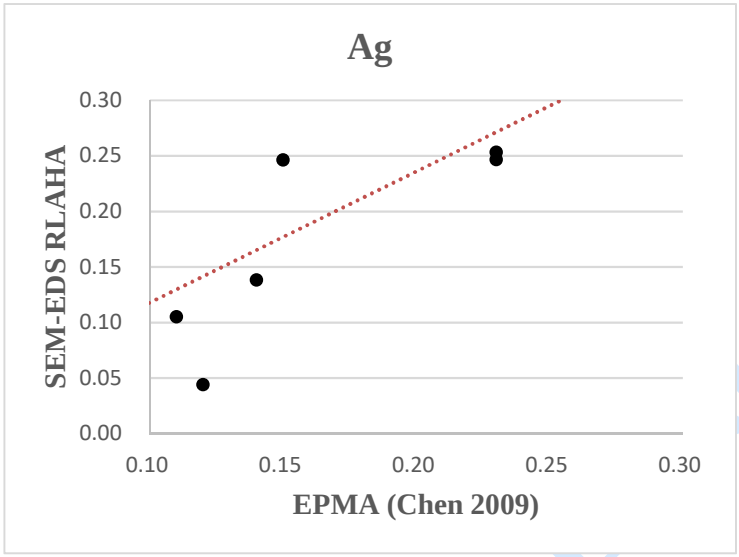

Figure 116 Comparison of silver in Hanzhong objects

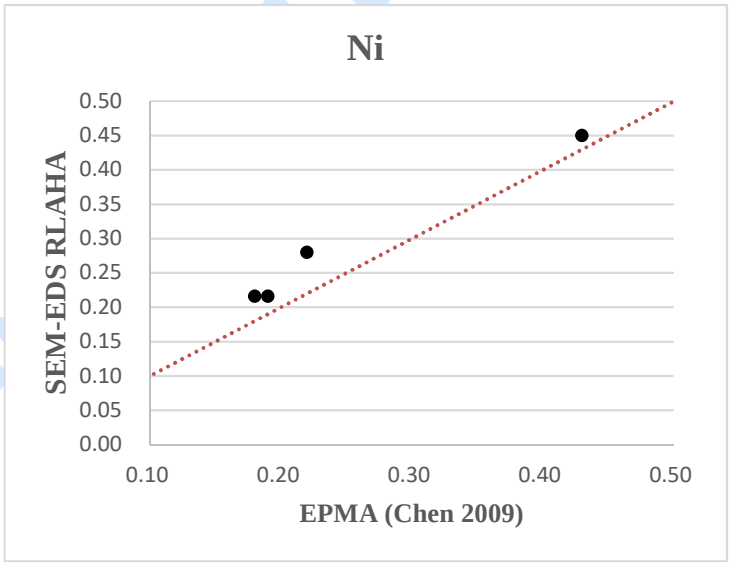

Figure 117 Comparison of nickel in Hanzhong objects

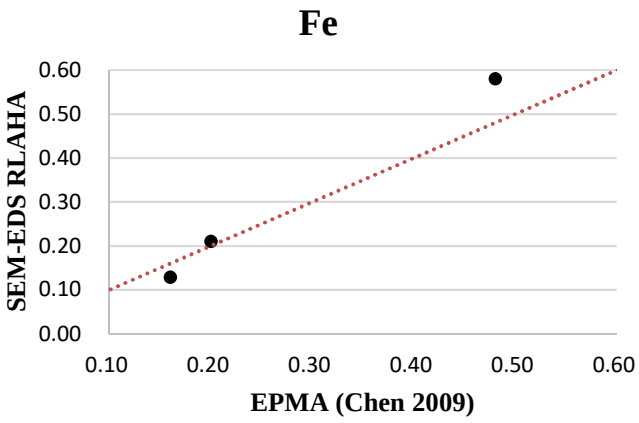

Figure 118 Comparison of iron in Hanzhong objects

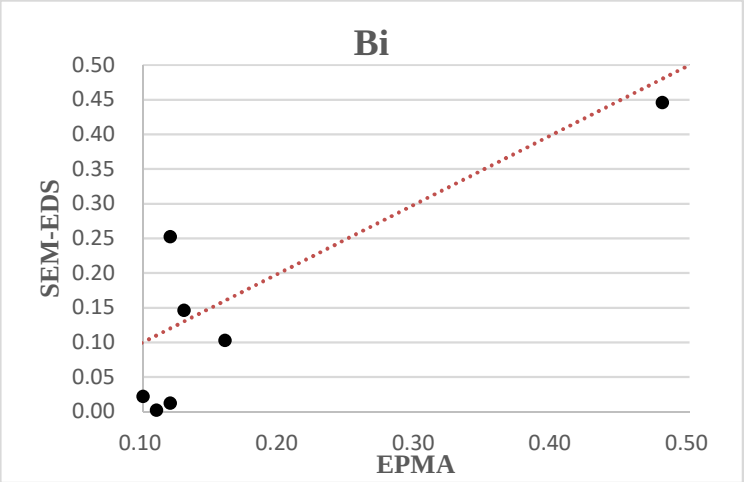

Figure 119 Comparison of bismuth in Hanzhong objects

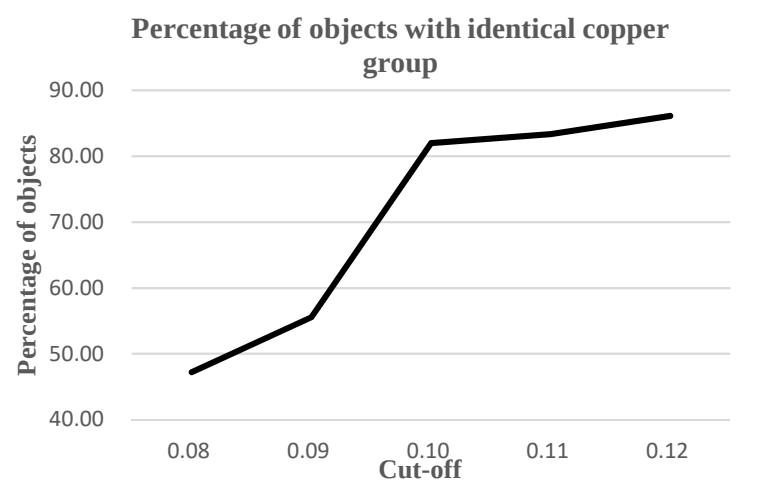

Figure 120 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs

Copper group

The analysis of copper group needs an agreement between a *group* of elements rather than an individual one. 27 out of 33 objects show exactly the same copper group based on the results by either SEM-EDS or EPMA with a 0.1% cut-off. One potential danger which could undermine this grouping is boundary effect. As has been discussed, the relative error is about 10-20% when the chemical composition is approaching 0.1%. Boundary effect here is defined as potential uncertainty on the final result of copper grouping of one object due to the fact that its chemical composition is very close to the cut-off. One way to mitigate this effect is to use an instrument with high resolution. The other way is to vary the cut-off and see which one is most effective to highlight the major patterns of the data. In accordance with Figure 120, 0.1% is arguably sufficient sensitive to characterize the most important data structure. Below it, the disagreement of copper groups between SEM-EDS and

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EPMA becomes considerably larger. The pattern remains substantially stable when moving the cut-off to 0.11% or 0.12%. It is therefore unnecessary to go beyond in this case. Further varying cut-offs of individual elements still shows a good agreement and we can see that the uncertainty is mostly caused by arsenic and silver (Figure 120-124). As discussed above, SEM-EDS cannot produce measurements of arsenic with a good accuracy. The concentrations of silver in four objects (0.08-0.12%) are very close to the cut-off therefore their copper groups become ambiguous. It is not problematic as the next profile analysis (Chapter Two) will illustrate the real percentages so one can take this uncertainty into account before interpreting the data.

Ruiliang Liu unplished thesis

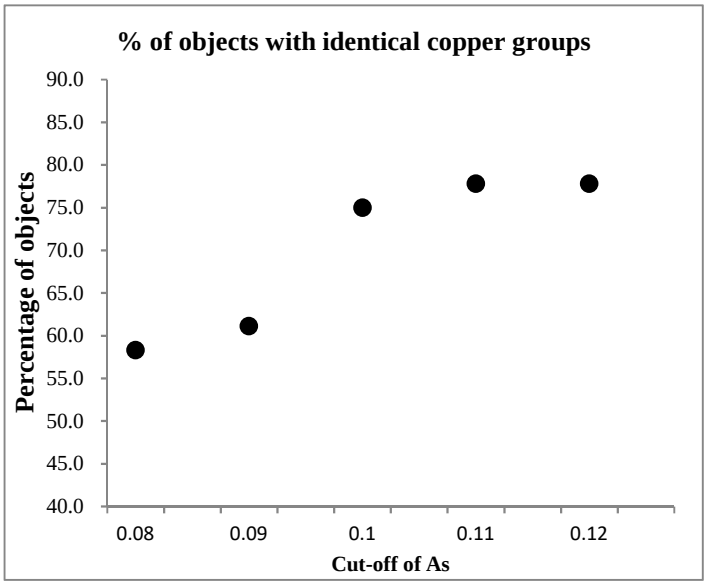

Figure 121 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of As (the cut-off for others is 0.1%)

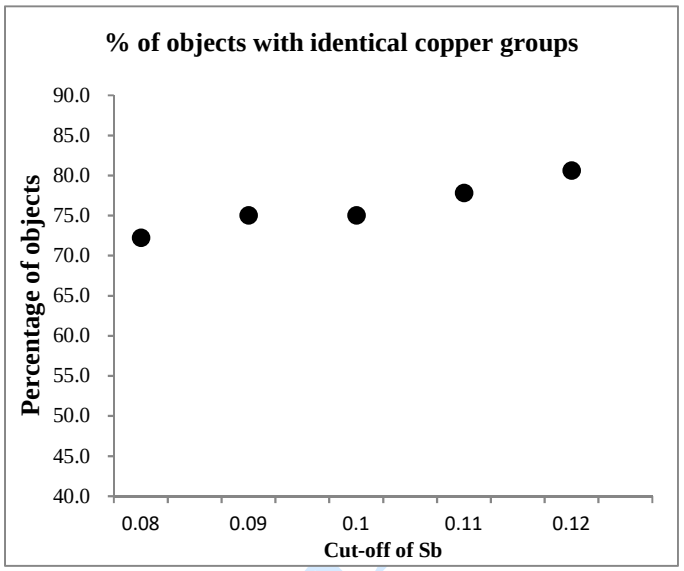

Figure 122 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Sb (the cut-off for others is 0.1%)

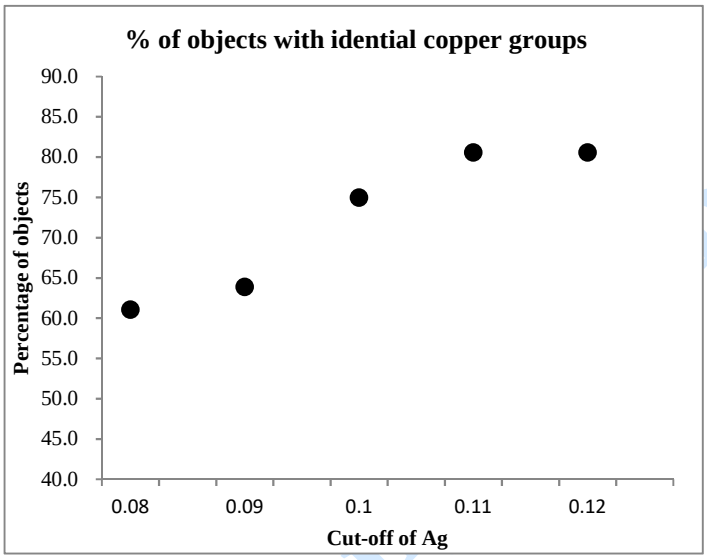

Figure 123 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Ag (the cut-off for others is 0.1%)

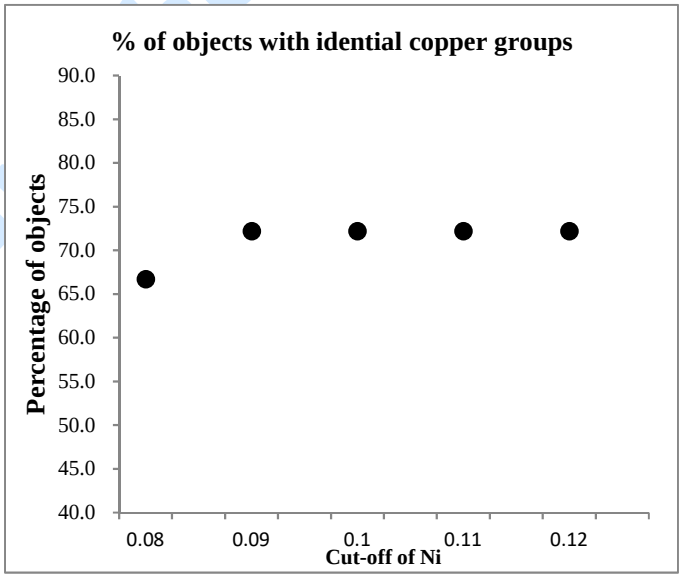

Figure 124 Percentages of objects in Hanzhong assemblage catalogued as identical copper group by different cut-offs of Ni (the cut-off for others is 0.1%)

In conclusion, the two datasets are essentially consistent and interchangeable. The major pattern in either of them is stable. There indeed exist a small number of objects which might be distinguished. Some of them appear suspicious and it might be

necessary to check the sample from the very beginning, *e.g.* sample ID, and hopefully reanalyze them. Before this scholars should be cautious when interpreting these data.

Case study: SEM-EDS and ICP-MS on Sanxingdui assemblage

Eight samples from Sanxingdui objects have been analyzed by both ICP-MS (Ma *et al*., 2012) and SEM-EDS. Unfortunately, most elements (Ag, Sb, Ni, Zn, Fe) in these samples are reported below 0.1% by SEM-EDS (RLAHA) so comparison is not possible. This makes the database even more limited. The difference of tin in this case is mostly below 1% in absolute. This significantly enhances our confidence to use the reported value of tin by SEM-EDS and ICP-MS in an interchangeable way. Compared with tin, consistency of arsenic is less remarkable but still good enough to build up real archaeological interpretations. Lead and bismuth are notoriously difficult. As in the Hanzhong assemblage, lead is systematically underestimated in SEM-EDS. This is very likely caused by the issue of overpolishing. Bismuth, in contrast, is overestimated. In this case, what can be concluded so far is that lead by SEM-EDS has only qualitative meaning. Given that polishing is not involved in pretreatment, lead reported by ICP-MS (solution based) could be more reliable in quantitative terms.

Unfortunately, the performance of ICP-MS is not described or assessed in Ma *et al*. (2012). In general, ICP-MS is far better than SEM-EDS in measuring trace elements.

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In this case study, copper group is again assessed by varying cut-off. Six out of the eight samples which are both analysed by ICP-MS and SEM-EDS show identical copper group however the cut-off changes. More crucially, on the level assemblage, all published datasets agree that CG1 (clean copper) and CG2 (As-only) are the top two groups (Table 7).

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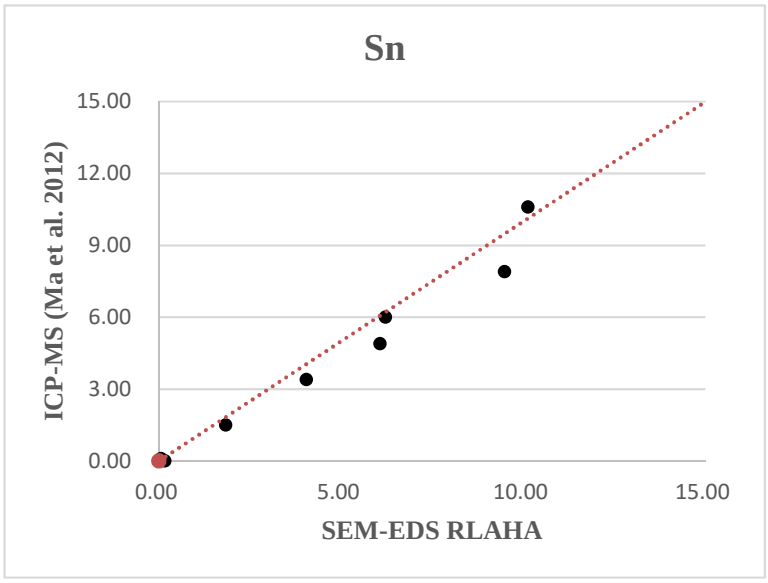

Figure 125 Comparison of tin in Sanxingdui objects

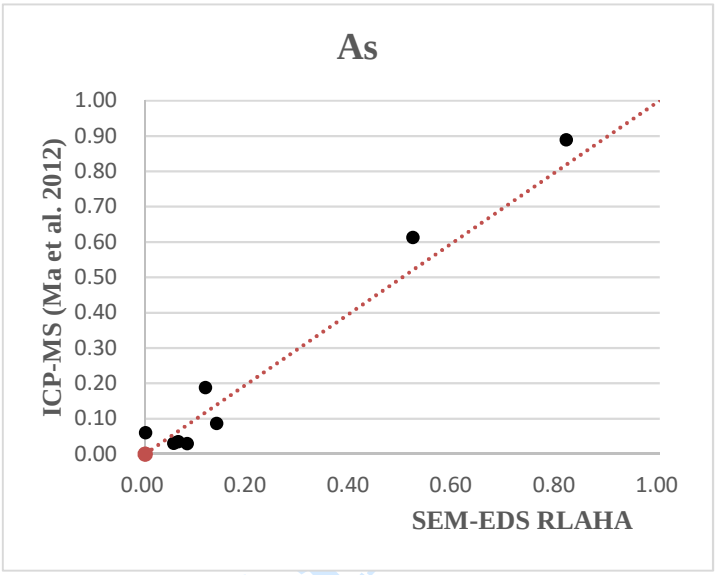

Figure 126 Comparison of arsenic in Sanxingdui objects

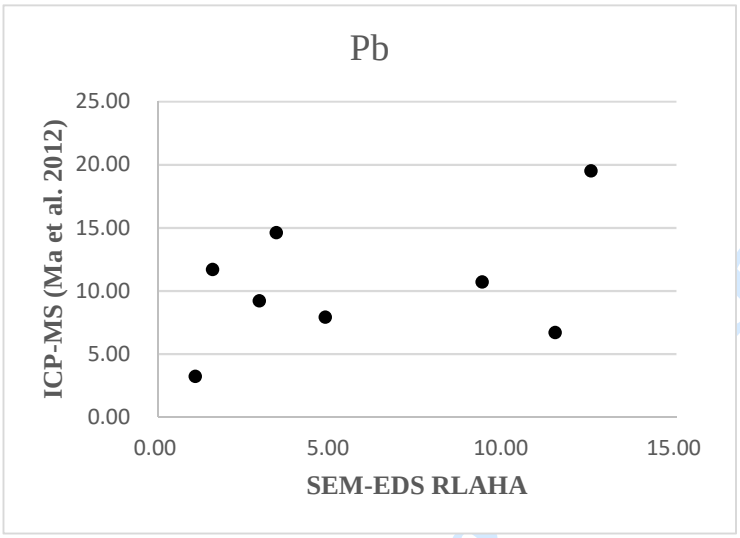

Figure 127 Comparison of lead in Sanxingdui objects

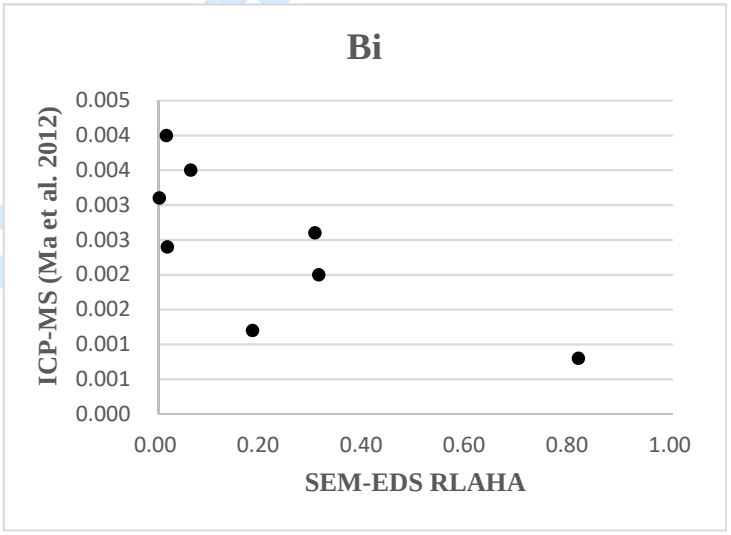

Figure 128 Comparison of bismuth in Sanxingdui objects

Table 7 Copper group distribution based on different datasets of Sanxingdui

Dataset	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16	Data entry
Ma et al. 2012	56.7	33.3	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	30
RLAHA	43.8	34.4	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	32
Cui and Wu 2013	70.6	17.6	0.0	0.0	0.0	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17

Case Study: Panlongcheng assemblage

39 objects have been separately analyzed by Chen *et al*. (2001) and Hao *et al*. (2001). A different set of 13 analyses can be found in He (2001). Three teams use SEM-EDS. Trace elements have been reported by Chen *et al*. (2001) with NAA but not in Hao *et al*. (2001). So in this case study we are only able to compare tin and lead between the two datasets. The difference of tin percentage is mostly (36 out of 39 objects) below 3% (Figure 129). Once again, tin is one of the best reported elements in publications. Lead in this case is still problematic. The values of lead reported by Hao *et al*. (2001) are constantly greater than those of Chen *et al*. (2001). However, with no information on polishing and assessment of the instrument with standards, it seems rather difficult to say which dataset is closer to the true percentage. Thus the safest way so far is to say these objects are all leaded bronze.

Intriguingly, a considerable difference can be observed from the analysis between the two teams above and He (2001). The data produced by He (2001) shows far less tin and lead. It involves at least two possibilities worthy of consideration. The first one could be that this disagreement is caused by different batches of objects from the same site, which means that all of these numbers are correct but different teams had chosen objects with different life histories. For instance, all the samples collected by He (2001) were from the same archaeological context and accidentally they were all made with low-tin recipe for some reason. Given the fact of a random sampling strategy indicated by the excavation numbers of those objects, this seems relatively

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unlikely. The second one could be erroneous analysis. There is no further information we can follow in the initial report.

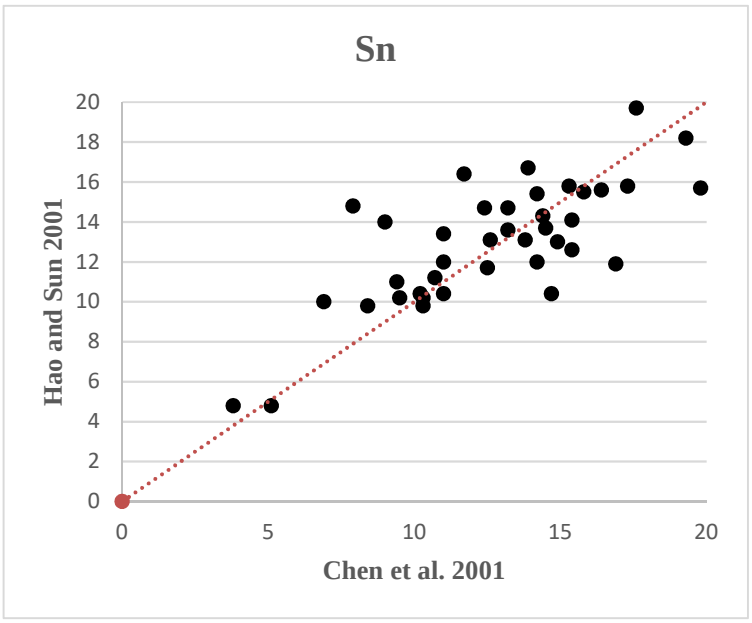

Figure 129 Comparison of tin in Panlongcheng objects

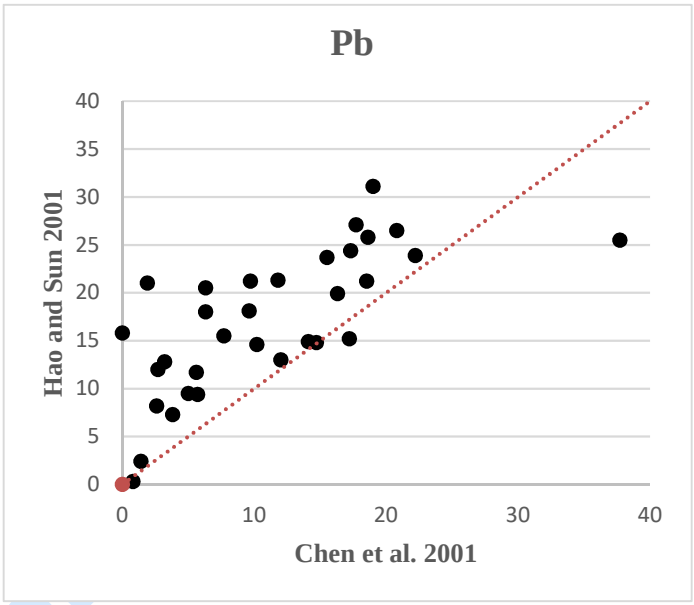

Figure 130 Comparison of lead in Panlongcheng objects

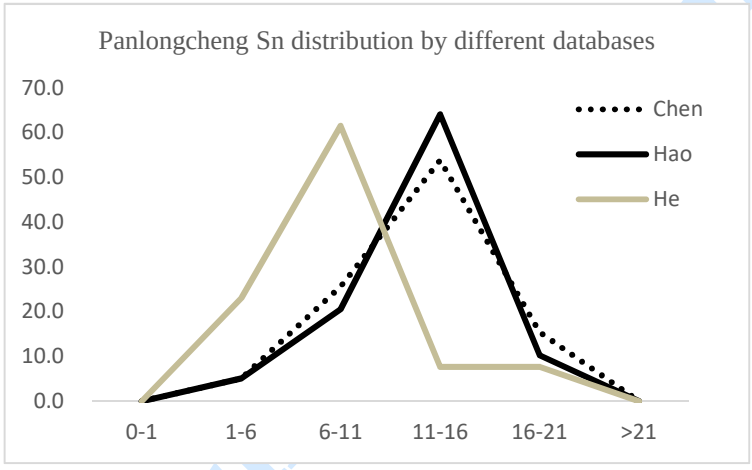

Figure 131 Percentage of tin in Panlongcheng objects reported by different teams

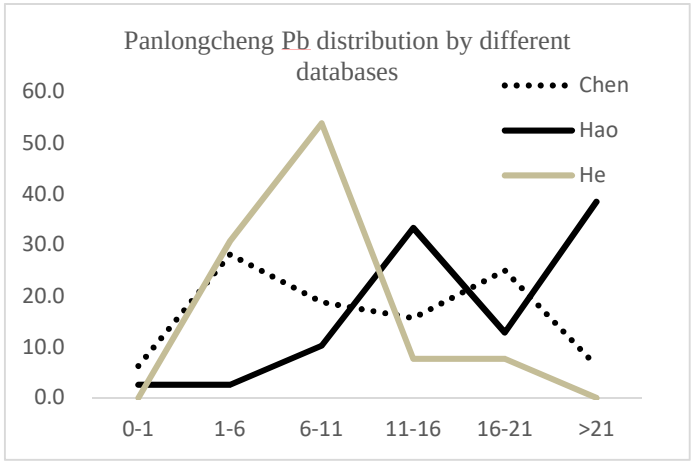

Figure 132 Percentage of lead in Panlongcheng objects reported by different teams

Case Study: Yinxu assemblage

Although metal objects from Yinxu have been frequently analyzed, however, very few objects, particularly vessels, own more than one chemical analysis. The Sackler collection provides multiple-spot analyses for seven vessels, which could, up to a point, answer the question of chemical inhomogeneity for large vessels. The maximum variation of tin between different positions of the same objects is less than 3%. But for lead this increases radically to 7%. The variation of trace elements appears rather insignificant. In spite of different sampling position (body or leg), they all lead to the same copper group. Indeed, seven objects with 15 measurements appears a very limited database. More objects with multiple and high-quality chemical analyses are still needed.

Scholars often use chemical composition to describe an assemblage of metal objects from the same site. Therefore, it is critical to understand the site-based variation by using chemical analyses from different laboratories or techniques. Metal objects from Yinxu have at least three large chemical databases, which provide an invaluable case study for this aim. The question here is that whether or not copper groups are a useful tool to capture the major and shared characteristics in different databases? As shown in Table 1, the distribution of copper groups between the Sackler collection (Bagley, 1987) and Yinxu Western Area (Li *et al.*, 1984) is quite close. Both of them show that the major copper groups are CG1 (clean copper), CG2 (As-only), CG9 (As-Ag), CG12 (As-Sb-Ag). The Freer collection (Pope, 1967) also shows that CG1 (clean

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copper), CG9 (As-Ag) and CG12 (As-Sb-Ag) are of high importance. Interestingly, CG4 (Ag-only) in the Freer collection shows a relatively high presence. One possibility is that this copper group (eight objects) might derive from a single batch production. Sadly, archaeological context is no longer accessible to help us further explore this issue. Alternatively, the measurement on silver was not accurately for the Freer collection.

Table 8 Comparison chemical databases of objects with Shang metropolitan style produced by different laboratories and instruments[24]

Copper Group	Sackler Collection (Bagley 1987)	Freer Collection (Pope 1967)	Yinxu Western Area (Li *et al.* 1984)
CG1	38.89	33.33	6.89
CG2	22.22	5.56	17.24
CG3	0.00	0.00	0.00
CG4	3.70	19.44	0.00
CG5	0.00	0.00	0.00
CG6	2.78	2.78	13.79
CG7	0.00	0.00	3.45
CG8	0.00	0.00	0.00
CG9	16.67	16.67	17.24
CG10	0.00	0.00	3.45
CG11	0.93	0.00	0.00
CG12	12.96	16.67	27.59
CG13	0.00	0.00	0.00
CG14	0.00	0.00	3.45
CG15	0.00	5.56	0.00
CG16	1.85	0.00	6.90
Data entries	108	36	28

[24] The measurement of the Sackler collection was conducted by P. Meyers, L. Holmes and E. Sayre through AAS for alloyings and NAA for trace elements. The elements of Cu, Sn, Pb, Zn and Fe were determined by wet chemistry whereas trace elements semi-quantitative spectrometry in Li *et al.* (1984). Freer measurements were done by wet chemistry for alloyings and AES for trace elements.

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3.4 Conclusions

This chapter has presented an immense amount of work required to evaluate the performance of one single instrument (SEM-EDS) and the difficulty of assessing and synthesizing data from different laboratories with different techniques. My observation is that even though noticeable differences can be detected for a few individual objects, the general pattern of the data is self-sustained. In every case study, measurement of tin presents an excellent quality between different laboratories and with different techniques (less than 3-5% in absolute percentage). Occasionally, tin is miscalculated but it immediately stands out against other datasets. By sharp contrast, the result of lead is subject to fluctuations. With regard to trace elements, a good agreement can be found for the question of presence/absence for an overall assemblage. More importantly, the concentrations of trace elements, particularly As/Sb/Ag/Ni, provided they are above the instrumental MDL, are also comparable.

Whilst this chapter is severely limited by the fragmented nature of legacy data, it can provide several benefits to this thesis and, in a longer term, to understand how to better engage scientific analysis with real archaeology, especially for China. As emphasized in many published works, no single technique stands superior to all others. Therefore it is always crucial to record as much information as possible for other people to evaluate the quality of the data (see Appendix IV for analytical hygiene). In order to offer a critical starting point to improve and standardize the data quality in a long term, I strongly suggest a project like Chase (1975) or Northover and Rychner (1998) should be established in China.

Puiliang Liu unpished thesis

Concerning a short-term benefit, the assessment on data quality offers a number of important precautions to this thesis. Clearly, the pattern of chemical compositions on the level of metal assemblage is significantly more robust one individual objects. Therefore, it is much safer to apply discussion to an assemblage rather than a specific object. Occasionally, some special objects are selected but I always question the data quality at first and try to use other information to constrain the interpretation. Likewise, though a variety of techniques can be involved to address one particular question, a reasonable consensus emerges for the presence/absence of one element (*e.g.* 1% for alloys and 0.1% for traces). This offers us a good starting point to illustrate a relatively more stable data structure for assemblages. In terms of quantitative analysis, the average of one assemblage could be badly affected by outliers and should be avoided. Instead, the distribution of elemental percentage (or profile analysis) is more honest and informative thus always pursued in this thesis. It has to be admitted that none of these could perfectly balance the thin line between the data quality and archaeological interpretation but all of these procedures help us to be more protected from making biased judgment with bad data and more opened to various possibilities.

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Chapter Four A comparative perspective: revisiting Panlongcheng metal assemblage

4.1 Introduction

Using the methodology set out in Chapter Two, this chapter investigates one major component of the metal supply network in the Central Plains of the upper Erligang period (*ca.* 1450-1300 BC). It focuses on a comparison of the chemical compositions of bronzes excavated at the sites of Panlongcheng and Zhengzhou (15th - 13th centuries BC). Previous comparative studies of the material culture lead to the mainstream conclusion that Panlongcheng was an outpost of Zhengzhou to secure especially the movement of metal from south to north (*e.g.* Bagley, 1977, 2014; Liu and Chen, 2009: 116-119; IA CASS, 2003: Chapter 8, 8; Zhang, 2014).

Thanks to the newly published chemical data on metal objects at Zhengzhou (Tian, 2013), we can now make a series of systematic comparative studies using the Oxford system and hopefully contribute more to the long-standing discussion of topics such as the movement and use of metal between Zhengzhou and Panlongcheng and local/nonlocal production (Kane, 1974; Steinke, 2014). Some newly discovered

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similarities and differences presented in this chapter may help archaeologists to deepen our understanding of the movement of metal during this period and ask more questions on the sociopolitical interactions.

After the Erlitou period, Zhengzhou clearly grew into probably the most important site in the Central Plains (Chapter One). While our knowledge about this site is rather limited, as most parts are still underneath the present-day city and have not yet been excavated, a range of extraordinary discoveries demonstrate its power and sophistication lasting for approximately three hundred years (*ca.* 1600 - 1300 BC). The scale of its city walls and its enclosed area is spectacular. The inner walled area is around 300 hectares in extent. The outer one is radically larger, occupying over some 2,500 hectares. The labour required for the construction of the outer walls must be considerably greater. Within the inner walled area are found a few large building foundations. These building are often recorded as palaces in the Chinese literature (Henan Institute of Archaeology, 2001: 320-329).

The prosperity of Zhengzhou can also be understood from its rich material culture and thriving craft productions. As summarized in Chapter One, there were multiple workshops of bronze, pottery and bone implements, which were distributed across the walled area. So far, no large elite tombs have been found at Zhengzhou. Our understanding of its bronzes is mainly formed on the basis of several famous hoards and a number of chance finds (Fang, 1999; Henan Institute of Archaeology and

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Zhengzhou Museum, 1983; Henan Museum, 1975). Together they add up to around 400 pieces. Among these one most telling piece is probably the massive *ding* (鼎) vessels from the hoard of Xiangyang huizu shipinchang. They have rectangular cross sections and are around 0.5 m high. The middle parts are covered by the famous *tao'tie* pattern. Whilst the purpose of these hoards remains unclear, the bronzes vividly illustrate the bronze-casting skills available to the elites at Zhengzhou. Compared to those of Erlitou, bronzes at Zhengzhou present many new types (*e.g. ding* 鼎, *gu* 觚, *jue* 爵 or *li* 鬲) and became dramatically larger in both size and weight. *Tao'tie*, as the major decoration on these bronzes, appeared more systematic and sophisticated (Figure 133).

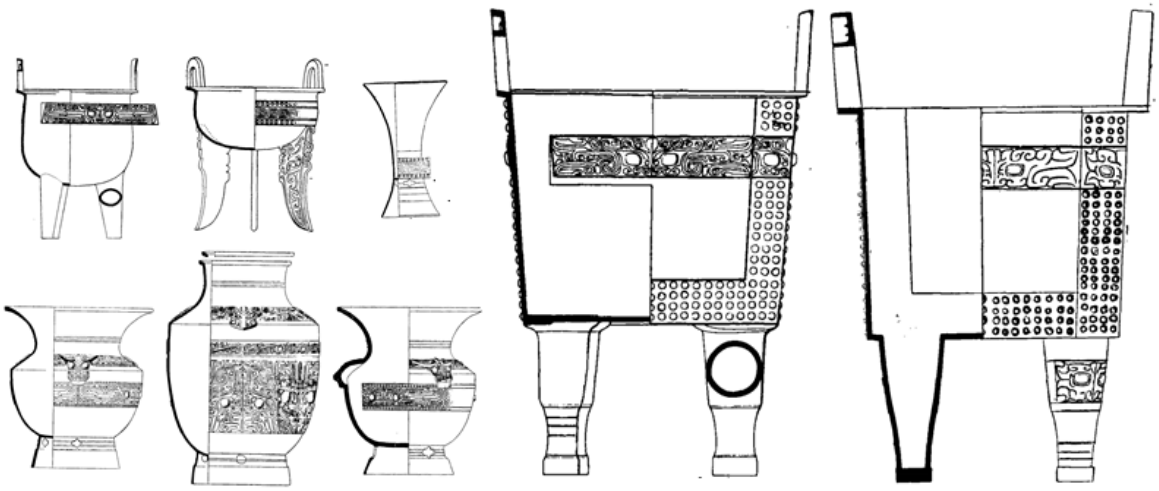

Figure 133 Selected vessels from the hoard of Xiangyang Huizu Shipinchang at Zhengzhou (after Henan Museum, 1975, Henan Institute of Archaeology and Zhengzhou Museum, 1983)

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The Erligang culture, which is usually defined by the pottery typology, was widely spread from the Central Plains to the Yangzi River valley and gave birth to many local variants (Wang, 2014). Its widespread geographical distribution also causes considerable discussion on how to comprehend the archaeological nature of the Erligang phenomenon (Bagley, 1977, 2014; Liu and Chen 2009: 131-148; Baines, 2014; Li, 2014; McNeal, 2014; Campbell, 2014; Chapter One).

The site on the southern edge of this distribution is named Panlongcheng, located on the south bank of the Yangzi River in modern Hubei province, *ca.* 450 km away from Zhengzhou. It was found during the local archaeological survey in 1954. Subsequently, a large-scale excavation was carried out and recovered a variety of archaeological materials, including large building foundations, rammed earth walls, foundries, tombs, bronzes, jades, pottery, stone tools. Excavation is still ongoing. As shown in Figure 134, the site of Panlongcheng can be roughly divided into two parts. All the three large building foundations are within an enclosing wall, with an overall circumference of *ca*. 1100 m (area *ca*. 75400 m^2, Hubei Institute of Archaeology, 2001: 14). Archaeologists suggest that these building foundations represent palaces and they were built up with similar technology at Erlitou and Anyang. In addition to the building foundations, one tomb (89HPCYM1) was found inside the walled section with pottery, jades, vessels and weapons of bronze. Most of the finds excavated within the wall are pottery fragments. The major body of finds is actually distributed outside the wall.

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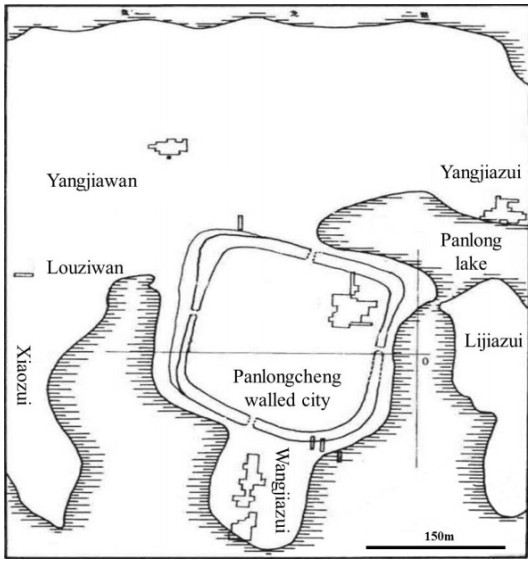

Figure 134 Outline of the Panlongcheng site

(after Hubei Institute of Archaeology, 2001: 8)



Figure 135 Reconstruction of the palaces at Panlongcheng

(after Hubei Institute of Archaeology 2001: 634, 637）

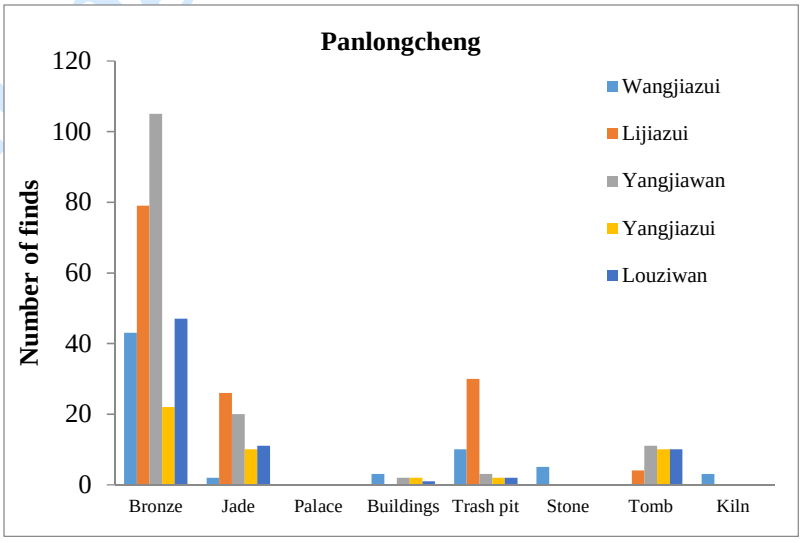

Figure 136 Summary of various finds in Panlongcheng

Among these, the largest tomb (PLZM2) was found at the Lijiazui site. It presents a typical burial of the Erligang culture (Zhang, 2014). The owner of the tomb is positioned in the middle of the tomb. One can find the typical Shang tomb structure *ercengtai* (二层台), the secondary layer of around half-metre high against the shaft pit (Bagley, 1999: 160), on top of which there are three human sacrifices. Ninety-one objects have been unearthed in this tomb, half of them are bronze. They form a typical Shang ritual set centred on the combination of *gu* (觚), *jue* (爵) and *jia* (斝) vessels, decorated by standardized *tao'tie*. So either the shape of the vessels or their decorations are almost identical to those discovered at Zhengzhou or northern sites contemporary with Zhengzhou (Hubei Institute of Archaeology, 2001: 446 and 493). The big axe might indicate the tomb occupant was a military leader (Hubei Institute of Archaeology, 2001: 500). A similar one has been found at the other Shang site of Gaocheng Taixi in Shandong province (Hebei Institute of Archaeology, 1985: 133). The range of bronze vessels unearthed suggests that the tomb occupant followed the ritual practices typical of Zhengzhou. As exemplified by PLZM2, both tomb type and ritual set are aligned with the typical Zhengzhou elite practice.

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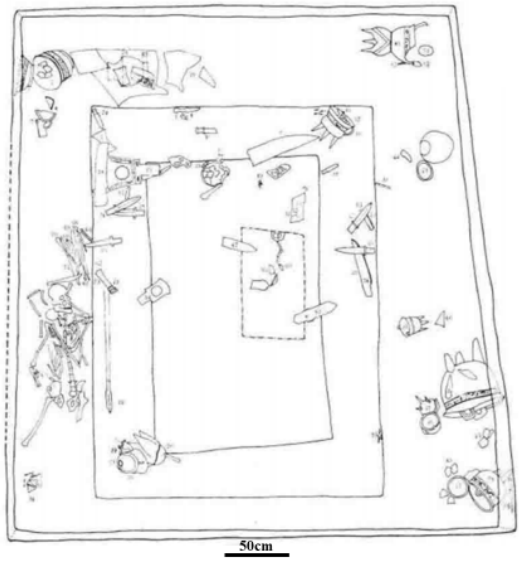

Figure 137 Tomb PLZM2 (after Hubei Institute of Archaeology, 2001:154)

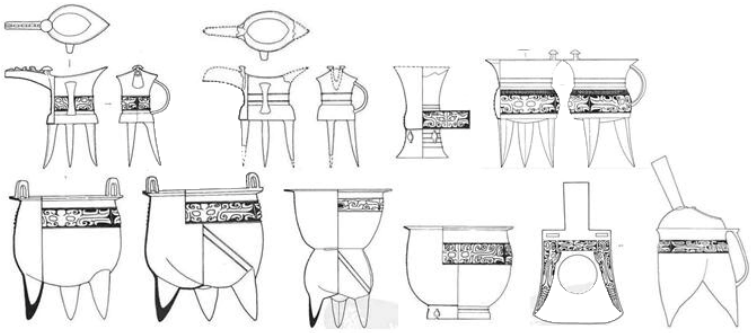

Figure 138 Some Bronzes in PLZM2
(after Hubei Institute of Archaeology, 2001:162-178)

Pottery draws a different and more diverse picture. Excavators have divided the local pottery into four types (Figure 139). While the A group mostly resemble those at Zhengzhou and other Erligang sites in the Central Plains, one can still see some clear linkage to the Hushu culture in the lower Yangzi River in Jiangsu province (C group) and the Wucheng and Wannian culture in Jiangxin (D group). The largest proportion of pottery is the B type, which is considered as local Panlongcheng group (Huibei Institute of Archaeology, 2001: 497-498).

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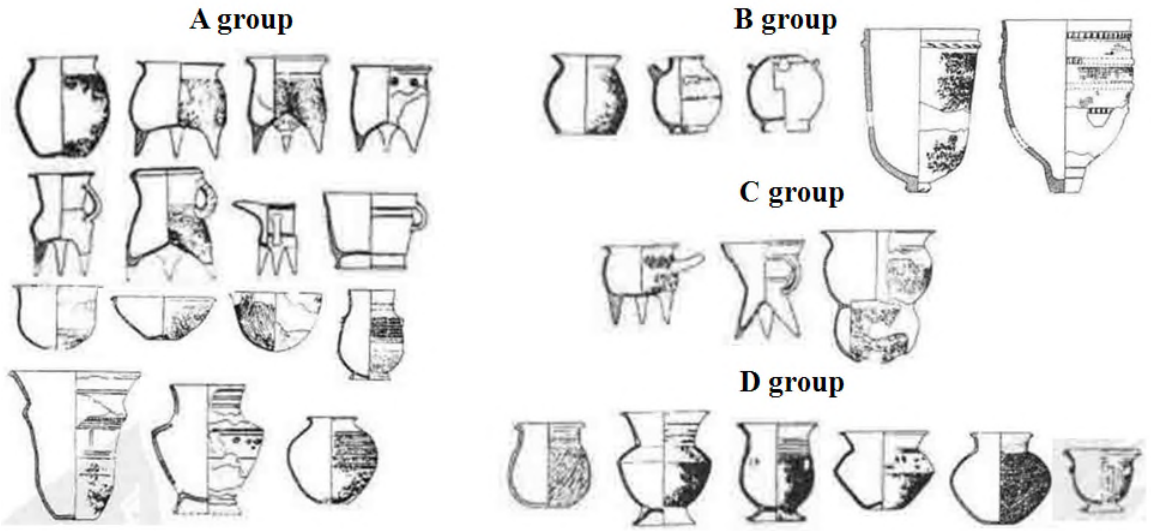

Figure 139 Four groups of pottery in Panlongcheng (after Hubei Institute of Archaeology, 2001: 495-496)

The importance of Panlongcheng has to be understood in the light of Zhengzhou. Bagley was probably the first western scholar to emphasise the close connection between Zhengzhou and Panlongcheng. As summarized by Bagley (1997), bronzes, jades and ceramics at the two sites strongly resemble one another. This is also true in the Chinese literature where materials in Panlongcheng are often labeled as the Panlongcheng variant of the Erligang culture (IA CASS, 2003: Chapter Eight, 8). Furthermore, considering that such similar material culture co-occurs at two different sites hundreds of miles away from each other, Bagley suggested a uniform Erligang empire, of which Zhengzhou was the central polity that controlled the subunit at Panlongcheng. He and others have argued that the establishment of Panlongcheng was a result of a military conquest and driven by the need for metal and other resources at

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the Zhengzhou court (Bagley, 1999: 168-171, 2014; Wang, 2014).

In a wider picture, Panlongcheng is not an isolated Erligang site along the Yangzi River. Further southwest are two other sites which present Erligang characteristics, Jingnansi and Tonggushan (Guo, 2001; McNeal, 2014; Xiang, 1993; Zhang, 2015). As with the discussion on Panlongcheng, the occurrence of the Erligang culture in the furthest south has encouraged scholars to consider the underlying impetus. Again, given the enormous demand for metal at Zhengzhou and the rich deposits along the Yangzi River, an overwhelmingly large number of scholars accepted that Panlongcheng was established as a local power or military outpost by the Zhengzhou polity to secure the supply of metal from the Yangzi River for the north (Bagley, 1977; Zhang, 1994; Liu and Chen, 2000, 2009: 116-119&2012: 285-289; Chen, 2003; Xu 2003; Fu, 2004; Shelach-Lavi, 2015: 239; Hubei Institute of Archaeology, 2001: 502-504; Zhang, 1994; Chen, 2003; Xu, 2003; Fu, 2004; Jiang, 1976; Li, 2001; Gao, 1985; Li, 2016a). Furthermore, the lack of abundant metal resources in the Central Plains adds support to this argument. Apart from mines in the Zhongtiao Mountains, there are very few copper mines near the Central Plains. Considering this, it becomes more likely that the establishment of Panlongcheng and its very evident connections with Zhengzhou were linked with the need to access copper and tin from the south.

At the Tongling conference in the summer of 2016, hundreds of small shafts or mines along the Yangzi River have been reported. They include some of the most

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well-known mining sites, such as Tongling, Nanling, Tongliing, Tonglvshan and Yangxin (Zhang, 1988; Anhui Institute of Archaeology and Tongling cultural bureau, 1993; Yu, 1993; Liu and Lu, 1997; Liu, 1998; Gong, 1989; Huangshi Museum, 1999; Xia and Yin, 1982; Chen *et al*., 2012; Hubei Institute of Archaeology *et al*., 2013; Figure 140). One example is the site of Jinniudong, just one of hundreds of very small-scaled shafts in the mountains (Anhui Institute of Archaeology and Tongling Cultural Bureau, 1989). At present, there is no comprehensive survey of all such sites and it is not possible to assess their productivity (Figure 141). The major discoveries at these mining sites include wooden structures and tools. One of the most impressive excavations is in the Tonglvshan site. Its structure provides an impression of a large-scale mining over a multi-generation period, although the known finds there, to date, belong to periods later than Erligang. Frequently discovered tools include stone hammers, wooden and bronzes tools (Figure 142 and 143). Considering the huge scale of mining activities in this region and the establishment of a site like Panlongcheng, it is highly likely that there existed a movement of metal from south to north.

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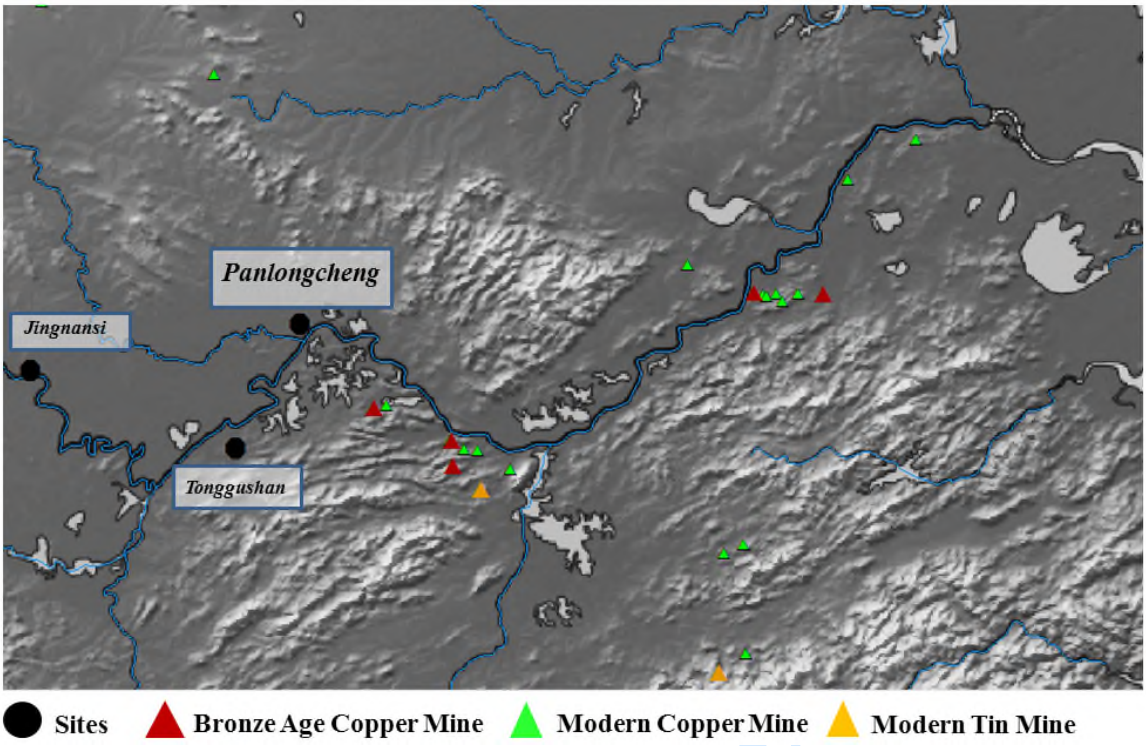

Figure 140 Distribution of metal deposits along the Yangzi river

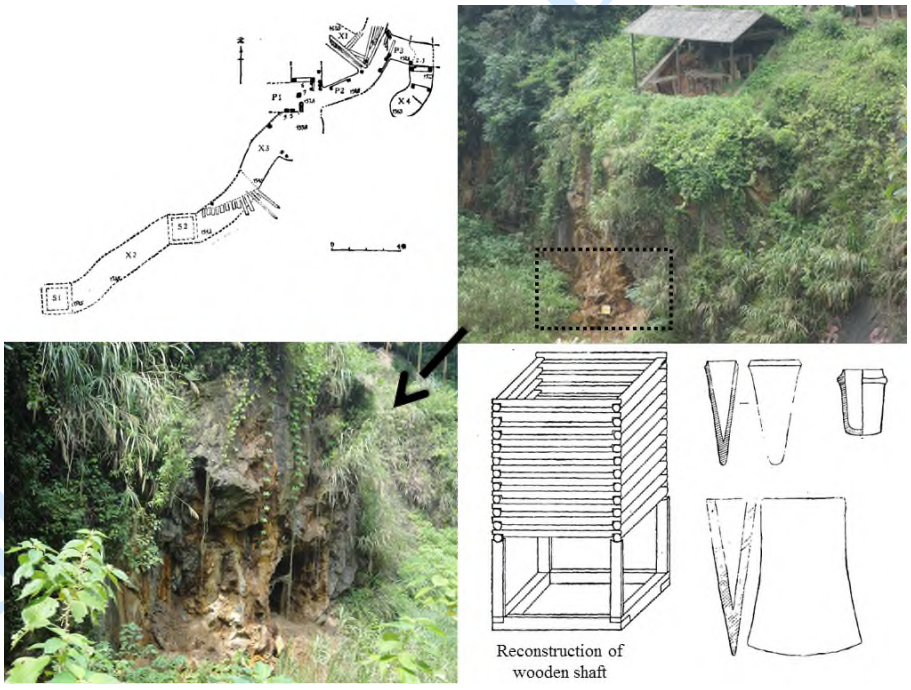

Figure 141 Jinniudong mining site

photos taken by the author and line charts are redrawn after Anhui and Tongling (1989)



Figure 142 Preservation of a tiny part in Tonglvshan mining site (Eastern Zhou Period)

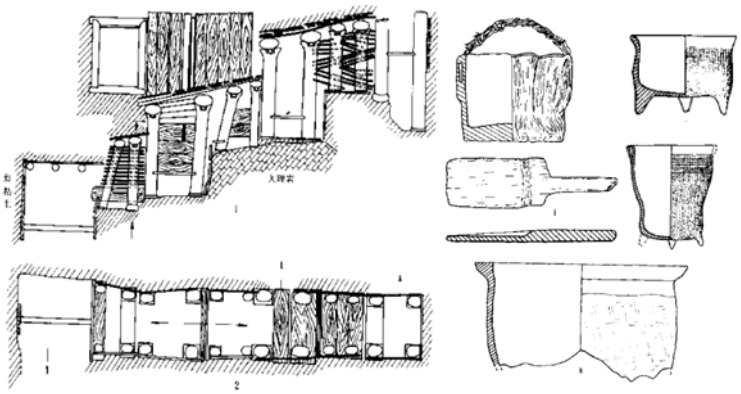

Figure 143 Reconstruction of the mining structure and excavated objects (after Huangshi Museum, 1999: 52, 129)

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4.2 Cross-linking Chronology

The dating of Panlongcheng is based on a variety of archaeological materials and radiocarbon dates. The first is a two-step process. Based on the stratigraphy, excavators divided the overall site of Panlongcheng into seven phases (Hubei Institute of Archaeology, 2001: 441-493). The second step is to cross-date each of the local stratigraphic layers with those at other sites through a comparison of archaeological remains, mainly of pottery. The watershed in Panlongcheng is the IV phase. As the I-IV phases all lie beneath city walls and palaces, excavators made the suggestion that the IV phase witnessed the beginning of the construction of the site walls and the palace, as similar structures are not found in phase I-III. Moreover, the use of bronze became increasingly important during the IV phase (Hubei Institute of Archaeology, 2001: 447-448).

Table 9 Chronological framework of Panlongcheng (Hubei Institute of Archaeology, 2001: 442-446)

Panlongcheng Phase	I	II	III	IV-V	VI	VII
Erlitou II phase	√					
Erlitou III phase		√				
Erlitou IV to Erligang lower I phase			√			
Erligang upper I phase				√		
Erligang upper II phase earlier					√	
Erligang upper II phase later						√

Compared to the chronological framework achieved by combining stratigraphy and typology, the one based on radiocarbon dating is much less sophisticated. The principal reason is that too few analyses have been done so far. Only four wood samples in the IV phase of Panlongcheng have been radiocarbon dated. After remodeling the dates with Oxcal, the result does not answer the question on when the walls were constructed. This is because it merely presents a very wide range of probability, as shown by the wide shaded range of probably two hundred years (Figure 144). Therefore, interpretation rooted in these radiocarbon dates alone is far from conclusive.

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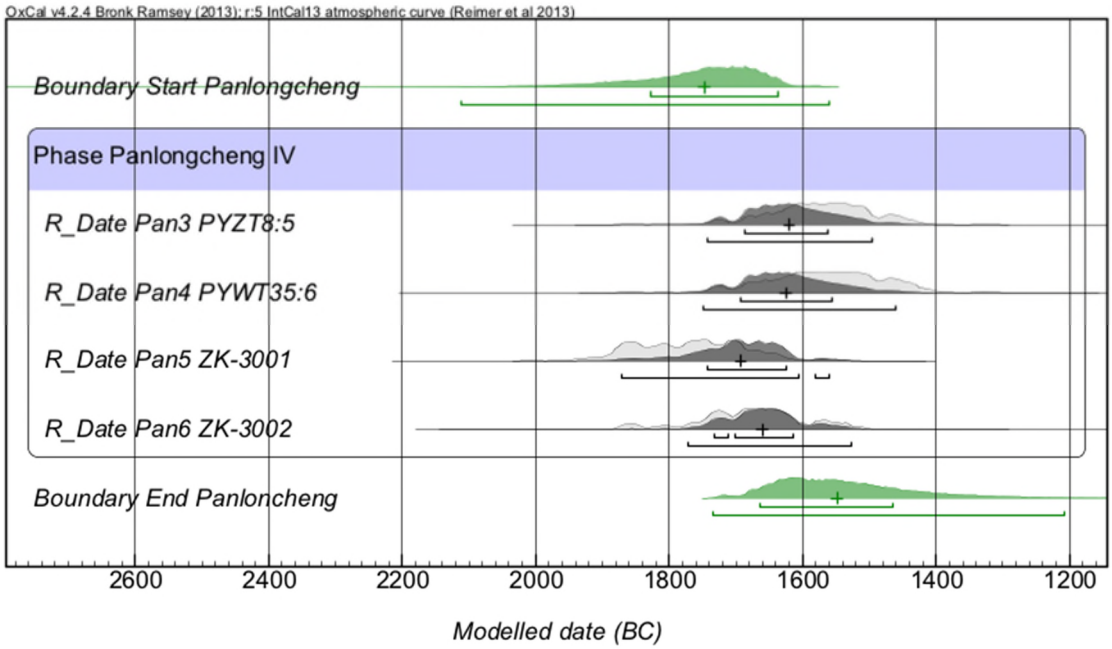

Figure 144 Remodelling radiocarbon dates for Panlongcheng IV

4.3 Previous scholarship on scientific analyses of bronzes: production and provenance

The question of local production of bronzes, or in other words, local workshops has been discussed in a considerable number of publications (Bagley, 1999: 170; Liu and Chen, 2012: 288; Chen *et al.*, 2001; Zhang, 2014). There is little doubt that the primary attraction of the bronzes at Panlongcheng is their almost identical styles (both shape and decoration) to those known from Zhengzhou. This stylistic similarity implies that the bronzes at Panlongcheng may have been imported from Zhengzhou. On the other hand they may have been made in the south by casters familiar with Zhengzhou practices, as suggested by the similar bronze styles and tomb structures.

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In the most recent excavations at Panlongcheng, Zhang Changping has pointed out that the traces of a local foundry for bronze casting can be detected from the section of Xiaozui at Panlongcheng. Portable XRF shows that soil in some areas of Xiaozui contain copper ten times greater than the rest. Some clay-based pieces might be moulds (Hubei Newspaper, 2016). As these are not yet officially published, it is difficult to make any judgment.

In parallel, scientific analysis of bronzes has been focused on the question of local production and metal provenance. The famous examples are lead isotopic studies (Peng *et al*., 2001; Sun *et al*., 2001). In accordance with traditional bi-plots of two lead isotopic ratios, normally $^{207}Pb/^{206}Pb$ against $^{208}Pb/^{206}Pb$, Panlongcheng shows both radiogenic and common lead, and this distribution overlaps with that of another site further south at Xin'gan Dayangzhou (Sun *et al*., 2001). The tentative conclusion from this is that the metal supply of Panlongcheng may have been based on more than one source, for either copper or lead. This argument is plausible if radiogenic and common lead isotopes which both have been identified at Panlongcheng derived from different places. It is however difficult to pinpoint the exact source of lead. Meanwhile, it is also hard to distinguish whether objects were made at Zhengzhou and Panlongcheng by lead isotopes alone since both radiogenic and common lead were used at both sites.

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Apart from lead isotopes, several teams have also carried out provenance studies from other perspectives. Chen *et al.* (2001) argued that recycling older objects seems less likely at Panlongcheng as no earlier site could afford such a large consumption. In terms of archaeology, this is a fair argument because even until now the scale of metal objects dated to the Erligang period at Panlongcheng is still largest along the Yangzi River. No other excavations can provide comparable discoveries.

Chen and colleagues also applied principal component analysis (PCA) to explore the number of metal sources in the dataset. While either an ingot excavated in the Tonglvshan site or the one smelted in the modern simulation by Tonglvshan copper ores appear rather different from other samples, bronze objects at Panlongcheng are clustered in a very narrow range (Chen *et al.*, 2001: 568-570). Such a strong compositional similarity of these bronzes is indicative of a shared source of copper and tin (Chen *et al.*, 2001: 569).

One common issue with PCA analysis is that scholars often consider the first two principal components because they contain the largest variance. In the case of Chen *et al.* (2001), however, the first two factors that are used to differentiate these objects can only cover 55.8% of variance (F1, 33.8%, F2, 22.0%, Figure 145), which means that the rest 44.2% of variance shown by the rest factors of PCA is completely ignored. Therefore, it is not pervasive to justify the argument of a shared source without taking the rest 44.2% of variance into consideration.

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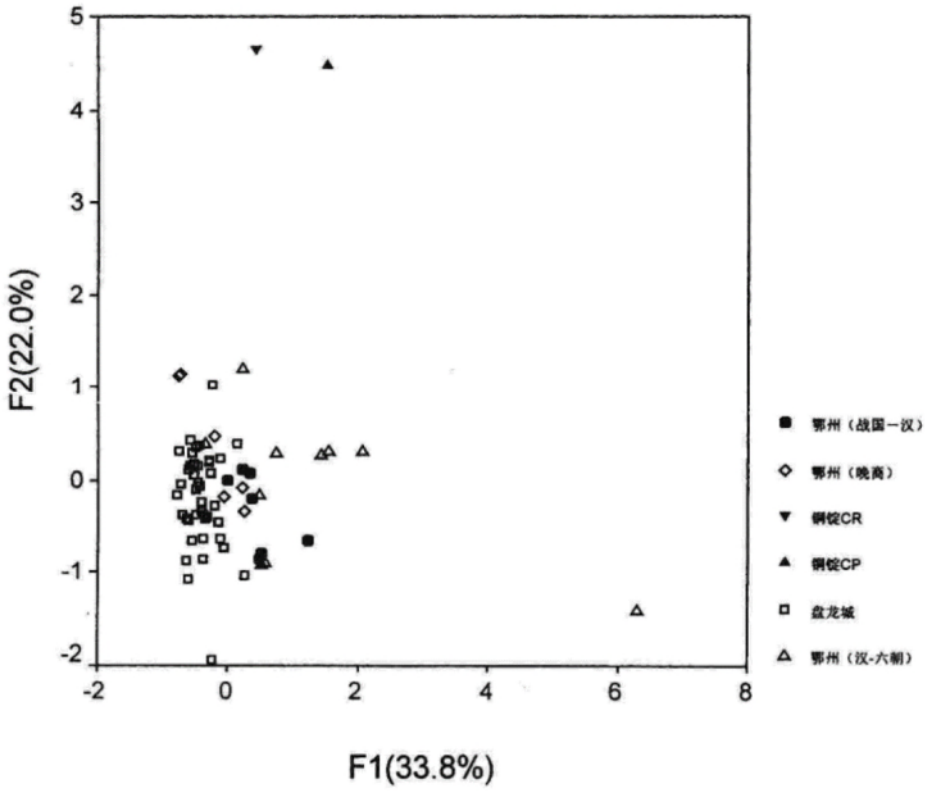

Figure 145 PCA analysis for Panlongcheng bronzes (after Chen *et al.*, 2001)

Clay core remains in legs and handles may also yield some interesting evidence. As a result of different geological history, the concentrations of calcium and magnesium in clays vary from south to north in China. This difference has also been found in the clay core buried inside the vessel at Panlongcheng, which implies some objects at Panlongcheng were locally made (Nan *et al.* 2007). The key issue is whether this difference was caused by geology or anthropogenic processing of the moulds remains not well explained.

All of the studies mentioned above have made important contributions. By using the Oxford system, this chapter aims to add one more clue to this discussion. The series

of comparative analyses in below highlights that parts of the metal assemblages discovered at these two sites shared some common supplies of copper and lead whereas the rest appear to have not. These discoveries could potentially help to advance our understanding of the metal movement between Zhengzhou and Panlongcheng, identify some locally produced objects and support the existence of local workshop(s).

4.4 Data Reprocessing

4.4.1 Summary of database

Several teams have worked on the different aspects of the metal assemblage at Panlongcheng. Their publications are summarized in Figure 146. In fact, three of them come from the same laboratory in the University of Science and Technology (Beijing), and they are primarily based on the same samples (Chen *et al*., 2001; Hao and Sun, 2001; Sun *et al*., 2001). Their works make significant contributions and offer an excellent opportunity to cross check data quality and correlate chemical analysis with lead isotopes. This chapter has generally relied on the chemical analysis in Chen *et al.* (2001) and lead isotopes in Sun *et al.* (2001). The Zhengzhou dataset is published in Tian (2013) with ICP-MS and ICP-OES.

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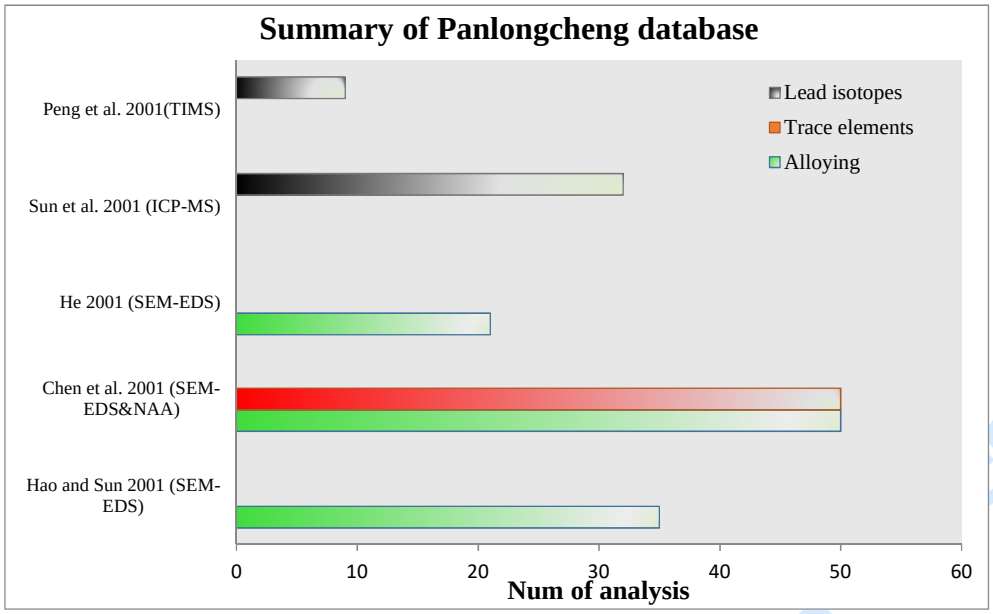

Figure 146 Summary of published databases for Panlongcheng metal assemblage (Data appendix)

Figure 147 presents the distribution of copper groups at both Zhengzhou and Panlongcheng. The right side of the figure shows a high percentage (peaks) of CG1 (clean copper) and CG (As-only) at both sites (see also the table below). However, the other four peaks, which do not match in intensity (CG's 4, 5, 9 and 11), suggest a considerable difference in the copper available at Zhengzhou and Panlongcheng. At Panlongcheng, 30% of copper-based objects are of either CG5 (Ni-only) or CG11 (As-Ni). Neither of these are strongly represented in Zhengzhou (<5%). However, another two different copper groups (CG4, Ag-only; CG9, As-Ag) are much more significant in Zhengzhou (36% in total) than at Panlongcheng (14% in total).

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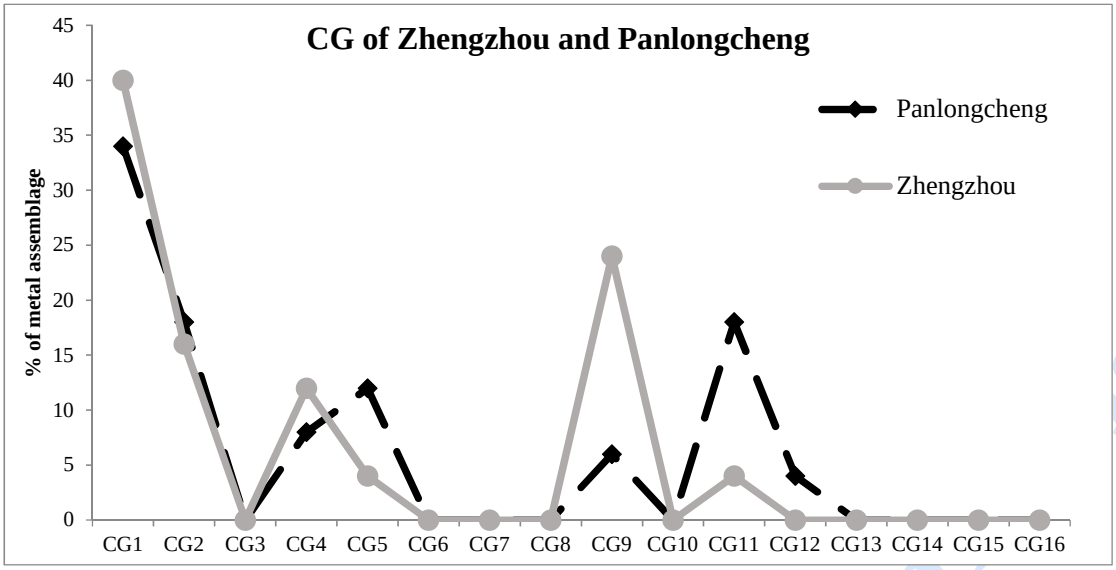

Site	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16	Data entry
Panlongcheng	34	18	0	8	12	0	0	0	6	0	18	4	0	0	0	0	50
Zhengzhou	40	16	0	12	4	0	0	0	24	0	4	0	0	0	0	0	25

Figure 147 Distribution of copper groups in Panlongcheng and Zhengzhou

Breaking down the copper groups into different object classes and vessel types reveals no significant patterns in favour of simplistic one-to-one relation (Figure 148). This might be attributed to insufficient number of analyses. Nevertheless, even vessels which has the largest number of data (n=43) contains a diversity of copper groups. No individual type of vessel (*ding, jia, gu, jue, zun*) is made from a single copper group. Certainly, more data is needed because when breaking the vessel into various types their numbers of data are also equally reduced. Based on the current database it seems to suggest that the underlying copper was not specific to different typologies at Panlongcheng.

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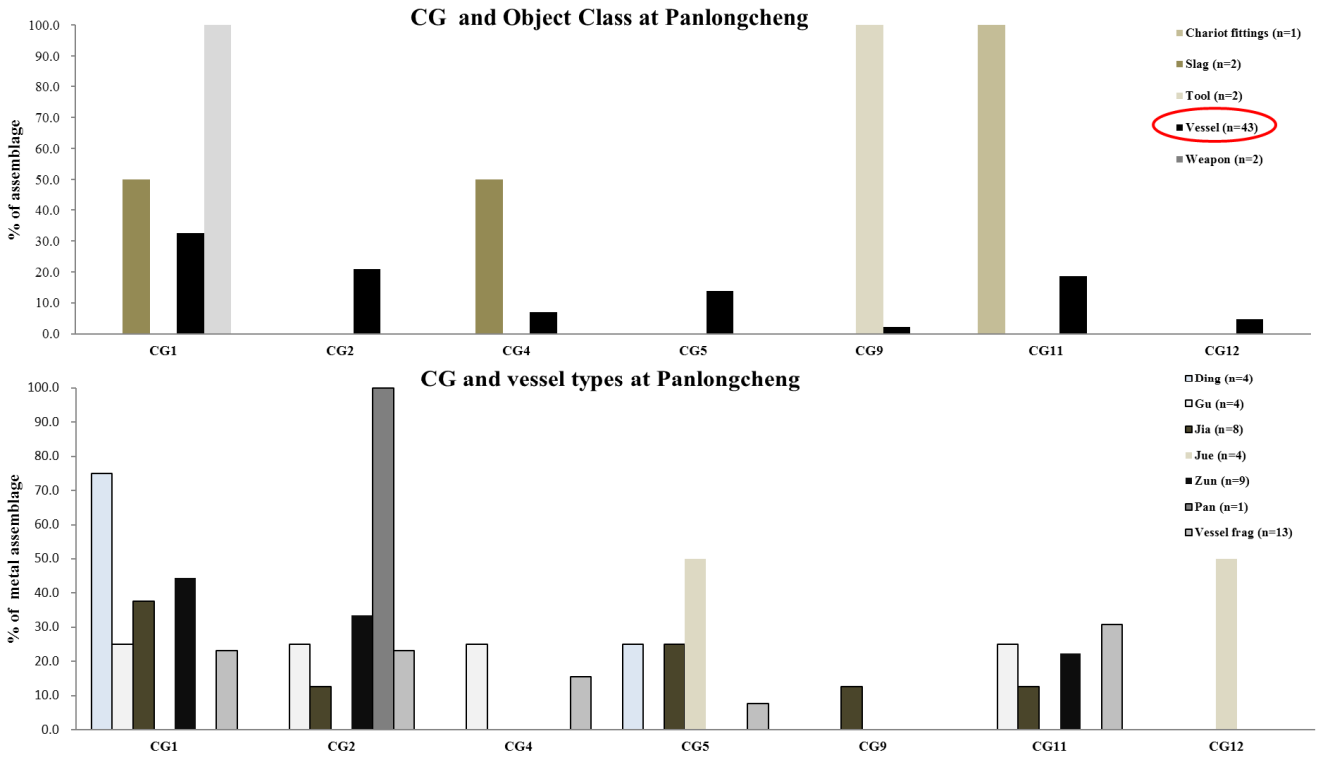

Figure 148 Copper groups and object typology at Panlongcheng

4.4.2 Alloying profile

Figure 149 and 150 illustrate the profiles of tin and lead in all of the analyzed vessels at Zhengzhou and Panlongcheng. Obviously they are all leaded bronzes. While the range of lead in vessels at both sites shows roughly the same pattern, the use of tin is quite different. Around 75% of vessels at Zhengzhou contain tin below 12% whereas it is over 12% in half of vessels at Panlongcheng. Moreover, nearly 25% of Panlongcheng vessels contain tin from 15% up to 20%. Such a large addition of tin is not found at Zhengzhou. This observation shall be further discussed along with other evidences in the later part of this chapter.

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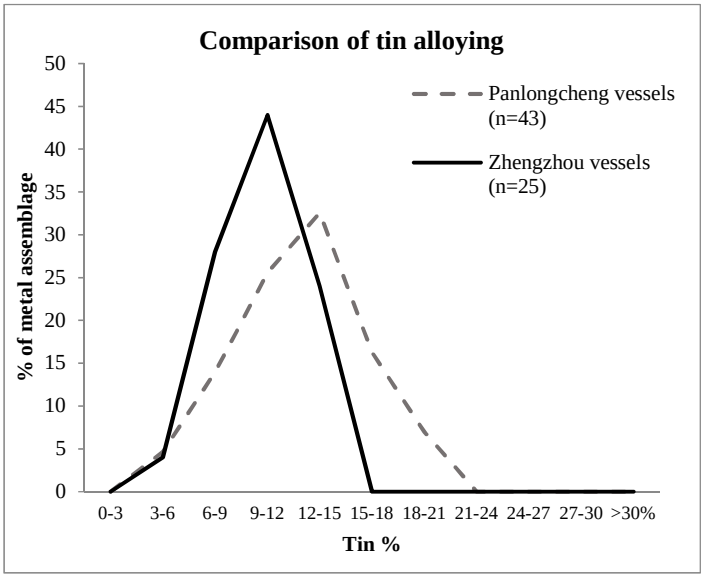

Figure 149 Tin distribution between Zhengzhou and Panlongcheng

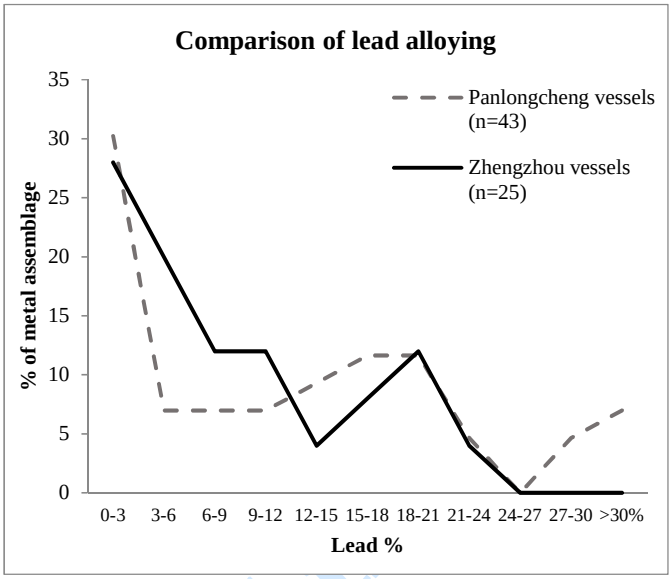

Figure 150 Lead distribution between Zhengzhou and Panlongcheng

4.4.3 New presentation of lead isotopes

A new way to present lead isotopic data has been devised by Pollard and Bray (2015; see also Chapter Two), which involves plotting one lead isotopic ratio against the inverse of the lead percentage. As explained in Chapter Two, this form of presentation offers two benefits. One is the introduction of the quantity of lead in the objects, which is essential in addressing the concerns that whether lead isotopes stand for copper sources or lead sources. Secondly, a mixing line could be observed if some objects are the result of mixing between different lead sources and the size of the data is big enough.

This new presentation has been employed to re-characterize the dataset for both Zhengzhou and Panlongcheng. The first impression of Figure 151 and 152, is the

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appearance of two important and well-known groups of lead isotopes (radiogenic and common lead). It is not surprising that the variation of radiogenic lead isotopes is remarkable and overlaps at both sites. As seen in Figure 151, a large number of data from Panlongcheng are distributed in the area $^{206}Pb/^{204}Pb$ ranging from 19 to 23 (Appendix VI for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$). This is also true for the dataset of Zhengzhou. What is more interesting is that, from this relatively limited number of data, we can still see a notable difference in lead isotopes. The variation of the common lead is much smaller than that of the radiogenic lead. Surprisingly, the common lead appears inconsistent between the two sites. Most of objects at Panlongcheng are over ~17 ($^{206}Pb/^{204}Pb$) but below ~17 at Zhengzhou (~16.5-15). This could mean than the source of common lead used by Zhengzhou and Panlongcheng was different (see below).

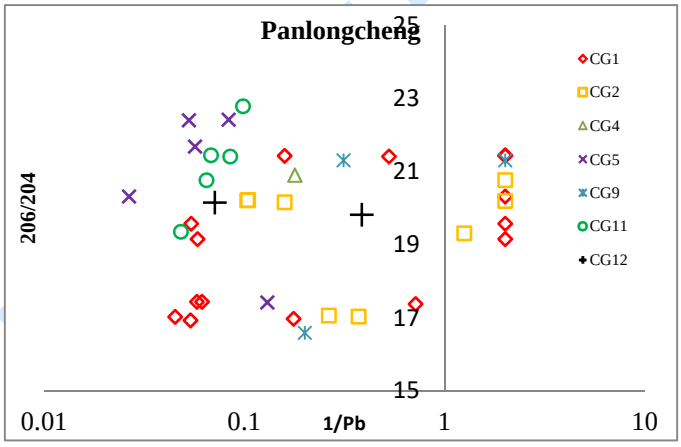

Figure 151 Plotting lead isotopes and percentages of Panlongcheng metals (Note: the exact number of the points may not be equal to that of Figure 147 as the lead isotopic data for some objects is not reported)

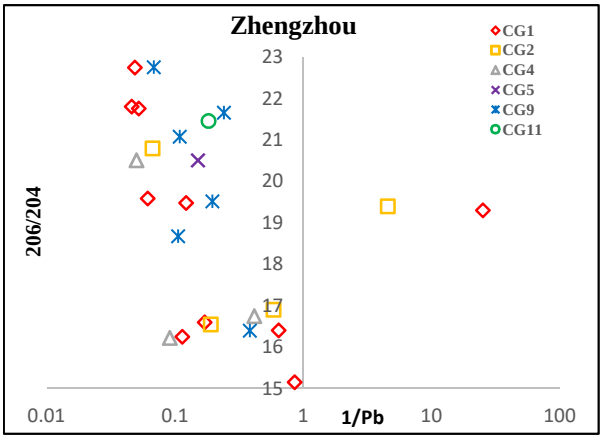

Figure 152 Plotting lead isotopes and percentages of Zhengzhou metals

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4.5 Discussion

4.5.1 Copper flow between Zhengzhou and Panlongcheng

Previously, owing to the lack of good-quality data for Zhengzhou and a method to characterize various trace elements in a straightforward manner, scholars have paid very little attention to a comparison of chemical compositions of the bronzes at the two sites, especially trace elements (Chen *et al*., 2001). It has been demonstrated now that both Panlongcheng and Zhengzhou share a large quantity of similar copper, with the majority as CG1 (clean copper) and CG2 (As-only). Given the huge number of literature arguing that Panlongcheng played a critical role in supplying metal resources from south to north, can we say that the similarity of chemical composition of the metal assemblages at Panlongcheng and Zhengzhou is a part of this archaeological story?

Although it is impossible to present an exclusive answer at the moment, it is necessary to point out that there was a persistent practice of using CGs1 and 2 (clean copper; As-only) *in the south*. Chapter Five demonstrates a prevalent use of CGs1 and 2 (clean copper; As-only) in the upper Yangzi River (Hanzhong and Sanxingdui). Analyzed southern bells in the Sackler collection also suggest that CGs1 and 2 (clean copper; As-only) came from the south during the Shang period (Chapter Seven, Rawson, pers. comm).

While this interpretation might be accompanied by a large degree of uncertainty,

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deriving from the ubiquitous distribution of these two copper groups across many sites in Bronze Age China (Pollard *et al*., in press-a and b), if we combine the argument of the exchange of metal and other resources between Zhengzhou and Panlongcheng that has been accepted by archaeologists for decades, we might be able to take a step further to say that at least some CGs 1 and 2 metal at Zhengzhou might originate from Panlongcheng. To test this issue however requires more chemical analyses and thorough characterization of local mines.

A related issue is when the copper mines along the Yangzi River started to be exploited? Local archaeologists strongly believed that the mining activities around this region can be as early as the Erligang period. However, they also admit that the modern mining industry has destroyed much of the evidence for ancient ones and the discovery of early pottery might not be able to solve this issue directly. Some more light can be brought from radiocarbon dating. The dates in Figure 153 are extracted from various publications (Excavation team of Gangxia ancient copper mines, 1988; Huangshi Museum, 1999; Liu and Lu, 1998; Xia and Yin, 1982). They are mostly made on wooden samples. By remodeling them in Oxcal, it shows that the starting point of mining along the Yangzi River can be traced to around 1500 BC, or the Erligang period. The primary concern with this result is the data quality. More high-quality data by AMS are necessary to test this result. However, compared with old scholarship which barely used software such as Oxcal to calibrate and model the radiocarbon dates, our result is still worth being presented. With calibration and

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modelling using Oxcal, it actually gives more confidence to local archaeologists that radiocarbon dating can help them resolve this issue.

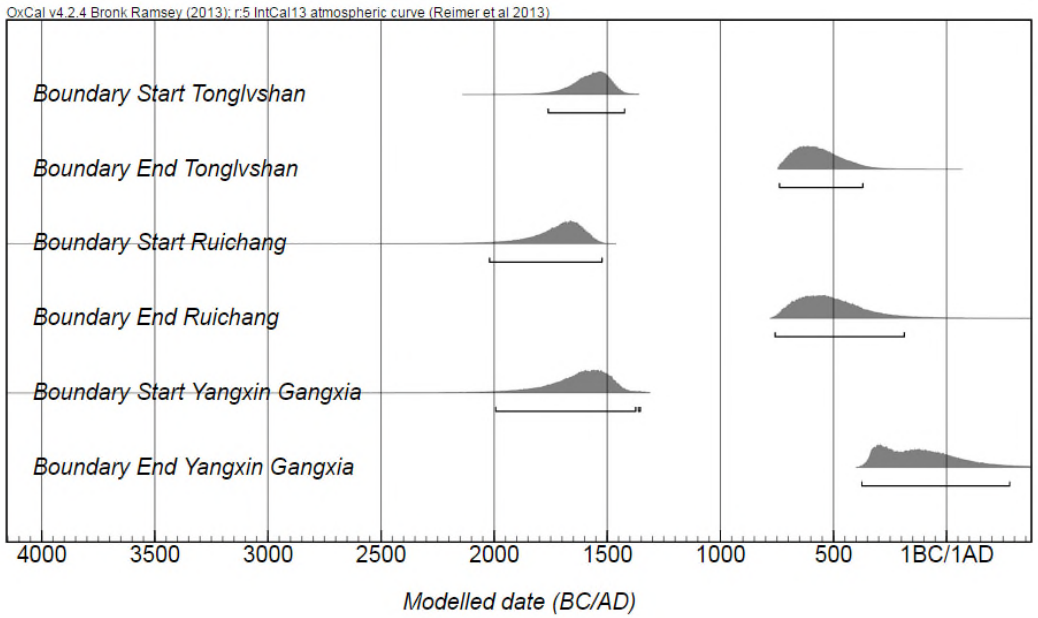

Figure 153 Radiocarbon dates for mines along the Yangzi River, remodeled by Oxcal (raw dates are in Appendix VII)

Apart from the mines in south, the other critical candidate which could produce CGs1 and 2 (clean copper; As-only) could be the Zhongtiao Mountains. However, the major obstacle is again attributed to the less sufficient amount of high-quality data in the publications (Cui *et al*., 2009, 2012; Liang *et al*., 2009). If indeed Zhongtiao accounts for the supply of CGs1 and 2 (clean copper; As-only), does it suggest an opposite movement of this type of metal from Zhengzhou to Panlongcheng?

Zhongtiao Mountains was almost certainly the key metal source to the Erlitou site (Liu and Chen, 2009: 37-44). A few compositional datasets have been published for

the metal objects at Erlitou (Zhao *et al.*, 2006; IA CASS, 2014; Jin, 2000; Liang, 2004). The distribution of copper groups from the dataset in Jin (2008) suggests that CGs1 and 2 (clean copper; As-only) are actually of very *little* importance at Erlitou. One may question this because Jin's data only contains thirteen objects. The next two larger but incomplete sets of data, IA CASS (2014) and Liang (2004), show that the *theoretical* maximum proportion of CGs1 and 2 (clean copper; As-only) are 30.8% and 39.9%, respectively (Table 10). (The word theoretical is used here because the concentration of arsenic is not completely reported in IA CASS (2014) and Sb is unavailable in Liang's measurements. So one has to guess their presence/absence.) This means that *at least* over 60% of the objects employed at Erlitou was *not* CGs1 and 2 (clean copper; As-only). It is indeed difficult to calculate that to what extent it is justified to characterize the copper supply from Zhongtiao by using the chemistry of objects at Erlitou, particularly considering the complicated geology within Zhongtiao and the time discrepancy between Erlitou and Zhengzhou (Jiang *et al.*, 2014). What can be argued is that the existing chemical analyses provide little evidence that the CGs1 and 2 (clean copper; As-only) prevailing in both Zhengzhou and Panlongcheng can be pragmatically originated to Zhongtiao.

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Table 10 Possible distributions of copper groups at Erlitou

% of Metal Assemblage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Data entry	Instrument
Jin (2000)	0.0	7.7	0.0	30.8	0.0	0.0	0.0	0.0	23.1	0.0	0.0	30.8	0.0	7.7	0.0	0.0	13	ICP-AES
IA CASS (2014) Assume Yes As	0.0	30.8	0.0	0.0	0.0	0.0	0.0	0.0	42.3	0.0	15.4	0.0	0.0	0.0	3.8	7.7	26	ICP-MS
IA CASS (2014) Assume No As	23.1	7.7	0.0	38.5	11.5	0.0	0.0	0.0	3.8	0.0	3.8	0.0	7.7	0.0	3.8	0.0	26	ICP-MS
Liang (2004) Assume no Sb	11.1	27.8	0.0	33.3	0.0	0.0	0.0	0.0	27.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18	AAS
Liang (2004) Assume Yes Sb	0.0	0.0	11.1	0.0	0.0	27.8	33.3	0.0	0.0	0.0	0.0	27.8	0.0	0.0	0.0	0.0	18	AAS

An important feature in the Panlongcheng trace elemental patterning is the presence of nickel. In comparison with those at Zhengzhou, around 30% of objects found at Panlongcheng contain nickel more than 0.1%, after removing tin and lead (Figure 154), which has not been noted before. These nickel-bearing objects are exceptionally interesting because, from the Erlitou period to Anyang, nickel-bearing coppers were generally absent from most of the sites of the Shang and Western Zhou periods. Out of the 79 objects of which nickel has been analyzed at Erlitou and Zhengzhou (Zhao *et al*., 2006; IA CASS, 2014; Jin, 2000), only five contain nickel greater than 0.1%. By contrast, metals at Panlongcheng and Hanzhong, the two sites which are linked by the Han River, show a clear proportion of copper with the presence of nickel (Figure 155; for nickel-bearing objects at Hanzhong see Chapter Five). In the later Anyang period, nickel was almost completely absent in all of the analyses known to us. It would be so interesting to exam the actual objects with nickel but unfortunately the official report merely published images for two of these objects (Appendix X).

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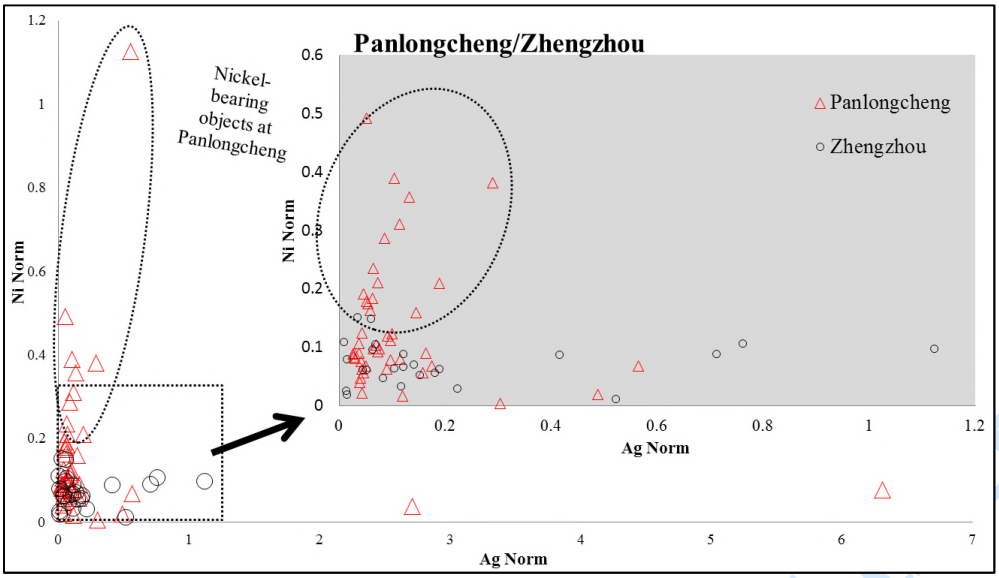

Figure 154 Nickel-bearing objects at Panlongcheng, with reference to those at Zhengzhou

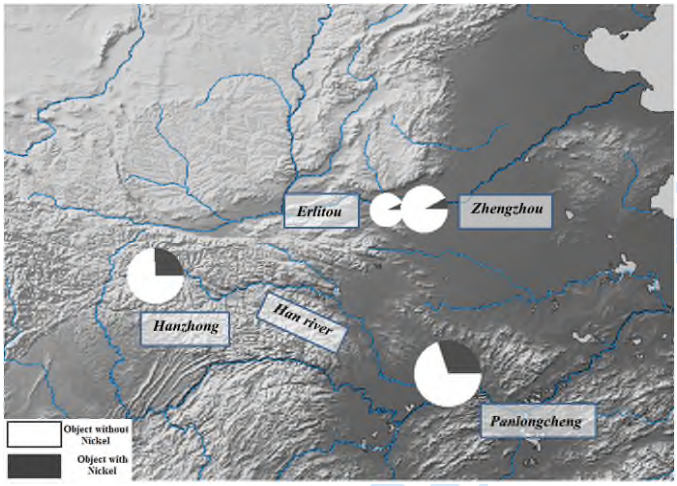

Figure 155 Distribution of nickel-bearing objects in pre-Anyang period

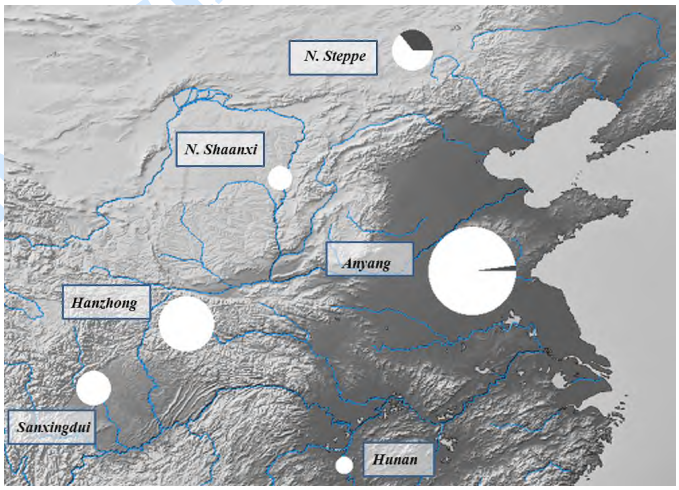

Figure 156 Distribution of nickel-bearing objects in Anyang period

Most nickel or copper-nickel deposits around the world are at the base of mafic and ultramafic bodies and classified as mantle-derived. Provided the silicate magma derived from the mantle was enriched in nickel/copper and had an efficient transportation to the crust, and that nickel was not significantly reduced in this process,

it can be saturated and deposited as Cu-Ni-S when sulfur is added (Barnes and Lightfoot, 2005). While modern China has the largest annual production of nickel across the world, the distribution of important nickel deposits shows that they are largely absent from the Central Plains area and the Yangzi River valley (Lightfoot and Evans-Lamswood, 2015). Some sporadic nickel deposits around the Central Plains have been mentioned in the literatures (*e.g.* Sun *et al*., 2014). However, they are either too deep for ancient mining (several hundred meters deep) or iron-nickel deposits (*e.g.* Wang *et al*., 2006). Interestingly, a few nickel deposits can be found in the Qinling mountains (Chen *et al*., 2009).

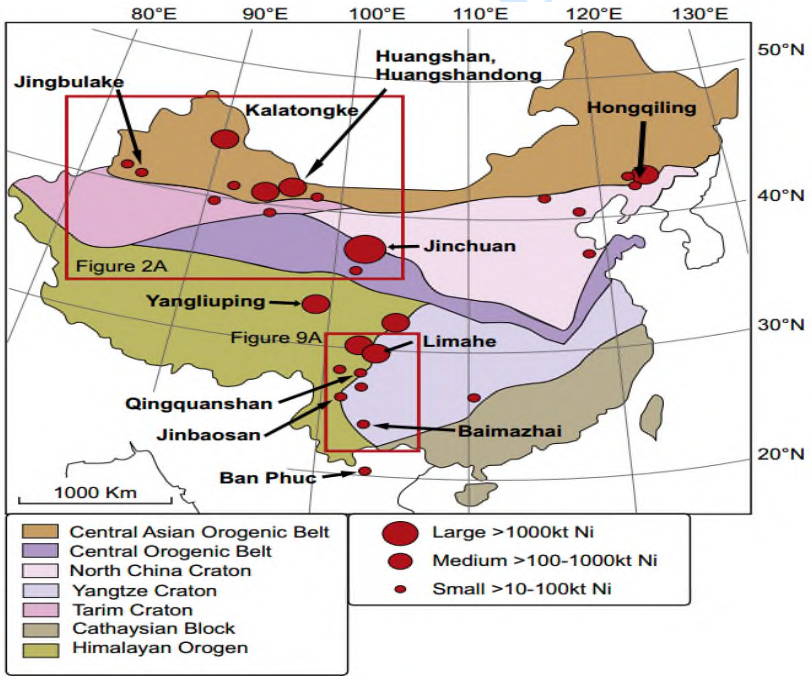

Figure 157 Distribution of nickel deposits in China (After Lightfoot and Evans-Lamswood, 2015)

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Therefore, the modern geological map and archaeological data offers a significant match. Nickel-bearing objects are not at all common from the major sites of the Erlitou, Erligang and Anyang periods, which is rather consistent with the rarity of nickel deposits in the Central Plains and the Yangzi River valley, as shown by the geological data (Figure 157). The rarity of nickel-bearing copper in both archaeological and geological evidence suggests that this sort of copper was produced by miners within some very small copper deposits and supplied to mainly Panlongcheng but rarely Zhengzhou.

There are two uncertainties which could affect these observations. First, only 25 analyses with trace elements and lead isotopes are available for metal objects at Zhengzhou. Many more analyses are required in the near future to test these observations. Related to the first issue, the second one is that 8% of the metal assemblage at Zhengzhou contains nickel over 0.1%, compared with 30% at Panlongcheng. The Chi-squared test is performed and it shows that this difference is statistically significant but we still need more data from Zhengzhou.

One may question the quality of data on these trace elements. In Chapter Three, we have carefully compared the analysis of alloying elements performed by different teams. So far, only one set of trace elements has been published for each of the above sites, therefore, there is no way to do a similar cross-check assessment. However,

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analytical instruments could offer a quite good protection. Both ICP-MS (Tian, 2013) and NAA (Chen *et al.*, 2001) are extremely sensitive to nickel, silver and other trace elements. Although the initial analytical report does not include the exact minimum detection limit of each element, it is probably well below 0.1%.

To summarize, the flow of copper between Zhengzhou and Panlongcheng may be more complicated than previously assumed. If we accept the widely agreed argument that Panlongcheng was set up by the powers at Zhengzhou to secure the metal supply from the Yangzi River for the north, it is possible to suggest that some CG1 (clean) and CG2 (As-only) flowed from Panlongcheng to Zhengzhou. However, a comparative analysis also indicates a substantial difference in the coppers at the two sites. It seems likely that nickel-bearing objects were possibly made with copper available only to Panlongcheng and not at Zhengzhou.

4.5.2 Comparison of the profile of tin

Comparing tin profiles between Zhengzhou and Panlongcheng can offer some further inspiration. The assumption is that the people who have a relatively more convenient access to tin (not necessarily from tin mines) are able to put more tin into their objects. The likeliness of producing high-tin objects by these people would be greater than those who do not have a stable tin supply. This argument is not necessarily correct, but stands as *a hypothesis* to be tested. Profile analysis of tin concentration of Zhengzhou and Panlongcheng above shows a high-low contrast (Figure 149). This

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difference becomes even clearer in Table 11. On the one hand, objects at Panlongcheng tend to show a higher proportion of tin in general. On the other, the objects contain over 15% tin, which is close to the highest levels of tin at the two sites, are exclusively to be found at Panlongcheng. This could imply that Panlongcheng may have had a more abundant supply of tin than Zhengzhou.

Table 11 Comparison of tin percentages in objects at Zhengzhou and Panlongcheng

Tin%	6-9	9-12	12-15	15-18
% of assemblage at Zhengzhou	28.0	44.0	24.0	0.0
% of assemblage at Panlongcheng	14.0	25.6	32.5	16.3

Furthermore, the Kolmogorov-Smirnov test (K-S test) is performed to double check this difference. K-S test is non-parametric and does not have to assume the two targeted datasets should follow a normal distribution. A detailed description of K-S test can be found in Pollard *et al*. (submitted). In this case, the observed maximum difference of the tin concentrations of objects at Panlongcheng and Zhengzhou is 0.42, greater than the critical value 0.34 (95% confidence). Therefore, it can be concluded that the possibility that objects at these two sites contain the same percentages of tin is highly unlikely (Figure 158).

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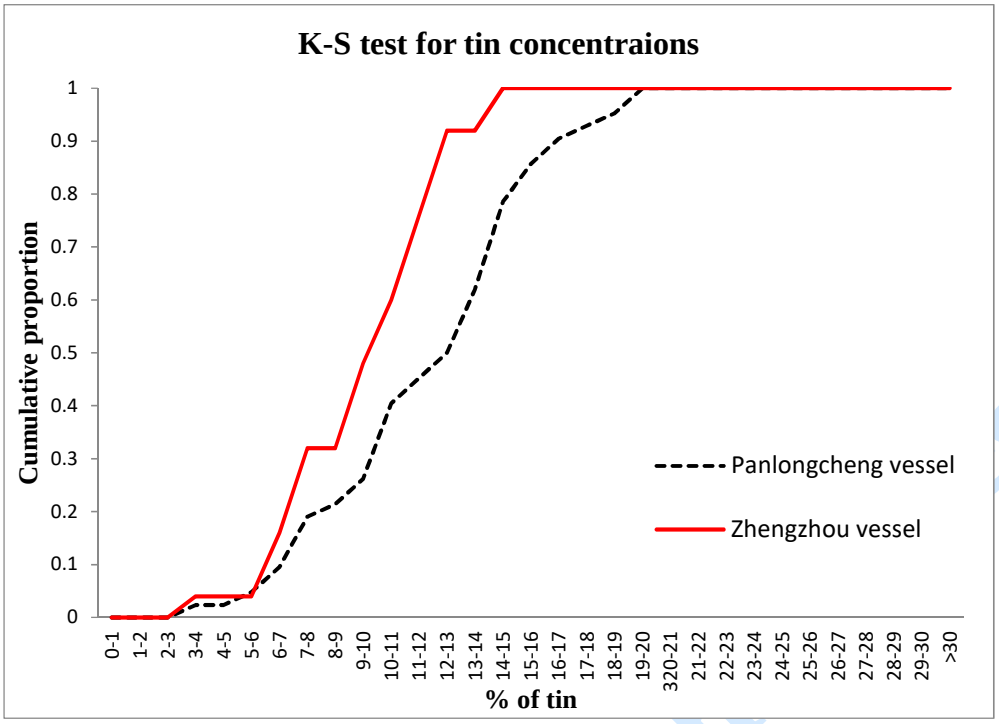

Figure 158 K-S test for tin distributions at Zhengzhou and Panlongcheng

This difference reflected by the use of tin can also fit into the overall geological distribution of tin mines in China. Modern surveys show that the tin mines are mostly distributed in the southern part of China (Figure 159 and Table 12). Those concerning the Shang period include Anhui, Hunan and Jiangxi. To our knowledge, the tin mine at De'an of Jiangxi might be the closest. In a summary, both chemical analysis and geological survey suggest a southern supply of tin during the Erligang period.

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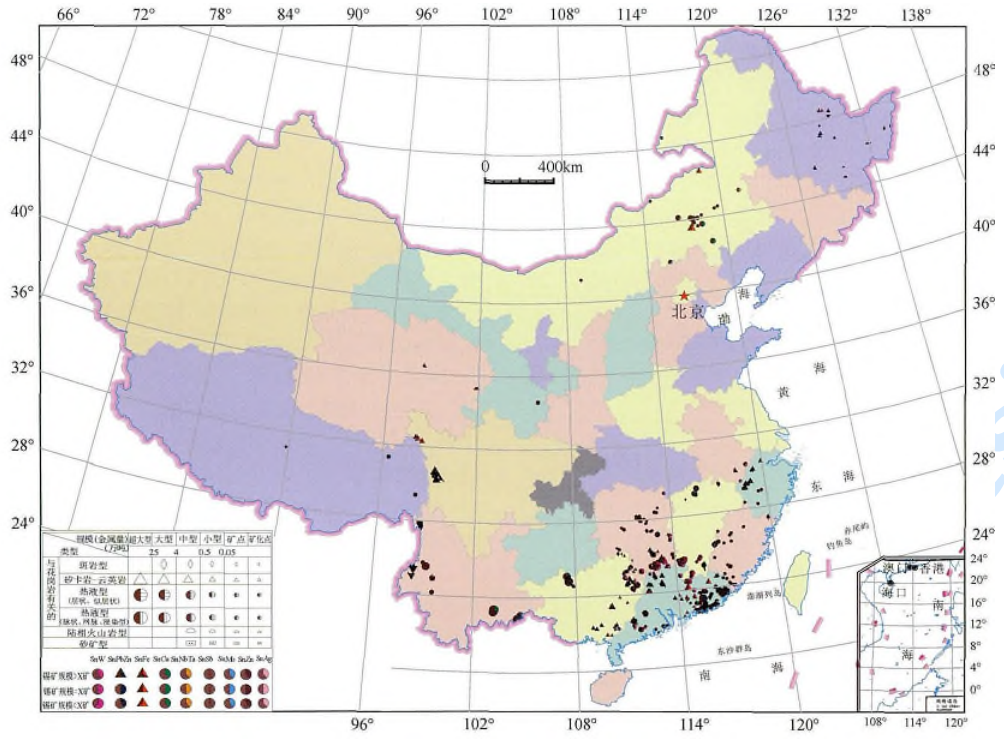

Figure 159 Tin mines from modern geological survey (after Chen *et al*., 2015)

Table 12 Information of tin distribution in modern China (Data from Chen *et al*., 2015)

Modern Province	Scale of mines (10000t)	Number of tin mines	Supper	Large	Middle	Small	Pits
Inner Mongolia	79.19	23		1	5	5	12
Heilongjiang	0.18	15				5	10
Anhui	0.02	4				1	3
Fujian	1.49	32			2	6	24
Jiangxi	24.92	76		2	8	19	47
Zhejiang	1	47				28	19
Hunan	92.29	124	1	4	18	14	87
Guangdong	57.82	183		4	21	46	112
Guangxi	88.8	201	1	6	24	32	138
Sichuan	3.4	50		3	7	11	29
Yunnan	128.89	52		11	7	26	8
Tibet	0.51	29				5	24
Gansu	0.72	12			1	3	8
Qinghai	3.98	22		1	3	4	14
Xinjiang	0.06	23			1	6	16
Total	483.27	893	2	30	92	211	558

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4.5.3 Combining trace elements and lead isotopes: lead sources and potential evidence of realloying

One line can be observed at Zhengzhou, particularly for CG1 (clean copper) and CG9 (As-Ag). Compared to Figure 151 and 152, a more obvious plotting of this line is in Figure 160 and 161 where only CGs1 and 9 (clean copper; As-Ag) are kept and others are removed to reduce the noice. The objects with common lead isotopes ($^{206}Pb/^{204}Pb$~16.5) appear to contain much lower amounts of lead (less than 5~10%) than those with radiogenic lead isotopes ($^{206}Pb/^{204}Pb$~19-23, most containing over 10% lead). It is almost certain that people in antiquity had no way to tell the isotopic difference. Then the question is why lead with different isotopic ratios was used differently? One possible answer is that the positive linear regression between lead percentages and lead isotopic values suggests a realloying process. In this process objects with a relatively low amount of lead with common lead isotopes were realloyed by adding more lead (adding another 5-10%) with radiogenic lead. In other words, this could imply that lead with different lead isotopes at Zhengzhou were sometimes added into copper in different stages. In other words, copper and lead at Zhengzhou were used differently. Interestingly, although 50 objects recovered from Panlongcheng have been analyzed for lead isotopes, we have not found similar structures within these data.

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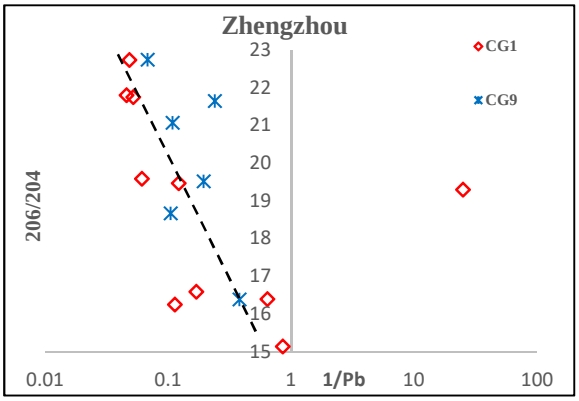

Figure 160 Plotting lead isotopes and 1/Pb of CGs1 and 9 (clean copper; As-Ag) in Zhengzhou

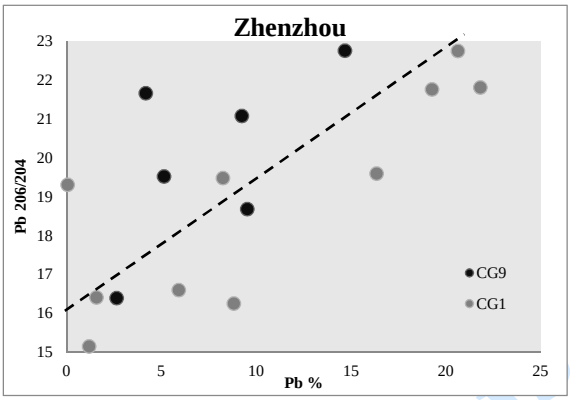

Figure 161 Plotting lead isotopes and percentages of CGs1 and 9 (clean copper; As-Ag) in Zhengzhou (see Appendix VIII for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$)

Both sites were heavily dependent on radiogenic lead, though it appears more dominant at Panlongcheng than at Zhengzhou (Peng *et al*., 2001; Sun *et al*., 2001). By considering the % Pb in the objects, it is most likely that the lead isotopes are related to the lead not the copper. Unfortunately, not all published lead isotopic measurements are reported with trace elements or alloy compositions of the vessels. As a different type of presentation, Figure 162 covers all of published lead isotopic data (with and without lead percentages) and only focuses on the internal variation of lead isotopes (Jin *et al*., accepted), including not only Zhengzhou/Panlongcheng but also Erlitou as a reference. The order of the data within each site is essentially arbitrary. If we have a careful look at the common lead isotopic region, a clear difference can be observed along the line of $^{206}Pb/^{204}Pb$ ~16.5, which is undoubtedly present in Zhengzhou but not at Panlongcheng. The reason that Erlitou is included is to show that the use of $^{206}Pb/^{204}Pb$ ~16.5, common lead, at Zhengzhou can be traced also to the earlier period. Therefore, it is possible that this sort of lead seen at Zhengzhou was already employed

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at Erlitou. With the aid of lead isotopes, we can see a continuous tradition of this lead from Erlitou to Zhengzhou. In contrast, the line of $^{206}Pb/^{204}Pb$ ~17.5, also common lead, is conspicuously absent in Zhengzhou and very rare at Erlitou, but strongly present at Panlongcheng. These similarities and variations have been summarized in Table 13. Here we can draw the conclusion that the bronze casters at Zhengzhou and Panlongcheng had access to rather different sources of common lead. Meanwhile, compared to the conventional way of presenting lead isotopes (Figure 163), the new graphic method sometimes helps to reduce the issue of overlapping and offers an easier way to capture the differences in the datasets.

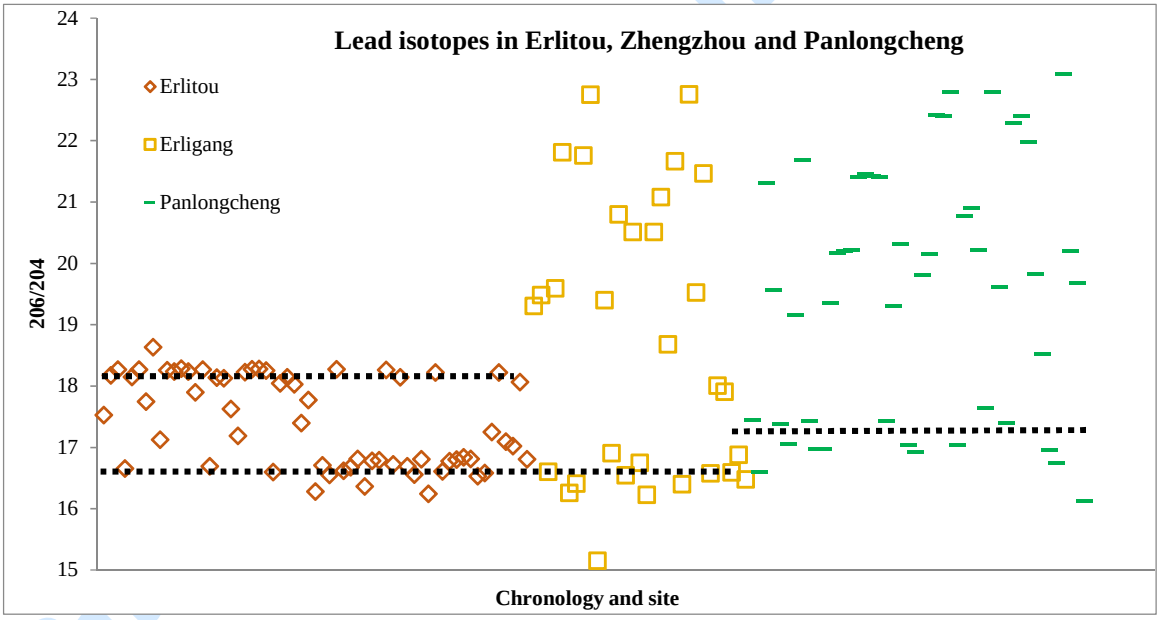

Figure 162 Lead isotopes distribution in Erlitou, Zhengzhou and Panlongcheng (Jin *et al*. accepted; Appendix IX for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

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Table 13 Presence/absence of various types of lead isotope signals

206/204	Erlitou	Erligang	Panlongcheng
(a) 16.5	x	x	
(b) 17.5	?		x
(c) 18.25	x	?	?
'Radiogenic'		x	x

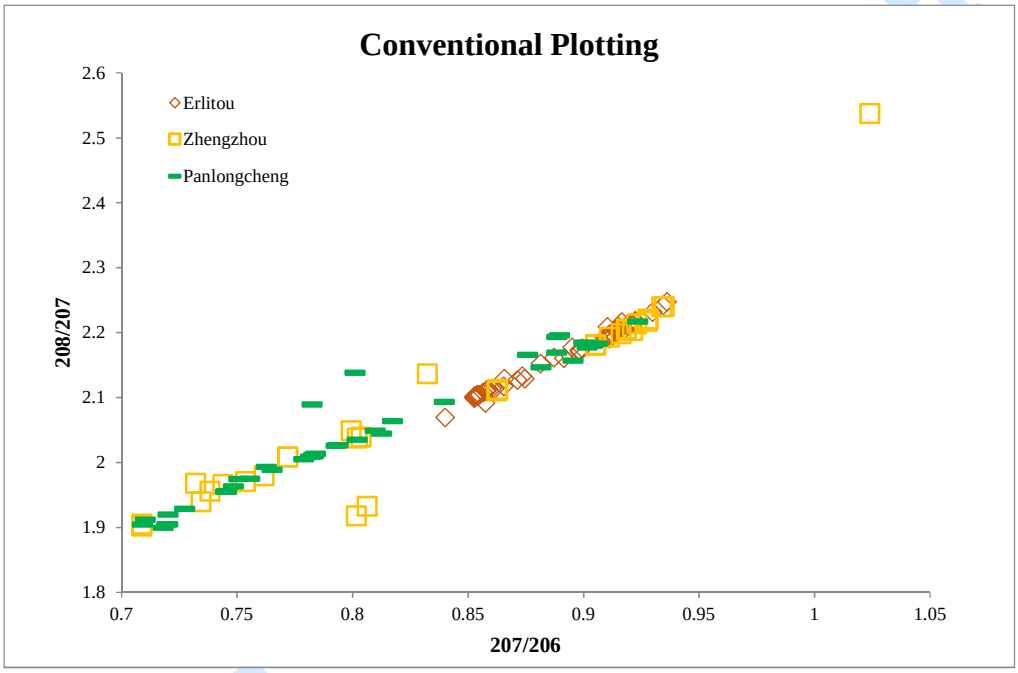

Figure 163 Conventional plotting of lead isotopes

4.5.4 Local production versus importation

Revealing the fact that copper and lead used at Zhengzhou and Panlongcheng were not the same helps to extend the discussion into the issue of local/non-local production. The question of whether the bronze objects at Panlongcheng, particularly the ritual vessels, were made locally or imported from Zhengzhou, has puzzled

archaeologists for many years. Whilst little archaeological data suggests any trace of local workshops of metalworking at Panlongcheng, Zhang (2014: 61-63) argued that:

"The bronzes themselves offer the best evidence of whether or not there were bronze foundries at Panlongcheng. One convincing piece of evidence comes from repairs…What is interesting about these repairs is that while some of them appear to be repairs of casting defects—repairs made immediately after casting – others appear to be repairs of damage that occurred during use… the casting technique used to make repairs, particularly repairs as substantial as a new leg, is not all that different from the casting technique used to make the vessel in the first place. Unless we are willing to believe that ding and jia were sent back to Zhengzhou every time they needed repairs, someone at Panlongcheng must have been able to cast bronze."

Based on the comparative work on metal chemistry discussed above, it is probable to say that some, but not all, of the copper and lead used at Panlongcheng, was different from that available at Zhengzhou. This may add one extra line of evidence to support the argument of local metal production at Panlongcheng. Unless Zhengzhou particularly produced some objects out of selected raw materials (*i.e.* containing nickel) and shipped them to Panlongcheng, which is extremely unlikely, the most reasonable scenario would be that Panlongcheng kept some local raw metal to produce objects for themselves.

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These tangible results on the issue of local production of metal is one pale reflection which be glimpsed from the profuse archaeological evidence. Yet over, other evidences such as pottery present to us a much diverse depiction (Figure 139). Judging from the variety of material cultures along the middle Yangzi River valley (Wang, 2014; Li, 2016b), a reasonable supposition is that there should be multiple groups of people with varying degree of inter-tribal rivalries. The complex landscape with thousand mountains within which plentiful rivers and streams are flowing across is also indicative of infeasibility of a direct control.

Therefore, it is imperative to ask more questions on the dynamics between Panlongcheng and Zhengzhou/other local sites along the Yangzi River. A stimulating parallel can be drawn from the model of Roman Britain (Pollard, pers. comm). Instead of a purely dependence on military conquest, Roman patronage and military protection exerted fundamental impacts on the local inter-tribal rivalries and the network between Britain and the continent. The exotic Roman goods can be used as some diplomatic gifts which enabled local leaders in Britain to establish enhance the sociopolitical bonds with their clients. In return, Romans could depose some these leaders simply by blocking these diplomatic gifts. Military protection offered by Roman soldiers to some Britain leaders was often used in exchange of goods and exotics (Cunliffe, 2014: 9). Although it is hard to say with any degree of precision that how this Roman-Britain model can be applied to the case of Zhengzhou and Panlongcheng, it is still useful to bear this in mind for the future study, particularly

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when it comes to the question of identity.

5. Summary

A range of archaeological characteristics suggest a close contact between Zhengzhou and Panlongcheng. This offers a crucial context within which to interpret the scientific analyses. A few preliminary conclusions can be drawn from the comparative studies based on the existing database and the Oxford system.

1. Comparison of copper groups provides a more subtle picture on the movement of copper between Zhengzhou and Panlongcheng than was previously recognized. A similarity in metal chemistry is to be expected in the light of archaeological observations and can be interpreted by the sharing of the same types of metal (CGs1 and 2, clean copper and As-only). Moreover, this chapter proposes one extra line of evidence that Zhengzhou and Panlongcheng probably had their own access to some different types of metal (copper and lead) which were not shared. These objects involve particularly nickel-bearing copper at Panlongcheng. Lead isotopes also show similarities as well as differences of objects between Panlongcheng and Zhengzhou, indicating the same story for the supply of lead. These differences need to be emphasized because some objects discovered at Panlongcheng are very likely to be local production. More analyses with not only alloying but also trace element data are necessary in the future.

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2. While it has been known that the alloying technology at both Zhengzhou and Panlongcheng is the same, however, it appears the concentration of tin in those objects from Panlongcheng is clearly higher than those of Zhengzhou. This difference might suggest that Panlongcheng was closer to the tin sources than Zhengzhou. A further deduction based on this would be that another impetus, probably more important, that drove Erligang people into the south Yangzi region was tin.

3. Combining lead concentration and its isotopic ratios enables us to visualize the process of realloying with lead at Zhengzhou. The clear mixing line suggests that the two sorts of lead at Zhengzhou (common and radiogenic) were used differently. This is not observable in the dataset of Panlongcheng, which actually has more measurements.

Although not completely conclusive, the results of a series of comparative works provide new information and possibilities on the interaction between Zhengzhou and Panlongcheng. To further test these preliminary results, a more holistic view is needed, including many more sets of basic data, not only chemical/isotopic compositions and the typology of metal objects, but, more vitally, radiocarbon dates and isotopic data of human skeletons, such as strontium. These data may enable us to link real objects to the exact persons (his/her burial time, origins and identities). Meanwhile, apart from Zhengzhou and Panlongcheng, more sites have to be covered, such as Yuanqu,

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Dongxiafeng, Jingnansi or Tonggushan, to achieve a more comprehensive picture of the relationship between north and south in the Erligang period.

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Chapter Five Characterization of metal chemistry in southwest China

5.1 Introduction

The focus of this chapter shifts from the middle Yangzi River valley to its upper area in southwestern China (Figure 164). Two important metal assemblages have been discovered at Sanxingdui and Hanzhong. Remains of city walls, widespread fine pottery, jades and settlements indicate that Sanxingdui in the Sichuan Basin was a significant centre from the early to mid-second millennium BC (Liu and Chen, 2012: 246). But the material in question dates to the late second and early first millennium and has been recovered from two sacrificial pits (Bagley, 1988, 1999; Bagley, 2001; Chen, 1997; Rawson, 1996; Sichuan Institute of Archaeology, 1999; Sun, 2013; Falkenhausen, 2002a; Xu, 2003a). The same sorts of deposition continued to the end of the second millennium at the perhaps later site of Jinsha at Chengdu (Chengdu Institute of Archaeology, 2002). A related practice of deposition, this time almost entirely of bronzes, has come to light in the Hanzhong region (Cao, 2006; Chen, 2009; Chen *et al*., 2016; Chen *et al*., 2009; Mei *et al*., 2009; Rawson, 2011; Falkenhausen, 2011; Zhao, 2006). Both the form of deposition and the categories of bronzes interred

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in these two regions show that the ritual practices and beliefs of the inhabitants differed remarkably from those of the Central Plains (Bagley, 1990; Rawson, 1996: 70-74).

By applying the Oxford system to the existing chemical analyses, it is possible to demonstrate that the copper used at both Sanxingdui and Hanzhong during the Anyang period was quite similar. It however contrasts significantly with the great diversity of copper types at Anyang. The same can be said for lead as well. I argue that these discoveries based on the application of the Oxford system contain important implications for the issue of the source of metal, importation versus local production and understanding the metal supply network.

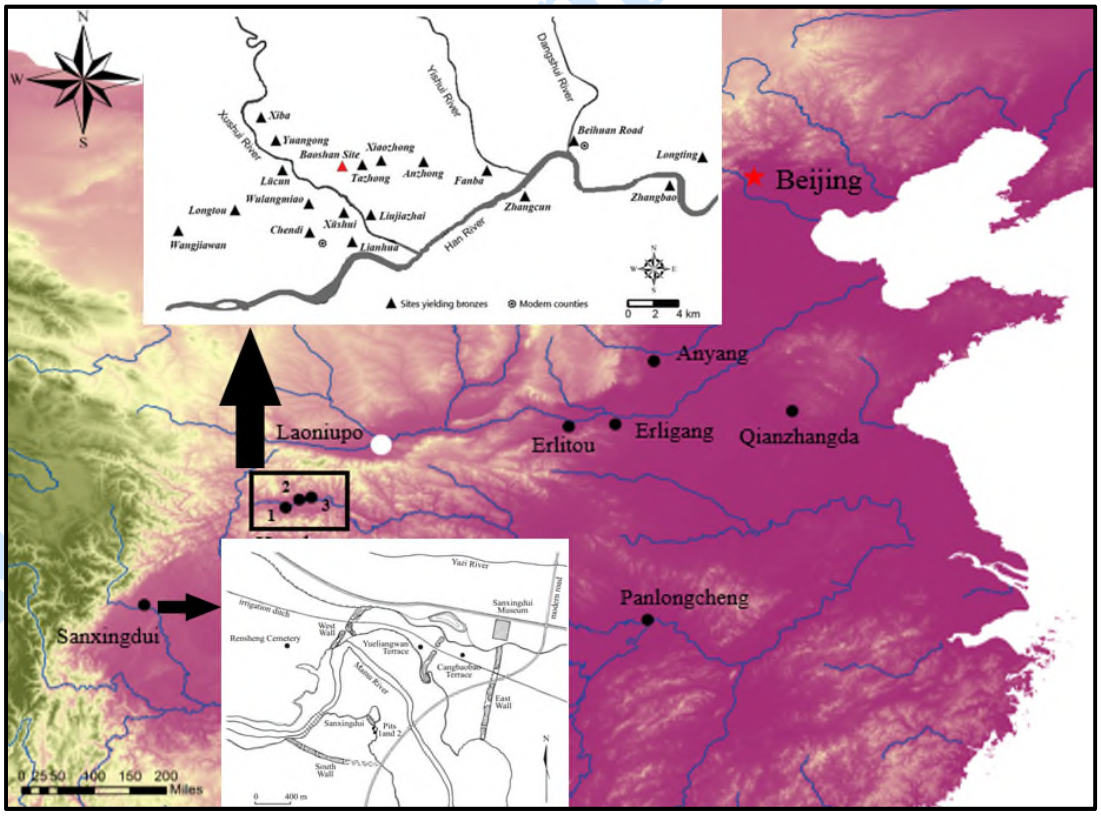

Figure 164 Location of Hanzhong and Sanxingdui (insert map are caches of Hanzhong, after Chen *et al.*, 2016, and the site of Sanxingdui, after Xu, 2001)

5.2 Sanxingdui

5.2.1 A review of the Sanxingdui metal assemblage

While a brief introduction of Sanxingdui has been presented in Chapter One, its materials and significance have to be discussed from a wider and deeper perspective. As noted by Bagley (2001: 12), "in the summer of 1986 *the archaeology of ancient China was turned upside down* by the discovery of an ancient city in the isolated western province of Sichuan".

Before the discovery of the two sacrificial pits, there was a long history of archaeological research in the Sichuan Basin. However, this region did not attract such special attention until the two sacrificial pits came to light. These two pits were found within the remains of a large walled area. The total number of objects found in the first pit (Pit I) is over four hundred, including bronzes, gold, jades, pottery, turquoise and elephant tusks. The second pit (Pit II) is even more remarkable. There archaeologists unearthed around 1300 objects (Figure 165).

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Figure 165 The excavation of Pit II, after Bagley (1990)

The introduction of this chapter and Chapter One can only present some selected objects from the two pits to facilitate the discussion below. While the archeological report contains probably the full list of objects and information (Sichuan Institute of Archaeology, 1999), three catalogues with much better images are strongly recommended (Bagley, 2001; Rawson, 1996; Sichuan Institute of Archaeology *et al.*, 2009).

The largest piece at Sanxingdui is from Pit II, drastically greater than any life-size human figure (Figure 166). It is 260.8 cm high and contains around 180 kg of metal (Sichuan Institute of Archaeology, 1999: 162). The combination of the unique design

Puiliang Liu unpis

and the massive scale certainly depicts a striking power and austerity to the audience. The entire figure is embodied by simple but strong outlines. His face is dominated by slanting eyes, broad nose and wide mouth with thin lips. He also has an immense pair of hands, coiled in both ends of the uplifted arms, presumably holding something. These greatly exaggerated and masculine features fit well into the overall image. By contrast, the patterns on his clothes are carved with extremely complicated and fine details. The figure is supported by a base into an even higher position. The base consists of four elephants, whose long noses are made into four legs and ears supporting the figure. For such a large piece to be made by the piece-mould technology, craftsmen had to cast it in sections and assemble it all together at the end (Xu, 2001). Originally, the figure was found in two parts broken at the waist. It is now repaired and displayed in the Sanxingdui museum.



Figure 166 Standing figure at Sanxingdui (after Rawson, 1996: 61-62)

Bagley (1988, 1990 a and b) suggested that the standing figure might not be an isolated piece. Excavation of fifty or so bronze human-like heads from the two pits could belong to other figures. Their bodies may have been in other sorts of materials and no longer preserved. Some of these human heads are also covered by golden masks on their face (Figure 167).

The category of masks is equally startling and several of them appear even grotesque. The one in the bottom left of Figure 167 is around 0.66 m in height and 1.38 m in width. Its most impressive feature is the pair of protruding pupils. The eyebrows, nose and mouth are surprisingly wide. The upper parts of its ears are shaped outwards and look like the wings of birds. Similar features can also be seen in the one on the bottom right of Figure 167, with a major difference shown by the upright projection rising from the nose and becoming coiled at the top. The sides of these masks all have holes, which might be designed to attach to architectural features as ornaments or some other function. There are also some small masks attached to animal bodies.

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Figure 167 Bronze human-like heads and masks at Sanxingdui,
the bottom two with protruding eyes are from Xu (2001: 110-111)

Pit II also yielded the two huge bronze trees. One is *ca.* 3.96 m high and the other is *ca.* 1.93 m (Sichuan Institute of Archaeology, 1999: 219). These two trees might be the prototype of those from much later periods, such as Eastern Zhou or Han dynasties. However, the bronze trees at Sanxingdui are decorated with elaborate birds and dragons. They were also probably made in sections and put together (Xu, 2001).

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Figure 168 One bronze tree from the Pit I, picture on the right is modified from Xu (2001: 62)

By comparison with either the human-shaped objects or the bronze trees, which are rarely found elsewhere in China, the ritual vessels and piece-mould castings appear more familiar and reminiscent of what has been already known at Anyang and the middle Yangzi River. Although at Anyang one can find a full range of vessel types, at Sanxingdui vessels are mainly *zun* (尊) and *lei* (罍). Taking *zun* (尊) from Sanxingdui as an example, though in a typical *zun* (尊) shape as found in the Central Plains, the

top left one in Figure 169 shows many similar features to that discovered at Funan in Anhui province (top right in Figure 169). These commonalities encompass big animal heads on the shoulders, snake-like patterns in high relief which gradually fade into the background of the body of the vessel, a human under the mouth of the animal and the large hollow crosses on the tall base.

The bottom left one in Figure 169 is excavated from Sanxingdui Pit II. Not only the shape of the vessel but also its intricate *tao'tie* pattern on the middle body show a direct or indirect connection to the production of ritual vessels in the Central Plains. However, the flaring undecorated mouth and duck-like birds sitting on the shoulders then suggest some elements deriving not from Anyang but the middle Yangzi River valley (Figure 169). Moreover, its wide and tall base and the nearly half-metre size are also uncommon at Anyang (Bagley, 1988, 1990 a and b; Rawson, 1996: 70-74). Similar vessels have also been found in the middle Yangzi River, such as Anhui or Hunan province (Figure 169).

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Figure 169 Zun vessels from Sanxingdui and the middle Yangzi (the top left one is from Sanxingdui, after Xu (2001: 140), the top right one is from Funan in Anhui province, after Bagley (1990b, both bottom ones are modified from Rawson (1996: 72-73), the bottom left is from Sanxingdui and the bottom right is from Hunan province)

Objects in other sorts of materials are equally spectacular, especially gold and jade. Gold was little employed in Bronze Age China (Rawson, 2015a). However, the sheath recovered from Pit II is approximately 142 cm in length and 463 g in weight (Sichuan Institute of Archaeology, 1999: 60). It is engraved with extremely fine decorations. Another small tiger in gold foil was found in Pit I. Taking into account the gold masks attached to bronze human heads and other fragmented pieces, the consumption of gold at Sanxingdui is considerable and differentiates itself from the rest of China.



Figure 170 Jade *ge* (戈), *zhang* (璋) and gold objects at Sanxingdui, the picture of tiger after Xu (2001: 132)

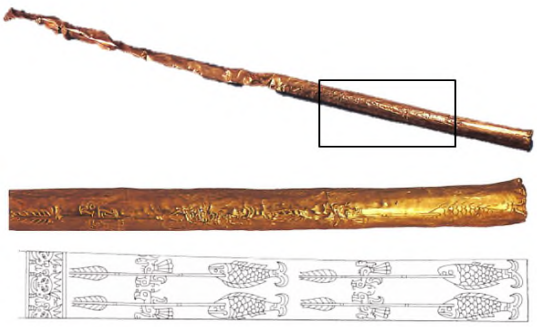

Figure 171 Gold sheath at Sanxingdui (after Xu (2001:71), length 1.42 m, diameter, 0.023 m and weight 463 g)

The production of jade in the Sichuan Plain was significant since the Neolithic period. An overwhelming majority of jades at Sanxingdui are blades, including two types, the *ge* (戈) and *zhang* (璋). *Ge* (戈) blades have a similar shape to the weapon *ge* (戈). However, much more scholarly attention are paid to the *zhang* (璋) sceptres (Figure 170). This type of jade has an odd shape. It is a long blunt strip with notches and

probably holes on the handle and a flaring or forked design on the top. Whilst its prototype appears unclear and probably can be traced to Erlitou, we are so fortunate to have discovered a tiny figure who kneels down and hold one *zhang* (璋), showing the way of utilizing these *zhang* (璋) sceptres (the top left in Figure 170).

Following the spectacular discovery of these two pits, scholars raised a series of archaeological questions, such as the nature of this deposition, its chronology, and how it could develop our understanding of the Bronze Age in the Sichuan Basin and beyond. Bagley was the first scholar who introduced the two sacrificial pits to western academia (Bagley, 1988; Bagley, 1990 a and b). His papers were published much earlier than the official excavation report (Sichuan Institute of Archaeology, 1999). In spite of the paucity of available materials at that time (sometimes Bagley had to use images from newspapers), his analysis and conclusions are very thoughtful and worth review even today. Regarding the purpose of the two sacrificial pits, he noted (Bagley 1990b: 60):

"Since their precise function or significance is not known, the jades do not shed much light on the nature of the Sanxingdui sacrifices, and other artefacts from the pits are no longer helpful. Some commentators in their first startled reaction to the finds doubted that the pits were sacrifices at all, but the excavations have convincingly refuted alternative theories. For example, it was speculated that the pits might be satellites of some as yet undiscovered tomb, but careful search has not located any

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trace of a burial in the neighbourhood. A suggestion that the pits were hoards or storage pits does not account for the deliberate breakage or the burnt animal bones, and if the pits were the result of some sort of spring cleaning of a temple or palace, it would be an odd coincidence that the discarded bronzes were buried at the very place they were cast. Finally, the suggestion that the pits contain debris buried by invaders who sacked the city and its palaces (on two separate occasions?) seems even less plausible: it is difficult to imagine why invaders would bury the items so neatly, or indeed why they would bury valuable loot at all. The evidence marshaled by the excavators argues compellingly that each pit represents a single sacrifice, performed on a majestic scale, involving burnt offerings of animals, bronzes, jades, ivory, cowries and other valuables".

It is generally agreed that the chronology of these bronze objects at Sanxingdui is equivalent to the early stage of the Anyang period (Bagley, 1988, Bagley, 1990 a and b, Falkenhausen 2002 a and b, Rawson, 1996, Sun, 2013, Chen, 1997, Ge and Linduff, 1990, Xu, 2003a, Bagley, 2001, Thorp, 1999; Sichuan Institute of Archaeology, 1999: 427-437). Scholars attempted to resolve the chronological issue by integrating a range of evidence, mainly including stratigraphy, pottery typology, bronze typology and radiocarbon dating. However, none of them appears completely flawless. Xu (2003a) provided an extremely detailed review on the history of this discussion. One has to point out that for such a crucial archaeological excavation, the fact that so far only two radiocarbon dates are published cannot be more frustrating. As suggested by Sun

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(2013), more materials such as the wood in the gold sceptre and burnt charcoal attached to the bronze vessels should be dated. These dates can help to sharpen our understanding of the absolute dates of these two pits. This may also play a vital role in our interpretation on many issues, such as the purpose of the depositions. All of these must require more radiocarbon dates.

Although the objects in the two sacrificial pits appear rather alien at a first glimpse, in fact, many similar or related stylistic and technological features or types of objects can be found in neighbouring regions. This illustrates a wide range of contact between Sanxingdui and the outside world. As firstly noted by Bagley (1988), the *zun* (尊) vessels at Sanxingdui show a strong resemblance to those found at Funan, Anhui province (Figure 169), suggesting a close contact between the Sichuan Basin and the middle Yangzi River valley. Rawson (1996: 72) further points out that the difference in the details of the *tao'tie* motifs at Sanxingdui shows that local craftsmen must be sufficiently familiar with at least more than one type of *tao'tie* from either Anyang or Hunan, whose bronze technology was ultimately rooted in the Erligang epoch.

While scholars agree that those vessels at Sanxingdui owe principal typological and technological influence to the middle Yangzi River valley and the Central Plains, their place of manufacture is an ongoing debate. The excavators (Chen and Chen, 1987，1989), and Rawson (1996: 70-72), argued that they were more likely made locally whereas Bagley (1988; 1990 a and b), Thorp (1999: 225) and Falkenhausen (2002 a

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and b) thought they could have been brought from the middle Yangzi River valley. In fact, the pieces selected by both parties to make these arguments are the *zun* (尊) and *lei* (罍) vessels but their final judgments, which fundamentally depend on prioritization of the observed stylistic similarities and differences, are difficult to assess.

Apart from the ritual bronze vessels, a wider network of distant communication can be illustrated by the other types of materials. The similarities of ceramics between Sanxingdui and Erlitou are emphasized (Xu, 2003a). One jade figure of the Shijiahe culture, a late Neolithic culture along the middle Yangzi River valley, seems to be the prototype for the numerous bronze figures interred at Sanxingdui (Falkenhausen, 2003). The constant finding of various types of jades in the Sichuan Basin, particularly *cong* (琮), *bi* (璧) and *zhang* (璋), provides evidence of contact to the Neolithic Liangzhu culture in the lower Yangzi River valley and to Erlitou in the Central Plains. As illustrated in Figure 172, the jade *zhang* (璋) is extremely widely distributed, from northern China to southeast Asia. Although the spread and adoption of this specific jade might be varied from one region to another, it however undoubtedly illustrates a nationwide network of communication in which Sanxingdui was one node.

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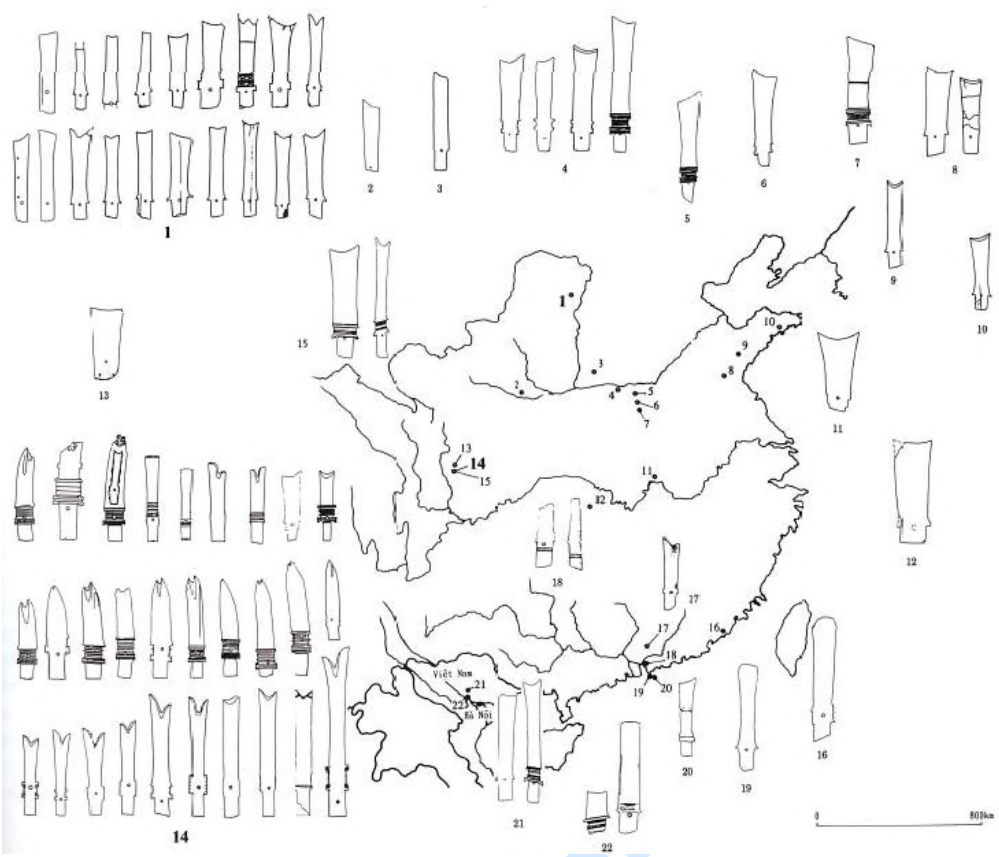

Figure 172 Distribution of the *zhang* (璋) objects, after Rawson (1996: 83)

As Bagley (1990) commented, the significance of the two sacrificial pits can be explained from two aspects. Firstly, it completely overwrites our understanding of the Bronze Age in the Sichuan Basin. Secondly, it overturns the entire picture in which Anyang used to be recorded in the centre and the surrounding regions are regarded as primitive. The extraordinary findings at Sanxingdui present to us a local entity which was as powerful as Anyang and well networked with the outside world,

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5.2.2 A review of scientific analyses of the Sanxingdui metal assemblage

Several teams have published the scientific analyses of the metal objects at Sanxingdui. In terms of metal provenance, the most well-known discussion is in Jin *et al.* (1995). He and colleagues argued that the high proportion of radiogenic lead found in most artefacts at Sanxingdui, which declines in the proportion of objects found in areas further from the Sichuan Basin, culminating in lower numbers of objects at Anyang, reinforces their previous view that the most likely source of this type of lead is on the border between Sichuan and Yunnan, which is based on comparing data between objects and ores (Jin, 1987).

Some different views have been proposed by Cui and Wu (2013). Firstly, they argued that all of the objects in the two Sanxingdui pits were made in a single batch. Their evidence is based on the following observations. (1) by comparison with the range of lead isotopes in other metal assemblages such as Xin'gan, Dayangzhou and Panlongcheng, that of the Sanxingdui bronzes is much narrower. This might suggest that the lead was extracted and used as a single batch. (2) the observation in Su (2003) that the surface of many bronzes at Sanxingdui are very coarse and not well polished, which could imply that these objects interred in the two sacrificial pits were produced as one batch in a rush for burial purpose.

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Secondly, although they agreed with Jin that radiogenic lead isotopes may be indicative of a shared lead source (because plotting the lead isotopic data of the Sanxingdui objects on a two dimensional graph produces a linear regression, or, as they believe, an isochron), however, they rejected Yunnan as the source of radiogenic lead and support the possibility of a source the middle Yangzi River (Cui and Wu, 2013: 246-247). The reason is that the holes in the bronze objects of Sanxingdui were made by cutting, such as is the way of making jades, rather than casting. But why? These holes could of course have been made very easily by casting but why did the craftsmen in the end choose grinding? One possible explanation proposed by Cui and Wu was that the people who made these objects were not the actual users, so they could not understand the design of the objects and the subsequent way of using them. This is why these holes were forgotten and had to be added by cutting later on.

The theory of Cui and Wu appears very difficult to follow at some points. The linear regression shown by the lead isotopic data might not be a properly defined geological isochron (Jin *et al*., accepted). The variation of lead isotopes appears not small if one considers all the data now published (*e.g.* 206/204 19.09~24.35). More critically, no one can fully understand how these objects were used or why they were buried at Sanxingdui. Those holes could have been made in some ritual performance. They could also have been added by someone when, after several generations, the original meaning and use of these bronze objects was modified or changed. Before knowing

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all of this very detailed information, it is hard to sell such a fine-grained story. This debate has illustrated very well the complexity and the difficulty of bringing various attributes together. As suggested in Jin *et al.* (accepted), it is now obvious that the radiogenic lead alone may not be diagnostic for provenance studies in some cases.

5.2.3 Re-characterization the Sanxingdui metal assemblage

Copper groups

A number of papers have published the chemical and isotopic analyses for objects at Sanxingdui (Zeng, 1989, 1991; Jin *et al*., 2008; Ma *et al*., 2012; Cui and Wu, 2013). Figure 173 shows the distribution of copper groups using the dataset in Ma *et al.* (2012). Over half of the objects are CG1 (clean copper, 56.7%) and one third is CG2 (As-only). Breaking down further the entire assemblage into vessels and other local styles reveals little difference (Figure 174). The distribution of arsenic in these two major copper groups can be found in Figure 175.

The dataset in Cui and Wu (2013) does not report the concentrations of antimony. But their measurements confirm the absence of silver and nickel. Based on Ma *et al.* (2012) and our own analyses (RLAHA Oxford), antimony appear not likely to be present in the metal assemblage of Sanxingdui (Chapter Three: Table 7). Therefore, as verified by these different teams, it is reasonable to say that the most important copper groups at Sanxingdui are CG1 (clean copper) and CG2 (As-only). The other datasets

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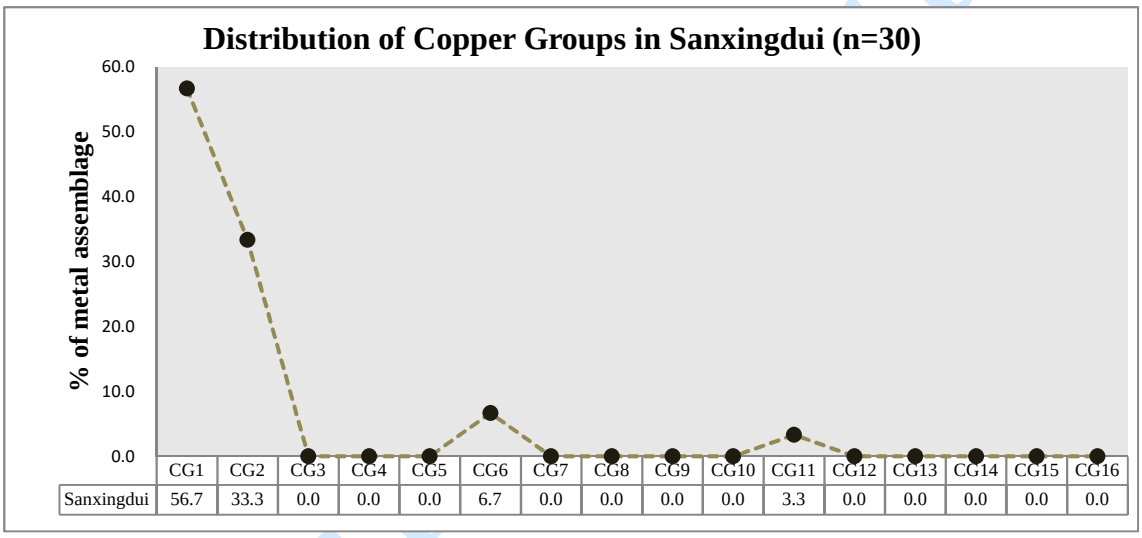
only report concentrations of alloying elements (Zeng, 1989, 1991; Jin *et al*., 2008).

It is noticeable merely around 15% of objects characterized as CG2 (As-only) contain arsenic greater than 0.2% (Figure 175). This means that the difference of objects between CG1 (clean copper) and CG2 (As-only) is marginal and in practice these two copper groups may reflect the same copper.



	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16
Sanxingdui	56.7	33.3	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0

Figure 173 Copper group distribution at Sanxingdui

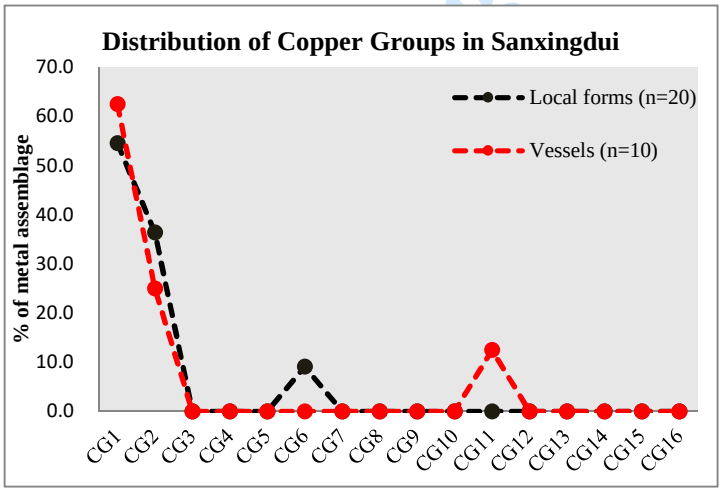


Figure 174 Copper groups of vessels and weapons at Sanxingdui

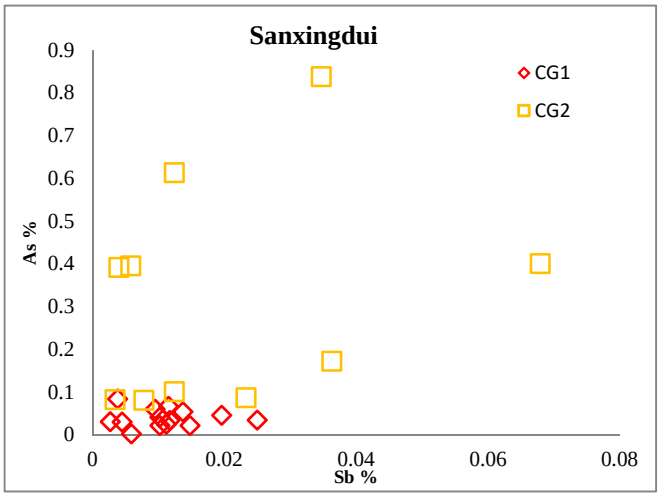


Figure 175 As and Sb distribution of CGs1&2 at Sanxingdui

Alloying patterns

Figure 176 has assembled all of the published data for Sanxingdui. A few vessels are rich in tin (>15%), whereas some objects of local forms are not. However, most objects, both the vessels and items in local shapes, display a wide range and appear to overlap significantly. This can be confirmed in Figure 177 and 178, in which the numbers of objects are converted into the percentage of the assemblages. The tin in the vessels is more than that in objects of local styles, but the lead percentage is essentially the same. No clear structure can be observed by plotting copper groups against alloying elements (Figure 179).

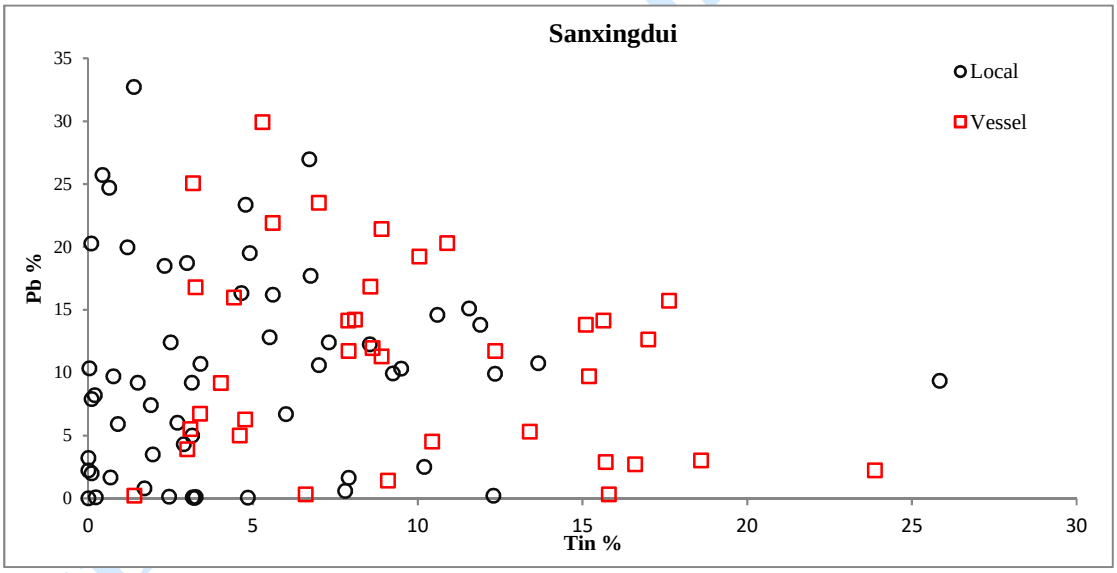


Figure 176 Plotting tin and lead of the Sanxingdui metal assemblage

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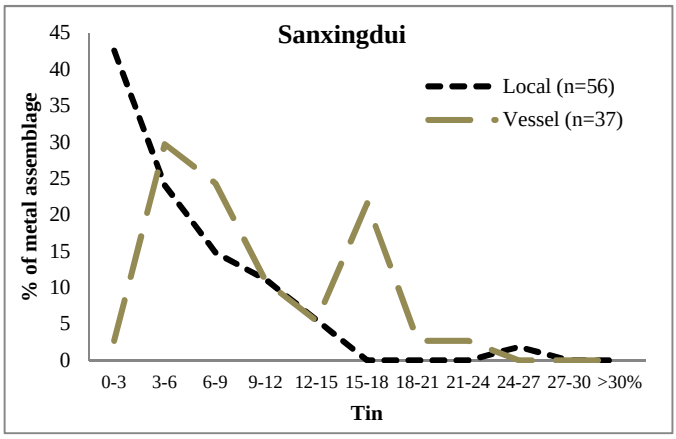

Figure 177 Tin profile between vessels and objects in local styles

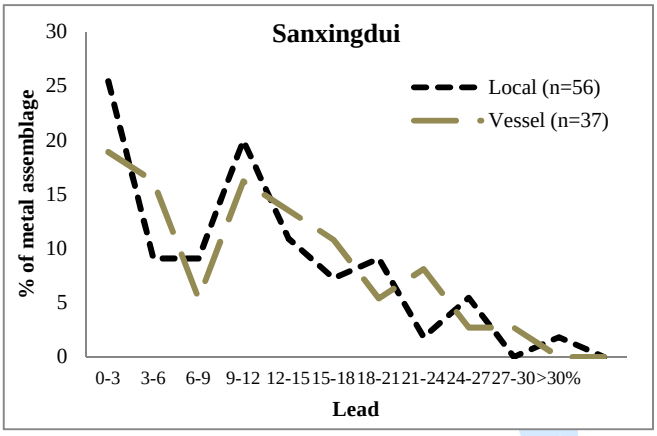

Figure 178 Lead profile between vessels and objects in local styles

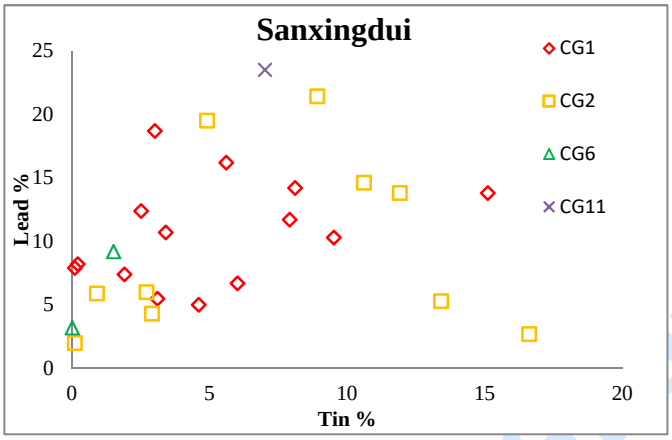

Figure 179 Combining alloying with copper groups

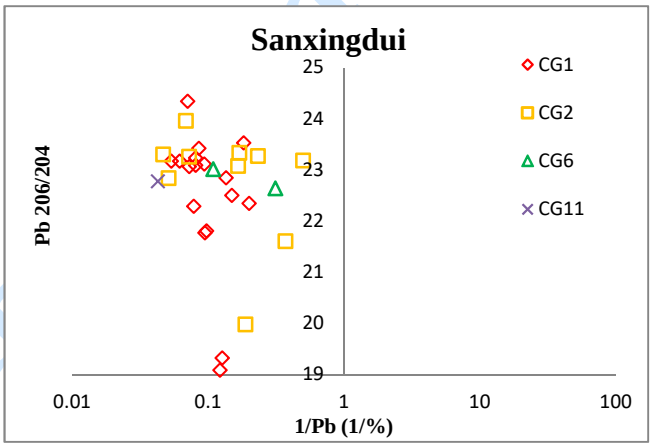

Figure 180 Plotting $^{206}Pb/^{204}Pb$ with 1/Pb (see Appendix XI for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

Lead isotopes

In Figure 180, all of the objects are plotted on the left hand side because every item contains lead greater than 1%. Their lead isotopic ratios ($^{206}Pb/^{204}Pb$) are all over 19, therefore represent radiogenic lead. The three objects which are below 19 are two dagger-axes and one *lei* (罍) vessel.

Ruliang Liu

In a short summary, the bronzes at Sanxingdui were made of leaded bronze and its lead content appears mostly radiogenic (Cui and Wu, 2013; Jin *et al*., 1995; Ma *et al*., 2012; Zeng, 1989, 1991). The new observation made here is the wide use of CG1 (clean copper) and CG2 (As-only) as the copper base and these two copper groups may actually point to the same type of copper.

5.3 Hanzhong

5.3.1 A review of the Hanzhong metal assemblage

The Hanzhong Basin, southwest Shaanxi Province, is on the Han River, where it meets with the Xushui and Yishui Rivers, near the two modern counties under Hanzhong city, Chenggu and Yangxian (Figure 164). Although seemingly isolated, Hanzhong is geographically well connected to many regions. Moreover, across the Daba-Micang Mountains, which are only around 1000 meters high, we immediately arrive at the Sanxingdui site on the Sichuan Plain. From Hanzhong to the east, the Han River offers a convenient means of transportation between Hanzhong and the middle Yangzi River region, including the Panlongcheng site. There are two principal routes around the Qinling Mountains (*c.* 2100 m) to the north of Hanzhong - either by directly crossing them, or by utilizing the river system in the northwest. This geographical setting indicates that in at least three directions (south, southeast and north), the Hanzhong people were able to make contact with other groups.

Typological similarities across a range of materials, particularly ceramics and metal artefacts, suggest that Hanzhong was in close communication with a variety of

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regions. According to the archaeological report (Zhao, 2006), a total of 700 copper-based objects have been discovered from 33 separate caches in Hanzhong (Figure 164), with another 10 objects collected by local museums. A number of scholars have undertaken detailed typological analysis of the Hanzhong objects and made comparisons with counterparts in other regions (Li, 1983; Tang, 1984; Zhao, 1996, 2006b; Huang, 2002; Wang, 2003; Cao, 2006; Sun, 2011; Rawson, 2011; Falkenhausen, 2011). The Hanzhong metal assemblage is often divided into two groups: 1, objects, particularly vessels, which closely resemble those from the metropolitan Shang areas and other regions, such as the middle Yangzi River valley; 2, a second group consisting of local objects unique to the Hanzhong Basin and surrounding regions, particularly sickle-shaped objects, sceptre-shaped objects, masks, discs and most of the weapons.

In particular, the connection between Hanzhong and Sichuan can be detected also by the similarity between certain objects. Li (1997) suggested that the bronze *zhang* (璋) discovered at Hanzhong were imitations of jades with similar forms in Sanxingdui and many other regions. The scarcity of jade materials at Hanzhong may explain why these people shifted to metals. In addition to sceptres, a range of materials show a close relationship with the Sichuan Plain. For instance, following Li (1983), Zhao (1996) also defined two groups of objects at Hanzhong. He argued that his defined B group of objects, including many kinds of weapons (triangle *ge* (戈) blades, *yue* (钺) decorated with frog/face or asymmetric *yue* (钺) and spearheads), masks, discs,

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sickles and sceptres, strongly resemble those found in the western part of the Sichuan Plain.

Typological study has also enabled archaeologists to establish a preliminary chronological framework for the metals found at Hanzhong. The two most comprehensive studies can be found in Zhao (2006) and Cao (2006). Zhao divided the entire metal assemblage at Hanzhong into five phases and through comparisons with standard objects found at Zhengzhou, Panlongcheng and Anyang, he argued that the metal objects at Hanzhong cover a long period ranging from Erligang to the Anyang IV phase. The framework suggested by Cao (2006) contains five groups of objects and three chronological phases. Albeit in a slightly different structure, the key evidence followed by Cao and Zhao are the ritual vessels and therefore their conclusions are basically consistent.

Near to these bronze caches, a site called Baoshan has been excavated (Figure 164). The most common remains at this site are a large number of fire pits. Their circumference is around 200 cm and the depths range from 40 cm to 650 cm (Northwest University, 2002: 25). A large number of pebbles, firing residues, animal bones and fragmented pottery are found inside (Figure 181). Some of them are found inside buildings and some are outside. Excavators claim that their function was probably something to do with daily life. The pottery morphology shows an extremely mixed pattern and suggests a variety of communications with adjacent regions.

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Detailed typological analysis on the pottery demonstrates this interregional communication (Dou, 2010). In general, the pottery assemblage found in Baoshan can be divided to four groups and indicates varying degrees of connection to one or more specific regions.

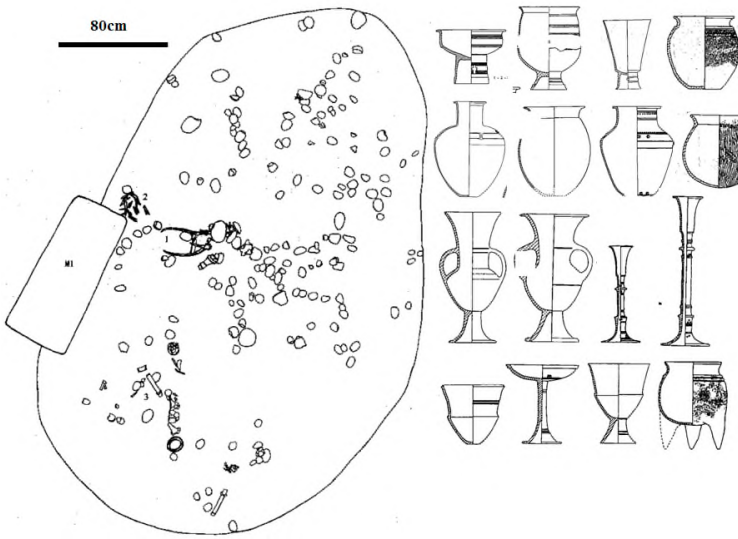

Figure 181 SH9 burning pit in Hanzhong and the excavated pottery
(after Northwest University, 2002: 40-44)

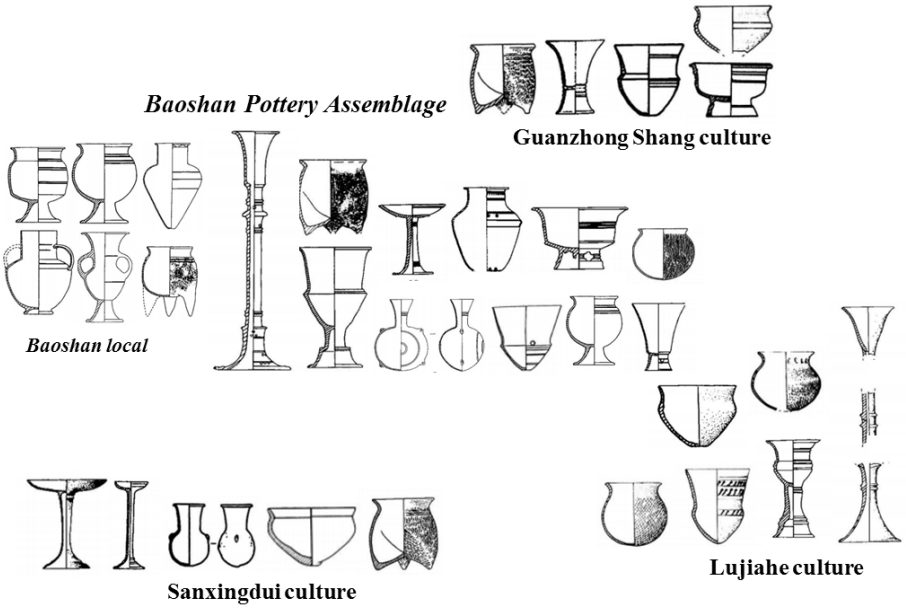

Figure 182 Pottery found in Baoshan

Table 14 summarizes the metal assemblage in each of the 33 caches found in the Hanzhong basin. Although a number of them have yielded few objects, in the caches with over 20 items, the combinations of vessels + weapons + objects of local forms have appeared repeatedly. In a very few cases, only vessels or weapons were found, but objects of local forms were never buried on their own. It is likely that most caches might be the result of some planned arrangement in antiquity. This pattern of depositing mixtures of available metalwork is striking and an important piece of evidence on how we might interpret metallurgy in the area.

Table 14 Summary of objects in Hanzhong caches

Pit Number	Vessel	Weapon	Objects of Other Forms						Total
			Sickle-shaped objects	Scepter-shaped objects	Animal masks	Human masks	Discs	Animal-shaped objects	
1980CHLTT	11	11	43						65
1981CHLTT	7	2	17						26
2004CHLTT	4								4
1999CHLXWT		1							1
1986CHYGXT		1							1
1986CHYGT		1							
1992CHBCT	1								1
1973CHLHT	1								1
1975CHWLT	1								1
1964CHWaT	1	20							21
1964CHWbT	18	2		3					24 (1 tree-shaped object)
1965CHWT	2								2
1974CHWT	1								1
1975CHWT	1	1							2
1988CHWT		2							2
1970CHWXT	1								1
1975CHWXaT	1								1
1975CHWXbT	5		16						21
1992CHWXT					1				1

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1990CHBK1	1								1
1963CHBSTT	1				15				16
1974CHBSTT	2								2
1955CHBSXT		21							21
1959CHBSXT	1								1
1976CHBSXT	2	97			11	21	283		414
2004CHBLT	1								1
CHLZT	1	1							2
1990YMAT	6								6
1979YXFT		31	3	10				6	51+ one bell
1964YZHCT	1								1
1981YZHCT	4								4
2002YCHBHT	1	1							2
1957YZHBT	1								1
1981YLTT	1								1
YLZT	2	6							8

5.3.2 A review of scientific analyses of the Hanzhong metal assemblage

Chemical analyses of the Hanzhong metal assemblage have been extensively discussed in publications (Chen, 2009; Chen *et al*., 2009; Mei *et al*., 2009; Chen *et al*., 2012a; Chen *et al*., 2016). Using 2% as the boundary, a variety of alloying types (also unalloyed copper) have been found, including not only bronze (Cu-Sn), leaded bronze (Cu-Sn-Pb) but also Cu-As, Cu-As-Ni and Cu-Sb. Correlating alloying types to object typology reveals interesting patterns. Chen and others (2009: 104-105; Chen *et al*., 2009; Mei *et al*., 2009) pointed out that sickles and sceptres, which are predominantly found in the Longtou and Xushui caches and are recognized as typical indigenous forms, are strongly related to their proposed “special alloying” types (Cu, Cu-As, Cu-As-Ni and Cu-Sb). These contrast with those vessels and weapons made from

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different alloying recipes, such as bronze or leaded bronze. Chen and colleagues (2009: 105; Chen *et al*., 2009; Mei *et al*., 2009) argued that the correlation between *special forms* and *special alloying* represents the local metal production. Sickles from the scientific excavation of the Baoshan site are also made from these so-called special alloys (Cu, Cu-Sb, Cu-Sb-Pb and Cu-Pb; Chen, 2009: 106). A linear regression of the concentrations of arsenic and antimony in sickles and sceptres indicates the use of some specific minerals (Chen, 2009: 90; Chen *et al*., 2009).

Chen (2009: 108) further stated that although no direct mining and smelting evidence has yet been found around Hanzhong, transmitted texts and modern geological surveys are indicative of at least a number of available metal resources in the local area, including copper (chalcopyrite, $CuFeS_2$, tetrahedrite, $Cu_{12}Sb_4S_{13}$, bornite Cu_5FeS_4, chalcocite Cu_2S, azurite $Cu_3[CO_3](OH)_2$), nickel (pentlandite, $(Fe,Ni)_9S_8$, millerite NiS, polydimite $NiNi_2S_4$, violarite $FeNi_2S_4$, gersdorffite NiAsS), antimony (stibnite Sb_2S_3, stibiconite $SbSb_2O_6OH$), lead (galena, PbS, cerussite $PbCO_3$) and arsenic (tennantite, $Cu_{12}As_4S_{13}$). “Special alloys” for sickles and sceptres could have derived from co-smelting these polymetallic ores (Chen, 2009: 108). With regard to sickles and sceptres of tin-bronze, Chen suspected that they might have been made by recycling other types of objects (Chen, 2009: 108-109). By using the Oxford system, we can further confirm his view on recycling as bronze/leaded-bronze sickles and bronze/leaded-bronze weapons/vessels in foreign typologies have *the same copper base* and their copper base appears rather different from that of objects called “special

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alloyings" (see below).

However, the alloying type of objects recovered at Sucun Xiaozhong is completely different from these sickles or sceptres. In spite of a diversity of types of object (weapons, discs, and masks), all of them are bronze or leaded bronze. The first conclusion made by Chen (2009: 111) was that the alloying technology for objects at Sucun Xiaozhong and the sickles and sceptres mentioned above is radically different. He and his colleagues further argued that objects from Sucun Xiaozhong should be made in a different region. Some implications can be drawn from the mining and smelting site of Laoniupo to the north of the Qinling Mountains. Several mould fragments have been excavated, suitable for casting items such as the discs, masks and weapons at Sucun Xiaozhong (See also Chen *et al.*, 2015; Chen *et al.*, 2016).

A similar discussion can also be applied to the five unalloyed local types of vessels (four at Xushui and one at Liujiazhai, close to Xushui; Chen, 2009: 112; Chen *et al.*, 2012a). These pure-copper vessels contain no other elements (As, Sb, Ni, Sn, Pb) in significant amounts, which is different from the sickles/sceptres at Longtou and Xushui or (leaded) bronzes at Sucun Xiaozhong. The obvious question is that were they locally made at Hanzhong? Chen and colleagues (2009: 113; also Chen *et al.*, 2012; Mei *et al.*, 2009) pointed out that in this case the Guanzhong Plain once again needs to be considered as a manufacturing source. One *li* (鬲) found in the hoard of Jingdang village of Qishan county in the Guanzhong Plain is typologically very

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similar to the unalloyed *li* (鬲) at Hanzhong (Cao, 2009: 282). Unfortunately, no chemical analysis has been carried out on these objects. They also referred to the two other *ding* (鼎) at the Zhanzipo site on the Guanzhong Plain which are pure copper and suggested a possible tradition of unalloyed copper in the Guanzhong Plain (Chen, 2009: 115). However, Chen admitted that it is difficult to rule out the possibility of local production for these unalloyed vessels at Hanzhong (Chen, 2009: 113).

Relevant discussion can also be found in Mei *et al*., (2009). By comparing analyses of the Hanzhong metals with those from other sites, Mei and colleagues have observed a number of differences and similarities. They suggested that the chemical and typological peculiarity of the sickles and sceptres at Hanzhong represent local characteristics. The *ding* (鼎) at Xushui is of poor casting quality and made from pure copper. This might indicate a local imitation of Shang metropolitan prototypes. On the other hand, apart from Hanzhong, the use of bronze and leaded tin bronze can be found at many other sites. Several objects in the Hanzhong assemblage contain strikingly large amounts of lead. This phenomenon has also been discovered at Panlongcheng, Sanxingdui and phases III and IV at Anyang, but nowhere else (Mei *et al*., 2009). As Mei *et al*. (2009: 1890) note:

"The high lead content is a notable technological characteristic of several Hanzhong bronzes, and the preliminary recognition of this characteristic is of significance for the understanding of the relationship between the central Shang area and its periphery,

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especially concerning contacts between the *Shang culture* in the Central Plains and *the Sanxingdui culture* in Sichuan".

Based on a series of typological and chemical associations with other sites, as summarized in previous publications, Chen *et al.* (2016) argued that a simplistic core-periphery model is unable to illustrate the complex communications at Hanzhong. This appears not a place which received influence from only core Shang areas but was rather a nodal point in a wider networking system. Therefore, the nature of the metal assemblage at Hanzhong is the representation of a multi-directional connection between the Hanzhong basin and other sites, including the Guanzhong Plain, the middle Yangzi River valley, the Sichuan Plain and the Central Plains.

One of the most important discoveries published by Chen and his colleagues is the "special alloying" at Hanzhong. This makes us to reconsider the definition of alloying and lead to some the key issue in a large number of archaeometallurgical studies. In the Oxford dictionary, the definition of alloying is "a metal made by combining two or more metallic elements, especially to give greater strength or resistance to corrosion". The words "greater strength or resistance" show that the central point concerning alloying is human intentionality. However, the human intentionality could be involved in different stages of metal production and is sometimes very difficult to capture and visualize within the archaeological records. For instance, people could intentionally select different types of minerals (*e.g.* hand-sorting by different colours)

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for co-smelting, or they could unconsciously mixed a range of minerals and smelt them together. They could also put minerals into metallic copper or smelt cassiterite and malachite separately and melt the resulting copper and tin together. The intentionality in these cases can be varied from zero to what we normally refer as deliberate alloying. Therefore, it is problematic to directly use the term "special alloying" to describe the sickles and sceptres which are "special [form] objects" (Chen *et al*., 2009). In Chen (2009: 108), he also admitted the possibility of unconscious choices.

"汉中地区铜矿中常含有黝铜矿、砷黝铜矿等矿物，部分金属矿床还可见铜矿到与辉镍矿、辉砷镍矿等矿物伴生的现象。这样的矿物组合特点，为*无意识*的"共熔还原"（co-smelting）提供了可能 [Minerals such as tetrahedrite (bearing arsenic) are frequently found in Hanzhong. In some metal deposits copper and polydymite (bearing nickel)/gersdorffite (bearing arsenic and nickel) are co-occurred. Such mineral combinations make *unconscious* co-smelting possible]".

However, while the terminology is ambiguous, it is improper to reject the argument of "special alloying" immediately. The fundamental reason is that no smelting sites have been discovered around Hanzhong. We still know very little about the entire technological chain for the ore smelting process therefore it is difficult to evaluate the underlying human consciousness.

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As mentioned above, archaeologists such as Zhao Congcang (Zhao, 1996) already pointed out that Hanzhong is in contact with the Yangzi River region, from the upper part (Sanxingdui) to the middle (Xin'gan). The close connection between Hanzhong and Sanxingdui can also be reinforced by use of lead (Mei *et al*., 2009). The third linkage between Hanzhong and Sanxingdui is from lead isotopic study. Previous lead isotopic analyses of 31 metal objects from the earlier Longtou caches to the later Sucun Xiaozhong shows that a majority of them contain radiogenic lead, the same kind of lead heavily used at Sanxingdui. Jin *et al.* (2006) further argued that there are potentially two routes along which the Shang culture could have moved into the Sichuan Plain. The first one (south) is through the Yangzi River. Hanzhong represents the second one from the north Guanzhong Plain, the Hanzhong Basin to the Sichuan Plain. As discussed below, both lead isotopes and copper groups suggest that copper and lead at Hanzhong and Sanxingdui are almost identical during the Anyang period, which implies that they may share the same supply of metal.

5.3.3 Key caches at Hanzhong

This section selects six major caches for further investigation because their objects are relatively well preserved for typo-chronological analysis and have associated chemical compositional results. Taken together, these six deposits yield a total number of 604 artefacts out of the total of approximately 700 from Hanzhong.

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Caches 1 and 2: Longtou

In the two caches of Longtou 1980CHLTT (65 artefacts) and 1981CHLTT (26 artefacts) (the number is the year of excavation and the letters an abbreviation of the location), the vessels may be dated to the later Erligang period (*c.* 1300 BC) on typological grounds (Zhao, 2006b). In the Longtou cache 1981CHLTT, for example, the *gu* (觚, 1981CHLTT: 7) immediately stands out because of its early pattern of decoration. It consists of simple raised lines which are restricted to the lower part of the body. The decoration on this *gu* (觚) is similar to the other four Hanzhong *gu* (觚) vessels (1980CHLTT: 7-10) and to the one *hu* (壺, 1980CHLTT: 4) vessel in the other cache of Longtou.

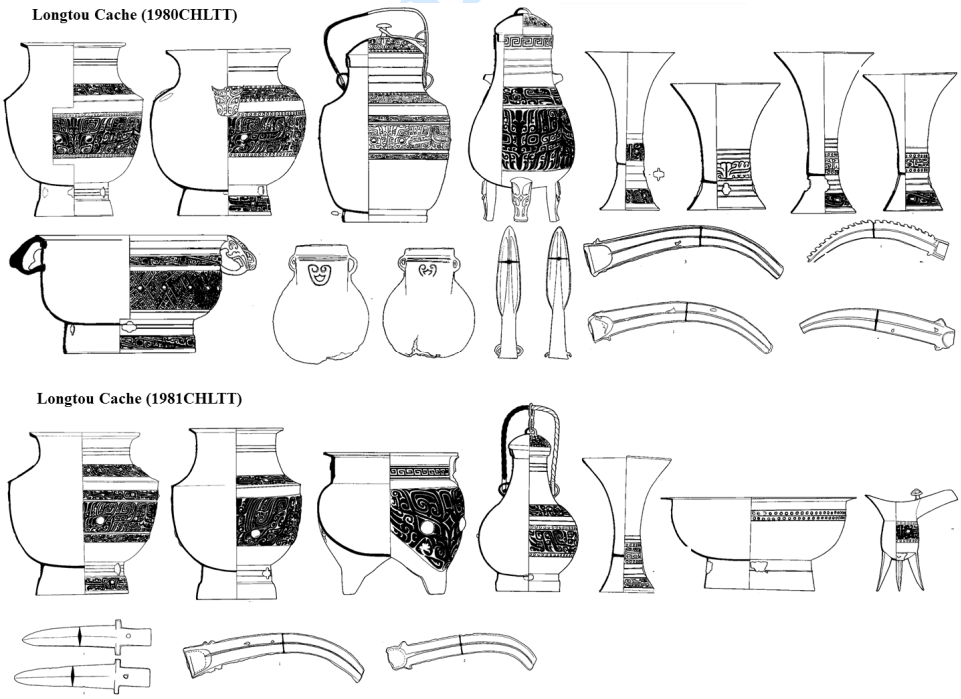

Figure 183 Selected objects from the Longtou caches

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Cache 3: Xushui

In the Xushui village cache (1975CHWXbT), the vessels are uniform and simple in terms of motifs (Figure 184). They include three *ding* (鼎) and two *li* (鬲) vessels. Another *li* (鬲) (1975CHWXaT: 1) was also found in the same village, but in a different cache. The only decorated *ding* (鼎) amongst them has very primitive repeated circles, and the rest are plain. These pieces are clearly different from the metalworking in metropolitan Shang areas, which are usually decorated with more complicated patterns. Sickle-shaped objects have also been uncovered in this cache.

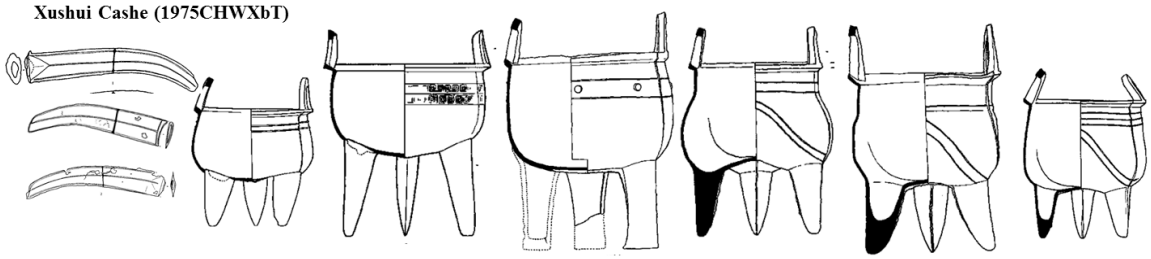

Figure 184 Selected objects from the Xushui cache

Cache 4: Wulangmiao B

Two caches (A and B) have been discovered in the village Wulangmiao. Only one *ge* (戈) blade has been chemically analyzed, so cache A is excluded. In the other cache, most pieces are fragmentary. A few objects display complicated decoration of the classical patterns often observed in the objects discovered in the middle Yangzi River during the Anyang period.

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Wulangmiao B (1964CHWbT)

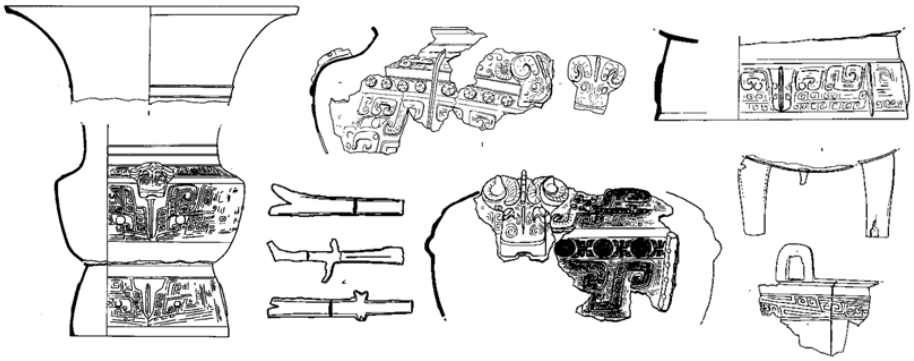

Figure 185 Selected objects from the cache of Wulangmiao B

Cache 5; Fanba

No vessels have been found in the Fanba cache (1979YXFT). Instead, a number of ceremonial *yue* (钺) objects with frog or *tao'tie* decoration are interred along with sickles, *zhang* (璋) sceptres and weapons. *Zhang* (璋) sceptres are of considerable interest since Hanzhong is the only place in which this type of object has been found in metal (Li, 1997). Zhang sceptres in jade are actually more ubiquitous (Figure 172). *Ge* (戈) blades appear very close to the standard Shang style and often regarded as imported. Various incomplete ornaments and three sickles have also been recovered.

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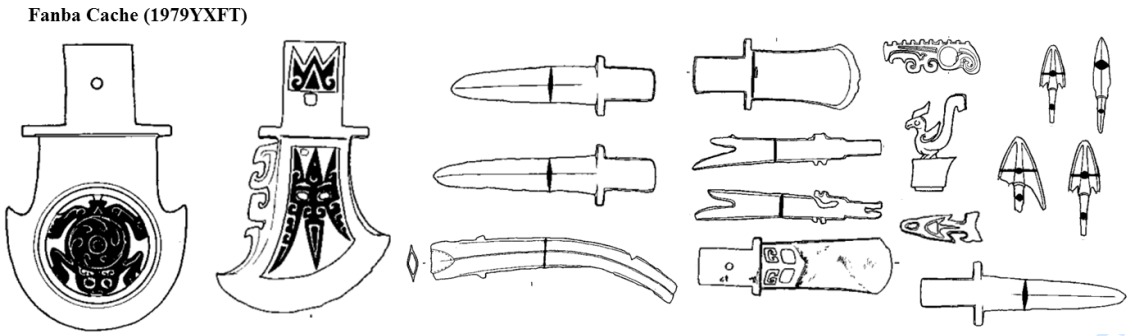

Figure 186 Selected objects from the cache of Fanba

Cache 6: Sucun Xiaozhong

The cache of Sucun yields the largest number of objects in Hanzhong, including two *fanglei* (方罍). They are both covered with unimpeachable Anyang-style decorations. The extraordinarily complicated pattern is designed with five layers. In the middle layer a typical Anyang dragon stands against a background of *leiwen* (雷纹). As Bagley (1999: 179) noted, a very similar version of the two *fanglei* (方罍) has also been found in the Fu Hao tomb, of the Anyang phase II. The sheer quantity of metal at Sucun Xiaozhong is also noticeable, accounting for nearly one third of the overall metal assemblage in Hanzhong, which is roughly half a ton.

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Sucun Xiaozhong 1976CHBSXT

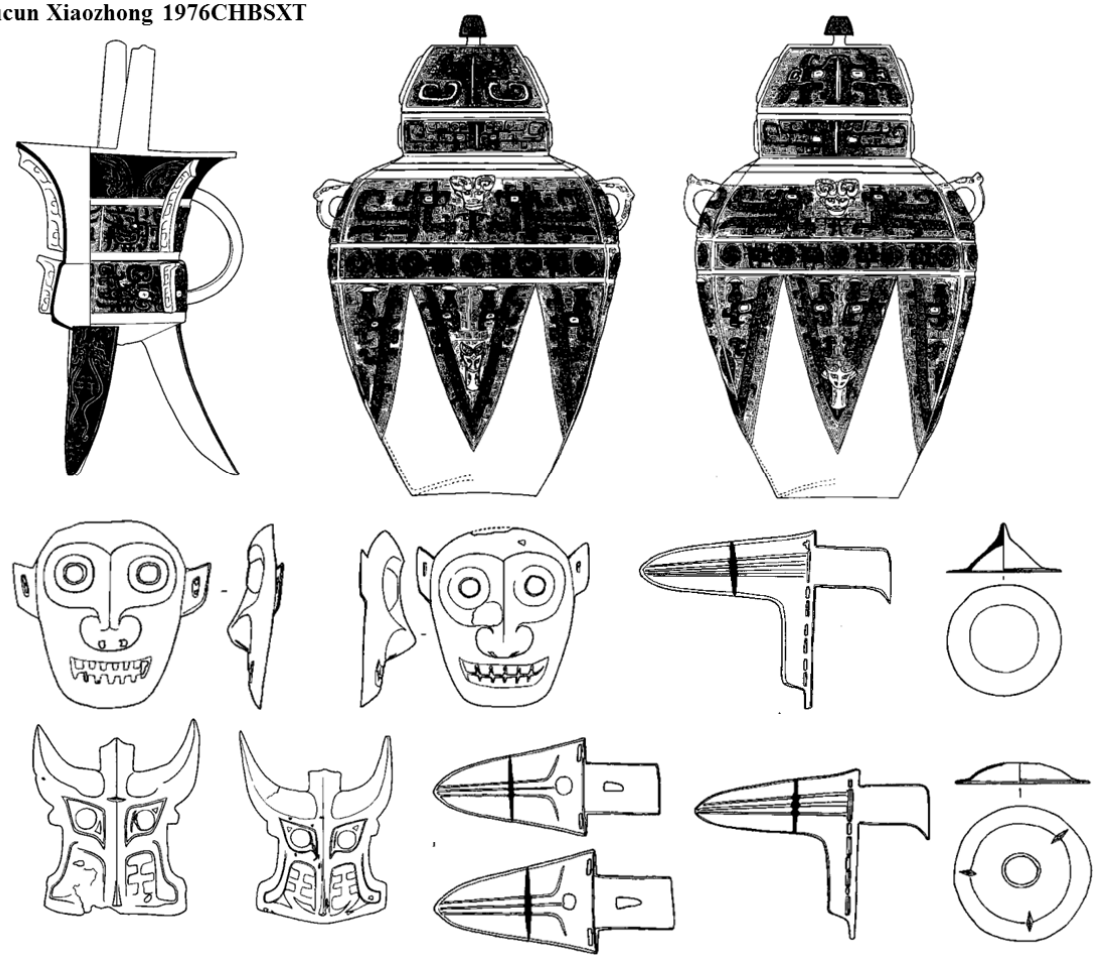

Figure 187 Selected objects from the cache of Sucun Xiaozhong

Ruiliang Liu

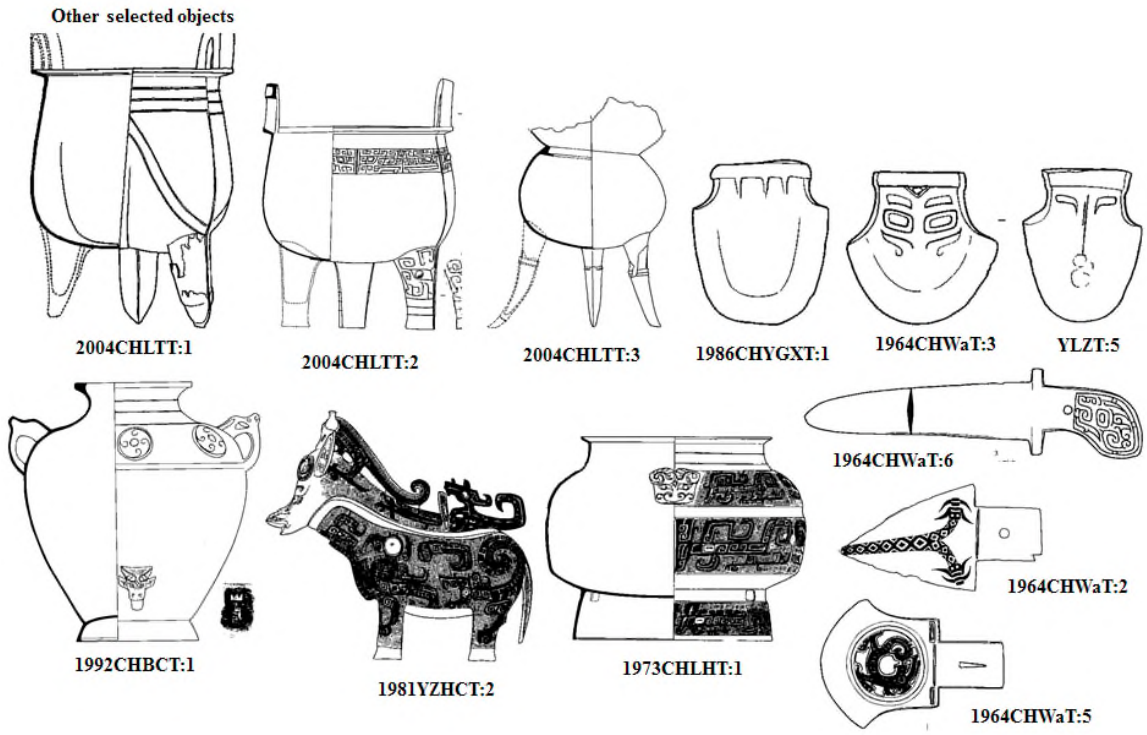

Figure 188 Selected objects from other caches at Hanzhong

Alongside the vessels, this thesis suggests that the sickle-shaped objects are also of critical chronological importance. Previously, because of their unique nature, scholars have tended to treat them as a single category of object. The two caches from Longtou together yielded over 70% of the sickle-shaped objects at Hanzhong. The rest are found in one of the Xushui caches (1975CHWXbT). What has been little considered is the internal typological variation in these sickles. The sickles found in the two Longtou caches are significantly longer and heavier than those from Xushui (Figure 189 and 190). In the Xushui cache, they were still in use, although they had become markedly shorter and lighter. These distinctive objects no longer appear in the cache of Sucun Xiaozhong, which is seen as later than that of Xushui from the vessel evidence. Our reflection on the typological shift above is that this is indicative of

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chronological change, and the pre-Anyang metalwork at Hanzhong can be divided into earlier Longtou and slightly later Xushui stages (Figure 191), which can also be attested by the vessel-based chronology in previous publications. As discussed below, by incorporating the chemical analysis, this change is more evident.

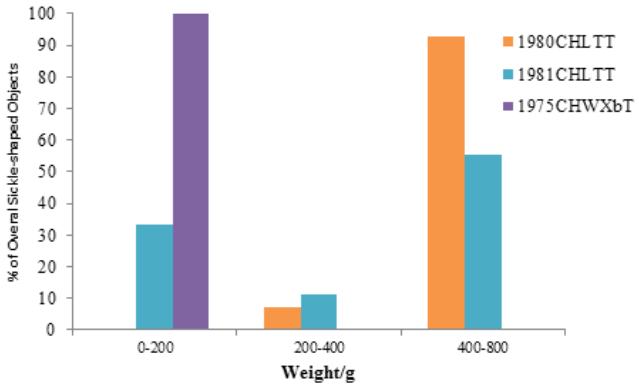


Figure 189 Comparison of weight in sickles

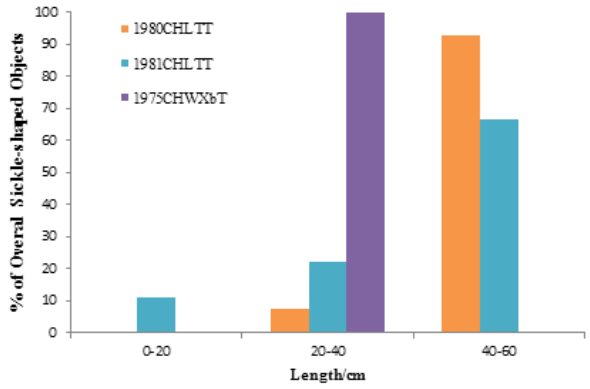


Figure 190 Comparison of length in sickles

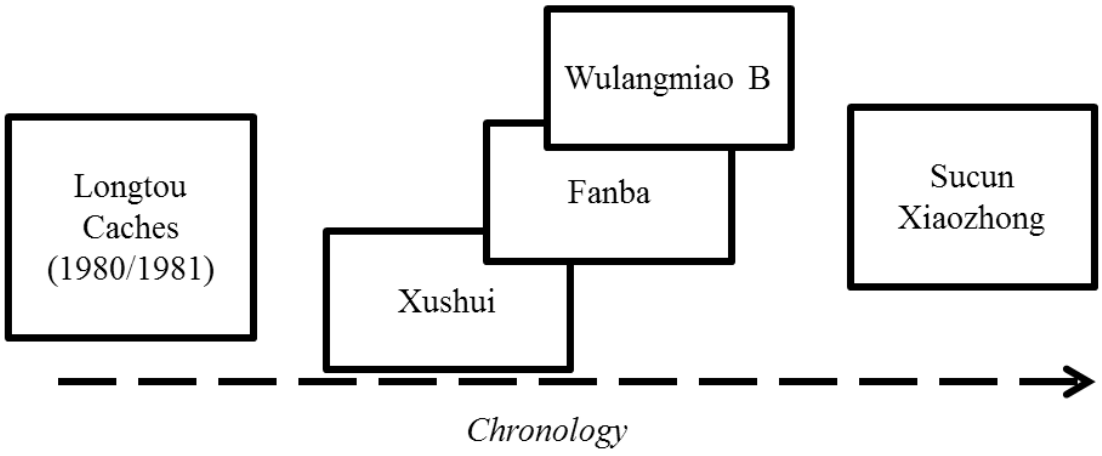


Figure 191 Chronology for Hanzhong

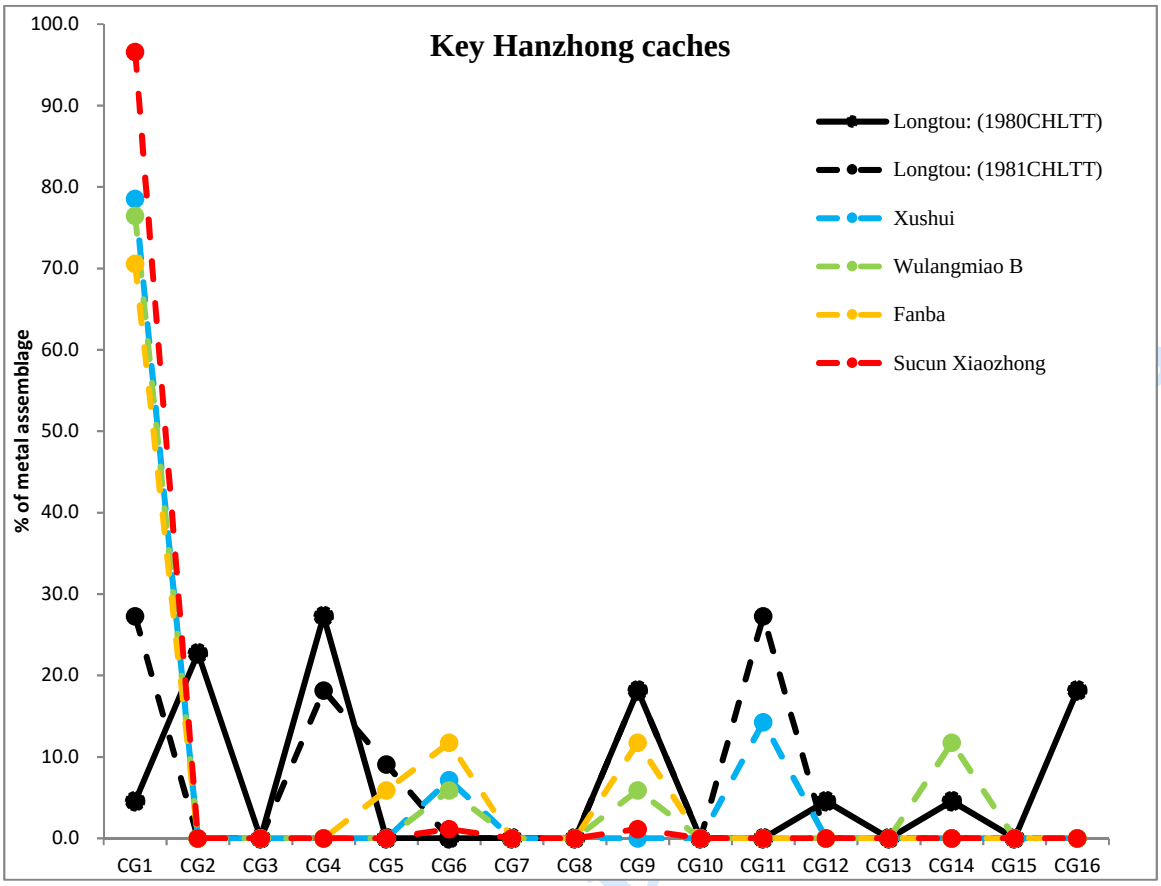
5.3.4 Re-characterization of the Hanzhong metal assemblage

Copper groups

Together with Mei *et al.* (2009) and Chen *et al.* (2009), Chen (2009) has reported the chemical composition of 204 objects from the Hanzhong assemblage. Their work includes a comprehensive list of trace elements analyzed by EPMA. Chapter Three has compared two datasets for the same objects at Hanzhong but from different laboratories (UCL/Oxford) with different instruments (EPMA/SEM-EDS) and it shows that they are in an excellent agreement. Figure 192 illustrates the distribution of copper groups of the key caches, of which the order indicates chronological progression. The earliest caches (Longtou 1980/1981CHLTT) have a variety of copper groups, including CG1 (clean copper), CG2 (As-only), CG4 (Ag-only), CG9 (As-Ag), CG11 (As-Ni), CG16 (As-Sb-Ag-Ni). When moving to the later caches, it appears that CG1 (clean copper) becomes overwhelmingly dominant. Especially in the cache of Sucun Xiaozhong, nearly all of the analyzed 85 objects contain the four diagnostic elements below 0.1%.

Scatter plots reveals another interesting aspect (Figure 193-196). A few objects in the caches of Longtou, Xushui and Wulangmiao B contain strikingly high quantities of arsenic, antimony and silver. This has been discussed in a series of papers by Chen and Mei (see above). Again, 85 analyses of objects at Sucun Xiaozhong are compressed to almost one single point, which means they contain few trace elements. This is radically different from the earlier caches.

Ruiliang Liu unplished thesis



Cache	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16	Data entry
Longtou: (1980CHLTT)	4.5	22.7	0.0	27.3	0.0	0.0	0.0	0.0	18.2	0.0	0.0	4.5	0.0	4.5	0.0	18.2	22
Longtou: (1981CHLTT)	27.3	0.0	0.0	18.2	9.1	0.0	0.0	0.0	18.2	0.0	27.3	0.0	0.0	0.0	0.0	0.0	11
Xushui	78.6	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	14
Wulangmiao B	76.5	0.0	0.0	0.0	0.0	5.9	0.0	0.0	5.9	0.0	0.0	0.0	0.0	11.8	0.0	0.0	17
Fanba	70.6	0.0	0.0	0.0	5.9	11.8	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17
Sucun Xiaozhong	96.6	0.0	0.0	0.0	0.0	1.1	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88

Figure 192 Distribution of copper groups for the key caches at Hanzhong

Ruiliang Liu

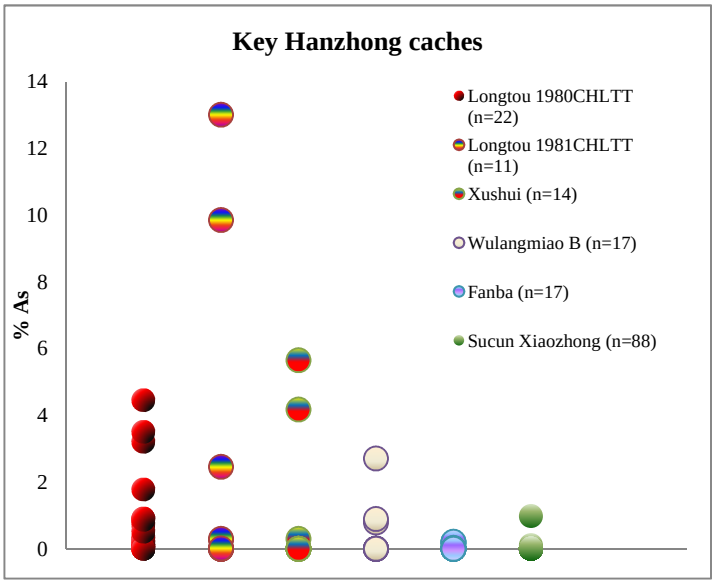


Figure 193 Variation of As in objects of the key caches at Hanzhong

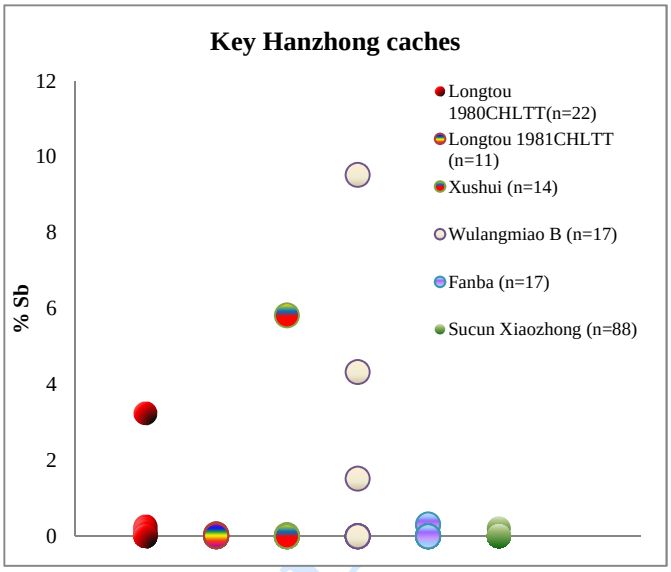


Figure 194 Variation of Sb in objects of the key caches at Hanzhong

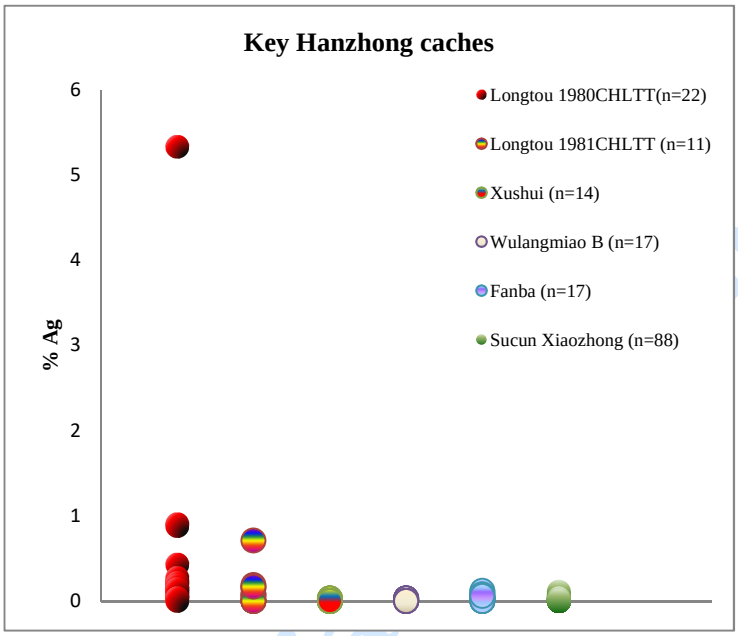


Figure 195 Variation of Ag in objects of the key caches at Hanzhong

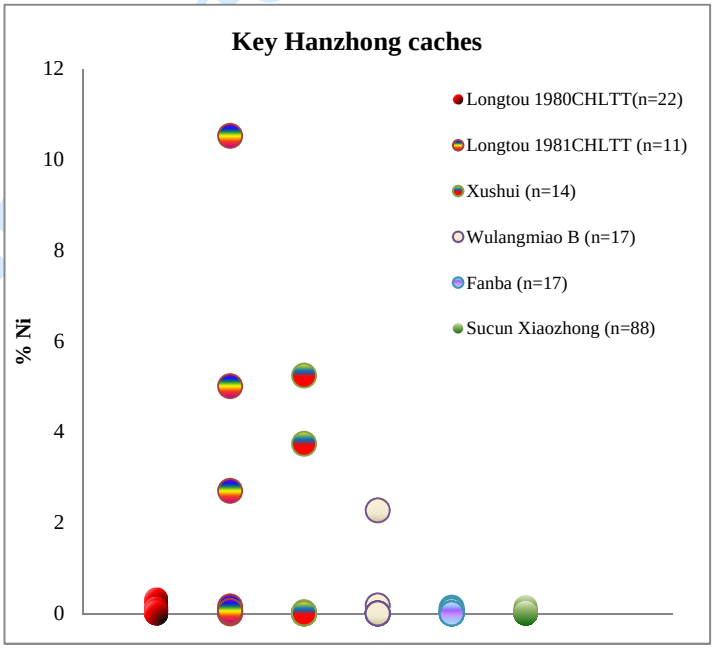


Figure 196 Variation of Ni in objects of the key caches at Hanzhong

Table 15 summarizes the chemical and broad typological characteristics of the six key caches outlined above. It is divided vertically into ‘Objects of other forms’, including sickles, sceptres, masks and discs. The second vertical section summarises the data for ‘Weapons’, the third ‘Vessels’. Each of these three artefact types is summarised for each cache, different colours of the block corresponding to different Copper Group (1 to 16). The position of the colored blocks within the table shows how much lead (horizontal position) or tin (vertical position) were contained in the artefact. As an example, for the Longtou Cache 1980CHLTT we have chemical data for four vessels. Three are made from copper of CG4 (Cu-Ag), one from copper of CG 2 (Cu-As). The alloying information for these four vessels is recorded as: A) Copper Group Four / Pb 5-15 / Sn 2-5. B) Copper Group Four / Pb 5-15 / Sn 5-15. C) Copper Group Four / Pb 15+ / Sn 5-15. D) Copper Group 2 / Pb 2-5 / Sn 5-15.

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Table 15 Summarization of copper groups, alloying and typology (Colour coding represents copper group, in each bracket, it shows the number of objects catalogued as one copper group, *e.g.* CG1x9, red representing CG1, means nine objects are catalogued to CG1)

		Objects of other forms: sickles/masks/discs						Weapons						Vessel					
Longtou Cache 1980CHLTT	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5	CG1x1 CG9x1 CG14x1 CG16x2	CG2x1 CG9x1			CG12x1		0-0.5				CG4x1		0-0.5					
	0.5-2	CG2x3	CG16x1					0.5-2			CG16x1	CG4x1		0.5-2					
	2-5		CG4x1					2-5						2-5				CG4x1	
	5-15							5-15				CG9x2		5-15			CG2x1	CG4x1	CG4x1
	15+							15+						15+					
Longtou Cache 1981CHLTT	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5	CG1x3 CG5x1 CG11x3						0-0.5						0-0.5					
	0.5-2		CG9x1					0.5-2						0.5-2					
	2-5		CG9x1					2-5						2-5					
	5-15							5-15						5-15					CG4x1
	15+							15+						15+			CG4x1		
Xushui Cache	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5	CG1x7 CG6x1 CG11x2						0-0.5						0-0.5	CG1x4				
	0.5-2							0.5-2						0.5-2					
	2-5							2-5						2-5					
	5-15							5-15						5-15					
	15+							15+						15+					
Fanba Cache	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5	CG5x1 CG6x2 CG1x2						0-0.5						0-0.5					
	0.5-2	CG1x2						0.5-2						0.5-2					
	2-5		CG1x1					2-5						2-5					
	5-15	CG9x2	CG1x2		CG1x2	CG1x1		5-15						5-15					
	15+		CG1x2					15+						15+					
Wulangmiao B Cache	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5	CG6x2 CG14x1 CG2x1						0-0.5						0-0.5					
	0.5-2							0.5-2						0.5-2				CG1x1	
	2-5							2-5						2-5			CG1x5	CG1x2	
	5-15							5-15						5-15			CG1x7	CG1x1	CG1x3
	15+							15+						15+					
Sucun Cache	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+		Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+	Sn\Pb	0-0.5	0.5-2	2-5	5-15	15+
	0-0.5							0-0.5						0-0.5					
	0.5-2							0.5-2						0.5-2					
	2-5							2-5				CG1x3	CG1x1	2-5					
	5-15	CG1x13	CG1x10	CG1x9	CG1x9 CG6x1			5-15	CG1x1	CG1x4	CG9x1	CG1x11	CG1x1	5-15					
	15+	CG1x19	CG1x2					15+						15+					

Although not visually straightforward at the first glance, the advantage of Table 15 involves the integration of four attributes of the metal assemblages, namely, copper groups (trace elemental patterns), alloying (tin/lead), object typology (local forms, weapons, vessels) and relative chronology (caches). One can easily grasp several major patterns.

A vertical comparison from earlier caches to later ones presents *a broad change in copper groups*, as illustrated by *multiple colours on the top but single red colour in the bottom*. Namely, a variety of colours are recorded for the two Longtou caches, which means many copper groups are present. In the middle stage, represented by Xushui/Fanba/Wulangmiao B, one can see that the red block is increasingly present, suggesting that CG1 (clean copper) becomes more common. In the bottom of Table 2, CG1 (clean copper) essentially predominates for all kinds of objects (animal/human masks, discs with central hole or projection, triangle *ge* (戈) blade and long-shaft *ge* (戈) blade). This is essentially as same as Figure 192 but here the typology and chronology are added. Very likely this illustrates a change in copper source, as discussed below.

Horizontally, it is easier for one to compare the copper groups and concentrations of tin/lead among objects of local forms, weapons and vessels in the same archaeological context (cache) and the same time period. In the two Longtou caches, objects of local forms are mostly placed in the top left corner, which means that their tin and lead are

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very low (< 2% in this case). By contrast, weapons and vessels in the same cache are either on the right-hand side (weapons: tin >5% and lead <2%) or on the bottom-left corner (tin >5% and lead >5%). It is also intriguing to see that weapons and vessels in the two Longtou caches are mostly CG4 (green blocks, Ag-only), with only three weapons of CG9 (As-Ag) and CG16 (all) and one vessel of CG2 (As-only). We can also see traces of these copper groups in the objects of local forms. In the later caches, the objects of local forms move towards bottom right. This is because their tin and lead are more significant. Again, we see a change in alloying technology of objects in the same cache but different typologies. Meanwhile, objects in local forms also present a change of alloying technology from earlier to later.

Lead isotopes

A combination of lead isotopes and lead concentrations is presented in Figure 197. Clearly, in the two Longtou caches both radiogenic and common lead isotopes are found. Considering the lead concentration, lead isotopes are more likely indicative of lead source because most of them contain a sufficient amount of lead (Chapter Two). By comparison with the data for Longtou caches, in later Wulangmiao B and particularly Sucun Xiaozhong, radiogenic lead appears increasingly dominant, indicating a changing emphasis in the lead supply. Although very few analyses have been published for the objects at Xushui and Fanba, they might be suggestive that copper with trace lead of radiogenic and common values were employed.

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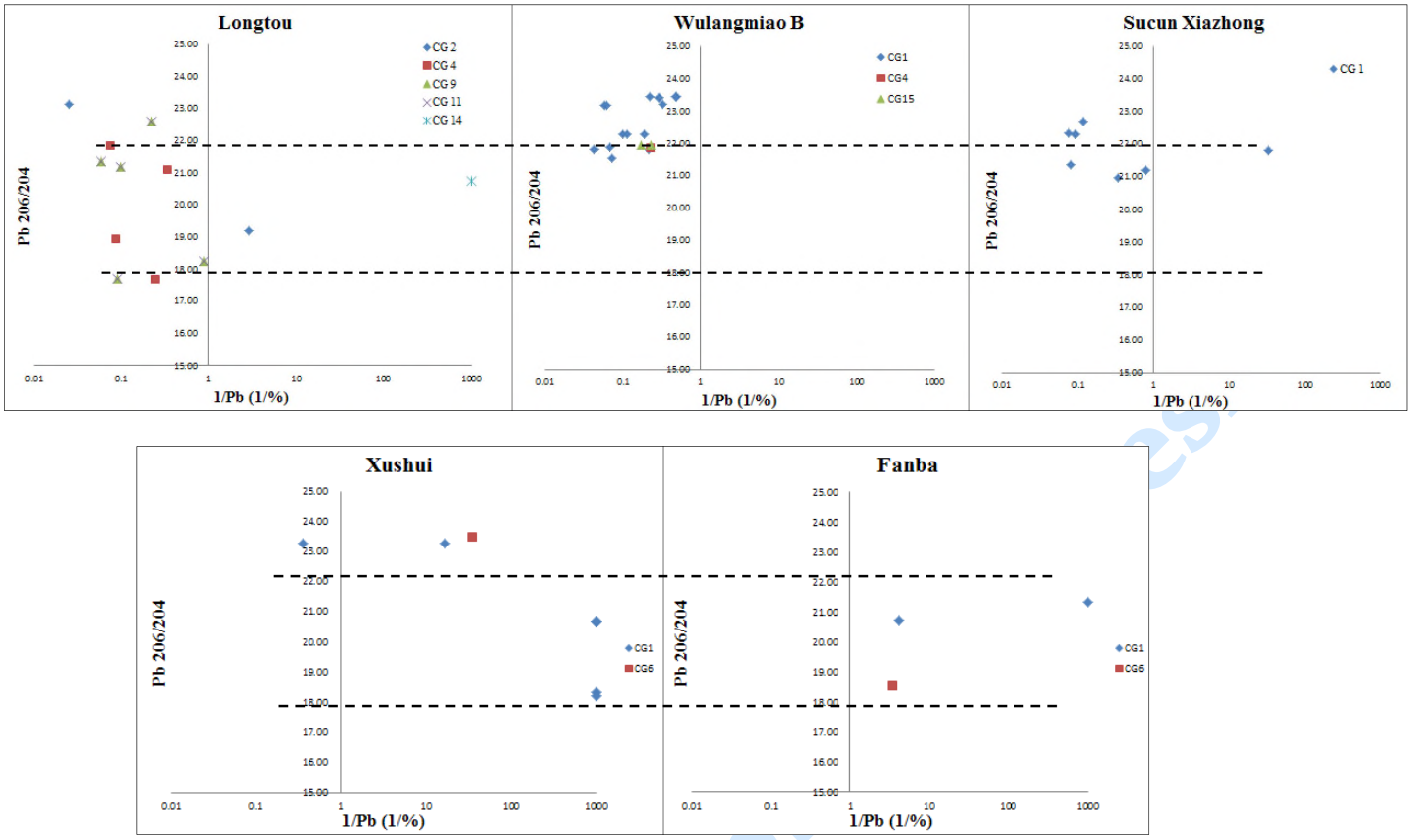

Figure 197 Plotting $^{206}Pb/^{204}Pb$ with 1/Pb for key caches at Hanzhong
(see Appendix XII for plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

5.3.5 Discussion

A narrative of Hanzhong: copper groups and alloying

To take the caches in turn, following the chronological sequence outlined earlier (Figure 191), some clear patterns quickly emerge. Between the two Longtou caches, remarkable differences can be observed among sickles and weapons/vessels. First of all, Chen (2009: 104-105) argued that these sickles were made by "special alloying", namely some of them contain arsenic/antimony/silver over 2%. This is in clear contrast to the weapons and vessels in the same cache which are alloyed with tin and lead. Therefore, as Chen suggested, it appears that sickles were locally made at

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Hanzhong from local sources of copper (Chen, 2009: 106-109).

His observation is rather stimulating. A further discussion can be drawn from the evidence of copper groups. Firstly, it is quite clear the copper groups in the sickles of Longtou caches are significantly more diverse (CGs1, 2, 4, 14, 9, 12, 16) than those of weapons/vessels co-occurred (primarily CG4). This reinforces the compositional difference between sickles and weapons/vessels and adds new evidence to the Chen's argument the latter ones were made from copper of different sources and imported into Hanzhong but the copper groups are more centred on the copper itself rather than alloying technology.

It is sometimes questioned whether the silver is a consequence of the added lead because silver could be naturally associated with galena. This seems unlikely in the case of Longtou (Figure 198 and 199). In the sickles, the concentration of lead is too low to provide the observed values of silver. As shown in Figure 198, if the silver were provided by the lead, which means that around 1.5% lead can carry *ca.* 0.3% silver, the original concentration of silver in the lead minerals would have to be up to 25%. This sort of super-silver-rich galena is extremely rare in natural minerals. Regarding the weapons/vessels, there might exist a linear regression between silver and lead. As discussed in the next chapter, the maximum silver in galena is generally around 1%. Therefore, the concentrations of silver in the objects in Longtou caches appear too high to be introduced purely by lead.

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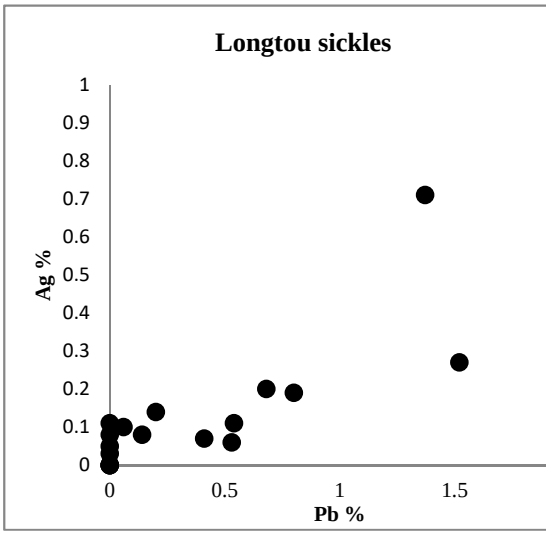

Figure 198 Pb-Ag assessment for Longtou sickles (see also Chen *et al.*, 2009: Fig. 6b)

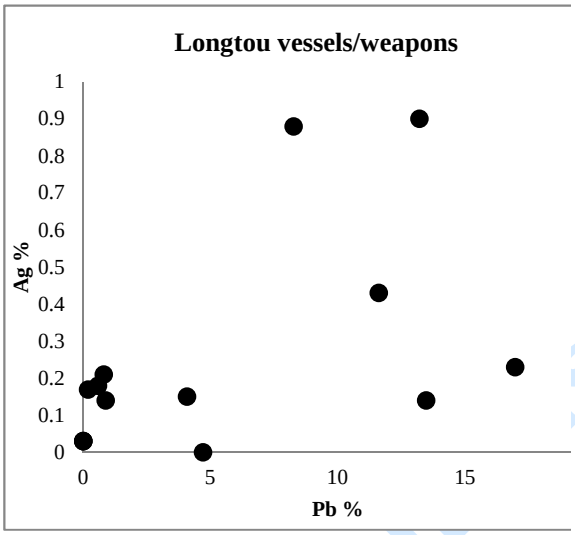

Figure 199 Pb-Ag assessment for Longtou vessels/weapons

The second difference is attributed to some sickles containing noticeable levels of tin or lead (Chen, 2009: 108-109). The implication is that these sickles might either have been made by recycling imported weapons or vessels (bronze or leaded bronze) into locally favoured objects, or from some more complex local minerals (polymetallic ores containing tin or lead; Chen, 2009: 109). Under the Oxford system, interestingly, all of the copper groups in sickles with over 0.5% tin and lead, namely CG2 (As-only, yellow), CG4 (Ag-only, green) and CG9 (As-Ag, blue) can be found in the category weapons/vessels (Table 15). Using the tool of copper groups, we can provide more independent evidence to disentangling the process of recycling. During this process, tin and lead might be diluted to some degree but the copper base was kept therefore their trace elemental patterns (copper groups) are the same.

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Another three sickles at Longtou (1981CHLTT) also merit particular attention. All of them are rich in sulfur (5.2%, 1.5%, 2.2%), which further attests that they were made from primary local metals with little recycling. More interestingly, these three sickles contain extremely high amounts of nickel (5.0%, 2.7%, 10.5%) and arsenic (13.02%, 2.46%, 9.86%). As we know from Chapter Four, nickel is quite rare in Shang bronzes and only at Panlongcheng have nickel-bearing copper groups been found. Here again nickel seems to have connected the two regions which are well linked by the Han River and belong to similar periods (Figure 155-156). One speculation would be that as sickles were not popular with Shang people, the Panlongcheng people could have recycled these sickles into, for instance, vessels or weapons. What is almost for sure is that at Hanzhong, under the same object of sickles, we can find evidence of using both primary and recycled copper at the same time to make the same type of objects.

In a brief summary, as discussed in a series of papers (Chen *et al*., 2009; Mei *et al*., 2009; Chen, 2009: 106-109; Chen *et al*., 2016), in the period represented by the caches at Longtou, Hanzhong people discovered access to local copper sources and developed the capability of casting their own objects, such as sickles. However, it appears that at this stage they had not grasped the mainstream alloying technology using tin and lead. The presence of tin and lead in objects suggests either recycling (into sickles) or importation (of weapons/vessels). Whilst local sources of raw metal were available, Hanzhong people still acquired objects from outside and it is critical to separate the underlying raw materials and finished objects. By using a refined

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technology and the Oxford system, this chapter continues adding more evidence to this narrative.

The major discovery of this thesis for Hanzhong metals starts from Xushui. We argue that the Xushui cache falls slightly later than the Longtou ones (Figure 191). This is supported by the typological changes of not only the vessels but also the sickles (Figure 189-190). At Xushui, only three sickles similar compositional signature as those at Longtou (CG6x1, As-Sb, CG11x2, As-Ni, or “special alloying”). What is startling is that alongside are the majority of sickles (70%) made of very similar clean copper (CG 1), un-alloyed with tin or lead. It seems that at Xushui most special objects were no longer made by “special alloying”.

The same pattern can be found in the vessels in the Xushui cache. The four analyzed vessels are also un-alloyed CG1 (the last four vessels in Figure 184). The vessels show either primitive or plain decoration styles, which are clearly different from the styles typical of the metropolitan Shang regions. It is notable that vessels and sickles from the same cache are also chemically similar but what is more attractive is to ask why these objects were not using the contemporary mainstream alloying technology of leaded bronze?

The same observation can be seen in the case of Fanba, roughly contemporary with Longtou. There has been found a different local form, sceptre. Like the sickles at

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Xushui, these sceptres *zhang* (璋) are also of CG1 (clean copper), half of which are unalloyed but the other are alloyed with tin or lead. No vessels are discovered at Fanba.

Wulangmiao B could also be contemporary with Xushui and Fanba. The three analyzed sickles recovered at Wulangmiao B, however, contain large amounts of arsenic, antimony or nickel with no tin or lead, being different from the vessels found with them, which are all CG1 (clean copper) and tin/lead alloyed. Unfortunately, all the vessels are fragmentary although one piece with an animal head and complicated background may indicate a middle Yangzi origin (Figure 185). While vessels/weapons are not available in all of the three caches (Xushui, Fanba and Wulangmiao B), their local types begin to show a mixture between the "special alloys" and CG1 (clean copper). Thereafter, CG1 (clean copper) appears to have become increasingly important, which can be further strengthened by the later cache from Sucun Xiaozhong,

Two *fanglei* (方罍) have been found in the cache of Sucun Xiaozhong and clearly link the deposit with the phase II of the Anyang period (Figure 187). While we unfortunately do not have chemical data for these two vessels, Chen has created a large dataset, comprising 85 artefacts, from this large deposit: 63 masks and discs (10 human masks, 2 animal masks, 27 hollow discs, 24 pointed discs), and 22 halberds. The earlier "special alloying" is completely absent. Instead, the metal is unanimously

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dominated by CG1 (clean copper), with varying levels of tin and lead addition.

In addition to the changes in copper groups and alloying technology, Sucun Xiaozhong also saw a dramatic change in lead isotopes. The lead in the bronzes from the earlier caches shows a very wide range of lead isotopes ($^{206}Pb/^{204}Pb$~17.5-25). Those from Sucun Xiaozhong are quite concentrated in the area of $^{206}Pb/^{204}Pb$~21-22.5 (Figure 197). Assuming that lead isotopes vary from one lead source to another, this might indicate a change in the source of lead at Hanzhong, from multiple sources to probably a single one around the period represented by Sucun Xiaozhong.

Following the stage represented by Longtou, the subsequent periods at Hanzhong witnessed a sharp rise of CG1 (clean copper) at Hanzhong and use of leaded bronze. This suggests a change in the copper supply and manufacturing technology. Compared to sickles at Longtou, objects discovered as Sucun Xiaozhong appear much more chemically standardized.

Importation or localisation: Sucun Xiaozhong

One key question is whether objects with a local character recovered from the cache of Sucun Xiaozhong were made at Hanzhong? Chen (2009: 109-112; also see Chen *et al*., 2016) suggested that the objects of Sucun Xiaozhong were more likely to be made elsewhere and imported into Hanzhong. The best candidate, he suggested, is the

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Laoniupo site on the other side of the Qinling Mountains. The most compelling evidence for this is that some metal objects and moulds at Laoniupo present undeniable similarities with objects at Hanzhong. The archaeological report records that the slag heap at Laoniupo was 18 m long and 0.5-2.0 m deep. Unfortunately, the majority of the slag was destroyed by modern road construction (Liu, 2001). Secondly, the technological characteristics of the objects at Sucun Xiaozhong are completely unlike earlier local objects, such as the sickles/sceptres which are widely recognized as being made by Hanzhong people. Therefore, though he does not completely rule out the possibility of local production, Laoniupo, or the broader Guanzhong Plain, is prioritized.

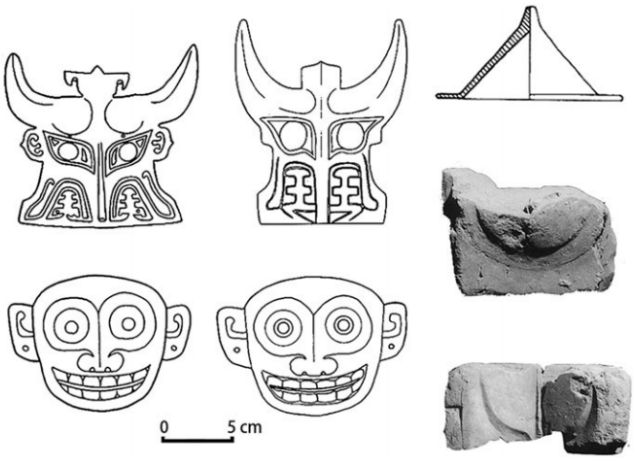

Figure 200 masks/discs from Hanzhong and moulds found at Laoniupo (after Chen *et al.*, 2016)

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There is no doubt that the two sides of the Qinling Mountains (Hanzhong and the Guanzhong Plain) were well connected in this period. The issue here is however the direction and mechanism of this communication. Preliminary analysis on the prills of slags in Laoniupo shows a large concentration of arsenic, antimony plus a detectable amount of nickel (Data appendix). With different batches of samples, Chen and colleagues have also obtained the same analytical results, which have been presented in the Tongling Ancient Mining Conference in 2016. Although these are not direct measurements of fresh objects at Laoniupo, it is still possible to see some evidence that the Laoniupo copper may not equal to CG1 (clean copper; Figure 201).

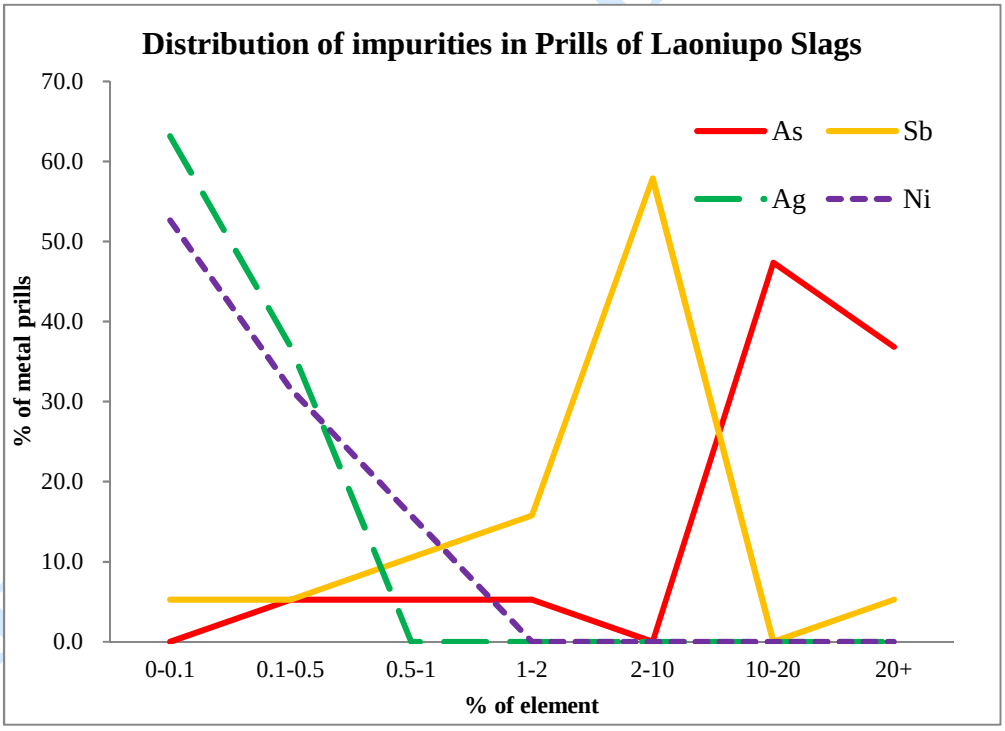

Figure 201 Analyses of copper prills
(measured at RLAHA Oxford, sample provided by Prof Jin Zhengyao)

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The other possibility is that the objects discovered from Sucun Xiaozhong in local forms were made from local source of copper. The reasons are followings. Firstly, the objects of Sucun Xiaozhong contain many distinctive local features. Ubiquity analysis of the two types of *ge* (戈) blades shows their predominance in Hanzhong. As shown in Figure 202 and 203, where the size of the circles represent the number of the objects in the local region, one can easily find that the numbers of the triangle *ge* (戈) and long-shaft one are significantly larger than those in other places. This is also true for the human and animal faces which are seldom found outside Hanzhong (Rawson, 1998). Such ubiquity analysis suggests that these objects are barely found in other regions and constrain our speculation to local production at Hanzhong. Secondly, the dominance of clean copper as a local supply becomes more likely in the light of the chronological sequence. The earlier Xushui caches already saw an increasing use of clean copper for the locally favoured form sickles (but shorter and lighter) but completely predominated in the later Sucun Xiaozhong. Such domination can be found nowhere else.

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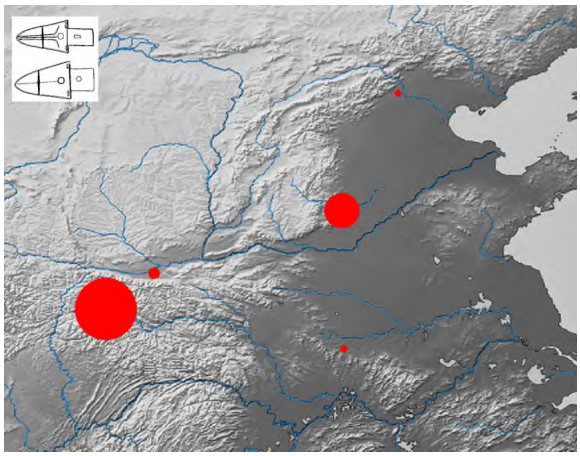

Figure 202 Distribution of triangle *ge* (戈) blade across Shang China (the size of circle representing the number of triangle *ge* (戈) blade in the local region)

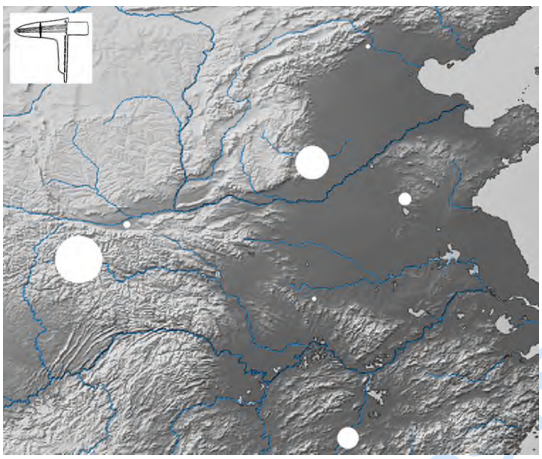

Figure 203 Distribution of long-shaft *ge* (戈) blade across Shang China (the size of circle representing the number of long-shaft *ge* (戈) blade in the local region)

We also need to consider the possibility that the movement of raw copper and the movement of finished objects could be separate. This means that objects at Sucun Xiaozhong could have been made locally but from imported raw copper from somewhere else. As a result, the object styles appear distinct but the internal chemistry remains the same as the original place. Given the strong resemblance between the copper at Hanzhong and Sanxingdui during the Anyang period (both were heavily relied on CG1), and the striking power of Sanxingdui, we still need to list Sanxingdui as a strong candidate which might have supplied copper to Hanzhong. If this is correct, it may well explain why people at Sanxingdui was able to achieve so striking metalwork and a wide range of network.

It appears slightly less likely that the raw copper for these objects at Sucun Xiaozhong were from the middle Yangzi River. As shown by the Panlongcheng metal objects

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with a variety of copper groups, the chemical signatures of copper along the middle Yangzi River are very complex, and thus differ significantly from that of Hanzhong. This chemical complexity could be reduced by the process of refining but it is hard to believe that refining could remove all impurities below 0.1%, as we seen in the objects at Sucun Xiaozhong.

Therefore, so far, in comparison with the current data from Laoniupo and the copper mines/objects along the middle Yangzi River, copper mines around either Hanzhong or Sanxingdui appear more likely as supply to Hanzhong in the Anyang period. Indeed, one has to very cautious as our understanding on mines at Laoniupo and along the middle Yangzi River is still not complete. To further test this argument, more works have to be carried out for slags, objects, and radiocarbon materials from Laoniupo and the middle Yangzi River valley.

5.4 Circulation of clean copper in Southwest China

As mentioned above, the dominance of CG1 (clean copper) at Hanzhong during the Anyang period is not an isolated case. This same phenomenon can also be found further southwest at Sanxingdui (CG1: 57%). Concerning the question of local production versus importation, the same analysis of objects at Sucun Xiaozhong can also be applied to those in the two sacrificial pits at Sanxingdui. Considering the chemical difference of objects between Sanxingdui and the middle Yangzi River, it becomes more likely that those of CGs1 and 2 (clean copper, As-only) at Sanxingdui

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were made from copper of either some unknown local sources, or imported from Hanzhong, but not from the middle Yangzi River, which may solve part of this long-standing debate centred on local production at Sanxingdui (Cui and Wu, 2013: 246-247; Rawson, 1996: 70-72; Bagley, 1988, 1990b; Thorp, 1999: 25; Falkenhausen, 2002 a and b).

By contrast, the metal chemistry in the Central Plains is more diverse. CGs1, 2, 9 and 12 (clean copper, As-only, As-Ag, As-Sb-Ag) are almost equally important at the site of Anyang (Figure 204). Meanwhile, both Hanzhong and Sanxingdui share a high reliance on radiogenic lead (Jin *et al*., 2006). Combining copper groups and lead isotopes illustrate a huge difference of metal used between southwestern China and that of the contemporary Anyang, where a great diversity of copper groups (CGs1, 2, 9, 12, clean copper, As-only, As-Ag, As-Sb-Ag) were circulated with both radiogenic and common lead (Jin *et al*., accepted; Jin *et al*., 1995; Jin *et al*., 2006).

It has become increasingly evident that the acquisition of copper and lead in southwest China and the Central Plains during the Anyang period was considerably different. Assuming that both are embedded in the same network (Pollard in press-a and b), one can draw the conclusion that these areas were emphasized on different parts of this network. The underlying reason might be attributed to their easier access to local deposits of copper and possibly lead.

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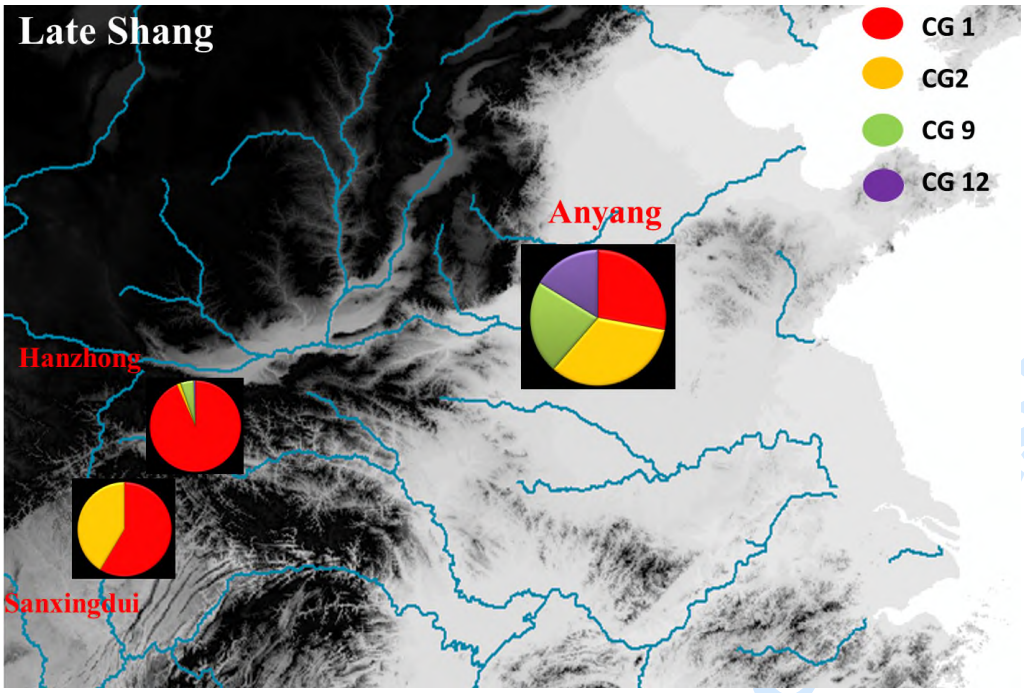

Figure 204 Copper group distribution in the late Shang period

5.5 Summary

Using a different method (the Oxford system), this chapter contributes to the discussion of the issue of production and movement of metal at Hanzhong and Sanxingdui. For the metal assemblage at Hanzhong, the new contribution is its considerable emphasis on CG1 (clean copper) of the metal objects found in the cache of Sucun Xiaozhong in the Anyang period, which remarkably contrasts to those objects dated to the earlier period, such as the Longtou caches. The typo-chronological analysis anchors Xushui to an intermediate stage, which shows continuity with earlier chemical signatures ("special alloying") and also foresees the subsequent rise of CG1 (clean copper). Putting the chemical data of the objects back

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their initial archaeological context and then comparing them along the chronological progression depicts a continuous life history on the metal production system at Hanzhong from birth to peak.

The majority of objects in Sanxingdui are also composed of CG1 (clean copper). Whilst the alloying technology of these objects has been extensively discussed in the literature, this discovery implies that all of these objects may share the same supply of copper as Hanzhong. This observation can be used as an independent indicator for mining surveys in the future. Although it is not yet possible to pinpoint the exact source of CG1 (clean copper), such a heavy reliance on this type of copper constrains the possibilities to within the south of the Qinling Mountains or the upper Yangzi River valley. More fieldwork in the future should be carried out in these regions.

Once we look beyond the Central Plains, the principal observation is the overwhelming use of CG1 (clean copper) in southwestern China. This stands out starkly in comparison with the Central Plains, where a variety of copper groups were used at Anyang. It appears more likely that Hanzhong and Sanxingdui during the Anyang period could share the same supply of CG1 (clean copper) whereas the Central Plains was reliant on multiple sources yielding different types of copper. The same story can be said for lead as well. While the strategies of acquiring metal in the Central Plains and southwestern China may be rather different, both were highly successful in building up giant metal production system.

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Chapter Six: a dynamic picture of metal production at Anyang

6.1 Introduction

In this chapter, I shall take up the most well-known site in the Bronze Age China, for major discussion. The site of Anyang (or *Yinxu*, 殷墟) is located around the present Anyang city and is often regarded as the last capital city of the Shang dynasty (*ca.* 1200-1046 BC, Chapter One). Decades of excavations at Anyang have revealed a huge variety of archaeological records in different kinds of materials. As a whole, these records illustrate a highly stratified society where the quality and quantity of materials accessed by top-elites, lower elites and ordinary people were remarkably different. Through integrating a range of evidence, including stratigraphy, pottery, bronzes and inscriptions, archaeologists routinely divide Anyang into four time phases termed Yinxu I to IV (*e.g.* Zou, 1964 a and b; Zheng, 1964; Zheng and Chen, 1985; Yue, 2004; Appendix I) .

Inherited from Zhengzhou, the bronze industry at Anyang is striking in many terms. Within this site, archaeologists have uncovered tens of thousands of bronze objects. The underlying metal production system has attracted huge scholarly attention since the very beginning. Moreover, the fact that its products, particularly bronze ritual

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vessels, appear in both the north and the south of the Central Plains, highlights its crucial position in the entire network of contact (Pollard *et al.*, in press- b).

This chapter revisits the seven most widely known chemical and isotopic databases through the Oxford system. The central questions in this chapter are twofold. Firstly, by using the Oxford system, what sorts of changes can be discovered through comparing chemical analyses of metal assemblages with each other? In particular, is it possible to visualize some compositional differences of metal objects used in different phases of Anyang or by people associated with different social status? If so, what are these changes and why? Secondly, to what extent was the metal production system at Anyang dependent on mixing and recycling? To be more specific, which parts of the metal production system were more likely to have relied on mixing and recycling and which not?

The argument is that, with the help of the Oxford system, it is feasible to discover and depict a series of changes in the chemical and isotopic compositions of metal assemblages. These changes are a result of, and reflect, the changes of metal supply/alloying practice in different time periods, the use of metal in a highly stratified society, and possibly some broader social movements. This comparative work starts to illustrate a considerable complexity of producing and acquiring metals in different contexts of Anyang and expands our understanding of the use of metal at this site.

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6.2 Characterization of key chemical databases for Anyang metals

6.2.1 Yinxu II phase: metal assemblage of Fu Hao

Data description

No large dataset has been published for the first phase of Anyang so we have to start from the second phase. Among the tombs dated to Anyang II phase archaeologists have found so far the only intact royal family tomb, that of Fu Hao, located in the Xiaotun village of Anyang (IA CASS, 1980). The rich tomb contents immediately highlight her important status. Though merely around 20 m^2, it yielded a remarkable inventory, encompassing 195 ritual bronze vessels, 271 weapons, tools and other small objects, 755 jades, nearly 700 stone objects, 15 pieces of shells, 3 ivory cups, 11 pieces of pottery, 8 human and 1 dog sacrifices (Figure 205). The total weight of metal is 1.6 tons (Bagley, 1999: 194-196). Moreover, a majority of the ritual vessels have inscriptions. The most common one is Fu Hao (Lady Hao), the name of the tomb occupant. According to many oracle bones, she was the consort of the King Wu Ding (*ca.* 1250-1192; Xia-Shang-Zhou Chronological Project, 2000: 60) and a highly important military leader. In archaeology, King Wu Ding is usually dated to the Anyang II phase so it is reasonable to say that Fu Hao was of the same period (Bagley, 1999: 194). This conclusion is also reinforced by the stratigraphy, typology of the bronzes, pottery and bone objects (*e.g.* Li, 1997; IA CASS, 1980: 221-230; Zheng and Chen, 1981).

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Figure 205 Selected objects from Fu Hao tomb,
pictures of jades after Institute of history and philology (2009)

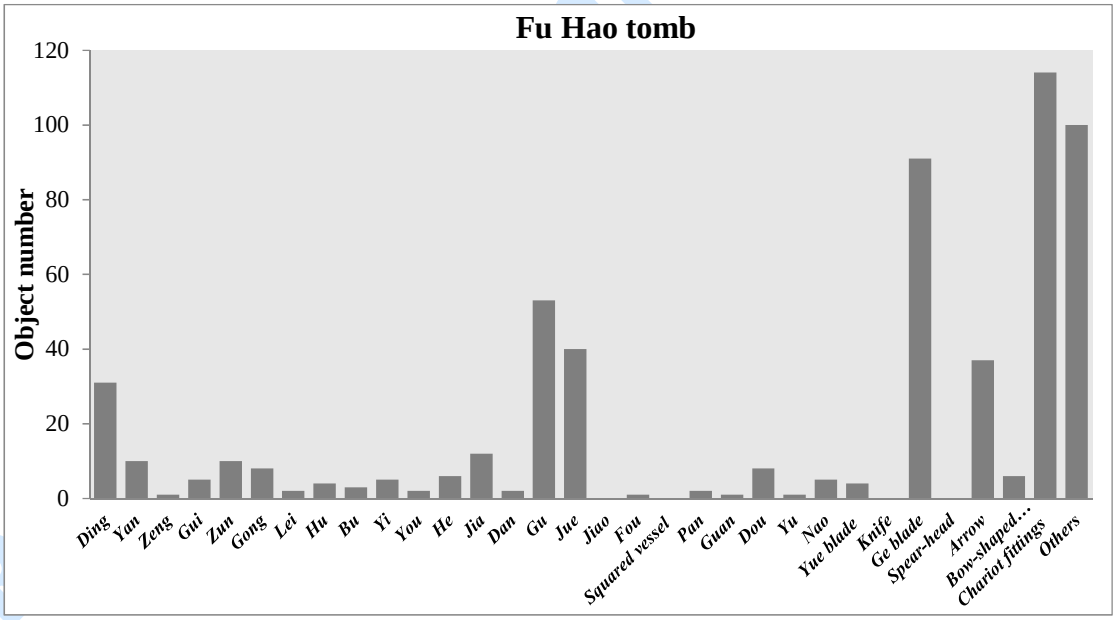

Figure 206 Summary of bronze objects in Fu Hao's tomb

Bagley (1999: 196) suggested that, in the light of the ritual vessels, there are at least three features which distinguish Fu Hao from the common people: the extraordinarily complicated designs, the huge size of some pieces, and the sheer quantity. In addition to the vessels, the other major category of weapons also deserves consideration. In particular, two huge bronze axe blades (*yue*, 钺) inscribed Fu Hao were unearthed, along with many steppe-type knives with animal heads, revealing her military and steppe identity. All of these observations highlight the bronzes of Fu Hao as representing the metals used by individuals of a high social status in the Anyang II phase.

In total, 91 objects have been analyzed with the method of wet chemistry for Cu, Sn, Pb and Fe, and AES for other elements (65 vessels, 12 weapons, 4 tools and 10 fragments). Forty eight out of them also have quantitative measurements on other elements of zinc, iron, nickel, bismuth, antimony, arsenic and silver (Li, 1982). The discussion in the original paper was mainly focused on the alloying elements (tin and lead). They found that vessels were made of both bronze or leaded bronze while weapons were exclusively bronzes (using 2% as the boundary for deliberate tin addition). The principal argument was that the purpose of adding lead was more likely to save the tin and improve the fluidity of the liquid during casting rather than reducing the melting point of alloying, since it can be lowered by only 83 degrees with 20% lead but 193 degrees with the same amount of tin. Instead, the addition of a proper amount of lead enables the alloying liquid to fill the moulds more efficiently

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and thus enhance the details of the decoration more effectively (Li, 1982). As observed by Li (1982), all of the analyzed weapons are tin bronze with less than 2% lead. Li suggested that this was due to the function of the weapons, as the lead can also reduce the hardness.

Data reprocessing

In the original dataset, Li also produced a wealth of information on trace elements. Using the methodology described in Chapter Two, two large copper groups show up, CG2 (As-only, ~55%) and CG9 (As-Ag, ~30%; Figure 207). Three much less insignificant copper groups are CG1 (clean, ~6%), CG3 (Sb-only, ~8%) and CG7 (Sb-Ag, ~2%).

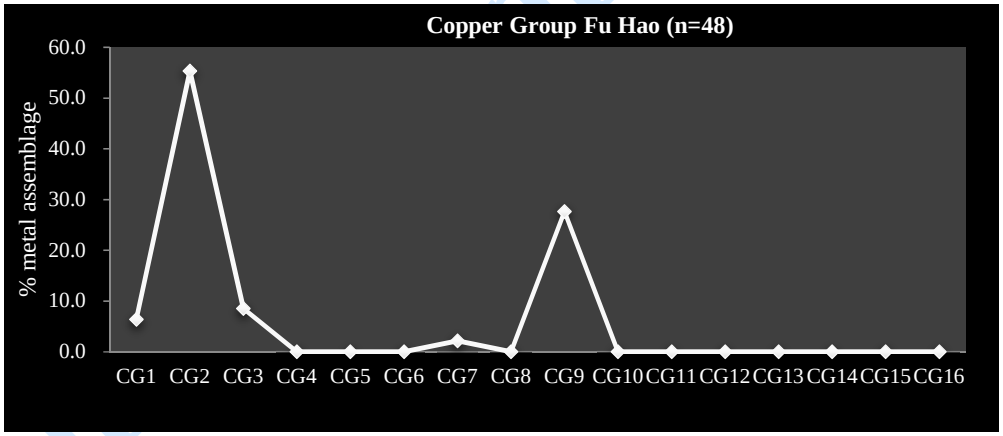

Figure 207 Distribution of copper groups of the Fu Hao metal assemblage

Further breaking down the category of vessels with most analyses shows that neither CG2 (As-only) nor CG9 (As-Ag) is unique to any single type of vessels (Figure 208 and Figure 209). Categories such as weapon contain too few analyses for any detailed division. The first observation is that typology and impurity patterns in this case are

not subject to a simple one-to-one relationship, suggesting that objects in the same type may have different copper groups.

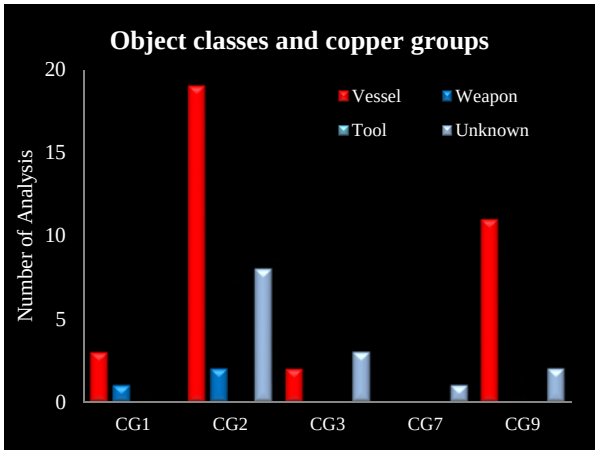

Figure 208 Summary of distribution of copper groups in each object class

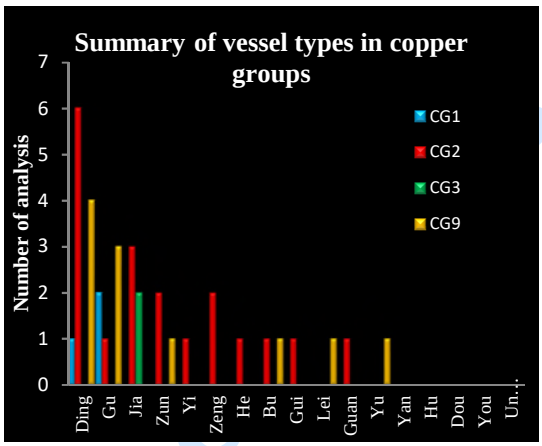

Figure 209 Summary of distribution of copper groups in each object class

What is more interesting is the plotting of the normalized concentrations of silver and arsenic (Figure 210, tin and lead removed). In fact, the actual difference of silver, which distinguishes CG2 (As-only) and CG9 (As-Ag), is very marginal. The maximum concentration of silver in these objects is only around 0.2%. Moreover, the concentrations of lead in objects of either CG2 (As-only) or CG9 (As-Ag) are no more than 3% so it is unlikely that the difference by silver is caused by addition of lead. Therefore, in this case, the CGs 2 and 9 (As-only; As-Ag) very likely represent the same type of raw copper. As discussed in Chapter Two, it is always essential to remember that the tool of copper groups involves two stages. One is the distribution of each copper group (presence/absence) and the other one is the exact percentages of

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the targeted elements (either profile analysis or scatter plotting). Combining these two stages together enables scholars to tell whether the different copper groups represent the different or same type of copper more clearly.

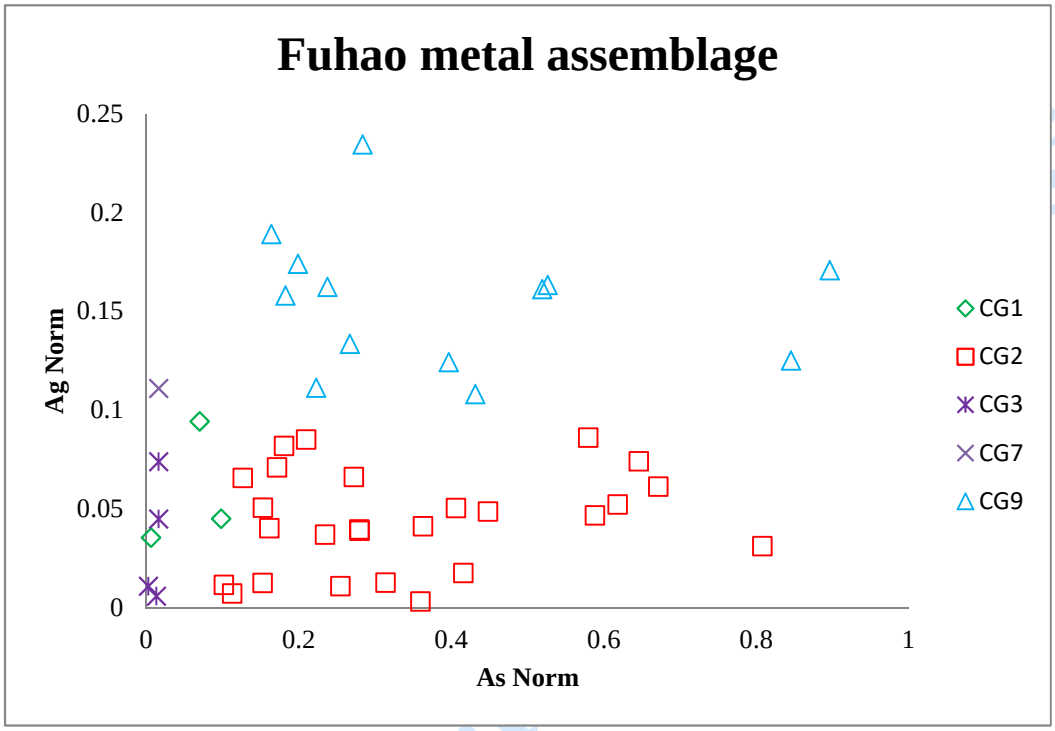

Figure 210 Distribution of arsenic and silver of the Fu Hao metal assemblage

It has been pointed out that the alloying types in the Fu Hao assemblage are primarily bronze or leaded bronze (Li, 1982). The profile of tin further shows a reasonably good symmetric or unimodal distribution (Figure 211). Around 90% of vessels contain tin between approximately 13-18%. The variation of tin in the weapons is slightly larger (~10-18%). Kolmogorov–Smirnov test under table shows that this visual difference suggests no statistically significant difference of the tin concentration in vessels and weapons (Observed maximum difference 0.23 < the critical value 0.41 on the confidence of 95%). By contrast, the profile of lead is confined to a very low

concentration in both vessels and weapons (0-3%; Figure 212). This phenomenon was noted in the original publication of Li (1982) and demonstrates a good command of alloying technology or a primary alloying signal. Given the high quality of these objects, their uniform trace elemental patterns and standardized alloying concentrations, it is further possible to argue that the objects discovered from the Fu Hao tomb were made from fresh metals and little recycling and mixing of old objects were involved.

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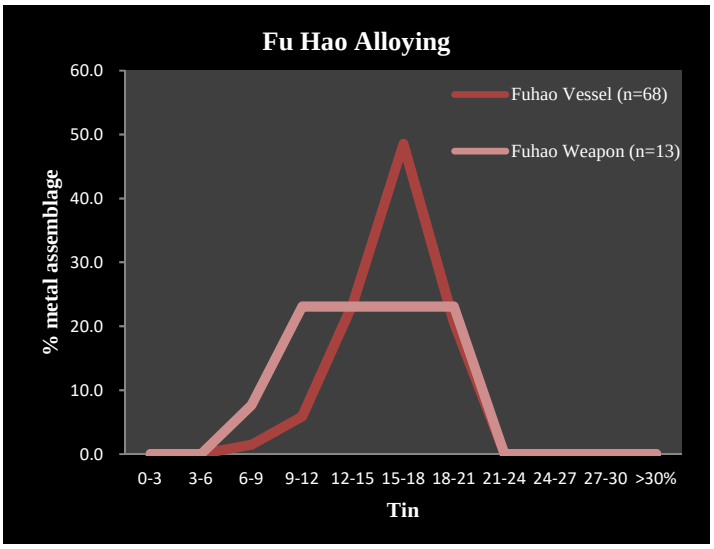

Figure 211 Distribution of tin and lead in the Fu Hao metal assemblage

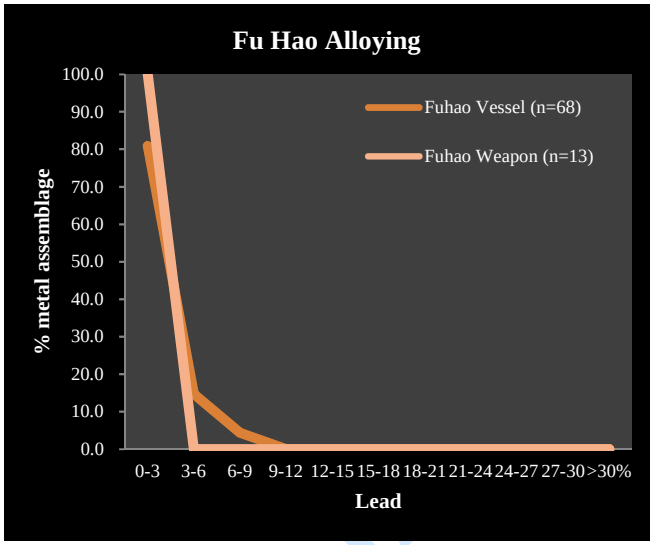

Figure 212 Distribution of tin and lead in the Fu Hao metal assemblage

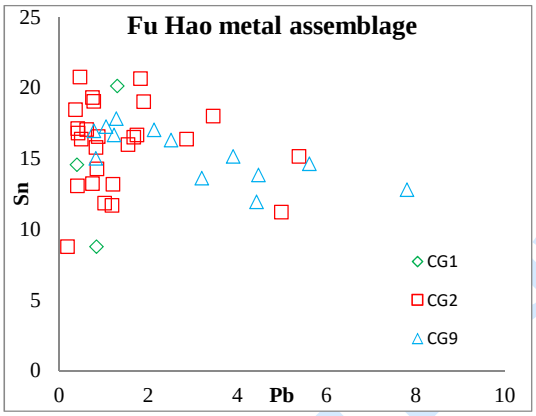

Figure 213 Distribution of tin and lead in the Fu Hao metal assemblage

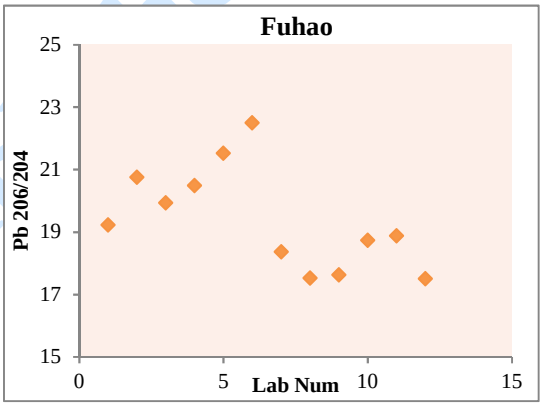

Figure 214 Plotting of $^{206}Pb/^{204}Pb$ of the Fu Hao metal assemblage (see Appendix XIII for plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

A few lead isotopic analyses of the Fu Hao metal assemblage have been reported in Li (2002b). However, their paper is about a general discussion on lead isotopes of Shang bronzes rather than a focus on the Fu Hao metal assemblage. Figure 214 shows the distribution of lead isotopic ratio $^{206}Pb/^{204}Pb$, which clearly includes both radiogenic lead and common lead.

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Two more metal assemblages dated to Anyang II phase have also been analyzed. The first one includes the bronze helmets interred from one of the king's cemetery (M1004) in Xibeigang of Anyang (Uchida and Iizuka, 2015). As show in Figure 215, the concentration of tin varies within a very small range. Nearly 90% of the 50 helmets contain tin between 12-18%. Meanwhile, the concentrations of lead in these helmets are all within ~0-2%, also a very narrow range. The pattern of both tin and lead in this case is extremely similar to that of vessels/weapons found at the Fu Hao tomb. No measurements on the four diagnostic trace elements and lead isotopes have been published for these helmets.

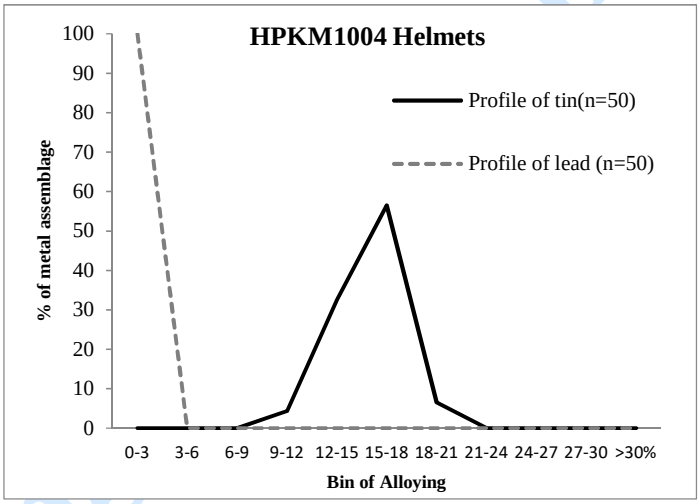

Figure 215 Distribution of tin and lead of the helmets in the king cemetery (M1004)

The other metal assemblage comes from Huayuanzhuang M54, a sizable tomb located just a few hundred metres to the southeast of Fu Hao. In *ca.* 15 m^2 archaeologists found 15 human sacrifices and nearly 600 objects, half of them being bronzes almost equal in quality to those seen in the Fu Hao tomb (IA CASS, 2007; Tang *et al.*, 1998; Xu and He, 2004). Moreover, Figure 216 and 217 show that the addition of tin was strictly controlled by the craftsmen. A similar illustration can be found in the original

report of analysis. Liu and colleagues argued that the deliberate controlled addition of tin shows the expertise on relationship between the alloying concentration and the resultant physical properties. The variation of using tin is related with the social rankings and periods of different individuals (Liu *et al*., 2007). One more point which can be added to the bronzes of M54 is the clear signal for primary alloying. In other words, these objects were very unlikely made by recycling other objects.

Based on the chemical analysis of metal objects in the three case studies (Fu Hao, M1004 and M54), it is more convincing to say that production of objects for elites were highly organized during the Anyang II phase and mixing or recycling finished objects as raw materials was very unlikely to be involved in the production of these elite objects.

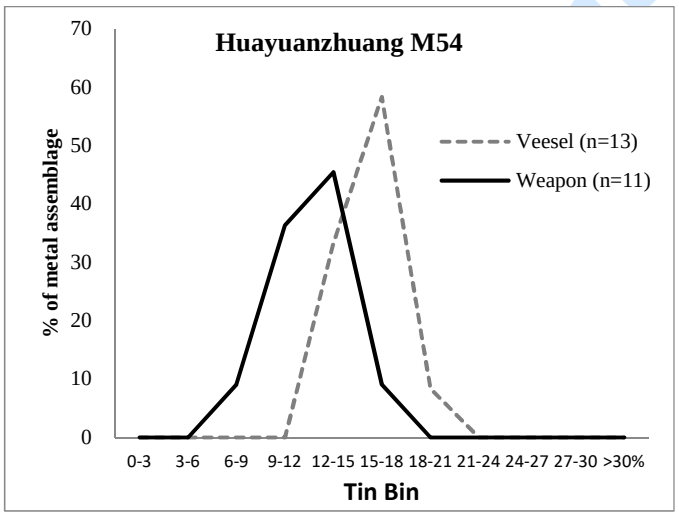

Figure 216 Distribution of tin in objects of Huayuanzhuang M54

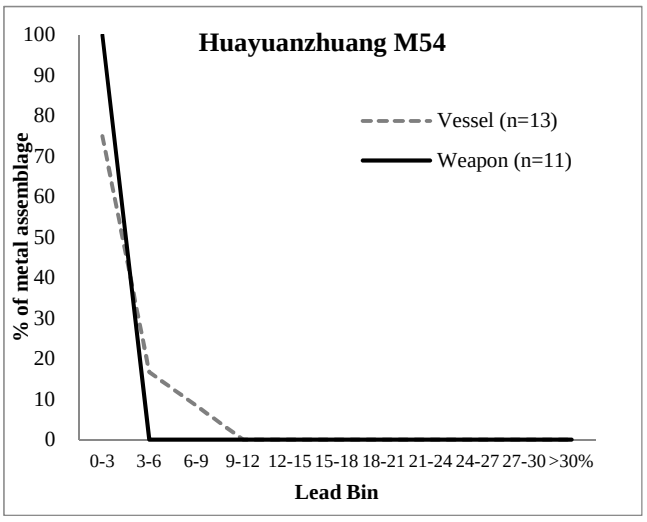

Figure 217 Distribution of lead in objects of Huayuanzhuang M54

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6.2.2 Yinxu III phase: Guojiazhuang M160

Data description

To the south of Anyang nearly 200 tombs have been discovered, which are collectively named after the Guojiazhuang tomb area (IA CASS, 1998). The number of tombs in each phase increased dramatically from the II to IV phase of Yinxu (Figure 218). Among them the most outstanding is M160. Similar to the Fu Hao tomb, M160 also represents an individual of high social status. His tomb is assigned to the third phase of Anyang, dated by typology of pottery, bronzes and inscriptions (Liu, 1998b; Yang and Liu, 1991; IA CASS, 1998: 124-126). Noticeably, located in the western part of this cemetery, M160 is probably the largest tomb in the Yinxu III phase, being approximately 12.5 m^2 (Figure 219).

Two hundred and ninety one metal objects were unearthed from M160. The total weight is up to 253 kg (IA CASS, 1998: 77). Before the discovery of M160, no burial in such size had been dated to this phase (Liu, 1998). The metal objects present a comprehensive picture for bronzes used in the late III phase. A full discussion of the typo-chronological analysis can be found in Liu (1998). There are four types of bronze inscriptions in this burial, *Yazhi* (亚址, 33 objects), *Yanhuzhi* (亚胡址, 3 objects), *Yahuzhi* (亚胡止, 5 objects) and *Zhong* (中, 3 objects). The character *Ya* (亚) is a military title and indicates a high social status. Its writing style also suggests a date in the Yinxu III phase (Yan, 2013: 124-126). The rest could be a clan sign (IA CASS, 1998: 124-126).

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Twenty six of these objects have been analyzed by Ji (1997) with wet chemistry for Cu, Sn, Pb, Zn, Fe and AES for others. As with the research in Li (1982), Ji (1997) also focused on the alloying types. Using 3% as the boundary instead of 2%, he discovered that apart from bronze and leaded bronze, M160 also has alloying types of pure copper and leaded copper. Inspired by the alloying types of the Fu Hao objects, which are predominately high-tin bronzes (also a few leaded bronze objects), Ji (1997) argued that tin, which is much rarer than lead, may have been linked to the social status of an individual. Therefore, the ritual vessels found in M160 are mostly high tin and low lead, which is similar to those of Fu Hao. The reasonable addition of lead can reduce the consumption of tin without sacrificing the technological properties of the object, such as hardness or colour. More intriguingly, the weapons of M160 contain more lead than the ritual vessels in the tomb (see below). Ji pointed out that the hardness of a weapon alloyed with lead becomes much lower than one alloyed with an equal amount of tin. For instance, the hardness of one weapon with 18-20% lead is only 60-70 HV but if it is alloyed with the same amount of tin, its hardness is around 170. Therefore, in theory, it is possible that leaded weapons were made for burial purposes rather than for practical use (Ji, 1997). While Ji (1997) presented a discussion on alloying type, little attention was given to the profile of tin and lead. Other elements were omitted.

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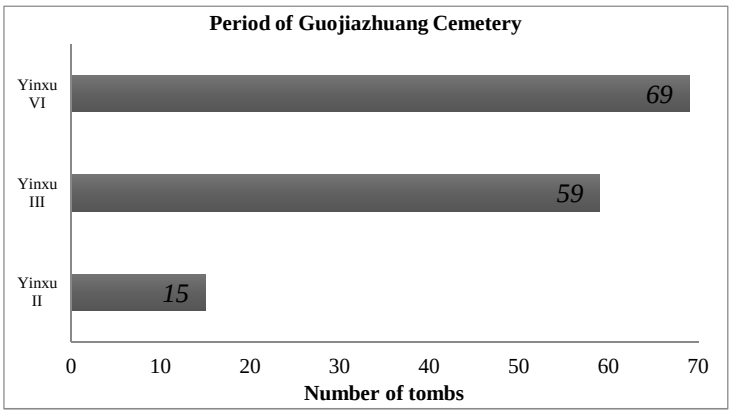
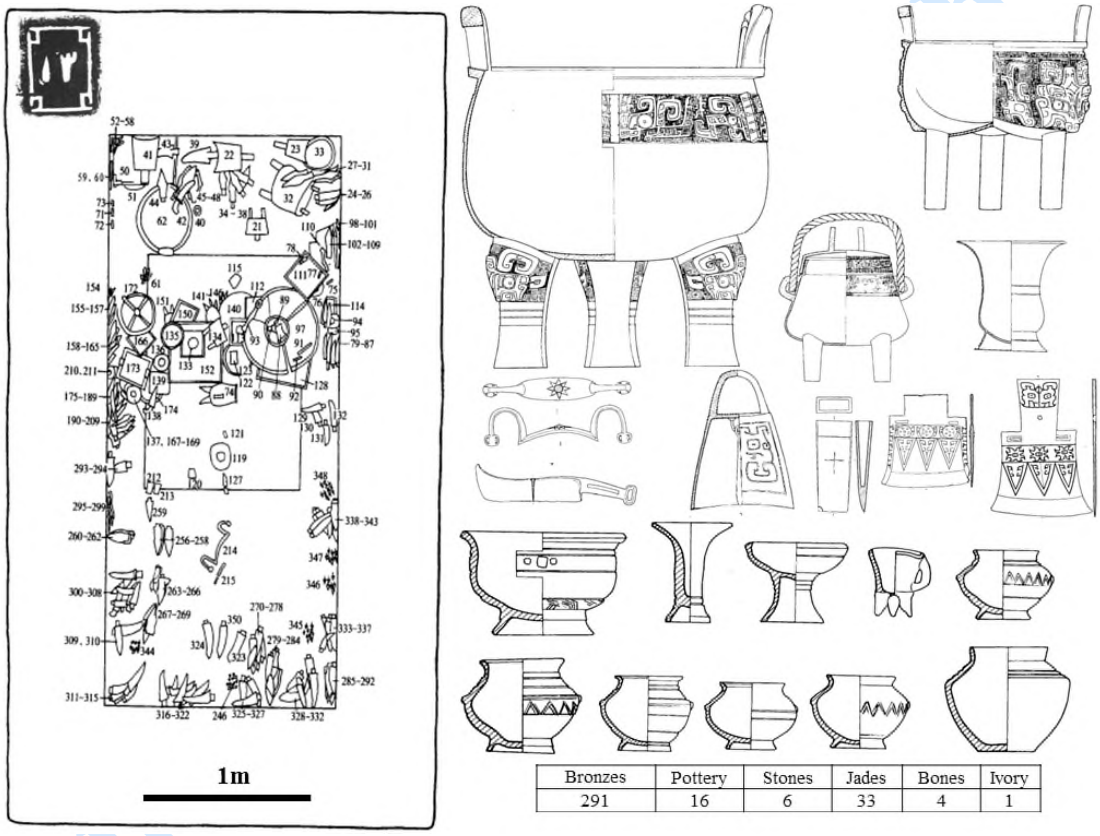


Figure 218 Number of tombs in each phase in the Guojiazhuang cemetery（IA CASS, 1998: 51）



Bronzes	Pottery	Stones	Jades	Bones	Ivory
291	16	6	33	4	1

Figure 219 The plan and contents of Guojiazhuang M160 (after IA CASS, 1998)

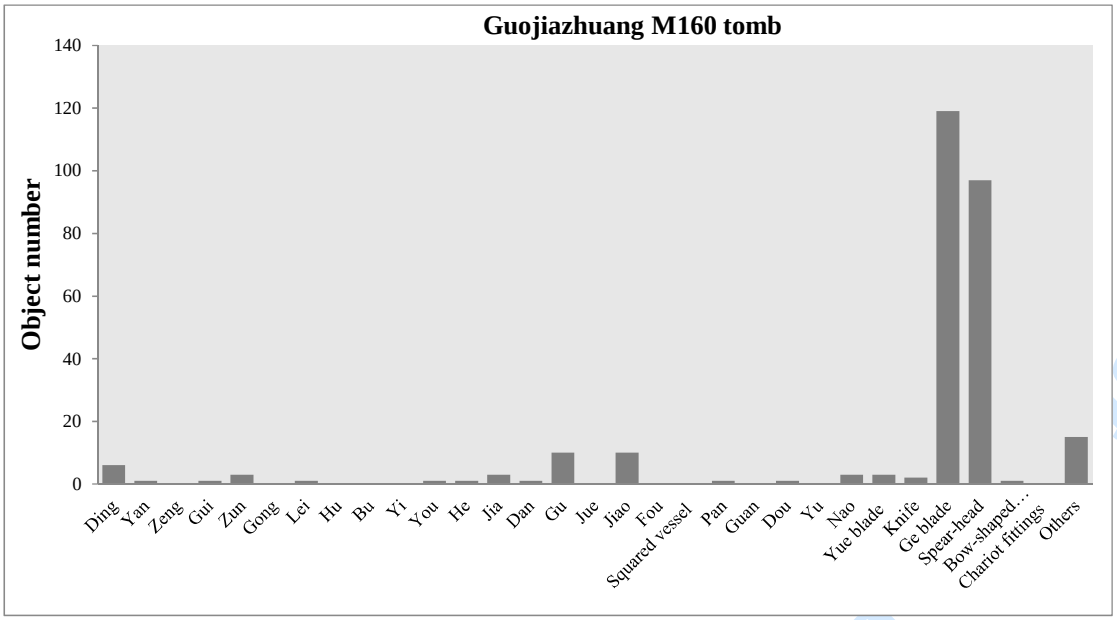


Figure 220 Summary of objects in Guojiazhuang M160 tomb

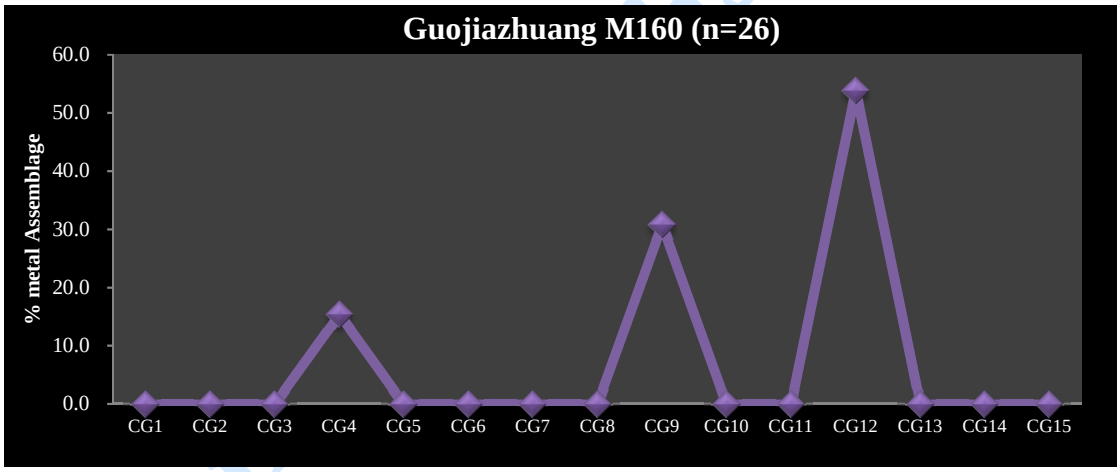


Figure 221 The distribution of copper groups in Guojiazhuang M160

Data reprocessing

The reason that M160 has been used for this discussion is not only attributed to its archaeological importance but also the fact that this is the only tomb in Yinxu III have the bronze objects been chemically analyzed and reported on a large scale. The

measurements of trace elements were conducted by atomic emission spectroscopy (AES) and the results were only reported in qualitatively (Ji, 1997). Ji used three categories to describe his results, "微" (trace amount), "√" (present) and "-" (characteristic line of the targeted element can be found). No information on the minimum detect limit has been provided in his original paper. We found the measurements of nickel are problematic. This is because at least fourteen objects in Ji (1997) have also been analyzed by Zhao (2004) with atomic emission spectroscopy, of which the minimum detect limit is around 0.005%. Nevertheless, Zhao's results show that the concentrations of nickel in most objects are no more than 0.02%, with only two exceptions (M160:111, *jia* 斝, nickel 0.106%; M160:152, *zun* 尊, nickel 0.139%). Unfortunately, only the results on Cu, Pb, Sn, Zn, Fe, Bi, Ni and Ag have been reported in Zhao (2004). Silver appears consistent between the two papers. It is indeed frustrating to find that for such important archaeological discovery the related scientific analysis has not been thoroughly done. Considering the limitations of these analyses, this thesis has to make an assumption that his category "微" (trace amount), "√" (present) imply that the elements are more likely present, except for nickel.

Figure 221 shows that the major copper groups include CG4 (Ag-only, ~15%), CG9 (As-Ag, 31%) and CG12 (As-Sb-Ag, ~54%; Figure 221). Except for CG9 (As-Ag), the other two copper groups are not found in the earlier Fu Hao assemblage. It is not possible to do profile analysis since all of trace elements are merely qualitatively reported.

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As noted by Ji (1997), the alloying types in Guojiazhuang M160 become more diverse, including pure copper, leaded copper, bronze and leaded bronze. Furthermore, the profiles of lead and tin (Figures 222 and 223) show that the pattern of alloying in vessels is very similar to that of the Fu Hao tomb. An approximately normal distribution of the tin can be seen in the vessels (~10-17%) and the concentration of lead is very limited (<5%). In weapons, however, the addition of lead is far more substantial (~2-20%), but tin appears more restricted (<5%). No lead isotopic analyses have yet been published for this metal assemblage. By comparison with the earlier metal objects in the Fu Hao tomb, M1004 and M54, the alloying practice represented by these in M160 appears less well controlled.

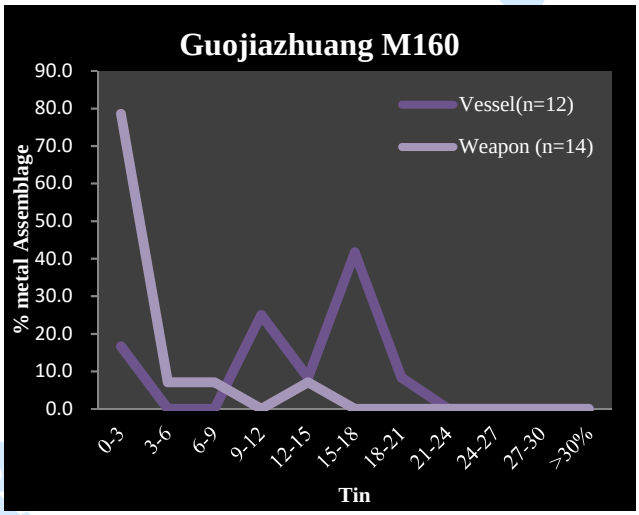

Figure 222 Distribution of tin in Guojiazhuang M160

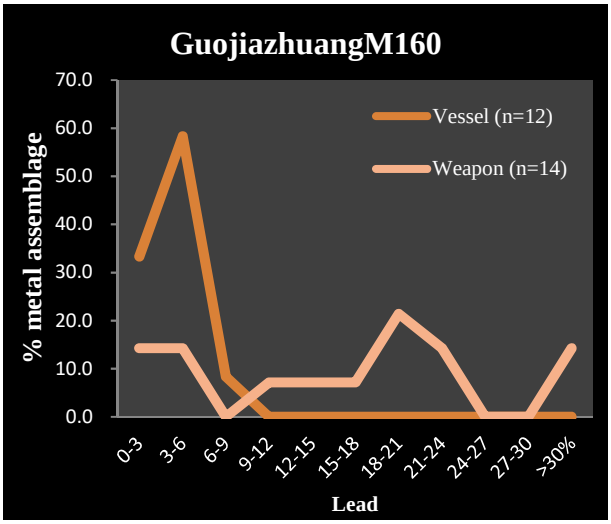

Figure 223 Distribution of lead in Guojiazhuang M160

6.2.3 Yinxu IV phase: North Liujiazhuang M1046

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Data description

The tomb of North Liujiazhuang M1046 is located in the south of Anyang, where over one thousand tombs have been found. The structure and size of M1046, together with its great wealth of objects and human sacrifices, show that this tomb was clearly superior to the others in this area. M1046 is widely regarded as the standard assemblage for the Anyang IV phase (IA CASS, 2004).

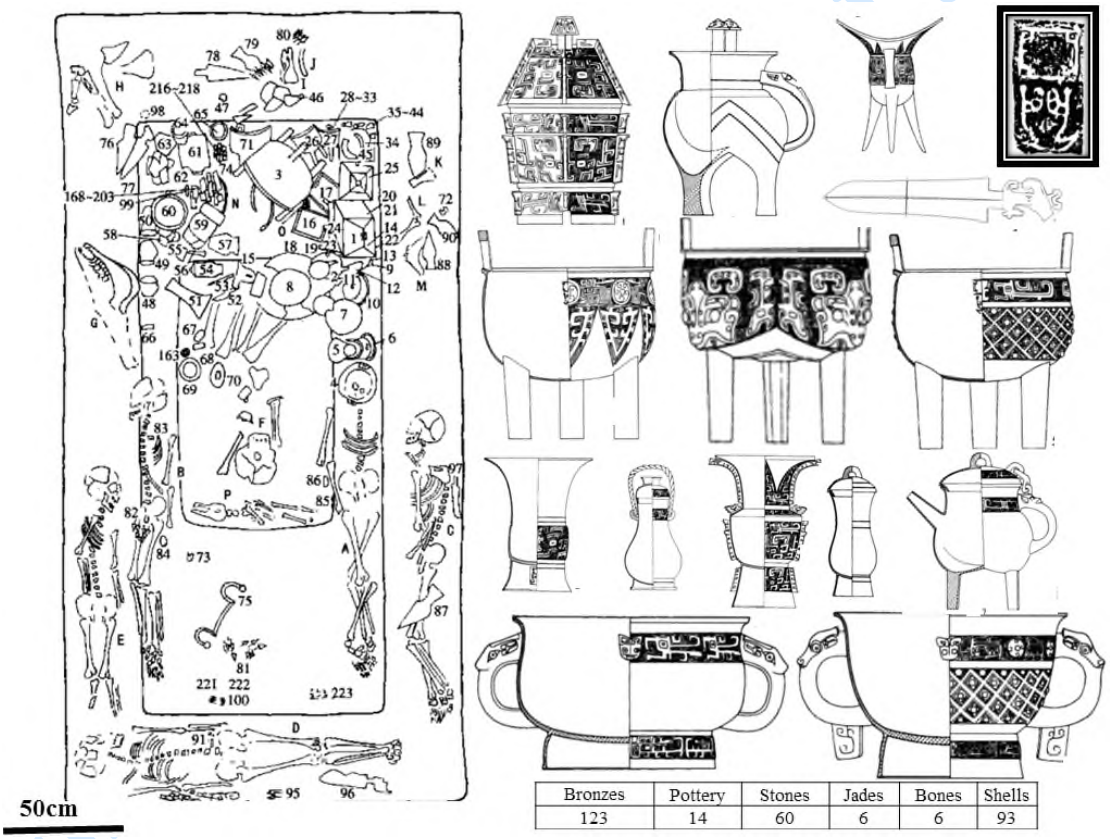

Figure 224 The plan and contents of N. Liujiazhuang M1046 (after IA CASS, 2004)

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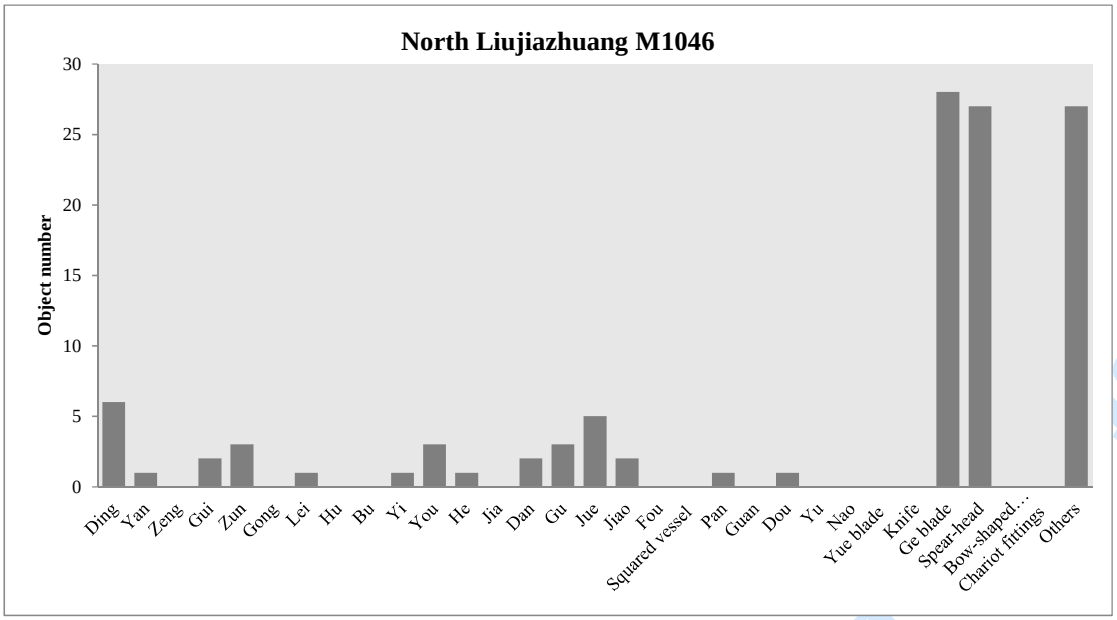

Figure 225 Summary of objects in North Liujiazhuang M1046 tomb

The chemical analyses by ICP-AES of nine vessels are reported (Zhao *et al*., 2008). The remarkable use of lead attracted her attention. On the one hand, considering the fact that lead is less effective than tin in improving the hardness and reducing the melting point of alloying, Zhao *et al.* (2008) argued that such a high leaded recipe was not a wise choice in terms of technology, though it could save a large amount of tin. But she also admitted that such a high addition of lead can increase the fluidity of alloying liquid which allows it to fill the moulds better and thus achieve finer decorations. However, Mei *et al.* (2009: 1885) pointed out that the fluidity or the mould-filling capability deceases dramatically if the lead percentage is over 15%. Considering this, the casting-ability might not be the fundamental driving force for such a high addition of lead (~27%) in these ritual vessels.

On the other hand, these analyses reinforce her observation that leaded bronze gradually replaced bronze from phases II to IV of Anyang (Zhao, 2004, see below).

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Therefore, highly leaded bronze, in particular, is one major feature of metal objects in Anyang phase IV (Zhao *et al*., 2008). There is little discussion of the trace elemental patterns in her paper though a range of elements are reported, including As, Ag, Ca, Fe, Sb and Zn.

Data reprocessing

The major feature reflected by the analyses of Zhao *et al.* (2008) is the profile analysis. It shows that all of them contain a very low amount of tin (4-6%) but a strikingly large amount of lead (24-28%), as shown by two distinctive peaks in Figure 226 and 227. The variations of tin and lead are extremely narrow (<4%) and illustrate a typical signal of primary alloying. If these vessels were made by randomly mixing/recycling old objects containing unknown amounts of tin or lead, they would more likely contain a much wider range of alloying elements. Therefore, this designed alloying also suggests that little mixing and recycling was involved to produce these elite vessels.

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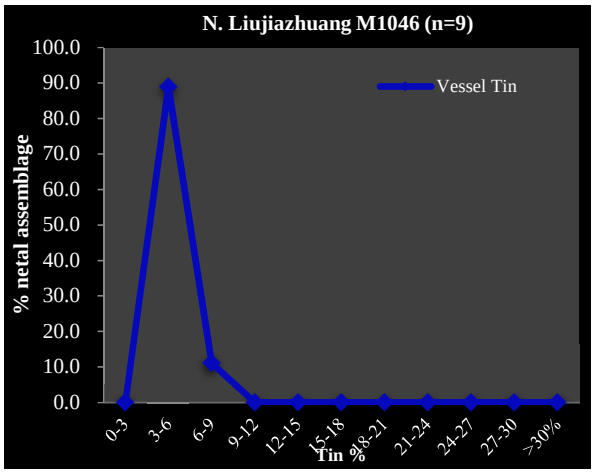

Figure 226 Alloying distribution of N. Liujiazhuang M1046 metal assemblage

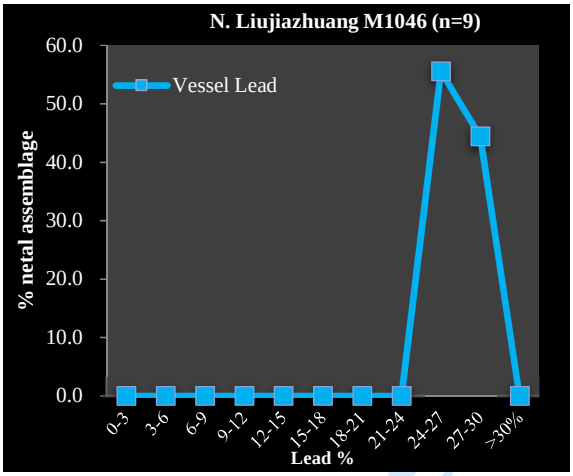

Figure 227 Alloying distribution of N. Liujiazhuang M1046 metal assemblage

The two diagnostic peaks in Figure 228 represent two copper groups (CG6 As-Sb, ~45%; CG9 As-Sb-Ag, ~55%) which predominate in the nine analyzed vessels in M1046 (Although nickel is not reported, based on the analyses of over 200 objects in Zhao (2004), it is reasonable to assume that nickel is absent). The difference of these two copper groups (CG6, As-Sb; CG9, As-Ag) lies in the concentration of silver (whether or not it is over 0.1%). However, the second stage of plotting the exact concentrations of silver reveals no significant difference. The maximum concentration of silver is only around 0.09% and only by taking out of tin and lead the concentration of silver of some objects becomes just over 0.1%, but still very close (Figure 229). Therefore, it seems that the two different copper groups might actually represent the same copper, which has been seen in the case of Fu Hao. In comparison with data of bronzes interred from Fu Hao, the major difference shown by M1046 (also M160) is the presence of antimony. Figure 230 shows that the variation of antinomy ranges from 015-0.45%.

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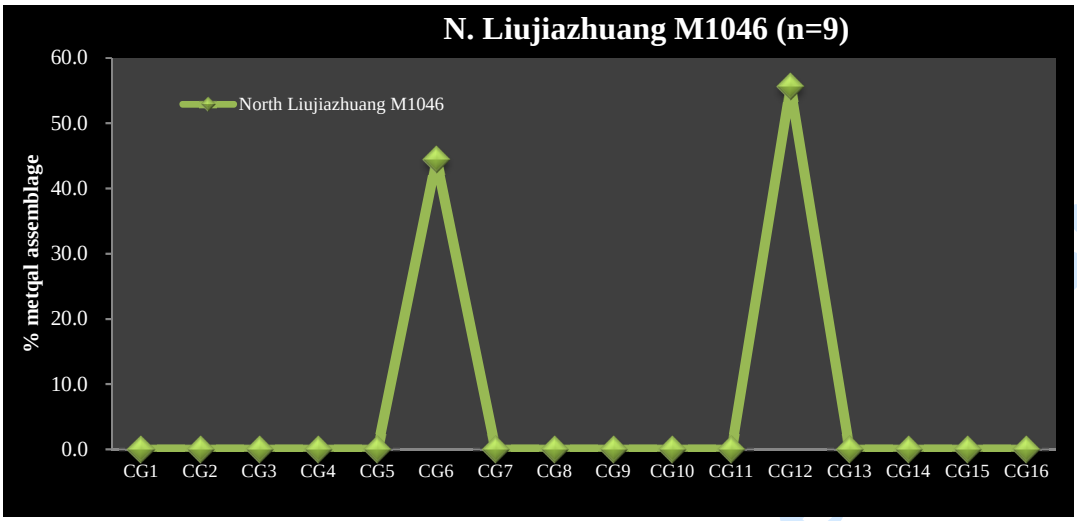

Figure 228 Distribution of copper groups

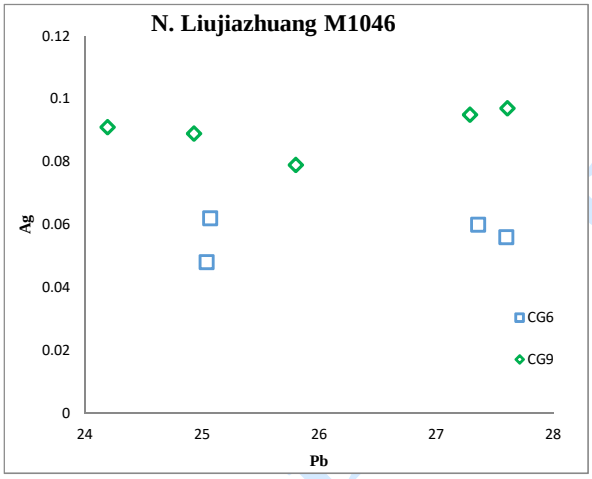

Figure 229 Distribution of trace elements in N. Liujiazhuang M1046

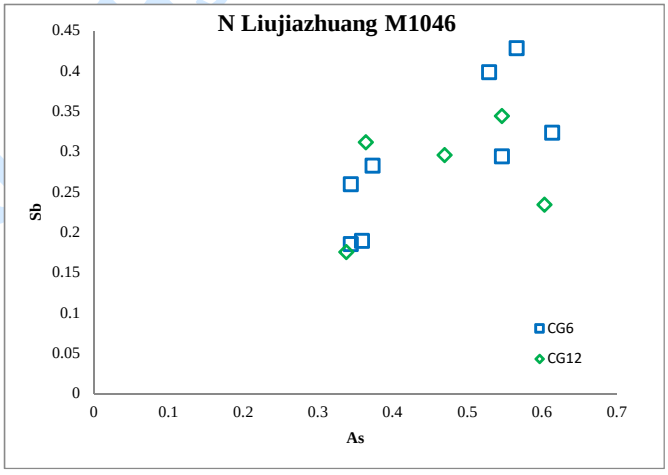

Figure 230 Distribution of trace elements in N. Liujiazhuang M1046

6.2.4 The Western Area

Data description

The Western Area (*Yinxu Xiqu*, 殷墟西区) is one of the most important sections at Anyang. It has revealed over one thousand tombs which can be further divided into

eight major areas (IA CASS, 1979; Figure 231). The chronological sequence of the tombs has been based upon pottery typology (IA CASS, 1979: 108-113; Han, 1997). This analysis suggests that the Western Area came into use by Anyang phase II and continued to receive burials down to the fall of the Shang (Figure 232; Han, 1997). Although the nature of the Western Area remains unclear (Han, 1997; Yang, 1999; Campbell, 2007: 151), the size and structure of the tombs, the limited number of objects and their poor quality suggest that these tombs with bronzes were more likely made for lower-elite persons rather than that of Fu Hao, or the top one of M160 or M1046.

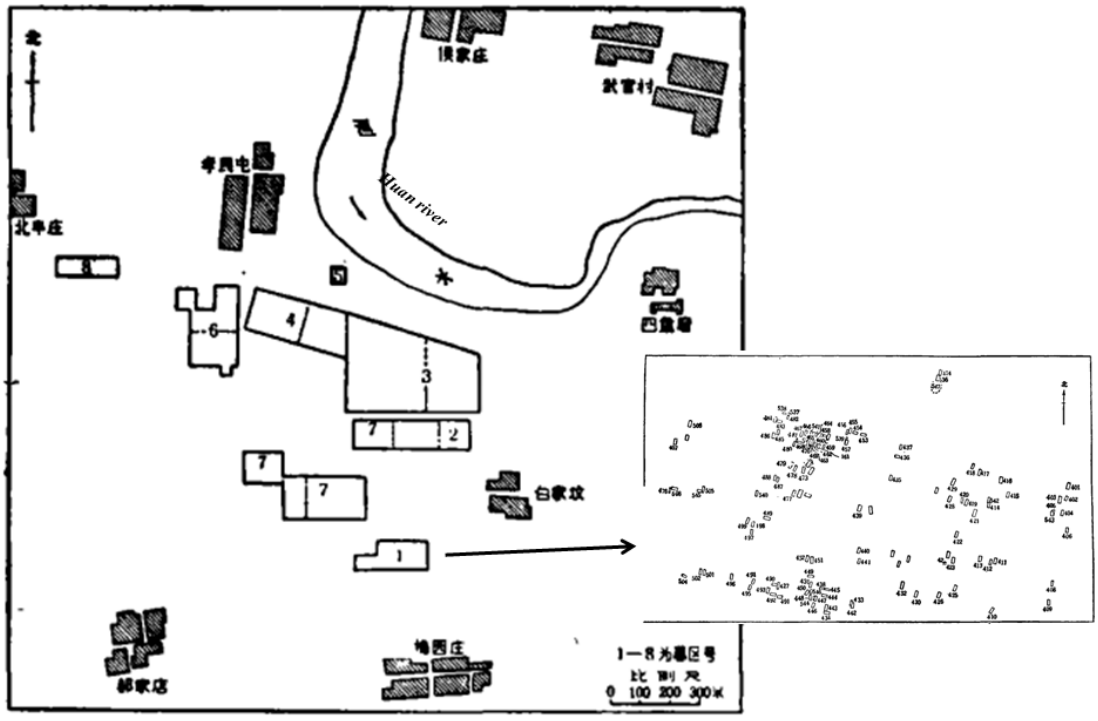

Figure 231 Plan of the Western Area (the number 1-8 in the big map represents each of the eight sections in the Western Area and the intersect map is the distribution of tombs in the first section; after IA CASS, 1997)

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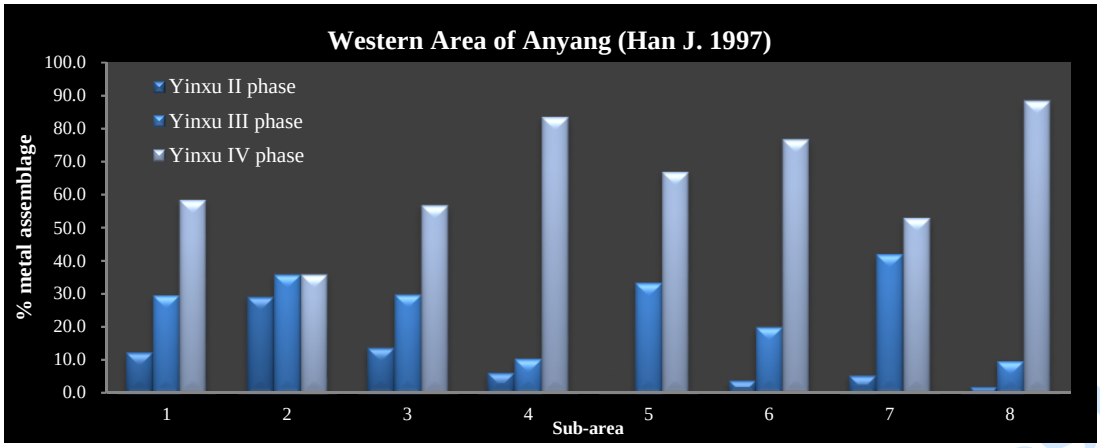

Figure 232 Chronology of tombs in the Western Area (data from Han, 1997)

The chemical composition of 43 objects has been reported from 25 tombs of the Western Area, 28 of which include trace elements (Li *et al.*, 1984; wet chemistry for Cu, Sn, Pb, Zn and AAS for others; Figure 233). As with the discussion of the metals in Fu Hao's tomb, Li and colleagues focused primarily on the alloying types. All of the four major alloys (pure copper, leaded copper, bronze and leaded bronze) were in the Western Area (Li *et al.*, 1984). A number of their observations are thought-provoking. High-tin ritual bronzes were more common in the earlier periods of Anyang but later periods saw an increasing use of leaded bronze. One possible explanation Li and colleagues proposed for this change in alloying composition was technological determinism, such as the pursuit of colour or the improvement of hardness (Li *et al.*, 1984). The other possible answer might be that, as time passed, difficulties in the supply of tin became more acute. As a result, it had to be gradually replaced by lead (Li *et al.*, 1984). The second observation made by Li and colleagues was that weapons buried with ritual vessels were all bronze or leaded bronze, while

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those of leaded copper and pure copper were more likely to be found in the tombs with no ritual vessels. This phenomenon might suggest that the alloying recipes were related to the social status of the tomb occupants (Li *et al*., 1984).

Data reprocessing

The first defining feature of the copper assemblages from the Western Area is that a variety of copper groups are present in almost even proportions. These include CG1 (clean copper, ~7%), CG2 (As-only, ~17%), CG6 (As-Sb, ~14%), CG9 (As-Ag, ~17%), CG12 (As-Sb-Ag, ~28%) and CG16 (~7%). Consequently, we see several peaks of observable height in Figure 234, instead of only one or two major peaks as found in the elite tombs of Fu Hao, M160 and M1046. Plotting absolute percentages of trace elements in various combinations reinforce this impression of diversity (Figure 235 and 236). For instance, the concentrations of arsenic and antimony present a wide range, from ~0.0 up to 1.6% and 1%, respectively. These are considerably larger than the variation in the objects of Fu Hao and M1046 and may indicate multiple sources of copper.

Interestingly, CG6 (As-Sb) and CG12 (As-Sb-Ag) in this metal assemblage appear in a pair. The reason that CG6 (As-Sb) and CG12 (As-Sb-Ag) can form a pair is that these two copper groups differ from one another only by one element. In this case, it is the presence or absence of silver. Theoretically, the concentration of silver can be enhanced by alloying or realloying with silver-rich lead. Plotting silver against lead

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shows a linear regression (Figure 237). This suggests that adding a large amount of silver-rich lead in this case could have moved CG6 (As-Sb) into CG12 (As-Sb-Ag), probably through (re)alloying. One can even guess that 100% lead could contain around 0.6% silver, which appears quite reasonable. The silver associated with Galena is normally no more than 1% (see below).

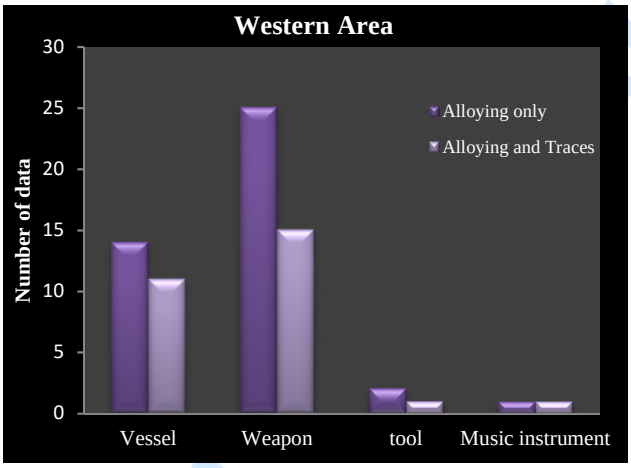

Figure 233 Summary of chemical analysis in the metals of the Western Area

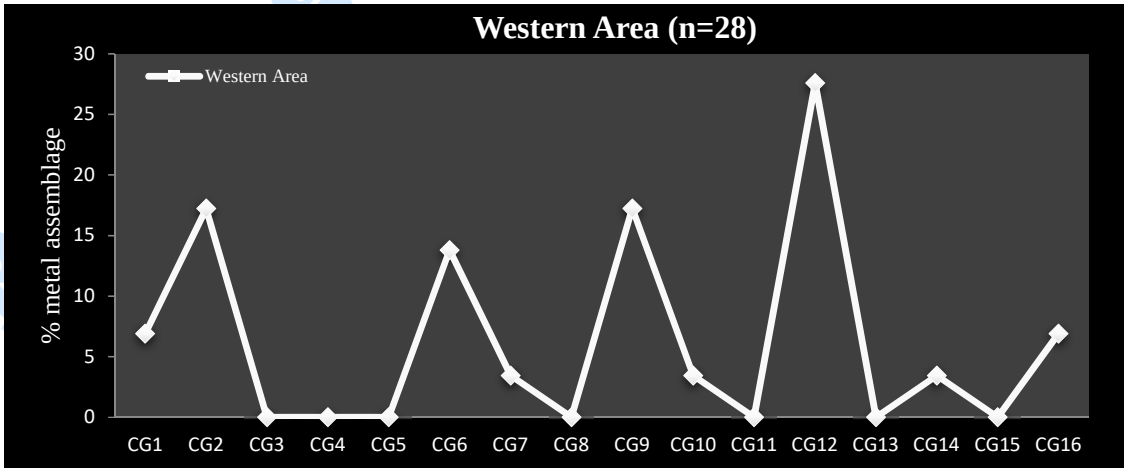

Figure 234 Distribution of copper groups in the Western Area

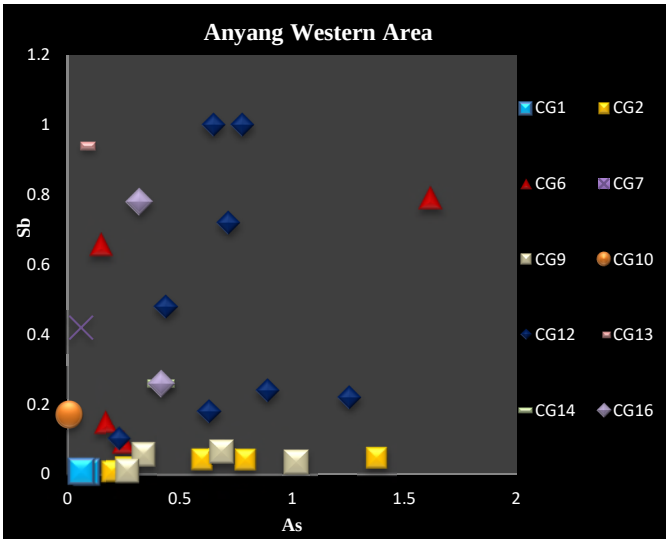

Figure 235 As and Ni in the Western Area

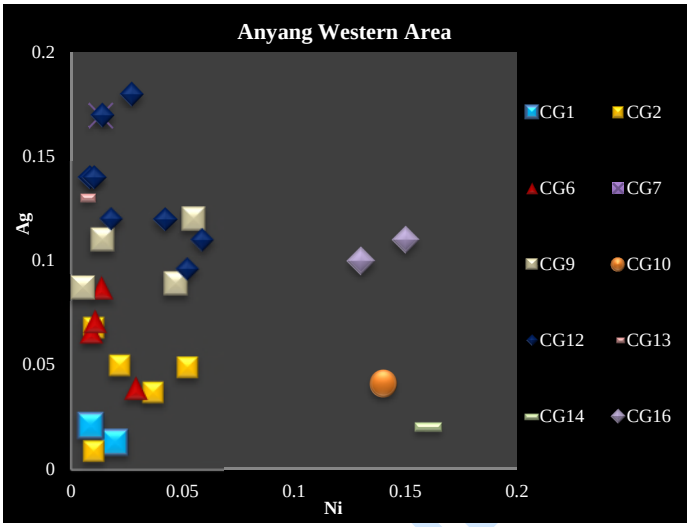

Figure 236 Ni and Ag in the Western Area

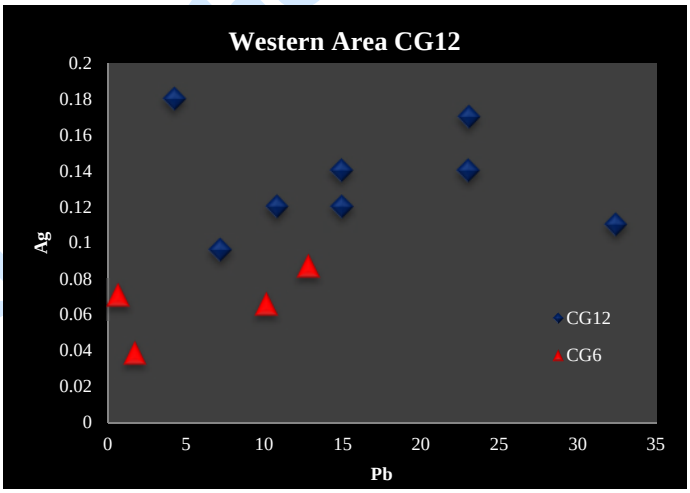

Figure 237 Ag and Pb in the Western Area

No symmetric distributions of tin and lead can be seen in the Western Area. However, the skewed pattern is common (Figure 238 and 239). While around 80% of analyzed objects contain tin less than 6%, some are still very rich in tin (~15%-20%). This is also true for the distribution of lead. The reason that the slope of the lead distribution is slightly less than that of tin is that the lead concentrations in several objects are over

Puiliang Liu

25%. This suggests a non-control of alloying elements. Mixing and recycling old/abandoned objects with unknown amounts of tin and lead was very likely involved in the production of metals found in the Western Area, which also echos the diversity revealed by the trace elements.

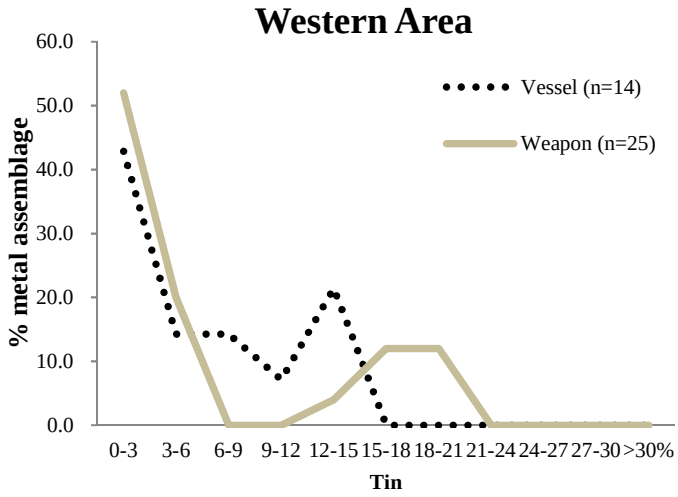

Figure 238 Tin distribution in the Western Area

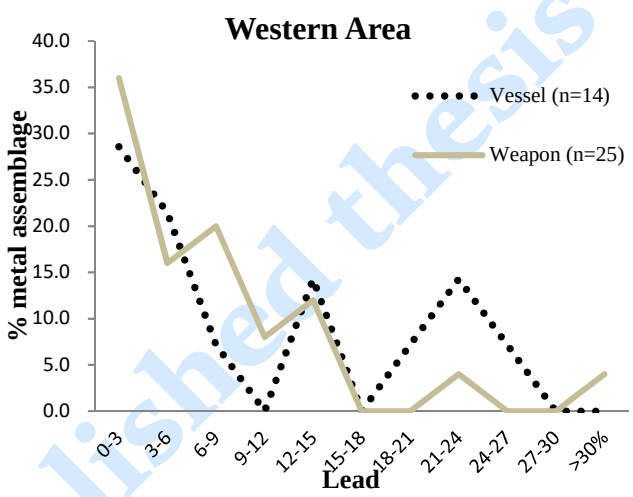

Figure 239 Lead distribution in the Western Area

6.2.5 Reprocessing the data in Zhao (2004)

Zhao (2004) analyzed the chemical compositions of 208 objects excavated at Anyang with AAS. More importantly, she has also recorded the chronological phase of each sample based on the four-phase framework. As noted by Zhao, the alloying patterns were not static at Anyang. It is a combination of technology, time periods and social status. There are a number of reasons for this situation, including the necessity for certain physical properties, the changing function of the objects, changing supply of tin and lead ,and using materials to reflect social status.

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Quoted from Zhao (2004: 256)

“铜合金的成分对铸造及机械性能有直接的影响…如果加入一定量的铅以代替部分锡的话，不仅可以起到降低熔点的作用，而且还可以有效地避免高锡铜的脆性。相应地提高了合金的充型能力...从殷墟文化一期到殷墟文化四期，铜容器中锡含量明显下降，铅含量逐渐升高。这可能是由于大部分铜容器为随葬品，其机械性能要求不高所致。兵器在殷墟文化一期到三期，锡含量逐渐降低，铅含量逐渐升高，与兵器在实际应用中要求锋利坚韧发生矛盾…不同级别墓葬中铜器的合金类型有很大区别。”

Translated: “the percentage of alloying has a direct impact on the casting process and mechanical properties… adding lead to replace tin can reduce not only the melting point but also the brittleness of high-tin bronze. Therefore, the alloying liquid can fill the moulds more sufficiently. From Anyang I phase to IV phase, the use of tin and lead were quite different, with the former being radically decreased whereas the latter being increased. This might be attributed to the possibility that these objects were made for burial purpose so few requirements of mechanical properties were needed. A similar pattern can be seen in the category of weapons but this is in contradictory to their practical purpose, such as hardness…Alloying types of metal assemblages in tombs of different status were hugely different.”

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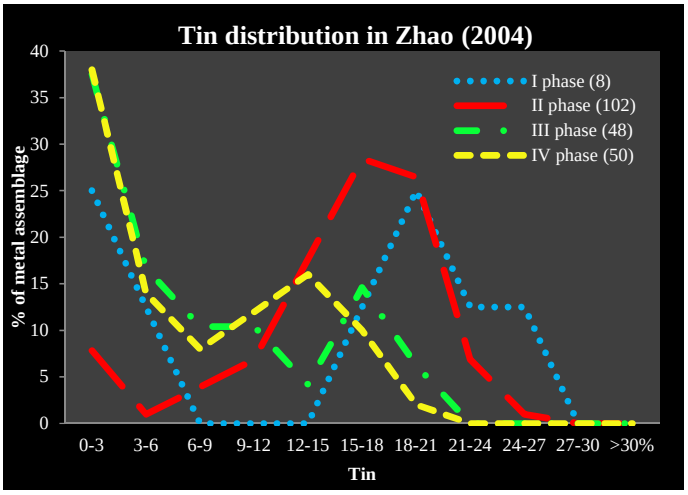

Figure 240 Variation of tin and lead across Yinxu four phases

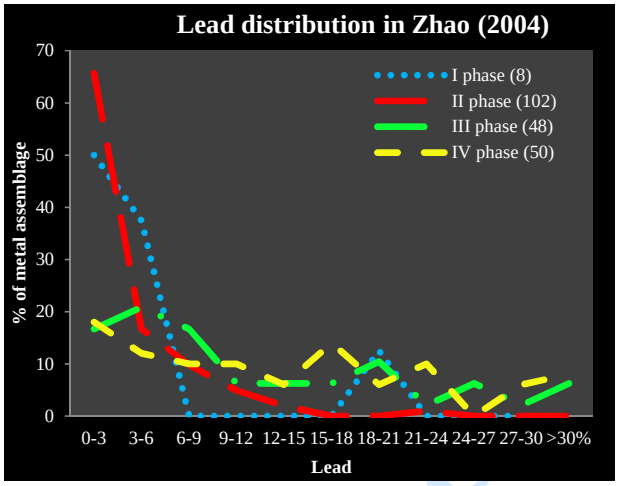

Figure 241 Variation of tin and lead across Yinxu four phases

One point that has not been explored in Zhao (2004) was the relationship between of the concentration of silver and lead. The relationship between lead and silver is important is that it can potentially affect the results of the copper group. In natural state, these two elements could occasionally be existed together. The concentration of silver in the lead mines (*e.g.* galena) ranges from approximately 0.03 to 0.5%. In general, the amount of silver in the lead ingots (presumably lead concentration close to 90-100%), or the yield of silver from galena, would be a few hundred ppm (<0.1%; Tylecote, 1987: 69).

This issue has been touched in previous discussion on the metal assemblage of the Western Area but the number of the analyses is very limited. The large set of data in Zhao (2004) provided an excellent opportunity to explore this issue more thoroughly. Figure 242 plots the silver against lead. Clearly, there is no simple relationship

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between these two elements. Although the amount of silver in some objects may have been affected by the considerable addition of lead, however, a large number of the analyses in which lead levels are less than 8% also contain a high proportion of silver (>~0.5%). This observation underlines the complexity of the lead supply at Anyang.

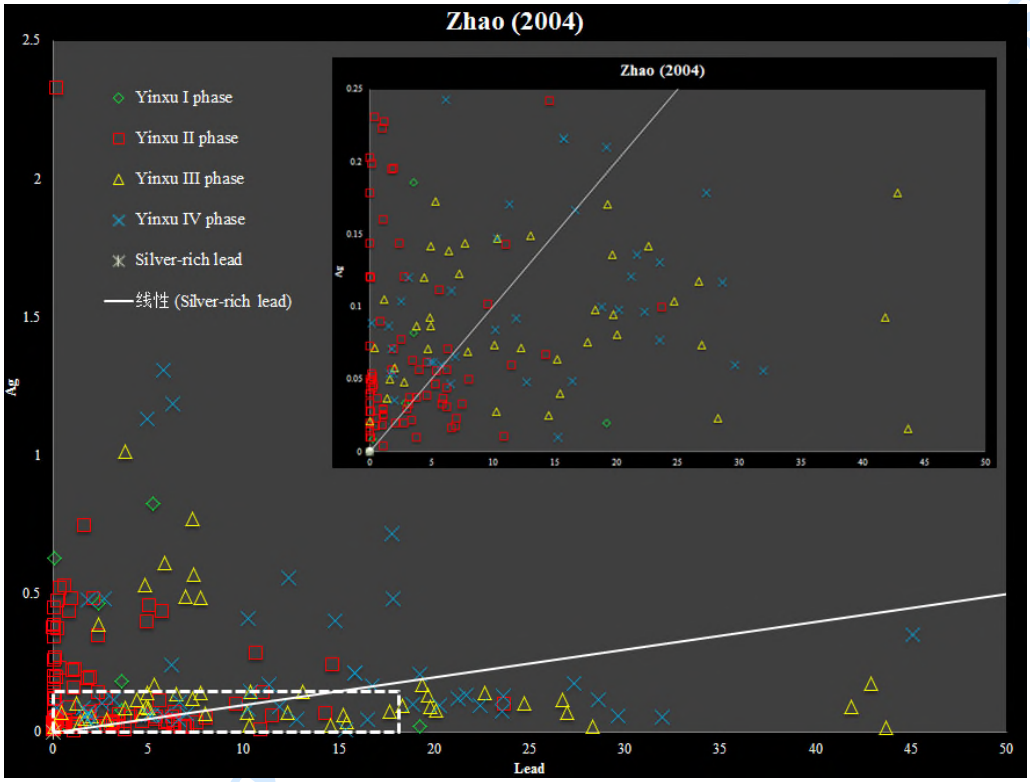

Figure 242 Plotting of silver and lead for Anyang metals (the silver in the objects above the write line are most likely associated with copper than lead)

A theoretical line is drawn on Figure 242 to show the possible effect on silver by adding lead. The line (y= 0.01x) represents the lead containing 1% silver, which would be considered a rich silver mine rather than a lead mines in the modern geology. The amount of silver in the objects below this line might be introduced by lead. It is equally possible that this part of silver is still associated with copper and lead plays no

part. However, the substantial amounts of silver in those objects above the line are more likely pertinent to copper. It is not possible to increase the percentage of silver beyond 0.5-1% just by adding merely 10% lead. Otherwise, the percentage of silver in the galena or lead cakes has to be 10%, which is highly unlikely.

The preliminary conclusion is that the association between lead and silver is not subjected to a simple linear regression, namely, that the addition of lead gave a clear rise to the concentration of silver. Although lead might contribute varying levels of silver to the final objects, it is necessary to bear in mind that the concentrations of silver in a majority of the objects at Anyang were more likely associated with the copper. Both possibilities have been suggested by previous case studies in this chapter. Objects of CG12 (As-Sb-Ag) of the Western Area were very likely derived from those of CG6 (As-Sb, Figure 237) but this cannot be easily seen in the assemblage of M1046 (Figure 229).

6.2.6 Sackler collection

The complete set of Shang data in the Sackler collection provides an ideal case study to demonstrate the power of combining alloying, trace elements and lead isotopes, which has been constantly suggested in a large number of publications. The initial datasets of the Sackler collection are attached in the back of the catalogue for future studies and little discussion is made by the author and analysts. Although all of the objects analysed are unprovenanced, it has been widely accepted that a majority of

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these objects were made at Anyang (Bagley, 1987). Thanks to Rawson who firstly carried out a typological analysis and removed those pieces typologically far from excavated Anyang items, we can reduce the noise generated by those non-Anyang objects (Appendix XIV).

In this Anyang group, there are four major copper groups, CG1 (clean copper, ~38%), CG2 (As-only, ~20%), CG9 (As-Ag, ~18%) and CG12 (As-Sb-Ag, ~13%). In terms of proportions, CG1 and 2 (clean copper; As-only) are clearly more significant than the other two (Figure 243). The difference between these copper groups includes not only the presence/absence of the four diagnostic elements but also their actual concentrations. For instance, CG12 distinguishes itself not only by clear presence of antimony but also the higher arsenic concentrations in the other three copper groups (Figure 244 and 245).

Ruiliang Liu unplished thesis

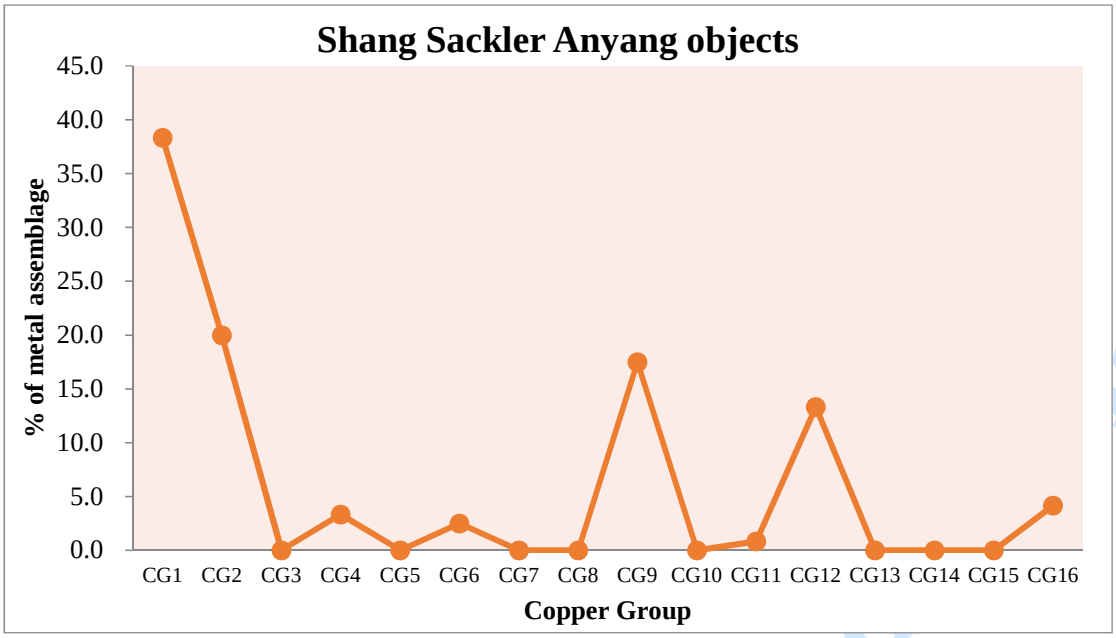

Figure 243 Distribution of copper groups in Sackler Anyang objects

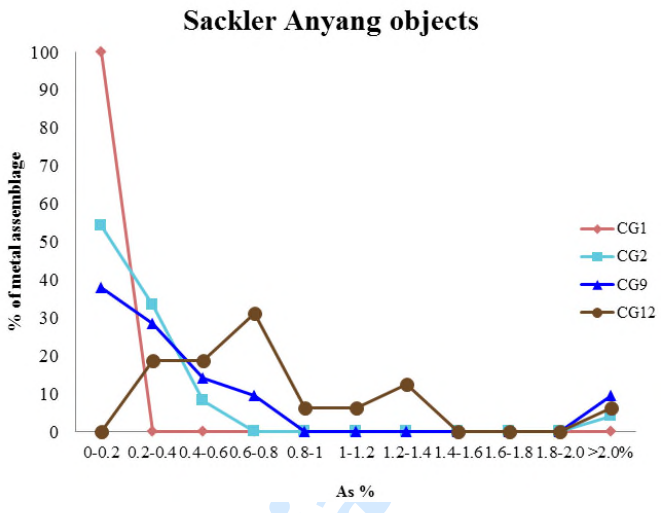

Figure 244 Arsenic distribution in the four major copper groups of Sackler Anyang

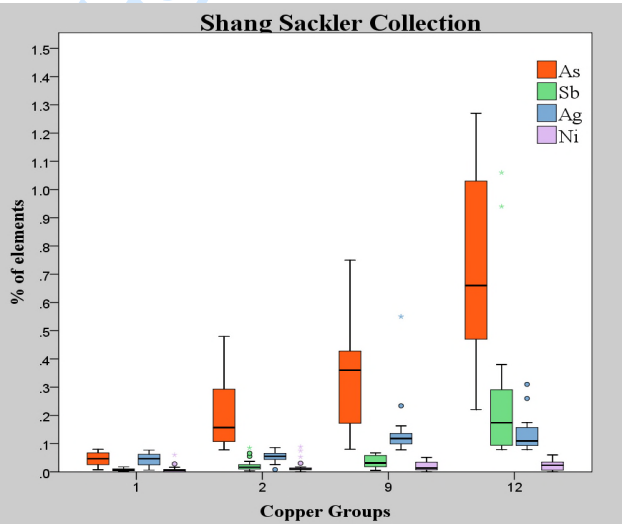

Figure 245 Distribution in the four major trace elements of Sackler Anyang

In regards to alloying types, all of them are either bronze or leaded bronze. However, a striking characteristic occurs if one attempts to combine alloys and impurities together. The alloying profile of CG12 (As-Sb-Ag) stands out because it is high lead (~9-18%) and low tin (~6-9%). This is in contrast to the other three major groups of

low lead high tin (Pb: <6%, Sn: ~12-18%; Figure 246 and 247).

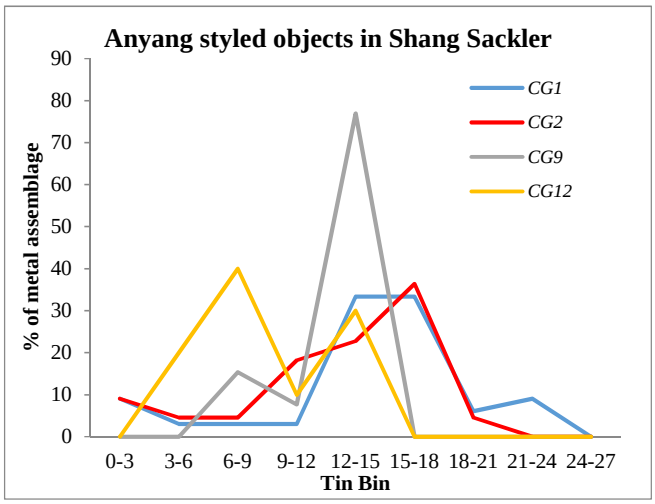

Figure 246 Profile analysis of tin for Anyang styled objects in the Shang Sackler collection

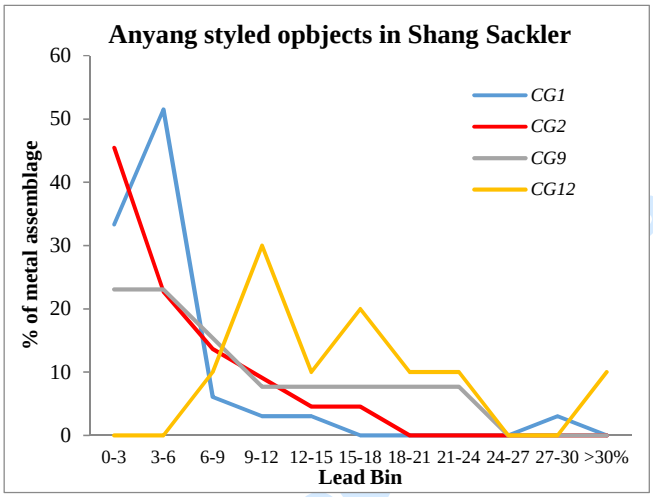

Figure 247 Profile analysis of lead for Anyang styled objects in the Shang Sackler collection

Two ways have been employed to display lead isotope data. The familiar pattern in Figure 248 reminds us the conventional interpretation that lead isotopes could be divided into two groups, namely, the radiogenic and common lead. An interesting linkage emerges by putting copper groups on the top of lead isotopes. Around 80% of CGs1&2 (clean copper, As-only) become strongly associated with radiogenic lead whereas 90% of CG12 is associated with common lead. CG9 appears evenly distributed. Again, in addition to its high percentages of lead, CG12 shows remarkable difference from the rest in terms of lead isotopes (Figure 249).

Ruiliang Liu unplished

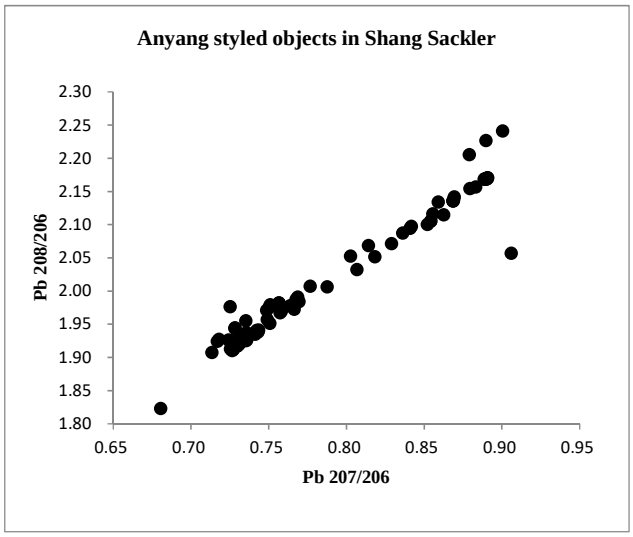

Figure 248 Traditional bi-plot of lead isotopes

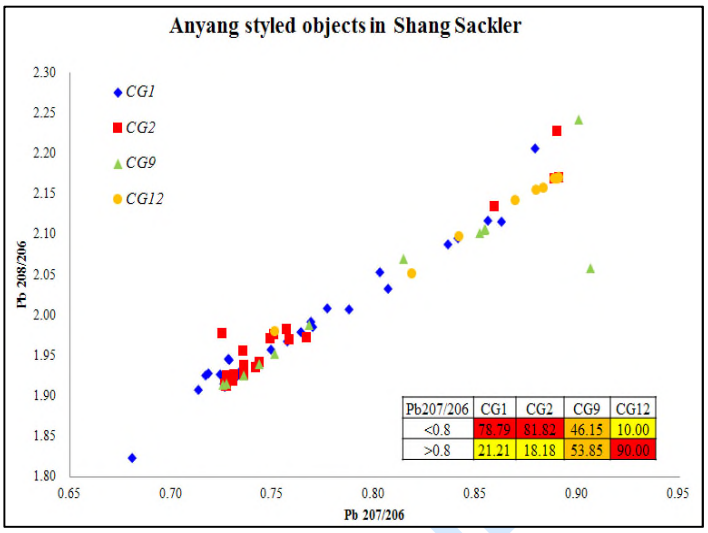

Figure 249 Combing trace elements and lead isotopes

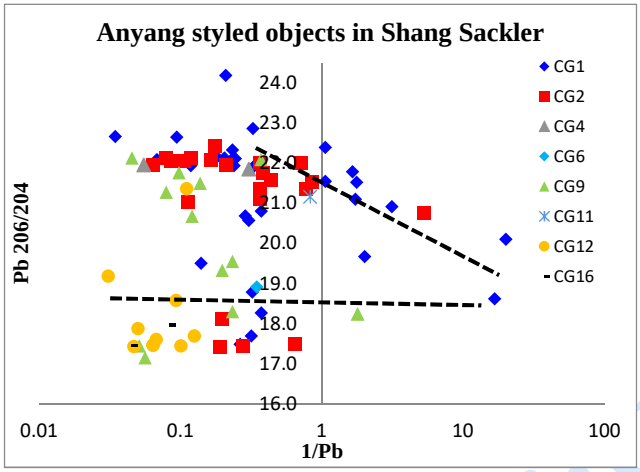

Figure 250 New plotting of lead isotopes and lead concentrations (see Appendix XV for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

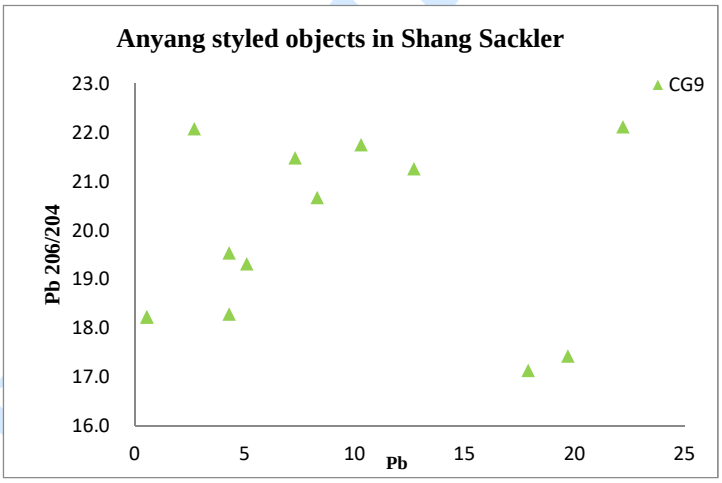

Figure 251 Plotting $^{206}Pb/^{204}Pb$ against lead percentage (see Appendix XVI for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

In the Sackler collection, a strong consistency among alloying practice, copper groups and lead isotopes has been noticed. Most CGs1 and 2 (clean copper, As-only) are alloyed with high tin low lead and show radiogenic lead signal. By striking contrast, CG12 (As-Sb-Ag) is alloyed with low tin high lead and show a heavy use of common lead. Further typological analysis on each object does not reveal other particularly useful information.

Ruiliang Liu

The major difficulty is the lack of the initial archaeological context. No evidence is available to find out the owner of each object or the exact phase of them, or whether some came from settlements and some from burials. While knowing these sorts of information is probably no longer possible, this case study shows that combining the data of alloying, trace elements and lead isotopes together can produce some archaeologically meaningful data structures. Through comparison with analysis of excavated pieces, it may be likely that this consistency between the three sets of data was a reflection on the objects used by people belonging to different social rankings and different time periods at Anyang. If these bronze artefacts were indeed made roughly during the same period, what this consistency among alloying technology, trace elements and lead isotopes suggests is that copper and lead from different sources were treated differently at Anyang.

The other way of presenting lead isotopes is to plot one lead isotopic ratio against lead percentages (Chapter Two). Apart from the pattern seen in the conventional plots that different copper groups were alloyed with different amounts of tin and lead, it is also arguably reasonable to suggest a mixing line in Figure 250 (Pollard *et al*. in press-a). Pollard *et al.* argues that:

"This line (the mixing line) represents alloying of copper with an isotopic value similar to that in the lower lead source ($^{206}Pb/^{204}Pb \approx 17.5$) with lead from the higher ('radiogenic') source ($^{206}Pb/^{204}Pb \approx 22$)."

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A similar line can also be found in objects of CG9 (As-Ag). This becomes slightly clearer in Figure 251, where the x-axis is the exact lead percentages rather than the inverse. The lead isotopes of objects containing lead below approximately 5% are characterized as common lead whereas those in objects with over 10% lead turn out to be radiogenic. The similar pattern has also been found in objects at Zhengzhou (Chapter Four: Figure 161). One likely interpretation would be that objects with high amount of lead (>~10%) were made by realloying objects with low amounts of lead (~5%). In this process extra lead was added, perhaps in order to facilitate remelting or recasting. Again, plotting the lead percentage and lead isotopes may help to discovery the process of realloying.

No matter which way is used to display the lead isotopes, the two groups of data, radiogenic and common lead, are always strongly presented. Meanwhile, the number of objects in between only accounts for a 10%. This structure carries some implications on the scale of mixing. If mixing was indeed performed on a large-scale at Anyang, then it would be difficult to see clearly two groups of lead isotopes separated from one another.

To briefly summarize, by using the dataset of the Sackler Shang collection, what needs emphasizing is that one can pragmatically combine alloying elements, impurity patterns and lead isotopes together and reveal a range of intriguing linkages between

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one another. This can be much more informative than just plotting two lead isotopic ratios alone. These linkages appear to reflect a highly planned and organized industrial system and imply that different types of copper were alloyed differently and associated with different sorts of lead. Further investigation requires the same quality of analysis on excavated metal objects.

6.2.7 Change in lead isotopes

Two large datasets of lead isotopes have been published, which include objects from various sites at Anyang. One is the data of Jin (2008: 162-163) and the other is Liu (2015). Jin's data are focused on vessels, whereas those in Liu (2015) are tools, chariot fittings and weapons. Another piece of useful information is that the specific chronological phase is available for each analyzed object. Plotting the lead isotopes with the chronological sequence reveals a very dramatic shift from radiogenic lead to common lead in both vessels and weapons. This was first noticed in Jin (2008: 162-163). The new contribution here is to show these data in a different and clearer format of presentation developed at Oxford (Jin *et al*., accepted). This radical change illustrates a fundamental change of lead supply at Anyang, which started actually not during the conquest of the Zhou people but during Yinxu III (Figure 252).

Ruliang Liu unplished thesis

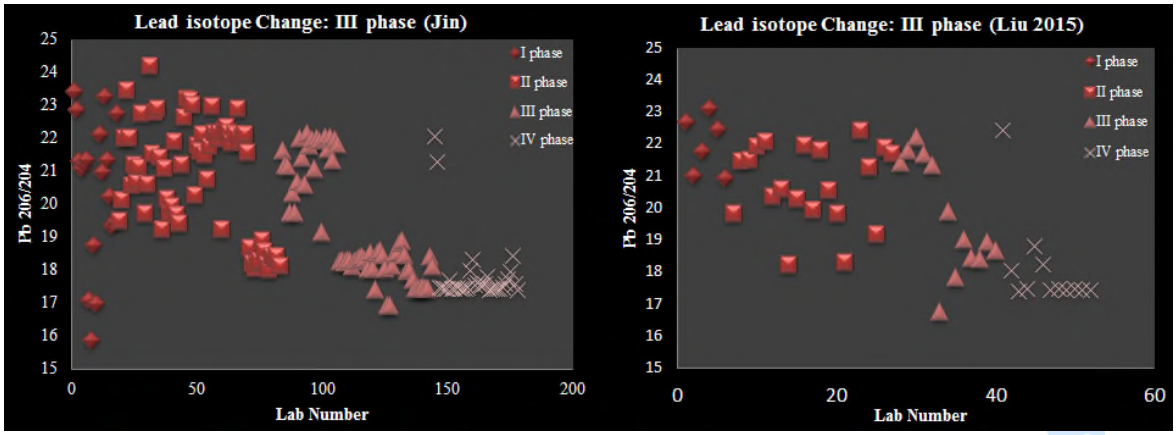

Figure 252 A sharp decrease of radiogenic lead in the III phase of Anyang (see Jin *et al*., accepted for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

Furthermore, as some objects were analyzed both by Jin (2008: 162-163) and Zhao (2005), it becomes possible to correlate the lead concentrations with the lead isotopes for the individual objects. The pattern in Figure 253 appears very similar to the one in Figure 250. More importantly, these objects are all from the scientific excavations at Anyang. The horizontal line in both figures means that the copper with lower isotopic values were alloyed with lead of the same values. Objects dated to the third phase show a similar structure those of CG9 (As-Ag) in the Sackler collection, indicating possible realloying by adding lead during this period. Unfortunately, there is not enough chemical data to do copper groups for objects in Figure 253.

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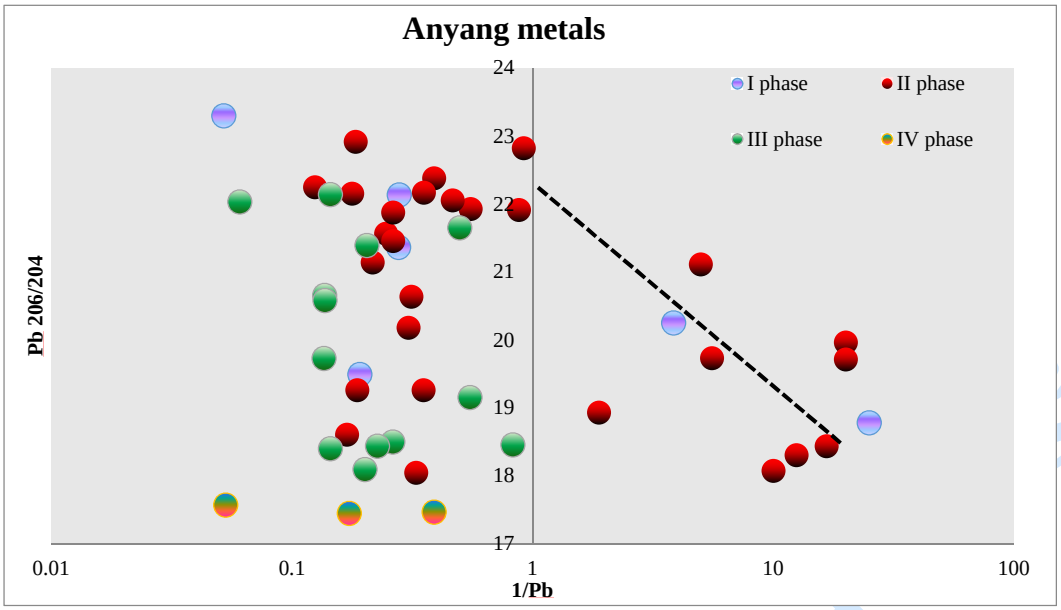

Figure 253 Mixing line: copper with common lead is alloyed with radiogenic lead (see Appendix XVII for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)

6.3 Comparative analysis

6.3.1 A vertical comparison: social status

Figure 254 has schematically listed all of the datasets from the top to the bottom in accordance with the social status of the tomb occupant. It is plausible to observe at least two important differences in metal chemistry above and below the horizontal red line, which separates objects of the top elites above (*e.g.* Fu Hao/M1004/M54/M160/M1046) and those of lower-elite people below (*e.g.* those buried in the Western Area). Here, the top and lower elites are just short-hand term to refer to the difference in the wealth of materials in their burials. These terms are relative but used to facilitate the discussion.

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As discovered by previous studies (Li, 1982; Li *et al.*, 1984; Ji, 1997; Zhao *et al.*, 2004; Zhao, 2008; Liu *et al.*, 2007; Uchida and Iizuka, 2015), one difference is the use of tin and lead. While the concentrations of tin and lead show a clear symmetric distribution in the top-elite metal assemblages (interpreted as primary alloying), those in the Western Area are subject to a typical skewed pattern (characteristic of secondary alloying). This means that the use of tin and lead in the metal production for elites was strictly supervised whereas it became much less organized for lower elites.

A possible scenario is that the provision of tin and lead to the lower elites (*e.g.* those owned bronzes but buried the Western Area) was not as abundant as that to the top elites, particularly tin which is much rarer than copper and lead. Craftsmen chose to prioritize objects for top people rather than lower ones. As a consequence, bronzes discovered from the top-elite burials were made by primary alloying while the rest show a skewed pattern. The latter was probably associated with the behaviour of mixing and recycling.

The original contribution of the current study is attributed to the new difference unveiled copper groups. In the Western Area, a variety of equally important copper groups (CG1, CG2, CG6, CG9, CG12 and CG16) were in use. This phenomenon can be explained by two reasons. One is that supply of copper in the Western Area was not as well-organized as that of top-elite ones. They may come from different sources

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therefore their trace elemental patterns differ from one another. The other one is that mixing and recycling, as suggested by skewed alloying pattern, can also result in this diversity of copper groups, or CG16 which contains all the four diagnostic elements (As-Sb-Ag-Ni).

In addition, the concentration of arsenic in the metal objects in the Western Area ranges from ~0% up to 1.6% and antimony ranges from 0% to 1%. Comparing to those top-elite assemblages, the variation of these impurities in metal objects in the Western Area appears significantly larger. This difference also implies that metal objects used by people of different social status at Anyang were likely to have been made of different types of raw copper. These coppers may derive from different sources and treated differently at Anyang. The source of these coppers determines the initial value of the impurities in the copper. It is also possible that the copper used to make elites' objects may be refined many times before casting therefore its impurities appear to be relatively reduced. As a joint result of these two factors, the percentages of these trace elements are quite different in objects of different people.

There are a number of caveats. Firstly, although these analyzed samples are from the Western Area, they are distributed in different tombs in the Western Area. In other words, there exists a discrepancy between the macro and micro-context. It is true that the Western Area broadly represents lower elite people at Anyang but zooming into different tombs or sections within this area may enable us to find more variation.

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Sadly, the current database is far from adequate to resolve such high-resolution issues. If we disaggregate the database of the Western Area into different tombs, we may only have three to five objects for each tomb. This brings about the second caveat. If the current database is very limited, the real structure could be obscured by the noise (outliers). For instance, some objects discovered from the Western Area might originally belong to one top-elite person but were later passed to somebody of lower status as reward. This would be less of a concern if more analyses were accumulated.

It is inevitable to argue that these compositional differences of bronze objects are a reflection of the organization of metal production and its subsequent distribution system at Anyang. Anyang was a highly stratified society. As reflected by many sorts of data, people of different social status had access to different sorts of materials and objects. This underlying rule can also be applied to the entire use of metal at Anyang, from acquiring, manufacturing to distribution. The fact that top elites used carefully alloyed copper with little impurities whereas lower elites used copper containing less-designed levels tin or lead plus a greater amount of impurities, probably even recycled copper, deepens our understanding of the issue of how copper, tin and lead were used within Anyang.

In light of the idea of organization, I suggest two lines (high and low) of production system to conceptually reconstruct the metal production system at Anyang. The high line was primarily to supply metal objects for top-elite level. The craftsmen who

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worked for this line benefited from abundant supplies of raw materials (fresh copper, tin and lead) and expertise in alloying technology. As a result, chemical analysis of the final products shows a uniform impurity pattern and primary alloying. A reverse situation can be found in the low line production of metal objects. Firstly, craftsmen may have had to rely more on mixing/recycling objects. Fresh copper was mixed with existing objects to be alloyed. Meanwhile, the concentration of tin and lead will sharply decrease due to this dilution. Secondly, craftsmen working for the low line might be less concerned about the source of raw materials. This might be true for their patrons (lower elites) as well. Consequently, the impurity patterns of products from the low line appear more diverse. Other evidence in favour of this two-line model can be found in Li's holistic/prescriptive model based on the observation of moulds (Li, 2003).

6.3.2 A horizontal comparison: chronology

A comparison of these metal assemblages dated to different time periods reveals a drastic change during Anyang III phase. With regard to alloying technology, Zhao (2004) demonstrated that there was clearly an increasing use of lead instead of tin during the third phase. A simultaneous change can also be found in lead isotopes (Jin, 2008: 162-163; Liu, 2015: 113-117). As emphasized above, the use of radiogenic lead declined in Anyang phase III and common lead became widely used into the Western Zhou. What can be further added by this thesis is the characterization of the copper

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itself. Phase III witnessed the rise of CG12 (As-Sb-Ag), or broadly speaking, the new intrusion of the antimony into the impurity patterns (M1046, the Western Area). All these changes have been dated to the third phase of Anyang (Figure 255).

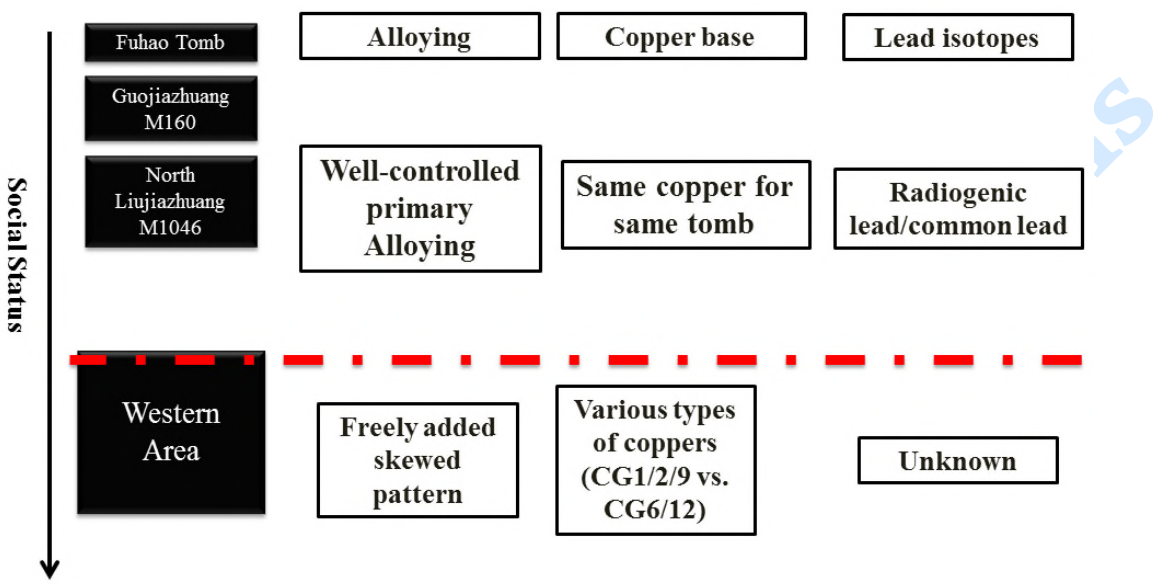

Figure 254 summary of metal chemistry in different social status

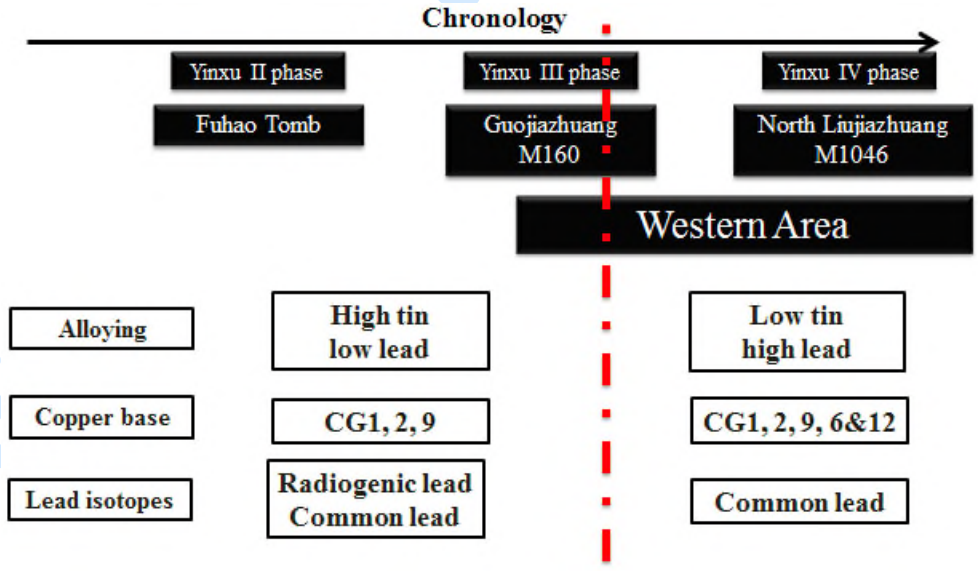

Figure 255 summary of metal chemistry in different phases

Quoted from the Anyang archaeological report:

“据初步分析，大约从殷墟第一期偏晚阶段起（相当于武丁早期），这里的靠东北地段开始营建了少数房子和窖穴（灰坑），但分布稀疏，遗迹多受破坏。到了殷墟第二期偏早阶段（约当武丁晚期），这一带一度变成当时的重要目的和祭祀墓主的祭祀场，同时，还修建了一些形制较大可能与祭祀有关的房子。大概到殷墟第二期偏晚阶段（约当祖庚、祖甲时期），墓地衰落，大型建筑开始废弃，出现破坏大型基址的小型房基和窖穴，但数量较少。到了殷墟第三期，小型基址增多，窖穴、灰坑也有所增加，它们的分布范围也较广。进入殷墟第四期，窖穴、灰坑更为密集，并新建了一些面积较小的房子。在其中的一些窖穴中，发现腐朽的谷物痕迹，可能是贮存粮食之用。由此可见，大概从殷墟第三期开始，这里又逐渐成了一处居住址。”

Translation: based on preliminary study, a few houses and hoards (trash pits) were loosely distributed in Northwestern Xiaotun. This area became a key place for important tombs and ritual activities. Meanwhile, a number of large houses were built here. However, the late II (King Zugeng/Zujia) saw recession, exemplified by the abandonment of tombs and large buildings. An increasing number of small tombs, building foundations and trash pits have been found in a wider distribution. In the IV phase, these became more common. There could also been found some small houses, where remains of agricultural products have been recovered. To summarize, this area was converted into a living area (from a ceremonial centre) in the Yinxu III phase (IA CASS, 1994: 70).

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This description suggests that the third phase of Anyang saw not only a change in metal production but also in the entire ritual and social system. As mentioned above, offerings to ancestors played a prominent role in the ritual system of Anyang. Abandoning the traditional ceremonial palaces and replacing them with an average community certainly signified a profound social movement. Although it is unclear what happened and why, connecting the change in metal chemistry and in the archaeological evidence enables us to refine these new, stimulating and delicate questions.

6.3.3 Mixing and recycling

Reprocessing all of these available datasets provides very little evidence of some large-scale mixing and recycling in the production of the *top-elite* metal assemblages, particular their ritual vessels. The symmetric distribution of tin and lead demonstrate that their addition was intentionally controlled during the manufacturing and can be considered as a signal of primary alloying. Meanwhile, their impurity patterns appear highly standardized in comparison with those of *lower-elite level*. Therefore, based on the current database, metal objects in these top-elite tombs, particularly elaborate ritual vessels, were very *unlikely* to have been made with recycling or mixing with other alloyed objects.

There are indeed some small traces of recycling or mixing in some top-elite metal objects, not in vessels, but in a few weapons. The lead in the weapons of M160 shows

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a very wide range (~10-25%). These weapons may be the products of recycling or mixing with other copper-based objects already containing lead.

By comparison with objects in elite tombs at Anyang, mixing and recycling may have been more common in the production of objects for lower-elite individuals. Metal assemblages in the Western Area, on the one hand, show a typical skewed pattern of tin and lead, both of which cover an extremely wide range and show little evidence of primary alloying (Sn: ~0-20%; Pb: 0-35%).

In addition to alloying profiles and the distribution of impurities, the other tool to identify mixing and recycling is through lead isotopes. The lead isotopic distribution in a classic bi-plot is often interpreted in two parts. The first one involves those areas in which objects are aggregated together. It means that one narrow lead isotopic range predominates in these objects. The second part is a long narrow area connecting those big aggregations. Objects plotted in these areas could be assumed to contain varying levels of mixed lead or copper Figure 256 and 257. As shown in Figure 249 and 250, which plots the Anyang styled-objects in the Sackler collection and excavated pieces, it turns out that only around ten objects sit in the middle between radiogenic and common lead but these account for roughly 10% of the overall database. This offers another line of evidence to the issue of mixing and recycling at Anyang.

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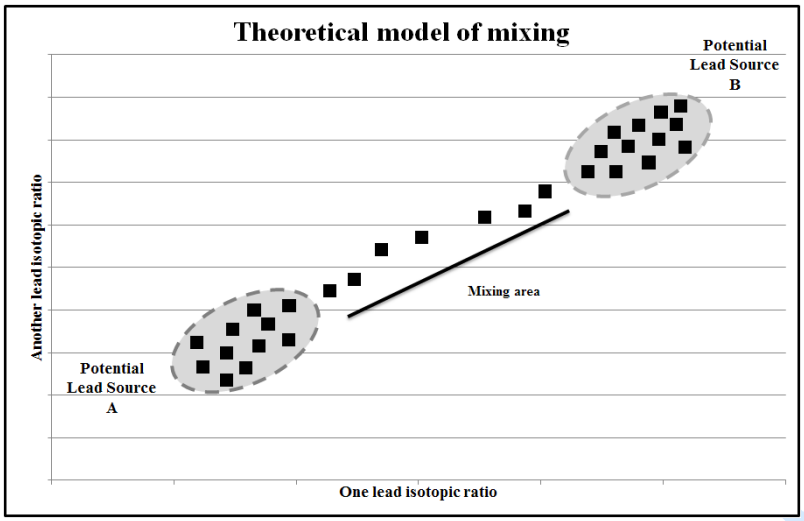

Figure 256 Theoretical model of mixing reflected by lead isotopes

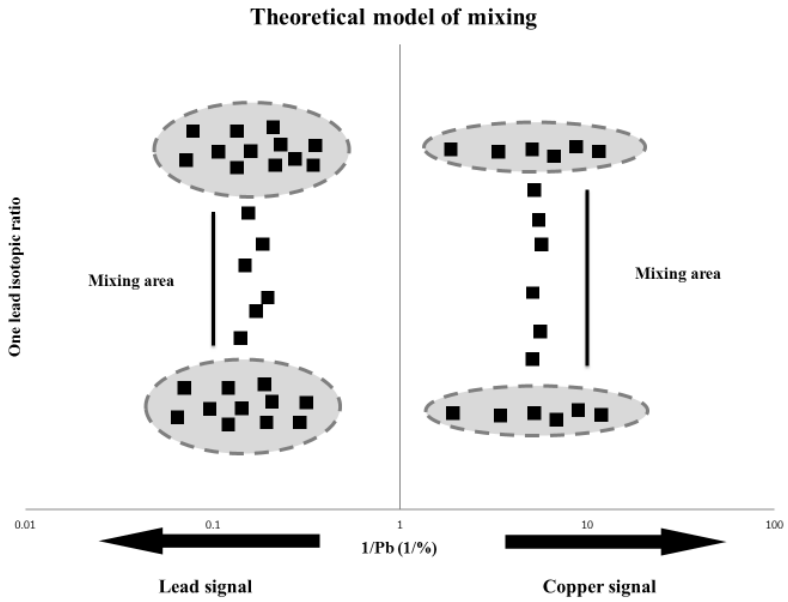

Figure 257 Theoretical model of mixing reflected by lead isotopes

Combining trace elements, lead isotopes and alloying profile could also bring extra light to the issue of mixing and recycling. In the Anyang group of the Sackler collection, one can see a range of linkages between alloying, copper groups and lead isotopes. The linkages among these three scientific attributes are useful to resolve the issue of mixing and recycling. If mixing and recycling had been performed constantly

at Anyang, such linkage would have disappeared because chemical composition of each object would have become heavily homogenized. Based on the existing database, it is at least true for high-quality ritual vessels.

6.4 Summary

The fundamental objective in this chapter is to deliver a set of systematic comparative studies on chemical compositions of metal assemblages and illustrate a series of changing scenarios within Anyang. While some of them have been discussed in previous publications, three major contributions are made in this chapter: characterization of copper itself, quantification of mixing and recycling, combine the Oxford system with the actual archaeological context.

1. Instead of using alloying or lead isotopes, which essentially characterize not copper but combination of copper with tin or lead, for the first time, scholars have been able to articulate the diversity of copper at Anyang with a set of simple terms (CGs1, 2, 9 and 12).
2. Based on the existing database, little evidence has been found to support any large-scale mixing and recycling of finished objects at Anyang. In particular, the chance that the elite ritual bronze vessels were made of recycled materials was fairly small. But a lot more data are required for weapons and objects used by lower elites, where the likelihood of mixing and recycling was probably higher.
3. The major changes in the chemical and isotopic compositions can be explained by

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the two attributes of archaeological context, chronology and social status. (1) The first change (vertical) derives from the contrast of objects owned by top- and lower-elite individuals. Top ones were able to acquire objects made of fresh copper with primary alloying whereas objects of lower ones may come from a multiple supply of raw materials with a higher likelihood of mixing and recycling. This is most likely to be a result of a highly organized production system (low-line/high-line model); (2) The second change (horizontal) was observed in the third phase of Anyang, which saw a set of simultaneous changes in metal chemistry, encompassing the drop of tin/radiogenic lead and the rise of lead/common lead, as previous studies discussed and the newly discovered copper groups (*e.g.* the use of CG12). These are further suggestive of some very critical changes in the provenance or network of metal supply to Anyang in different phases.

This chapter is focused on the chemical and isotopic changes of metals confined within Anyang. However, it does not touch on the question of provenance. The next chapter will investigate this issue in a wider geographical context.

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Chapter Seven Overview on metal movements in the late Shang period: a big picture

7.1 Introduction

"at all times, the bronze-casting societies had to draw in resources from distant mines, both south and north, creating and perpetuating a major regional network, which must have required strong organisation for its success. The network was only one component within a complex bronze industry. This industry had a dominant centre that spread its ritual practices and its technologies, supporting a high quality bronze production, which also required mastery of many different resources, a whole range of different skills and co-ordination of large groups of people in highly demanding tasks, such as the casting of numerous massive bronzes." (Rawson in press-b)

The idea of a network becomes increasingly critical to the understanding of the entire Shang world. No site during this period existed in vacuum and they were all connected to one another through this network to varying degrees. Sites like Anyang absorbed enormous amounts of various resources from outside regions, such as oracle bones, jades, clays, horses, food, ivory or turquoise. This vividly demonstrates the

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power of this network. The movements of copper, tin and lead also benefitted hugely from this network and can be used by archaeologists to reflect upon this network.

The central question in this chapter is what picture of the movement of metal can be drawn from the existing chemical and isotopic database? The previous discussions in Chapters Four to Six are case studies focusing on a regional level. By mapping data from as many sites as possible, this chapter argues on the nationwide scale that the existing database illustrates three broad but different models of people obtaining metals during the late Shang period (a 'horizontal view'). These broad models are primarily defined by the types of copper used in different regions and why they are different from one another. Under these broad models, there were a variety of smaller-scale metal movements, in the form of either raw materials or completed objects. Meanwhile, a systematic set of comparative studies of metal assemblages dated to different stages of the entire Shang period show that the network was not at all static and we can see the changes of metal movements or the network of metal supplying system throughout this period (a 'vertical view').

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7.2 Regional and chronological comparison

7.2.1 Copper groups

A horizontal view on the distribution of copper groups

Figure 258 summarizes the distribution of the copper groups in metal assemblages in

different regions, dated to the Anyang period (*ca.* 12th BC – 11th century BC). The first and foremost demarcation can be drawn between the Central Plains and the borderland regions, or the arc (Rawson, 2015 a and b; Tong, 1987). Anyang in the middle shows the maximum number of copper groups. The four major groups include CG1 (clean copper), CG2 (As-only), CG9 (As-Ag) and CG12 (As-Sb-Ag). One can also see a variety of other copper groups in small but observable proportions, such as CG6 (As-Sb). In sharp contrast, each borderland region shows a clear dominance of one or two copper groups, which is visually presented by the colour coding on the map (Figure 258). During the Anyang period, over 90% of the analyzed metal objects at Hanzhong are CG1 (clean copper: see Chapter Five). Likewise, over 50% of the analyzed metal objects at Sanxingdui are also this type of copper. Therefore, as argued in Chapter Five, both Sanxingdui and Hanzhong in the southwestern part of China shows a strong preference of clean copper, suggesting a potential existence of a local copper source (Chapter Five). The pie chart on the north side of the Qinling Mountains is a summary of copper prills in slags found at the Laoniupo site. Whilst a variety of copper groups are illustrated, the high percentages of arsenic and antimony imply that the final produced objects were most likely to be CG6 (As-Sb) at Laoniupo (Chapter Five). Intriguingly, objects in steppe forms interred in the further north (northern Shaanxi) are also characterized as CG6 (As-Sb). It is not possible to judge as yet whether Laoniupo supplied copper to North Shaanxi. Perhaps they used different copper mines which are governed by similar geological conditions and therefore the copper chemistry appears the same as that at Laoniupo. What one can

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suggest now is that copper in the north side of the Qinling Mountains in Shaanxi province stands out due to the presence of arsenic and antimony as a combination in its local copper. The third area is the northeastern part of China. This is a well-known region for early mining activities. High-quality radiocarbon dates demonstrate that mining activities were carried out in the late Shang period, such as the Xiquegou site (Wang and Fu, 2015). However, the chemical analyses on either slags or objects are still far from being adequate. The preliminary analyses conducted by the University of Science and Technology Beijing indicate that copper recovered from this region are often associated with tin, lead, arsenic, antimony and silver in different combinations (Dong, 2012:11-13; Li and Han, 1990). Local minerals associated with major metallic elements include malachite, azurite, chalcopyrite, bornite, cassiterite, cerargyrite, argentite, ferrohydrite, magnetite, pyrite, marcasite and galena (Jiang *et al*., 2010; Shi *et al*., 2003; Yao *et al*., 2012). So far, no large datasets on trace elements of objects in this region have been published. Simply as a reference, the pie which represents this region is based on objects locally made but dated to the Eastern Zhou period (Wei *et al*., 2006). More chemical analyses need to be performed in the future.

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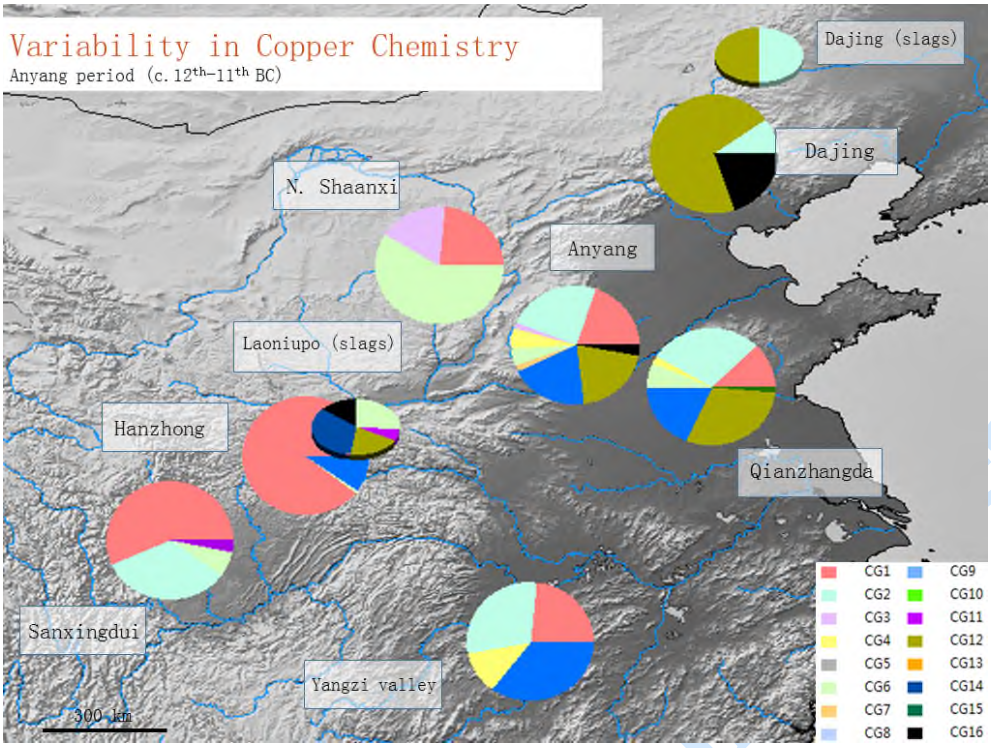

Figure 258 Distribution of copper groups in the Late Shang period (data source: Ma *et al*., 2012; Chen, 2009; Liu, 2015; Wei *et al*., 2006; Dong, 2012; Zhao, 2005; Bagley, 1987; Li, 1982; Li *et al*., 1984; Ji, 1997; Zhao *et al*., 2008; Chen *et al*., 2001; RLAHA unpublished data, Dajing is later than the Anyang period)

Models of copper procurement

It appears more likely that people who lived in the borderland regions such as Sanxingdui, Hanzhong, Laoniupo, North Shaanxi and northeastern part of China based their own metal production on intraregional sources (*intraregional-source model*). This means a general movement of copper from mines to workshops in the same region and converted into objects via a sequence of stable smelting and alloying practice. The "region" here is defined by the shared use of the same copper group(s), which are presumably the same type of copper in the case of these borderlands. For instance, Sanxingdui and Hanzhong are in the same region because both were heavily

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dependent on clean copper or copper with very low level of arsenic (CG1/2).Though the exact source of this type of copper is not yet known to us, these preferences of specific types of copper in each regions offer some independent indicators for mining surveys in the future.

At the same time, one may also need to accept that chemistry only allows us to trace copper up to some certain points. As explained in Chapter One and Two, the metal chemistry can be altered dramatically in the course of human interaction. For instance, the copper ores from hundreds of different mining shafts may be gathered together at one smelting site and the smelted copper from a variety of these smelting sites came to one bigger site where they were all heavily refined and mixed (*e.g.* a Centralization model, Pollard, Rawson, pers. comm.). Under such circumstance, it is no longer feasible to trace the finished objects to each specific shaft via comparing their chemical data to that of ores. Therefore, even though we can discover these local mines or shafts one day, without very thorough knowledge on smelting activities and human organizations, we still have to be very cautious about comparing objects and ores and judging the provenance.

The diversity of copper groups in the Central Plains then can be better explained by a *multi-source model* (or interregional model, Pollard, *et al*., in press a and b), which means that it absorbs copper from many different regions (Yangzi, Laoniupo and the Northeast). As a result, the copper used at Anyang is illustrated in multiple colours

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(Figure 258). Indeed, mining archaeologists have already postulated this model in the texts (*e.g.* Hua and Lu, 1996). For the first time it is possible to visualize this model onto a single map that highlights the strategy used by Anyang people to obtain copper.

Regarding the Yangzi River, a different model (*complex geology model*) is necessary to explain the existence of various copper groups. It is an intermediate model between the intraregional model and multi-source one. As discussed in Chapter Four, this region is enormously rich in copper sources and a variety of local groups of people started mining activities in a rather early period, at least the late Shang period. It is hard to believe that people who can easily obtain metal from local mines chose to spend much more effort and import large quantities of copper from a number of remote regions, though we do have examples that people lived in Sardinia in antiquity imported copper from Cyprus while the local copper mines are abundant (Pollard and Bray, 2015).

One possible reason for the multiplicity of copper groups is that the genesis of copper resources along the Yangzi River is governed by a complicated geological background as this region is just on the collision between two large tectonic plates (Yangzi and Sino Korean craton). Most copper mines in this region are sulfide deposits containing a greater diversity of impurities than oxide ones so that the chemistry in the copper from different mines tends to vary (Chang *et al.*, 1991; Mao *et al.*, 2009; Pan and Dong, 1999). In addition, different groups of people might have performed a variety

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of smelting or refining technologies which could further affect the copper chemistry. This model can be called an intraregional-source model as well, but we choose to use a different term to highlight its different causality from the one that has been used for the borderlands.

These three models incorporate the currently observed distribution of copper groups during the late Shang period and suggest some fundamental reasons driving this distribution. While the current size of the database is not ideal, these models, considering both archaeology and geology, may become better defined in the future when more data become available.

Figure 259 is the best schematic map we can present based on the current data. The Central Plains sit in the middle and connect to almost everywhere, directly or indirectly, through the network. The similar distribution of copper groups between the Central Plains and Yangzi suggest a massive movement of copper between the two regions (CG1, clean copper; CG2, As-only; CG9, As-Ag). Here we distinguish this as the *southern movement of copper*.

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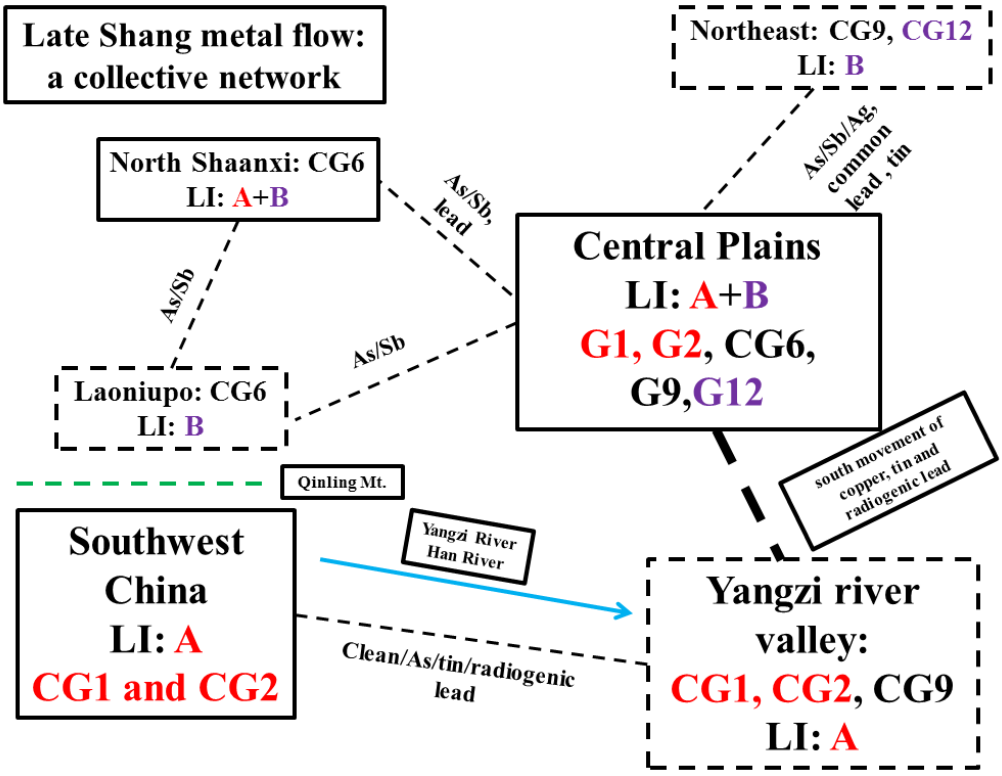

Figure 259 movement of metal during the late Shang period (LI: lead isotopes; LI A: radiogenic lead; LI B: common lead, regions in dash square needs more data in the future)

A careful reader may already spot that the proportion of CG12 (As-Sb-Ag) is also significant at Anyang but does not appear in the Yangzi region. Originally I thought this type of copper was a result of communication between the Central Plains and northeastern China. However, the field trip in the summer of 2016 with Prof Jessica Rawson, Prof Mark Pollard and Prof Chen Jianli to the mining sites in the northeast China made me reconsider this possibility. In reality, the copper mines such as Xiquegou in the northeast are nearly 850 km away from Anyang, which is over 150 km further from Anyang than the Yangzi mines. Moreover, archaeologists have concluded that mining activities carried out in northeast during the Anyang period were rather small-scale (Dong, 2012: 198). Even 10% of metal production at Anyang

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required tons of metal. So the scale between the northeast and Anyang appears not matching, which makes it even harder to accept that all of CG12 (As-Sb-Ag) came from such a remote and simple structured local society.

Apart from northeast, there are some other possible routes which can also lead to CG12 (As-Sb-Ag). One is by adding silver-bearing lead into CG6 (As-Sb, possibly from Laoniupo or northern Shaanxi), so it would be turned into CG12 (As-Sb-Ag). It is plausible as the data published in Zhao (2004) shows that some lead, although not all of it, indeed contains sufficient levels of silver and make this change (Chapter Six: Figure 237 and 242). The second route is mixing CG6 (As-Sb) with CG9 (As-Ag) together - in theory it could produce CG12 (As-Sb-Ag). Apart from these two routes, which are both associated with remelting, the third one, which is equally likely, is that objects of CG12 (As-Sb-Ag) in the middle Yangzi River have not yet been chemically analyzed. All of these possible scenarios may have happened during the Shang period and jointly contribute to what we now see as CG12 (As-Sb-Ag).

Apart from the major movement of copper from the south of the Central Plains, there were a range of relatively smaller-scale movements of copper. The small proportion of CG6 in the Central Plains was probably a result of copper moving from Laoniupo or North Shanxi. It is also likely that there was a constant copper movement between Hanzhong and Sanxingdui and some of their CGs1 and 2 (clean copper; As-only)

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metal derived from the southwestern part of China that ended up in various regions, such as the middle Yangzi River (along the Han River), the Central Plains, or even northern Shaanxi.

The three models and discussion of the supply of CG12 (As-Sb-Ag) plus many other copper groups are all parts of the network. It has to be borne in mind that these models and discussion set out above are constructed from a database which is very limited and patchy. Therefore, they may be very simplified and only able to represent small parts of the reality. Regions in dashed squares in Figure 259 desperately need more data. Accordingly, our understanding of this extensive network can be further sharpened.

A vertical view: changes in copper supply to central China

A vertical comparison among the metal assemblages of Erlitou, Zhengzhou and Anyang shows that although similar copper groups reoccurred in these metropolitan sites, the relative proportions of each copper group at these sites were dramatically different (Figure 260). In the Erlitou site, CG9 (As-Ag) and CG12 (As-Sb-Ag) were two of the major copper groups. Surprisingly, CG1 (clean copper) was basically absent, whereas CG4 (Ag-only) was an important proportion. The site of Zhengzhou saw a sharp rise of CG1 (clean copper) and a significant fall of CG12 (As-Sb-Ag). Meanwhile, while CGs2 and 4 (As-only and Ag-only) were still present in Zhengzhou,

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their proportions were considerably different from those in Erlitou. Only CG9 (As-Ag) remained roughly the same. Averagely speaking, CGs1, 2, 9 and 12 (clean copper; As-only; As-Ag; As-Sb-Ag, respectively) are the four major copper groups. The biggest difference between Zhengzhou and Anyang could be attributed to the CG12 (As-Sb-Ag). As a whole, quoting from Pollard *et al.* (in press-a),

"the differences in the relative importance of the copper groups further suggests that the network supplying metal to Erlitou and the Erligang phase emphasised different sources within the network than was the case in the network supplying Anyang."

Site	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16	Data entry
Erlitou	0.0	7.7	0.0	30.8	0.0	0.0	0.0	0.0	23.1	0.0	0.0	30.8	0.0	7.7	0.0	0.0	13
Zhengzhou	40.0	16.0	0.0	12.0	4.0	0.0	0.0	0.0	24.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	25
Overall Anyang	19.7	23.0	1.7	5.4	0.0	4.2	1.7	0.0	19.2	0.4	0.4	19.7	0.4	0.4	0.8	2.9	239

Figure 260 Summary of copper group distribution of Erlitou, Zhengzhou and Anyang

Archaeology and geology in the Bronze Age Central Plains shows an intriguing but conflicting picture. While the Central Plains is a very metal-poor region, it managed to produce the largest quantity and probably highest quality of bronze objects in the late second millennium BC. However, metal does not move but is moved by people. The scale of their metal production in the Central Plains during the Shang period cannot be achieved without an efficient network. People living in the Central Plains, particularly during the Anyang period, relied on different supplies of metal from different regions. The changes in the metal chemistry offers indicators of changes of metal supplies and very likely to be a reflection on the dynamic relation between the

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Central Plains and the metal-supplying regions. Beyond the Central Plains, one can see many powerful groups of people using different/same types of copper and set up a variety of efficient production centres. Together with the Central Plains, they depict a comprehensive and complex metal supplying network in which the movement of objects and raw materials were in large quantities and constant changes.

7.2.2 Distribution of alloy types

A horizontal view: comparison of alloy distributions across regions

Two ways of characterizing alloying elements are suggested in the Oxford system. They were initially designed to explore the movement of alloys across different regions. The hypothesis was that craftsmen who had easier access to the deposits of tin or lead tended to add more into the copper.

However, the outcome of applying the same characterizing method to China is completely different from those observed in Europe and Iran. In the Alpine region, Perucchetti *et al.* (2015) discovered a clear contrast of using tin between the two sides of the Alpines. Tin-bronze in the northern Alpine is considerably less ubiquitous than that in the southwestern side, which could suggest a possible movement of tin based the distinct difference of tin percentage between the west and east side of the Alpines (Figure 261).

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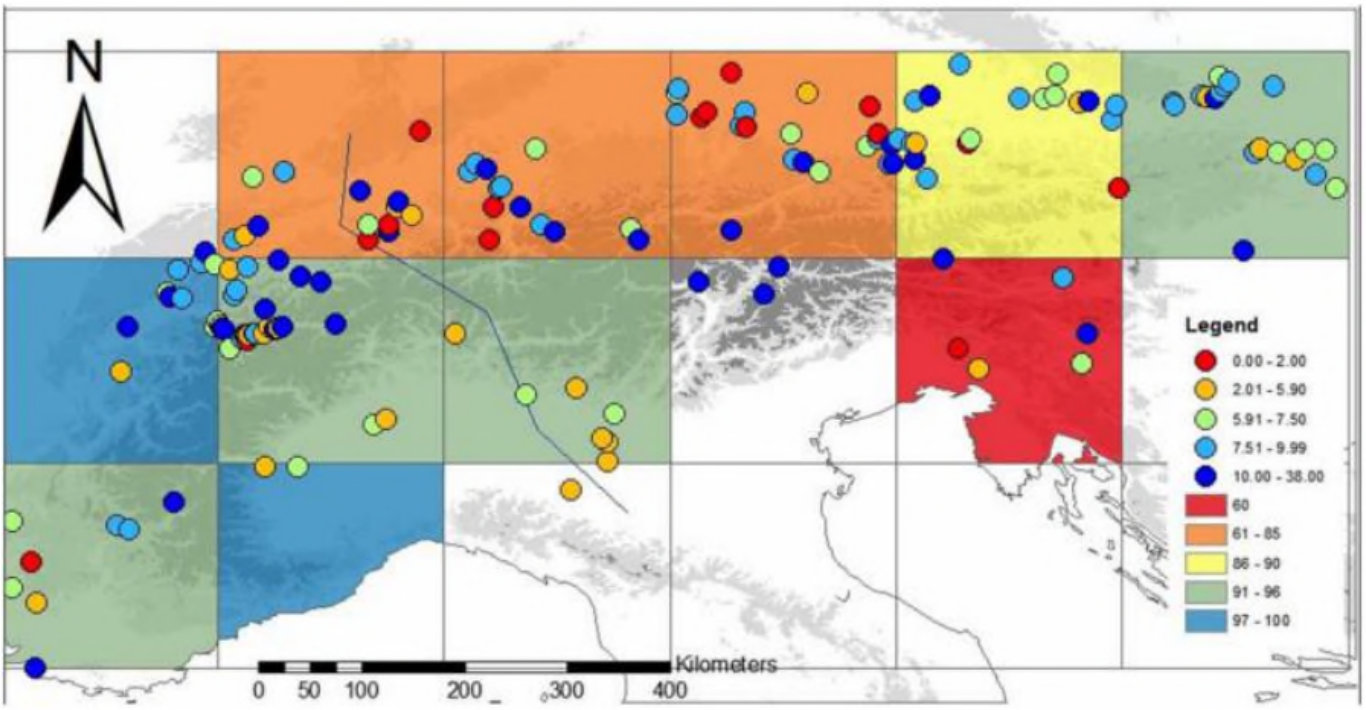

Figure 261 Tin movement in Alpine region (after Perucchetti *et al*., 2015; the colours of the points are the average of tin percentages in the overall metal assemblages from one site and the colour of each square represents the percentage of tin bronze in that region)

A similar case can be found in Cuénod *et al*. (2015). The contrast in the tin profile of Mesopotamian and Luristan suggested a movement of tin between these two regions (Figure 262). But in central China, which is roughly of a similar geographical size, no significant variation in the use of tin and lead can be found. Instead, the same type of alloying (tin-bronze/leaded bronze) was followed on a strikingly nationwide scale since the period of Erlitou (Figure 263-264).

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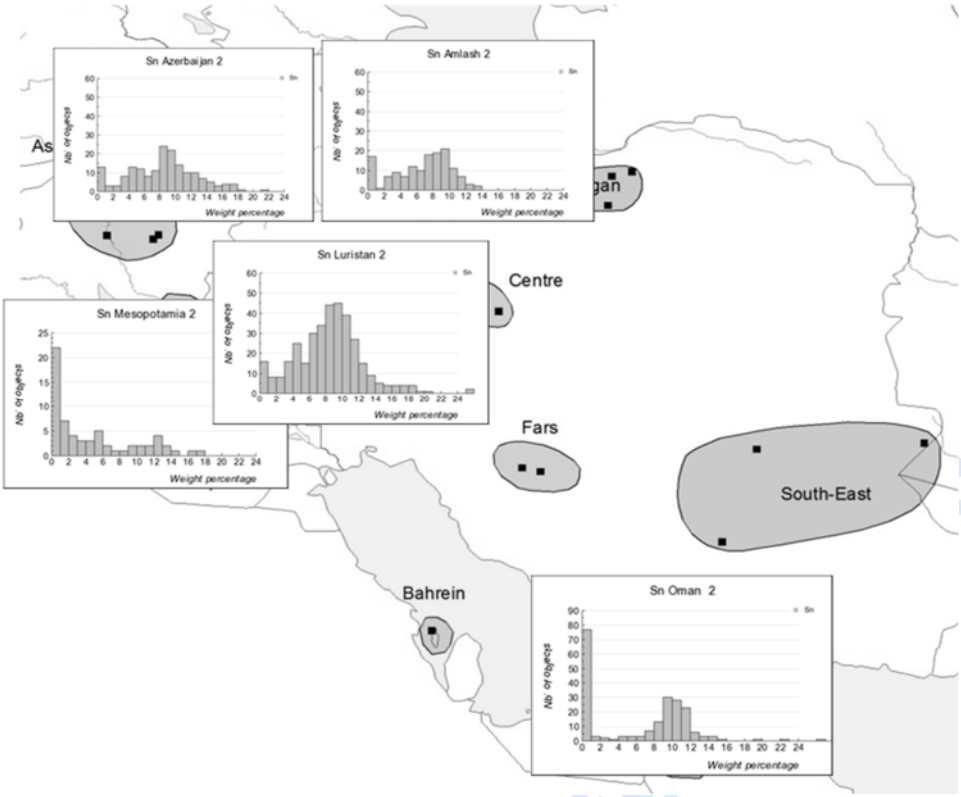

Figure 262 Tin movement in Mesopotamia and Iran plateau (after Cuénod *et al.*, 2015; the symmetric distribution of tin (primary alloying) in Luristan suggests a rich tin supply whereas the skewed tin in Mesopotamia (secondary alloying) is indicative of recycling tin from bronze, possible from Luristan)

This pattern raises quite a few far-reaching questions. Through what mechanism did Erlitou people have a command of metallurgy, as well as know how different metals should be combined together before casting? Why did the Erlitou people in the very beginning of the Chinese Bronze Age jump to leaded bronze which was also used in the late European Bronze Age? Why was a similar recipe employed on such a wide scale? Was it the result of a centre-diffusion model, or local polymetallic geology, or both, varying from one region to another? Answering these questions needs a lot more data but what can be argued now is that without a powerful network it would hardly be possible to see people living in so different areas having access to both tin and lead and who achieved a wide use of leaded bronze across such a vast land.

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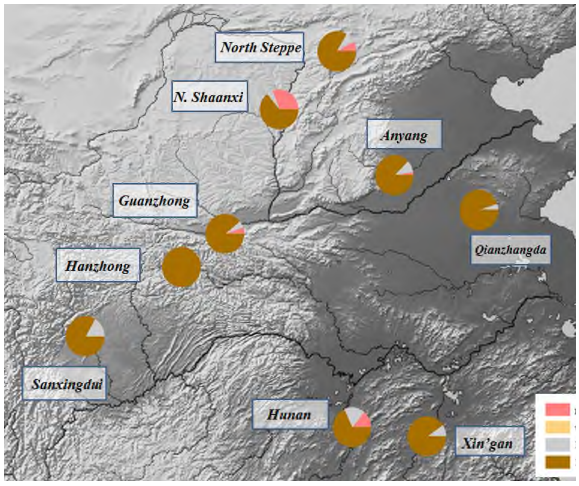

Figure 263 Alloying distribution in the late Shang period (see data appendix in the thesis for the source of data)

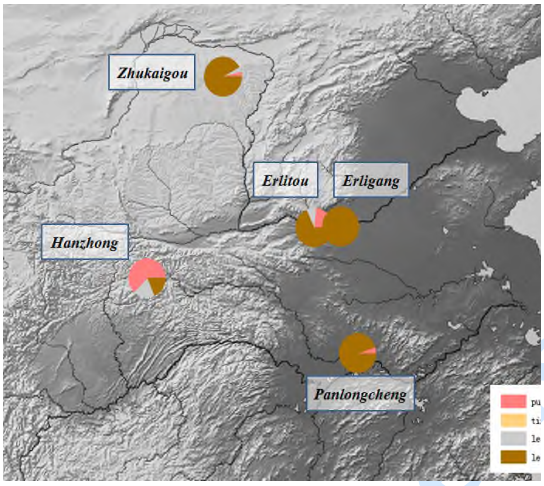

Figure 264 Alloying distribution before the late Shang period (see data appendix in the thesis for the source of data)

The profile distribution of tin and lead reinforces the homogeneous pattern identified above. No particular regions stand out by using radically more (or less) tin or lead during the late Shang period (Figure 265-271), like Luristan or Mesopotamia in Figure 262. One exception is that, as discussed in Chapter Four, the addition of tin at earlier Panlongcheng was more lavish than that at Zhengzhou, suggesting that during the Erligang period tin came from the south (see also Figure 265). More importantly, tin mines are mostly found to the south of the Yangzi River, such as in modern Hunan and Jiangxi province.

It is also import to note that tin may travel in different forms. In addition to tin ingots or cassiterite, it can also travel as part of a pre-alloyed metal. This idea comes from the discussion with Chinese mining archaeologists (Prof Li Yanxiang, Prof Chen Jianli and Prof Chen Kunlong), who discovered that the raw metal in the northeastern part of China after smelting were immediately copper-tin alloys. Therefore, it is also

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possible that some proportion of tin at Anyang derived from the northeast.

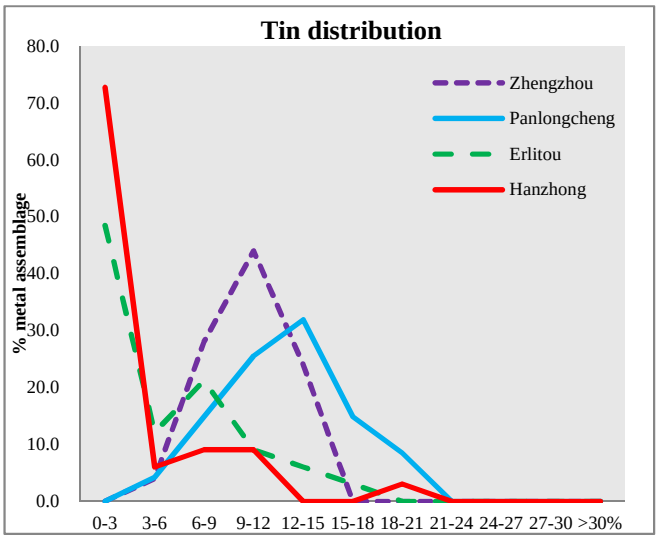

Figure 265 Variation of tin in the pre-Anyang period

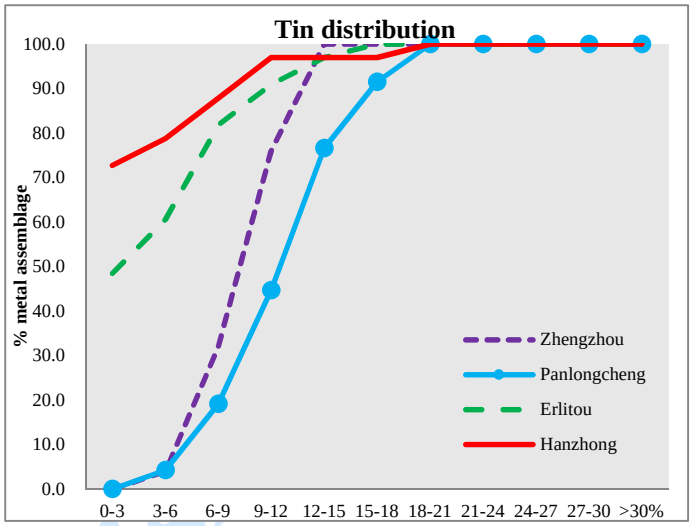

Figure 266 Cumulative frequency analysis of tin variation in the pre-Anyang period

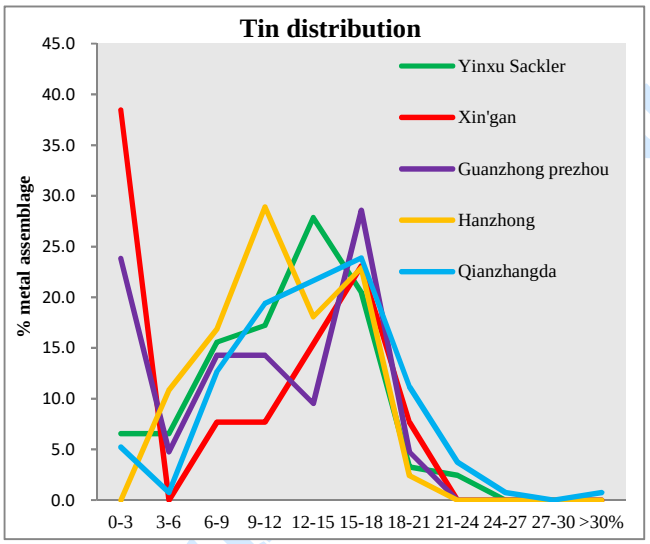

Figure 267 Variation of tin in the Anyang period

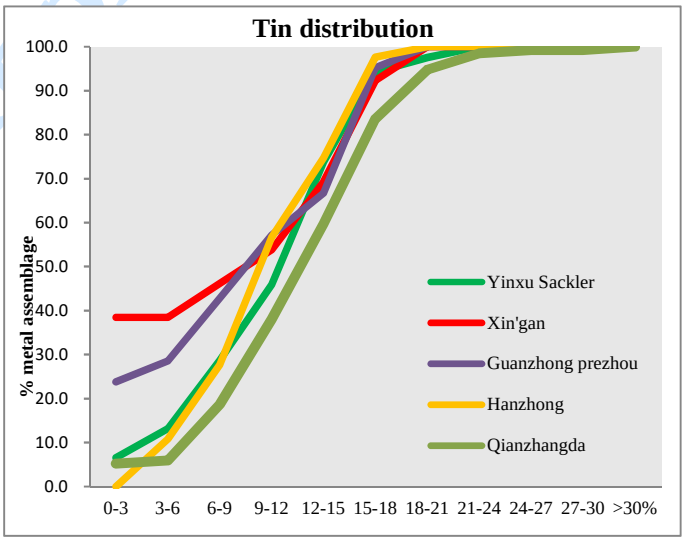

Figure 268 Cumulative frequency analysis of tin variation in the Anyang period

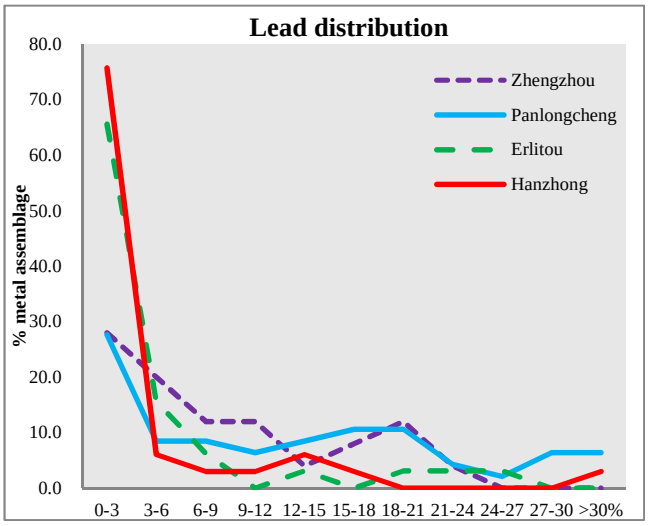

Figure 269 Profile of lead in the pre-Anyang period

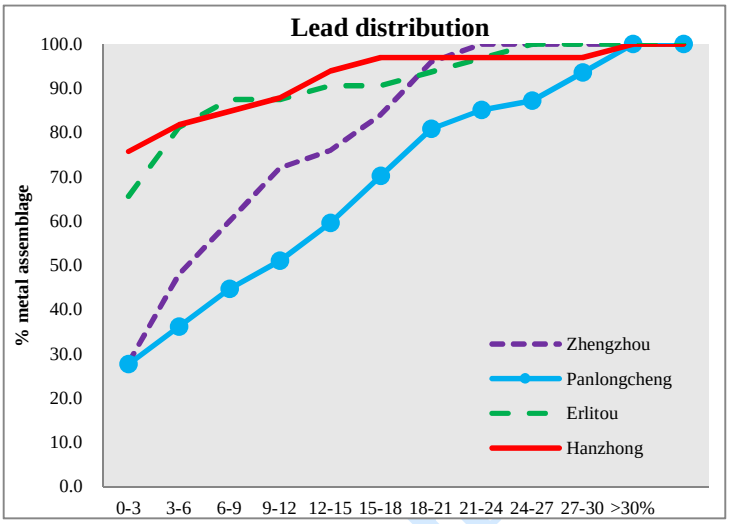

Figure 270 Cumulative frequency analysis of lead variation in the pre-Anyang period

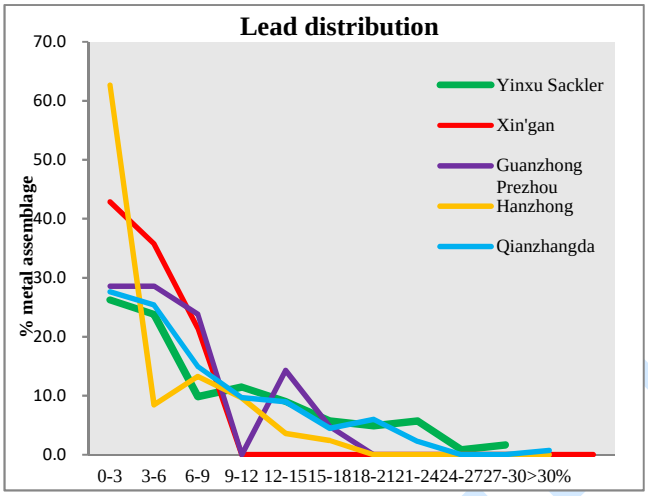

Figure 271 Profile of lead in the Anyang period

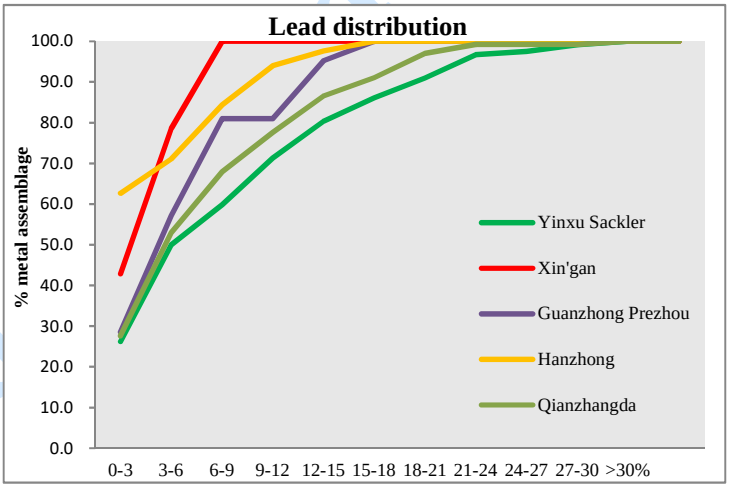

Figure 272 Cumulative frequency analysis of lead variation in the Anyang period

Intriguingly, the variation of tin profile between Zhengzhou and Panlongcheng can no longer be observed during the subsequent Anyang period. High tin bronzes show up at both Anyang and Xin'gan to the south of the Yangzi River (Figure 267). In a vast area interconnected by a powerful network, the assumption in the very beginning that people who have easier access to tin/lead tend to add more into the copper may not be valid. It is probably because the existing network had been significantly more

intensified during the Anyang period than that in the preceding periods so that the production and consumption regions became less distinct. The movement and use of tin was more affected by the sociopolitical choices rather than geographical barriers, which is sort of the similar story as the price of oil in the modern society. Its rises and falls are much more determined by the geopolitical competition between different countries rather than actual transportation distance. Therefore, for a vast area, once it is interlinked by a powerful network, the movement of metals inside can become more associated human decisions rather than natural distance.

A vertical view: changes in tin and lead in central China

Putting together the profiles of tin and lead illustrates the changing use of alloys at the sites of Erlitou, Erligang and Anyang (Figure 273 and 275). Here the cumulative frequency analysis is also presented for cross referencing (Figure 274 and 276). Based on probably the largest database we can assemble (Erlitou 78 analyses; Zhengzhou 42; Anyang 414), it shows that alloying practice experienced significant changes between these sites. Firstly, the broad range of tin and lead (skewed distribution) suggests that Erlitou people seemed not able to control the concentration of alloying as well as people at Zhengzhou and Anyang. It could be that either they did not have good knowledge on alloying practice or they did not have enough tin and lead. The concentration of tin in the Zhengzhou metal assemblage shows a typical symmetric distribution, which in the cumulative frequency analysis is a steep slope. This means

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that tin was added in a deliberately controlled manner. A similar pattern is found in the metal objects at Anyang in its first and second phase. In comparison with the objects at Zhengzhou, people at Anyang in the earlier phases added around an extra 5% of tin into copper (Figure 273). This is indicative of a richer supply of tin in the early phases of Anyang, particularly the second phase. It is also interesting to ask that, since Panlongcheng, the assumed Shang outpost in the south, was abandoned around this period, through what mechanism did Anyang people manage to obtain even more tin from the outside?

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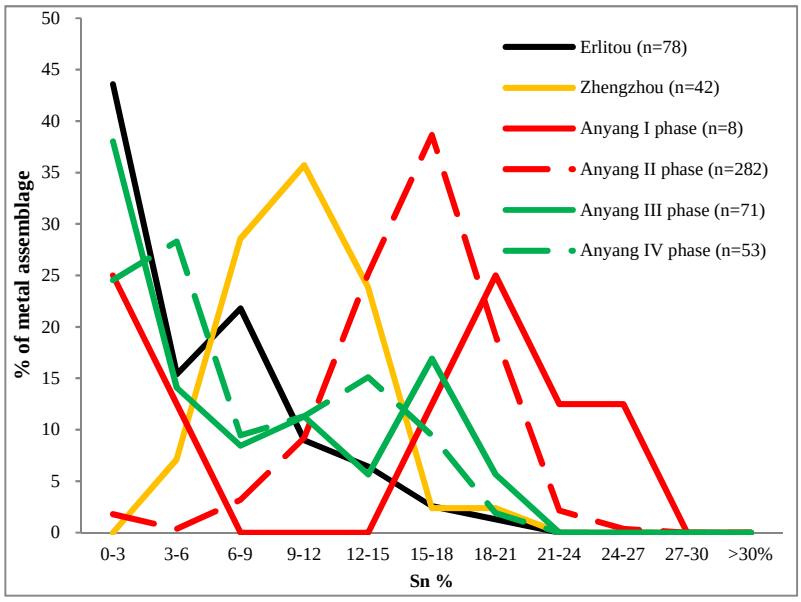

Figure 273 Profile of tin in objects at Erlitou, Erligang and Anyang

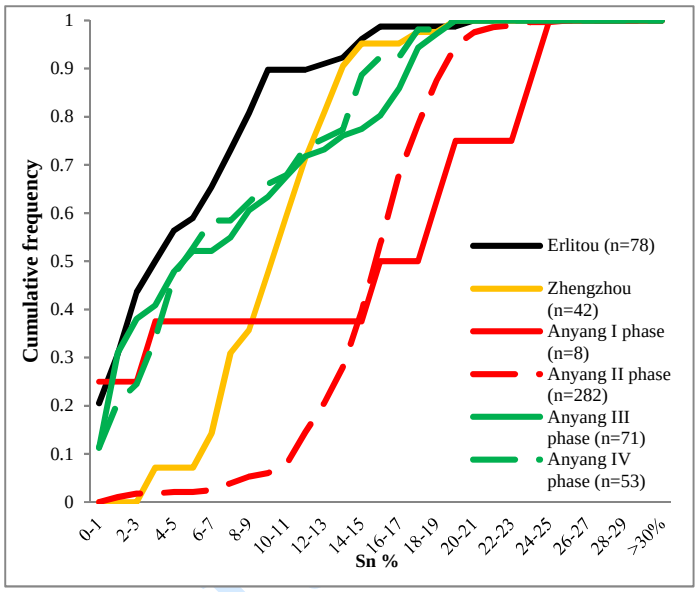

Figure 274 Cumulative frequency analysis of tin in objects at Erlitou, Erligang and Anyang

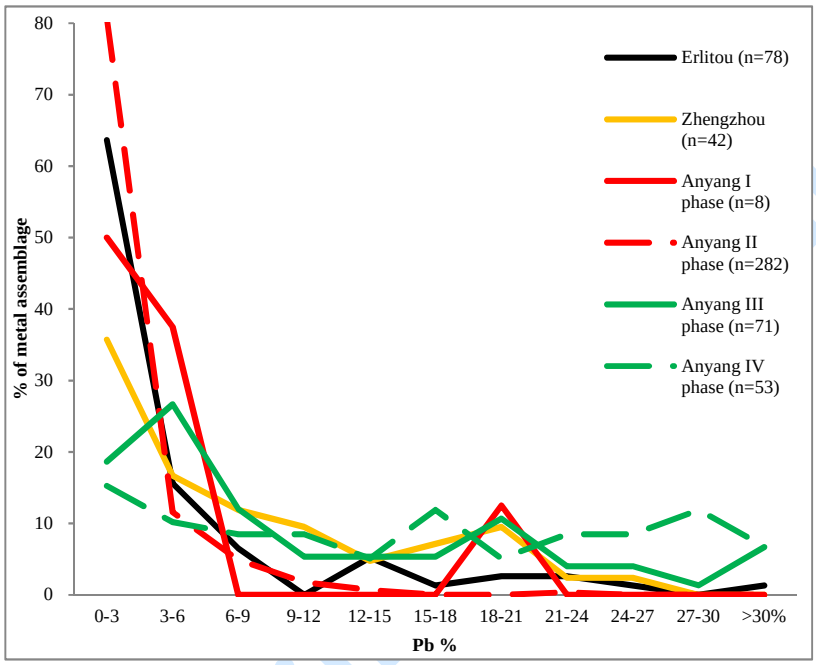

Figure 275 Profile of lead in objects at Erlitou, Erligang and Anyang

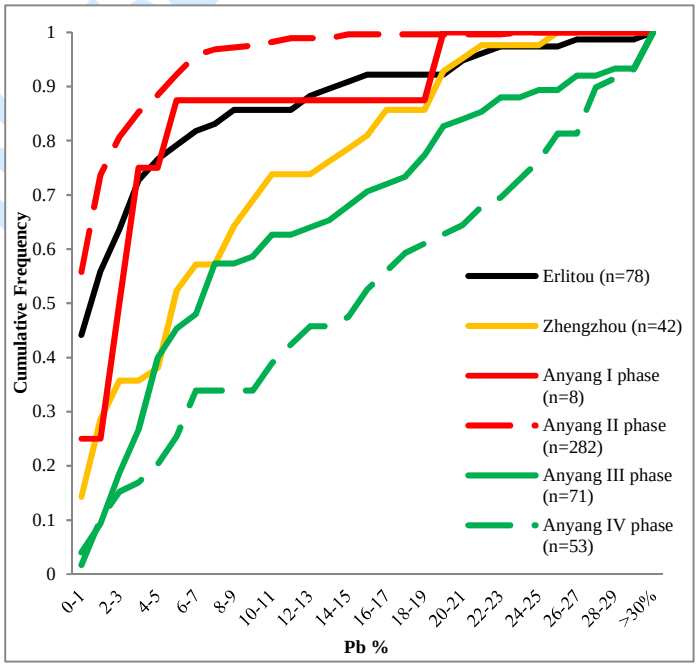

Figure 276 Cumulative frequency analysis of lead in objects at Erlitou, Erligang and Anyang

While it is as yet difficult to give a clear answer, one possibility is that the way the Anyang people obtained tin from the south was changed and became more efficient. It is likely that the negotiation with the south was changed following the abandonment

of Panlongcheng and the rise of the Wucheng culture, which was located in northern Jiangxi Province and is even closer to the tin mines (Chapter One). The other possibility might be that Anyang people discovered a new supply of tin in the earlier phases.

However, as discussed in Chapter Six, the third phase of Anyang saw a radical change of alloying practice. Lead took the place of tin and became more dominant in copper-alloying. It is much clearer in the cumulative frequency analysis where the lines of the third and fourth phase are plotted further towards bottom right (Figure 276). Using cumulative frequency analysis, one can also test whether tin or lead was used differently between the third and fourth phase. The observed maximum difference for tin and lead between these two phases are 0.10 and 0.25, respectively. Both are smaller than critical value of difference, which in this case is 0.27. Therefore, one can say that at the 95% level of confidence, no significant difference of using tin or lead can be found between the third and fourth phase at Anyang (Pollard *et al.*, submitted).

While these changes cannot immediately tell us where the tin or lead came from, it is possible to make a broad estimation of the overall quantity of tin and lead available at different sites in a relative way. In comparison with Erlitou, Zhengzhou was very likely able to obtain much more tin. This can be explained by the establishment of Panlongcheng as a Shang outpost in the south. However, Anyang in its early phases

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can get even more tin than Zhengzhou. They might have found other tin suppliers, possibly in the northeast, or made a deal with southerners, such as the Wucheng people in Jiangxi. The use of tin sharply declined from the third phase, which was probably a combination of a social choice and tin crisis (Chapter Six).

The lead isotopes offers a different lens to look at the movement of lead in China, since most objects contain lead over 1~2%. Plotting the lead isotopes on the map shows a clear emphasis on radiogenic lead in the south throughout the Shang period (Figure 277 and 278). Its proportion became gradually smaller when moving to the north. This ubiquity analysis suggests that the source of radiogenic lead may come from the south in a broad term but until now no one has been able to pinpoint the exact location. As reviewed in Chapter Two, Jin argued that this sort of lead should be traced back to southwest China (Jin, 1987, 2008) but Cui and Wu proposed the middle Yangzi River valley (Cui and Wu, 2008). Other scholars suggested Qinling as the source for radiogenic lead (Saito *et al*., 2002).

The fundamental limitation is that until now, no lead smelting site has been identified and dated to the Shang period. So it is not possible to compare isotopic data of objects to those of ancient mines. Essentially, this question contains two components: (1) how many sources were extracted to produce radiogenic lead during the Shang period (single-source model versus multi-source model); (2) where was the mine(s) for this sort of lead. While it is not possible to answer the second question directly, this

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chapter can offer some insights on a big-picture level.

It is widely accepted that the radiogenic lead is extremely rare in geology. In probability terms, if one makes a guess that one out of ten lead mines may be radiogenic, given the assumption that the Shang people could not distinguish radiogenic from non-radiogenic lead, the chances that they extracted two radiogenic lead mines independently (two independent events in mathematical terms) is 1/10*1/10=1/100. From a statistical point of view, this would mean that if the Shang dynasty repeats one hundred times, they may have discovered two different radiogenic lead mines once. Although still above zero, the chance of multiple source of radiogenic lead is incredibly lower than the probability of a single source. Without further evidence, based on the assumption that using radiogenic lead was purely by chance during the Shang period, the most likely model is the single source.

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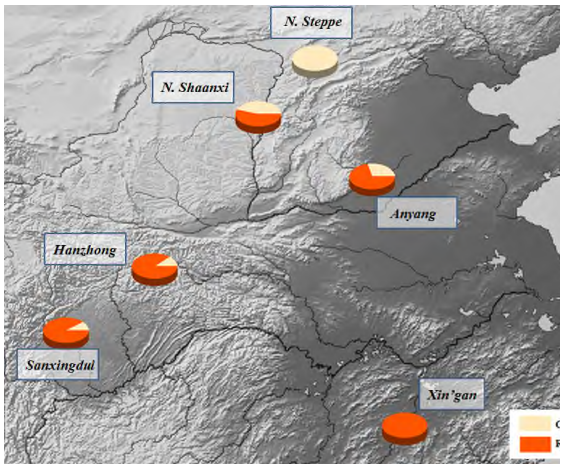

Figure 277 Lead isotopes in the Anyang period, data source: Jin *et al.*(1994, 1995, 2006, 2008, 2001), Tian *et al*. (2010), Liu (2015), Wang *et al.* (2006), Peng *et al*. (1997, 1999), Li (2002), Bagley (1987), Chase (1996-97), Takahama *et al*. (2001).

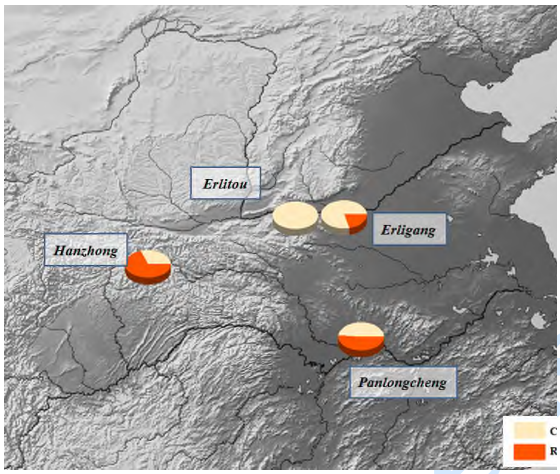

Figure 278 Lead isotopes in the Anyang period, data source: Jin *et al*. (1990, 2001, 2006), Wang *et al*. (2006), Sun *et al*. (2001), Peng *et al*. (1997, 1999, 2001), Cui and Wu (2008), Tian (2013)

In addition to the radiogenic lead, common lead also played a crucial role in metal production during the Shang period. Both Jin *et al*. (accepted) and Cui and Wu (2008) suggested a multiple-source model for common lead, but using different approaches. As shown in Figure 279, different dashed horizontal lines may represent different supplies of common lead and one can easily see that those for Erlitou, Erligang and Anyang were quite different. For instance, one common lead supply represented by the dashed line at the bottom was significant for Erlitou and Zhengzhou but had almost completely disappeared at Anyang. One can easily see that the picture of common lead supply is quite different from the model of radiogenic lead. In general, it has been agreed that the lead supply of Shang was based on multiple sources (Jin *et al*., accepted; Cui and Wu, 2008: 43).

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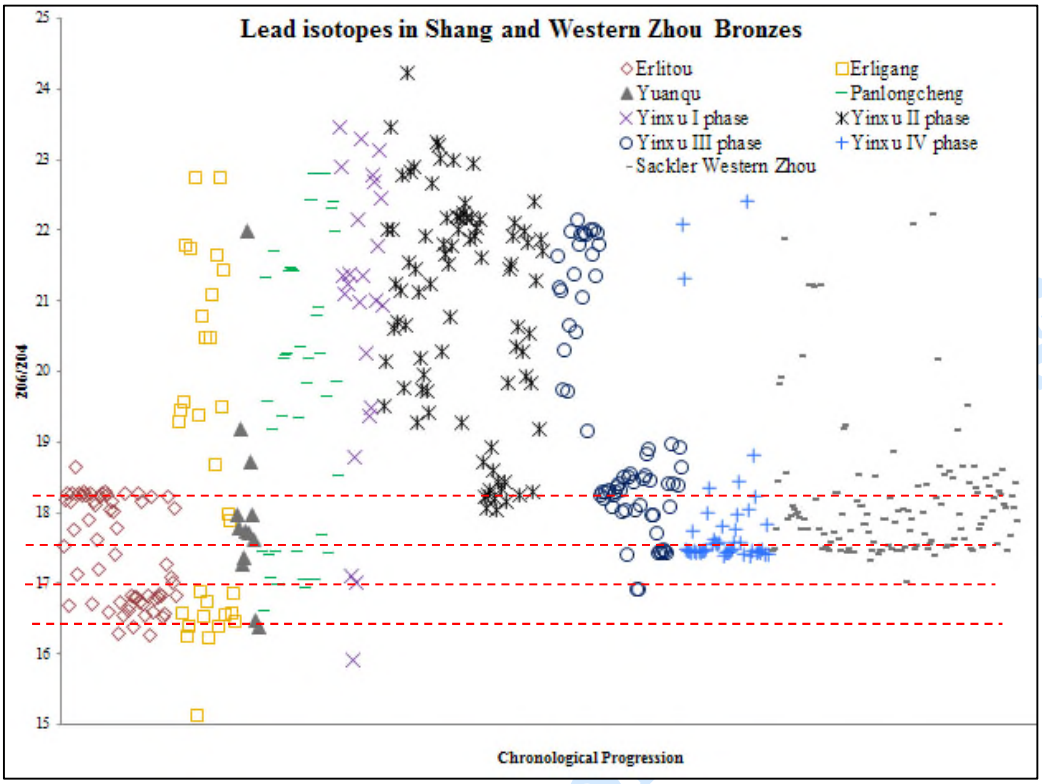

Figure 279 $^{206}Pb/^{204}Pb$ values for vessels from Erlitou, Erligang, Panlongcheng, Yuanqu, Anyang, Western Zhou (after Jin *et al*., accepted)

In summary, mapping altogether all this information reflects a delicate and complex network, through which copper, tin and lead derived from various regions, traveled in different forms and moved into a range of sites in different periods. It is believed that multiple sources of copper contributed to the overall circulation through this network and each region placed emphasis on different parts of the network. Tin was very likely derived from Yangzi in the south and possibly northeastern China. More than one lead mine were exploited during the Shang period and one of them yielded radiogenic lead. So far, applying the Oxford system to the existing database allows us to present some big pictures on the movement of metal. Much more data are necessary in the future to

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do more detailed analysis.

7.3 Future work

Compared to the huge quantities of natural resources that were moved around during the Shang period, the network of metal movement shown above is a very broad observation. To improve the resolution of our picture on this topic, two principal foci of work are suggested for the future.

7.3.1 More and better scientific analysis of metal objects

Copper-alloy objects are one of the most concrete parts of the archaeological records on the metal production during the Bronze Age, but it has to be treated as an assemblage of different attributes. In terms of scientific analysis, it often combines not only copper but alloying elements such as tin, lead, arsenic or others. These are all equally important chemical attributes of one single object and each of them deserves good scientific analysis to be characterized and expressed. This thesis strongly suggests that in the future all of the scientifically analyzed copper-based objects should be reported with at least three sets of data, alloying elements, impurities (including at least As, Sb, Ag, Ni, Zn, Co, Bi and Fe) and lead isotopes. A more comprehensive analytical protocol can be found in Chapter Three (Appendix IV). The copper base can be characterized by the trace elemental patterns and lead isotopes can be used to describe lead, or sometimes the copper as well. No independent scientific analysis has been widely used to characterize tin. Tin isotopes might be helpful in some way (Haustein *et al.*, 2010; Pernicka, 2013). The advantage of having all of these datasets together is that they enables scholars to discuss copper, tin and lead

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independently and offer an opportunity to disentangle the process of how these metallic elements became a single object. More crucially, if this sort of analyses is available for metal *assemblages* across various times and space, archaeologists can reconstruct the major relationships between metal and humanity and use it as a proxy to deepen our understanding of the changes in the sociopolitical interaction between different groups of people.

It is known to scholars that conducting scientific analysis on bronze objects is not easy and straightforward. We need to cope with issues concerning museum curation, funding limitations or ethnics. To be more pragmatic, even though it is not possible to immediately carry out a nationwide project on metal analysis in China, one can always start to fill the holes in the current database. For instance, data on objects in the middle Yangzi River valley and Guanzhong Plain are still very limited. Some of objects in these two regions already have analysis of alloying elements by SEM-EDS. It would be much easier if one could locate the old mounted samples and re-analyze them for trace elements. Lead isotopic analysis can be carried out on the corrosion of the bronze objects (Snoek *et al.*, 1999). Even by following this stepwise way our understanding of many issues can be significantly improved.

7.3.2 Modeling uncertainties

Once Chinese scholars have achieved a large database, at least as sizable as the current European one (more than 20,000), it becomes possible to quantify our

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interpretations to some degree. Scientific analysis comes with an uncertainty. So does scientific excavation. However, one advantage of using scientific analysis to start with is that its systematic uncertainties can be quantified in mathematical terms. For instance, Chapter Three shows that if one reports an object with 0.5% nickel with RLAHA SEM-EDS, it means the true value of nickel concentration is likely to be between 0.45-0.55% (~10% relative error). Other instruments may have larger or smaller errors. Two issues must be carefully considered. As discussed in Chapter Three, the first one is that this sort of information is often absent in publications. The second one is that once it becomes available, how can one *build and quantify these uncertainties into our archaeological interpretations*. One possible way is to combine a big database, probability calculation and iterative modeling. The best parallel might be the Oxcal program for radiocarbon dating. As illustrated in Figure 280, based on the actual profile of the concentration of variables (*e.g.* arsenic/antimony/tin/lead/ or the ratios of lead isotopes) in metal assemblages in Region A and Region B, in theory, it is possible to calculate whether mixing metals from Region A and B can produce the ones found in Region C. If the program is sophisticated enough, it is also possible to calculate the level of probability the original proportions of A and B before mixing. One way is to start from 100% A metal assemblage and 0% B metal assemblage, and compare the result of mixing the two assemblages with the chemistry of the C metal assemblage. This can be automated in a computer by dropping the percentage of A metal assemblage (*e.g.* 99%, 98%, 97%...) and increasing the percentage of B metal assemblage (*e.g.* 1%, 2%, 3%...). The other way to do this sort of mixing modeling is

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firstly insert an initial value, telling the program that, for instance, 70% of A metal is probably (on XXX probability) remelted to produce C objects, and ask how much B metal is necessary to be mixed with A and on what probability, which is essentially a Bayesian model (Bronk Ramsey, 1994, 1995, 1998, 2001). If no mixing was involved during this process, then the probability should be zero. It is also possible to build other rules into the program, such as the rate of arsenic loss during the high temperature process. This kind of program already comes into use in modern scientific sphere, particularly in isotopic studies (Jackson *et al*., 2009; Moore and Semmens, 2008). The Oxford group is currently developing a similar model but specifically designed for metal studies.

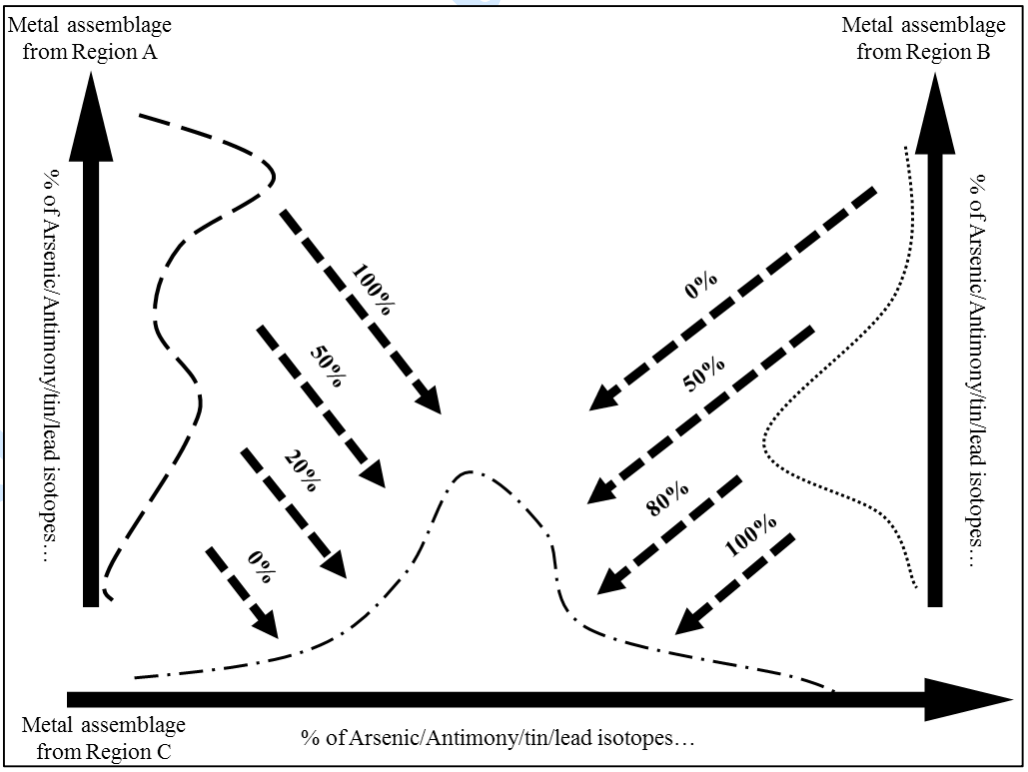

Figure 280 Modeling possible mixtures of copper-based objects from different regions

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Chapter Eight: Conclusions

"I believe the true line of research lies in the careful noting and comparison of the smallest details." (Flinders Petrie Museum)

While I shall continue the similar topic in the next three years with the Flame project, the end of the Shang period gives this thesis a convenient close point. The major task set out in the beginning is to capture and picture the changes in metal chemistry within a systematic framework (copper groups, alloying elements, lead isotopes and a combination of these three sorts of data) and explore the underlying explanations (movement of metals). Therefore, to accomplish this task, a substantial number of figures, tables and maps are delivered in previous chapters. One immediate impression from these comparative studies is that the similar/different types of metals reoccurred in different time periods, geographical regions or archaeological contexts. The central argument is that these changes in metal chemistry can be explained by changes in the provenances of metal, its movements, organizations of their production and interaction between various groups of people, all of which help to broaden and

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deepen our knowledge on sociopolitical connectivity between various groups of people therefore must be interpreted properly.

8.1 From points to networks

Using chemical compositions or lead isotopes to provenance metal has not been a novel application in archaeometallurgy. The provenance school in archaeology has been confronting criticism in many ways, ranging from the suspicion on the quality of the data, the worrying of geological complexity, the impact of human choices to the down-to-earth conclusions (Chapter Two). Nevertheless, just imagine Chinese archaeologists suddenly discovered one bronze at Anyang with inscription recording explicitly that the metal used to produce this object was from X region. To what degree does this inscribed object improve our situation? It might contain some value if we have not realized that X region can also contribute the metal circulation at Anyang. Otherwise, it is hard to be persuaded that such a piece of information could exert a devastating impact on our current level of understanding.

One of the key objectives in this thesis is to convey that the chemical analyses of metal objects contain information on not just provenance but a series of others. Metal does not move but it is moved by humans. In other words, metals were extracted and moved by humans but equally have power to reshape human societies. Archaeological relevance should be attributed to the mutual integration or interaction between metal

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and humanity. Along this strand of study, provenance of course plays a critical role but definitely not the whole picture. Moreover, one has to admit that owing to the potential mixing and recycling happened at different stages of metal production, insufficient number of analyses and incomplete information on metal mines, it is not yet possible to assign objects to a unique metal source in an absolutely unambiguous manner. The result offered by many provenance studies has to be perceived as a probabilistic argument.

The beginning of the thesis points out that one of the most extraordinary features during the late Shang China is the scale of metal production, particularly at Anyang. It was a period in which the metal objects interred from top elites tombs are sometimes calculated by the unit of ton. Along with a growing number of excavated mines, the questions that are attractive to archaeologists are not only the provenance but also the strategy. Taking Anyang as an example, the startling contrast between the remarkable number of bronzes and relatively poor metal sources raises the question that through what strategy Anyang managed to obtain enough metal supply?

It is understandable that people living the metal-rich places were more likely to procure metal within their region. The best examples are those who lived from the upper to the middle Yangzi River and established prosperous metal industry. Such prosperity is not just reflected by the quality and quantity of the finished objects found in those regions but their uniform chemical and isotopic composition. Chapter Five

Ruiliang Liu unplished thesis

demonstrates that the metal production at Hanzhong and Sanxingdui relied significantly on CG1 (clean copper) and radiogenic lead (intraregional model). This uniformity was replaced by a more diversifying chemical signature in the bronzes around the middle Yangzi River (geology-complex model).

By stark contrast, people in relatively metal-poor regions, such as the Central Plains, achieved an even more gigantic metal industry. These people must have pushed a different strategy (multi-supply model, Chapter Seven). By comparing the different metal assemblages made at Anyang in different phases, Chapter Six gains further insight into the changing supply of metal to Anyang. Each of the four phases saw different emphasis on the major types of copper and lead employed at Anyang. More changes can be seen if we project out chronological axis back to the period of Erlitou and Erligang. Very likely, these changing patterns were results of changing contact between the Central Plains and other regions.

Under this multi-supply model, what becomes more supervising is that very little evidence has been found to support a large-scale mixing and recycling at Anyang. The Oxford system is designed not to replace the classical provenance study but accommodates both provenance and mixing/recycling. Its capability of revealing mixing and recycling has been shown in the case of Hanzhong where imported bronze objects were turned into local sickles. However, while evidently Anyang sucked in metals from a variety of places, based on the current database, it appears unlikely to

Ruiliang Liu unplished thesis

say that a significant proportion of metal used at Anyang had been mixed. The underlying reason might be that most of our high-quality analyses are of ritual vessels from top-elite tombs so that the current picture is not comprehensive enough to represent the entire metal production system at Anyang (high/low-line of production). For instance, weapons may be different. If this was true, it would suggest that the production of different categories of objects followed different strategies as well.

To summarize, on a broad level, these strikingly different strategies forced people to move around and a powerful network emerged. People in the metal-poor regions had to negotiate with those in metal-rich region and build up sociopolitical bonds to facilitate exchange of metals, and those who lived metal-rich region also had to search in the mountains for new sources and consider how to use their metals to exchange other necessities. The resulting interaction can be performed in many diversified ways (exchange, trade, political treaties or warfare) and could be varied from one case to another. However, all of them together contribute to stimulating and sustaining the powerful network. It becomes viable to move tons of metal over hundreds or even thousands kilometers, underpinning the efficiency of communication and labour organization in this network.

It is worth noting that the movement of metal may just be one way of conceiving this network. Many other commodities and exotics must also flow within it as packages. For instance, the Central Plains is known as the food-producing region. It is

Ruiliang Liu unplished thesis

reasonable to propose that the most effective tool in the negotiation with other local powers might not be arrows but millet. Their elaborate bronze ritual vessels may be another candidate as well. Chapter Seven makes the first attempt to visualize this network for metal movements but it would be more interesting to compare and correlate the network of metal to that of other materials, such as jade.

Under the paradigm of network, a relevant and perhaps more commonly encountered question in the archaeological literature is localisation versus importation. Study of the locally produced objects enables archaeologists to draw a life history of the local production system whereas importation of objects from regions outside can help to confirm a direct or indirect connectivity in between. In a subject such as Chinese archaeology which is heavily oriented by object typology, the issue of localisation versus importation on bronzes is often solved by the comparison of shapes, styles or decorated patterns. This thesis has contributed an extra line of evidence to the discussion, mainly from the perspective of chemical compositions. This can be best reflected in the course of reconstructing local production at Hanzhong, where we have very good-quality datasets (Chapter Five). The relatively high amounts of arsenic, antimony and nickel in the sickles recovered from the Longtou caches represent the locally made metal objects, in terms of both shape and chemistry (see publications of Chen and Mei in Chapter Five). A few sickles however stand out due to the lack of these diagnostic elements but noticeable percentages of tin and lead. The trace elemental similarity between these exceptions (leaded bronze sickles) and

Ruiliang Liu unplished thesis

weapons/vessels typologically identified as non-local products but discovered from the same caches signifies that some imported objects (*e.g.* imported weapons) were probably recycled into those of locally favoured forms (leaded bronze sickles; see Chapter Five for previous scholarship). In later periods, the increasing dominance of clean copper (CG1) and diversity of local typologies (animal/human masks, different weapons and discs) illustrate a much stronger and more standardized metal production system at Hanzhong, which in turn provides one more chemically diagnostic criterion for judging local and non-local products. Similarly, the strong dominance of CG1 (clean copper) at Sanxingdui is suggestive of an intensive local production system. The other case study of localisation versus importation is between Zhengzhou and Panlongcheng. Although a considerable number of publications accept that bronzes present a strong typological resemblance and those found at Panlongcheng were more likely made at Zhengzhou, the comparative studies in Chapter Four shows that the raw copper and lead used at these two places were not completely the same, implying that the two places had some different metal supplies from each other. These results encourage scholars to reconsider the metal exchange between the two places more subtly on one hand and how to separate the movement of raw materials and finished objects or how to combine typological study and chemical analysis on the other hand. Meanwhile, is it necessary to reconsider the dynamics between Zhengzhou and Panlongcheng?

Ruiliang Liu unplished thesis

8.2 From objects to assemblages and scales

While comparative studies in this thesis and many other archaeometallurgical studies are performed on the level of assemblages, the definition of an assemblage is variable and case specific. In essence, object "assemblage" is an analytical tool for scholars to approach specific archaeological questions. Therefore, because its definition is virtually dependent on the targeted archaeological questions, it varies from one case to another. In most situations, it is very convenient to consider objects from the same archaeological context as one assemblage. In Chapter Five, objects which were recovered from the same archaeological context (the same cache at Hanzhong or sacrificial pit at Sanxingdui) are regarded as one assemblage. Similarly, in Chapter Six, objects from the same tomb (Fu Hao tomb, M54, M1994, M160, M1046) are taken as one assemblage. One can also go beyond the archaeological-context based definition and select objects from the same time/space/typology as one assemblage, such as all of metal objects from southwestern China, or objects distributed in four phases at Anyang.

Probably one of the best expressions of being scalable is to use varying levels of metal assemblages for comparative studies. On a very broad level, comparing metal assemblages from multiple regions and time periods allows us to draw a schematic picture of the movement of metal, which can be called the nationwide scale. The dominance of clean copper in southwestern China during the late Shang period shows

Puiliang Liu unpished thesis

a clear contrast to the types of metal used at either Anyang or middle Yangzi River, suggesting a different metal supply in the southwestern China at that time and a possible local source of copper. Likewise, the wide distribution and high proportion of radiogenic lead in objects found in the southern China during the Shang period also suggest the lead supply between south and north are different. The rise and fall of different copper groups and lead isotopes in the objects recovered from Erlitou, Zhengzhou and Anyang, are all indicative of a changing manner through which copper and lead were sucked into the Central Plains. Sometimes if we are only focused on two regions, this could be called regional scale, such as Chapter Four (Zhengzhou and Panlongcheng).

Dropping slightly down to focus on various smaller assemblages within a single region, one can improve the resolution of the picture for that specific region. For instance, Chapter Six has analyzed the bronze assemblages each by each and concluded a series of synchronized changes dated to the phase III at Anyang, encompassing alloying technology, and the supply of tin, lead and copper (the contextual scale). More intriguingly, these changes could be further interconnected to some more profound sea-change happened in the sociopolitical sphere at Anyang in the same time. This sort of information might have been lost if we merely stay on the nationwide scale. Yet equally important to note that without further comparison to other regions on the nationwide scale it is not possible to know the source of metal in different phases of Anyang. While most parts of the thesis are focused on the

Ruliang Liu unplished thesis

contextual/regional/nationwide scale, scholars can also go further beyond and compared, for example, China and the Steppe, which might be called continental scale.

Alternatively, we can also select individual objects for comparison. Using the assemblage is a convenient starting point to help scholars identify interesting individual objects (sometimes called outliers). It is always useful to check individual objects if their chemical signatures stand out from others. They may be made for special purposes or derived from another region with a different metallurgical practice.

Using the tool of assemblage in China has an extra advantage. A large number of chemically analyzed objects in China are from museum collections, of which the original archaeological context is no longer available (*e.g.* Sackler collection). Although their data cannot be used on the contextual scale, they can still make vital contributions to the regional and nationwide scale. It sometimes can quickly help us increase the quantity and quality of our database. For instance, greatly thanks to the high-quality data of the Shang Sackler collection, Chapter Six successfully combines alloying compositions, trace elements and lead isotopes together and reveals a remarkable consistency as a result of a highly sophisticated production organization at Anyang.

Ruliang Liu unplished thesis

8.3 The use of legacy data: a stepping stone

Another major task for this thesis is to assemble a large number of legacy data. The construction of such database immediately offers at least two benefits. On one hand, it allows us to quickly identify the existing gaps (Figure 281-283). These gaps can be firstly observed in the uneven distribution of chemical and isotopic data in different regions. The number of data for objects discovered at Anyang has significantly exceeded those of other regions. By contrast, data for the sites along the middle Yangzi River during the late Shang period is still much less sufficient. Also, as mentioned above, the number of analyses of weapons at Anyang is radically unproportional to that of ritual vessels. One the other hand, scholars are still struggling for find a set of excavated objects dated to the late Shang period equipped with all alloying elements, trace elements and lead isotopes. This is even true for those pieces discovered at Anyang. Up to now, we are still using the data published for the Sackler collection to represent Anyang and to show how to combine the three sorts of data together in a Chinese context. Fortunately, Chinese scholars have already realized these issues and some PhD theses in recent years attempt to publish the three clusters of data altogether. I believe the gaps shall be quickly bridged in the near future.

Puiliang Liu unpublished thesis

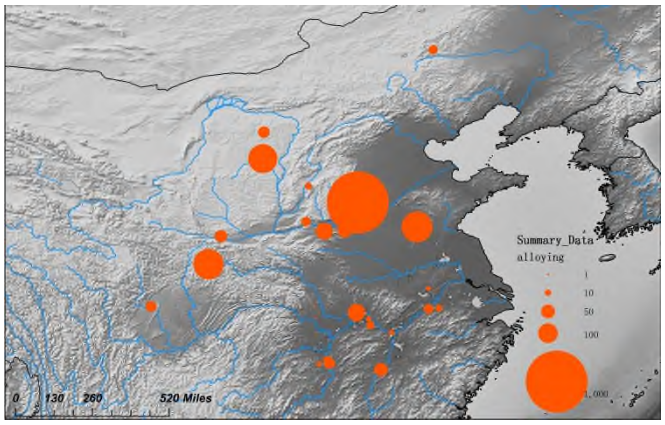

Figure 281 Summary of alloying data for Shang China

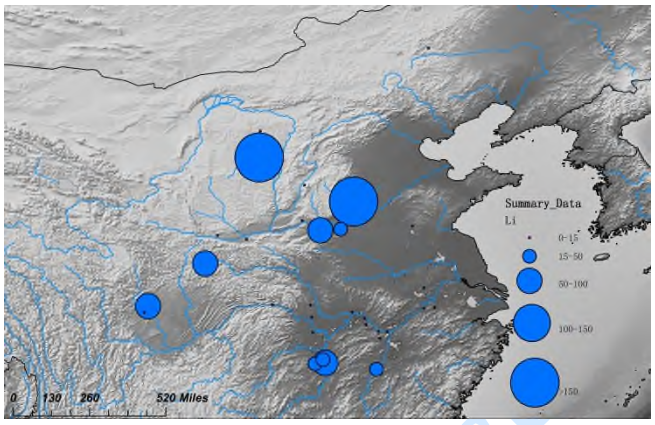

Figure 282 Summary of alloying data for Shang China

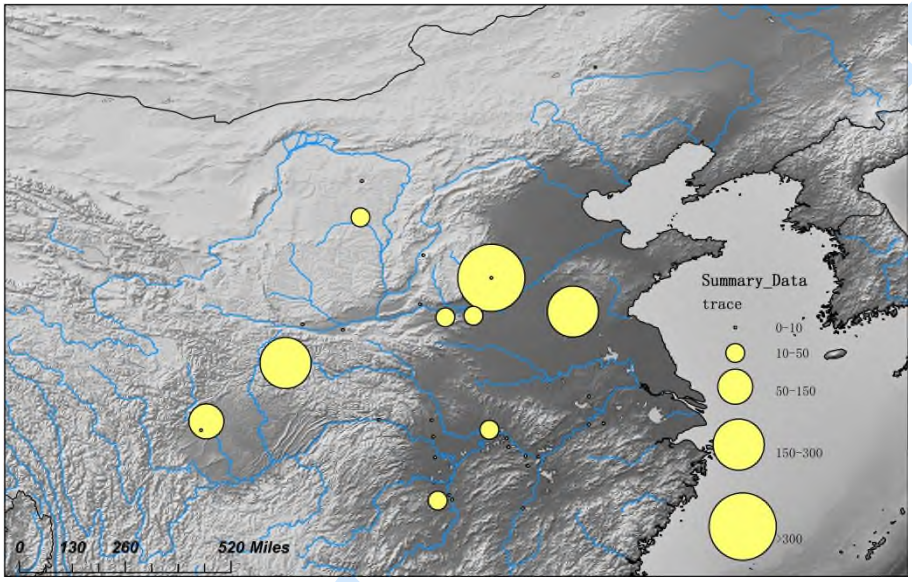

Figure 283 Summary of trace element data for Shang China

Ruliang Liu

The principal concern about exploiting these old data to make archaeological narratives is the precision and accuracy. In the western academia, the quality of measurements is often monitored a series of round-robin experiments among different laboratories (see Chapter Three for further references). While this could offer a number of useful indications for the data quality assessment, virtually it is a snapshot and unable to guarantee all the data published from the same laboratory have the same level of precision and accuracy. In order to carry out a much more thorough

assessment on the quality of legacy data, ideally, we need all sorts of information list in the analytical hygiene in Chapter Three, which appears basically impossible for current literature. Taking a step back, the more details on the analytical process are released, the more thorough assessment can be conducted.

The thesis follows two threads of evidence to check the data quality. Chapter Three demonstrates the protocol on how to record and evaluate performance of one instrument (SEM-EDS) step by step. By analyzing eleven primary standards and sixteen secondary standards and comparing the analytical results with the certified values, we have pretty good understanding about the standard deviations, relative errors and minimum detect limits. These sorts of information play a pivotal role in estimating the uncertainty of the data of the archaeological samples with unknown compositions. Subsequently, a number of archaeological samples have been imported and analyzed in Oxford and their results are used to compare with those from published sources. The other way to check the quality of the published data is to find those objects which have been repeatedly analyzed and make comparisons.

The data assessment is also carried out on two different scales (individual objects and assemblages) and three aspects (alloying percentages, trace elemental percentages, and distribution of copper groups). Measurements on tin from the different laboratories produce an excellent agreement while lead is generally tumbling quantitatively. With regard to trace elements, the presence and absence of arsenic,

Ruiliang Liu unplished thesis

antimony, silver and nickel of objects of the same assemblage (*e.g.* from the same site) are largely agreed between various publications. Although, the number of the overlapped measurements on these trace elements is rather limited, the current work shows that their results, once greater than the minimum detect limits of the instruments, are generally acceptable.

While it cannot be denied that the quality of legacy data is notoriously difficult to be evaluated and there exist plenty of holes in the literature, what needs to be emphasized is that through a patient and detailed comparative analysis, it is still viable to identify the reliable data for archaeological interpretations and exclude the unreliable ones. Essentially, using scientific data to tackle archaeological questions is a balanced choice. All of the data contains some parts of useful information but one needs to make sure to choose the right set of data to answer the specific question.

8.4 Future works: resolution

In an archaeometallurgical seminar at the Beijing University in the summer of 2016, a scholar proposed a stimulating question that since the number of chemical analysis of Chinese bronzes is considerably less than that in Europe, is it still feasible to reconstruct the movement of metals for Bronze Age China? The key word to answer this question is *resolution*. While it is certainly true that the size of the chemical database in Europe and Russia may be ten times larger than that in China, as current

Ruiliang Liu unplished thesis

scholarship as well as this thesis demonstrates, the last one hundred years, particularly the most recent three decades, generate an accumulation of data for Chinese bronzes which can be no longer ignorable. This group of data builds up the basis for this thesis. In spite of various kinds of drawbacks in this database, inherent to all archaeological studies, the current picture is essentially an approximation to the reality. In several places, this thesis attempts to list and prioritize different possible scenarios and tries not to write down a definitive and isolated answer. This aims to create an open discussion and some useful reference for future studies. Hopefully, the fuzziness and ambiguity can be reduced and the resolution shall be improved when more chemical analyses and archaeological information are released.

It is widely known that taking samples from bronze objects is increasingly difficult due to the museum curation. Even though museums themselves agree to be more engaged with scientific studies, however, they would like to see more work to be done by non-destructive analysis, such as portable XRF. I have no intention to decry the work of portable XRF and it is still probably the most frequently-employed instrument for a quick survey on the chemical composition of bronzes in a museum. However, it is our responsibility to keep informing the museum staff and archaeologists that there is an intricate balance between the quality of the analytical results and the resolution of information we hope to achieve (Pollard pers. comm). There is no doubt that instruments such as portable XRF have some fundamental limitations (*e.g.* poor minimum detect limits for trace elements). As a consequence,

Ruiliang Liu unplished thesis

the results can only produce a low-resolution picture for archaeologist.

One more pragmatic way is to start from the gaps pointed out by the database created in this thesis. For objects which have alloying and trace element data we can just sample corrosion for lead isotopic analysis. For those which have to be analyzed by SEM-EDS but only for alloying elements we can try to retrieve the mounted samples and reanalyze them by EPMA for traces. Meanwhile, we can apply newly developed technology to old analyzed objects, such as tin isotopes (Pernicka, 2013). This allows us not only test the adaptation of the new technology in archaeology but also make it easier to combine new sorts of data with existing database or compare the archaeological conclusions based on different analytical techniques. We can also choose to focus on the objects from the gap regions or in gap typologies, such as Guanzhong/middle Yangzi River or weapons at Anyang. Bridging these gaps can effectively enhance the resolution of the entire picture. Once these gaps have been fulfilled, the size of the database for Chinese bronzes can be said sufficiently enough to support some higher-resolution analysis, such Bayesian modeling proposed in Chapter Seven but using more variables (*e.g.* eight trace elements instead of four).

In the long term, only focusing on the finished object seems not enough. Two large categories of data are capable of making crucial contributions. One is the characterization of mines in antiquity. Despite the argument that focusing on metal chemistry could offer some indications of local sources of metal independently from

Ruiliang Liu unplished thesis

archaeological surveys, there is no doubt that searching and characterizing mines in antiquity can make significant contributions to our knowledge. This part of the work has already been realized among Chinese Bronze Age specialists. In field trips in the last three summers in China, we found that an increasing number of Chinese archaeologists devote themselves to surveys of mines in antiquity and have already got very fruitful results (Chen, 2015; Dong, 2012; Li, 2011; Li *et al*., 2015; Li and Han, 1990; Liu and Lu, 1998). New mining shafts come to our map on an annual basis. These works offer an exciting starting point of a new era of Chinese mining archaeology. However, confronted by such a vast landscape, this fieldwork on mining sites in China is still at the beginning. There are still no tin or lead mines which can be safely dated to the Shang period. As more and more ancient mines are plotted on the map, we also need to think about how to characterize one metal mine. More subtle work needs to be done in the future on the chronological duration of the excavated mines, the geological background, the smelting technology and the compositional signatures of the products. Without detailed characterization of these categories it seems unlikely to establish a high-resolution link between the objects discovered at the archaeological sites and mines in the deep mountains. This issue becomes more urgent as we are now almost certain that those bronze assemblages belonging to top-elites at Anyang were not made from mixing. It seems that a small step has been made to justify the potential to provenance these objects. Nevertheless, it has to be emphasized that whether mixing different raw metals happened in other stages, such as smelting or refining (*e.g.* the centralization model), is highly nebulous.

Ruiliang Liu unplished thesis

The other one is the chronological resolution. Chapter Seven provides a schematic network of copper movements during the late Shang period. But it is in theory still possible to break down the map into different phases in this period, just as the dynamic picture of the four Anyang phases in Chapter Six. Chinese archaeologists already set up a reasonably high-quality chronological framework for the entire Bronze Age China. All of the local archaeological cultures have been divided into several phases and each is equivalent to the four phases of Anyang. In principle, the network of metal movement in late Shang can at least divided into three maps with higher chronological resolution (Anyang I-II, III and III). To achieve this, what is necessary is not just high-quality data from different phases of Anyang but the same-quality data from other regions labeled with a better chronological resolution.

We might question where is our final destination (the highest resolution)? One proposed answer is to draw a parable between the metal in Bronze Age and the oil in the modern societies, which can be adequately illuminating but perhaps not completely correct. Nowadays, what is interesting about the oil industry is not really its movement or provenance (because they are all well recorded online), but the price of oil (or crude). The price of one barrel falls sharply from over 100 dollars in 2014 to 30 dollars this year. Although a great many factors result in this dramatic drop, the direct outcome is the huge economic pressure on oil-producing countries such as Russia but considerable boost to oil-consuming country, such as China. Surprisingly, the biggest global oil producer, Saudi Arabia chooses not to reduce the output of crude.

Ruiliang Liu unplished thesis

Instead, they are pushing a different tactic, continue rigging and pumping. This is partly due to their obsession with Iran, and party due to the expectation that the low price shall ultimately drive out other high-cost producers, such as the new-born shale producer in US. It is arguably correct to say the price of oil in the modern society is not just a result of supply versus demand but a reflection on the geopolitical interaction. As one of the most strategic resources in Bronze Age, metal may have played a similar role therefore can be used as a proxy to investigate human interactions. Of course, it is not possible for archaeologists to accumulate data as detailed, accurate and abundant as those consultants and observers in the modern oil industry. But the increasing amount data in the future can certainly improve the resolution of our current picture.

The other more archaeologically relevant way is prosopography (Blanco-González, 2014; Keats-Rohan, 2007; Parpola, 1998; Bray, pers. comm). Simply speaking, this offers a systematic framework to correlate all biographic fragments of raw metal or finished objects in an integrated and rich manner. Hundreds kilos of ores were extracted from one shaft, moved to the closest site, mixed or not with ores from other shafts in a furnace for smelting. The yielded raw copper was subsequently refined with or without being mixed with other copper and become a proper unit of copper for casting. This unit of copper may allow casters to finish ten objects in the end. Some may the inscribed ritual bronze vessels while others are just ordinary weapons. Both could be alloyed with designed recipe. But each of these objects may have started the

Ruliang Liu unplished thesis

same/different life history. Ritual vessels may be used for decades, deposited and excavated by archaeologists. They could also be looted or recycled into other objects by enemies. The same story may happen for weapons as well. The conception of prosopography is to put these highly fragmented pieces of biographic information in parallel, in order to modularize and automize the integration of these very elementary units of information. While no one is able to obtain all sorts of biographic information within one life cycle of every individual object, which is inherent to all archaeological branches, just outlining the major episodes in their lift history is already promising and encouraging.

For instance, two bronze *gu* (觚) vessels in the Sackler collection are nearly identical on a typological ground (Figure 284). Their columnar silhouette and delicate patterns suggest a standardized and highly crafted technology involved in their creation. While no residual analysis has been conducted, we are almost certain that both were used for offering wines. Additional information on their ownership can be learned from its inscriptions. The square ya character is indicative of a person served in a high military position. Its writing style also infers a date around middle Anyang phase, which can be supported by the typology. The chemical compositions of these two vessels show a well-selected alloying recipe, demonstrates the sophisticated craftsmanship, as suggested by their typology (Table 16). The high-tin/low-lead and radiogenic lead assign the date to Anyang I or II phase. The fact that these two highly similar vessels are in the Sackler collection may allow us to propose that these two *gu* (觚) vessels

Ruiliang Liu unplished thesis

were produced around early period of Anyang, used by a high elite, deposited somewhere, recovered together and moved to US. They are probably together throughout the entire life trajectories.

The example above is just how different pieces of biographic information may be integrated together via the linkage of different databases (typology, inscription and chemistry) on a very micro level (two objects in this case). It is a quick example to show how to link different databases and create a concise description of the life history of these two ritual vessels but experts in each field must have more interesting and insightful information to offer. The Oxford system has designed a series of analytical tools to correlate three different databases, alloying, trace elements and lead isotopes. Developing these tools is a fruitful but also an extremely hard and iterative process. Ultimately, through integrating a variety of databases on more different archaeological topics, we are gradually able to create a web of knowledge which can be mutually checked and enhanced, in which the chemical database is just one part of it.

Ruiliang Liu unplished thesis



Figure 284 Two identical vessels, the same life history (after Bagley, 1987)

Table 16 Chemical and isotopic data on the two vessels above (from Bagley, 1987)

Museum Number	Cu	Sn	Pb	As	Sb	Bi	Ni	Fe	Zn	Ag	Co	Total	206/204	207/204	208/204	207/206	208/206
34	77.6	16.9	4.1	0.062	0.00344	NAF	0.0045	0.062	0.00289	0.038	0.00073	98.77356	22.11411	16.06811	42.27554	0.7266	1.9117
35	78.4	14.7	5.9	0.061	0.0043	NAF	0.0163	0.026	0.0036	0.06	0.00323	99.17443	22.07018	16.03399	42.15846	0.7265	1.9102

Ruiliang Liu unpublished

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Appendix

Appendix I Summary of Anyang-period King-specific chronological frameworks by various scholars

	Before Pangeng	***Pangeng, Xiaoxin, Xiaoyi***	***Wuding, Zujia, Zuyi***		***Lingxin, Kangding, Wuyi, Wending***	***Diyi, Dixin***
Zouheng (1964)			**Yinxu I phase**	**Yinxu II phase**	**Yinxu III phase**	**Yinxu IV phase**
			YM232, YM333	YM388, YM188, YM331, Wuguan 59M1, Wuguan Big Tomb, HPKM1001, Sikong M157	YM238, HPKM1002, Sipanmo M8, **Fuhao M5**, Sikong M304, Gaolouzhuang M8	Sipanmo M6, Sipanmo M4, Sikong M239, HPK M2020, HPKM1003, HGH10
Zhang (1997)		YM232, YM333, YM388, YM188, YM331		Wuguan Big Tomb, **Fuhao M5**, YM238, HPKM1002, HPKM1400	Sikong M51, Sikong M53, Gaolouzhuang M8, HGH10	
Zheng and Chen (1985)		**Yinxu I phase**		**Yinxu II phase**	**Yinxu III phase**	**Yinxu IV phase**
		Early	Late			
		YM232, YM333, YM388, SJM1, M3, J1	Wuguan 59M1, YM331	Wuguan Big Tomb, YM238, YM188, **Fuhao M5**, Xiaotun M17, Xiaotun M18	GM2508, PNM172	GM2579, GM1713, 82Xiaotun M1, Sikong M53
Yang and Yang (1985)		**Yinxu I phase**	**Yinxu II phase**			**Yinxu III phase**
			Early	Middle	Late	
		YM232, YM333, YM388, YM331, SJM3	YM188, 59Wuguan M1, Xiaotun	**Fuhao M5**, Xiaotun M17, Xiaotun M18, GM613	PNM172, GM198, GM907, SikongM51	GM269, GM284, GM793, GM1053, GM1573, Sikong M53, GM1713

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			73H13			
Zhu (2009)		YM232, YM333, YM388, Sanjiazhuang M3	YM331, YM188, 59Wuguan M1	**Fuhao M5**, Xiaotun 17, Xiaotun M18, Sikong M539, 83Sikong M663, GM613, Xuejiazhuang M3, PNM105, GM161	57Gaolouzhuang M8, SikongM51, PNM172, Qijiazhuang, M269, **Guojiazhuang M160**	Sikong M53, GM269, GM2579, GM1713, 83GuoM1, Guojiazhuang North M6, 82Xiaotun M1
Yue (2004)	**Yinxu I phase**			**Yinxu II phase**	**Yinxu III phase**	**Yinxu IV phase**
				Early	Late	Early	Late	
	YM232, YM333, YM388, Sanjiazhuang M3, J1, 99AHDM10			YM331, YM188, 59 WuM1, Xiaotun 73H13, some bronzes in Fuhao tomb	**Fuhao M5**, Xiaotun M17, Xiaotun M18, Siokong M539, 83 Sikong M663, YM238, 95GuoM26, Huayuanzhuang M54	Qi M269, 63PNM172, GM2508, GM907	**Guojiazhuang M160**, GM198, Sikong M51, 82Miaopu M54	**North Liujiazhuang M1046**, 82Xiaotun M1, GM1713, Guojiazhuang North M6, Liujiazhuang North M9, Sikong M53, Qijiazhuang M63, Qijiazhuang East M231
Huang (2013)				Fuhao tomb, Huayuanzhuang M54, Xiaotun M18, Xiaotun M238, Guojiazhuang M26, North Liujiazhuang M793, Wuguan W8, 80 Dasikong M539, 83 Dasikong M663, 86 Dasikong M29, South Miaopu M58, 1957 Gaokouzhuang M58,	Guojiazhuang M160, Eastern Qijiazhuang M269, 1958 Dasikong M51, 1957 Xuejiazhuang M8, North Liujiazhuang M637, Dasikong M101, Tijiakou M3			Dasikong M303, North Liujiazhuang M1046, Angang Wu Shenghuoqu M6, 86 Guojiazhuang M6, 83 Liujiazhuang M9, Western Area M1713, 58 Dasikong M51, 58 Dasikong M53, Western Area M2579, 1982 Miaopu M41, Qijiazhuang M41, Qijiazhuang M63, Qijiazhuang M231, Qijiazhuang M235, Guojiazhuang M53, Eastern Dasikong M7, Western Area M07, Xiaomintun M17, South Liujiazhuang M66

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Appendix II Implications of recycling from bronze inscriptions

豅侯鼎 西周早期前段 1964年10月陝西西安市長安區馬王鎮張家坡西周墓葬（M1.7） 集成02457

豅（鼬）厌（侯）隻（獲）巢，孚（捋）毕（厥）金胄，用乍（作）蘆（旅）鼎。

Early Western Zhou:
capture armours and make a *ding* (鼎) vessel





Ruili hesis

昔須甗　西周中期前段

昔須眾遣（遣）東征，多鈞（勳）工（功），孚（俘）戈，用乍（作）父乙寶隣（尊）彝，巽子，日庚。

Middle Western Zhou: capture *ge* (戈) blages and make a *zun* (尊) vessel





員卣　西周早期　集成 05387

鼎（員）從史旗（旗）伐會（鄶），鼎（員）先內（入）邑，鼎（員）孚（俘）金，用乍（作）旅彝。

Early Western Zhou: capture copper and make a vessel





過伯簋　西周早期　集成 03907

過白（伯）從王伐反荊，孚（俘）金，用乍（作）宗室寶隣（尊）彝。 Early Western Zhou:
capture copper and make a *zun* (尊)vessel





I would like to express my best appreciation to Prof Jessica Rawson and Dr Liu Li who kindly provide information on these inscribed vessels. Here I only select four of them which are dated to early-middle Western Zhou. There is a large number of pieces with similar content of bronze inscriptions in the Jicheng database.

Appendix III: Mixing model for lead isotopes

Assume that we mix two components A and B in differing proportions specified by a parameter f defined as:

$F = A/(A+B)$

Where A and B are the weights of the two components in a given mixture. The concentration of any element X in such a mixture is

Where A and B are the weights of the two components in a given mixture. The concentration of any element X in such a mixture is

$X_M = X_A \cdot f + X_B \cdot (1-f)$

Where X_A and X_B are the concentrations of element X in components A and B, expressed in weight units. Since X_A and X_B are constants for any suite of samples formed by mixing A and B in differing proportions, **X_M is a linear function to f**:

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$X_M = f\cdot(X_A - X_B) + X_B$

Consider mixtures of two components A and B having not only different concentrations of lead but also different $^{207}Pb/^{206}Pb$. The total number of ^{207}Pb atoms in a unit weight of such a mixture is:

$$^{207}Pb_M = Pb_A\cdot Ab_A^{207}\cdot N\cdot f/W_A + Pb_B\cdot Ab_B^{207}\cdot N\cdot(1-f)/W_B \quad (1)$$

Where Pb_A and Pb_B are the concentrations of lead, Ab_A^{207} and Ab_B^{207} ate the isotopic abundances of ^{207}Pb, and W_A and W_B are the atomic weights of lead in component A and B are the atomic weights of lead in component A and B, respectively. N is Avogadro's number and f is the mixing parameter between A and B.

Similarly,

$$^{204}Pb_M = Pb_A\cdot Ab_A^{204}\cdot N\cdot f/W_A + Pb_B\cdot Ab_B^{204}\cdot N\cdot(1-f)/W_B \quad (2)$$

By (1)/(2), we get

$$\begin{aligned}(^{207}Pb/^{204}Pb)_M &= [Pb_A\cdot Ab_A^{204}\cdot N\cdot f/W_A + Pb_B\cdot Ab_B^{204}\cdot N\cdot(1-f)/W_B]/[(Pb_A\cdot Ab_A^{204}\cdot N\cdot f/W_A + \\ &\quad Pb_B\cdot Ab_B^{204}\cdot N\cdot(1-f)/W_B] \\ &= [Pb_A\cdot Ab_A^{207}\cdot f\cdot W_B + Pb_B\cdot Ab_B^{207}\cdot(1-f)\cdot W_A]/[Pb_A\cdot Ab_A^{204}\cdot f\cdot W_B + \\ &\quad Pb_B\cdot Ab_B^{204}\cdot(1-f)\cdot W_A] \quad (3)\end{aligned}$$

Here, we need to introduce approximation that the atomic weights of lead and abundance of ^{207}Pb in component A and B are identical.

$$W_A = W_B \qquad \text{and} \qquad Ab_A^{204} = Ab_B^{204} = Ab^{204}$$

Therefore, (3) can be further reduced to

$$(^{207}Pb/^{204}Pb)_M = [Pb_A\cdot Ab_A^{207}\cdot f + Pb_B\cdot Ab_B^{207}\cdot(1-f)] / \{Ab^{204}\cdot[Pb_A\cdot f + Pb_B\cdot(1-f)]\} \quad (4)$$

As $Pb_M = Pb_A\cdot f + Pb_B\cdot(1-f)$
(Pb_M is the concentration of lead in the mixture, Pb_A and Pb_B are the concentrations of lead in the initial components, A and B, respectively),
(4) can be further reduced to

$$(^{207}Pb/^{204}Pb)_M = (^{207}Pb/^{204}Pb)_A\cdot Pb_A\cdot f / Pb_M + (^{207}Pb/^{204}Pb)_B\cdot Pb_B\cdot(1-f)/Pb_M \quad (5)$$

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Eliminating f in (5) by f= $(Pb_M - Pb_B)/(Pb_A - Pb_B)$ result in a reduced (5) below.

$(^{207}Pb/^{204}Pb)_M = (1/Pb_M) \cdot \{ Pb_A \cdot Pb_B \cdot [(^{207}Pb/^{204}Pb)_B - (^{207}Pb/^{204}Pb)_A]/(Pb_A - Pb_B)\}$
$+[(^{207}Pb/^{204}Pb)_A \cdot Pb_A - (^{207}Pb/^{204}Pb)_B \cdot Pb_B/(Pb_A - Pb_B)]$

Therefore,
$(^{207}Pb/^{204}Pb)_M = (1/Pb_M) \cdot k + b$

Where $k = Pb_A \cdot Pb_B \cdot [(^{207}Pb/^{204}Pb)_B - (^{207}Pb/^{204}Pb)_A]/(Pb_A - Pb_B)$ and $b = (^{207}Pb/^{204}Pb)_A \cdot Pb_A - (^{207}Pb/^{204}Pb)_B \cdot Pb_B/(Pb_A - Pb_B)$

To summarize, the lead isotopic ratio of the mixture is a linear function of the reciprocal of lead concentration of the mixture.

Appendix IV: Analytical hygiene

As pointed out in the introduction chapter, the fundamental limitation of the chemical database in China is being inadequate and fragmented. One batch of objects has been repeatedly and extensively sampled for alloying analysis but no trace elements or lead isotopes are published. The purpose of the analytical hygiene suggested below is *not* to illustrate a perfectionist analytical protocol or published standards, though it is part of our inclination, but more like a stepping stone to a discussion about a more systematic and well-considered framework to present scientific analysis on archaeological samples.

This is essentially a database of metal objects which includes all kinds of information available to archaeologists.

1. Sample description

- ✓ Basic information:

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- Sample number.
- Sample size.
- Sample weight.
- Sample photo.
- Visual assessment on corrosion.

✓ Sampling strategy:

- Single/multiple sample(s)
- Sampling position (rim, body, handle, leg, repairing, etc.).
- Sampling method (cut, drill).

✓ Conserved/not conserved[25].

✓ Conductor of sampling.

✓ Current location of samples.

2. Object description

✓ Basic information

- Excavation/museum number.
- Object class (vessel/weapon/tool/ornaments/chariot fittings/fragments/unknown)
- Object type (weapons for example, dagger, knife, sward, axe, halberd, arrow, etc)
- Object size (height, width, etc.)
- Weight.
- Object image (line graph and coloured photo)

✓ Chronology of the object

- Possible dates.
- Dating technique (typological reference, radiocarbon dates in associated context, stratigraphy)

✓ Casting technique: assemblage of moulds and models.

✓ Current location of the object.

3. Context description (archaeology)

✓ Basic information:

- Site name

[25] Sometimes it is difficult to tell the sampling position if the object is conserved afterwards.

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- Site location (coordinates)
- Object context (hoard, tomb, house, foundry, etc)
- Associated objects (e.g. pottery)
- Reference (archaeological report, publications, museum exhibition).

✓ Chronology of the context

- Possible dates
- Radiocarbon/luminescence dating, object typology, stratigraphy, etc)

4. Analysis description

✓ Sample preparation

- Solid sample: procedures of mounting, grinding, polishing and cleaning.
- Liquid sample: procedures of dissolution and concentration.

✓ Instrument description

- Location of the instrument (laboratory).
- Primary standards.
- Secondary standards.
- Internal standards
- Blanks
- Calibration.
- Instrument assessment (precision, accuracy, matrix effect correction).
- Associated publications

✓ Analytical protocol

- Flow chart of operation.
- Operational settings.
- Associated evaluation or publications.
- Operator.
- Date of analysis.
- Daily monitor of the instrument.
- Running order of analysis.

5. Result description

- Targeted elements (Cu, Sn, Pb, As, Sb, Ag, Ni, Zn, Co, Bi, Fe, O, S, etc).

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- Targeted isotopes (Pb isotopes, Sn isotopes).
- Raw total/normalized total of chemistry
- Associated errors.

Virtually no publication can cover all sorts of information listed above, even though it is still not the most comprehensive agenda we can put forward. But one can immediately see huge potential brought by this analytic hygiene. This is not a way to look backwards but more forwards.

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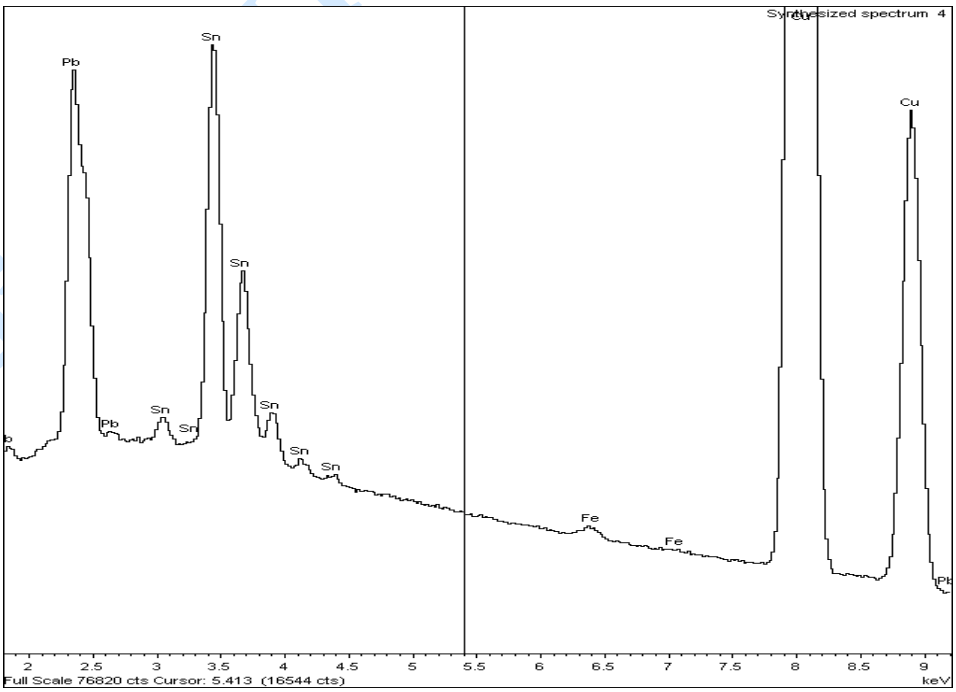
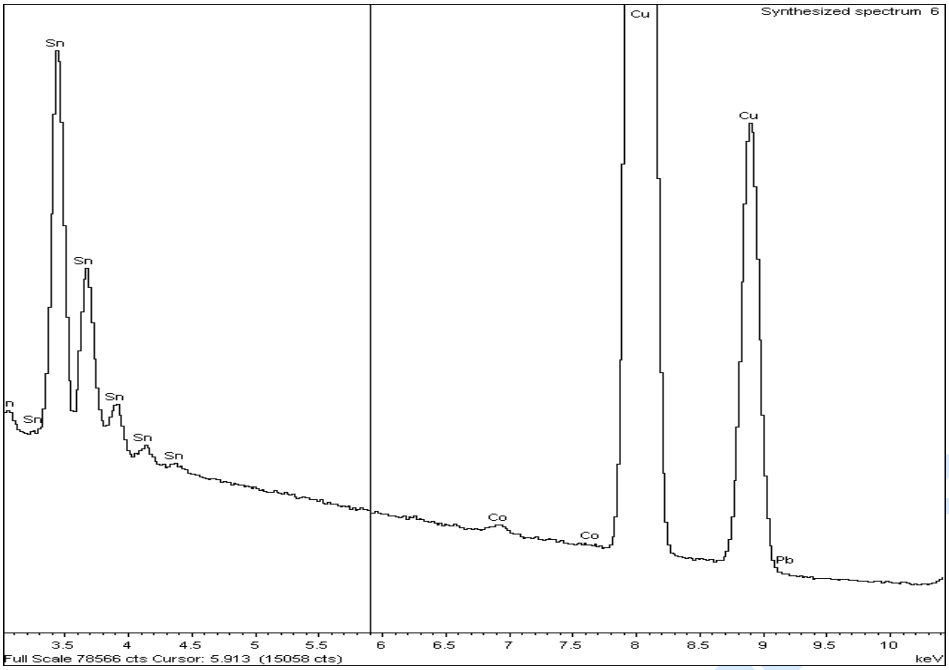
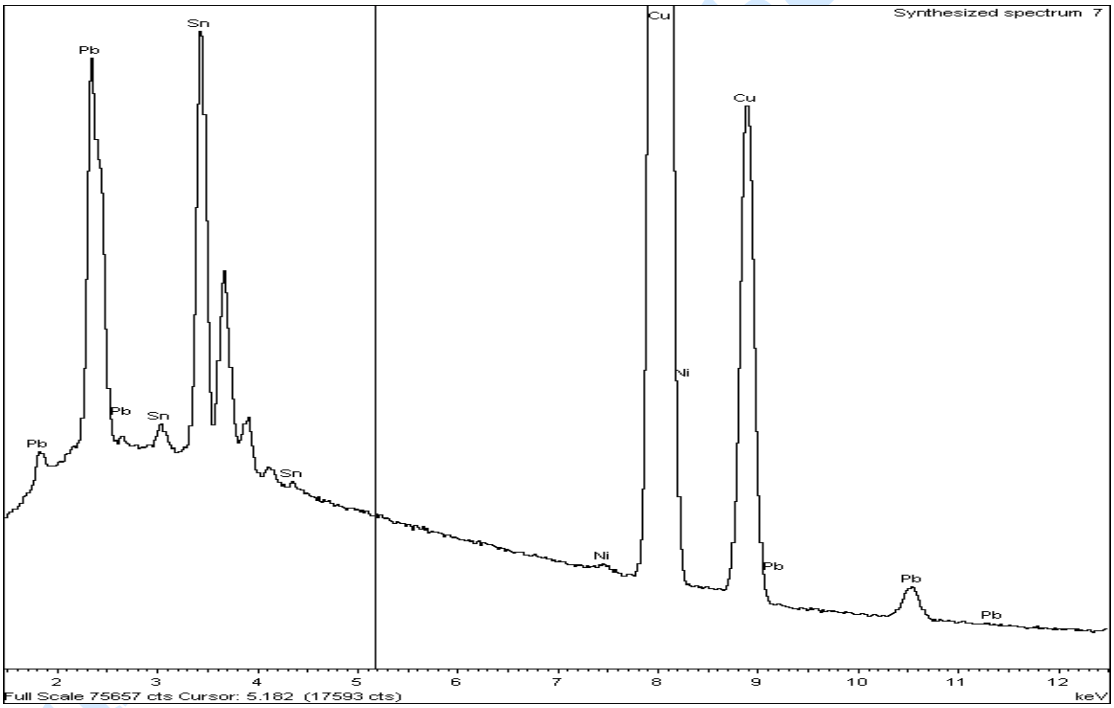
Appendix V Estimation of minimum detect limit



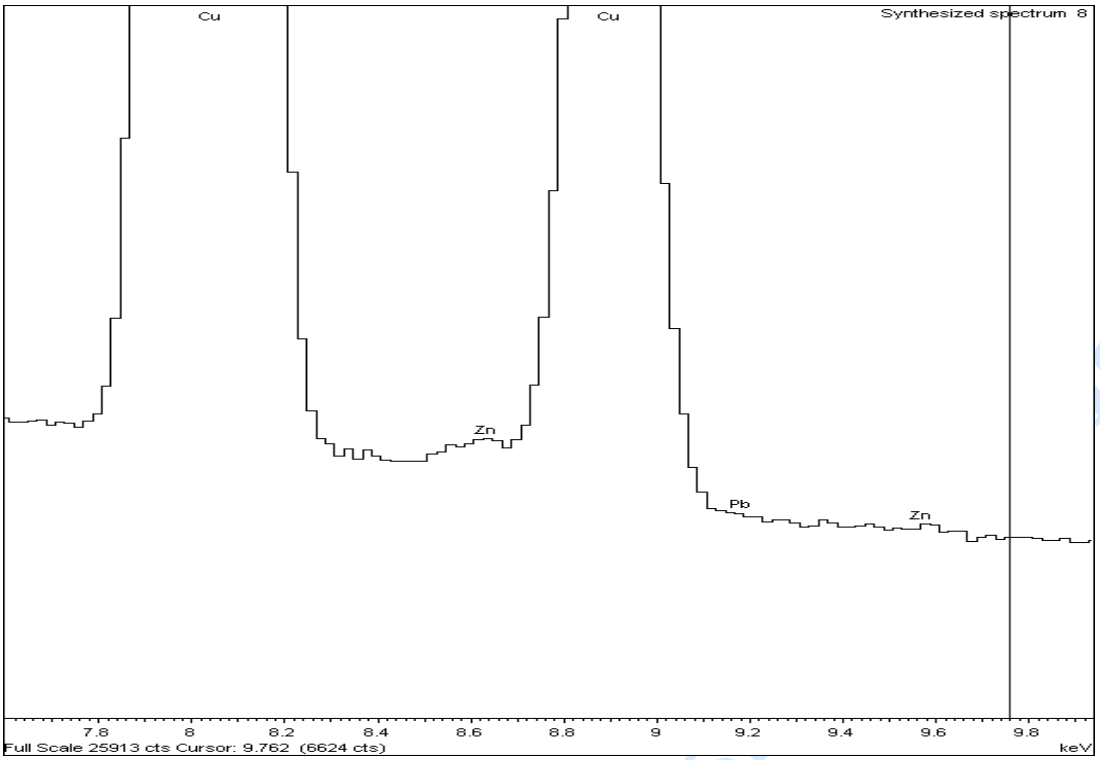
Synthetic spectrum for Fe 0.1%



Synthetic spectrum for Co 0.1%



Synthetic spectrum for Ni 0.1%



Synthetic spectrum for Zn 0.2%

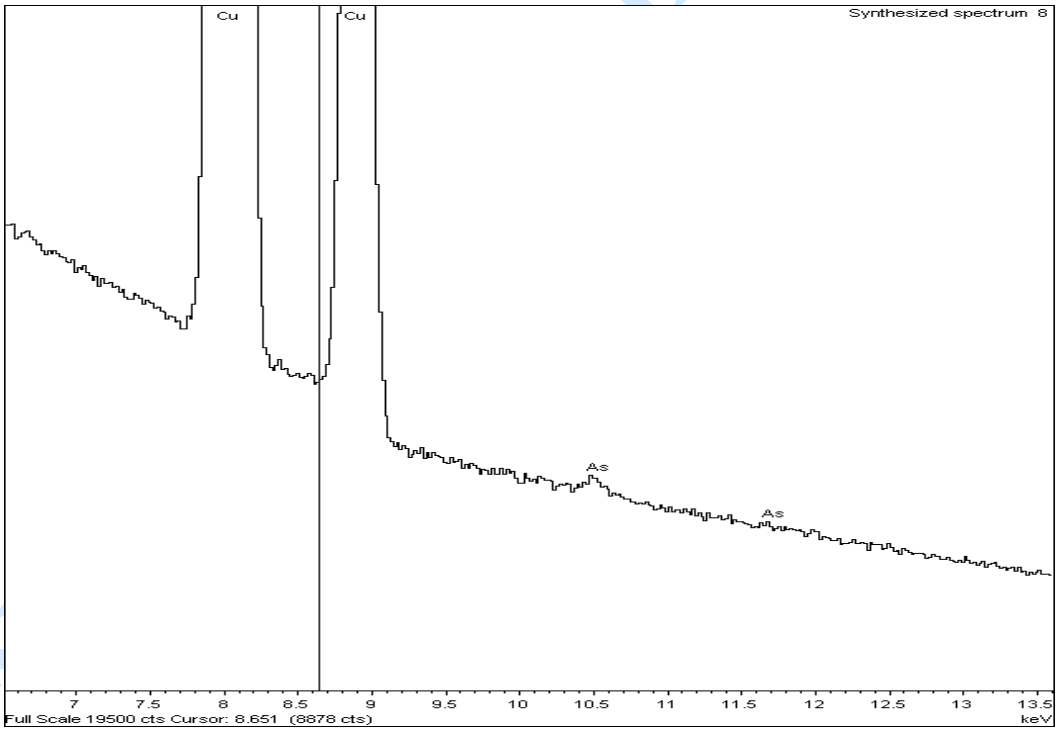
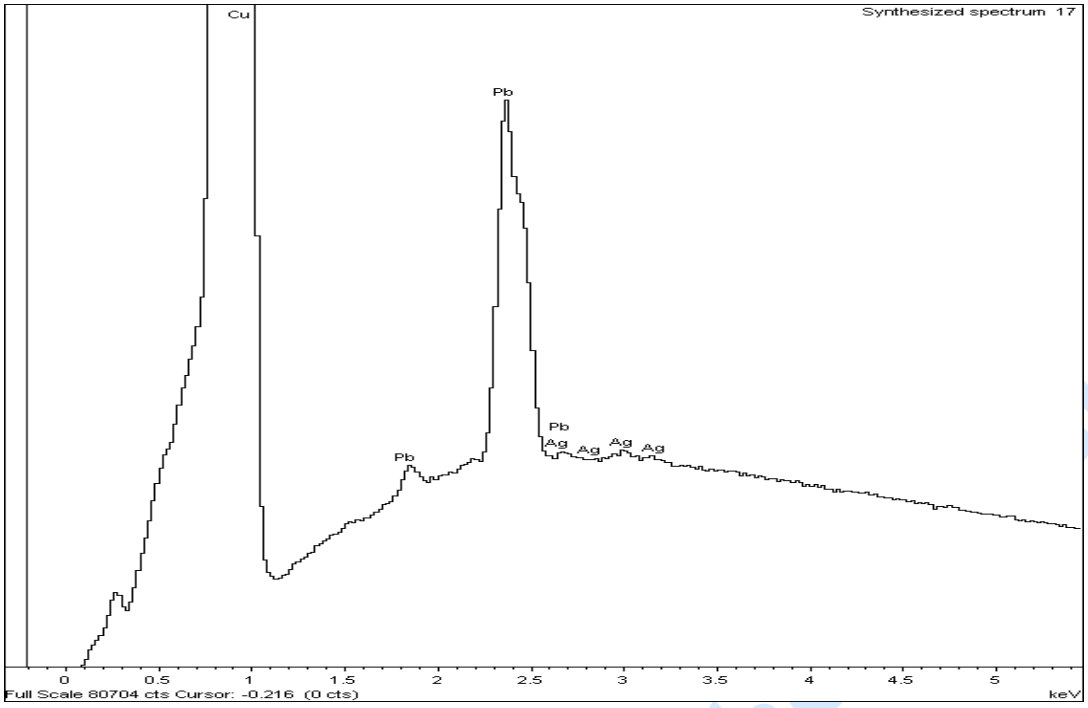
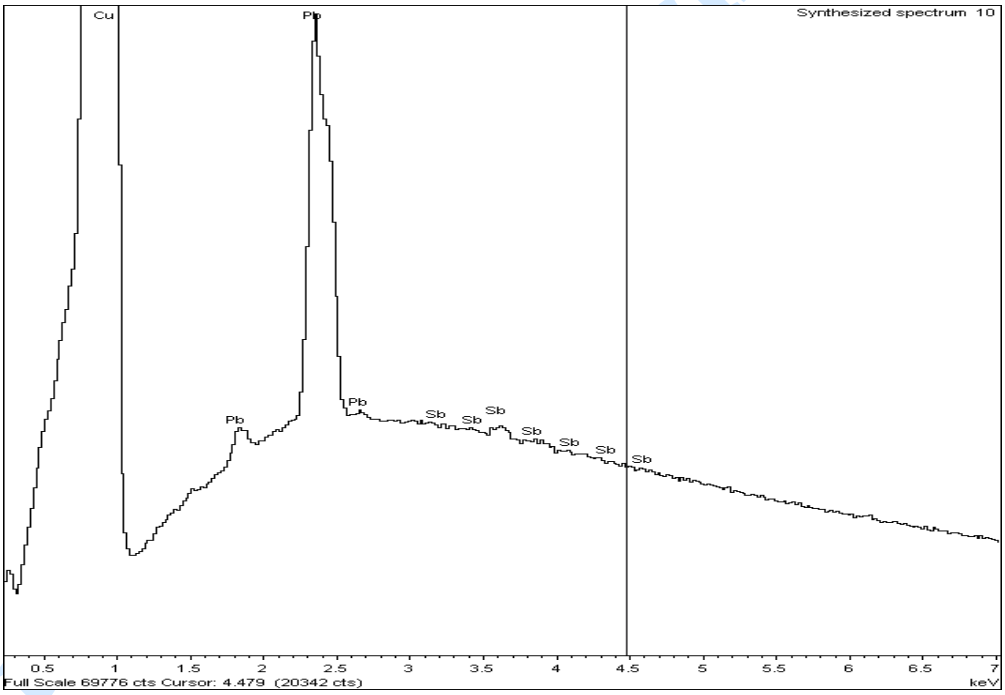


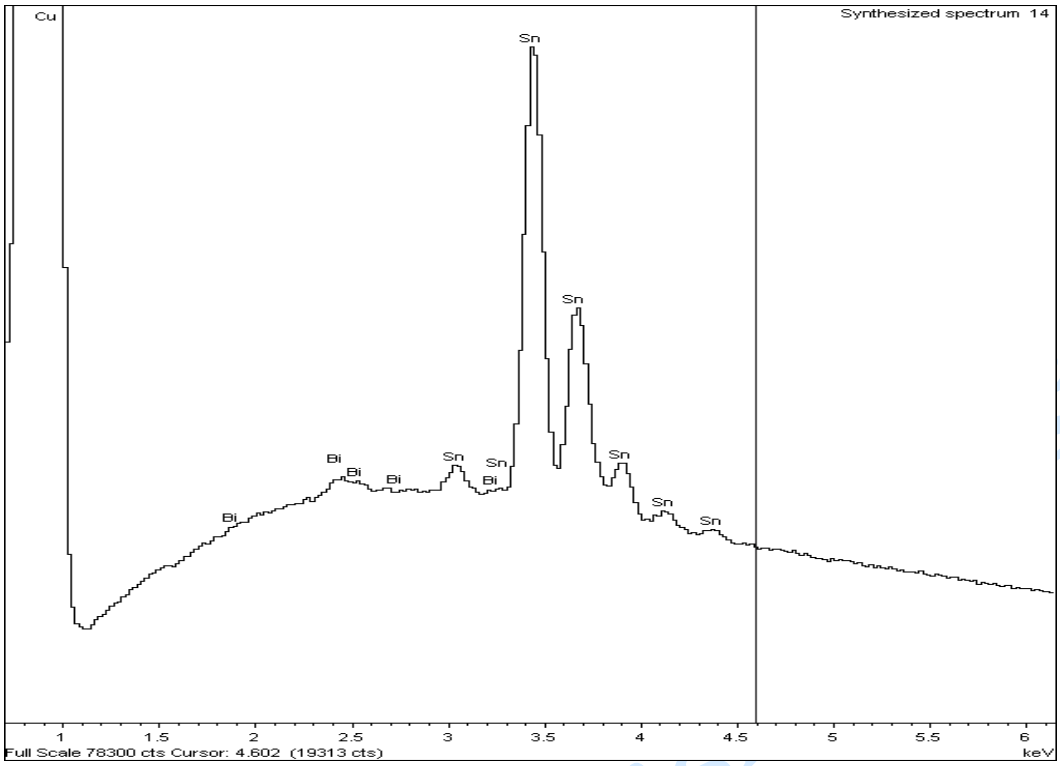
Fig. 46 Spectrum for As 0.15%



Synthetic spectrum for Ag 0.1%

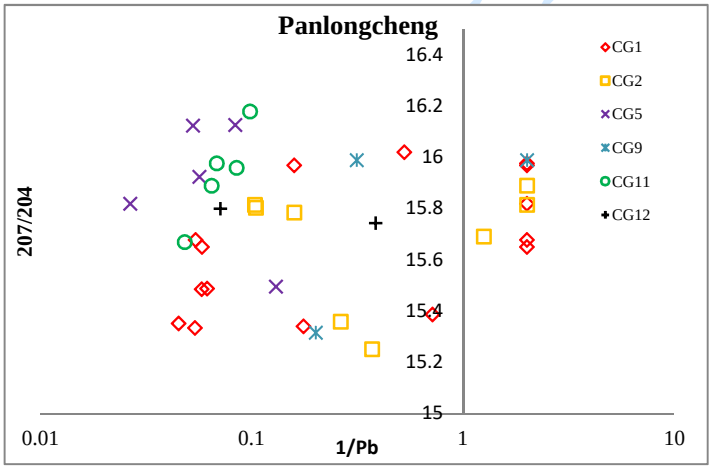


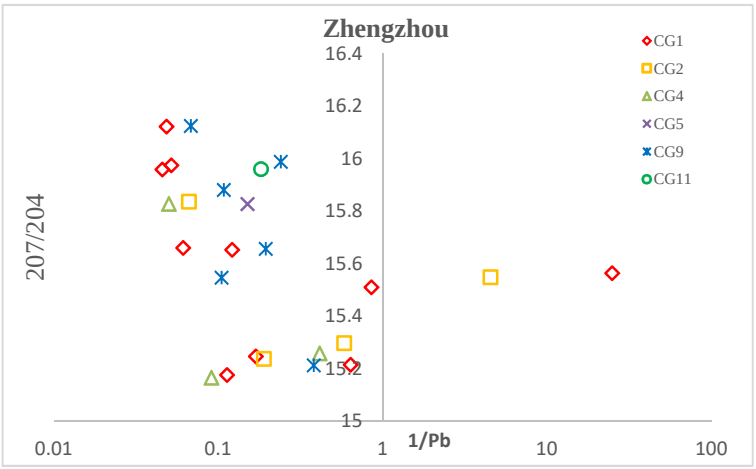
Synthetic spectrum for Sb 0.1%

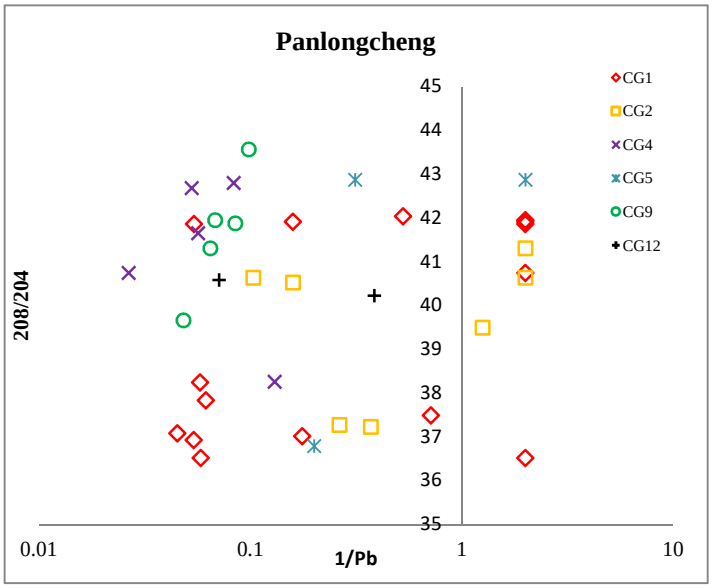


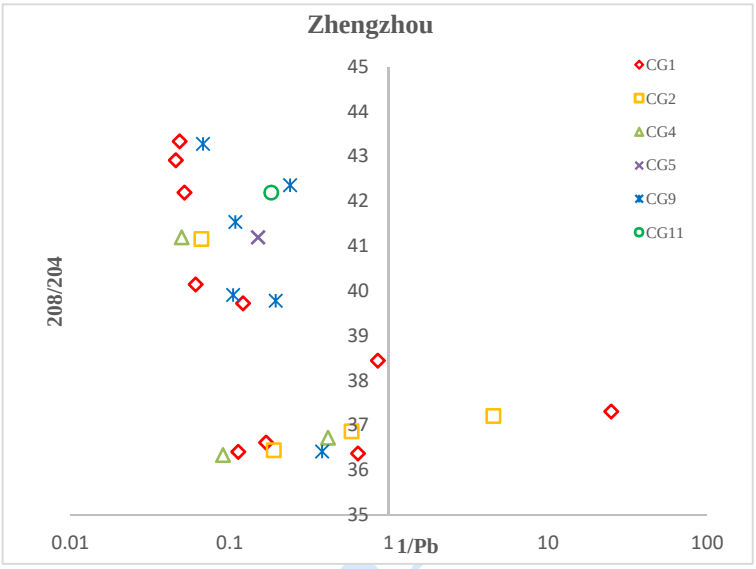
Synthetic spectrum for Bi 0.15%

Appendix VI: Plotting lead isotopes and percentages of Panlongcheng and metals ($^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$)









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Appendix VII Radiocarbon dates for mines along the Yangzi River

Sample Number	Sample materials	Site	Uncalibrated dates	Uncertainty	Ref
Tonglvshan 1	Wood	Tonglvshan	2750	70	Huangshi museum 1999
Tonglvshan 2	Wood	Tonglvshan	3140	80	Huangshi museum 1999
Tonglvshan 3	Wood	Tonglvshan	3260	100	Huangshi museum 1999
Tonglvshan 4	Wood	Tonglvshan	3150	80	Huangshi museum 1999
Tonglvshan 5	Wood	Tonglvshan	3185	70	Huangshi museum 1999
Tonglvshan 6	Wood	Tonglvshan	3140	80	Huangshi museum 1999
Tonglvshan 7	Wood	Tonglvshan	2810	80	Huangshi museum 1999
Tonglvshan 8	Wood	Tonglvshan	2795	75	Huangshi museum 1999
Tonglvshan 9	Wood	Tonglvshan	2750	65	Huangshi museum 1999
Tonglvshan 10	Wood	Tonglvshan	2680	75	Huangshi museum 1999
Tonglvshan 11	Wood	Tonglvshan	2470	75	Huangshi museum 1999

Tonglvshan 12	Wood	Tonglvshan	2735	80	Huangshi museum 1999
Tonglvshan 13	Wood	Tonglvshan	2600	80	Huangshi museum 1999
Tonglvshan 14	Wood	Tonglvshan	2430	65	Huangshi museum 1999
Tonglvshan 15	Wood	Tonglvshan	2075	80	Huangshi museum 1999
Tonglvshan 16	Wood	Tonglvshan	2795	75	Huangshi museum 1999
Tonglvshan 17	Wood	Tonglvshan	3265	100	Huangshi museum 1999
Tonglvshan 18	Wood	Tonglvshan	2485	75	Huangshi museum 1999
Tonglvshan 19	Wood	Tonglvshan	2575	135	Huangshi museum 1999
Tonglvshan 20	Wood	Tonglvshan	3205	400	Huangshi museum 1999
Tonglvshan 21	Wood	Tonglvshan	2720	80	Xia and Yin 1982
Tonglvshan 22	Wood	Tonglvshan	2705		Xia and Yin 1982
Ruichang 1	Wood	Ruichang	3330	60	Liu and Lu 1998
Ruichang 2	Wood	Ruichang	3310	60	Liu and Lu 1998
Ruichang 3	Wood	Ruichang	3220	70	Liu and Lu 1998
Ruichang 4	Wood	Ruichang	3120	80	Liu and Lu 1998
Ruichang 5	Wood	Ruichang	2630	80	Liu and Lu 1998
Ruichang 6	Wood	Ruichang	2440	70	Liu and Lu 1998
Ruichang 7	Wood	Ruichang	3220	90	Liu and Lu 1998
Ruichang 8	Wood	Ruichang	2720	80	Liu and Lu 1998
Ruichang 9	Wood	Ruichang	2950	90	Liu and Lu 1998
Ruichang 10	Wood	Ruichang	2500	60	Liu and Lu 1998
Yangxin 1	Wood	Yangxin Gangxia	2075	80	Gangxia Mining Archaeology Team 1988
Yangxin 2	Wood	Yangxin Gangxia	2475	80	Gangxia Mining Archaeology Team 1988
Yangxin 3	Wood	Yangxin Gangxia	2575	80	Gangxia Mining Archaeology Team 1988
Yangxin 4	Wood	Yangxin Gangxia	2680	75	Gangxia Mining Archaeology Team 1988
Yangxin 5	Wood	Yangxin Gangxia	2705	80	Gangxia Mining Archaeology Team 1988
Yangxin 6	Wood	Yangxin Gangxia	2720	80	Gangxia Mining Archaeology Team 1988
Yangxin 7	Wood	Yangxin Gangxia	2810	80	Gangxia Mining Archaeology Team 1988
Yangxin 8	Wood	Yangxin Gangxia	2875	80	Gangxia Mining Archaeology Team 1988
Yangxin 9	Wood	Yangxin Gangxia	3140	80	Gangxia Mining Archaeology Team 1988
Yangxin 10	Wood	Yangxin Gangxia	3150	80	Gangxia Mining Archaeology Team 1988
Yangxin 11	Wood	Yangxin Gangxia	3260	80	Gangxia Mining Archaeology Team 1988

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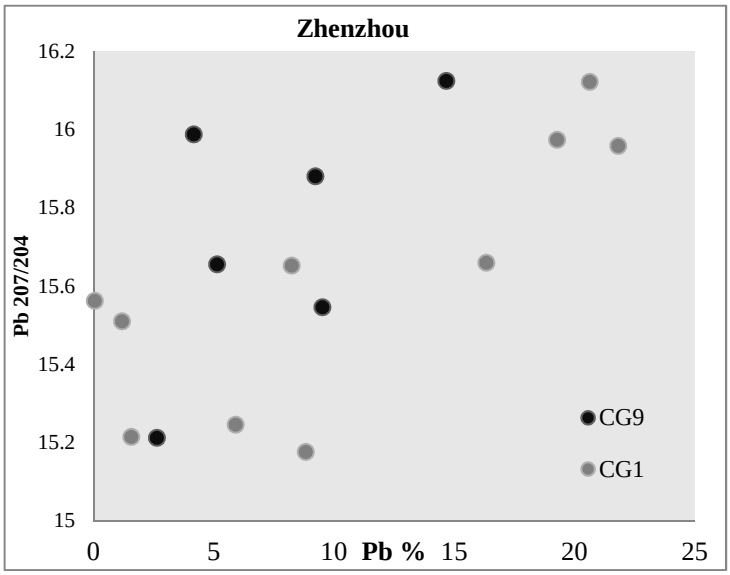
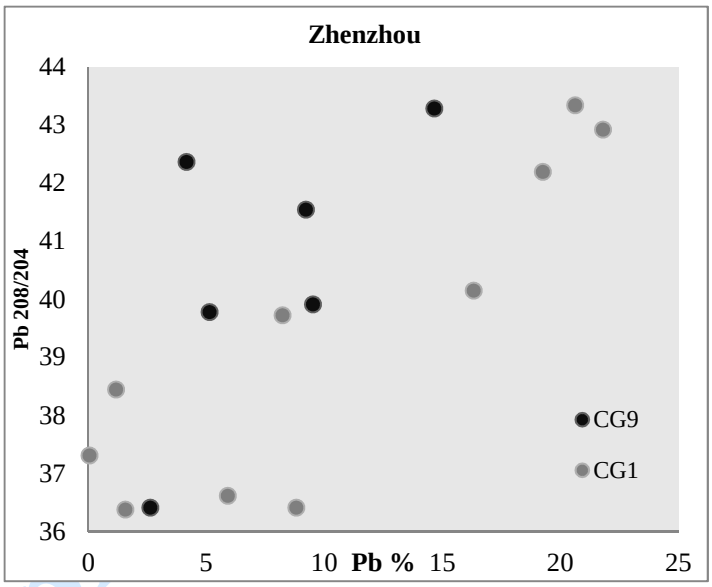
Appendix VIII Plotting lead isotopes and percentages of CGs1&9 in Zhengzhou ($^{207}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$)





Appendix IX Lead isotopes distribution in Erlitou, Zhengzhou and Panlongcheng (Jin *et al*. submitted)

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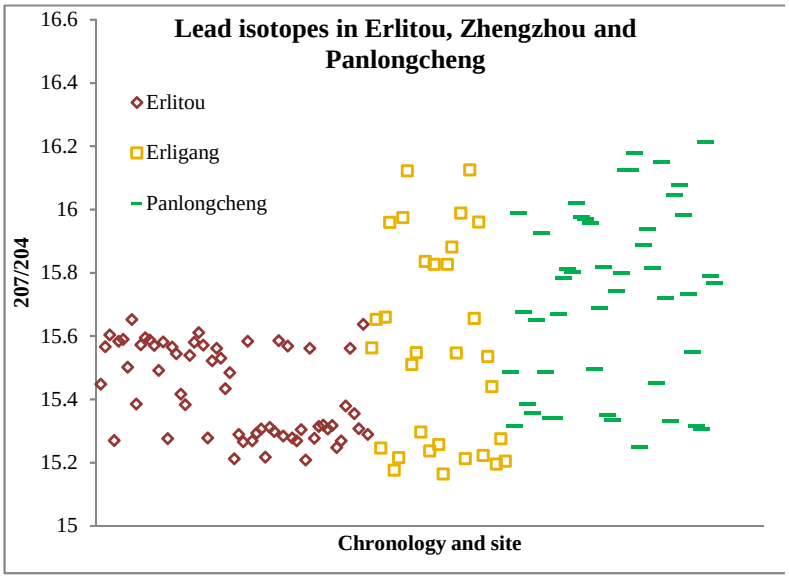
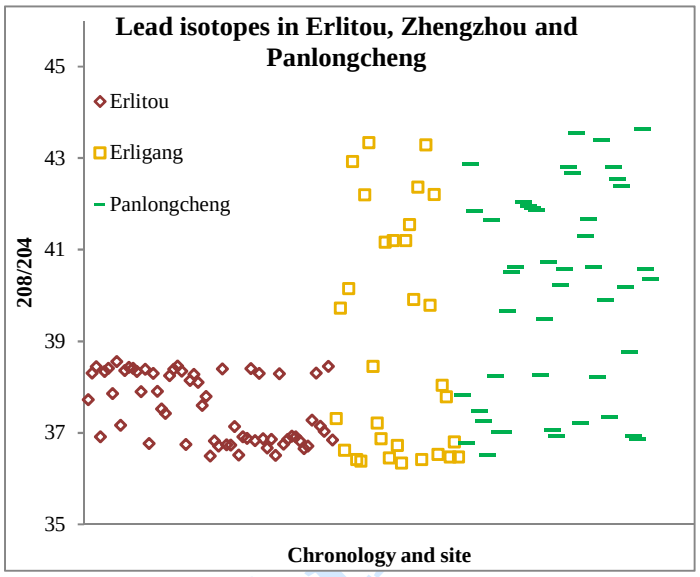
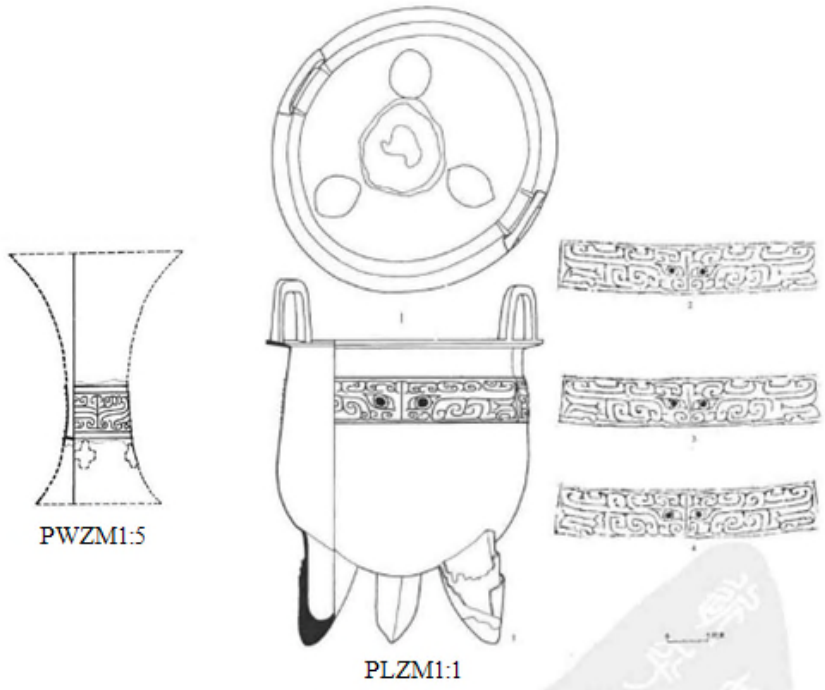
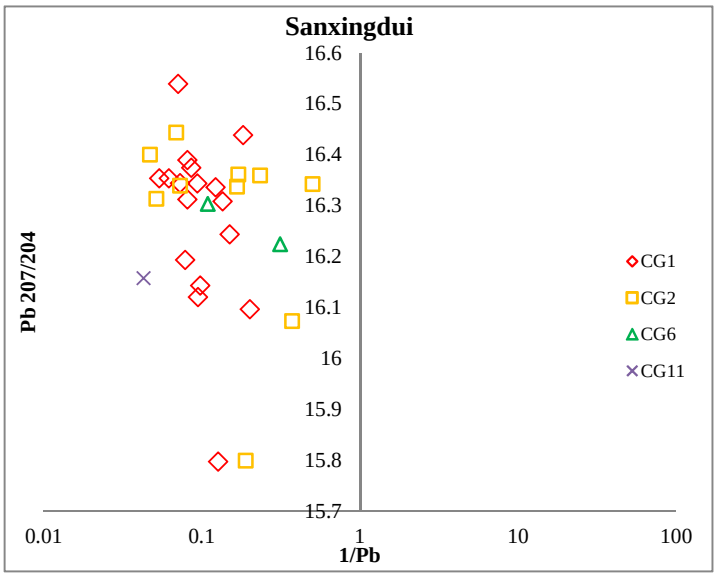


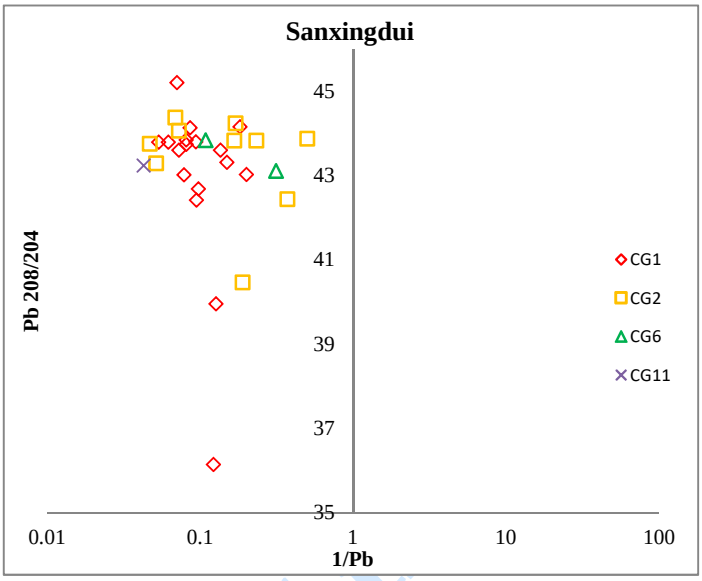


Appendix X Nickel-bearing objects at Panlongcheng (after Hubei Institute of Archaeology, 2001)



Appendix XI Plotting $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ with 1/Pb (%) for metal assemblages at Sanxingdui





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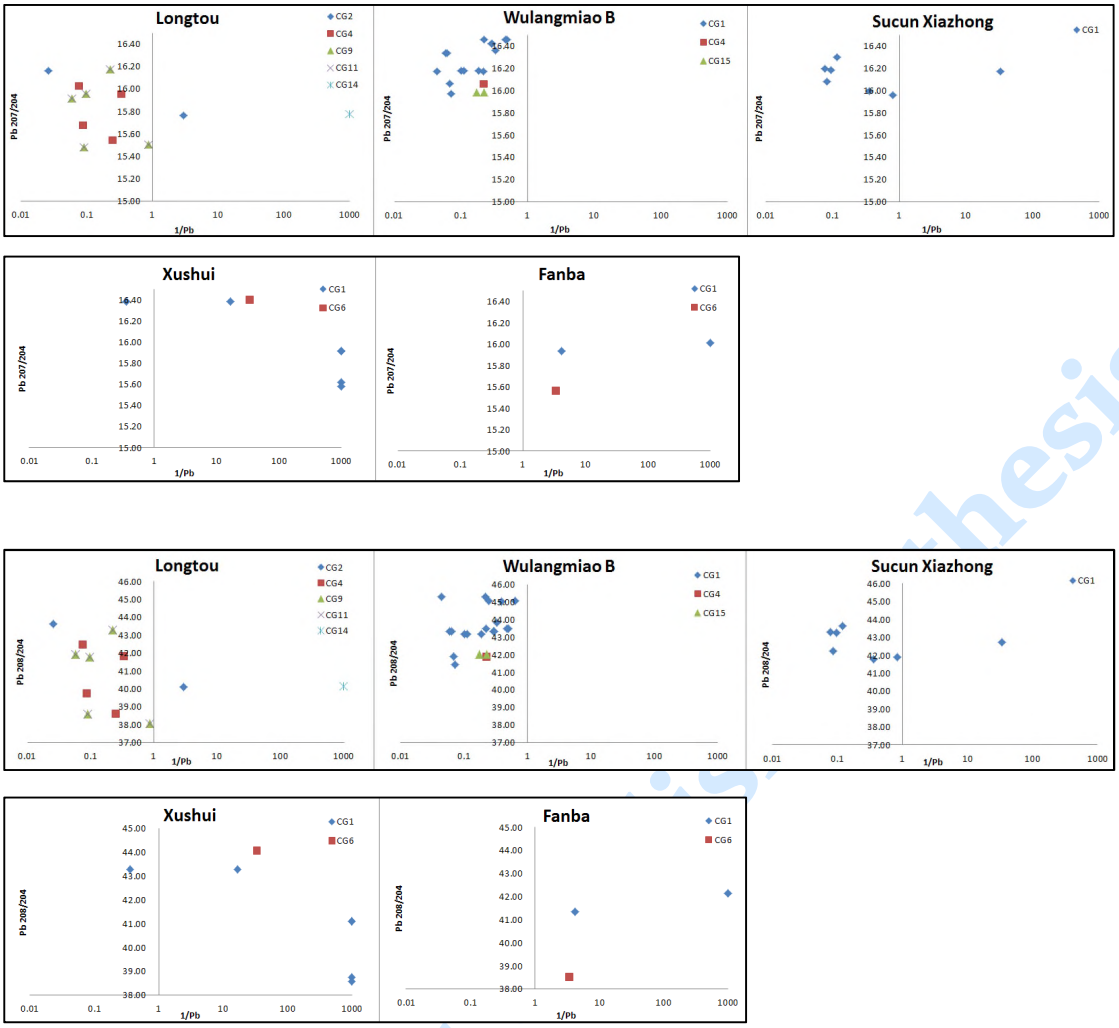
Appendix XII Plotting $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ with 1/Pb (%) for metal assemblages at Hanzhong



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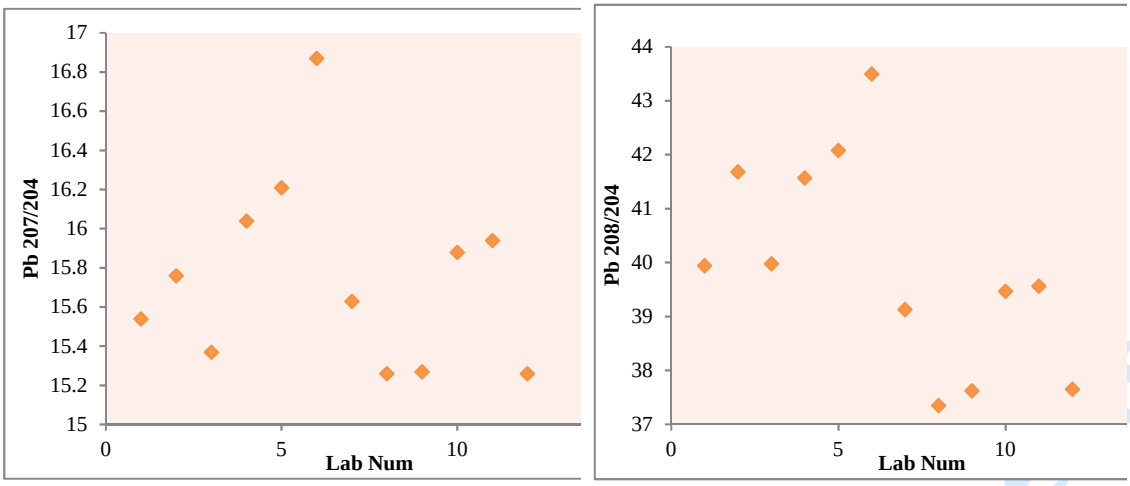
Appendix XIII Plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ in objects at the tomb of Fu Hao



Appendix XIV Objects in the Shang Sackler collection identified as Shang metropolitan objects in the Anyang period (courtesy of Jessica Rawson)

11Va	10V	192L	382V	386V	17V
11Vb	239V	13S	384V	37V	249V
90V	19V	375V	143V	337V	14V
264V	342V	341V	31V	137V	303V
213V	378V	89C	43V	89V	346V
304V	33V	328V	82V	214V	192V
226V	323V	337C	169V	2V	183V
206V	294V	18V	95V	164V	44V
84V	25V	179V	15V	39V	53V
345V	25L	3V	5V	317L	

Appendix XV Plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ in objects in the Anyang group in the Shang Sackler collection

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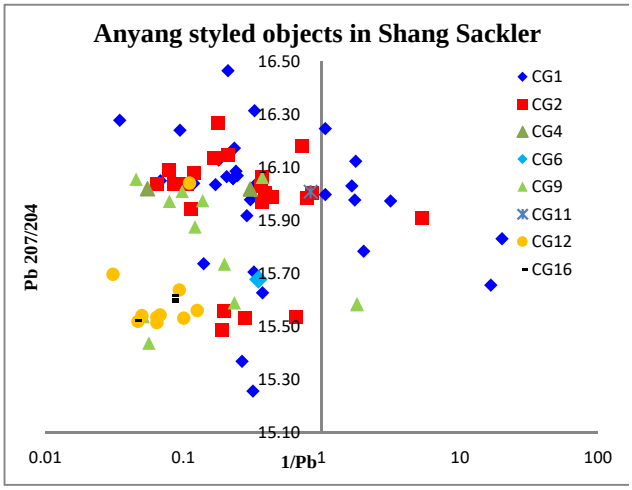
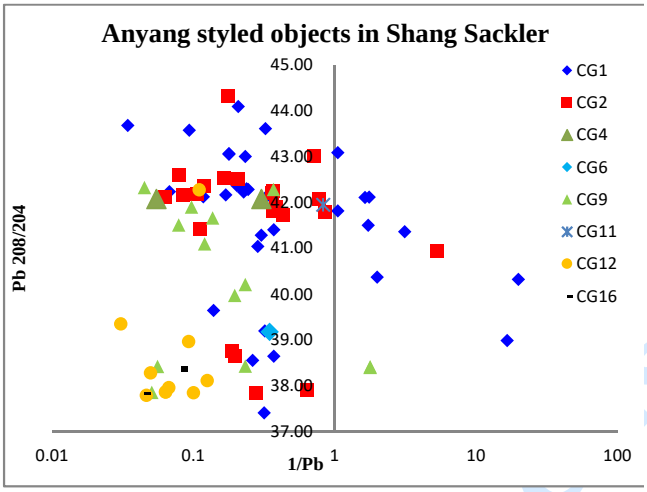
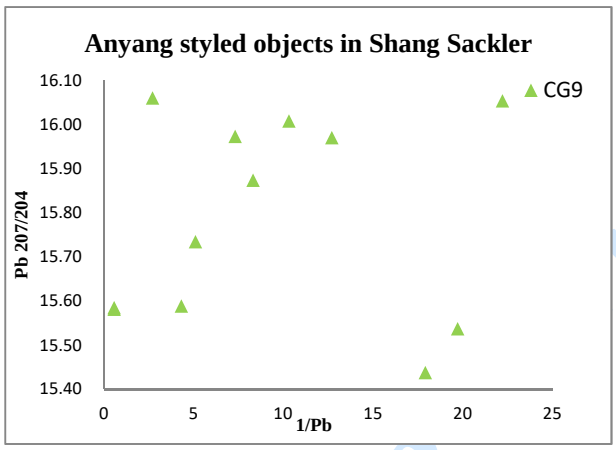
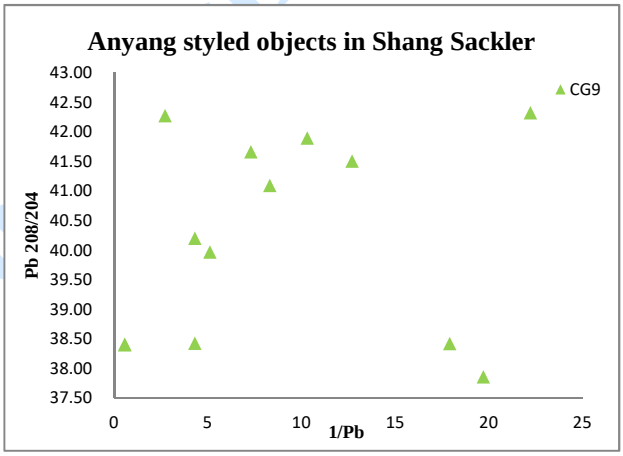




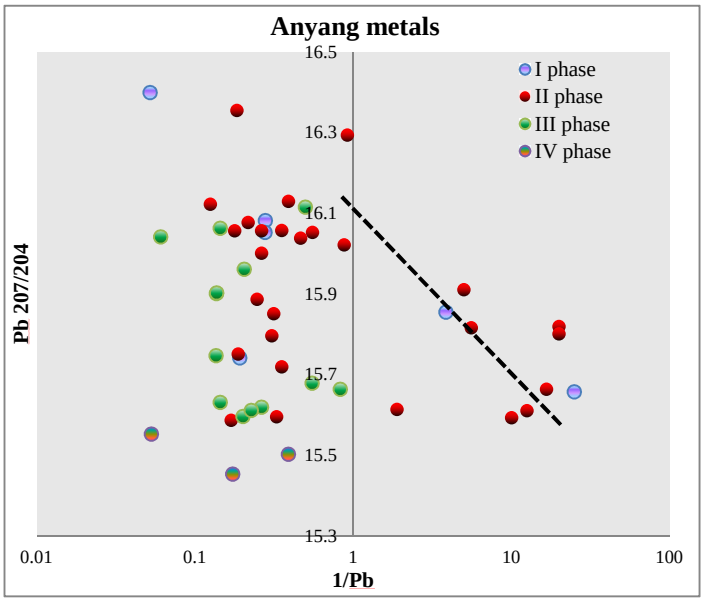
Appendix XVI Plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ in objects of CG9 in the Anyang group in the Shang Sackler collection

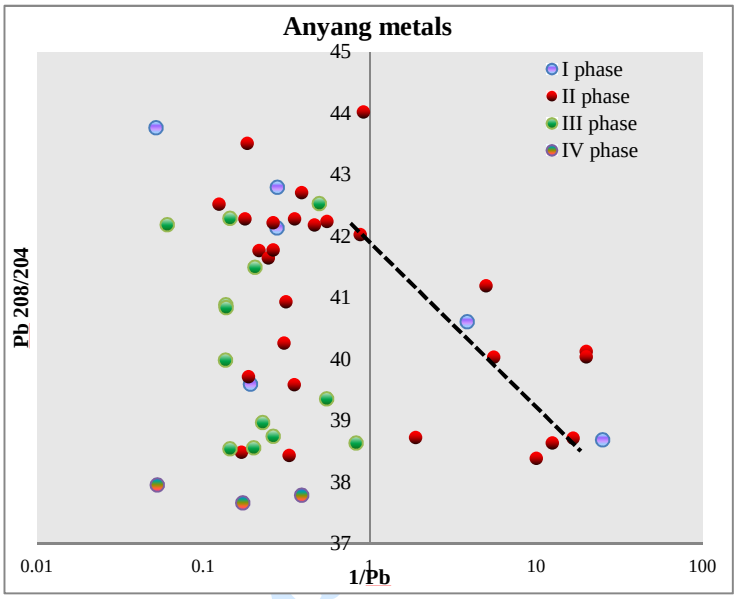




Appendix XVII Plotting of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ in excavated objects at

Anyang





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List of publications

Liu, R., P. Bray, A. M. Pollard, and P. Hommel, 2015, Chemical analysis of ancient Chinese copper-based objects: Past, present and future, *Archaeological Research in Asia*, **3**, 1-8.

Pollard, A. M., P. Bray, P. Hommel, Y.-K. Hsu, **R. Liu**, and J. Rawson, in press-a, Bronze Age metal circulation in China, *Antiquity*. (correspnding author)

Pollard, A. M., P. Bray, P. Hommel, Y.-K. Hsu, **R. Liu**, and J. Rawson, in press-b, 利用牛津研究体系深化对中国青铜器的认识, *Kaogu*. (correspnding author)

Jin, Z., **R. Liu**, J. Rawson, and A. M. Pollard, accepted, Revisiting Lead Isotope Data in Shang and Western Zhou Bronzes *Archaeometry*. (correspnding author)

Zhangsun, Y. Z., **R. L. Liu**, Z. Y. Jin, A. M. Pollard, Lead isotope analysis reveal the key role of Chang'an in the mirror production and distribution networtk during the Han dynansty, accepted, *Archaeometry*.

Pollard, A. M., J. Rawson, **R. Liu**, Some recently rediscovered analyses of Chinese bronzes from Oxford, submitted, *Archaeometry*.

Bray, P., A. Cuénod, C. Gosden, P. Hommel, **R. Liu**, and A. M. Pollard, 2015, Form and flow: the 'karmic cycle' of copper, *Journal of Archaeological Science*, **56**, 202-209.

Pollard, A. M., Y.-K. Hsu, **R. Liu**, and J. Rawson, submitted, Chinese Bronzes: From Alloy Composition to Alloying Practices, *Journal of Archaeological Science*. (correspnding author)

Ruiliang Liu unplished thesis