Physical Barriers, Cultural Connections: a Reconsideration of the Metal Flow at the Beginning of the Metal Age in the Alps

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Abstract

This thesis considers the early copper and copper-alloy metallurgy of the entire Circum-Alpine region. It introduces a new approach to the interpretation of chemical composition data sets, which has been applied to a comprehensive regional database for the first time. An extensive use of GIS has been applied to investigate the role of topography in the distribution of metal and to undertake spatial and geostastical analysis that may highlight patterns of distribution of some specific key compositional element.

The Circum-Alpine Chalcolithic and Early Bronze Age show some distinctively different patterns of metal use, which can be interpreted through changes in mining and social choices. But there are also some signs of continuity, in particular those which respect the use of major landscape features such as watersheds and river systems. Interestingly, the Alpine range does not act as a north-south barrier, as major differences in composition tend to appear on an east-west axis. Conversely, the river system seems to have a key role in the movement of metal. Geostastical analyses demonstrate the presence of a remelting process, applicable also in the case of ingots; evidence that opens new and interesting questions about the role of ingots and hoards in the distribution of metal at the beginning of the Metal Age. New tools and new analysis may also be useful to identify zones where there was a primary metal production and zones where metal was mostly received and heavily manipulated.

Acknowledgments

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This thesis is dedicated to my father.

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1 Introduction to the thesis

Overall this work aims to convey a new perspective in the study of the ancient metallurgy in the Circum-Alpine region. Most previous studies have focused on provenance and the technology (more specifically alloying practice) of ancient metals (e.g. Hartmann & Sangmeister 1972; Junghans *et al.* 1960, 1974; Krause 1989; Ottaway 1989; Otto & Witter 1952). A series of other important questions are more rarely considered: how metal was used and perceived by ancient societies, how it was moved, how it was manipulated, what happened to it in the time period between its extraction at the ore source to the time and place where it was deposited (see Chapter 3). The biographical cycle of metal, as shown by Ottaway, has rarely been considered in its entirety, with most studies focussing only on the first few events, such as pinpointing centres of production.

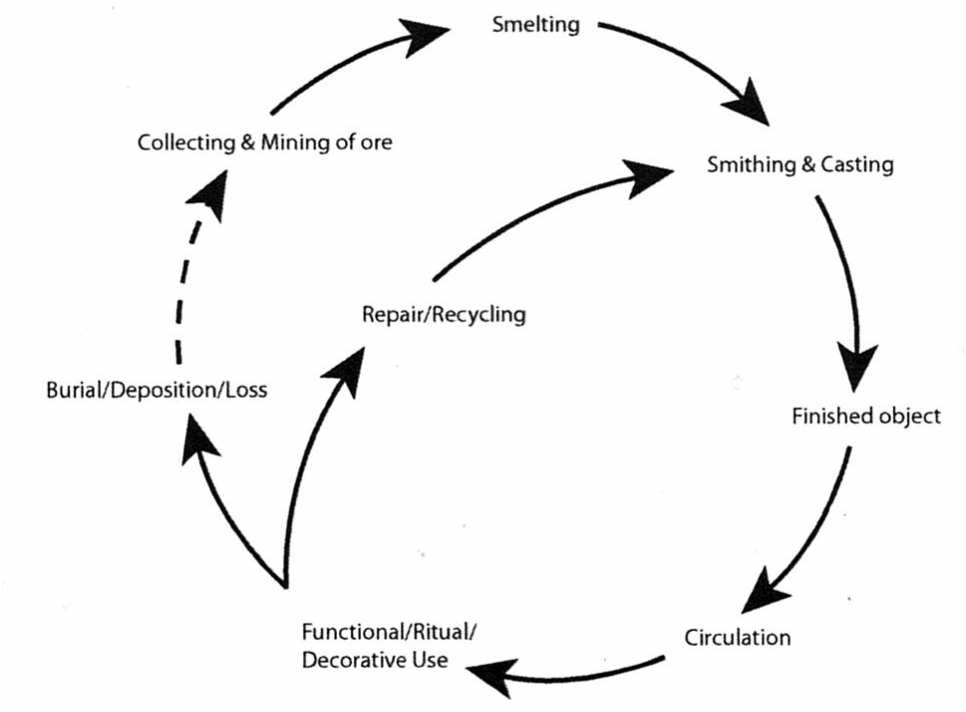

Figure 1: metal cycle from production to deposition from Jennings (2013), modified from Ottaway (2001).

In other words, if the life history of an artefact may be seen as an alphabet, we know ω (where the object was found), and most of the authors are trying to find out α (where the copper came from), but the rest of the story is underlooked. If we consider object biography not merely as birth (primary manufacture) and death (final deposition), but as a complex socially determined journey between the two, then it is this journey which, through evidence of re-use, recycling, movement, exchange and deposition, reveals the understanding of artefacts made of metal (Pollard *et al.* 2014). This is part of a new concept of the material culture: the Flow Model, that indicates how artefacts (in this case metal) were perceived in society, how they moved in space and through time and how these perceptions and movements changed the object's physical properties: the shape, colour, the weight and the chemical composition (Bray *et al.* 2015; Pollard *et al.*

2014; Sainsbury *et al.* in press) (see Chapter 3). The Flow Model has a strong theoretical underpinning, based on concepts such as the agency of objects (Gosden 2005) and the processes of innovation and acceptance of new material (Derevenski & Sørensen 2002). The entire life cycle of metal is studied, with its social implications: from smelting to the final deposition through a series of passages of use, reuse, recycling and reshaping.

The life cycle of metal has not been played out on a 2D sheet, but obviously occurred in a real, topographical, world, therefore it is essential to fully utilise GIS approaches to explore metal flow. The use of GIS in archaeology has exponentially increased in the last 10-20 years. A series of key articles and books witness the growing interest of the archaeologist in this technology (see Chapter 4). Research has covered both the practical application of GIS and theoretical approaches, addressing questions such as how to study past landscapes, what was the landscape for human populations in the past and what did this landscape mean? Importantly, how do we avoid over-valuation of visible, detectible and mappable remains in the comprehension of the human interaction with space (see Chapter 4)? Landscape is no longer studied as a blank, objective background to human action but is now defined by the subjective perception of different cultures that move within it. This thesis aims to integrate archaeometallurgy with the on-going discussion about the relationship between space and human action, for instance Llobera (1996, 2000, 2001), Michelaki *et al.* (2014) and Ingold (1993). The Circum-Alpine region (Figure 2) in the transition from the Copper Age to the Early Bronze Age (circa 3600-1600 B.C.) has been chosen as a case study to test this new approach.

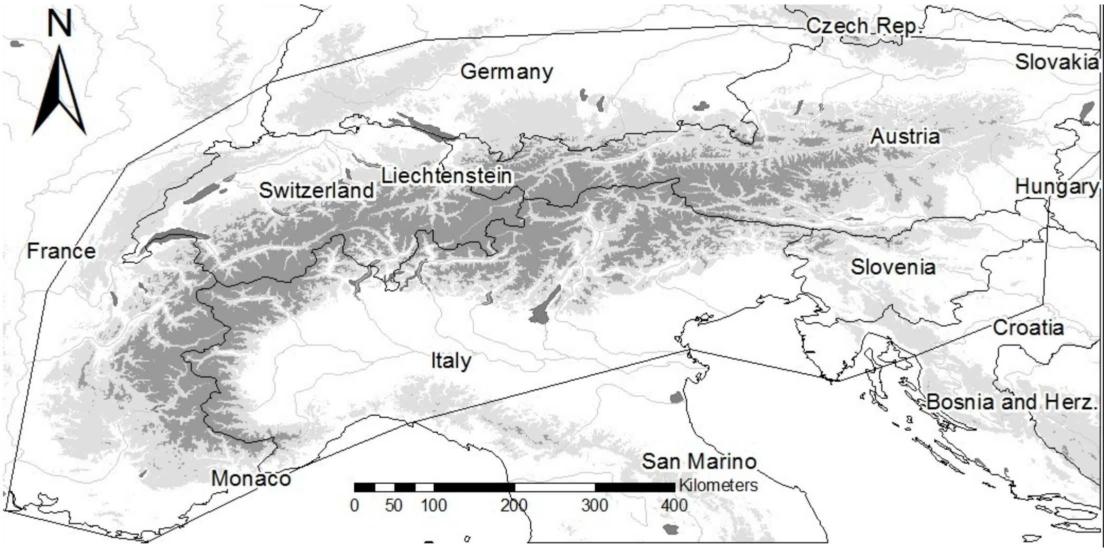

Figure 2: the study area of this thesis: the Circum-Alpine region.

Adopting such a large scale of space and time is fundamental to properly understanding the complete life cycle of metal, many events of which may have occurred far away from the original mines. The prehistoric Alps are an interesting case study because of dramatic topography and the existence of many different possible sources of metals (see Chapter 5). Within the chosen time period there were different kinds of copper-based metals with different mechanical properties in circulation (see Chapter 6), so it is possible to speculate about the choices that led ancient people to use one metal rather than another. Moreover, there were a series of different archaeological cultures (see Chapter 7) and the relationships between their geographical range and the flows of metal may be explored. A key question is whether metal movement occurred independently of the presence of different cultures or if there were issues of acceptance of a type of metal that created cultural barriers.

Archaeometrical studies in this region have mainly been focused either on the northern or the southern regions of the Alps. Transalpine contacts between people who lived in the north or the south have been hypothesized by some archaeologists (e.g de Marinis & Brillante 1998), but there is no archaeometric study of the development of the ancient metallurgy in the Circum-Alpine region as a whole (see Chapter 3). It is undoubtedly a very significant region for the beginning of the Metal Age: for the frequency of metalliferous deposits, the number of possible mines and the evidence for exploitation of some of them from a very early period. It must be remembered that Monte Libiola is the oldest mine with evidence of exploitation in western Europe (fourth millennium: Maggi & Pearce 2005). The substantial evidence for prehistoric mine exploitation is discussed in Chapter 5. Metallurgical contacts within the region are cited in a number of works (see Chapter 2), but there is still a lack of an overview, and, above all, a lack of a shared methodology to look at ancient metallurgy in different regions.

These differences are mainly due to the different academic schools linked to different countries. The German school has created a growing interest in an interpretation of ancient metallurgy that takes into consideration the biography of metal (Ottaway 2001), but without taking recycling into consideration. This provides some social interpretation about the production and use of metal (in particular, Krause 2003, Kienlin 2010: see Chapter 2). However, their attention has been primarily focussed on the Carpathian Basin and the central-eastern zone of the north Circum-Alpine region. The work of Cattin (2007; Cattin *et al.* 2009, 2011) could link Switzerland to this narrative. On the other hand, in Italy the situation is dramatically different. As Dolfini has observed, there is still a perception of archaeometry as a complementary subservient discipline of archaeology, which, in turn, still thoroughly relies on typochronology. As a result, the narrative is simplistic, if not wrong, as new radiocarbon dates and analyses demonstrate (Dolfini 2010, 2014b). This picture is further complicated by the fact that in the Circum-Alpine region there is also a lack of regional scale chronological and archaeological synthesis, as shown in Chapter 7. This thesis cannot have the ambition of giving the ultimate word on such controversial and complex issues, but it aims to at least draw a synthetic picture under one theoretical perspective, namely the Flow Model.

This thesis proposes to reconsider the available chemical, chronological, and geographical data using a new model, and to work towards a new regional synthesis. In particular, the objectives of the project are to:

1. Order the data in a structured manner;
2. Develop new tools to combine chemical, archaeological and geographical data;
3. Understand the flow of different types of metal (copper, copper with impurities, bronze) within the region and across time;
4. Evaluate the importance of re-melting and remixing of metal within this flow;
5. Understand the role of topography in the movement of metal.

The first seven Chapters of the thesis provide the context and background to tackling these objectives. Chapter 2 is an overview of the most important prehistoric archaeometallurgical work in the Circum-Alpine region (the south-east of France, Switzerland, southern Germany, Austria, Slovenia, northern Italy). Chapter 3 discusses more specifically the need for new perspectives and new methodologies in the study of ancient metallurgy and highlights how the approach developed in this thesis can add to previous conclusions. Moreover, it explains about the creation of different "copper groups", namely how different trace elements associated with copper are used to define different compositional groups. Chapter 4 is dedicated to the theory and use of GIS, highlighting its possibilities, limitations, and why it is an appropriate tool to study the flows of metal. Chapter 5 provides information about the region, its geology, the possible metal ores and the topography. In Chapter 6 there is a description of the material taken into consideration in this thesis: copper, arsenical copper, copper with impurities and the tin-copper alloy, bronze. Chapter 7 considers the chronological periods utilised in this research and the cultural groups identified by the archaeologists in the Copper Age and the Early Bronze Age.

Chapter 8 is dedicated to the first and second objectives of the research: the creation of an ordered database. Information about each field of the database is provided, discussing specific issues that may occur during the compilation of a large database created by acquiring information from different sources, which in themselves used different analytical methodologies and utilised differing chronologies. There is also an explanation of the GIS tools specifically created and used for this research.

The third and fourth points of this thesis are developed in Chapter 9 for the Copper Age and 10 for the Bronze Age. Ubiquity analysis (Banning 2000, 109) is combined with geostatistical analysis to plot the average loss of volatile elements (particularly arsenic) from copper-alloy over distance and time, as discussed by Bray and Pollard (2012). In Chapter 11 some specific issues about the introduction and the use of tin in the Alps are dealt with using the Flow Model as the interpretive key.

The fifth objective is examined partly in Chapters 9, 10 and 11, and more fully in Chapter 12. Using GIS the frequency of occurrence of each of the compositional groups of material and how this frequency changes over space and time are highlighted. This analysis allows the possibility to suggest the location of the original centres of production for each group, and the extent to which these groups have spread over time - so that hypotheses regarding possible metal exchange routes can be proposed, and specifically how these routes were influenced by the presence of mountain topography. Chapter 12 is more specifically related to topography: in particular the role of mountains as a barrier to movement and of rivers as a means of transport are tested.

In conclusion, instead of focusing attention only on the provenance of metal, in this thesis the movement of metal in the Copper Age and Early Bronze Age in the Alps is analysed: how it changed over time, how it was influenced by cultural choices, and whether the topography of the territory had a direct impact on the nature of the flow of metal.

2 A History of the Archaeometallurgical Research in the Circum-Alpine Region

This Chapter provides an overview of the history of the research in archaeometallurgy, with particular reference to the Circum-Alpine region. Most of the data discussed here has been incorporated into the database used in this thesis, and hence this Chapter also serves as an introduction to the various data sources. The Chapter considers the specific theories and hypotheses proposed by different research groups, and proceeds to evaluate the methodology they used to generate their findings. A discussion follows, to identify the common points of previous researchers, and suggest what future directions should be considered.

2.1 The Beginning

The Enlightenment culture and its efforts to understand scientifically the world was probably the most fertile soil where the idea of applying scientific analysis to archaeological artefacts could flourish, so that in the 18th century the first "archaeometallurgical" research appeared. Martin Heinrich Klaproth has usually been considered as one of the first, if not the first-ever "archaeometallurgist" (Otto & Witter 1952, 19). He used gravimetry to determine the major chemical composition of a group of coins (Klaproth 1807, 351–358). Nevertheless, according to a recent work of Pollard (Pollard, 2014), the first "archaeometallurgist" was Michel Jean Jérome Dizé (1764-1852) who analyzed eight coins using gravimetry; his results gave information only about the amount of tin present (Dizé 1790).

In the 19th century, Mallet in his Doctoral thesis first recognised that prehistoric copper artefacts were made not only with copper and copper oxides but also copper sulphides, in particular chalcopyrite (1852). Therefore the idea of a link between chemical composition of metal artefacts and their provenance started to appear, as first hypothesized by Göbel (1842) and Wocel (1853, 716–761). He, and Berlin in another independent study (1852), claimed also that the gradual increase of tin content is a good tool for determining the relative age of the bronze, setting the basis of dating artefacts according to their composition. In 1842 Göbel undertook analysis on 120 artefacts from the Baltic region and divided them into groups that, according to the author, should reflect different ethnic groups (Pernicka 2011, Göbel 1842). The work of Fellenberg (1860-1865) and Schrötter (1861) also set a fundamental point in the history of archaeometallurgy when they declared the importance of elements that are “alien” in respect of the metal alloy - namely the trace elements - which can be the most important in regard to the provenance of the raw material. Following the idea of Wocel, they stated that understanding the metal source would be possible by analyzing the chemical composition of artefacts and recognizing the presence/absence of these so called “alien elements”. By the middle of the 20th century, the theoretical ground was fertile enough to develop a program of research on the chemical composition of ancient artefacts.

2.2 Otto and Witter and the Halle group (1952)

At this time, finally, large-scale programs of chemical analyses on large groups of ancient metal artefacts began. The first fundamental work during this period was produced by Otto and Witter, from the University of Halle, whose results were published in the 1952 "Handbuch der ältesten vorgeschichtlichen Metallurgie in Mitteleuropa".

The aim of this work was to understand prehistoric metallurgy in Europe using chemical analysis, in contrast to the typological classification of metal artefacts. Historically, their project was not the first with the ambition of working with large numbers of artefacts: in 1869 von Bibra published the results of analyses made on 1250 metal artefacts from different historical periods (Bibra 1869). Otto and Witter, conversely, decided to focus only on one period to increase the consistency of their work: the very beginning of the Bronze Age. They organized a program of research to analyse a substantial number of artefacts (n=1300) from all around Europe, from Ireland and Denmark to Italy and from Spain to Romania (Otto & Witter 1952, 1–21).

Otto and Witter recognized the importance of trace elements in artefacts as fingerprints of the raw material and metal ore, but valued the importance not only of the presence/absence of determined elements, but also of their percentage (Pernicka 2011). Hence they developed their own atomic emission spectrometry (AES) methodology that allowed them to obtain quantitative analysis: the samples from the artefacts were melted to form two electrodes, and then a high voltage was applied between the two electrodes, causing the emission of light whose wavelength was dependent on the chemical elements in the sample. The intensity of the light gave information about the quantity of each element in the sample (Pernicka 2011, 28). Moreover, they understood also the importance of metallography to study the manufacturing process of the artefacts. This, in turn, gave an input to the development of experimental archaeology: the authors underlined the importance of recreating metal artefacts and studying them with metallography to understand which kind of traces different processes could produce. Indeed, they claimed the need of modern artefacts produced using ancient types of metal, to have standards to compare their metallurgical results (Otto & Witter 1952, 53–57).

Otto and Witter analysed more than 1300 artefacts and created seven groups of metal according to the artefacts' compositions: "pure copper", "raw copper" (that indicates "copper with small traces of other elements"), "arsenical copper alloy", "*Fahlerz* (defined by the authors as "copper with a higher percentage of trace elements than raw copper") with a high percentage of silver", "*Fahlerz* with a low percentage of silver", "other kind of metal", and "tin-copper alloy". These groups were further divided according to the percentage of presence of tin, lead, silver, gold, nickel, cobalt, arsenic, bismuth, zinc (Otto & Witter 1952, tab.I–VI). Two further groups were dedicated to slags and to material from the Middle East respectively. Here it is necessary to note that they considered tin and copper as a unique "block of metal" and did not consider copper and tin as two separate and independent components of bronze.

The creation of these chemical groups was based only on the authors' observations, without any statistical treatment of the data. Although their ability in the manual formulation of the groups was recognized by later authors (Ottaway 1982, 94–65), such a subjective technique was not acceptable for scientific research and, of course, was soon replaced by statistical analysis (see Section 2.4).

Finally, these authors investigated chronological and geographical patterns linked to their groups to hypothesize the provenance of material and some trade-routes (Otto & Witter 1952, 60–82). With regard to chronology, they accepted Childe's theories about a linear technological evolution of metallurgy, from copper to arsenical copper, *Fahlerz*[1], and tin bronze (see Section 3.1.1)(Childe 1944; Otto & Witter 1952, 5) and agreed with the suggestion of dating objects according to their chemistry (Otto & Witter 1952, 5). As regards the provenance, first it has to be noted that the aggregation of artefacts was determined only according to modern political boundaries. They claimed a provenance for almost all the German artefacts from copper ores in Saxony, a conclusion obviously tainted by nationalist forces that were, of course, very strong at the middle of 20th century (Pernicka 2011, 28).

[1] Since now then "*Fahlerz*" is referred to copper with a percentage of As, Sb, Ag, Ni, Bi between 0.1-10%

2.3 Pittioni and the Vienna group (1930-1950)

Another contemporaneous and important group of researchers was established in Vienna, whose most eminent member were Preuschen and Richard Pittioni (Pernicka 2011). This group also had the aim of looking for the provenance of ancient metal artefacts through compositional analysis and trace elements evidence, and they focused their research on the Alps and the Balkans (Hungary) (Pernicka 2011, Preuschen & Pittioni 1939).

The researchers of this group had a strong metallurgical background as they were mining engineers (Pernicka 2011, 28). They spent time evaluating the consistency of archaeometric research: arguing against Witter, they pointed out that only with a significant amount of data of the same period and a specific form, can a consistent hypothesis be formulated about the provenance of a group of artefacts with a similar composition (Pittioni 1957, 3). This is an important basis for research, quoted, amongst others, by Ottaway (1982,74). Pittioni (1957, 3) declared explicitly that it is quite impossible to understand the provenance of a single object because the metal ores are too heterogeneous, and the composition of copper is not entirely the same at all depths of the deposits. Consequently, the composition of two single objects from two different points of an ore body could give two different compositions. According to Pittioni, a lack in geological knowledge led Otto and Witter to attempt to identify the provenance of each single objects (Pittioni 1957, 3).

The heterogeneous nature of metal ores also implies that the presence of a single specific chemical element in an artefact is never crucial in determining metal groups (Pittioni 1957, 4). Useful information might only be derived by the combination of the presence of some specific elements: antimony, arsenic, lead, nickel, silver, bismuth and tin (Pittioni 1957, 7). Iron was considered not to be diagnostic, as it is universally present in copper ores; aluminium, calcium, magnesium and silicon, as well, were ruled out as non-specific (Pittioni 1957,v 7). A crucial consequence of the Viennese groups idea of combination of presence/absence of elements as the main priority in data collection, was their decision to undertake only semi-quantitative analysis, namely without numerical values for the concentrations. Figure 3 shows how they published their data.

Nr.	Objects	Cu	Sn	Ag	Al	As	Ca	Fe	Mg	Mn	Ni	Pb	Sb	Zn	Bi	Au	V
	Barreringen A																
1	Metallkern 1	HM	Sp	++	-	++	-	++	-	Sp	-	Sp	+	-	+	-	-
2	Metallkern 2	HM	Sp	++	-	++	-	++	-	Sp	-	Sp	+	-	+	-	-
3	Oberfläche1	HM	Sp	++	-	++	-	++	-	Sp	-	Sp	+	-	+	-	-
4	Oberfläche2	HM	Sp	++	-	++	-	+	-	Sp	-	Sp	+	-	+	-	-
	Barreringen B																
5	Metallkern 1	HM	Sp	++	-	++	-	++	-	-	Sp	Sp	+	-	+	-	-
6	Metallkern 2	HM	Sp	++	-	++	-	++	-	-	Sp	Sp	+	-	+	-	-
7	Oberfläche1	HM	Sp	++	-	++	-	+	-	-	Sp	Sp	+	-	+	-	-
8	Oberfläche2	HM	Sp	++	-	++	-	+	-	-	Sp	Sp	+	-	+	-	Sp
	Barreringen B																
9	Metallkern 1	HM	+	++	-	++	-	++	-	-	Sp	Sp	+	-	+	-	-
10	Metallkern 2	HM	+	++	-	++	-	+	-	-	Sp	Sp	+	-	+	-	Sp
11	Oberfläche1	HM	+	++	-	++	-	+	-	-	Sp	Sp	+	-	+	-	Sp
12	Oberfläche2	HM	+	++	-	++	-	+	-	-	Sp	Sp	+	-	+	-	Sp

Figure 3: example of publication of data of Pittioni, from Pittioni (1957: Tab. 1).

Unfortunately, because of this semi-quantitative approach, their data is not useful for current research from a statistical perspective, as pointed out by

Ottaway (Ottaway 1982, 175–176), who tried to convert their data into numerical data. Whereas her efforts were successful with occasional symbols used by Otto and Witter and the Stuttgart group, data from Pittioni were impossible to convert and, hence, could not be included in her database. For this reason, more than 6000 analyses are now completely unable to be used (Pernicka 2011). Although we agree with the philosophy of Pittioni, we also concur with Ottaway and have not used these data in this thesis.

Even though the data that this research group produced cannot now be used, the importance of their work within the research framework should not be undervalued. Apart from the assertion that a large number of contemporary objects are necessary to assign provenance, the group from Vienna also espoused another feature of modernity: recognizing the importance of a multidisciplinary approach in archaeometallurgical research, including the contribution of geology (Pernicka 2011). Indeed, the Vienna group analyzed not only finished artefacts, but also slags and metal ores. Moreover, they spent time to undertake geological research in the Alpine region to identify the possible ores and to look for sites that had evidence of ancient smithing processes (Pittioni 1957, 7–16).

2.4 The Stuttgart group (1960-1970)

Around the middle of the twentieth century in Stuttgart a group of researchers in ancient metallurgy was created, whose most eminent personages were

Siegfried Junghans, Edward Sangmeister and Manfred Schröder (usually referred as "SAM", from the acronym of the name of the project: the S*tudien Anfangen Metallurgie* project) (Pernicka 2011). The declared aim of their research was the study of the origin and spread of copper and bronze in Europe by examining the material itself scientifically, namely by means of spectral analysis and numerical statistics (Junghans *et al.* 1968a, 6).

The field of research of the SAM group was broader than their predecessors: for the first time the entire European continent was taken into consideration. So, in this case, their geographical unit was not coincident with their area of research: they divided it into different area sub-units, according to modern barriers and topographical elements used as barriers (i.e., rivers and mountains) and they created distribution maps of objects with common chemical compositions.

The extent of the territory of interest and the necessity to have a statistically valid sample size pushed the authors to make as many analyses as possible, ultimately more than 22,000 analyses. They published the first 1000 results in 1960, added 9,000 in 1968 and finally reached the number of 22,000 in 1974. At this time, they also reconsidered their previous analyses, republishing some of them because in some cases arsenic and antimony were underestimated by the instrument (Junghans *et al.* 1974). The analytical technique used by the Stuttgart group was OES, following the footsteps of Otto and Witter and, hence, undertaking quantitative analysis. They focused on eleven elements: tin, lead, arsenic, antimony, silver, nickel, bismuth, gold, zinc, cobalt, iron. The quantity of copper was not calculated.

The authors recognised the most significant boundaries in the percentages of presence of bismuth, antimony, silver, nickel, and arsenic (Junghans *et al.* 1960, 57). Hence, Klein, the statistical expert of the group, decided to use these elements to develop his statistical frequency analysis: he tried to create groups where the frequency distribution of the percentages of each of the elements can be represented as a Gaussian curve. As a result of this statistical analysis Klein defined 12 groups of metal, as shown in Figure 2. A group was considered "secure" only when it reached a threshold that would not change even with increasing the number of samples (Junghans *et al.* 1960, 58). However, it is to be noted that, due to the statistical method applied, a few samples which were very close to the limits of the groups might be assigned to either one group or another (Junghans *et al.* 1960, 58).

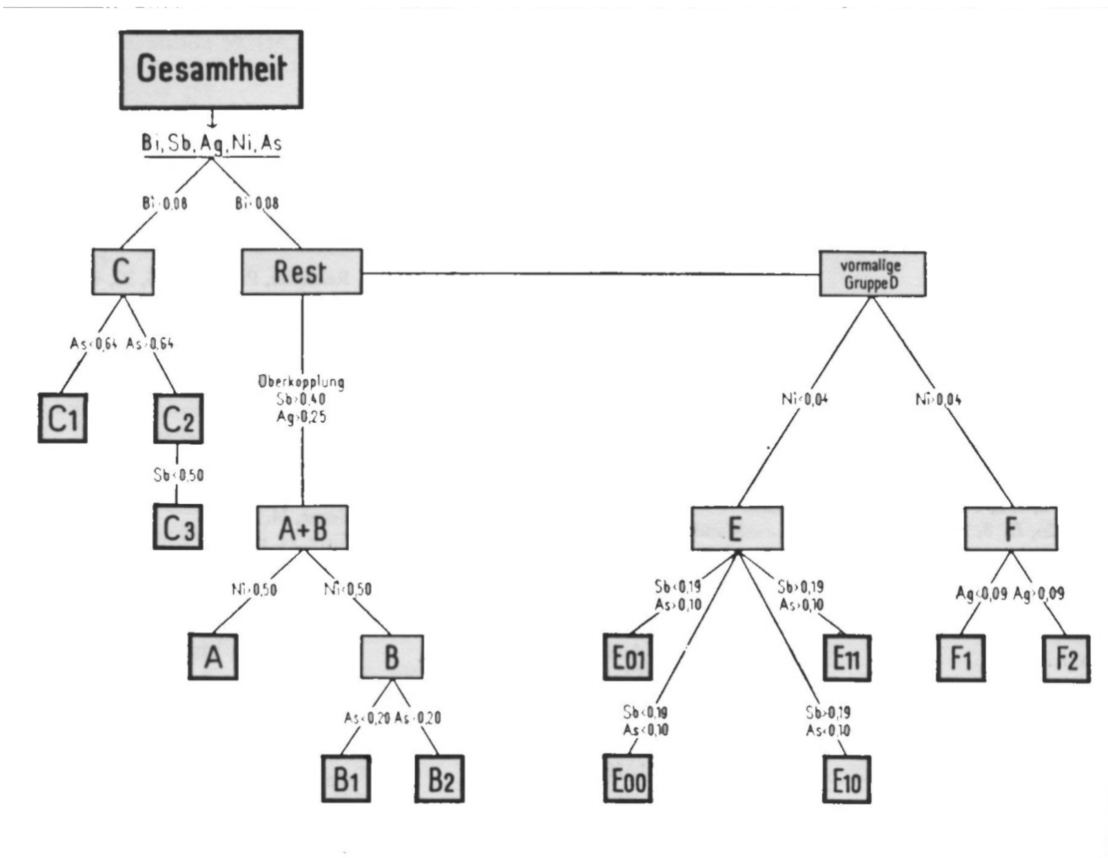

Figure 4: groups of metal artefacts according to their composition, from Junghans *et al.* (1960: Tab. 1).

To improve the statistical quality of their research, and seemingly accepting the criticism of the Viennese group about the irrelevance of the percentage weight of each chemical element when considered in isolation (Pittioni 1957, 4), when the Stuttgart group published a second set of analyses in 1968, they performed their statistical analysis by plotting each element against the other elements, a so called "two dimensional analysis" (Junghans *et al.* 1968b, 13). With this technique, the authors have created a first hypothesis of subdivision of artefacts into groups, and this subdivision was subsequently refined to consider the percentages in weight of individual elements, in particular those of Ag, As, Bi, Ni and Sb. As a result, instead of 12 groups, 29 groups of materials were defined.

However, most of the groups that were already identified in the 1960's publication were confirmed once again: the new results helped only to further refine the original groups (Junghans *et al.* 1968b, 15).

A number of criticisms were raised with regard to their statistical methodology by Waterbolk and Butler (1965). They argued against both the methodology and the representation of their results. They strongly criticized the methodology due to its lack of consideration of the archaeological background, stating that the Stuttgart team has "thrown the analyses all into one pot, with the hope that mathematical means will bring them out of the pot again in a logical order" (Waterbolk & Butler 1965, 230). This decision had a series of consequences: some artefacts were assigned to groups with characteristics of a period different from the chronology of the other artefacts (Waterbolk & Butler 1965, 232). Other artefacts were placed in several different groups even though they were from a homogenous archaeological context and – as Waterbolk and Butler pinpointed - had a mostly homogenous composition (Waterbolk & Butler 1965, 237). Finally, small groups of artefacts with distinct characteristics may not have been recognized (Waterbolk & Butler 1965, 233). A further criticism of the methodology was that it had not been consistently applied for all the recognized groups: in fact only group A had all the elements distributed in a Gaussian curve (Waterbolk & Butler 1965, 231). Moreover, Waterbolk and Butler pointed out that in certain cases the significant information is not the percentage of an element, but its ratio with other elements (Waterbolk & Butler 1965, 238).

The new representation was also criticized since, if further analyses were undertaken, it would be difficult to compare the results with the proposed groups, so that judging the probability of the artefact belonging to one group or another would be impossible (Waterbolk & Butler 1965, 233). Therefore, the methodology proposed by these two authors was to start with artefacts from a homogenous context, like a hoard, and represent graphically the distributions of the elements considered as important (see Figure 5).

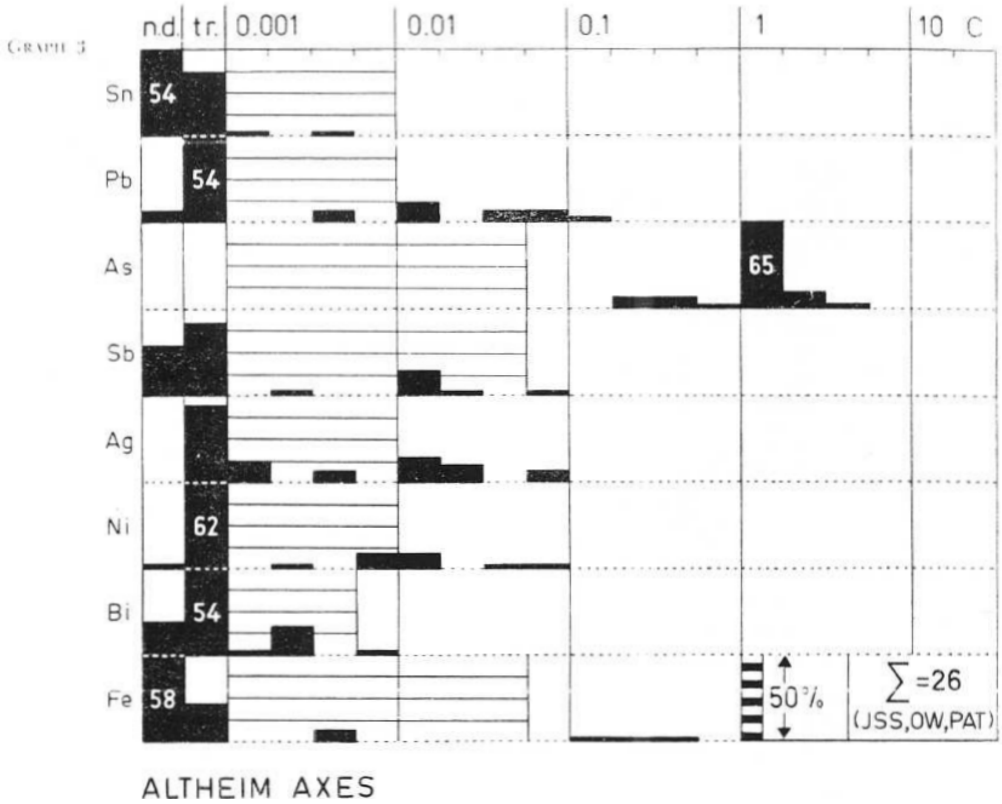

Figure 5: example of publication of data from Waterbulk & Butler (1965: Graph. 3). In this graph the composition of 26 Bronze Age axes from Altheim are compared. For each element, for each span of composition in log scale (not detected, traces, 0.001, 0.01, 0.1, 1 and 10%) the frequency of the number of objects is given in percentage. Each line in a cell indicates 10% of frequency, the entire cell filled represents 50% of frequency; If a frequency is >50% the percentage is written in number. The graph shows that the compositions of the objects are very similar.

The criticism drawn by the Stuttgart group has been generally accepted, but, as Ottaway also pointed out (Ottaway 1982, 97), the methodology proposed by Waterbolk and Butler is hardly usable with a complex dataset, such as the data produced by different laboratories or with a large number of data. Moreover, here it seems necessary to highlight the limits of Waterbolk and Butler's considerations. The supposed general homogeneity of artefacts from closed contexts – like hoards - might lead to the conclusion that the analysis undertaken on one artefact is valid for all the others. The cases of the axes from the Burzanella hoard (Emilia Romagna, Italy) and from the Pieve Albignola hoard are examples of analysis undertaken on objects from the same context and similar in their shape which have been demonstrated to have a different chemical composition (Angelini *et al.* 2010; Pearce 1991, 77–79).

The Stuttgart group was also criticized for the evaluation of bismuth as a discriminant element. Slater and Charles (1970), indeed, pointed out that the behaviour of bismuth, with its low solubility in copper, melting point much lower than copper and, in the end, high segregation during solidification, causes unreliable analysis. Consequently, they said that this element should not be chosen to discriminate groups of artefacts based on their composition.

The conclusions of the SAM group were similarly questionable. As a matter of fact they tended to rely on the groups that they identified – with the discussed issues about the methodology used to create them - as the expression of a metal ore: each group is a different metal ore. This led to some peculiar conclusions: for example, since the metal in central Europe and northeast of the Alps at the beginning of the Early Bronze Age was similar to the metal in the British Isles in the same period, they hypothesized long distance contact from the north of the Alps to the British Isles, notwithstanding a gap in the continental zone between the two (Hartmann & Sangmeister 1972). It is now known that the metal in the British Isles is from the Ross Island (Bray & Pollard 2012), but has a similar composition to that produced at the same time in central Europe. With regard to Italy, they claimed that all the Copper Age metal in northern and central Italy was from the northern Alpine mines, and this claim was questioned by Barker (1971) (see Section 2.7.1).

The acceptance of these critiques does not undermine the fundamental importance of the Stuttgart group's work for modern research. A critical point was the decision to adopt the methodology proposed by Otto and Witter, rejecting Pittioni's concerns about the validity of quantitative analysis. Their choice was probably due to the decision to use statistical analysis, hardly possible without definite numbers. Indeed, it was a beneficial decision for succeeding researchers, since the data records of more than 20,000 artefacts are still available and usable. The database of the Stuttgart group is still the richest in Europe, an essential reference for any kind of study about European archaeometallurgy. As a matter of fact, the present database consists mainly of their data, as they have recently been re-published by Krause (2003).

2.5 Ottaway

In 1978 Ottaway published her PhD thesis "*Aspects of the Earliest Copper Metallurgy in the Northern Sub-Alpine Area and its Cultural setting*", soon followed by two books, one dedicated to archaeology and society and the other, "*Earliest Copper Artefacts of the North alpine Region: Their Analysis and Evaluation*", published in 1982, dedicated to the analysis of metal artefacts. The aim of Ottaway was "to study the earliest metal artefacts in the north Alpine region in their cultural context" (Ottaway 1982, 11). In this large subject, the chemical analysis of metal artefacts was supposed to provide some clues about the development of early metallurgy in the north Circum-Alpine region – if it was independent or not - and about ancient metal trades.

Ottaway was the first researcher who decided to work not only with her own analyses, but also to use all the other analyses made by other authors in order to have a more comprehensive look at the situation of her study region. So for the first time, the question of comparing different analysis was posed. She was able to include data from the Stuttgart Group and from Otto and Witter, but not data from the Vienna group (see Section 2.3). Ottaway was not able to evaluate the precision of the other laboratories by herself, and therefore she accepted the declaration of 8-16% of precision stated by the Stuttgart group as good enough. She estimated a precision of 10% for her own analyses. She also accepted the criticism raised by Slater and Charles (1970) about the segregation of lead and bismuth, and other authors (Charles 1973; Richards & Blin-Stoyle 1961; Slater 1972) about segregation and enrichment of some elements due to different melting points, low solubility in copper, mechanical work, etc… In other words, she accepted the heterogeneity of metal artefacts as a fact, but considered that the large number of data available rendered these heterogeneities insignificant (Ottaway 1982, 74–78).

The analysis of the artefacts were undertaken using neutron activation analysis (NAA) and atomic absorption spectroscopy (AAS) and the results of these two methods were compared (Ottaway 1982, 69–82). Ottaway decided to analyze Zn, As, Ag, Sn, Sb and Au with neutron activation; Pb, Bi, Ni and Fe with atomic absorption spectroscopy.

Ottaway has the merit of being the first researcher who used cluster analysis in archaeometallurgical research. As a matter of fact, she accepted the criticism raised by Waterbolk and Butler (1965) and Slater and Charles (1970) against the Stuttgart group's statistical methodology, but rejected Waterbolk and Butler's proposed methodology (see Section 2.4). Hence, she decided to adopt cluster analysis, a methodology that implied a multivariate analysis (where the variables not only included the percentage of elements, but also the weight of the artefacts). The application of cluster analysis in archaeology was started in 1969 by Hodson when, by way of example, he undertook the analysis of a group of *fibulae* using some physical parameters, such as the foot length, the bow length and the number of coils (Hodson 1970). This methodology has the clear advantage of being more flexible than the methodology used by SAM. In fact, once new materials are added, the computer can recalculate the similarities and create new groups. Moreover, the use of computer calculation is an attempt to reduce subjectivity. Since then, the methodology of cluster analysis undertaken by computer has been routine in all archaeometallurgical studies, with appropriate software upgrading over the years, to the most recent studies (e.g., Krause 2003; Merkl 2011). Even the recent criticism of this methodology (see Section 3.2.1) should not decrease the importance of Barbara Ottaway in the history of the methodology applied to archaeometallography.

According to her results, the artefacts were initially divided into two groups: bronzes (objects containing more than 2% of tin, an amount that can be related to deliberately alloying) and “copper” artefacts, which have mostly copper with minor traces of other elements (Zn, As, Ag, Sn, Sb, Pb, Bi, Ni, Co, Au, Fe). Once again, as with her predecessors, she considered tin bronzes as a unique “block of metal”. Cluster analysis identified ten groups (or clusters) of copper, the first of which, representing copper with only small traces of impurities, has been further divided into five sub-clusters (see Figure 6). The bronzes were divided into six clusters on the basis of the amount of tin present.

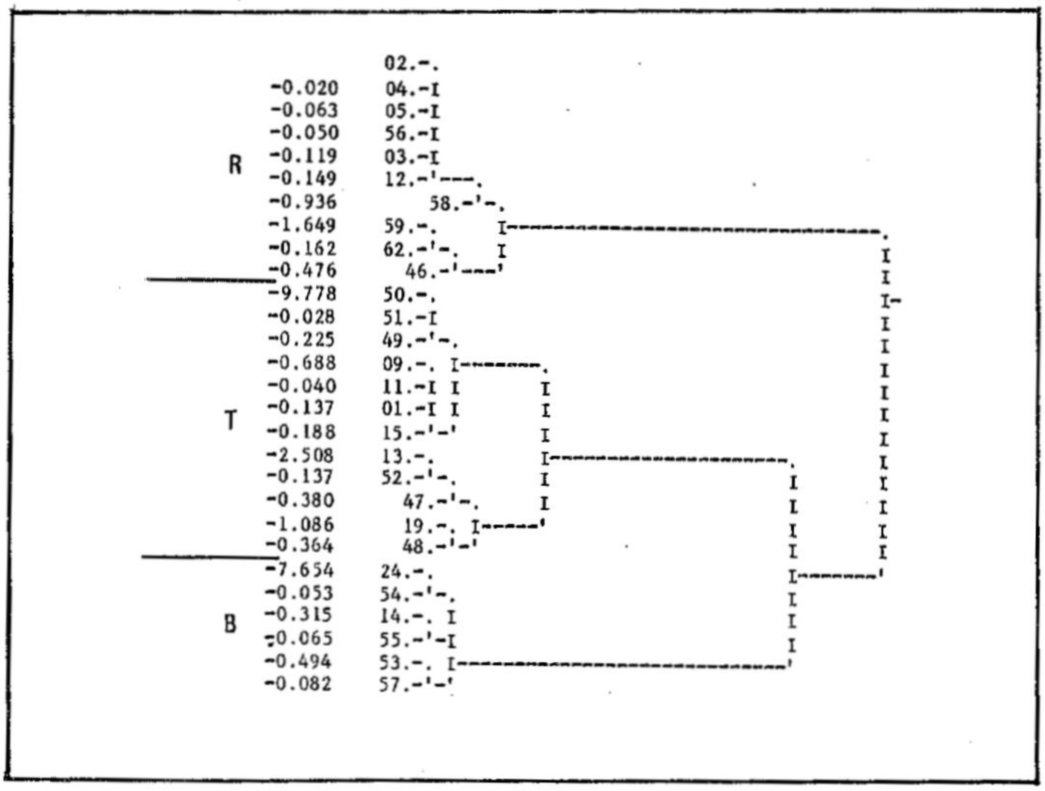

Figure 6: cluster analysis used by Ottaway (1982).

Ottaway highlighted the relationship between arsenical copper and the earliest cultures (Ottaway 1982, 121–131) and tended to explain this presence of arsenic as intentionally alloyed. She also noticed the different composition of daggers and axes, namely daggers containing more percentage by weight of impurities (Ottaway 1982, 156), opening a debate which continues today (see Section 6.2). Finally, she recognized a difference between copper used for copper production and for bronze production (Ottaway, 1982: 156). Therefore, she also tried to relate different cluster to different copper ores, but in the end admitted that it was unsuccessful (Ottaway 1982, 171–180). Hence, finally she posed the question of whether the aim of elemental analysis of metal artefacts should be to identify ancient metal ore sources, especially on a large scale, namely the entire European continent. Considering that all the attempts made in the past, including her own, were unsatisfactory, she pioneered a debate about the use of trace elements to determine provenance (see Section 3.1). Moreover, she introduced a new approach: trying to understand the relationship between different types of metal and specific cultures, on a smaller, more manageable scale.

2.6 The "Stuttgarter Metallanalysen-Project" (SMAP) (2003)

The legacy of the Stuttgart group was inherited by Pernicka and his group at the Max Planck Institute in Heidelberg between 1987 and 1997. As with their predecessors, the German researchers' objective was to understand ancient metallurgy, in particular the rise of copper and of bronze production. In particular, Krause dedicated a study to the origin of metallurgy in the zone between Carpathian basin and Baltic Sea (Krause 2003). They proceeded in two directions: on one hand they contributed to expanding the database by adding many new analyses, especially from East Germany, within the *Frühe Metallurgie in Zentralen Mitteleuropa* project (FMZM). On the other, they reconsidered all the work produced by the Stuttgart group within the framework of the new ideas and new technologies in the "Stuttgarter Metallanalysen-Project". The FMZM project was part of the SMAP. The project focused on eastern Germany, the region formerly known as the German Democratic Republic, where the well-known political and historical issues had caused a delay in research. The attention of the researchers was focused on Neolithic/Early Bronze Age artefacts, since they were mainly interested in the origin of the Metal Age, particularly the origin of copper and of tin-bronze production.

Within this project about 2,400 new analyses were undertaken by Pernicka in Heidelberg using neutron activation analysis (NAA) and X-ray fluorescence (XRF). Where the transport of artefacts was not allowed by museums, a portable XRF instrument was used. The analyses undertaken using both methods demonstrated that XRF analyses were not always reliable and, consequently, some of the results obtained with XRF were not included in the SMAP database (Krause 2003, 26). The new analyses obtained within the FMZM project contributed the SMAP project, together with many other analyses, such as those undertaken by the Heidelberg group, the Prague group, and those by Valentine Rychner (Krause 2003, 27). With these new data, the database has reached the number of more than 40,000 analyses.

The management of so many heterogeneous data was, of course, very complex, beginning with the issue about how to translate information written in Cyrillic characters (Krause 2003, 21). A fundamental issue was understanding if and how data obtained from different laboratories using different techniques can be compared, a recurrent topic in the history of archaeometric research since Ottaway's work. As mentioned below, Pernicka dedicated a study to the reliability of SAM data (see Section 8.1.2.2). Krause added that, considering the limitations of old instruments and, above all, comparing results obtained by analysing the same objects, the "old analyses", undertaken using optical emission spectroscopy (OES) are broadly comparable in terms of precision and detection limits. In contrast, many of the data obtained with more modern methods have much higher precision and significantly lower detection limits (Krause 2003, 18–22).

Another aim of the project was the creation of a digital map with all the metal results. The aim was very ambitious considering the computers available at the beginning of the nineties: both the computing power and the GIS packages were not sufficient to manage such a large amount of data. Moreover, their sources were not always clear about the provenance of analysed material, and even when the site name was given, finding it on a map was not a simple task. Consequently, a broad impression has been given, leaving the task to improve the geographical information to future researchers (Krause 2003, 22, 25). Similar difficulties have been highlighted with the chronology (Krause 2003, 25), with much also left to future researchers. As a matter of fact, defining a chronology for metal artefacts for a region as wide as the European continent is an ambitious task. Even considering new information from ^{14}C dates, most of the metal artefacts are the result of old research or occasional finds, so without any scientific data about stratigraphy. Under these circumstances, the chronology of metal artefacts still owes very much to the typological studies, with a strong implicit regional feature (see Chapter 7 and Section 8.1.2.1 for further discussion about the chronology).

The method of statistical analysis employed was still cluster analyses, following in the footsteps of Ottaway. The data was based on the elemental concentrations of arsenic (As), antimony (Sb), silver (Ag), nickel (Ni) and bismuth (Bi). These elements were the same as those used by the Stuttgart group, therefore the researchers of the SMAP project took the occasion to re-evaluate the results obtained by the Stuttgart group's statistical analysis, finding that their conclusions were broadly correct, in the most general aspects (Pernicka 1995, 97). But they went further with the analysis. Considering gold, silver, nickel and – with limitations - cobalt as markers for provenance, and the other elements as characteristic of both provenance and processing, the element pairs silver/nickel, arsenic/antimony and arsenic/tin were chosen to clarify questions of the source of the initial ore and the processing conditions (Krause 2003, 19). Gold was excluded, since in most cases it was below the detection limit with OES (the technique used by SAM). According to the SMAP researchers, recycling of material was probably happening, but this did not change significantly the chemistry of the artefacts and its effect on the cluster analysis was considered as irrelevant (Krause 2003, 145).

Their consideration after statistical analyses was that there were two categories of cluster. A group of clusters – "major clusters" refers to types of metal that were widespread in Europe, strongly linked to specific cultures (Corded Ware, Bell Beakers, and Únětice) and that signify specific changes at the beginning of the Early Bronze Age, whereas minor clusters, with a smaller number of artefacts, were expressions of local metallurgical activities. As a matter of fact, Krause used the major clusters to propose a chronology for the Early Bronze Age in Central Europe: in a very early period there was a sporadic use of *Fahlerz* – i.e. copper with small quantities of arsenic, antimony and silver (Horizon I); at the beginning of the Early Bronze Age (2300-2200 B.C.), there was the establishment of the use of *Fahlerz* (Horizon II). A third Horizon was characterized by the appearance of "east Alpine Copper Type", that differs from the previous *Fahlerz* in the presence of nickel; and then, in the final phase of the Early Bronze Age, east Alpine Copper became predominant (Krause 2002, 33–44; 2003, 26 and 88–129).

Moreover, Krause underlined the importance of the Carpathian socially-differentiated society on the development of metallurgy, and of the Únětice culture as a precursor of bronze technology (Krause 2003, 257–262). The idea that the development of metallurgy is linked to complex and hierarchical societies is recurrent in the work of Krause. In fact, the presence of north Alpine cemeteries with many metal objects (Sections 7.2.2, 7.2.4) contributed to the development of a theory, according to which in the transition from the Copper Age to the Early Bronze Age elite groups emerged that controlled the three main mining district in the Alps and also the distribution of metal through ingots: *Ösenringe* and *Spangenbarren* in the east, axes of Salez type in the central region, and axes of Neyruz type in the west (Krause 2003). This model explains the colonization of the highlands of the Alps as a search for metal sources. A complex society is also seen as the motor for technological improvements, possibly acquired from the nearby Únětice culture, both in smelting techniques (in particular to smelt *Fahlerz*) and also in production techniques, namely with the appearance of tin-copper alloy and lost-wax casting.

The work of the Hiederberg group is remarkable for their attempt to reorganize and manage the large amount of data from decades of research on ancient metal compositions. Their idea of using GIS is also valuable and is now achievable with the technologies now available, a task that this thesis attempts to perform. Conversely, their choice of using cluster analysis might be subject to some criticisms (see Section 3.2.1). Moreover, the idea of Early Bronze Age metal production as evidence for a hierarchical society has since been questioned by Kienlin (see Section 2.8.2).

2.7 Other analysis: museums and exhibitions

Other analyses were made under the initiative of the museums that contain metal artefacts.

2.7.1 Pigorini's museum (1970)

In 1970 almost 100 artefacts from the Pigorini Museum, Rome were analysed. The artefacts covered the Copper Age through the entire Bronze Age, and were geographically spread along all the Italian Peninsula, although a precise location was, in most of the cases, impossible to obtain. The sampling was undertaken by Barker and the analyses by Elizabeth Slater using atomic absorption spectroscopy (AAS), which was preferred to OES because it was considered to be more accurate and sensitive. This technique required a predetermination of the elements to be analysed; in this case the choice was: tin, lead, arsenic, antimony, iron, nickel, bismuth silver and zinc. (Barker 1971, 209–210).

The results were not statistically analysed: Barker merely used them, together with already published data of SAM and Otto and Witter to give a general picture of ancient metallurgy in Italy. He positioned himself in opposition to the Stuttgart Group's proposal of several metal groups in Italy, each linked to groups outside the peninsula, and hence an expression of metallurgical expertise coming from outside. Barker claimed that there were two main metallurgical groups and a relationship was hypothesized between them *and* the two main Italian Eneolithic cultures (Remedello in the north – characterised by copper with arsenic - and Rinaldone in the centre – that had copper with arsenic and antimony). Barker proposed a picture of local metal production with also the exploitation of local ores and this was an occasion to advocate new research on those local mines that might have been candidates to be exploited in antiquity, a challenge that was only in recent times accepted by Artioli (Artioli *et al.* 2008, 2014). It has to be stressed that Barker was not denying contacts with other cultures, but only claiming a local metallurgical production that, of course, was part of existing exchanges across Europe (Barker 1971, 187–190).

2.7.2 "Civici Musei di Pavia" (1995)

In the publication of the catalogue of "Civici Musei di Pavia" by Pearce 29 objects were analysed by Berzero using NAA to determine copper, arsenic, antimony, silver, cobalt, iron, iridium, nickel, gold, tin, tungsten and zinc, and AAS to determine copper and lead. A multivariate statistical analysis with principal components analysis (PCA) was applied to the data (Pearce 1991). The objects were 28 axes from the "Pieve Albignola" hoard and one ingot from "Sabbione". Two axes presumably from the hoard were published both as from Pieve Albignola (Patroni 1906, 56) and from San Martino Siccomario, loc. Sabbione (Ponte 1964, 179). So the objective was to verify the homogeneity of the hoard and verify if the ingot identified as coming from "Sabbione" might be part of the same hoard.

Statistical analysis highlighted the presence of four groups, based on the tin content (so, once again, the analyses was undertaken considering tin and copper as a single "block of metal"): finished axes (with tin content between 4.9 and 8.4 %), unfinished axes[2] (with tin <1%), a finished axe broken in antiquity (with 15.6% of tin) and the two axes and the ingot referred to as coming from San Martino Siccomario, made of almost pure copper (copper 99.85% and tin 0.075% in all these three cases) (Berzero *et al.* 1991, 166). The hoard of Pieve Albignola had six more axes, now housed in the Pigorini Museum, Rome, that were analysed both by SAM and by Barker.

The results were first discussed by Pearce in his doctoral thesis "Il territorio di Milano e Pavia tra Mesolitico e Prima Età del Ferro". First, he correctly observed how inaccurate it might be to presume homogeneity of composition in the case of closed contexts, e.g. hoards or burials. As touched on before, this bias might be derived from Waterbolk and Butler's proposal about the way to approach metal analysis of ancient artefacts. Considering only the material referred to as Pieve Albignola – the first three compositional groups - Pearce interpreted the refined axes as "finished products", the unrefined axes as ingots - and the broken axe an object that was conserved with a view to recasting (Pearce 1994, 77–79). These concepts have been resumed by Pearce more recently, in 1998 and 2007, when he proposed also the concept of *aes formatum* for the supposed ingots, which

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[2] "Unfinished" refers to artefacts that were not further worked after casting, and still have heavy flashing.

means ingots considered as valuable and acceptable for their dimensions rather than for their weight.

2.7.3 "Le terramare. La più antica civiltà padana" (1997)

Another work worthy to be mentioned here is the catalogue published as a result of the exhibition "Le Terramare. La più antica civiltà padana" in Modena (Lombardy, Italy) in 1997. It represented an interesting holistic study of the phenomena of the terramare, a peculiar settlement typology characteristic of the northern Italian Bronze Age. In addition to the presentation of the sites, studies about landscape archaeology, paleoenvironment, stone, wood, bone and horn, textile pottery and metallurgical industries, trade-routes, paleoanthropology and cults were included.

A chapter was dedicated to new analysis of metal undertaken by Garagnani, Imbeni and Martini using AAS. These analyses were the opportunity to speculate about the provenance of copper, and, consequently, tin was excluded and the data renormalized for statistical analysis. The applied statistical methodology was a multivariate analysis represented in 3D where the three axes were the three principal components. Metallographic analysis was also undertaken (Garagnani *et al.* 1997, 557–558).

The authors claimed a great variability among the artefacts, both compositionally and structurally. The objects were divided into three groups according to manufacture: axes and daggers were cast and subsequently subject to cycles of heating and hammering; pins were only cast and had a higher percentage of tin; ingots were made of copper with traces of sulphur (Garagnani *et al.* 1997, 560). The attempt to determine provenance was unsuccessful, mainly because of a lack in the knowledge of the composition of possible candidate ancient metal ores. Moreover, the authors mentioned recycling activities as a further complication of the picture, but without any further comments on evidence that they might have found (Garagnani *et al.* 1997, 561).

2.7.4 The British Museum (2003)

Other analyses have been undertaken in the occasion of the publication of the catalogue of "Prehistoric Metal Artefacts from Italy in the British Museum" in 2007 and a brief report was provided by Hook (Hook 2007, 308–323), anticipated by a paper presented at the international conference Archaeometallurgy in Europe, 24-25-26 September 2003, Milan, Italy (Hook 2003). Hook examined the chemical composition of more than 100 artefacts from the entire Italian Peninsula, dated from the Copper Age to the Early Iron Age. Among them, only one axe was from the Circum-Alpine region in the Copper Age. Most of the objects were analysed with inductively coupled plasma-atomic emission spectroscopy (ICP-AES); exceptions were 14 artefacts that were previously analysed with AAS and a few that were considered too thin or too corroded to be sampled (the sampling method was drilling using a 1mm drill). In this last case XRF was used on unpolished surfaces and, consequently, only qualitative information was obtained (Hook 2007, 308). ICP-AES was preferred over AAS because it is faster and more sensitive to tin and arsenic content, but bismuth was analysed with AAS (Hook 2003, 58).

Hook decided not to undertake cluster analysis, preferring a simple, visual representation with box and whisker plots. The author obviously warned that, due to the small amount of data covering such a large span of time and space, the outcome should be taken carefully. He proposed chronological segregation rather than geographical, and supported the idea of technological improvement as the reason behind compositional change, a topic of discussion in Section 3.1.1. According to Hook the higher amount of arsenic in Copper Age daggers and halberds compared to contemporary axes is due to the search for an increase of hardness, a theory already called into question by Budd *et al.* (1992) and Pearce (1994). He also noted an increase in tin content and, at the same time, a standardization of the percentage in weight of tin through the Bronze Age. Proper brass was not recorded by the author, and leaded copper was registered only in a few more complex artefacts dated to the Late Bronze Age (Hook 2003, 58–61). Another pattern recognised was an increase of trace elements through the Bronze Age, interpreted – especially as regard iron - as an enhancement of technology, as suggested also by Craddock and Meeks (1987). Remarkably, geographical groups were identified only in three cases: four Early Bronze Age axes from Agrigento (Sicily), eight Early Bronze Age axes from Terni (Umbria) and three Final Bronze Age from Como (Lombardy), according to their peculiar combination of trace elements (Hook 2003, 63; 2007, 310).

2.7.5 "Museo civico di Storia Naturale" (2011)

176 objects have recently been analysed on the occasion of the publishing of the catalogue of metal objects in the "Museo civico di Storia Naturale" in Verona, Italy. The museum has a rich collection of metals – thousands of objects - coming from finds in stilt houses of the Lake of Garda. These findings were not the result of scientific excavation but, in most of the cases, simple collection of material on the occasion of drainage works near the lake. The selection criteria for analysis, hence, was focused on those artefacts from closed, more reliable contexts, such as hoards or burial (Salzani 2011, 48). The analyses were undertaken with XRF on samples taken from the inner part of artefacts, to avoid corrosion. In the case of 31 artefacts lead isotope analysis was also undertaken using multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS)(Pernicka & Salzani 2011, 89).

The aim of the analysis was to obtain information about provenance and production technology of the materials, but the state of research, and in particular the lack of knowledge about possible mine ore characterizations, did not allow more than a generic data presentation and suggesting some further research questions. Then, Salzani stated a revival of the theory (further discussed in Section 3.1.1) of change of composition with time, with copper and arsenical copper in the Copper Age, *Fahlerz* at the beginning of the Early Bronze Age, and tin bronze in a more advanced phase of the Early Bronze Age. But she noticed that in a southern territory (Emilia) the beginning of the Early Bronze Age was characterized by the smelting of local sulphate ores, and that this was part of the "European" flow of *Fahlerz* (Krause 2002) only in the second part of the Early Bronze Age (Salzani 2011, 59). As further research suggestions, Salzani highlighted the importance of the development of dating techniques that may help to give a more reliable chronology for metal artefacts. Moreover, as Barker also claimed (see Section 2.7.1), she called for research into possible mineral ores to better understand raw material flows (Pernicka & Salzani 2011, 92; Salzani 2011, 59).

An important observation is the great variability in the composition of ornaments. In particular, five pendants dated to the end of the Middle Bronze Age-Recent Bronze Age were produced with tin content between 75-100 percent, a result without comparison in northern Italy (Salzani 2011, 60). The objects made mainly of copper were subjected to statistical analysis, specifically cluster analysis, to group them according to their composition and to speculate about different provenances of raw material. The elements chosen as variables were As, Ni, Sb, Ag and Bi, following the example given by SAM and Krause (Bressan & Salzani 2011, 99). Two main groups appeared: arsenical copper and bronze plus *Fahlerz* artefacts. At a lower level the bronzes were separated from *Fahlerz* whose origin was unclear also because of their uncertain provenance and consequently uncertain chronology (Bressan & Salzani 2011, 101).

In the end, the author was forced to admit that the small number of samples, in addition to the lack of chronological information and knowledge of possible mineral sources produced questionable analysis, which would only permit limited consideration of the dataset (Bressan & Salzani 2011, 102).

2.8 Others

In order to give a broader overview of the state of the archaeometallurgical research in the Circum-Alpine region, two other corpora of analysis are discussed here, namely the recent work of Cattin *et al.* (2011) and Kienlin, noteworthy in the present work.

2.8.1 Cattin *et al.* (2009, 2011)

Some smaller research studies were done by Cattin *et al.* in Switzerland. In 2009 an article was published about the isotopic analysis of almost 100 objects from St-Blaise, in Switzerland. The information about the chemical composition of those objects is from an unpublished thesis and is not included in this thesis. Data are from two chronological periods: an early period belonging to the Luscherz, Saône-Rhône and Early Corded Ware, and an younger period corresponding to the Middle and Late Corded Ware Culture (see Section 7.1.4). In these two periods the authors noticed differences both in the chemical composition and in the lead isotopes of the objects. In fact, in the first phase there were mainly artefacts made of pure copper or copper with nickel, and lead isotopes are compatible with local ores, a mine in Germany and one in Spain; in the second phase copper with antimony and copper with arsenic, antimony, silver and nickel dominated. In this last phase the lead isotopes signal became more complex and different sources and different workshops were hypothesized.

In 2011 Cattin *et al.* analysed 10 artefacts from Valais canton, in Switzerland, dating to the first phase of the Early Bronze Age (A1 in Reinecke chronology). This work was in response to a request for studies which use a mixture of compositional analysis, isotopic analysis and geological considerations about the possible metal ores (Pernicka 1998, 265; 1999, 169). Compositional analyses were undertaken using MC-ICP-MS (Cattin *et al.* 2011, 1224). According to the composition, the objects were distinguished into three groups and lead isotopic analysis roughly confirmed this partition, highlighting also an interesting scattering in the ratio of isotopes that might suggest recycling activities (Cattin *et al.* 2011, 1225–1228).

Most of the artefacts did not have a well-defined isotopic composition, so that local production or many other possible sources in the western Mediterranean and central Europe may be equally supposed. In the case of one artefact, the lead isotopes pattern was so well defined that it was possible, for the authors, to correlate it to a specific, local mine. This was very important because it was evidence of local mining activity. Equally interesting was a group of three artefacts with very similar composition and a well-defined isotopic pattern that were considered hints of a common source and manufacturing technique. The isotopic ratio was peculiar, since it was completely different to the ones of the Alpine region. Three possible candidates were Bulgaria, Spain, and central Italy and the authors tended to support Tuscany as a possible source. Hence, long distance trade-routes, even Transalpine, may be hypothesized even from the first phase of the Early Bronze Age (Cattin *et al.* 2011, 1228–1231).

2.8.2 Kienlin (2006-2010)

For his doctoral thesis Kienlin studied ≅ 150 axes from the north Circum-Alpine region: he undertook compositional analysis using scanning electron microscopy – energy dispersive X-ray analysis (SEM-EDX) and also metallography. His results were published, apart from in his thesis (Kienlin 2008), in an article (Kienlin *et al.* 2006) and further discussed in 2010, in a book that contains also the results of some additional analysis from the Carpathian basin (Kienlin 2010). In that book there is also an attempt to give a social interpretation of what had already been observed with the analyses.

Kienlin spotted that, first of all, in the Copper Age there were cycles of cold work and reheating on the objects, but the presence of arsenic did not determine the amount of work, and all the axes were reduced by 20-30% in thickness. Hence, he refuted the statement of arsenical copper being perceived as a desirable material for its hardness. The presence of oxides, according to the author, is not sufficient to state that objects were cast in open moulds, but it could be due to the presence of different steps in the melting and casting process (Kienlin 2010, 70; Kienlin *et al.* 2006, 456). From the Early Bronze Age the author analysed three groups of axes from the first phase (Salez, Neyruz and Saxon type) and a group of axes from the last phase (Langquid type).

The chronology of the first three group is still debated (Kienlin 2010, 155; Kienlin *et al.* 2006, 462, see also Section7.2.1). In the case of the axes of Salez type, he recognized a different level of work according to the content of trace elements and interpreted this as some kind of awareness of the metallurgists about the relationship between percentage of trace elements and hardness (Kienlin 2010, 181, 2010, chap. 7; Kienlin *et al.* 2006, 458–462). The case study of axes of Salez type is further discussed in Section 13.3.

In the case of the Saxon and Neyruz axes, the author underlined how the presence of tin did not change the level of work applied to the objects and interpreted this as a lack of proper awareness of the effects of tin on the hardness of metal. This awareness was recognized in the final stage of the Early Bronze Age, in the case of Langquid type axes, which have a standardized amount of tin and level of work applied to the objects (Kienlin 2010, chap. 7; Kienlin *et al.* 2006, 462–464).

As regards the social aspects of metallurgy, Kienlin refuted the Krause's proposal of the development of metallurgy as dependent on complex and hierarchical societies (see Section 2.6). According to Kienlin, the exploitation of the mines in the Early Bronze Age took place through small-scale activities organised on a seasonal basis, ruled by communities that were not necessarily ranked, in a way that is considered as "Neolithic". This is also suggested by the fact that there were very few stable settlements found in the highlands, contrary to what is observed in more recent phases of the Metal Age. In Kienlin's words "Mining may carry strong ritual connotations, and it can often be observed that ritual ‘control’ is interwoven with the ‘care’ of special resources by social groups or individuals who are seen has having close relationship with transcendental powers” (Kienlin 2010, 180). Moreover, there is not clear evidence that the distribution of metal occurred under the control of some kind of elite, and this is also linked to his negation of the use of axes as ingots (Kienlin 2010, 181).

Finally, a number of analyses have been undertaken in Italy as part of holistic study of a particular site. This was the case for the work of Angelini (2004, 2007), Angelini and Salzani (2005), Angelini and Artioli (2006) Angelini *et al.* (2010), Northover (forthcoming). Broader projects are the PhD thesis of Angelini who discussed the Middle and Recent Bronze Age in northern Italy, and the I.I.P.P. (Insitituto Italiano di Preistoria e Protostoria), in a project studying Bronze Age metallurgy in northern Italy (de Marinis 2009) but these projects are still forthcoming.

2.9 Discussion

The interest of research on ancient metal artefacts has a long tradition. For more than two hundred years many analyses have been undertaken and much has been written. However, in this long history, questions and methodology have remained relatively unchanged. Questions have mostly been focused on two key issues - provenance and technology - but criticisms of these issues have arisen in the last decades. The effectiveness of trace element analyses to determine provenance was repeatedly questioned because of segregation of some elements (e.g. bismuth) in the artefacts and because of the heterogeneous nature of metal ores. Doubts occurred also about the classical conception of the development of metal production that changes only because of an improvement in productive technology and in order to enhance the mechanical properties of the finished object. Recently other new possibilities have been posed as possible explanations for different compositions, such as the search for a specific colour (Pearce 2007).

There is now the tendency to look in a different way to analyse the database, trying to also gather information about the use of metal artefacts and how they were considered in ancient societies. In particular, recycling is now being strongly reconsidered, and as a specific characteristic of just those periods for which it was mostly underestimated - the Copper Age and Early Bronze Age. These themes and the new perspectives are discussed in the next Chapter.

3 Old and New Perspectives

After the excursus on the history of the research in the previous Chapter, this Chapter provides some theoretical discussion about the use of compositional analysis: what have been the purposes and the methodology of the research in the past and how new perspectives could improve our knowledge of the ancient use of metal.

3.1 Previous uses of chemical data

3.1.1 Technology

The first aspect considered here is the idea of technology. Since the three age system proposed by Thomsen in 1836 (Stone Age, Bronze Age, and Iron Age) the prehistory of humans has always been seen as a subsequent improvement of tools, made from time to time with a “better” material, where “better” refers to its properties in terms of hardness and efficiency of production. This model was most clearly articulated by Gordon Childe with his idea of a materialistic technological improvement of metallurgy (Childe 1944, 7). This straight line of technological improvement was so integrated into the base of all archaeometallurgical research that even in 1999 Doonan stated: “Nowhere in this world of techno-environmental determinism were issues of human choice [...]. In such a deterministic world, humans could be easily removed from archaeological discourse" (Doonan 1999, 72). Following this line of thought, pure copper was considered to be the starting point of the Metal Age, but it was replaced by arsenical copper, in a "more advanced phase of metallurgical development" (Charles 1985, 25), which, in turn, was replaced by *Fahlerz* and, finally, tin bronze (Chernykh 1992, 4; Steiniger 2005, 250–256). This idea of a punctuated chronological technical improvement is so embedded that some scholars still tend to date objects according to their composition (e.g.,David-Elbiali 2000; Salzani 2011, 58–60; Steiniger 2005, 256; see Section 7.2.1).

This model is not without criticism. In particular the alleged superiority of metal to other materials such as stone or wood has been repeatedly denied by archaeological experiments, which is also evident from the fact that stone and wooden tools have been used for centuries after the appearance of metal. Moreover, as claimed by Gillis "The need to use metal... is not universal", giving as an example ancient western Mexican cultures which, although having metal ores in their territory and despite living next to metal using cultures, refused to use metal until 600/800 A.D. (Gillis 1999, 140). But also considering only metal, the supposed improvement of hardness or malleability claimed for arsenical copper and *Fahlerz* has been questioned since the 90's. Budd, in his doctoral thesis (Budd 1991), highlighted that arsenical copper artefacts were not cold hammered. His results have been recently questioned by Kienlin (2008), but even the last author does not support the use of arsenic to harden material, because he noticed that metal artefacts with or without arsenic were worked in a similar way. Artioli pointed out that Copper Age axes from the north of Italy were not cold hammered, but hammered and then annealed and softened

(Artioli 2007, 907–908). In consideration of the fact that, as Northover claimed in 1989 (Northover 1989, 113), arsenical copper is not better than pure copper in terms hardness if not cold worked, it is clear that the reason behind the choice of one kind of metal rather than another was not necessarily its supposed utilitarian quality improvements (see Section 6.2. for comparisons between pure copper and arsenical copper). A further hint was suggested by Pare (2000, 27), speaking about the adoption of bronze, which was absolutely predominant over copper in the Bronze Age. If the choice of bronze was due to its supposed improvement in terms of hardness, then there is no reason why it should have been adopted for ornaments, as well. Considering the well-known rarity of tin (among others, Pare 2000, 7), a utilitarian point of view would have judged it as a waste of a precious resource.

3.1.2 Provenance

The use of chemical analysis to establish the provenance of raw material has not been without its critics. As mentioned above, Ottaway, in 1982, posed the question of the usefulness of continuing with this line of inquiry, admitting that her own attempts were not so successful (Ottaway 1982, 197–181). Budd *et al.* in 1992 synthesized the problem in three main points: alteration produced by smelting, heterogeneity of the artefacts, and the lack of representativeness in a metal artefact of the entire ore body (Budd *et al.* 1992, 678). The effects of alteration due to smelting may be minimized by the careful choice of "significant" elements, namely those elements that have a geochemical behaviour similar to copper. Table 1 shows this group of elements according to Goldschmidt's classification and Pernicka's experimental observations (Goldschmidt 1937; Pernicka 1999).

Technology	Provenance and/or technology	Provenance
Al, B, Ba, Be, Ca, Cr, Cs, Fe, Ga, Ge, Hf, K, Li, Mg, Mn, Mo, Na, Nb, P, Rb, S, Sc, REE, Si, Sr, Ta, Ti, Th, U, V. W, Y, Zr	As, Cd, Co, In, Hg, Re, Sb, Se, Te, Tl	Au, Ag, Bi, Ir, Ni, Os, Pd, Pt, Rh, Ru
Sn > ca. 1% Zn> ca. 5% Pb > ca. 5%	Sn < ca. 1% Zn< ca. 5% Pb < ca. 5%	

Table 1: elements grouped according to the information that they may provide, modified from Pernicka (1999: Tab. 1). In the first column there are elements that were present in the original source, but can remain in the final objects depending on the technology used to produce metal. Sn, Zn and Pb are considered as intentional addiction over a certain percentage. In the second column there are elements that tend to remain with the copper, no matter the working technique, as they are chalcophile elements. As and Sb might have been intentionally added (see Section 6.2), Sn, Zn and Pb are considered as part of the ore under a certain threshold. The third column indicates the elements whose presence was depending solely on the presence in the copper ore.

The heterogeneity of metal may be resolved with a proper sampling strategy, which Pernicka stated as taking a minimum sample of 3 mg (Pernicka 1986, 25). Still, segregation of bismuth and lead should be remembered here (Slater & Charles 1970), and, moreover, bismuth is often present in percentages below the detection limit of some instruments of analysis (i.e. below 0.1 or even 0.01%) so that in many cases a “false negative” may occur. Therefore it may not be so reliable in terms of provenance, even if it is a chalcophile element and has been included by Pernicka in the “reliable” elements. The most critical point remains the lack representativeness in a metal artefact of the entire ore body. Problems occur even if a larger number of elements are taken into consideration, as Berthoud *et al.* demonstrated when investigating how the composition of artefacts differs from copper ores in the Middle East (Berthoud *et al.* 1980). If things are complicated even when aware of the mines that have been used, it is clear that the hope of gaining satisfying results with only chemical analysis, in a much more complicated situation, as the European one is – with many more small ore sources, not yet well investigated - is too optimistic. Moreover, these attempts consider recycling as a possibility that does not significantly affect the chemistry of objects (Krause 2003) but some authors have declared their doubts about this assumption (e.g. Garagnani *et al.* 1997). Indeed, the methodology used in this thesis (see Section 3.2) hypothesises that the information about recycling is an integral component of the data set.

3.1.2.1 Lead Isotopes

New results in this field of research are now possible, by combining lead isotope analyses with chemistry. The isotope ratio indicates the age of the geological ore from where copper has been exploited and it does not change with smithing operations. When the use of lead isotopes was first hypothesized in the sixties, it was thought to be the ultimate solution to establishing the provenance of material. Nevertheless, this technique soon demonstrated its limitations: not only that different ores may have similar ages, but also the same ore deposit may be formed as a series of different genesis phases and consequently have different isotope ratios at different depths. In addition, a map of the chemical and isotopic characteristics of potential mines is necessary to reach the goal of provenance. This point was first highlighted by the group in Vienna (see above) and confirmed even by supporters of trace elements as indicators of provenance (e.g. Pernicka 1999, 169). Artioli has recently started such a project for Alpine ores and published some preliminary results (Artioli *et al.* 2008, 2014).

3.2 A new perspective: the Flow Model

The main problem with the traditional approach is that it did not consider the real behaviour of real people. Some sporadic and praiseworthy attempts have been done in that sense (for instance the reflections of Pearce about arsenical copper in northern Italian Copper Age (Pearce 2007)). But this is an exception to a general picture in which how they perceived metal, how they created, exchanged, used, re-used, recycled and deposited it was not properly taken into consideration. The Flow Model is an attempt to consider the entire life history of an object: from its creation to its final deposition. In reality, the "life cycle of metal" does not finish with the human discard of metal. Post depositional effects have influences both on the chemistry (Tylecote 1979), and the microstructure of the objects (Northover, personal communication), but for the sake of simplicity these effects are not taken into consideration here. Most sampling is done so that unaltered metal is analysed (see Section 8.1.2.2 on the validity of the database) and the analysis is therefore taken to be representative of the composition of the object "in life".

Recycling is not taken here to be meant in a modern "economic" or "ecological" way of the reuse of waste objects as a source of raw material to produce new objects, but as an "umbrella term" that considers all the ways in which an object could be reused, and that involves both form and substance (Sainsbury *et al.* in press). Needham (1998) hypothesized that recycling was a fundamental part of metal flow from ores to all the communities that were using metal. Taylor (1999) stated that, considering the estimated amount of metal produced, only 0.01-0.1% of the metal that was circulating at the beginning of Metal Age has been found. He proposed recycling as a possible explanation of this loss, distinguishing between "legitimate" and "illegitimate" recycling processes. Legitimate refers to metal recycled by the same community that had produced it. Illegitimate refers to communities or cultures that recycled metal artefacts obtained from other communities. Most likely, these objects were taken after wars or removed from places where it had been intentionally disposed of by other communities, especially in graves. The attempt to avoid illegitimate recycling, according to Taylor, might be an explanation of the "hiatus" in the presence of metal in the Balkans in a second phase of the Copper Age (Taylor 1999, 22–32). Bray and Pollard recognised in the British Early Bronze Age a "linear" re-melting of axes into axes and daggers into daggers (Bray and Pollard 2012). They provided a social explanation to recycling: an object produced by a community, when traded to another community, could have been reshaped to make it more acceptable for the receiving community. This concept of "acceptance" of objects was pointed out also by Derevensky and Sørensen (2002). They emphasized the importance of the "comparability and compatibility with familiar objects [...] based on visual, functional and symbolic similarities" when an alien artefact is brought into a community. This concept may be well applied at the origin of Metal Age, metal being the "alien" factor that needs a familiar shape to be accepted.

The recycling process could also reflect a simple change of shape through hammering, without passing through the *liquidus* state. This is the case observed by Jennings in some Swiss razors (Jennings 2013). Furthermore, Artioli in 2007, dealing with his results about metallography on Copper Age axes from the north of Italy stated that "mechanical working in the Copper Age was not used to harden the metal, but rather to slightly reshape the axe after casting" (Artioli 2007, 907). This pattern recognised in metallography may be the hint of a "reshaping" process, namely, mechanical work and annealing applied to objects to change their shape without melting.

3.2.1 The Flow Model - A new model that questions old methodologies

Recycling and re-melting has been more or less explicitly considered by archaeometallurgists as "a problem" that could, hopefully, be ignored (Krause 2003, 145; Pernicka 2014, 258). There was the assumption that metallurgy during the Copper Age and Early Bronze Age was a very new technology with plenty of available raw material, so that the recycling aspects were very limited (Pernicka 1998, 264; Pernicka, 2014, 258). This assumption was the basis of the treatment of chemical data through cluster analysis. Ottaway, as mentioned previously, was the first to use this methodology in a broad study about the composition of ancient metal artefacts. Since then, it has never been questioned, and all subsequent researchers have just improved the software used. In cluster analysis, computers calculate the proximity of artefacts according to the similarities of their variables' values and create a number of groups containing "similar" objects. In the case of archaeometallurgical analysis the variables are usually the trace elements and other physical details, like the dimensions and the weight. The fact that it is undertaken by computer program may give the impression that it is an objective methodology. On a deeper analysis, this is not the case: if the analysis goes on indeterminately, the result will be just one group. The researcher is the one who has to decide a threshold where the computer should stop finding neighbours, and hence, in the end, subjectivity is implied. But a more serious issue is that cluster analysis can hide some important information about the behaviour of elements. This is due to the fixed nature of categories implied in groups resulting from cluster analysis. In other words, once an artefact is included in one group it is considered as having nothing in common with artefacts of other groups. The Flow Model has demonstrated that this is simply not true. Bray demonstrated that in the British Isles at the beginning of the Metal Age metal artefacts were subjected to cycles of reshaping causing a loss of the most volatile elements (arsenic and, at a slower rate, antimony) (Bray *et al.* 2015; Bray & Pollard 2012; Pollard *et al.* 2014). In consideration of this it may be thought that a group of metal objects, after some passages of reshaping, will completely lose arsenic. Using cluster analysis the resulting group of metal without arsenic will be considered as having nothing in common with the starting group, with arsenic.

Social engagement with metal through processes such as reuse, recycling, and curation were rarely considered important by previous analysts. The Flow Model (Bray *et al*. 2015) offers an alternative that unites the available legacy scientific datasets with knowledge from process metallurgy, archaeological and geographical context, combined in a new conceptual approach. Rather than provenance, it offers an empirical model of metal flow, in which objects are seen as snapshots of a wider metal 'stream'; their final scientific characterization including echoes of their previous forms and contexts, incorporating changes due to recycling. Of course, the observation made above that arsenic and antimony are affected by both technological and ore chemistry factors is completely in accordance with the behaviour set out in Table 1 above (Pernicka 1999).

3.2.2 A new methodology for a new model: ubiquity analysis of groups of material, and levels of arsenic in space and time.

The Flow Model is an attempt to capture, value and analyse what has been previously considered as "background noise" in the cluster analysis. As already mentioned, it uses a holistic approach that take into consideration the entire life cycle of metal, with a particular interest in the use and perception of metal by society. The Flow Model differs from the approach of Jennings (2013) because, instead of studying the life of single objects, it uses the information contained in big datasets. In Section 3.1 it has been underlined how the attempts to use the chemical database to gain information about the provenance and the technology of metal artefacts has been problematic and frustratingly unsuccessful. This is arguably due to the fact that recycling has been always been considered as ignorable, rather than an important factor that determines the chemistry of objects and that, could, indeed, be captured and studied. This may be achieved with a two step method applied to big datasets (Bray *et al.* 2015).

Firstly, there is the attempt to quantify the loss of the most volatile elements (arsenic and secondarily antimony) that, after some processes of re-melting, tend to drop (Sabatini, *in prep*). This depletion generally tends to increase with distance from the possible source of the metal, or the primary centre of production, and through time (Bray and Pollard, 2012). Secondly, the use of ubiquity analysis (the percentage of a particular assemblage made up of a particular type of copper or alloy: (Banning 2000, 109)) allows us to identify in time and space where a specific kind of metal was more common and hence from where it was acquired and possibly recycled (Bray *et al.* 2015). The idea is that closer to a primary centre of metal production there are relatively more objects with the composition of metal that is produced there, and also, there is more "fresh metal", with a higher percentage of the most volatile elements. In a region that is far from the primary centres of production there is metal coming from several different sources, and consequentely there is more variation in the chemistry of the assemblage. Moreover, there is a higher tendency to recycle and mix material, which results in the depletion of the most volatile elements.

There is a specific point that now requires attention: defining what "groups of metal" are. As said above, the typical approach to the study of ancient metal artefact through cluster analysis is inadequate because it obscures useful archaeological structures in the data, associated with recycling, oxidative loss linked with use, mixing, alloying, and so forth. The new method of grouping elements is open, simple, universal, and, above all, it is **not** based on the assumption that each of the resulting groups represents a unique source of metal. First, there is the creation of 16 copper groups, according to the presence/absence of four key elements: As, Sb, Ag and Ni. This choice is governed by the fact that they have been consistently recognised as being diagnostic of copper identity in some way (Table 1). Moreover, at least for this thesis, they have been used in all the previous chemical-typological work (see Chapter 2). These four elements capture much of the variation seen in copper mineral deposits, pass into the cast metal during the smelt, and then behave differently based upon different technological processes – for example different oxidation rates upon remelting. Bismuth was not taken into consideration even though it is claimed to be a diagnostic element for the mineral deposit (Ernst Pernicka 2014; Ernst Pernicka 2011b; Ernst Pernicka 1999) because, when present, it is often in very small quantities, below 0.1%, and, often, close to the detection limit of analytical instruments, so that there might be too many "false negatives", as explained in Section 3.1. More importantly, it was not analysed by all the authors included in this database and, consequently, the consistency of the database would have been affected.

The possible combinations of presence and absence of the four elements are 16, as shown in Table 2. The resulting groups are labelled 1 to 16, the order being arbitrary, but based on increasingly complex impurities in the copper.

Elements	Group
Cu	1
Cu, As	2
Cu, Sb	3
Cu, Ag	4
Cu, Ni	5
Cu, As, Sb	6
Cu, Sb, Ag	7
Cu, Ag, Ni	8
Cu, As, Ag	9
Cu, Sb, Ni	10
Cu, As, Ni	11
Cu, As, Sb, Ag	12
Cu, Sb, Ag, Ni	13
Cu, As, Sb, Ni	14
Cu, As, Ag, Ni	15
Cu, As, Sb, Ag, Ni	16

Table 2: compositional groups obtained with the methodology of the Flow Model.

In order to allocate an object to a group the first step is to calculate the percentage of copper in those cases where it was not reported in the analysis (such as the SAM database). This is simply done by summing all the weight percentages of the elements that have been analysed and subtracting the result from 100. The second step is subtracting those elements that are considered intentionally added; our starting assumption is that the As, Sb, Ni and Ag in the object are associated with the copper and not the alloying elements. Deliberate addition of alloying elements would therefore have a diluting effect on the percentage of the trace elements in the copper. In our case only tin is thought to be "intentionally alloyed" and not "accidentally part of the copper source". If tin is present over 1%, it is considered to be a deliberate addition, but in order to obtain a systematic classification of the copper, we remove all tin from the composition. Characterizing the level and distribution of tin is of course crucial to understanding metal flow, and occurs in parallel with investigating the copper-base composition (see Chapter 11). The difficult question of the intentional addition of As is introduced in Sections 6.2 and discussed in the light of our results in Section 9.6.

After the subtraction of the alloying elements, the percentages by weight of the other elements are normalised to 100%. The presence/absence of As, Sb, Ag and Ni after this re-normalisation is then used to allocate the object to a specific group. The threshold to determine if an element is present or absent is taken to be 0.1%, which is above the detection limit of the analytical techniques used to analyse the bulk chemistry of metal objects, at least in the case of this study (see Section 8.1.2.2). For example, the chemical analysis of a pin from Erde (Switzerland) is reported by SAM (SAM 4188) as:

Cu	Sn	Pb	As	Sb	Ag	Ni	Bi	Au	Zn	Co	Fe
	1.12	0	0.31	1.45	0.77	0.98	0.004	0	0	0.005	0

Cu= 100 – (1.2 + 0.31 + 1.45 + 0.77 + 0.98 + 0.004 + 0.005) = 95.36%

For each element x:

$$Xnormalised = x * \frac{100}{TOT - Sn}$$

Where TOT is the sum of all the elements detected (Cu, Sn, Pb, As, Sb, Ag, Ni, Bi, Au, Zn, Co, Fe).

For example, from the above analysis:

As normalised = 0.31*100/(100-1.12) = 0.3135%

In this example As, Sb, Ag and Ni exceed the threshold of 0.1 %, so this object is allocated to copper Group 16 (YYYY). It is important to reiterate that each compositional group is not seen as deriving from a single source, and each copper source is not necessarily expected to produce copper of just one compositional group (Pollard *et al.* 2014).

This approach has another advantage with respect to cluster analysis: it is universal. Because they are only the starting point of the analysis, the same 16 groups may be applied in all time periods and in all regions, In contrast, the groups obtained with clusters are linked to specific data sets. This makes the Flow Model methodology more flexible and universal, and makes it easier to compare data from different geographical zones or time period.

Another limit of the traditional archaeometallurgical studies has been the little attention dedicated to space, not only to transport raw materials, but also finished objects, ideas, "metal recipes" and perceptions of metal objects. The Flow Model is a dynamic approach to the study of ancient metal; therefore some tools that allow capturing this dynamism in a 3D space needed to be developed. Changes in the ubiquity of specific Copper Groups can be properly captured and represented in a map. Additionally, the depletion of volatile elements, especially As, can also be mapped. It is also important to go beyond simple spatial (2D) mapping to take into consideration the characteristics of the territory: its elevation, the topography, and the river systems (3D). In the next Chapter we will discuss these issues, together with the use Geographic Information Systems (GIS) to address them.

4 Introduction to the use of GIS in archaeometallurgy: theoretical and practical issues.

Since this thesis is based on the use of GIS, this Chapter gives a brief introduction to GIS, in particular focusing on what it is, what its potentiality is, and what are the issues related to its use. In particular, some observations are made about the advantages of using GIS in archaeometallurgical research.

There are significant advantages in the use of digital maps over manual techniques, in particular in the possibility of editing and overlaying many different maps onto the same digital basemap (Bailey & Gatrell 1995, 51). But digital mapping also has its limitation. In particular, there is not the possibility of "interrogating" a digital map, or undertaking calculations on the elements added to a map (Bailey & Gatrell 1995, 52). But this is possible with the use of a Geographic Information System (GIS). A GIS is "a computer-based set of tools for capturing (collecting), editing, storing, integrating, analysing and displaying spatially referenced data" and is defined by "a minimum set of 'functions' that a piece of software should include in order for it to qualify as a GIS" (Bailey & Gatrell 1995, 52). So two points are fundamental: the location, namely the presence of spatial references (coordinates), which are a basic requirement in common with digital mapping, and also the possibility to calculate and manipulate data. The calculations can be done both according to the location and according to attributes that can be related to the objects that are mapped. In the first case, it is possible to understand the spatial relationship among objects that are mapped. For example, it is possible to determine which points are in a particular region. But GIS gives also the possibility to store associated data, attributes related to the spatial objects. Data are usually organised in databases and, consequentially, most GIS systems exploit the potential of relational database management systems (DBMS). These are software that store, manipulate and allow the rapid retrieval of data in a database. They are based on tables, in which rows are entities and columns are features or attributes (Bailey & Gatrell 1995, 52).

Essentially, GIS "is used to see patterns in space"; it is a way to order and to schematise the information according to a spatial scheme (Goodchild 1996, 253). GIS allows the researcher to:

- Collect large amounts of data, of many different natures (chemical data, context data, chronology, etc.);
- Manipulate data;
- Create, as result, new maps.

Many GIS software packages are commercially available, and currently there is also a flourishing development of open source GIS, but ESRI™ ArcGIS is still the most user-friendly and powerful program on the market. It allows significant flexibility: new analytical tools can be created as needed to satisfy new research questions, with the integration of Python™ 2.7 scripts. Consequently, ESRI ArcGIS has been used in this work.

As Savage (Savage 1990, 25–29) states, GIS has been used in archaeology mainly in three fields:

- Site location modelling;
- GIS procedure-related studies (theoretical studies about the implication and legitimacy of using GIS in archaeology);
- Landscape archaeology.

Landscape can be thought of as "the spatial manifestation of the relations between humans and their environment" and it is determined by two structures: the socio-historical and the physical structures (Crumley & Marquardt 1990, 73–75). So it can be studied from an ecological point of view (physical data) or a phenomenological perspective, trying to understand how humanity perceives space (Ingold 1993; Wheatley 2000).

The action of people in the physical environment is not always visible, if there are not material remains as witness. But when this relationship is visible, it can be manifested in two forms:

- Artefacts: discrete, transportable material;
- Features: spatially fixed remains of past activities.

Both of these sets of evidence can be included in a GIS, assuming the spatial information is available. But if artefacts are being analysed – as, indeed, in this research - then their *mobility* must be remembered. Artefacts may lie in the same place where they have been created or not, and are the evidence of connections, trade, exchange and, eventually, the movement of people in their landscape. Some hints of this process of movement may be revealed by the use of GIS.

But the use of GIS in archaeology has not been exempt from criticism. This is due mainly to an inappropriate comprehension of its limits. The first, most obvious, limitation of GIS is the inadequate representation of time. GIS may give an excellent representation of space, with 2.5D (or pseudo-3D) maps, but archaeologists are necessarily always working in four dimensions, where time is as equally important as space, since archaeological remains are always the result of processes that endure in time. When an artefact-map is created, for example, it must always be remembered that each artefact may have been deposited soon after its creation or may have been "in circulation" for a long period, and may have been used and modified in many ways. So, what appears to be a static situation (a map) is, in reality, like a picture or a frame in a movie. Indeed, of hundreds of different movies, since every artefact has its own story (Gosden & Kirsanow 2006). "Spatial analysis" – stated Goodchild – "is primarily analysis of form whereas understanding requires analysis of process" (Goodchild 1996, 256). This aspect should always be borne in mind when interpreting a map.

The second criticism concerns the language used in GIS, namely terms used as input for programming languages, which require simple, discrete categories. Consequently, what is a complex reality needs an interpretation to be described in terms of simple categories. So, for example, the boundaries of a site (which may be unclear) are often represented in a map as a simple line. Obviously reality is not made of discrete values, and this kind of simplification, as well, should be accounted for. One precaution that can reduce, if not avoid, the issue caused by the fuzziness of spatial boundaries is an accurate choice of scale.

The topic of scale and, relatedly, the areal unit, has long been debated by, amongst others, Costall (2006), Gaffney and van Leusen (1995), Goodchilde (1996), Harris (2006), Harris and Lock (1990) and Wheatley (2000). Scale has an effect on the interpretation of data and should be chosen carefully. It can also have an effect on the representation of data: a site in a large scale study may be represented as a point, on a smaller scale the actual extent of the site should be shown (Harris 2006). *Areal unit* is equally important: larger space units create more stability, but mask geographical variations that might be perceived at a smaller unit aggregation (Goodchild 1996; Harris 2006). This issue about the areal unit and its consequences in the analysis is known in the literature as MAUP (Modifiable Areal Unit Problem). The *region* of the research must necessarily be defined, and by "region" is meant "a spatial configuration at a scale at which certain phenomena exhibit recognizable areal distribution" (Crumley & Marquardt 1990, 76). And this is another potentiality of GIS: the flexibility of the program allows testing of different areal units and deciding which one provides a better representation of the phenomena of interest. But, in any case, one should acknowledge that local precision has implications for the scale at which data can be meaningfully aggregated. For example, in this research there are the analyses of patterns on a large scale – i.e. the entire Circum-Alpine region - but even so, some data needed to be excluded because their positions are not sufficiently accurately recorded, such as the ones referred to in the bibliography as from "Italy" or "Middle Europe".

The third criticism is the risk of over-valuing only things that can be mapped. In other words, there is the risk of stressing the materiality of human behaviour and forgetting the culture, rituality and choices (Gaffney & van Leusen 1995, 374–377). Nevertheless, further thinking on this point highlights that, at least, what can be seen and mapped is the result of human behaviour, and can provide information on “the way communities perceive and interpret their environment” (Gaffney & van Leusen 1995, 370; Renfrew 1982, 11). In other words, the key to a correct and fruitful use of GIS is never to forget that it is a tool for research - it can analyse data and produce data, but the need for consequent archaeological and sociological *interpretation* of the data should never be forgotten.

4.1 The use of GIS in archaeometallurgy

In this section we would like to discuss why we think that GIS is a useful tool in archaeometallurgical studies. Coming back to the simplest definition of GIS, it is a database that has spatial references. So, first of all, it is a database, and this research requires a good database system to manage the huge amount of data of chemical analyses on metal objects from the entire Circum-Alpine region. ArcGIS is not only able to collect and store large amounts of data, but it also has the possibility to interrogate and select data, using SQL. There is also the possibility to undertake calculations, both using one of the numerous tools already available in the program, but also creating new tools using Python. But, quite obviously, the key capability of GIS is the incorporation of the spatial element.

This capability has been underutilised in previous research on metal composition, which has tended to place more emphasis on statistical analysis of the compositional data.

Studies that properly considered the geographical factor have been limited to the landscape studies of mines and centres of metal production (Ben-Yosef *et al.* 2010; Hanke *et al.* 2010; Levy *et al.* 2002), and, in the Circum-Alpine region, a project on Trentino, (forthcoming, personally communicated by Professor Annaluisa Pedrotti). The “Stuttgarter Metallanalysen-Project” (SMAP) run by Pernicka and Krause was planned to have more broad use of GIS, but the technologies in the nineties were not developed enough to manage such a big database (Krause 2003, 22–25) and ultimately their use of GIS was limited to digital mapping.

This thesis calls for a major use of GIS also in the study of the distribution of finished objects. This, of course, means facing the issues as posed in the previous section. One of the topics that deserves more attention than has been given in previous work is related to the area of study and the areal unit. The typical spatial approach in archaeometallurgical research has been limited to separating the area of analysis into zones (e.g. northern Italy, France…), often determined by modern boundaries (e.g. SAM, Slater & Charles 1970, Hook 2003). For archaeometallurgical studies that were considered “regional” or “local”, such as Switzerland, the entire area of analysis was considered as the unit of area (Rychner 1995; Verney & Bocquet 1998) and there were no geographical considerations in the research. In some other cases, simple distribution maps have been created, but the geographical analysis generally did not proceed beyond this point (Celauro *et al.* 2014; Krause 2002, 2003) (Figure 7).

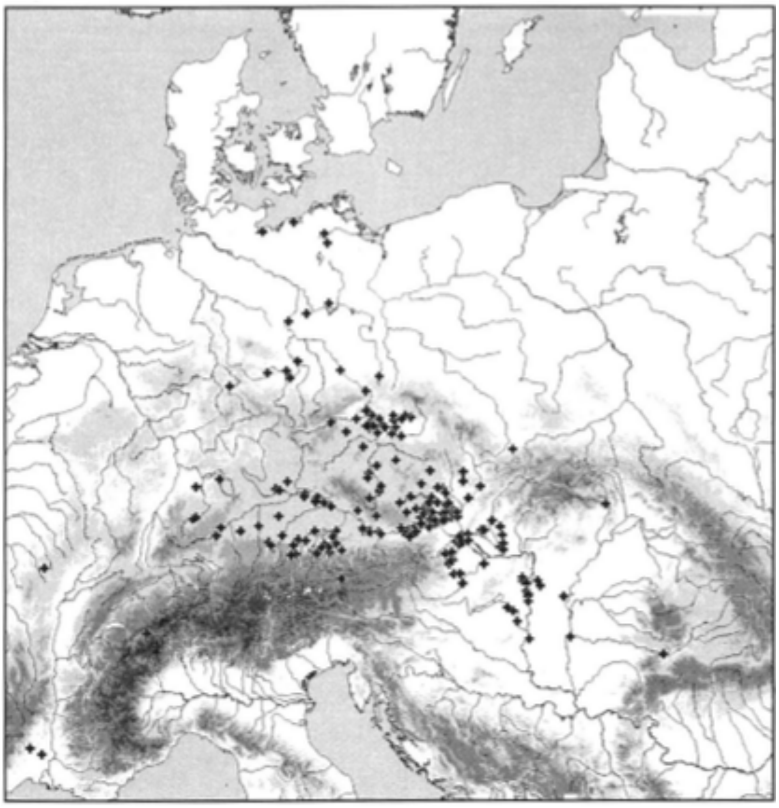

Figure 7: map of distribution of the objects with the cluster FB1 composition from Krause (2003).

The approach of Krause, which implies that the chosen location specification (map unit) is simply the site where each metal object was found, represented as a set of points, could be intuitively considered as the easiest and best solution. However, in order to undertake ubiquity analysis (namely calculate the percentage of objects with a specific composition in a determined area, see Section 3.2 and, more specifically, 3.2.2), the site is not a convenient choice because there will be a number of single finds that will result in "100% of objects have the same composition". In this case a larger areal unit is necessary but, again, the choice of this area should be made carefully.

In the 1970s the SAM project has made the same calculation – i.e. to estimate the percentage of object with the same metal composition - using arbitrary areas in Europe (Figure 8). Those areas were determined using a mixture of modern boundaries and topographical features, such as rivers. However, if rivers were used as a means of transport (see Section 12.1), then the use of them as boundaries would be problematic. The state of technology available to the SAM group allowed them only to choose areal units according to some criteria that might be reasonable to the researchers, and maintain them through the entire research, because, of course, mapping and calculating was very time consuming.

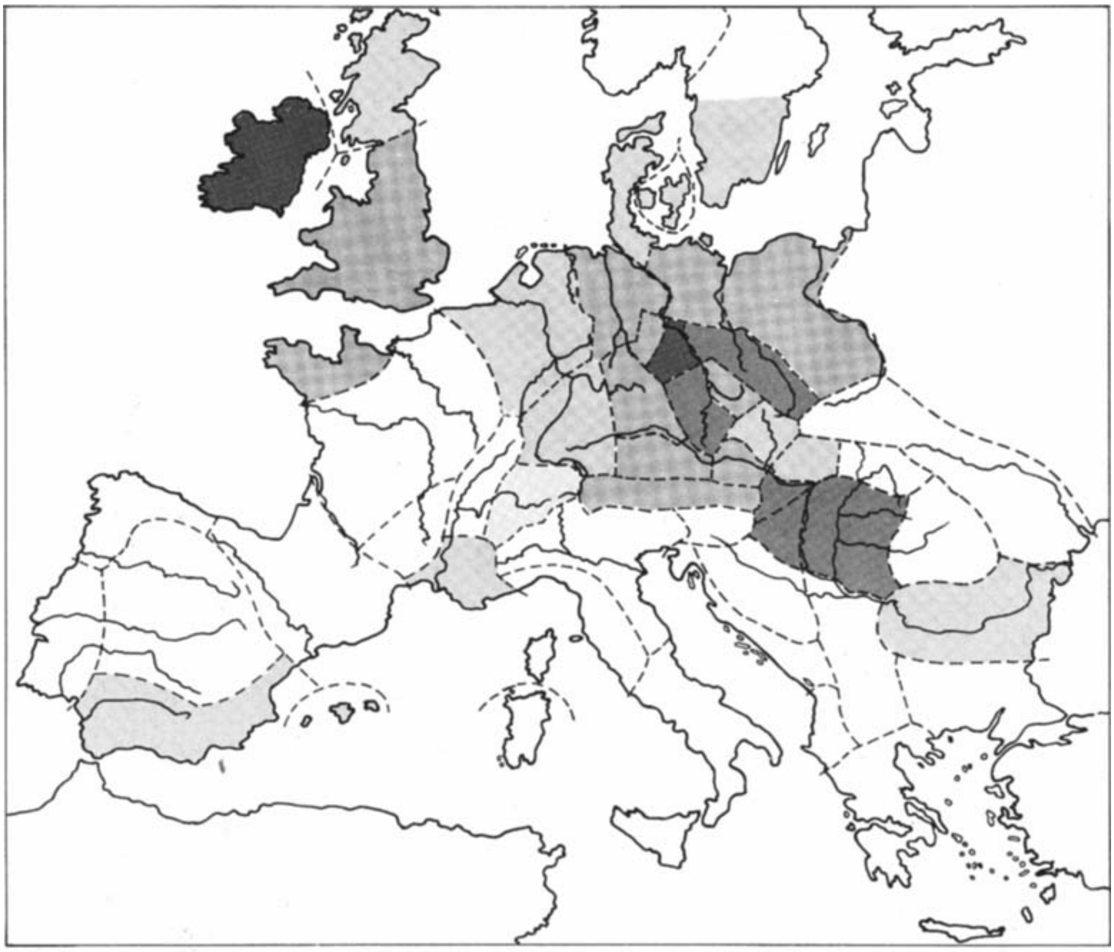

Figure 8: map of the presence of cluster FB1, which roughly corresponds to Group 12, from Hartmann and Sangmeister (1972).

With the modern technologies there is now the possibility to vary the areal unit and repeat the analysis with various parameters until the best solution is found that represents the phenomena being analysed. Modern boundaries can be used, or topographical elements, such as the boundaries of river basins. A simple geometrical net can also be used (like a grid based on the UTM coordinate system) or areal units created that account for the density of findings in space. The areal unit can also be a single site. What is important is:

- to be explicit about what area has been chosen and why;

- to utilise the *flexibility* of GIS by iterating the analyses with different areal units.

So, instead of fixed maps whose boundaries were arbitrarily determined beforehand, GIS allows a more dynamic relationship with the maps, providing feedback from the maps themselves. We think that this possibility should be exploited in modern archaeometallurgical research.

Another key capability of ArcGIS is the possibility to introduce the topographical variable. The possibility to conduct overlays that actually generate new information may be applied to chemical data and topographic maps. Topography has been under-investigated in the research of archaeometallurgy in Europe and the maps are often only a 2D visualization of a world that is in 3D. Rivers, lakes or mountains have not been adequately accounted for, so far. Furthermore, this is linked to the topic of human movement. As mentioned in Chapter 3, the history of the research shows a static perception of the archaeometallurgy. This is true both in terms of chemistry, and this is the point highlighted by Bray in his research about recycling, and in terms of actual movement of real people in the world. Is it possible to track the possible routes of movement of people bringing metal? Were these routes influenced by the presence of rivers and mountains? GIS is a tool that can help us to answer these sorts of questions and, for this reason, it has been used in the present research.

5 The Circum-Alpine Region: Geology and Geomorphology of the Study Area

One of the main aims of this research is trying to understand how metal moved in prehistory, taking into consideration the geographical and topographical aspects. Therefore, it is useful to give an introduction about those aspects in the region taken in consideration, namely the Circum-Alpine region. Information is provided in terms of the complex geology of the region, how this influenced the presence of metallurgical minerals and where the copper ores are located. Secondly, there is some information given about the geomorphology of the Alps and the best known transalpine passes as these could be factors that influence the movement of people in the Alps.

5.1 The geology

The Alps are a mountain belt that run from France to Austria, and further, as the eastern extremity dies away into the Hungarian Plain. They are 1200 km long and 250 km wide, with peaks of over 4000 m and are geologically divided into the western part (from Liguria to Lake Constance) and the eastern part that then runs to the Hungarian plain (Collet 1927, 3). The megacontinent Pangaea, during the Mesozoic (252 to 66 million years ago), fragmented, leading to the formation of the Tethys Ocean. Following this, a collision of the Eurasian and Apulo-African tectonic plates that began at the end of Mesozoic led to the formation of the Alps.

This process, still continuing, eventually destroyed the Tethys Ocean (Graciansky *et al.* 2011, 1–2). The western Alps is part of the Eurasian plate and is sinking beneath the eastern plate (Collet 1927, 7), where the highest peaks are located. Hence, geologically, the Alps are made of three main groups: one of European origin, one of oceanic origin and one of Apulo-African origin (Graciansky *et al.* 2011, 29) (Figure 9).

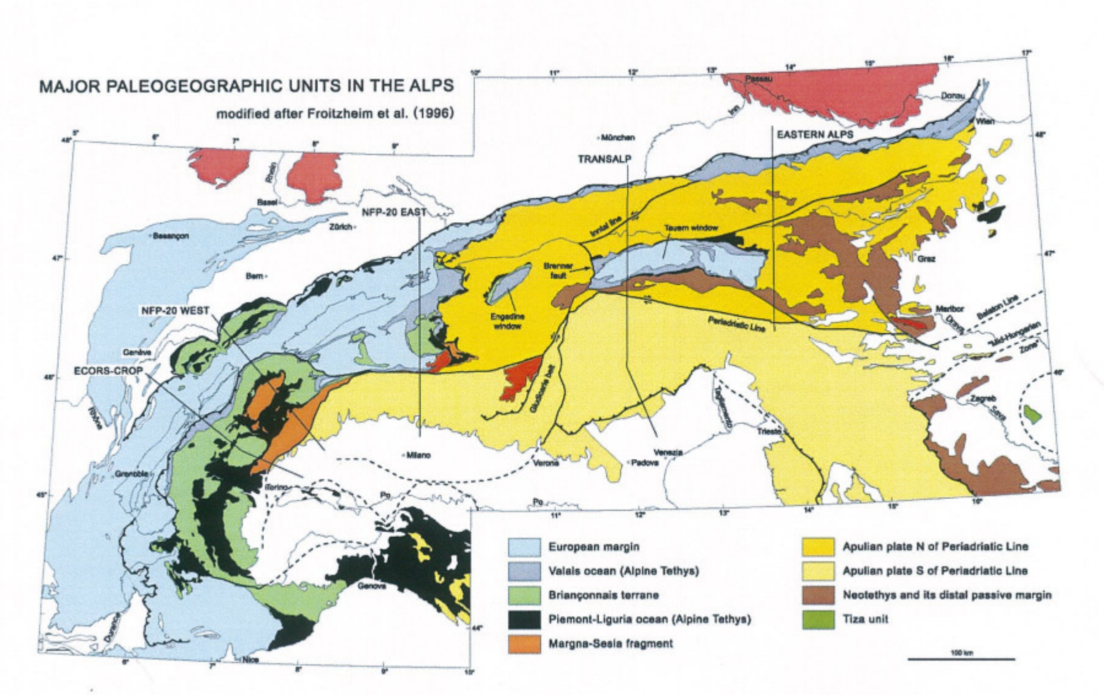

Figure 9: geology of the Alps, from Schmid *et al.* (2004). Three main zones are evident: the blue shades indicate the European plate, the black and green have an oceanic origin and the yellow shades indicate the Apulo-African original plate.

The Alps are rich in minerals, and their resources have been exploited since the Stone Age, as witnessed by the exploitation of jadeite to manufacture axes (Amico 2005; Bouard 1993; Bouard & Fedele 1993). With the advent of the Metal Age, it may be hypothesized that numerous copper quarries and mines were opened. It has to be noted that the archaeological evidence for mining exploitation could be underestimated, for a number of reasons: known mines are hard to date; the exploitation of local, superficial ores (exploiting copper carbonates and oxides) which may have been completely exhausted, leaving few, barely recognizable archaeological traces of mining activity; and the exploitation in more recent time could have destroyed more ancient traces. In this Chapter information is provided about the main copper ore deposits in the Alps, and in particular about the trace elements present.

5.2 The copper ores

Most of the hypothesized (and known) copper mines are from the further eastern or western zones of the Alps. In the central zone of the Alps, at least in the south, there are number of possible copper mines, named by Pearce (2007), but there is no evidence of exploitation in prehistoric times, and they have not yet been properly studied to determine their mineralogy. Figure 10 sums up the mines that have been studied by archaeometrists as possible ore sources. The relevant database is in Appendix III and the mines are discussed in Secion 8.1.3.

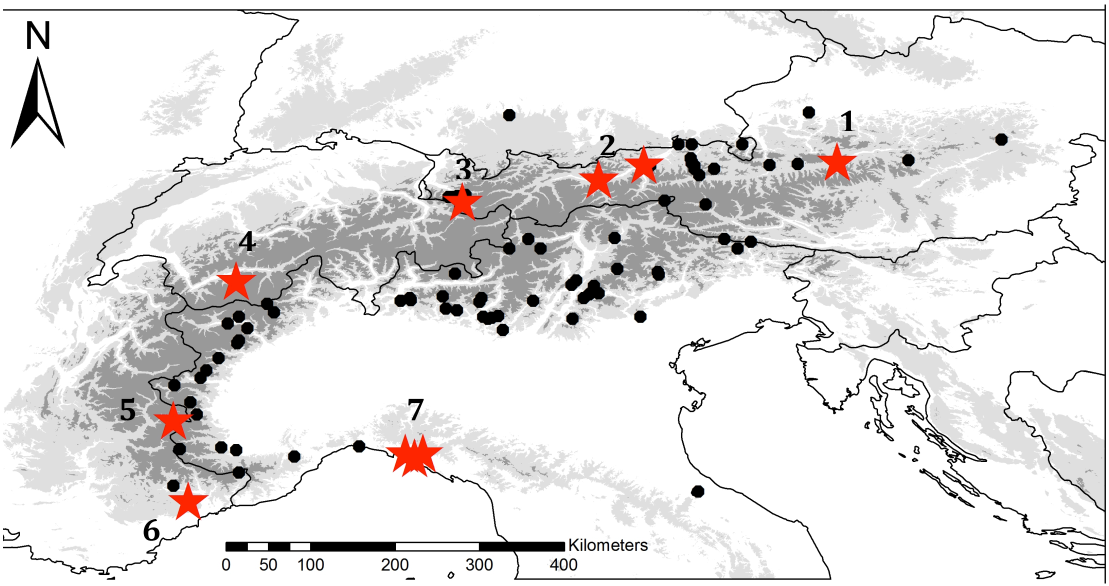

Figure 10: principal mines in the Alps. Sources are given in Appendix III. With the red star are indicated the mines that have evidence of prehistoric exploitation. (1) Mitterberg, (2) Schwazer-Brixlegg, (3) Montafon, (4) Valais, (5) Saint Véran, (6) Clue de Roua, (7) Libiola, Monte Loreto e Valle Lagorara.

In the east there are very important and well-known mineral bodies. Some mineralizations are the result of hydrothermal activity[3] in the Devonian (419.2 ± 3.2 - 358.9 ± 0.4 mya). These are dominated by the so-called "grey minerals": sulphosalts such as tetrahedrite, chalcopyrite, pyrite, and nickel sulphide. Some of the ores, in particular chalcopyrite formations, are connected with Jurassic ophiolites (an outcrop of oceanic crust and upper mantle in the continental crust). Minerals such as copper and iron rose to the crust in solutions that were

[3] Mineralization that occurs when rich in mineral water, heated by geological activity, as in magma chambers or in correspondence to plates, reach the surface from fissures of the terrestrial crust

then exhaled into sea water during the expansion of the Tethys Ocean, which was abducted during the formation of the Alps (Finlow-Bates & Tischler 1983, 15–16; Schulz 1983, 20).

In the Austrian Alps there are several mines, especially in a zone called *Nördliche Grauwackenzone*, made of Triassic carbonate rocks and mesothermal[4] metamorphic rocks, such as schists, phyllites and quartzites. One of the most important is Mitterberg, in Salzburger Land, whose secure exploitation is given from the Middle Bronze Age (Kienlin 2010, 125). The exploitation of the mine in an early phase as yet remains a hypothesis. Schwaz-Brixlegg is a syngenetic[5] copper deposit whose main ore mineral is tetrahedrite with silver and antimony within the Lower Devonian "Schwazer Dolomit". This copper was enriched in arsenic during the Variscan and Alpine Orogenies. Some slags are from the site of Münchshöfen that has been related to the nearby mining district of Brixlegg. The layer where the slags were located has been radiocarbon dated to 4500-3650 cal. B.C. (Bartelheim *et al.* 2002; Höppner *et al.* 2005) but the interpretation of the remains as slags has been contested (Kienlin 2013). If they were genuine slags, this would be the first evidence of metal production in the Alps. If not, it hints that metal production in the north of the Alps may only have begun in the second millennium, at the onset of the Early Bronze Age. Montafon valley has two types of copper ores: a primary ore body in Permocarboniferous clastic rocks and Lower Permian Alpine Verucano and a secondary siderite-rich copper lode in

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[4] 200-300°C

[5] the mineralization occurs contemporaneously to the formation of the rocks that contains metals

Scythian clastic rocks. Copper was extracted from chalcopyrite and *Fahlerz*[6] with antimony and arsenic. (Cierny 1997, 76; Goldenberg 1998, 9–11; Tropper & Vavtar 2009, 2–4). Mining activities in Schwaz-Brixlegg and Montafon from the Early Bronze Age are not yet conclusively proven, but are hypothesized due to the presence of fortified hilltop settlements such as Buchberg, St. Veit-Klinglberg and Montafon (Kienlin 2010, 125–128; Krause 2007). In the case of Buchberg, metal production is demonstrated by the presence of slags (Höppner *et al.* 2005).

The south-east of the Alps also contains several known mines of chalcopyrite and arsenopyrite (Artioli *et al.* 2008, 140). Some of these mines were exploited from the end of the Copper Age, as proved by the numerous slags in the valleys of Trentino, but pinpointing which of them is not yet possible (see Section 7.1.7). They are the product of sulphidic hydrothermal deposits (Cierny *et al.* 1998, 25). In Slovenia, in the upper part of Val Gardena there are numerous copper deposits in clastic sedimentary rocks, among which the most important is the copper deposit Škofje, rich in silver and with significantly lower proportions of Zn, Pb and As than the ores of Tyrol (Drovenik 1983, 88–92).

In the western part, in south-eastern France many mineralizations are linked to continental palaeosurfaces (Féraud 1983, 94–133). In the Maritime Alps there is the Cians formation, which has a paleosurface origin, being a Permian sedimentary formation. It is made of sub-vertical limestone and dolomite veins enclosed in a carbonate sandstone level, which, in turn, contains veins of native

[6] copper with a percentage of As, Sb, Ag, Bi between 0.1-10%

copper which are also very rich in arsenic. It was exploited in prehistoric times, as testified by the mine of Clue de Roua (Rostan & Mari 2005, 139–141). In this case, native copper was extracted, so smelting was not required. Radiocarbon dates indicate activity in the Early Bronze Age I (2200-1800 B.C.) (Carozza *et al.* 2010).

In the Ligurian Alps and the northern Appennines copper veins are in ophiolite and at the contact between basalt and an outcrop of serpentine breccia (Maggi & Pearce 2005). Here the site of Monte Loreto represents the first evidence of expoitation of a copper mine in western Europe. In fact, a shaft found in the mine was dated to 3637-3372 B.C.[7] and a charcoal find in the archaeological fill 3011-2629 B.C. (Dolfini 2013; Maggi & Pearce 2005; Pearce 2007). In close proximity, there were two other mines that possess traces of prehistoric exploitation: Libiola and Valle Lagorara. An oak pick-handle found in Monte Libiola has been dated 3494-2915 B.C. and 3622-3112 B.C. (samples n. GIF-7213 and Bln-3367 respectively). From a Valle Lagorara a fragment of chalcopyrite was discovered that might be interpreted as a slag. If this is true, it is evidence for contemporaneous exploitation of this mine with Libiola and Monte Loreto, as it was found in a layer radiocarbon dated to 3483 -3033 B.C. (Pearce 2007).

In a northern zone the copper veins are linked to ophiolites. The mine of Saint-Véran in the Hautes Alps, whose evidence of exploitation is secure from the Early

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[7] All the radiocarbon dates of this thesis have been re-calibrated using OxCal version 4.2 with Intcal 2013

Bronze Age, has a strata-bound copper deposit that is a made of ophiolites and sediments subjected to metamorphism at high pressure. The mineral from which copper is extracted is bornite (Cu_5FeS_4) (Bourgarit *et al.* 2010). The entire *chaîne opératoire* of metal production has been discovered in Saint-Véran. The exploitation of the mine has been radiocarbon dated at least from 2300-1750 B.C. (date from an architectural element of the mine). Bornite was extracted from this mine, and remains of charcoal and slag prove the smelting of copper at a close distance (350m) to the mine, but it might have been exploited also for native copper (Bourgarit *et al.* 2008, 2010).

Finally, in Switzerland there is the possibility that there was a copper mine in Valais that could have been exploited in prehistory. There is no evidence of Bronze Age copper mining or smelting furnaces, so a more specific location is not possible. Metal production is only suggested by chemical and isotopical analysis in some finished artefacts (Cattin *et al.* 2011).

5.3 The geomorphology and climate

As a young mountain belt (the youngest in Europe), the Alps are steep and high, with deep fluvio-glacial valleys. Their geomorphology is mainly determined by glacial and post glacial events in the Quaternary. As a matter of fact, A. Penck and E. Brückner named the "classic" four glacial events (Gunz, Mindel, Riss and Wurm) from the rivers of four fluvio-glacial deposits (Penck & Brückner 1901). The morphology changes from the south to the north of the Periadriatic Seam, with the first region made of separated peaks whereas the second one can be seen, not as a series of autonomous features, but as "steps" of differing altitude across the same staircase (the so called "Alpine style") (Chardon & Castiglioni 1984, 15).

The mountain chain is surrounded by important river valleys (see Chapter 13). The most important rivers are, from the west:

- The Rhône, that rises in Switzerland, in Valais, crosses the Lake Geneva, runs west to Lyon, where it turns to the south and flows into the Mediterranean Sea, close to Marseille. One of its main tributaries is the Saône, which runs from the north and joins the Rhône in Lyon. The Saône and Rhône are navigable, but the latter has difficult sections due to strong currents.
- The Rhine is one of the longest rivers in Europe. It rises in Switzerland, in Grisons, and runs north, through Lake Constance. It is divided into different sections and, in this thesis, the Alpine Rhine and the high Rhine are taken into consideration. One of its main tributaries in the high Rhine is the Aare. The Alpine and high Rhine and the Aare are only partially navigable, because of their rapids and gorges.
- The Danube is the longest river of Europe. It originates in Germany, in the town of Donaueschingen, in the Black Forest and then flows southeast for 1,914 km. It is almost all navigable, as well as its main tributaries. Only the first section is considered in this thesis.

- The Po is the main Italian river. It rises in Monviso, in the western Alps, runs from west to east, and flows in the Adriatic Sea. It is mainly navigable.

The Copper Age and the Early Bronze Age were part of the Subboreal climatic period, which means it was cooler and dryer than the preceding Atlantic, but still warmer than present days (Ravazzi & Pini 2013). A proof of the deterioration of the climate with glacial advances is given by the existence of the Ötzi mummy. In fact, he could have been preserved because the snow that covered him has never melted since his death. Nevertheless, in the Subboreal period there were fluctuations in the glacier line (Hormes *et al.* 2001; Joerin *et al.* 2006). Figure 11 shows the registered fluctuations of the glaciers in the Alps.

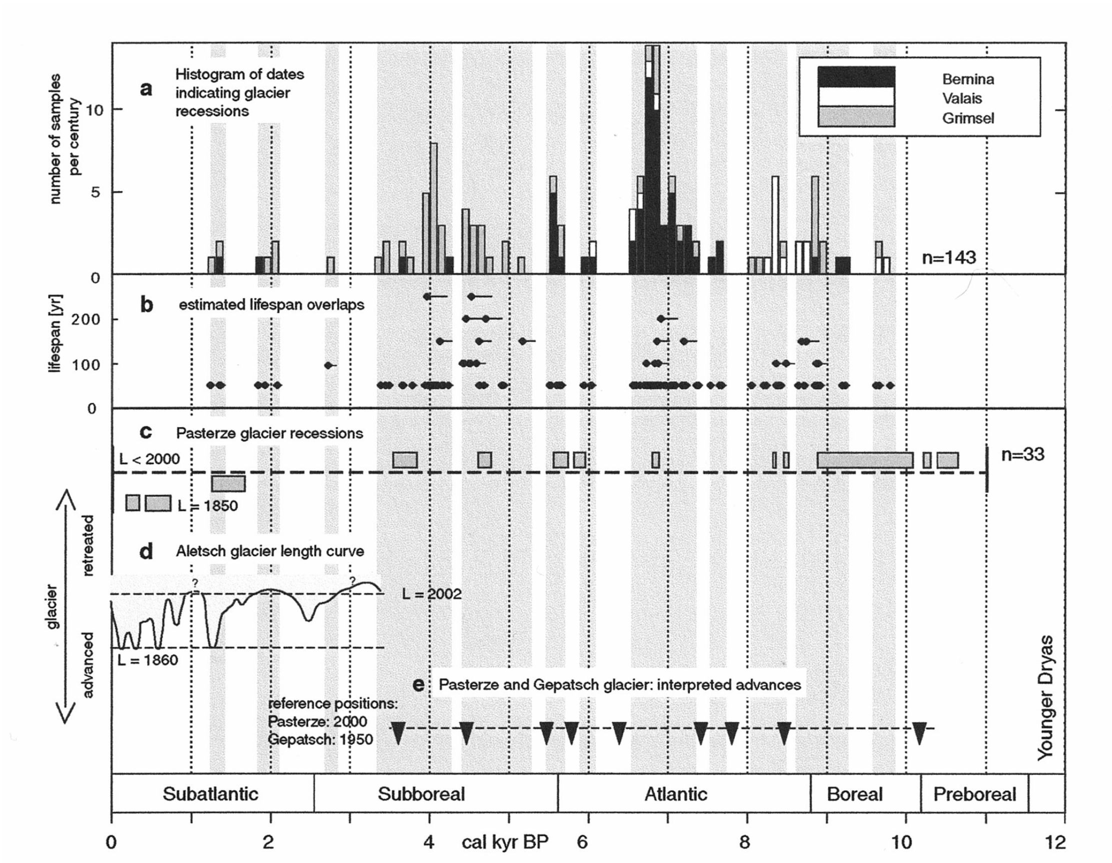

Figure 11: data on glacier recession events (in grey), from Joerin *et al.* (2006). The event at 4000 BP corresponds to the beginning of the Early Bronze Age.

There was a phase of regression dated 2350-1450 B.C., corresponding to the beginning of the Bronze Age (see Section 7.2). According to some authors, this event led to an increase of human activities in the high altitudes, including mining activities (Carozza *et al.* 2010; Krause 2003).

Despite their extreme geography, the Alps have never been a barrier to humans. A number of passes have meant that travellers have always been able to make their way across the Alps, at least in the warm season. Understanding which of the Alpine passes have been used in the past, and in what directions, is an easier task if written texts are available. As for prehistory one must rely only on archaeological finds, which are often single finds, whose only archaeological context comes from parallels of the artefacts from larger lowland sites, or ethnographic archaeology (Della Casa 2007, 109). But with the help of written texts it may be possible to have at least an idea of which were the principal routes at least from Medieval and Roman times.

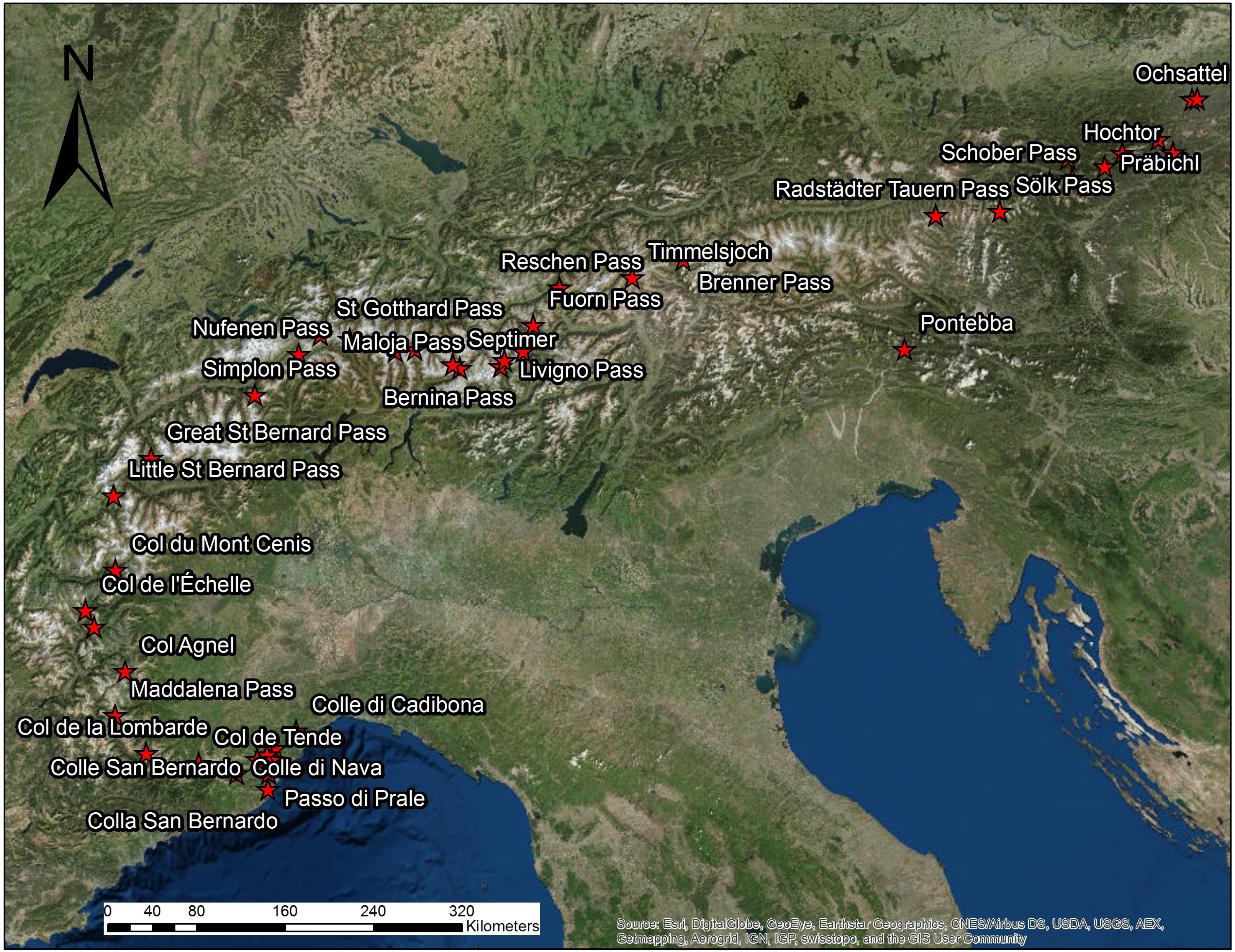

Figure 12: major passes in the Alps.

The western region of the Alps is easier to cross, as the mountains form only a single main chain, broken by many passes from the Rhône to the east, such as Col de Tende, Col de l'Argentière (Maddalena Pass), Col Lautaret, Mont Genève, the Mont Cenis, the Little and Grand St. Bernards. At least in Medieval times, the most important passes were Mont Cenis, from Val di Susa in Italy to the Rhône valley, and St. Bernard, at the head of the Val d'Etremont, and that of the Dora Baltea (Tyler 1930, 48–51).

In the central group things are more complex, since the width of the Alps increases, and there are many dangerous gorges. The known major passes are Simplon, St. Gotthard, the Lukmanier, the Septimer, and also San Bernardino (Casa 2007, 110; Tyler 1930, 2). St. Gotthard, which is the shortest connection between the Swiss Plateau and the south Circum-Alpine lakes, has often been considered as unused in prehistory, because of the difficulty to walk through the Schöllenen gorge (Della Casa 2007, 114) and it was recorded as being opened only in the thirteenth century (Tyler 1930, 18). As it is, no prehistoric archaeological finds have been found to the south of Amsteg. On the other hand, it has been recently proposed that people may have taken alternative bypass routes, as suggested by the remains of a settlement found at *In Group* promontory, which controlled St. Gotthard and the Leventina valley (Casa 2007, 115). More significant archaeological remains indicate the ancient use of the Simplon and the San Bernardino passes, and the latter is the shortest and fastest connection – four days of travel by foot - between Lake Constance and Ticino, through the Rhine valley (Casa 2007).

In the east there were the Reschen-Scheideck and, further, the Brenner and the Pontebba (Tyler 1930, 2). The most important one, at least historically, was undeniably the Brenner, which links southern Bavaria and the Danube with the Po valley. It was important for several reasons; it links crucial river systems, making it is possible to exploit the Danube, Inn and then the Adige and Po valleys. It is comparatively low and easy to pass (1370 m.), and free from snow for most of the year. As well as the main path, there are possible detours, for example by the Pusterrthal, the Val Sugana, ways to the west of Lake Garda, the way by the Upper Adige and over the Reschen-Sceideck, so that it is possible to speak of the "Brenner System" (Tyler 1930, 111–114). Another relevant pass in this zone is Giogo di Tisa, used by Ötzi to cross the Alps from north to south (de Marinis & Brillante 1998), but the fact that it has been covered by snow from the death of Ötzi (dated 3350-3120 B.C) indicates that was probably unused since then.

Further east there were other routes, but they were less used, since the mountain belt in this zone is divided into more than a chain, each of them with a number of ridges. Even accepting that those ridges are relatively low, the fact remains that more than one had to be crossed, increasing the difficulty of the passage. The most important of those was Pontebba, which links Carinthia to the Venetia plain, and that has the advantage of being significantly lower (1162 m.) and with less snow (Tyler 1930, 134–136).

In the Circum-Alpine region the Copper Age marked the beginning of the inhabitation of the inner and higher parts of the Alps, as indicated – in the first instance - by the rock engravings of Valcamonica (Fedele 2013, 47–49). Furthermore, pollen analysis in the Alps leads us to believe that in this period the practise of pasturing animals began (Ravazzi & Pini 2013, 79–83), as witnessed also by the remains of ovicaprid (Del Lucchese 1998, 453–454).

6 Metallurgical Background

As explained in Section 3.1.1 many authors have explained the human choice to use one kind of metal rather than another in the light of supposed "technological improvement". In this Chapter is some information about the materials used in the Circum-Alpine region at the beginning of the Metal Age, namely copper, arsenical copper, copper with impurities (i.e. *Falherz*) and bronze. A brief discussion of each material's physical properties is provided.

6.1 Copper

Table 3 shows the main physical characteristic of copper (from Henderson 2000, 210; Mottana *et al.* 2004, f. 1).

Colour	Red
Lattice system	Face-centred cubic (Fcc)
Hardness	50 VPN[8]
Specific Weight	8.93
Melting point	1084 °C
Boiling point	2595 °C

Table 3: main characteristics of copper

[8] Vickers hardness test (Smith & Sandland 1922)

In nature, copper can be found in a pure form or in copper minerals, most of which are oxides, carbonates and sulphosalts (see Table 4) (Mottana *et al.* 2004; Venerandi 1999).

Native Copper	Cu
Cuprite	Cu_2O
Malachite	$Cu_2CO_3(OH)_2$
Azurite	$Cu_3(CO_3)_2(OH)_2$
Chalcopyrite	$CuFeS_2$
Chalcocite	Cu_2S
Bornite	Cu_5FeS_4
Covellite	CuS
Enargite	Cu_3AsS
Bournonite	$CuPbSbS_3$
Tennantite	$Cu_6[Cu_4(Fe,Zn)_2]As_4S_{13}$
Tetrahedrite	$[Cu, Fe, Zn]_{12}Sb_4S_{13}$

Table 4: principal copper minerals.

Native copper is very rare and is formed by sulphate reduction in a redox condition of ultrabasic ores. It may be found both in copper sulphate mines but also removed, after having been eroded, transported and redeposited (Henderson 2000, 210; Mottana *et al.* 2004, f. 1). The most common copper bearing mineral, and consequentially, the most important for copper production, is chalcopyrite.

As mentioned, copper is a soft material, since its hardness is about 50 VPN. Cold working does not greatly increase the hardness of pure copper: it can reach a maximum of about 100 VPN, whereas copper alloys can reach a much higher level of hardness (American Society for Metals. Reference Publications 1989; Northover 1989, fig. 13.3; 13.5).

6.2 Arsenical Copper

Arsenical copper is a binary alloy of copper with arsenic. It made its appearance very early in the history of metalworking and was probably the first alloy used by humanity: it is known that in Europe it was broadly spread from at least the fourth millennium B.C.

Arsenic belongs to the trigonal system, and it rarely appears as well-formed crystals, but rather as an aggregation of microcrystals, usually in sulphosalts - e.g. orpiment (As_2S_3), arsenopyrite (FeAsS) – as part of hydrothermal lodes (Mottana *et al.* 2004, f. 7). Minerals containing both arsenic and copper are listed in Table 5. Arsenic may also be present in the tetrahedrite group, as is further explained in the paragraph dedicated to *Fahlerz*.

Orpiment	As_2S_3
Arsenopyrite	FeAsS
Olivenite	Cu_2AsO_4OH
Enargite	Cu_3AsS_4
Tennantite	Cu_3AsS_3

Table 5: principal arsenic minerals.

The binary phase diagram of arsenical copper (Figure 13) shows the status of equilibrium of the solution made of arsenic and copper. Arsenic is soluble in copper up to 8% (α phase); more elevated percentages of arsenic allow the β phase to form, which results in a more fragile metal (Cu_8As). With 30% of As there are several phases forming and which are stable only for a short compositional range: γ phase (Cu_3As) - trigonal, stable from 850 °C to the room temperature – and then the δ phase forms (Cu_5As_2), which is stable at temperatures between 710 to 385°C (Heyding & Despault 1960).

All phase diagrams are an idealized representation, in which liquid and solid phases are always homogeneous, whereas concentration gradients of solid and micro-segregations are well known, as are the origin of the dendritic microstructures (Budd 1991, 49; Northover 1989, 111). Moreover, the diagram does not take into consideration the contribution of oxygen, which is taken up especially in the pouring operation (Northover 1989, 111–112) and which might be the cause of porosity and brittleness in the material (Budd 1991, 42–49; Northover 1989, 111–112). Arsenic was important for this particular point, because the formation of As_2O_3 is preferred to Cu_2O, so arsenic behaves as a deoxidant, and improves the qualities of the resulting material (Budd 1991, 48–49; Merkl 2011, 74).

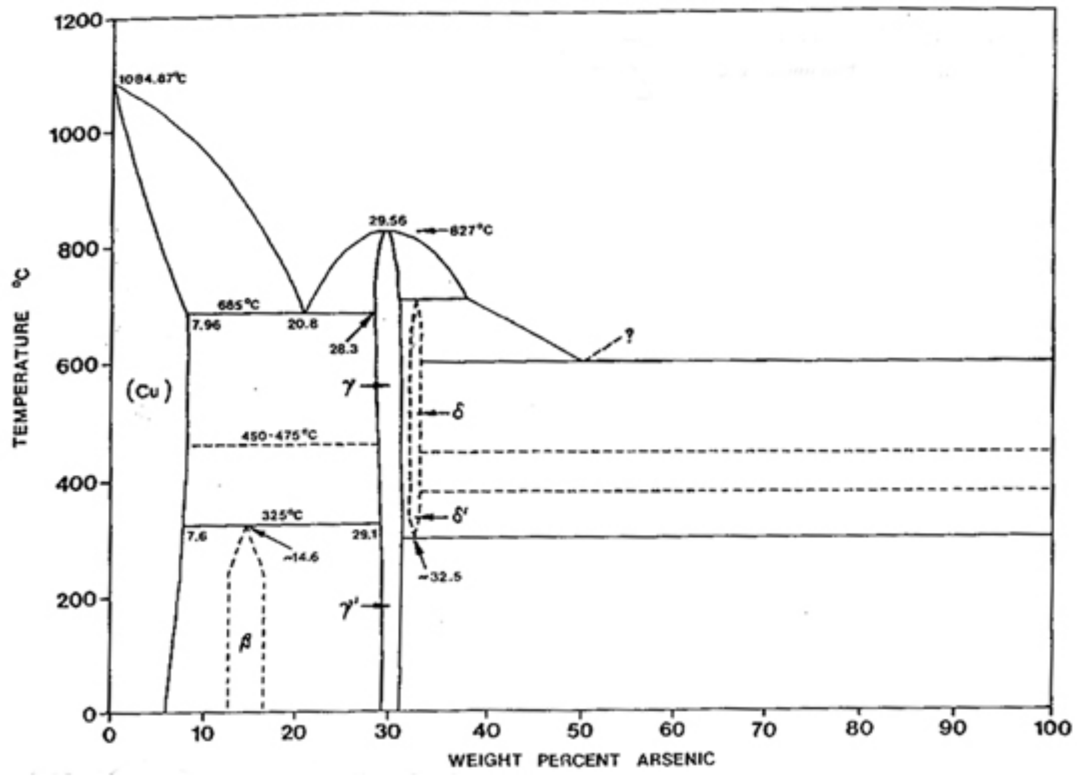

Figure 13: phase diagram of arsenic and copper, from Budd (1991).

Historic material rarely exceeds 10% of arsenic, so most studies of the mechanical properties of arsenic copper use alloys up to this percentage. Arsenical copper has a lower *liquidus* temperature point than pure copper, and is well known for its ductility which, according to Northover, might have led ancient metalworkers to consider hot working an unnecessary complication (Budd 1991, 54–56; Northover 1989, 112). Of modern experiments on arsenical copper, the most studied property is hardness (i.e. the resistance of the material to plastic deformation), and how this increases with cold working (Lechtman 1996). Figure 14 shows that, without the contribution of cold working, there are no noticeable differences in terms of hardness between pure copper and arsenical copper for percentages of arsenic below 3.5%. However, within this range cold working creates a significant improvement if the work is brought to a reduction of 30% of thickness. But, if the work is carried on to a reduction of 60% of thickness, there is nosignificant improvement in hardness. Over 4% of arsenic increases the hardness of the material even without cold working, and significantly increases with cold work. It should be noted that this is not comparable to the level of increase of hardness tin bronze gives us, since tin is twice as effective as arsenic in hardening. The hardness obtainable with 5% of tin may be reached with at least 8% of arsenic. On the other hand, arsenic in nature is much more common than tin (see Section 6.4), so having a high percentage of arsenic in copper would be much easier. Moreover, the ductility of arsenical copper is better than that of tin bronze.

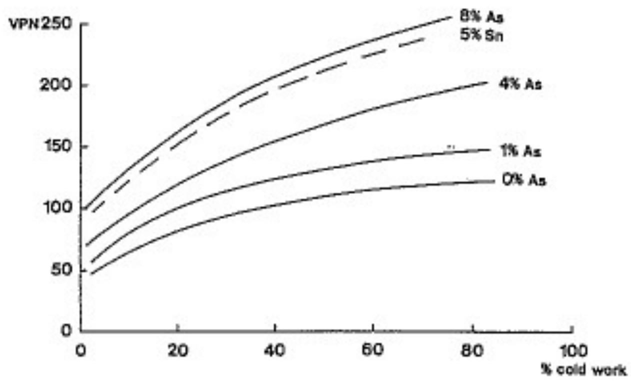

Figure 14: variation of hardness with cold work for Cu-As alloys, from Northover (1989).

According to the standard model of Wertime (1964), arsenical copper was the next step in the development of pyrotechnology after copper extraction, and was intentionally manufactured for its supposed superiority compared to the mechanical properties of pure copper (Wertime 1964, 1260). Currently this model is no longer supportable for a number of reasons:

- As radiocarbon dates prove, arsenical copper was contemporaneous with copper (Killick 2005, 485);

- The pattern of the use of arsenic copper is quite complex but in particular cultures, such as in the Circum-Alpine cultures, the use of arsenical copper seems to be related to particular types of objects. The reason for this choice over copper may be technological and/or cultural, (see below);
- The supposed improved hardness in arsenical alloy is effective only if artefacts were cold worked and this was not always the case (Artioli 2007, 907–908; Budd 1991). It should be borne in mind that ancient humans might have been looking for other characteristics, such as castability, colour, or toughness.

Another difficult issue is to determine if arsenical copper was the result of the addition of arsenic to the melting process or of co-smelting minerals that naturally contained arsenic (Budd 1991, 14–23). Experimental archaeometallurgy has demonstrated that it is possible to obtain artefacts with several percent of arsenic independently of the quantity of arsenic in the copper/arsenic bearing minerals (Budd *et al.* 1992; Lechtman & Klein 1999) and this supports the co-smelting model. On the other hand, a recent theory posits the use of *speiss*[9] as an alloying agent (Rehren *et al.* 2012; Thornton *et al.* 2009), but this has yet to be found in Europe.

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[9] There are two main types of speiss to be considered in archaeometallurgy. Ferrous speiss is typically a mixture of arsenical iron and iron arsenides, while base-metal speiss is typically a complex mixture of copper, nickel, iron and/or silver as arsenides and antimonides, often with some sulphur and lead. (Rehren *et al.* 2012; Thornton *et al.* 2009)

6.3 *Fahlerz*

According to Otto and Witter (1952), the term *Fahlerz* indicates "copper with a higher percentage of trace elements than raw copper" and *Fahlore* indicates an ore where there are copper sulphosalts with other elements, in particular arsenic, antimony, silver, but also bismuth, lead, zinc and others. Among these sulphosalts, the tetrahedrite - tennantite series, in particular, is very important for the variety of its chemical species. In general the term "tetrahedrites" is used to indicate the series of minerals that range from tetrahedrite *sensu stricto* (Cu_3SbS_3) to tennantite (Cu_3AsS_3) (Mottana *et al.* 2004, f. 18). Its structure allows the presence of mono-, bi- and trivalent cations and it may be described with the general formula:

$M^{+}_{10}M^{2+}_{2}M_4^{3+}S_{13}^{2-}$

Taking into consideration all the elements that may be part of tetrahedrite, another generic formula would be:

$(Cu, Ag)_{10}(Zn, Fe, Cd, Cu, Mn, Hg)_2(As, Sb, Bi)_4(S, Se, Te)_{13}$ (Ixer and Pattrick, 2003). Some tetrahedrites have only Cu as the monovalent cation, but some have a high percentage of Ag. If silver takes the majority of the M^{+}_{10} cation, the mineral is called freibergite. Usually there is a positive correlation between silver and antimony. The most common elements for the M^{2+} ion are iron and zinc, and experimental data revealed a correlation of iron with silver (Pattrick & Hall 1983). A high concentration of mercury makes the mineral schwarzite. Bi is usually rare, but may be found at high concentration in association with species rich in bismuth, as in pegmatite, and, in this case, the mineral is called annivite.

Tetrahedrites are found in hydrothermal deposits of medium-low temperature (200-400°C) and over a wide range of redox conditions, usually in association with other minerals containing copper, lead, zinc and silver. Nickel is often present in archaeological material named as *Fahlerz*, but it has to be noted that nickel is not in the tetrahedrite series. On the other hand, it might be found in other hydrothermal minerals, such as niccolite (NiAs), ullmannite NiSbS, zigonite ($NiCo(SO)_4$) and gersdorffite (NiAsS) (Anthony 1990; Mottana *et al.* 2004, f. 22).

In general, it has to be said that the co-presence of different chemical elements improves the mechanical properties of the alloy. There are some chemical species, such as bismuth or antimony, that individually have negative effects on copper, causing brittleness and cracks, but their negative effects are counteracted by the positive effects of arsenic and nickel (Merkl 2011, 75–77). The *Fahlerz* material has a lower solidification temperature, more tensile strength, more malleability and ductility than copper, but, above all, it is harder. Figure 15 shows the results obtained by Kienlin *et al.* (2006) on a number of analysis on Copper Age and Early Bronze Age artefacts in the north of the Alps. The Hindelwangen group, with a high percentage of trace elements and few or null cold working has a hardness comparable to that which may be obtained only with a reduction of 50% of thickness of a copper material.

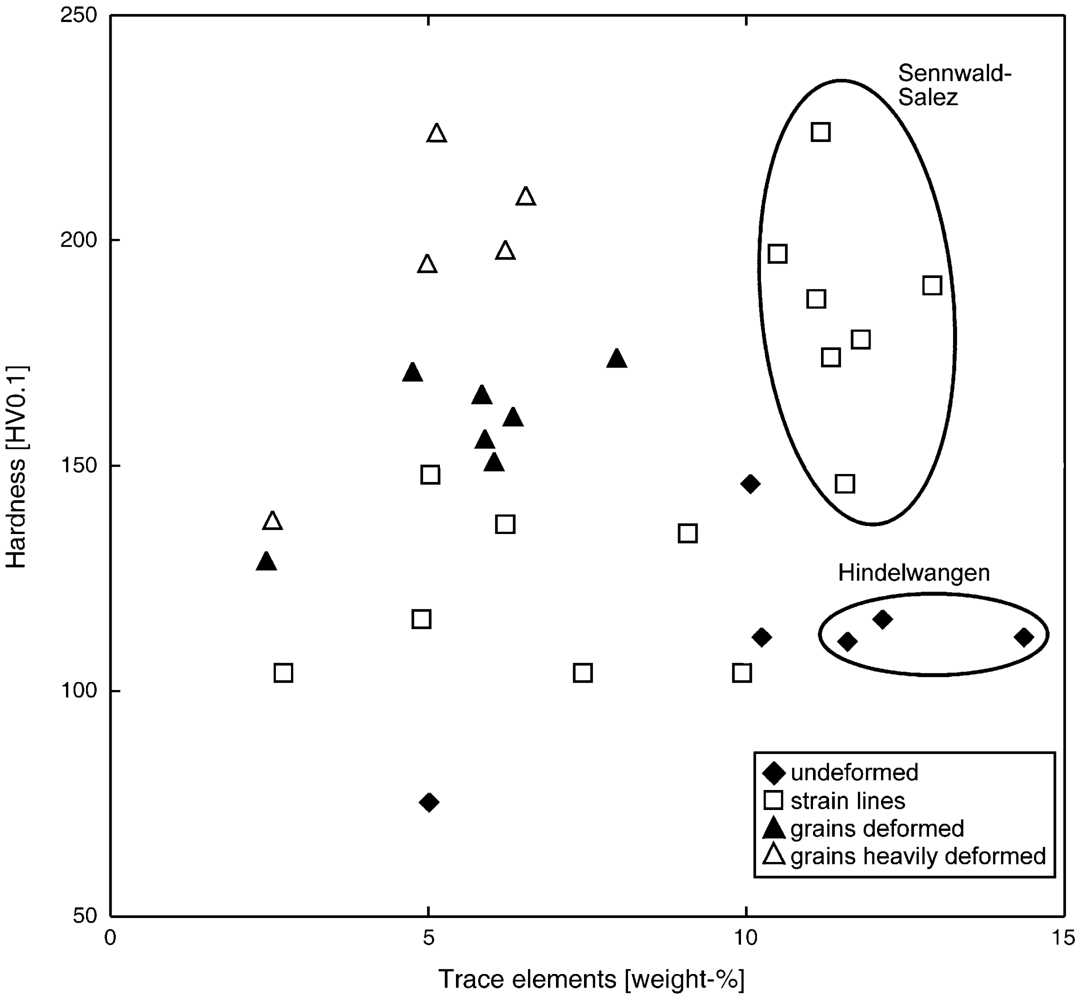

Figure 15: variation of hardness for artefacts against the sum of the percentage in weight of the impurities, from Kienlin *et al.* (2006).

6.4 Bronze

Bronze made of tin and copper is considered as the first securely intentional alloy made by humanity, since the debate about the intentionality of arsenical copper is still open. Tin usually occurs as oxides, such as cassiterite (Sn_2O) or in sulphide minerals, such as stannite (Cu_2FeSnS_4). It has been hypothesized that stannite, with its natural co-presence of copper and tin, was used to produce an unintentional alloy, in the same way as the *Fahlerz* material, which then led to an awareness of the changing of properties of copper with the addition of tin (Cierny 1997, 81). But Cienry himself noted that the known mines of stannite in Europe are too few to support this statement (Cierny 1997, 81). Moreover this hypothesis assumes that ancient people would have recognised the presence of the same element in stannite and in cassiterite, which is quite hard to support.

Most tin was probably obtained from cassiterite. It is quite rare and the most important sources are alluvial. Major deposits are in Erzgebirge (Germany), Cornwall (UK), Brittany (France), north of Portugal and Galicia (Spain). In Italy it can be found in Tuscany and Sardinia (Cierny 1997, 80).

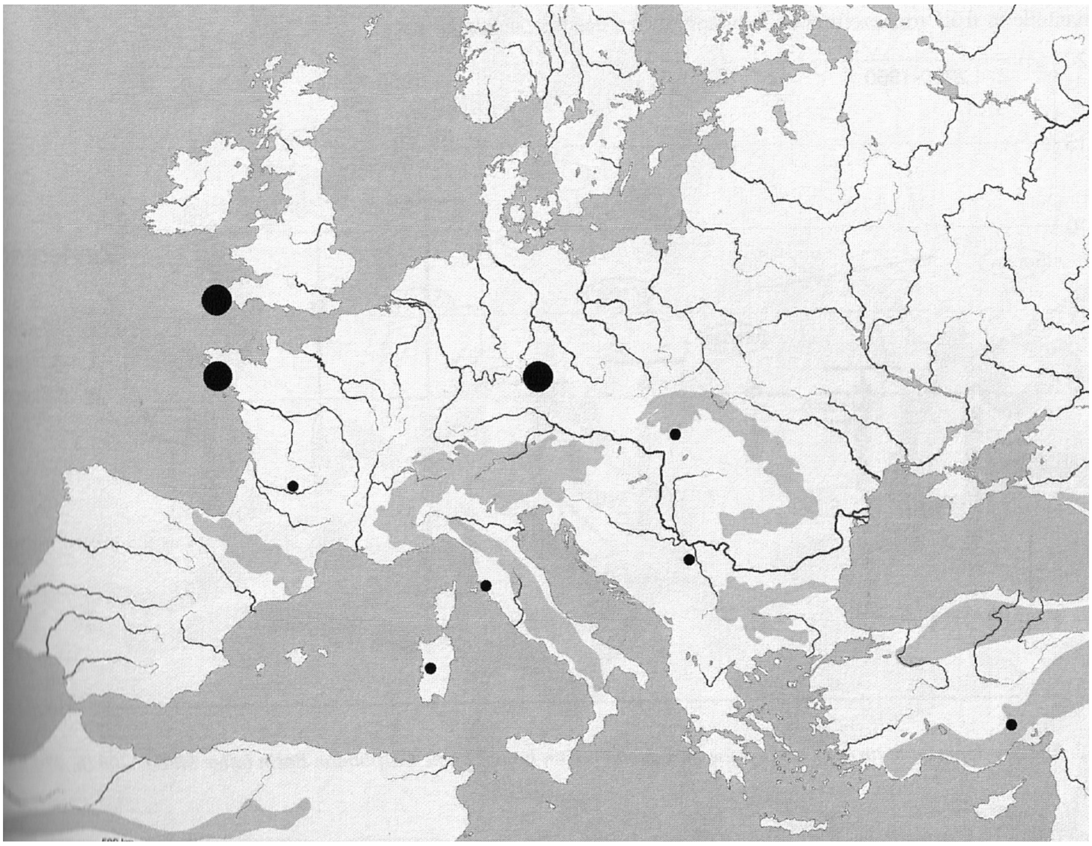

Figure 16: principle tin ores in Europe, from Keinlin (2010).

Smelting tin from cassiterite is quite an easy operation, since it is an oxide. Tin may be obtained in a reducing environment, at 231^{o}C, from the reaction:

$SnO_2 + 2CO \rightarrow Sn + 2CO_2$ (Cierny 1997, 81)

The phase diagram of copper-tin is quite complicated (Figure 17): tuning it has required several years, mainly because most of the reactions only happen very slowly. For percentages of Sn <15% the α phase forms, which is harder and more ductile. Above this percentage, up to about 30% of tin, bronze materials are made of α and δ phases and the latter is the cause of brittleness. Some copper artefacts with a high percentage of tin (>20%) may have been produced, in the past, for “artistic” choices, such as Roman mirrors, because the segregation of tin causes a white and shining surface (Scott 1991, 26–27). Most archaeological artefacts were made of bronze with less than 15% of tin. As said, this is a hard material: bronze made with 5% of tin, even without cold working, is double the hardness of pure copper. The comparison between bronze and arsenical copper has already been discussed above.

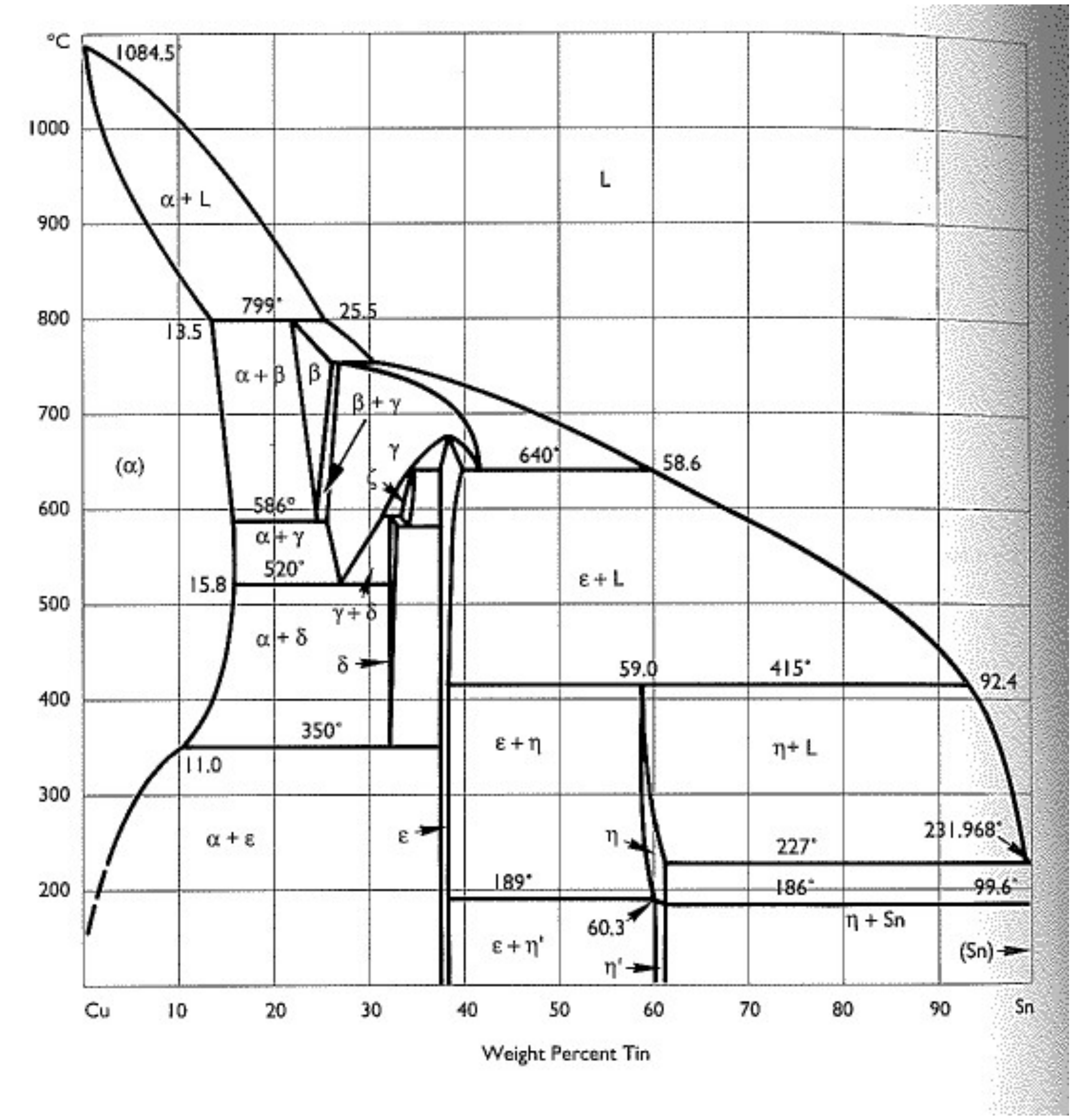

Figure 17: phase diagram of copper and tin, from Scott (1991).

6.5 Metal Production

The reduction of copper from oxides and carbonates is a relatively easy task, which may be undertaken in simple crucibles, where charcoal is used as fuel and acts as a reducing agent. With oxides, the following reaction happens:

$2C + O_2 \rightarrow 2CO$

$Cu_2O + CO \rightarrow 2Cu + CO_2$

With carbonates:

$2C + O_2 \rightarrow 2CO$

$CO + CuCO_3 \rightarrow 2CO_2 + Cu$ (Tylecote 1962)

Recently it has been claimed that this process was also used to smelt copper from sulphide copper ores (Martinek & Sydow 2004). A more advanced and complex technique to smelt copper from sulphide ores is based on a two-step process. First, the mineral is roasted. The process of roasting is achieved through bonfire combustion at temperatures of 350 - 450 °C. This process both completely removes sulphur and creates copper oxide, according to the following reaction:

$Cu_2S + 2O_2 \rightarrow 2CuO + SO_2$ (Rehder 2000).

In the second phase, the roasted material is reduced as a copper oxide. This two-step process is the one used in the Mitterberg region from the Middle Bronze Age (Kienlin 2013).

The process of smelting can be undertaken with or without slagging. No-slagging smelting chronologically pre-dates slag smelting. Smelting sites could utilize crucibles, but their most basic form is simply a hole in the ground, with the copper ore mixed with the charcoal and pooling in the bottom of the pit when smelted. Copper minerals, raised to a temperature of 900 - 1000 °C using carbon combustion, in a reducing environment, produce metallic copper, as a result of the reactions cited above. However, this process is not very efficient. Part of the copper drops to the bottom of the crucible, but a part remains as inclusions in the slag. So, at the end of smelting process, copper prills are extracted by hand, and this occurs after the breaking up of the crucible and slag. The necessary temperatures and conditions to create liquid metal free from molten slag are not reached; and so, no-slag smelting forms the base of the very first copper production processes (Henderson 2000; Tylecote 1962). Once the prills are collected, they are melted together to create a larger mass. In this process, especially during the earliest phases of metalworking, oxygen may be absorbed. This process does not create many slags and it may be difficult to pinpoint them and correctly interpret them as slags, because they may be confused with the remains of casting and metalworking (Kienlin 2013).

A technologically more advanced process is referred to as slagging. During the process of slagging, the aim is to create a fluid slag over metal so that it could be tapped - while more or less pure metallic copper is created at the bottom. If the mineral vein is very rich in quartz, iron was added to make the slag more fluid. Quartz is usually added to eliminate iron, creating olivine in the process. The slag that is produced is basically fayalite, which is an iron silicate. Analysing the process in more detail, matte, a product made from fluid metal and slag, is also created. Matte is a mixture of copper and iron sulphate, with a low melting point, containing 15% to 60% copper, which can be subsequently re-melted to create further copper. So a complex production is created, a process where different smelting cycles are used in order to obtain a purer form of copper (Craddock & Meeks 1987; Henderson 2000; Rehder 2000; Tylecote 1962). Recovering slag deposits at archaeological sites is most probably the first big sign of the presence of an ancient metallurgical workshop. Moreover, slag analysis can give information about material provenance, mining, and smelting techniques (Cattoi *et al.* 2000).

7 Introduction to the Archaeology of the Region, with special regard to Metallurgy

The term “archaeological culture” is a necessary concept, but difficult to define. It is generally used to indicate that there is a common funerary ritual, a particular kind of settlement system, or a broad similarity of artefact typology in a particular time and space. In any case “cultures” should never be seen as strictly defined by boundaries because, in particular during the Copper Age; similar features were common in different “cultures” and none of the different cultural aspects were specific to only one single culture (Steiniger 2005, 297–299). Bearing this in mind, and considering inevitable simplifications in this argument, this section draws a framework of the different archaeological cultures in the Circum-Alpine region through the copper Age and the Early Bronze age (*circa* 3600-1600 B.C.). This is mainly for two reasons:

- -The first one is that, although this research is focusing on specific aspects of the archaeological record (in particular metallurgy and its chemistry, geography and topography) the archaeological background must be included;
- Secondly, even though prehistoric cultural “barriers” should not be considered as fixed and linear, it is important to interpret the behaviour of metallurgy and different metal compositions in the light of the different cultural zones, to see if and when cultural differences had an impact on the different use of metal.

In this Chapter, there is a brief description of the main characterisations of the different archaeological cultures in the Copper Age – Early Bronze Age, as they have been described by authors from France, Italy, Switzerland, Germany and Austria. But it has to be taken into consideration that there are several discordances between these authors. In particular, there is a severe issue relating to chronology, as is discussed in more detail below. **Error! Reference source not found.** (modified from Dolfini 2013, 43) is an attempt to give a general idea of the chronological frame for the region and time considered.

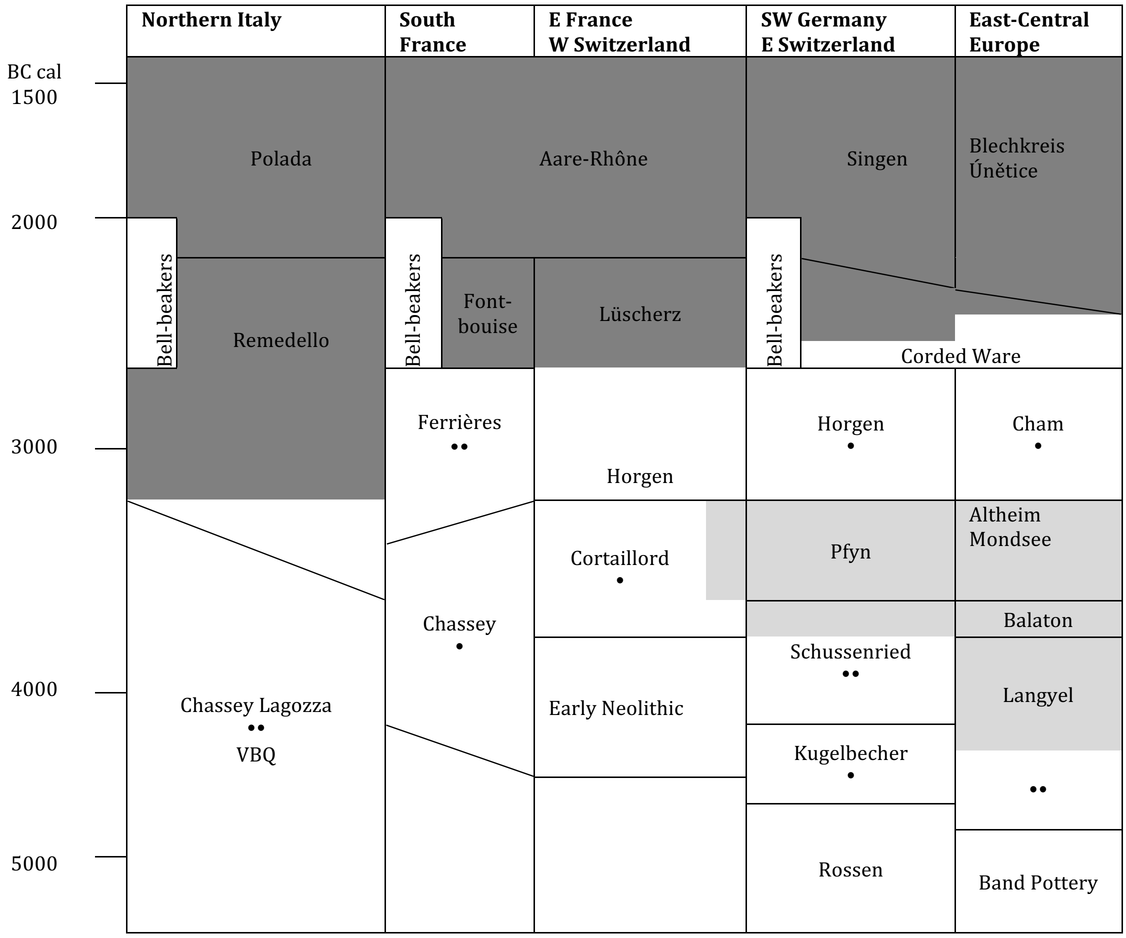

Figure 18: chronological table modified from Dolfini (2013). In light grey there is the first copper production in the Alps; in dark grey a fully developed metal production. Dots indicate sporadic metallic finds in cultures that are not considered as metal producers, but as metal users where metal objects were imported from elsewhere.

In the fifth millennium in the Circum-Alpine region there are only sporadic metal artefacts, which may have been the result of trading with other cultures that had already developed metal production. This may have been followed by a phase of pioneering attempts at local metal production, even though it is not possible to demonstrate that it was undertaken as part of a complete process of the entire *chaîne opératoire* (see among others: Dolfini 2013; Kienlin 2013; Pearce 2007).

7.1 The Copper Age in the Circum-Alpine Region

Traditionally the Copper Age has been linked to important changes in the history of humankind, such as metal production, but also technical innovations that indicate a major exploitation of agriculture resources, such as the ard and chariots drawn by animals, and use of the secondary product of milk. (Milisauskas & Kruk 2002a, 2002b; Sherratt 1981). Recent research has shown that most of the cultural elements traditionally associated with the Copper Age, especially the use of milk and milk products, but also the first appearance of metal production, should actually be attributed to Neolithic times (Sheridan 2014).

As a matter of fact for some regions "Copper Age" is not recognised as a distinct period, because the introduction of some innovations, such as the use, but also the production, of metal did not change significantly what are considered to be "Neolithic cultures". This is the case for the north Circum-Alpine regions, where metallurgy is not considered as fundamental in the definition of the local cultures until the Bronze Age, because the first metal-producer societies still had pottery styles and an economy that was considered a direct evolution from the previous, non-metal using, societies. Conversely, in other regions, such as the southern part of the Alps, significant changes are recognised and "Copper Age" (or "Chalcolithic" or "Eneolithic") is used to indicate that period when the use of metal was spread and metal working was proved by the presence of numerous crucibles (Dolfini 2013).

In this thesis, for consistency's sake, the term "Copper Age" is used in the sense proposed by Dolfini, which includes what is identified as "Late Neolithic" in the north Circum-Alpine region, and indicates a period from *circa* 3600 B.C. to *circa* 2200 B.C.. Within this period in different zones of the Alps some different cultures may be recognised, but in this thesis it has been decided to consider the Copper Age as a single period for two main reasons: first, because it is difficult to synchronise the different sub-periodizations of the different zones of the Alps, and, secondly, because the number of metal artefacts is too small to be further sub-divided. Nevertheless, in this Chapter there is a brief description of the principal cultures of the Copper Age, as synthetically represented in Figure 19Figure 20 and Figure 21.

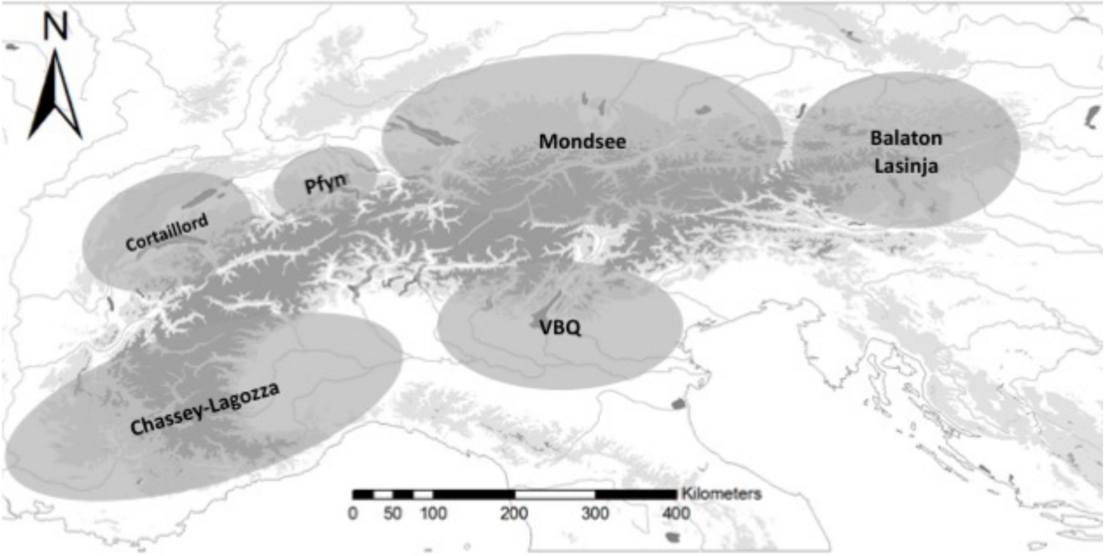

Figure 19: the Circum-Alpine cultural groups in 4000-3400 B.C.

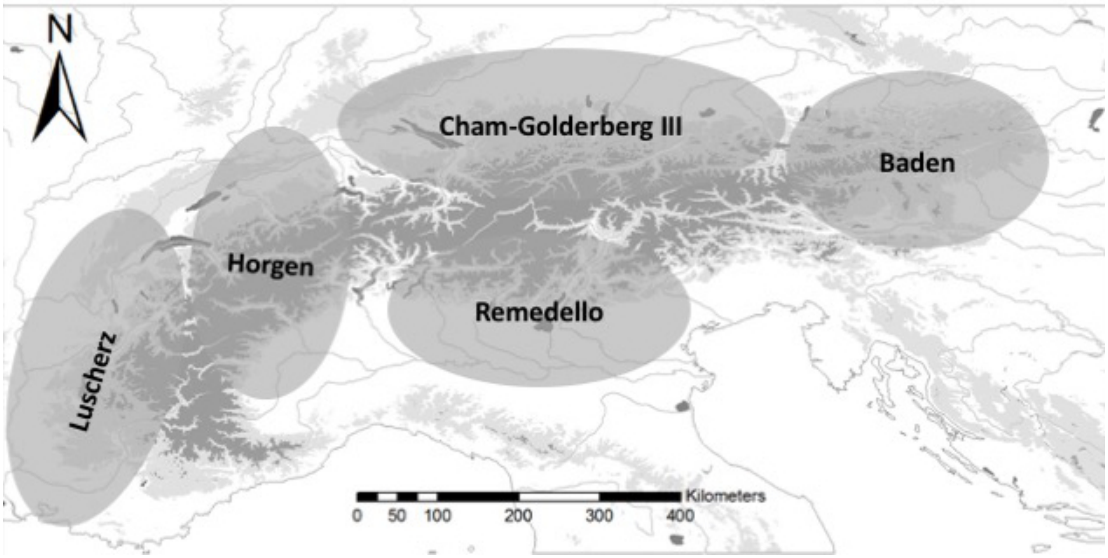

Figure 20: the Circum-Alpine cultural groups in 3500-2800 B.C.

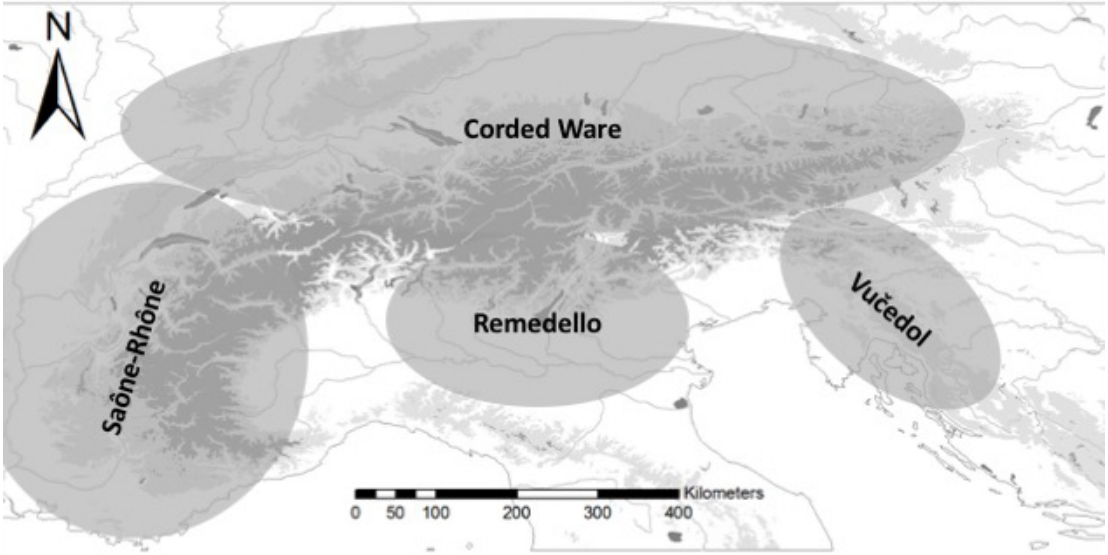

Figure 21: the Circum-Alpine cultural groups in 2800-2200 B.C.

The Copper Age also witnessed some almost pan-European cultural phenomena: the *tumuli* in eastern Europe, and megaliths, mostly spread along the Atlantic coastal region, but well represented also in the western Alps and western Italy. Another important pan-european phenomenon was the spreading of the Bell-Beaker culture at the end of the central European Copper Age/beginning of the Early Bronze Age. Approximately simultaneously, in most of the north Circum-Alpine region, there was also the Corded Ware Culture. For practical reasons, this Chapter does not follow a strictly chronological order: first there is a brief presentation of these two large-scale cultures, followed by descriptions of local cultures and local aspects of the Bell Beakers and the Corded Ware cultures.

7.1.1 The Bell Beaker Culture

The definition of the Bell Beakers – a people? a culture? a trend? – has been debated for decades (Heyd 2001; Müller 2013). Nowadays, thanks mainly to the research on stable isotopes in bones, there is some accordance with the idea that this phenomenon was related to the movement of small groups of people, males, who spread a cultural package around Europe which included a particular mode of burial, specific burial goods for the elites, and types of metal technology. The earliest ^{14}C dated Beaker artefacts were found in the Atlantic coast of the Iberian peninsula, at the beginning of the third millennium, 2900-2800 B.C. (Müller & van Willingen, 2001) and from there the type spread into an extended zone of Europe. In the Alps they arrive in the second half of the third millennium (Guilaine *et al.* 2001; Neugebauer & Neugebauer-Maresch 2001; Nicolis 2001).

This culture was mainly defined by the burial pottery: a beaker with an inverted bell shape profile with horizontal decorations around the body, that differed regionally (Sherratt 1994, 251). At least in the Circum-Alpine region, the burial ritual was similar to the Corded Ware Culture – single inhumations with the body on its side and with sexual differentiation of the grave goods: the males had the beaker, armguard and weapons – usually daggers and/or arrowheads - and females had ornaments (Merkl 2011, 21–24; Sherratt 1994, 251). In the western zone of the Alps Beaker goods could be found in multiple burials (Sheridan 2014). Circum-Alpine Bell Beaker burials are differentiated from the culture of Corded Ware by the orientation of inhumations: males and females were oriented north-south with males laid on the right side and females on the left (Merkl 2011, 22). According to the cranio-morphology it is possible to determine that new (Beaker) people spread from west to east, with Corded

Ware people being dolichocephalic whereas Bell Beakers people were brachycephalic (Heyd 2001, 403–404; Müller 2013, 496). Hungarian researchers perceive the appearance of the Beaker culture as the marker for the beginning of the Bronze Age, because it coincided with a cultural change and a significant increase in metal production. On the other hand, German researchers tend to include it in the Copper Age, and mark the beginning of the Bronze Age with the Únětice Culture (Krause 2003, 55; Merkl 2011, 23–24).

7.1.2 The Corded Ware Culture

The Corded Ware culture (Figure 21) is defined by the typical pottery used as a burial good: it is a drinking vessel – called a beaker - that is decorated in horizontal bands on its upper half. This was typical of male burials, together with a shaft hole axe called a "battle axe" (Sherratt 1994, 192). The information about this culture is mainly acquired from its cemeteries: they consist of single inhumations, in which the orientation of the bodies was determined by gender: both males and females were in crouched position facing south, but males were west-east oriented and females east-west (Merkl 2011, 21).

7.1.3 The Copper Age (Late Neolithic) in the south-east of France

In the first half of the fourth millennium in France, along the Rhône, there was the Chasséen culture which had metal evidence: tools and weapons (Ottaway

1989, 21) (Figure 19). But Strahm questioned the local production of these artefacts and considered the few metal finds to be imported (Strahm 2005).

In the course of the fourth millennium the existence of a number of cultures or, better, local cultural groups is hypothesized. The Rhône valley was influenced by the Lüscherz culture (Figure 20), whereas further west, in the Mediterrean Languedoc there was the Fontbouisse culture (Gutherz & Jallot 1995). There were also influences from Italy, in particular there was evidence of importation of metal objects. For example, in Fontaine-le-Puits a number of burials had the typical metal set of the Remedello culture: axes, awls, pendants and Remedello type daggers (Bocquet 1997b; Strahm 2005) and also a tomb with material ascribable to the Rinaldone culture, in particular the typical dagger (Strahm 2005).

In the third millennium the Saône-Rhône Culture stretched along the Rhône; it had pottery similar to the Corded Ware culture (see above), but with a metal production which linked this culture to those of southern France (Cocchi Genick 1996, 87–88). But, at the same time, there is also the spread of the Bell Beakers (see above). In any case, the presence of metallurgy had not caused deep changes in society during the Copper Age, and the metal production seemed to be related to localised production by small groups (Strahm 2005).

In the western Alps Bell Beaker culture made its appearance at approximately the same time as in Switzerland, namely the second half of the third millennium (Müller & van Willingen 2001) and was contemporaneous to the Rhône culture

(Strahm 2005, fig. 2). Most of the sites were burials and the "typical" Beaker burial artefacts were also found in multiple burials, burials in caves and in megaliths. As a matter of fact, megalithic monuments are the most represented type of burial (Guilaine *et al.* 2001). The typical artefacts, besides the beakers, include Palmela points, grip-tongue daggers (Strahm 2005, 31), awls, beads and, more rarely, flat axes and bracelets (Cattin 2008). Despite this, Ambert considers the assemblage to be of local production and not the result of a Bell Beaker influx. His statement is enforced by the evidence that most of the artefacts, even the ones that have a typical "Beaker shape", have a kind of metal – copper with lead, antimony and silver - that could be related to the mines of Cabrières (Hérault) – known to have been exploited since the forth millennium (Ambert 2001).

7.1.4 The Copper Age (Late Neolithic) in Switzerland

In Switzerland, at the beginning of the fourth millennium there was the Pfyn culture that showed similarities with the cultures of Central Europe (Stöckli 1993, 36–37) (Figure 19). Related to the Pfyn culture there is a significant number of metal artefacts and also moulds that were found, which suggested local casting. The possibility of smelting is not excluded as there appeared to be mining of copper ores near to the sites (Ottaway 1989, 20). Some pottery has been interpreted as possible smelting crucibles (Ruttkay *et al.* 2004) because they have traces of chalchopyrite on the surface, but more recent archaeometric studies on the pottery demonstrated that the chalcopyrite was probably an effect of post-depositional phenomena (Rehren 2009). The Hornstaad-Hörnle copper disc, dated to the beginning of the fourth millennium was found in Badensee. According to Klassen this has an Italian kind of metal and could have been the one of the first traces of transalpine metal connections (Klassen 2010). In fact, the metal has As, Sb, Ag, Ni and in this Early period similar metal was only found in northern Italy (Valle Fontega, S. Bricci di Lavagno) so Klassen was inclined to think that it was produced in the same region and then exported.

In the western zone another culture was recognised (Cortaillod) (Figure 19), that had occidental influences, from the Rhône valley (Stöckli 1993, 33–35). It had metal objects but without proof of local production, and archaeologists tend to hypothesize an importation of metal from the neighbouring Pfyn culture (Cocchi Genick 1996, 84).

In the second half of the fourth millennium the intensity of metal finds seemed to decline, with the Horgen culture (Figure 20), considered as a "regression" (in terms of quality of the material culture, for instance of the pottery) and, in general, a derivation from Pfyn (Stöckli 1993, 37). Horgen influences were recognisable even in northern Italy, in particular from the presence of its typical pottery named "White Ware" (de Marinis 1992, 403; de Marinis & Pedrotti 1997, 289–290).

In eastern and central Switzerland the appearance of the Corded Ware culture (see above) (Figure 21) marked a deep cultural change and a sign of the beginning of a strong link between this region and Central Europe (Cattin *et al.*

2009). Migration of people, either in large scale or as a result of migration of small groups, is hypothesized (Giligny & Michel 1995; Michel 2002; Stöckli 1993, 50).

In western Switzerland the Corded Ware culture had some peculiar, local characteristics and for this reason, it is called the "Corded Auvenier culture" (Stöckli 1993, 49). As explained, the Corded Ware culture is mostly known for burials. However, in western Switzerland there is one known Corded Auvenier culture (Stöckli 1993, 50) and, conversely, there are a number of well-known settlements connected to this culture (Cattin 2008; Stöckli 1993; Höneisen & Speck 1990). In Switzerland the Corded Ware phase coincided with a rich metal production (Ottaway 1989, 20), in particular in Vinelz and Saint-Blaise, and both weapons (daggers and axes), ornaments (beads) and awls are well represented (Cattin 2008; Ramseyer 1987; Strahm 1971, 1994). The Bell Beaker culture in this region is dated 2500-2000 B.C. (Müller & van Willingen 2001) and it is well represented, in particular in burial sites (Höneisen *et al.* 1993; Stöckli 1993). Conversely, according to Cattin, only a few metal artefacts could be interpreted as belonging to the Beaker culture (Cattin 2008).

7.1.5 The Copper Age in southern Germany-Austria

In south-west Germany and Austria at the beginning of the fourth millennium there was the Mondsee culture (Figure 19). For this culture metal working has been hypothesized by the presence of finished copper artefacts (such as daggers and axes) and of some pottery interpreted as crucibles (Ruttkay *et al.* 2004), but, as with the Pfyn culture, Rehren (2009) explained the presence of chalcopyrite on the surface of the crucibles as a post-depositional effect. Another hint for a metal production, at least in Austria, is given by some slags from the site of Münchshöfen that have been related to the nearby mining district of Brixlegg. As discussed in Section 5.2, if these are genuine slags, then this is the first evidence of metal production in the Alps.

In the next period (3300-2800 B.C.), the intensity of metal finds seemed to decline in the north Circum-Alpine region, when there is the establishment of the Cham and Goldberg III cultures in Germany and Austria respectively (Figure 20). Finally in the second half of the third millennium, in this zone there was the contemporaneous presence of the Corded Ware (Section 7.1.2) and the Bell Beakers culture (Section 7.1.1).

In Austria, Corded Ware (Figure 21) is particularly known for its burials, and the metal goods consisted of blades, rolled sheets, spirals, bracelets and necklaces (Cattin 2008; Neugebauer-Maresch 1994). Bell Beakers were contemporaneous and similarly known from their burials. Typical Beaker artefacts, such as tongue-grip daggers, and awls, were found (Cattin 2008; Neugebauer & Neugebauer-Maresch 2001; Neugebauer-Maresch & Neugebauer 1998).

In southern Germany there are at least 100 sites ascribable to the Corded Ware culture, but, conversely, few metal artefacts are found (Cattin 2008; Heyd 2000). More than 200 sites have been interpreted as Beaker, mostly burials, but settlements and single findings are also documented (Cattin 2008; Heyd 2000) and dated at the end of the third millennium (Müller & van Willingen 2001). Typical beaker metal artefacts are found, such as grip-tongue daggers, triangular daggers, awls (Cattin 2008; Heyd 2000; Matuschik 2004).

7.1.6 The Copper Age in the east of the Alps

In the north-eastern limit of the Circum-Alpine region, which roughly corresponds to western Hungary, Slovenia and Istria, there is an important change from the Neolithic (Merkl 2011, 17; Ottaway 1982, 20; Tasić 1995, 35–36). The new culture, set at 4300-4000 B.C., is properly considered as "Copper Age" or "Eneolithic". Slovenian authors tend to speak of "Lengyel colonization" or "the Alpine *facies* of Lengyel", considering this to be the Lengyel culture with an origin in Pannonia (Korošec 1958, 83–93). For other authors this is seen as the Lasinja culture, a local culture with influences of Lengyel (Tasić 1995). Nevertheless, the excavations in Resnikov prekop, Ajdovska jama pri Nemški Vasi and Drulovka, recognised two different phases: a proper Lengyel phase (or Alpine facies) with painted vessels and tall-footed goblets, and a later phase (Lasinja culture, see below) (Tasić 1995). The Lengyel culture is characterised by the presence of a number of metal finds, such as axes, spirals and sheets of copper (Merkl, 2011, 17; Ottaway, 1982, 20).

The Lengyel culture is later replaced by Balaton Lasinja I (4000-34000 B.C.), which is recognised as an influence of the Vinča culture on the pre-existing

Lengyel (Cocchi Genick 1996, 73; Tasić 1995). They were semi-nomadic people, and settlements are found both in the lowlands and highlands (Tasić 1995). Its later expression is Balaton Lasinja II (4000-3400 B.C.) (Figure 19). These cultures can be linked to some hoards with copper and gold discs (Chernykh 1992, 51; Merkl 2011, 17) and crucibles that may indicate at least secondary local metal production (Ottaway 1989, 20).

In a later period (3500-2800 B.C.) (Figure 20), there was the establishment of the Baden culture, usually linked with the use of ox-drawn chariots. It was a culture characterised by small settlements, both open air and in caves, and small cemeteries with distinctive burial rites (Cocchi Genick 1996, 74). The bodies were in a crouched position, with a different orientation and different goods according to gender (Merkl 2011, 21). The pottery production includes the characteristic anthropomorphic figurines. On the other hand, metal production decreased (Cocchi Genick 1996, 74; Merkl 2011, 20–21).

Finally, at the end of the Copper Age and the beginning of the Bronze Age (2900-2100 B.C.) this region witnesses the Corded Ware phenomena first and later the Bell Beaker culture, and the Únětice culture in the Bronze Age (Merkl 2011, 21–24) (Figure 21). In Slovenia there was a regional variation of Vučedol culture, known for the lake-dwellings of Ig in the Ljubliana Marsh (Bregant 1971; Tasić 1995, 85). This culture yielded several copper finds, including shaft hole axes, and moulds used in casting.

7.1.7 The Copper Age in the north of Italy

In this period the south Circum-Alpine region is divided into two cultural districts: in the east there is the last phase of the VBQ (“Vasi a Bocca Quadrata”), in the western zone there is the Chassey-Lagozza (Pessina & Tiné 2008, 59) (Figure 19). In northern Italy the first metal finds appears in the very last phase of the VBQ (4500-4000 B.C.) (Cocchi Genick 1996, 173; Dolfini 2013, 27; Ottaway 1989, 20), but the first evidence for metal production, with the use of crucible smelting, is dated to 4000-3600 B.C., (Dolfini 2013, 27). Botteghino (PR) is an interesting case, because it is a site in the lowlands that is situated in the Po plain, so at some distance from the possible ore locations. Here a crucible was found and radiocarbon dates from the same layer calibrate to 4501-4365 B.C. (Dolfini 2013; Marzatico 2011). The existence of slags, and therefore of metal activities, is questioned, because it may be hard to distinguish slag from the remains of casting and metal working (Dolfini 2013). Pottery that may be related to metal production was found also in Mezzocorona (Borgonuovo), a site dated to the final Neolithic - Early Copper Age (beginning of the fourth millennium).

In a later period (3600-2200 B.C) (Figure 21) there was a blossoming of metal production in northern Italy, linked to cultures that are considered to belong to the “Copper Age”. There is proof of mining activity from the fourth millennium (Maggi & Pearce 2005), and evidence of systematic metal production, mainly in the north-east, in Trentino (Artioli *et al.* 2003; Cattoi *et al.* 2000; Colpani *et al.* 2006; Peroni 2001). The first sites with metal-working evidence are dated to the fifth millennium, but their metal production activity is not secure. In the site of Romagnano Loch (TN) a crucible has been found, but there is no evidence of slags and/or smelting activity. The layers above and below have been radiocarbon dated respectively to 2280-1970 B.C. and 3700-3380 B.C. (Pearce 2007). There is evidence of smelting activities and metal production in the valleys and rock shelters. In Acquisgrana (Besenello) there is a furnace and some slags, dated after 3340-2900 B.C. (dates from an underlying burial) (Pearce 2007; Pedrotti 2001). Riparo Gaban (TN) have evidence of slags, tuyères, a crucible, and a furnace dated before 2613-2333 B.C. (dates of the overlying layer) (Pearce 2007; Pedrotti 2001). For Montesei di Serso (Pergine Valsugana) there are no available radiocarbon dates, but the site has been dated to the Copper Age/Early Bronze Age. Here, remains of a furnace, slags, tuyères, awls, and a copper mould for an eyelet axe have been uncovered (Marzatico 2011). Other Late Copper Age sites with smelting activities are Millan and Gudon (BZ), where more than 200 kg of slags were found, in addition to a tuyère and some metal objects (Colpani *et al.* 2006). The open question, in this case, therefore, is which mine was exploited? Recently, a campaign to study mines that were possibly exploited in prehistory in the south of the Alps has been undertaken by Artioli and his team in Padova. The results, at the moment, are still preliminarily (Artioli *et al.* 2003, 2008; Giunti 2011).

Metal artefacts are found almost solely with burials, since very few settlements dated to the Copper Age have been discovered. The Remedello culture (Figure 20 and Figure 21) is named after a cemetery near Brescia, in the Po valley, where there are single burials with sexual differentiation according to the goods: males have axes and daggers made of stone or copper, females have pottery and ornaments made of copper. De Marinis, using a "horizontal stratification", splits the cemetery into two phases: the oldest burials are in the centre of the cemetery, the more recent ones at the edge. The chronology is defined, in particular, by the shape of the flint daggers and by the presence of copper daggers in the more recent burials. There is also a further use of the cemetery linked to the Bell Beaker culture (de Marinis & Pedrotti 1997; de Marinis & Valzolgher 2013, 344–347). But this chronology has been recently questioned by Dolfini (Dolfini 2014a, 2014b). In this period there is proof of transalpine contact: the White Ware pottery, related to the Horgen culture, is found, for example in Colombare di Negrar (Cocchi Genick 1996).

In the mountainous region there is another burial ritual in the Copper Age, namely multiple depositions in caves, defined as "facies of Vecchiano" (Cocchi Genick 1996, 228–231). It consists of a complex ritual of a multiple burial including the manipulation of bodies. From these sites there are also some metal artefacts, mostly represented by awls, beads and bracelets. The presence of metal shaft hole axes is notable in Tuenno and Piglonerkops, which represents proof of contact with the transalpine cultures and, in particular, the Slovenian area (Barfield 2007, 1984; Pedrotti 2001). Particularly notable is the site of Isera la Torretta (TN), which is one of the few known settlements recording the transition from the Neolithic to the Copper Age, and dated with a series of radiocarbon dates. It also provides evidence for the return to highland settlement after the hiatus of the V.B.Q. culture, which preferred settlements in valleys (de Marinis & Pedrotti 1997; Pedrotti 2001). Those settlements might be related to mining activity.

The western region of the south Circum-Alpine region is linked to the transalpine cultures in the Rhône basin, as testified by the material culture (Ferrero & Padovan 2013, 268–269; Venturino Gambari 1998, 52) and some ritual sites with *menhirs* (Ferrero & Padovan 2013, 287). In terms of metallurgy there are copper objects in context dated 3400 BC in Alba, Piedmont (Gambari & Venturino Gambari 2003; Zoppi *et al.* 2006). Moreover, in Liguria, there is the mentioned site of Monte Loreto (see Section 5.2), but this activity is not reflected by the number of metal artefacts, which is, indeed, very low.

Evidence of Bell Beaker culture is only sporadic (Ferrero & Padovan 2013, 286–287). A part from the mentioned material from Remedello, fragments of pottery were found in some settlements (Montanari 2001; Poggiani Keller *et al.* 1998). Metallic objects from Beaker contexts are very rare: from Fiesse a copper axe and a dagger (de Marinis 1994; Montanari 2001), two awls from Monte Covolo (Barfield 1995; Montanari 2001), and awls from Riparo Valdesi.

7.2 The Early Bronze Age in the Circum-Alpine Region

The transition between the Copper Age and the Early Bronze Age is not strictly determined by the transition from the use of copper to the use of tin bronze, which usually occurs later (see Chapter 11 for a discussion about the introduction of bronze technology into the Alps). In the Circum-Alpine region the change is marked by the appearance of new cultures: Polada in northern Italy; Rhône in south-east France and western Switzerland; Blechkreis (with Singen, Arbon, Neckar and Straubinger sub-cultures) in eastern Switzerland, southern Germany and western Austria; Unterwölblinger and Veterov in south-eastern Austria; and the Únětice Culture further north-east (Figure 22). The origin of these cultures is multifactorial: it has been seen as a mixture of local traditions and influences from the Bell Beaker and Corded Ware cultures (Kienlin 2010, 121), plus Carpathian influences (Krause 2003, 250). As explained in Section 5.3, the passage from the Copper Age to the Early Bronze Age is also marked by better climatic conditions that allowed an increasing human presence in the mountains, possibly including mining activities.

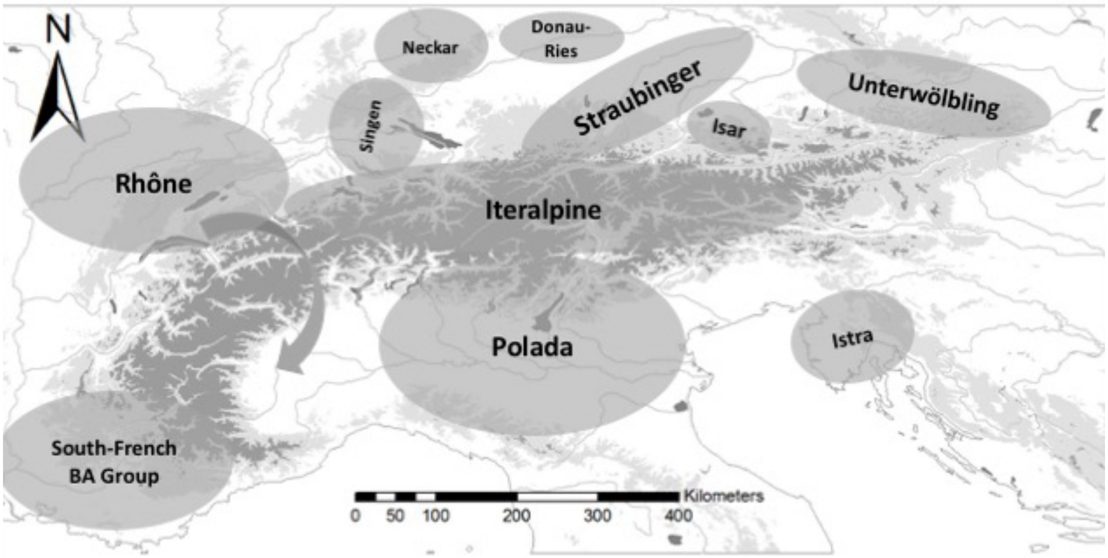

Figure 22: the Circum-Alpine cultural groups in the Early Bronze Age.

Following new radiocarbon dates, it is well accepted that in the Circum-Alpine region the beginning of the Early Bronze Age is set around 2300/2200 B.C (among others, David-Elbiali 2000, fig. 14; Della Casa 2013, fig. 39.3; Guilaine *et al.* 2001; Krause 1989; Nicolis 2013, 694; Pearce 1998, 57; Strahm 2005; Vital 2005). There are several further divisions, mostly defined by regional studies, and the same region often has different chronological framework proposed by different authors (e.g., Krause 2003, p.55, tab. 23). This sequence is built on typochronology – especially on pottery - and radiocarbon dates of some key sites. A summary of the available radiocarbon data from the north Circum-Alpine region is in Figure 23.

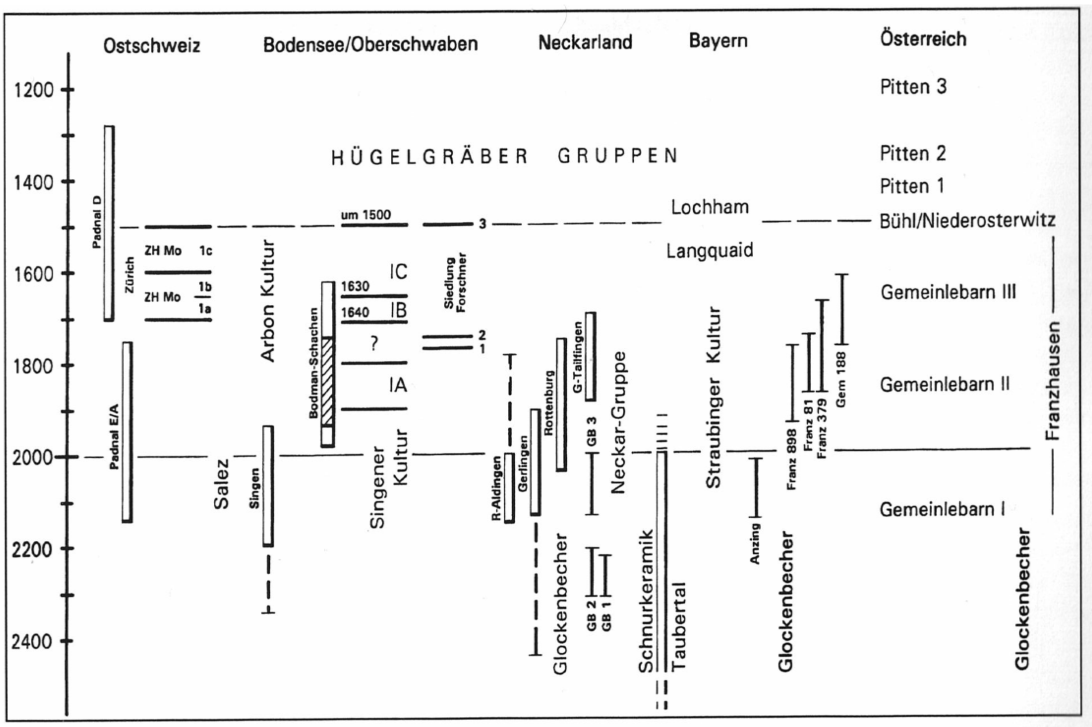

Figure 23: available radiocarbon dates (cal B.C.) from the north Circum-Alpine region, from Krause (2003, 77).

In the first phase most of the dates are from burials, such as, for example, the Singen cemetery (Krause 1988, 1989), some burials from the Neckar culture (Becker *et al.* 1989) and, in Switzerland, Thun and Sion-Petit Chasseur (David-

Elbiali 2000). From the second phase of the Early Bronze Age there are more dates available from Switzerland (David-Elbiali 2000, 368–369; Krause 2003, 76–77; Menotti 2001, 25) and southern German settlements (Krause 2003, 76–77). A general review of the available radiocarbon dates in sites considered as "Bronze Age" in France has been produced by Vital, based in particular on the Jura Lakes (Vital 2005). In northern Italy the sequence built on some lake-dwellings covers the entire span of the Early Bronze Age (de Marinis 2000). In Austria there are few dates available, mostly from settlements (Rassmann 1996) and only one date is available from the cemetery of Gemeinlebarn (Neugebauer 1998). In Slovenia there are dates from Ljubljana Marsh (Menotti 2001, 25).

An Early Bronze Age chronology that may be applied to the entire Circum-Alpine region has three phases. In the north these three phases are A1 (2300/2200-2000 B.C.), A2a (2000-1800 B.C.), and A2b (1800-1600 B.C.) (e.g., David-Elbiali 2000, fig. 14; Krause 2003, fig. 34). This subdivision has a good correspondence to the chronological framework drawn by de Marinis for the Early Bronze Age in northern Italy: EBA I corresponds to A1, EBA IB and EBA IC to A2a and EBA II to A2b (de Marinis 2005; Nicolis 2013, 694).

7.2.1 The chronology of metal objects

Unfortunately, most of the metal artefacts are from graves and hoards, and linking them to the absolute chronology sequence is not an easy task, because most of the dates are from settlements. Krause (2003) proposed a typochronological sequence based on the dates of some key-sites and key-typology. His starting point was the cemetery of Singen, because its activity was limited to the first phase of the Early Bronze Age, and radiocarbon dates were available, dating from 2200-2126 B.C to 2138-2030 B.C In this cemetery there were some Amorico-British type daggers and oar-headed pins. It has to be noted, thought, that the dates have been reported by Krause using 1σ. Dates recalibrated with OxCal 4.2 operating with IntCal 13 and reported with 2σ enlarge the time span and the dates are from 2466-2200 to 2141-1900 B.C. Dates from Thun – in Switzerland - proved the presence of metal-hilt daggers and eyelet pins at least by 2000 B.C. In Singen there were no eyelet pins, hence Krause considers this type as typical of the Early Bronze Age 2a. Another key type were the globe-headed pins, found in a grave of the Gemeinlebarn cemetery in Austria. This cemetery has one radiocarbon date available (1892 -1560 B.C., so corresponding to the end of the Early Bronze Age 2a and Early Bronze Age 2b), but it was not from a burial with pins, so this date for the globe-head pin is derived from the comparison of the other goods of the burials (Neugebauer 1991).

The issue is that there are not many available dates to build a solid chronology, and new dates could call into question the entire framework already built. For example, the introduction of tin-bronze production in the Alps is still a debated topic (see Chapter 11). Moreover, typochronology still uses the metal composition as a proxy for dates, which is a circular argument. For instance, if the authors tend to believe that a high percentage of tin (over 5 %) could have appeared only in a second phase of the Early Bronze Age, then they date artefacts with a high percentage of tin to the second phase. For example, the Salez type axes are considered by some authors older than the Nyeruz type, because the Salez type does not have tin, while some of the Neyruz type axes do have it (Krause 1988). Some authors tend to split the chronology of the Neyruz type axes into two phases: axes without tin are older (A1) and the ones with tin are younger (A2a) (e.g. de Marinis 2005). Other authors date all the axes of Neyruz type to the A2a period (e.g. David-Elbiali 2000). Another example is the dates proposed by David-Elbiali for some Swiss daggers. There are some daggers whose typology is considered old and comparable to types found in other cemeteries dating to the Early Bronze Age A1. These are the daggers with two rivets from Collombey Muraz, Chamonson and Sierre Noez that are similar to daggers found in the cemetery of Straubinger. But the daggers of Collombey Muraz and Sierre Noez have tin (6.30% and 3.35% respectively), therefore David-Elbiali stated that those types are from a later period in Switzerland (David-Elbiali 2000, 60–61). Similar considerations were proposed for some Amorico type daggers (David-Elbiali 2000, 61).

Bearing in mind these issues, Section 8.1.2.1 explains the attempt of this work to take into consideration the different possible dates proposed for single objects. In this Section a general picture of the main Early Bronze Age cultures is provided, that is generally more broadly accepted, as is shown in Figure 22.

7.2.2 The Early Bronze Age in southern-east of France and Switzerland

In the north Circum-Alpine region, the western zone was characterized by the Rhône culture, which was present along the Rhône, in southeast France and western Switzerland. Vogt believed it to be differentiated from the east of Switzerland (and furthermore, from Germany and Austria) by the metal production: in the western part there was tool production by hammering pure copper, in the eastern part (the so called "Blechkreis": see below) a proper production sequence has been identified beginning with smelting (Vogt 1948, 68). Vogt's interpretation was based on incorrect assumptions – not least because he mixed up objects of different dates, from the Chalcolithic to the Middle Bronze Age – but the existence of two cultural regions in Switzerland – an eastern and a western one - is still accepted (Krause 2003, 45–47).

The burial tradition is a good marker of the difference between western and eastern Switzerland, since in the western part, besides the Copper Age tradition of crouched bodies, there was also the innovation of the supine position (David-Elbiali 2000, 306–319). In the eastern part the bodies were always crouched (Krause 2003, 46) and the style of burial goods was different, even if this zone was also influenced by the Atlantic world (Krause 2003, 47). Hoards were a common feature since, on both sides of Switzerland, hoards of axes were more frequent than those composed of *Ösenringe* (see below). Considering settlements, Krause identified another cultural group: both eastern and western Switzerland had lake-dwelling sites, but in the eastern zone there is also a group of settlements in the highlands, possibly related to mineral exploitation.

However, recent excavations, carried out in occasion of the construction of new motorways, reveal the presence of highland settlements also in the western zone (see for example Schopfer Luginbühl *et al.*, 2011). Therefore, the observation of Krause seems to be biased by the state of the archaeological research.

The culture in the western part of Switzerland and south-east of France, along the Rhône, is called the Rhône culture. The Early Bronze Age in the French part of the Rhône is very poorly documented. Della Casa (2013, 710) recognised a continuity with previous cultures, such as the Beaker culture and Fontbouisse culture, whereas Vital (2005) refused the hypothesis of continuity with the local Copper Age tradition. In particular, the burial tradition had influences from the Beaker culture in the orientation of the bodies (north/south), whereas in a later phase of the Early Bronze age the orientation was east/west. A number of settlements have been discovered in the Rhône valley and in the French lake region (Billaud *et al.* 2007; Billaud & Marguet 2005; Cattin 2008; Vital 2005). Metal artefacts were few: pins, awls, torques, ornaments, daggers and axes, mostly belonging to a recent phase of the Early Bronze Age (Bocquet 1997a; Cattin 2008).

In central-east Switzerland there are few archaeological records from the first phase of the Early Bronze Age and most of the information is from burials. In particular, burials have been documented in Thun, in the high valley of the Rhône, and in the megalithic dolmen of Petit-Chasseaur, Sion (Hafner, 1993). The burial ritual was inhumation, but it was mixed in terms of position of the body. The goods were gender-related, with ornaments specific for females and weapons for males (David-Elbiali, 2000, 306–319). Hoards are represented and a deposit of Neyruz type axes in Sierre is identified by Hafner (1993).

Only in a second phase of the Early Bronze Age is there a good documentation of settlements, in particular with lake-dwellings. Metal artefacts include, besides Neyruz type axes, oar headed pins, ornaments such as lunulae, and triangular blades. From a second, phase pins with disc or trapezoidal heads, dagger with socketed hilt – Rhône type - and tiaras of Ollon and Conthey types are recorded (Cattin 2008; David-Elbiali 2000; but see Chapter 11 about the dating of socketed hilt daggers). In Sigriswil-Ringoldswil a huge metal hoard was found, whose content was mainly daggers with socketed hilts and flanged axes (Hafner 1993). In a final phase there were no more torques or tiaras and there were daggers with rhomboidal section and trapezoidal profile (Broc type), axes of Bevaix, Sion, Ollon, Roseaux, Onnes, Langquid, Lodigiano and Robbio Desor types and pins with pierced heads (Cattin 2008; David-Elbiali 2000).

7.2.3 The Early Bronze Age in southern Germany-Austria

As explained, eastern Switzerland, southern Germany and Austria are part of the *Blechkreis* culture, defined in 1948 by Vogt by its metal production and by having features that indicate an influence from the Únětice culture. Some authors recognized it as a development of the combination of Corded Ware and Beaker cultures (Merkl 2011, 25). It is further divided into several small regional groups: Arbon, Low and High Rhine, Neckar, Singen, Lake Constance, Ries, Lech, Danube, Straubinger and Isar, amongst which there are differences in burial ritual and goods (Krause 2003, 48–49) (see Figure 24). In particular, in the eastern region the cemeteries contained more individuals (even hundreds), whereas in the western zone, in particular in Switzerland, cemeteries usually had only a few individuals (Krause 2003, 45–55). Similarly, there was a trend of a decreasing number of metal artefacts within the cemeteries further east, and a corresponding increase in the number of artefacts made of bone (Lißner 2004).

Hoards, too, showed a similar pattern of geographical differentiation, since, in the eastern region, they were present in large numbers, and they were mostly composed of *Ösenringe* and *Spangenbarren*, whereas in the western part there were significantly fewer hoards, made of axes: Salez type in Lake Constance and Neyruz in the Swiss Midlands (Krause 2003, 51). The settlements also showed differences between groups, in particular between the lowland and the highland group, with the last possibly linked to metal ore exploitation and, perhaps, even with traces of fortifications and social differences, but the data is too sparse to enable the formulation of a clear picture (Krause 2003, 51).

The *Blechkreis* shows a continuity with the older cultures, as testified by burial rite (individual burial with different orientation according to gender) and the burial goods that are characterized by the same objects (pots, daggers for males and ornaments for females), even though their typology changed (Merkl 2011, 26). Typical metal artefacts of the first phase were oar headed pins, pins of Hokheim type, flanged axes of Salez type, daggers with triangular blades, awls, *lunulae*, armrings (Krause 1988; Lißner 2004). In a second phase there were clover headed pins, pins with punctured head, flanged axes of Neyruz type (although, see above for the discussion about the chronology of this type of axe), flanged axes of Langquid type, daggers with midrib, and daggers with a sinuous profile (Cattin 2008; Hochuli 1993; Lißner 2004; Probst 1996; Rageth 1993).

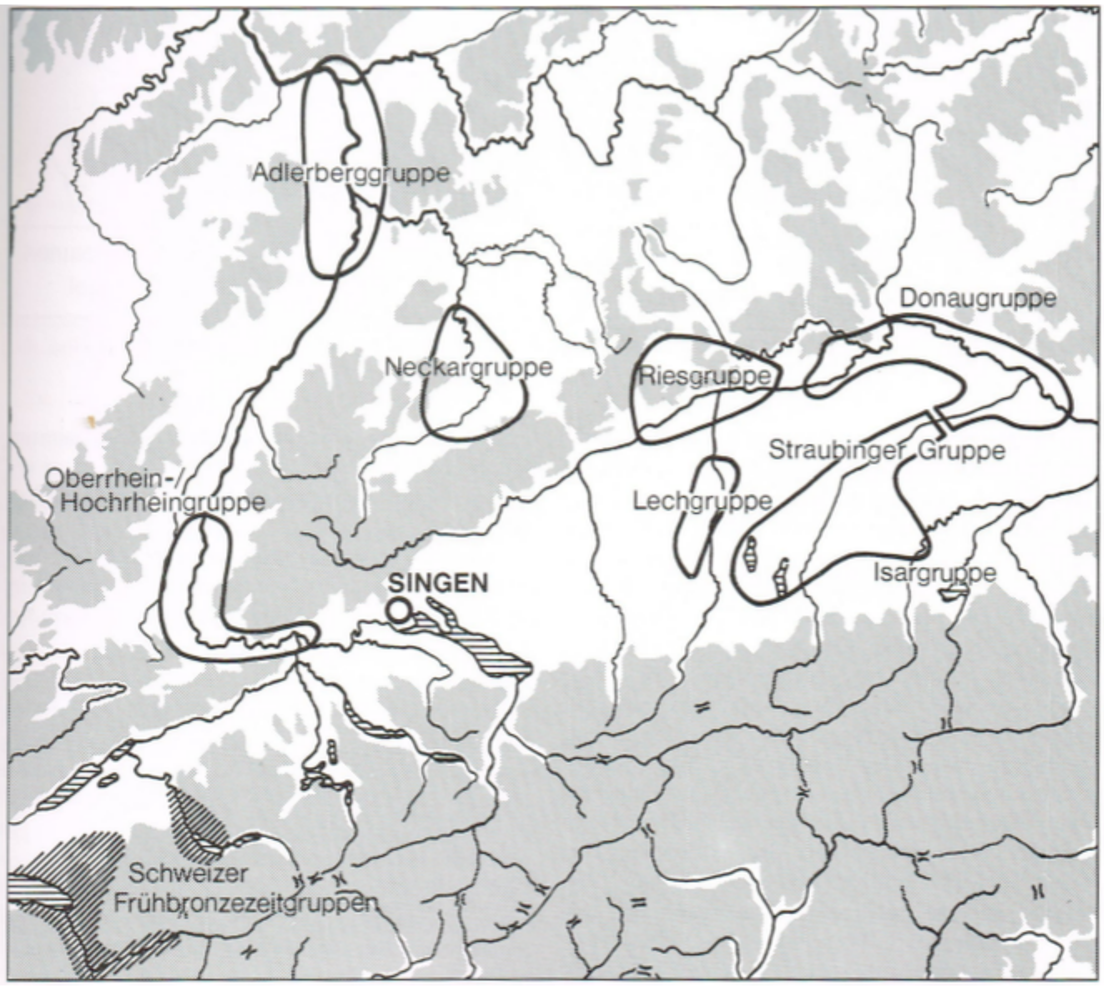

Figure 24: groups of the Blechkreis, from Krause (1988).

7.2.4 The Early Bronze Age in the east of the Alps

Further east, the beginning of the Bronze Age is connected with the appearance of the Únětice Culture (Krause 2003, 55) that no longer had sexual differentiation in the graves, although maintaining the inhumation ritual, with bodies on the right side and heads to the south (Harding 2000, 82). It and its neighbouring cultures (see below) were responsible for extensive metal production, with also the use of *tuyères* (Harding 2000). This culture is usually linked to the phenomenon of large metal hoards, solid hilt daggers, *Ösenringe, Spangenbarren,* and tin enrichment of copper objects, to create a silverish patina (Sherratt 1994, 257–259). Scholars hence recognized geographical differentiation between north and south of the Danube. In the north of the Danube there was first the Únětice Culture (2200-2000 B.C.) and then the Veterov Culture (2000-1600 B.C.), which has fortified settlements with clear features of metal production: slags, moulds, and ingots (Kienlin 2010; Krause 2003, 53–55). The most important cemetery is Böheimkirchen and Gemeinlebarn F. The burials had a sexual differentiation according to the orientation: males were oriented north/south and females south/north. From Gemeinlabern there are decorated axes, flanged axes, globular headed pins, and armrings (Cattin 2008; Neugebauer 1998).

To the south of the Danube there was first a group called Unterwölblinger (2200-1800 B.C), which still had sexually determined inhumations, not by goods but only by the orientation of the body (Harding 2000, 80). The most important sites of this culture are two cemeteries and a hoard. From the cemetery of Franzhausen II there is an important collection of metal artefacts, with more than a hundred pins, over 70 armrings and torques; from Unterwölbling there are disc headed pins, rolled headed pins, spiral headed pins, tiaras, beads, and *Ösenringe*. From the hoards of Ragelsdorf there are hundreds of artefacts, mainly

Ösenringe, spiral bracelets and flanged axes (Cattin 2008). In a second phase, corresponding to the final phase of the Early Bronze Age (1800-1600 B.C.) the Veterov Culture existed in this zone (Krause 2003).

In Istria there was a culture (Istra) with elements linked back to the Copper Age and even the Neolithic. Settlements were still in caves, and there was a tradition of tumulus burials. One of the most typical metal artefacts belonging to the Istra culture is the small triangular dagger, such as those found in Javorika (Mihovilic 2002).

7.2.5 The Early Bronze Age in the north of Italy

The Bronze Age in northern Italy marked a period when metal artefacts are no longer from burial contexts, but mainly from settlements. After the transition from the Copper Age to the Early Bronze Age, the evidence of metal production fell into decline, whereas metalworking is actually documented in numerous sites. Crucibles and moulds were found in Ledro (TN), Fiavè (TN), Malegno (BS), Colle del Lazzaretto (BG), and in the province of Belluno (Marzatico 2011).

The Polada culture in the Garda region is defined mainly by its settlements (lake-dwellings) and domestic pottery (de Marinis 2000; Montanari *et al.* 1996). Polada is possibly an evolution of the Bell Beaker culture, because, besides the burial tradition in caves, in some settlements considered as belonging to the first phase of Polada, elements of the Beaker culture have been recognised, such as some decorative motifs on pottery and copper awls (Marzatico & Tecchiati 2002; Montanari *et al.* 1996). But there are also authors who suggest a contribution of people from the Danube region (Fasani 2002). Based on the radiocarbon dates obtained from Lavagnone, de Marinis proposed a division of the Early Bronze Age that reflects the north Circum-Alpine division. In the first phase typical materials were flanged axes of Remedello, Torbole or Polada type; daggers with arched base, from 2 to 5 rivets, blades decorated with lines, the first metal hilted dagger, lunulae and oar headed pins. In a second phase there were metal hilted daggers and eyed headed pins, and in the last phase disc headed pins (de Marinis 1992).

The western part, from the Adda river, is differentiated from the Polada culture. It had elements that recall the Copper Age, in particular the pottery. For this reason, and because there are, in general, few archaeological remains, this zone has been considered as marginal with respect to the blossoming centre of the lake-dwelling archeological group of Polada (Mollo Mezzena 1997; Montanari *et al.* 1996). Metal objects, instead, had Bronze Age shapes that show links to the Rhône culture. Settlement traces are found in the highlands, probably linked with pasture or with metal ore exploitation (Del Lucchese 1998; Del Lucchese & Odetti 1996). Burial traditions are a further element of continuity with the Copper Age: some were in caves (Montanari *et al.* 1996, 68–73).

It seems likely that the further eastern zone of northern Italy has stronger connections with transalpine cultures (Gambari 1998, 65–71; Montagnari Kolelj 1994; Montanari *et al.* 1996). Even the settlement strategies are different from the eastern to the western part of Italy, because instead of dwelling villages there are settlements on drumlins, occupation of caves and, possibly, in the latest phase of the Early Bronze Age, there are the first appearances of hillforts, from which the Middle Bronze Age culture of this zone was named the "Castellieri culture" (Montanari *et al.* 1996, 63–68).

7.3 Discussion

It is undeniable that the archaeological framework of the Circum-Alpine region in the fifth to third millennia B.C. is very complex. This complexity may be summed up in a number of points:

- Many different cultures have been recognised, and there was often a chrono-spatial overlap between two or more cultures (for example the Corded Ware and Bell Beakers culture both interact with local cultures).
- The history of the research is fragmented, with different schools per country. This means that a synthesised, overall view is lacking.
- There is an uneven knowledge of the different cultures. This is for three main reasons: firstly, because of an uneven number of remains for the different material cultures; secondly because an uneven number of remains have been catalogued and studied. Finally, some cultures have a strong chronological framework based on radiocarbon dates, whereas in other cases the chronology is based only on typology, and only recently has been questioned in the light of new analysis (for example, the Copper Age in Italy, see Dolfini 2014b).

This situation may lead to certain confusion and it is undeniable that much more work should be done to synchronise the studies of different areas of the Circum-Alpine region. These uncertainties are reflected in this work: as explained in Section 8.1.2, to cope with them in a reasonable way, the results of analyses with different chronological frameworks is provided and the differences and the similarities of the obtained results are highlighted.

8 The construction of the database GIS and the tools used in this thesis

In Chapter 4 it has been explained that, in summary, GIS is a georeferenced database that gives the possibility to undertake calculations and statistical analysis. This Chapter explains the structure of the database used in this research and the tools used to undertake the ubiquity analysis and to test the depletion of arsenic in space, as explained in Chapter 3.

8.1 The Database

The first step of the research was the construction of the table for the main research database. This database incorporates all the information that has been acquired about the chemistry (Chapter 6) and the archaeology (Chapter 7) of the objects, in addition to information about the available copper mines in the study area (Chapter 5). This information, with the capability of the ArcGIS program, may be linked to the topography of the territory (Chapter 5). In the following Section there is a brief discussion of the structure of this database, and how some methodological issue have been dealt with. The database is composed of three different sections: a table of sites, a table of objects and a table of mines, which are presented as three appendices on the attached CD-ROM.

8.1.1 The Table of sites (Appendix I)

The table of sites records information on the locality where the objects were found. The principal fields are: the name of the site; the municipality in which the site is located; the type of the site, and the geographical coordinates. The most important field is the name of the site. "Name of the site" refers to the most common way to indicate a specific site in the archaeological literature and it is reported in the original language. This field is named as the "primary key" in SQL language, which means that it uniquely identifies each row in a table; therefore two sites cannot share the same "name of the site". In reality more than one archaeological site might have the same name. This is possible, for example, when at a particular place there is a settlement and a related cemetery. In this case the "Name of the Site" is created using the most common name in the archaeological literature plus a Roman numeral that uniquely identifies each specific site. In some cases the specific site of recovery of the material was not known. In these cases, usually a generic indication of provenance is provided such as "province of Turin" or "Lake Garda". In these cases, the small scale of uncertainty will not invalidate the consistency of this study, based as it is on a much larger scale; therefore the general geographical attribution was assigned as "name of the site". In other cases the uncertainty of provenance was unacceptable (e.g., the cases of "Italy" or "Central Europe", as here the area of uncertainty is equal to or larger than the area of the present research) and artefacts were not entered into the database.

The municipality is the smallest political unit where the site is located. In the case of generic attribution, the generic attribution was repeated in this field. It was recorded, as it is known in English, to allow the reader to easily recognise the geographical position of the site.

For the "type of the site" field a range of possibilities were considered: settlement, burial, megalithic burial, hoard, metallurgical hoard, single find, find in water, unknown, and not known. The distinction between burial and megalithic burial was set for two different reasons: firstly, the possibility of a link between different burial traditions and different metal compositions cannot be excluded. Secondly, megalithic sites often contain multiple burials, occurring in different periods. They are, in other words, open contexts, whereas single burials (both with inhumation and cremation rites) are closed contexts, which are universally considered to provide the most reliable chronological sequence as they only have one phase. Hoards are a closed group of objects, usually in pits. They were frequently composed only of one or a few categories of metal, such as *Ösenringe.* Some of them have been considered by the archaeologists as "metallurgical hoards", for example the ones that contain axes with an unusual shape and without use wear, such as the hoard of Pieve Albignola (de Marinis 2006a). The difference between "unknown" and "not known" is that "unknown" refers to material whose origin is unknown, as specifically recorded in the archaeological literature. This is the case of artefacts found by untrained people, for example farmers or workmen during civil excavations, and reported to authorities. "Not known" refers to artefacts whose origin the author has not been able to discover, and which further research might clarify.

The geographical coordinates were recorded as the authors included in the original research report. The main source of the geographical coordinates was Krause (2003), but cross-checking was undertaken, in particular for those regions that were not the main focus of Krause's research. This verification process revealed several mistakes for geolocation data in the Krause database. Most of the geographical references for the lake-dwelling villages are from http://www.palafittes.org/; the geographical coordinates for the megalithic burials were obtained from http://www.megalithic.co.uk/; the other sites' coordinates were checked with Google Earth. Different sources may give coordinates using different coordinate systems. In particular, data have been acquired in UTM, Gauss Kruger and WGS84. To maintain consistency in the database, only one coordinate system was used – WGS84 - and data expressed according to other systems were re-projected to WGS84 using the reprojection tool in ArcGIS.

8.1.2 The Table of objects (Appendix II)

Overall, 4732 chemical analyses undertaken on metal artefacts dating to the Neolithic/Copper Age or Early Bronze Age from the Alps were collected. The complete chemical database is provided in Appendix II (Table of Objects) on the CD-ROM. Chemical data were mainly acquired from Krause's database (Krause 2003) and related bibliography, with the addition of some other authors (Table 6). The unpublished analyses of 35 new objects (kindly provided by Peter

Northover) were also included. The chronology of these unpublished artefacts has been based on Pedrotti (2001), and also personal communication with A.L. Pedrotti.

Author	no. of objects	method
Angelini and Artioli 2007	3	EPMA
Angelini 2007	1	EPMA
Angelini 2004	1	SEM-EDS point analyses combined with DIP
Angelini et al. 2011	5	EPMA
Angelini and Salzani 2005	2	SEM-EDS point analyses combined with DIP
Ottaway 1982	70	NAA and AAS for Fe, Ni, Pb, Bi
Barfield (in de Marinis 2005)	1	?
Barfield and Broglio (in de Marinis 2005)	1	?
Berzero (in de Marinis 2005)	28	NAA and AAS for Cu and Pb
Budd 1991	2	EPMA
Hook 2003	2	ICP-AES
Höppner 2005	18	EDXRF
SMAP project	4	EDXRF
Mille PhD	39	?
Ghislanzoni (in de Marinis 2005)	1	?
SMAP project (in Krause 2003)	28	NAA
Kienlin 2008	70	AES
Leoni 1981(in de Marinis 2005)	1	OES
Marchesetti 1889 (in de Marinis 2005)	1	OES
Matteoli and Storti 1982	4	OES
Northover (partially published in de Marinis 2005)	92	EPMA
Otto and Witter 1952	229	AES
Pernicka 2011	64	EDXRF
Perucchetti unpublished MsC	11	EPMA
Rennes university in Krause 2003	33	?
Rieder in Krause 2003	11	?
Rychner and Kläntschi 1989	33	ICP-MS
SAM 1960-1974	3903	AES
Slater 1971	9	AAS
Louvre analysis in Krause 2003	40	?
Cattin 2011	7	LA-ICP-MS

Sperl in de Marinis 2006	1	OES
Turin museum in Krause 2003	1	?
Vien in Krause 2003	9	OES
Zürich museum in Krause 2003	4	?
? in de Marinis 2005	2	?

Table 6: summary of the references for the "table of objects".

The table of objects provides specific detail on the metal objects. It is formed by the fields "Analysis", "Object", "Objects_transated", "Type", "Site", "Age", the fields of the dimension of the object, chemical elements, "museum", "method", "Copper Group", "Type of metal", the ratio of lead isotopes and "bibliography". "Analysis" consists of an acronym for the person or group of people who undertook the analysis and the number of the analysis as it was first published.

The field "object" indicates which kind of artefact it is. Where possible, a brief description has been provided, both in the original language, as reported by the author of the analysis, and translated into English. Under "type", a specific three digit numerical code is assigned to each category of artefact, using the classification proposed by Krause (2003) (Table 7). In this classification, the first digit (the hundred unit) is a major typological group (e.g. '1' = axe), which is followed by a two-digit code for specific types within that typology. This thesis focusses mainly on the first digit of the classification: axes, daggers, ornaments and ingots, because statistical analysis requires a large amount of data (30 objects at least), which is not possible to achieve with finer subdivisions. At this broad level the classification should be considered as reliable, but it has been checked, when possible, with the available drawings from SAM and Otto and Witter's publications.

Most of the objects classified as axes or daggers have quite a general subclassification, which is reliable. For instance: most of the axes are simply flat axes or flanged axes without any further specification about the typology. As said, in this thesis the first level of analysis is a simple division into the main categories. Detailed consideration about the typology occurs only when specific anomalies in the broader picture are discussed (for example, axes of Salez type or the axes of Pieve Albignola).

The numerical classification was considered useful and convenient in order to perform quick searches based on the category of the artefacts. In fact, in an SQL query extracting a group of objects with similar characteristics, looking for a specific code is much simpler than looking for a description that can use different words to describe very similar objects. However there are some areas that could be improved. The least clear part of this classification is that which divides rings (defined by the code starting with 4) and sheet and wires (5xx). For instance, the lunulae of Les Places are arbitrarily divided into two categories: lunulae with the code 411 and lunulae with the code 512. Similarly unconvincing is the distinction of spirals into two categories (409, 416, 417 on one hand, 528-529 on the other), so objects in the 400 and 500 groups are considered as single group in this thesis. More generally, the broader classification of “ornaments” includes everything between 400 (rings), 500 (sheets and wires), 600 (pins) and beads (801, 803). The division between ornament-rings and ingot-rings is determined both from the typology, but also from the type of site, because the ingot-rings were found in hoards and ornament-rings in burials (Krause 2003).

Table 7: list of codes for different categories of artefacts, following Krause (2003):

Axes and chisels
101 = undetermined axe
102 = flat axe, undetermined
103 = flat axe, southern form
104 = flat axe, long (axe)
105 = flat axe, long (axe) with indented butt
106 = flat axe, crosswise (axe)
107 = flat axe, crosswise (axe) with indented butt
109 = flanged axe, cast blank
110 = flanged axe
111 = flanged axe with indented butt
112 = flanged axe with strips
113 = flanged with strips and indented butt
114 = Únětice axe
118 = spooned axe
119 = shoulder axe (?)
122 = shaft hole axe, single-edged
123 = hammer-axe
127 = double-axe
128 = cross-axe; cross-edged heel
129 = simple hammer
131 = axe-hammer
134 = flat chisel, wedged
135 = flanged chisel
136 = chisel

Daggers and swords
201 = flat dagger or dagger undetermined
202 = dagger with socketed hilt
203 = dagger with socketed hilt, knob
204 = dagger with socketed hilt, handle
205 = dagger with socketed hilt, rivet
206 = dagger with socketed hilt, blade
207 = halberd, staff, head
208 = halberd staff, butt
209 = halberd rivet
210 = halberd, blade
212 = dagger with midrib
213 = dagger, rivet
214 = handle
215 = grip-tongue dagger
216 = notched dagger
217 = dagger, type Cyprus
219 = long dagger or short sword
226 = plate sword with rivets

Spears and arrowheads, knives, sickles and saws
301 = spearhead, undetermined
302 = socket spearhead
307 = arrowhead, undetermined
310 = knife, undetermined
311 = knife, flat and straight
312 = knife, flat and bent

317 = sickle

Rings
401 = ring, undetermined
403 = Ösenhalsring
404 = ring fragment, usually arm ring
405 = arm ring, undetermined
406 = arm ring, closed
407 = arm ring, massive, wired
408 = armband
409 = arm spiral
410 = arm cuff
411 = lunula
413 = bumped ring, big; loop ring
414 = bumped ring, small; loop ring
416 = spiral, small
417 = spiral roll
418 = ring, small, open, wired

Sheets and wires
501 = strip
502 = strip, decorated
503 = copper tube
504 = plate sheet of metal, rolled on one side
505 = plate sheet of metal, rolled on both sides
506 = plate sheet of metal, multiply rolled
507 = pendant, undetermined
512 = lunulae
513 = ornament disc
514 = metal disc
517 = spiral
518 = flat brooch
519 = spiral brooch
521 = wire
522 = headband
523 = plate collar
525 = belt plate
526 = spiral of sheet
527 = wire
528 = Spiral; wired spiral; wired ring
529 = spectacle spiral
530 = spiral pendant

Pins
601 = pin, special form; Form undetermined
602 = pin staff
603 = disc-headed pin, small, no decoration
604 = disc-headed pin, big, decorated
605 = Horkheimer pin
606 = sleeve pin
607 = knot-headed pin, Cypriot
608 = clover-head pin
610 = roll head pin, simple
611 = oar headed pin
612 = three arms pin
613 = ring-head pin
614 = clover-head pin
615 = eyelet pin

616 = globular head pin, perforated obliquely
619 = rhombic-headed pin
622 = wheel head pin
623 = pin, Type Regelsbrunn
624 = nail head pin
626 = pin with massive head or staff
627 = cone head pin
628 = cone head pin, perforated horizontally

Ingots, casting residues and -forms, raw material, ore material
701 = ingot, special or undetermined form; raw material
702 = Ösenringbarren
703 = Ringbarren
704 = Spangenbarren
705 = Spangenbarren, flat
709 = axe-ingots
710 = copper cake
711 = piece of metal just cast, form undetermined;

Miscellaneous
801 = beads
803 = tube bead, olive form
806 = awl
807 = awl with eyelet
808 = metal pin; metal rod
809 = nail
811 = standard
814 = button

It is fundamental that, in the field “site”, the provenance of each artefact is exactly the same as the one that was inserted into the “Site” field in the table of sites. This correspondence allows the creation of a “one to many” relationship between the two tables so that each artefact can be linked to its site of provenance, associated artefacts, and its particular characteristics. The field “Museum” indicates the museum where the artefact is stored and, where possible, the inventory number. In the field “Bibliography” the publication of the chemical analysis and the object is stored.

8.1.2.1 The chronology

Establishing the chronology of the artefacts raises many issues because working with such a wide geographical area forces us to merge, simplify and often struggle with different schemes. One such issue regards the phase term "Copper Age": as mentioned above (Chapter 7.1) it is not universally recognised across the Alps, and in the northern zone the term "Late Neolithic" is preferred. In this research all the artefacts from the Late Neolithic/Copper Age (*circa* 3800-3600 B.C.) to the end of the Early Bronze Age (*circa* 1600 B.C.) were taken into consideration. The number of artefacts from the previous period was not sufficient to undertake statistical analysis. A finer subdivision of the Copper Age artefacts may be considered, according to the chronology proposed by some authors (e.g. de Marinis 1997 for the northern Italian Copper Age) but recent work demonstrates the inconsistency of this chronological framework (Dolfini 2010, 2013, 2014a, 2014b) and it was decided to maintain consistency by referring to all the objects belonging to the Copper Age, or Late Neolithic in the north of the Alps, simply as "Copper Age".

In the Early Bronze Age (as mentioned in Section 7.2.1) there is significant consensus between the different authors proposing chronological frameworks. The main remaining issue is not sequence or nomenclature but that different authors propose different absolute dates for the same objects. The main body of the database is formed by data from Krause 2003, which, in turn, is derived from the SAM database. The chronology attached to the SAM dataset published by Krause in 2003 was revised by him at that time (Krause 2003, 24), even though there are some inconsistencies (for example, in the database some metal hilt daggers are considered A1, whereas in the text it seems that the author considers them to be A2a). This chronological system has been confirmed by a series of papers focussing on specific regions, including the north Circum-Alpine region (Krause 1998, 2002). Indeed, this chronology is confirmed in other works on the northern Circum-Alpine metallurgy, such as Kienlin (Kienlin *et al.* 2006; Kienlin 2008).

In northern Italy the two main chronological sequences are the ones proposed by de Marinis (2005; 2006b) and Carancini (1996; see also Carancini & Peroni 1999). Since Carancini's framework has been questioned repeatedly, it was decided to disregard it for the purposes of this research. Moreover, de Marinis' chronology holds the distinct advantage of being comparable with Krause's, with the exception of certain objects from the Italian north-west. Similarly, the dates for western Switzerland there is also another chronology proposed by David-Elbiali (2000) which is significantly different from that proposed by Krause (2003) (see Table 8).

In this work an effort has been made to take into consideration the different dates provided by these scholars, and to explain how the subsequent interpretations differ according to each system. In any case, the chronology of the database should be taken as a relative chronology, rather than an attempt to completely revise the chronology of the metal artefacts in the Circum-Alpine region, an objective that is beyond the aims of this project.

	Dates B.C.	**Krause**	**David-Elbiali**	**De Marinis**

CA	≈4000-2200	10, 12, 15, 20, 22, 25	_	Neolithic/CA
A1	2200-2000	3	A1	A1a
A2a	2000-1800	4	A2a	A1b/A1c
A2b	1800-1600	5	A2b	A2

Table 8: chronological phases used in this work and correspondence with other authors

8.1.2.2 The analytical data

All the chemical elements recorded by the authors are included in the table. This means that even if an element that was detected only by one author it has been entered. The complete list of all the chemical elements recorded in the research database is Cu, Sn, Pb, As, Sb, Ag, Ni, Bi, Au, Zn, Co, Fe, Mn, Sr, W, Ir, Ru, Se, Te, O, Cl, and S. It is important not to enter anything if a laboratory has not analysed for that element. There is a difference between "0", which is a valid numerical value, and <NULL> that means "no data". In order to undertake geostatistical analysis, data must be expressed purely numerically, i.e., without symbols intended to convey semi-quantitative observations, such as +, <, > or ~. In the case of data published by Otto and Witter and Junghans *et al.,* such symbols were converted into numerical values using the system proposed by Ottaway (1982, XXIII) (Figure 25). In other cases a number of simple assumptions are made: where the symbol indicates the presence of an element as "trace" or "less than detection limits", the value of half the detection limit is assigned. So, if for an element the detection limit is 0.01%, 0.005% is assigned to substitute for "trace" or "<0.01". The original data are retained in the "notes" column.

	0.01% (except Bi & Au)	TRACE		+	++	+++	≥0.05%	≥1.0%	≥10%
		SAM	O&W						
Sn	–	0.01	0.01						15
Pb	0.005	0.002	0.005						15
As	0.004	0.002	0.005						
Sb	0.004	0.002	0.005						
Ag	0.005	0.002	0.005						
Ni	0.005	0.002	0.005						
Bi	0.0005	0.0002	0.001						
Au	–	0.0002	0.0002	0.0003					
Zn	0.005	0.002	0.005						
Co	–	0.005	0.005	0.008	0.03	0.05			
Fe	–	0.001	0.001	0.02	0.03		1.5	3.0	

Figure 25: correspondence between symbols and numbers, from Ottaway (1982).

The field "method" records the method of analysis used by the scientist. One may question the practicality and wisdom of including incomplete and old data within a single database (see Table 6). Analyses undertaken with older techniques may not be as accurate and precise as modern methods, and almost universally calibration and secondary standard data are not given in journal publications. Pernicka (1986) considered this question in the context of the feasibility of using the SAM data, which were obtained using OES (Junghans *et al.* 1960, 1968, 1974), and concluded that they are comparable with data obtained by modern techniques, such as electron probe micro-analysis (EPMA). Firstly he pointed out that the method of sampling and the size of samples of SAM (40 mg) was good enough to have a proper representation of the artefacts, even taking into account the heterogeneity of metal objects (Pernicka 1986, 24–25). The sensitivity has been established as sufficient: SAM data has a detection limit of ng/g; Pernicka recognized that, actually, this was lower than necessary for the purpose of using trace elements to determine the provenance, because, "at such low levels, many elements tend to be ubiquitous" (Pernicka 1986, 25). Pernicka also claimed that the precision of SAM was enough to be able to undertake consistent cluster analysis. Indeed, the variation of weight percent of trace elements in ancient artefacts is so high that groups of artefacts may be sorted out even with low precision data (Figure 26). Pernicka verified that cluster analyses undertaken on the same set of objects analysed with a precision of 30% and of 5% have given similar results (Pernicka 1986, 25). The SAM samples were at that time still available for more analyses to be undertaken, and therefore their results were compared with the results obtained by his own group in Heidelberg, showing a good correlation (see Figure 27) and accuracy (Pernicka 1986, 26).

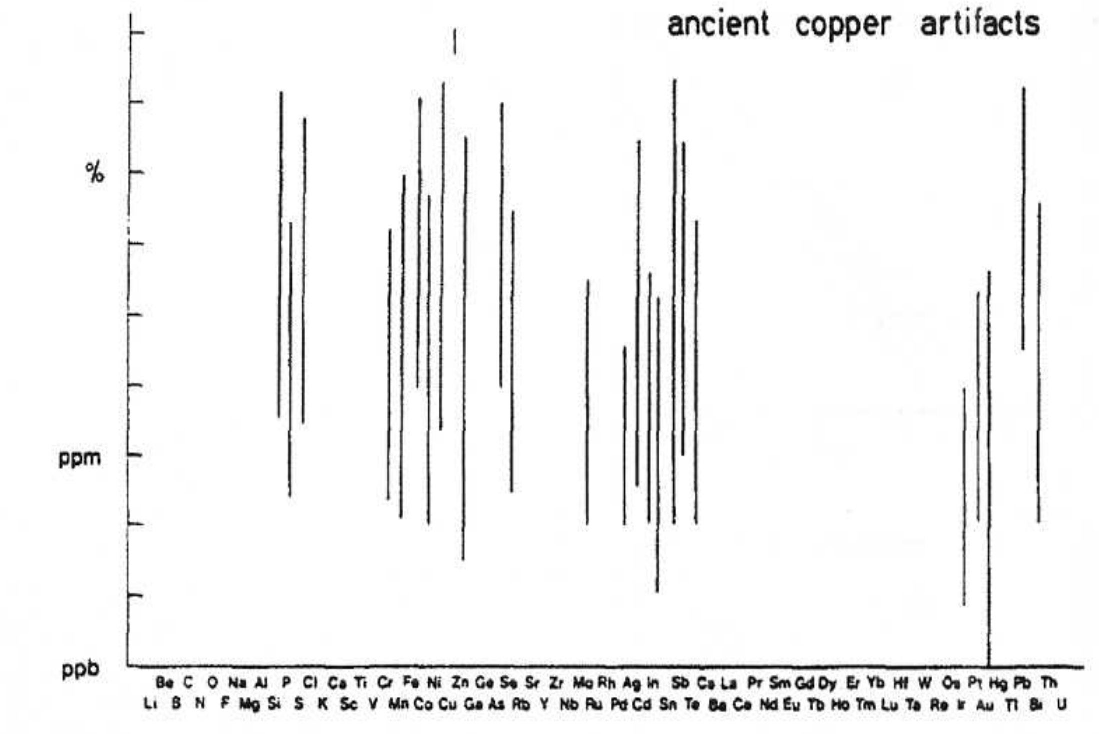

Figure 26: variation of percentage in weight of trace elements in ancient artefacts from Pernicka (1986, fig.1).

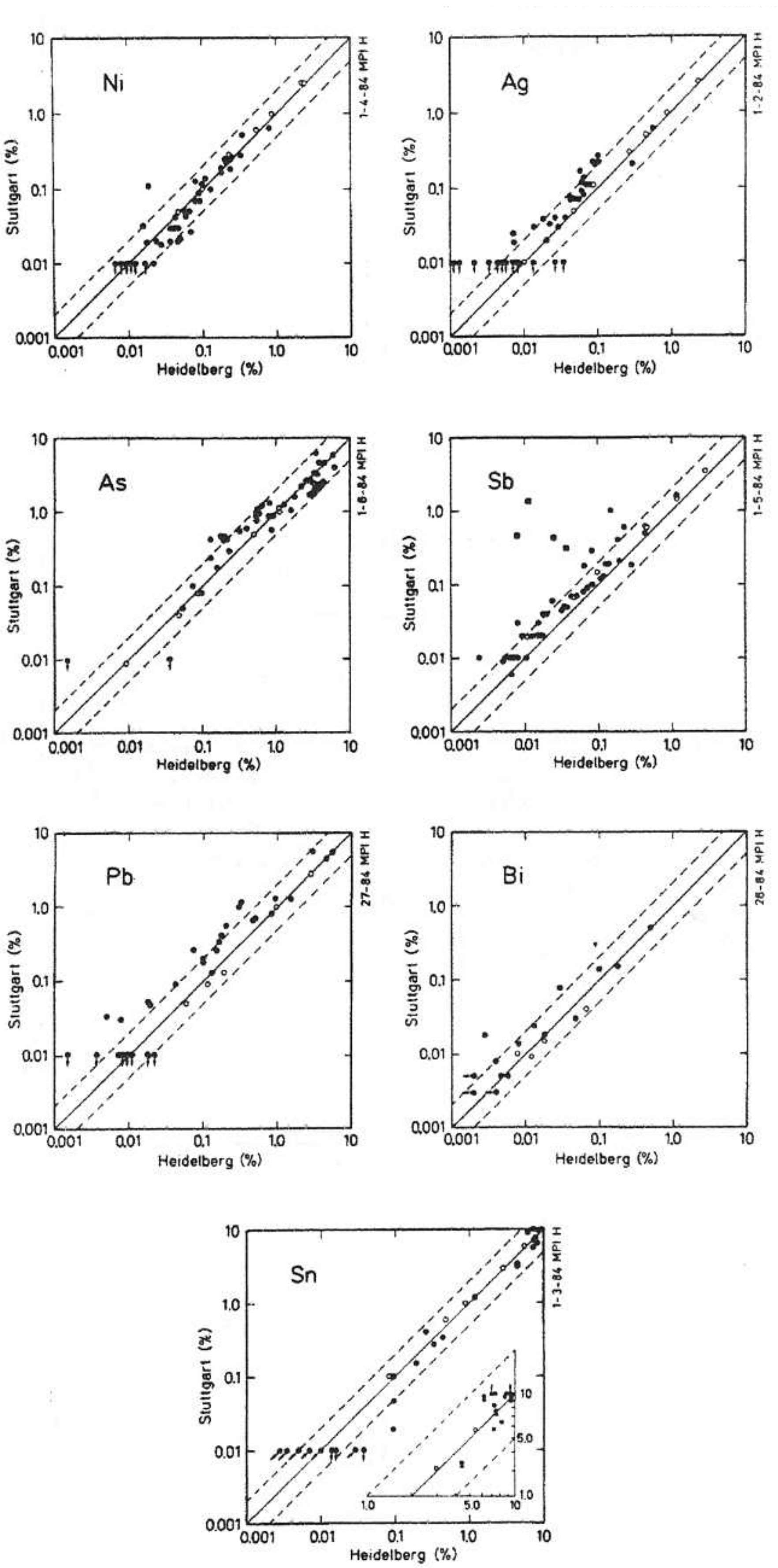

Figure 27: comparison of SAM and data obtained in Heidelberg from Pernicka (1986, fig. 2).

Rychner and Northover (1998) also undertook a comparative study of the several techniques used to analyse ancient metal artefacts. The results obtained with optical emission spectroscopy (OES), inductively coupled plasma atomic emission spectroscopy (ICP-AES), atomic absorption spectroscopy (AAS), X-ray fluorescence (XRF), electron probe micro-analysis (EPMA) and neutron activation analysis (NAA) were compared and the authors concluded that "The modern analytical techniques are capable of producing accurate, reproducible data that can […] be used interchangeably with other data and behave similarly in cluster and classification" (Rychner & Northover 1998, 31). According to Rychner and Northover the accuracy of XRF was more problematic, since the interlaboratory comparisons showed quite a wide range of results. Lutz and Pernicka (1996) also compared data obtained with a portable XRF and those obtained with NAA, demonstrating a general comparability between the two sets of results. It seems likely that the problems faced with XRF by Rychner and Northover were due more to human mistakes in different laboratories rather than an essential deficiency of the technique. Finally, Merkl (2011, 89; fig. 8.4, 8.5) undertook principal components analysis (PCA) on data obtained by Otto and Witter, the SAM group, and Krause, and presented the results in a scatter plot. He observed that analyses on the same objects by different laboratories are usually clustered together. The few outliers were identified as individual errors of measurement. It may be concluded that, within limits, data obtained by different methods, by different laboratories, and at different times, can be compared.

8.1.2.3 Copper Groups

In this research it has been decided to not analyse the chemical composition data using cluster analysis, which, since Ottaway (1982), has been the most common method used on metal artefacts. As explained in Section 3.2.1, this procedure obscures useful archaeological structures in the data, associated with recycling, oxidative loss linked with use, mixing, alloying, and so forth. In this thesis the grouping technique explained in Section 3.2.2 has been used to sort the chemistry of the objects. Two programs were created to calculate the groups. First, the program of Appendix IV normalise data to 100% after the subtraction of tin, as explained in Section 3.2.2. The second program (Appendix V) allocates each artefact to a compositional group based on the presence/absence of As, Sb, Ag and Ni. The threshold to define the presence of an element can be set by the user of the program, filling a dedicated field. In this thesis, the threshold was set at 0.1% (Figure 28). The result of the calculation is a series of maps, divided according to the time period and the chemical group.

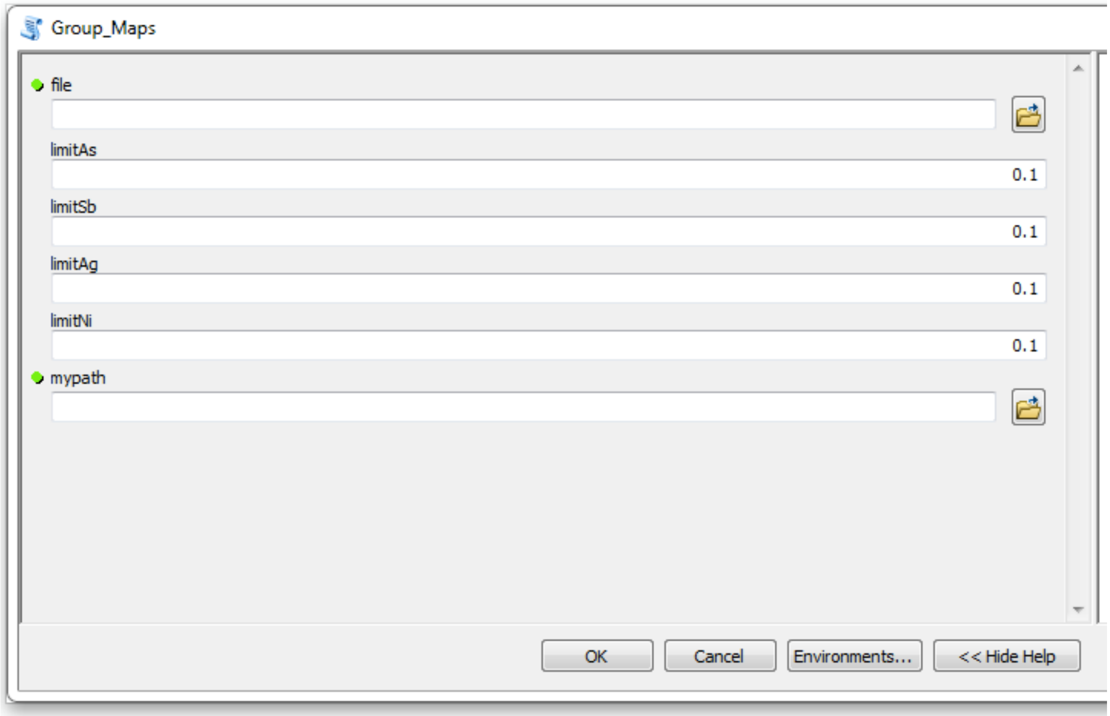

Figure 28: dialague box of the program "Grouping" in Appendix V.

In Appendix II, the field "Copper Group" shows to which Copper Group each object is assigned. There is also a further field - "Type of metal" -, which indicates if the object is made of pure copper, arsenical copper, tin bronze or *Fahlherz*.

8.1.2.4 Lead Isotopes

Finally, the lead isotope field records information about the ratios Pb^{208}/Pb^{204}, Pb^{207}/Pb^{204}, Pb^{206}/Pb^{204}, Pb^{208}/Pb^{206}, and Pb^{207}/Pb^{206}. Unfortunately the number of artefacts analysed by lead isotope ratio is at the moment too small to allow regional analysis in the Circum-Alpine region. Nevertheless, the proposed database aims to be the starting point for future research, and consequently data that could have interesting future applications, like isotope ratios, have been included.

8.1.3 The Table of mines (Appendix III)

This table (see Appendix III) provides information about the possible mines in the Alpine region. The information are acquired from the literature, more specifically from Artioli *et al.* (2008); Bourgarit *et al.* (2010); Cattin *et al.* (2011); Giunti (2011); Goldenberg (1998); Höppner *et al.* (2005); Pearce (2007), and Tropper & Vavtar (2009). For each mine there is information about the name and location of the mine, the minerals present (abbreviated according to Siivola & Schmid (2007)), the principal impurities in the copper, the type of mineralization and name of the parent mineralized zone.

8.2 Geostatistical Analysis

In this paragraph the tools used to undertake ubiquity analysis and geostatistical analysis (see Section 3.2) are presented. The first is a tool specifically created (Appendix VI) and explained here. The second is a tool already present in the ArcGIS 10.2 package.

8.2.1 "Percentage P1": the tool for ubiquity analysis on Copper Groups

The tool for the ubiquity analysis requires as an input a table that has a field with the 16 Copper Groups of presence/absence (see Table 2), calculated as explained in Section 3.2.2. The second input required is a polygon map. This polygon map could be a grid (for example a grid that divides the map into 2 columns and 2 rows) or another type of polygon (as, for example, fluvial basins, or modern political boundaries). For each polygon of the polygon map, the program calculates the percentage of presence of each of the 16 Groups.

The choice of the polygon map is an issue linked to the MAUP problem (see Chapter 4). In this thesis, after some empirical attempts, it has been decided that the most fruitful polygon map that best shows the differences of distribution of the elements is a grid, in which each square is 1° longitude x 1° latitude on the WGS84 Coordinate system, and this is the unit used in Chapter 9, 10 and 11. This choice allows most of the squares to be populated by at least four objects and, at the same time, the squares are small enough to catch some interesting local variation (such as a hoard with a peculiar composition). In Section 12.1 the same tool has been used with the drainage basins as polygons and the results of the two aggregating systems are compared.

8.2.2 "Percentage Element": the tool for ubiquity analysis on a specific element

The operation of this tool is very similar to that in the previous Section, but, instead of having four preset elements (As, Sb, Ni, Ag), the user decides which element is to be analysed. Similarly to "Grouping" (Appendix V), the user is also able to determine the threshold that indicates if the element is "present" or “absent”. In this thesis the element chosen is tin and the threshold of presence is 1%. The spatial distribution of alloys with tin can give us a range of insights: it can help us to identify the possible routes of tin movement, the possible provenance zone for the tin itself, and it can highlight which of the Circum-Alpine cultures were more receptive to the adoption of the tin-copper alloy.

8.2.3 Geostatistical Analysis of arsenic depletion

After ubiquity analysis, the second step is to consider arsenic and its distribution in space and time. In order to achieve this each Copper Group that contains arsenic must be considered. For each group, geostatistical analysis is undertaken to verify whether arsenic is geographically randomly distributed or if there are zones with significantly higher or lower levels of arsenic: a pattern that may be an indicator of recycling activity, as hypothesized by Bray and Pollard (2012). For each Copper Group containing arsenic, two geostatistical analyses have been undertaken: Spatial Autocorrelation Global Moran’s I and Anselin Local Moran’s I. Global Moran’s I determines if the level of an attribute is somehow dependant on space, or if the values of an attribute (in this case arsenic) are randomly distributed.

The formula for Global Moran’s I is

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

and S_0 is

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}$$

Where n is the number of objects, z indicate the deviation of the attribute of the objects *i* taken into consideration from the mean (in this case, arsenic), $w_{i,j}$ is a function to weight the distance between the object i and its neighbours (the objects j) (typically, the inverse of the Euclidean distance), j are all the objects in a radius defined by the maximum of the minimum distance calculated per each object in this dataset. In other words, I is defined as the sum of the cross product of the deviations of each objects and their neighbours from the mean weighted according to the distance.

The z score indicates if there is a spatial correlation:

$$z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}}$$

Where:

I is the result of the I function on the observed values and E [I] is the expected values of I. The threshold for E[I] is given as:

$$\mathrm{E}[I] = -1/(n-1)$$

V [I] is given as:

$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2$$

and E [I^2] is:

$$\begin{aligned}
\mathrm{E}[I^2] &= \frac{A - B}{C} \\
A &= n\left[(n^2 - 3n + 3)S_1 - nS_2 + 3S_0^2\right] \\
B &= D\left[(n^2 - n)S_1 - 2nS_2 + 6S_0^2\right] \\
C &= (n-1)(n-2)(n-3)S_0^2 \\
D &= \frac{\sum_{i=1}^{n} z_i^4}{\left(\sum_{i=1}^{n} z_i^2\right)^2} \\
S_1 &= (1/2)\sum_{i=1}^{n}\sum_{j=1}^{n}(w_{i,j} + w_{j,i})^2 \\
S_2 &= \sum_{i=1}^{n}\left(\sum_{j=1}^{n} w_{i,j} + \sum_{j=1}^{n} w_{j,i}\right)^2
\end{aligned}$$

The z_i score indicates if the NULL hypothesis should be retained or rejected. The level of confidence is given in the table below:

z-score	p-value (Probability)	Confidence level
< -1.65 or > +1.65	< 0.10	90%
< -1.96 or > +1.96	< 0.05	95%
< -2.58 or > +2.58	< 0.01	99%

Table 9: table that indicates the correspondence between the z-score and their level of statistical significance

Providing that the distribution was not random (i.e. the z value was <-165 or>1.65), then if the values of z_I are positive there is a positive spatial correlation (namely there are spatial clusters of either high or low values). If the values of z_I are negative there is a negative spatial correlation (namely the values are dispersed) (Mitchell 2005).

This analysis is *global*, namely it takes into consideration all the records of a database and gives information of the global distribution of these records in space. The Anselin Local Moran's I statistic of spatial association is a "local indicator of spatial association" (Anselin 1995). Instead of having a global index for the global spatial distribution of a specific value (say, arsenic), here there is a function resolved for each object *i* in the dataset, defined as:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j}(x_j - \bar{X})$$

Where S_i^2 is

$$S_i^2 = \frac{\sum_{j=1, j\neq i}^{n} (x_j - \bar{X})^2}{n-1} - \bar{X}^2$$

Similarly to the Global Morans' I, the z_{Ii} score indicates if there is spatial autocorrelation, and it is defined as:

$$z_{I_i} = \frac{I_i - \mathrm{E}[I_i]}{\sqrt{\mathrm{V}[I_i]}}$$

where:

$$\mathrm{E}[I_i] = -\frac{\sum_{j=1, j\neq i}^{n} w_{ij}}{n-1}$$
$$\mathrm{V}[I_i] = \mathrm{E}[I_i^2] - \mathrm{E}[I_i]^2$$

$E[I_i]$ is the expected value for I_i and I_i the observed value.

E [I_i^2] is calculated according to the following formula:

$$
\begin{aligned}
\mathrm{E}[I^2] &= A - B \\
A &= \frac{(n - b_{2_i}) \sum_{j=1, j\neq i}^{n} w_{i,j}^2}{n-1} \\
B &= \frac{(2b_{2_i} - n) \sum_{k=1, k\neq i}^{n} \sum_{h=1, h\neq i}^{n} w_{i,k} w_{i,h}}{(n-1)(n-2)} \\
b_{2_i} &= \frac{\sum_{i=1, i\neq j}^{n} (x_i - \bar{X})^4}{\left(\sum_{i=1, i\neq j}^{n} (x_i - \bar{X})^2 \right)^2}
\end{aligned}
$$

In this case, the NULL hypothesis is referring to each i object and indicates that the values of i is as similar to the values of the surrounding neighbours as it would be if the objects of the dataset were randomly distributed. If the NULL hypothesis may be rejected, then a positive value of z_{Ii} indicates that the values of i are significantly similar to the other ones of the dataset, or, in other words, this indicates if the object i is part of a spatial cluster of high or low values. A negative value of the z_{Ii} values indicate the objects have a statistically significantly different value from the ones of its neighbour, or, in other words, it indicates if it is an outlier with low values in a zone of high values or with high values in a zone with low values. The level of confidence is the same as in Table 9.

A few observations should be noted.

- The sum of the local indicators is *proportional* to the global indicator, but it may happen that there are *local* patterns that disappear when the entire global dataset is taken in consideration (Anselin 1995). In these cases it is good to look carefully at the meaning of those patterns;
- In order to have reliable results both for the Global and the Local Moran's I tests the dataset should have at least 30 objects (Mitchell 2005);
- Both for the Global and the Local Moran's I assume that the distribution of the value taken in consideration (in this case arsenic) has a normal distribution.

In this case, arsenic does not always have a normal distribution. A future proposal to improve the use of GIS in archeometallurgy is writing a code that allows one to undertake non-parametric analysis, using the median instead of the mean. In this work the pre-set tools of ArcGIS 10.2 were used, whilst being conscious of possible bias. For each case the normality and the log-normality of the distribution has been tested and the distribution that is closest to normal has been used to undertake the Global and the Local Moran's I test.

9 The Flow Model in The Copper Age

In Chapter 3 a new model to study ancient metallurgy has been described. This model is an attempt to answer the question of how metal was really used and perceived by people, and how it moved though time and space. It was explained that, for the work undertaken here, the methodology for this new model is a two-step analysis: on the one hand, the analysis of the distribution of different metal groups though ubiquity analysis, and on the other hand, the analysis of the spatial distribution of arsenic.

For the entire Copper Age (see Section 8.1.2.1) a series of maps that show the result of the ubiquity analysis are presented, one for each of the copper groups that were present. The maps are produced using the dedicated program created for this thesis (Appendix VI), and the geostatistical analysis, as explained in Section 8.2. In the resulting maps, the percentages of presence are visually indicated with a range of colour shades. A minimum threshold of four objects per areal unit was imposed to ensure the results are statistically meaningful; therefore zones that have less than four artefacts are left blank. The information about the location of the artefacts is provided in the maps with dots, whose size indicates the real number of objects.

A second set of maps is created for Copper Groups that contain arsenic (see Section 8.2.3). Black dots indicate those sites where there is a spatial cluster of high levels of arsenic. White dots are sites where there are low levels of arsenic in a zone characterised by a high level of arsenic. Blue dots indicate a spatial cluster of low level of arsenic. Yellow dots indicate outliers with a high level of arsenic in a zone with low level of arsenic (Figure 34 and Figure 36).

The extent of archaeological cultures (see Chapter 7) is superimposed on the maps. This allows discussion of possible "cultural barriers" in the movement of metal and about the importance of the tendency of a culture to reject or accept different metal compositions. In those cases where the distribution pattern of a single category of artefact (dagger, axe, ornaments, ingots) is significantly different from the general pattern, a map for the single category of artefact is provided and discussed.

As explained in Section 7.1 the Copper Age in the Circum-Alpine region is characterized by a complex picture where local cultures emerge together with some pan-European phenomena. The chronology of the region is more securely agreed in the northern zone, in particular in Switzerland, whereas in Italy is still debated. As explained in Section 8.1.2.1, in this thesis all the artefacts from approximately 3600 to 2200 B.C. are grouped together. Consequently, any short-term, local phenomena are not visible, but, on the other hand, it is possible to better appreciate the general patterns that endure for more time. Figure 29 shows the deposition of metal in the Copper Age, divided into metal associated with human burials in caves, cemetery burials, and settlements.

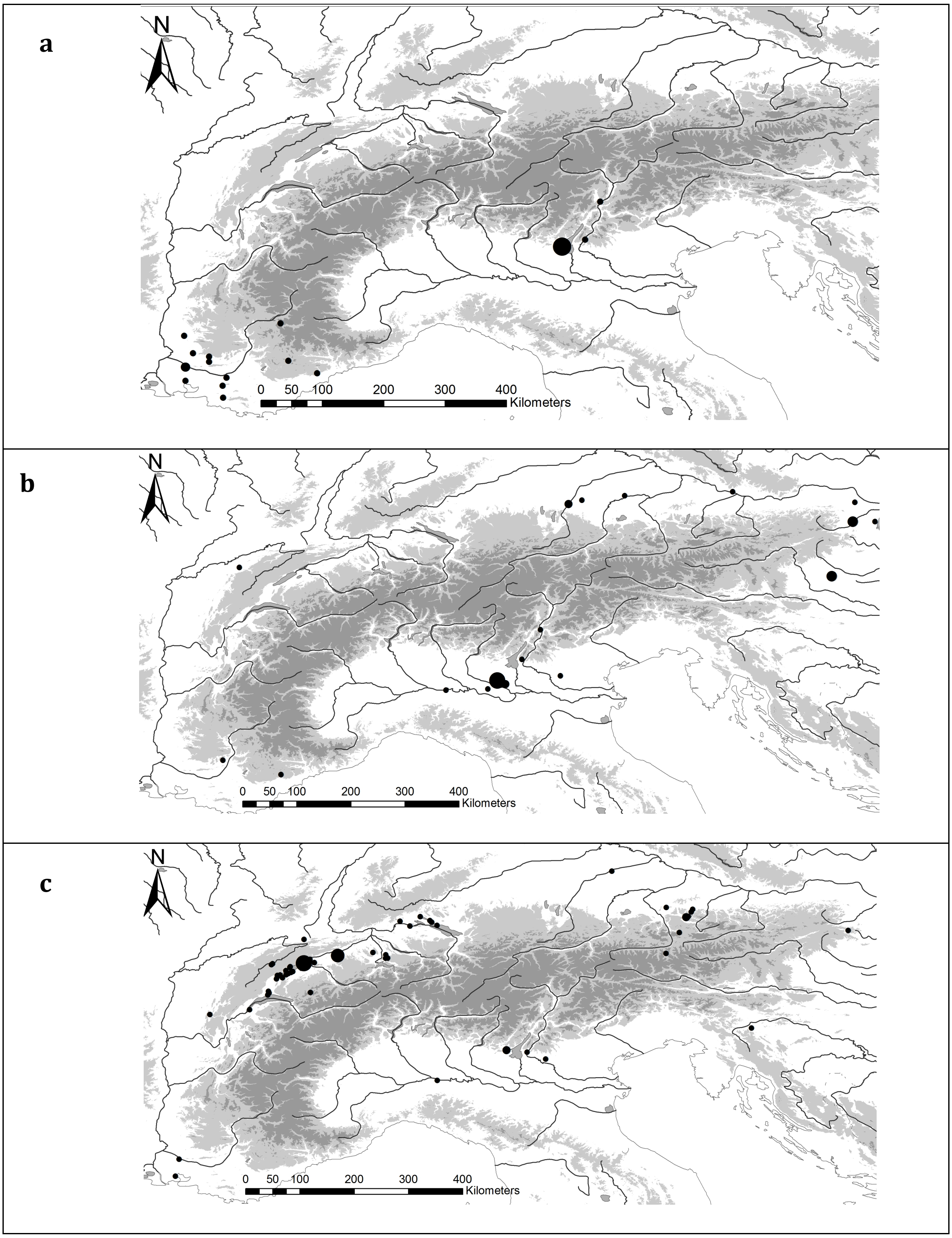

Figure 29: from above: (a) map of burials in caves, (b) burials in graveyard and (c) settlements in the Copper Age. The size of dots is proportional to the number of metal objects.

The distribution of objects depends on the different cultures. In particular, in Switzerland and southern Germany there were a significant number of metal objects from settlements, in particular St. Blaise, Vinelz from the Corded Auvernier culture. In France, Italy and Austria the presence of metal was more related to burials than in France. In Trentino (in correspondence to the "facies of Vecchiano") there were multiple burials in caves, whereas in the Po valley and in Austria there were single burials, in particular from the Remedello culture and its homonymous cemetery.

In the Copper Age a wide variety of different compositions are well represented. Considering the entire region, roughly 55% of all the analysed metal artefacts are made of either clean copper (Group1) or copper with traces of arsenic (Group 2) (see Table 2). The remaining artefacts show other combinations of arsenic, antimony, silver and nickel: at least seven different Copper Groups, including pure copper and arsenical copper, are well represented, in a range of 8% (Group 9) to 4.3% (Group 7) (Table 10). Other groups are populated at below 5% ubiquity.

Group1	Group2	Group3	Group4	Group5	Group6	Group7	Group8
127 (24%)	170 (32%)	10 (1.9%)	34 (6.4%)	40 (7.5%)	9 (1.7%)	23 (4.3%)	5 (1%)
Group9	**Group10**	**Group11**	**Group12**	**Group13**	**Group14**	**Group15**	**Group16**
42 (8%)	1 (0.2%)	18 (3.8%)	11 (2.1%)	4 (0.8%)	8 (1.5%)	7 (1.3%)	24 (4.5%)

Table 10: number and percentages of objects per compositional group (see Table 2) in the Copper Age.

9.1 Copper Groups 1 and 2

The graph of arsenic in Group 1 and Group 2 confirms that they are two specific copper groups and that Group 1 is not just the tail of Group 2, as a result of setting the limit of presence of 0.1% to define copper groups (Figure 30).

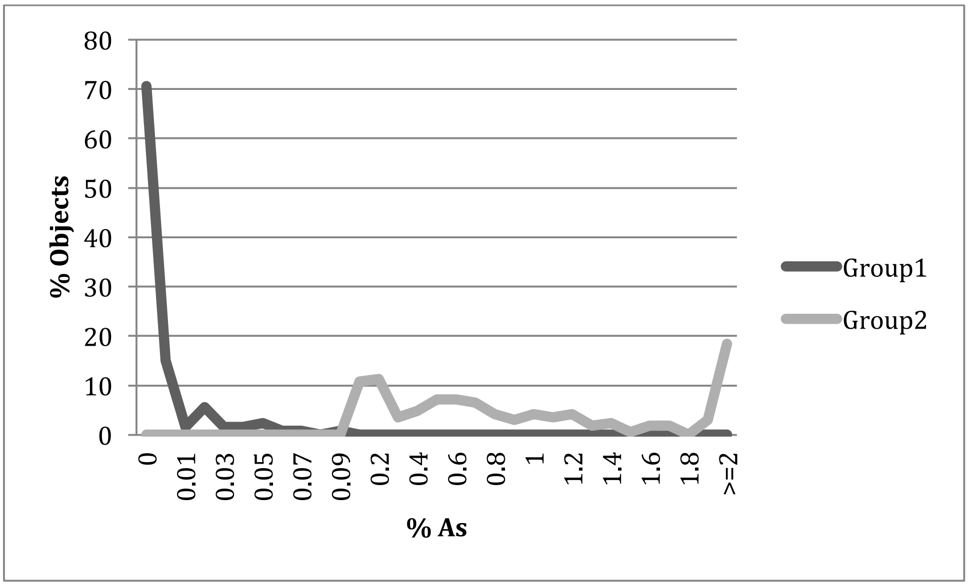

Figure 30: percentages of objects made of Copper Group 1 and Group 2 per level of arsenic in the Copper Age. Copper Group 2 has a bin width of 0.1 because it has, by definition, >0.1% of As. For Copper Group 1, which has <0.1% of As, a 0.01% bin witdh has been chosen.

The spatial distribution of the compositional groups is not homogenous, but reflects a geographical preference. Figure 31 shows a series of pie charts with the main composition in the different zones of the Alps. If a zone is not populated with at least four artefacts it is not represented.

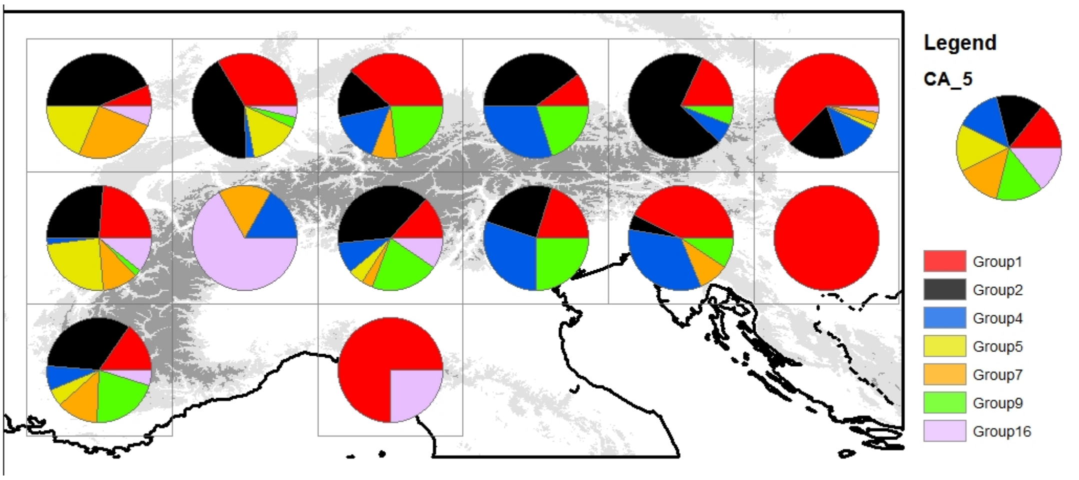

Figure 31: pie charts showing the percentages of objects made with different compositional groups in different zones in the Copper Age.

It is clear that artefacts made of pure copper and arsenical copper are distributed throughout the Alps, but the map shows slight east-west differences that may be significant: whereas arsenical copper (Group 2) is more dominant in the western part, pure copper (Group 1) predominates in the further east (Figure 32 and Figure 33). In general, in the western part there are ≈ 20% of artefacts made using pure copper and ≈ 30% in arsenical copper, whereas in the eastern part these percentages are reversed. So, the zones more influenced by the Vučedol culture are the ones with the least percentage of objects made of arsenical copper.

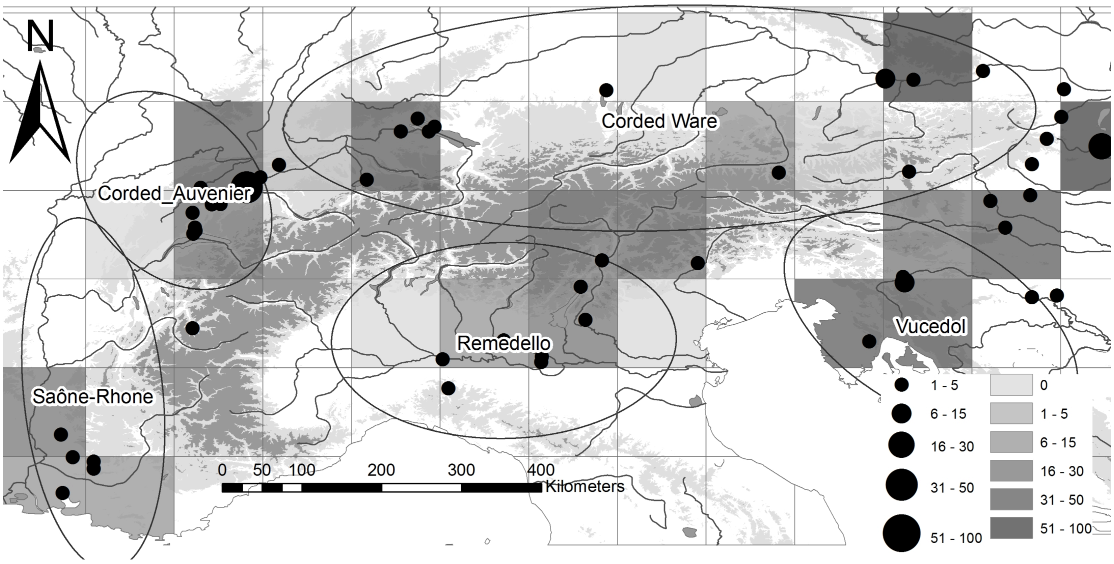

Figure 32: percentages of objects made of Copper Group 1 per zone in the Copper Age. Blank squares indicate that there are not enough objects to undertake statistical analysis, with a minimum threshold set at 3 objects. The size of dots indicates the number of objects made with this composition. There are a slightly higher percentage of objects made of pure copper further east, and the percentage decreasing going west, with a further hotspot in Switzerland.

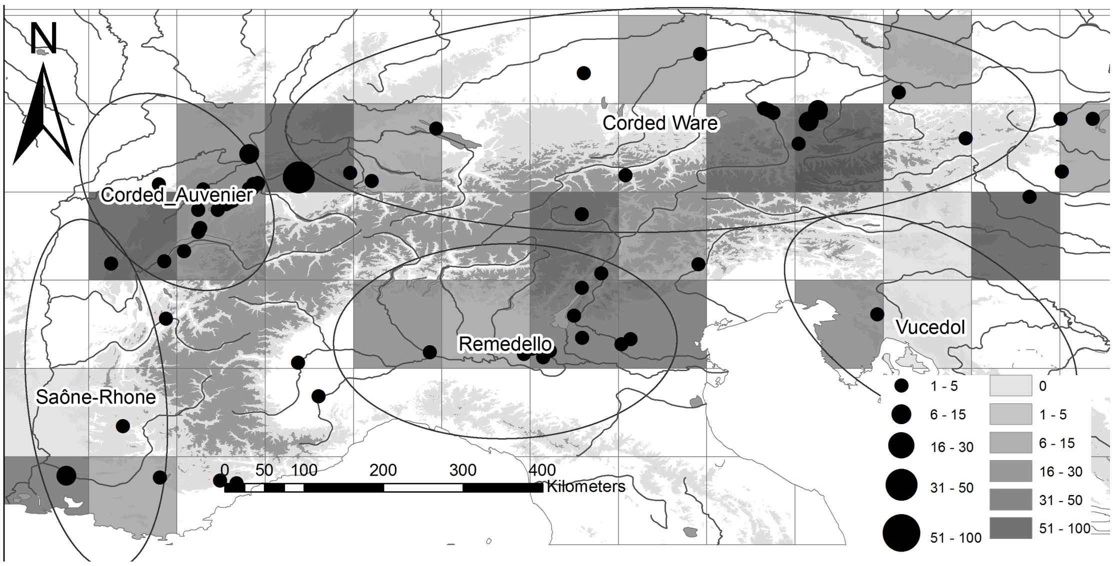

Figure 33: percentages of objects made of Copper Group 2 per zone in the Copper Age. Map symbols are as in Figure 32. There is a slightly higher concentration of Copper Group 2 in the west, which creates an approximate mirror image of Figure 32.

This is also true when considering different categories of artefacts, such as axes and daggers. Ornaments with arsenical copper are less well represented in general, and this is true even in the western part of the study area.

9.1.1 Spatial Distribution of Arsenic in Copper Group 2 (Copper with As) Metal

There were a total of 174 objects with this composition: 61 axes, 27 daggers, 13 awls, 64 ornaments, six halberds and three unidentified fragments. The analyses were undertaken using a log-distribution. The Global Moran's I Spatial Autocorrelation indicates that there is a geographically randomly distribution of arsenic. The Anselin Local Moran's I Cluster and Outliers analysis was able to pinpoint clusters of high and low levels of arsenic: the clusters of high percentage of arsenic are defined in north-eastern of Italy; in the north-east of the Alps there are clusters of low percentage of arsenic (Figure 34).

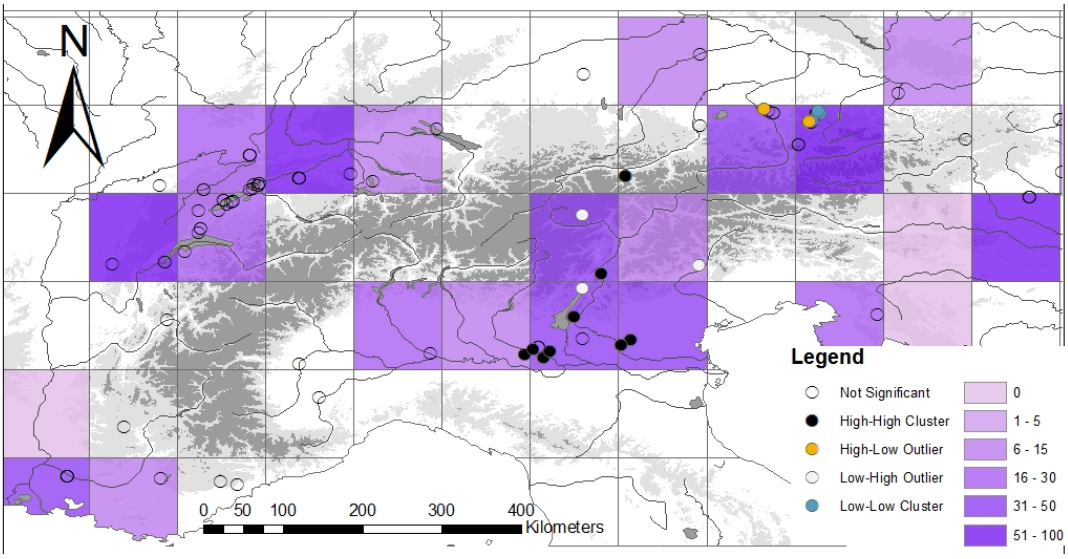

Figure 34: comparison between the percentages of objects made with Copper Group 2 per zone and the result of Anselin Local analysis on arsenic level in objects.

This result is due mainly to the distribution of halberds that have a much higher average percentage of arsenic than all other categories (Figure 35).

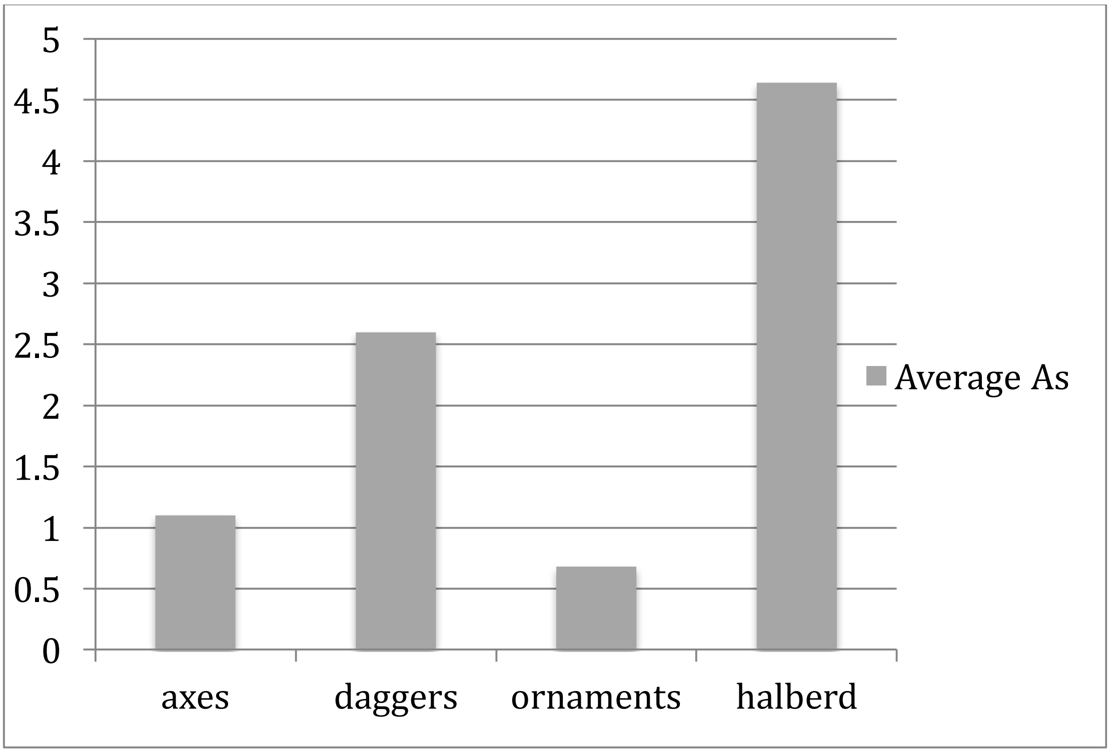

Figure 35: means of the percentage of As per category of artefact.

Halberds are solely focused in the north-east of Italy, explaining the spatial cluster of high levels of arsenic in that zone if the entire assemblage of artefacts is taken into consideration. If the single categories are considered, the picture of spatial clusters of arsenic changes significantly. There are too few halberds and daggers to undertake analysis for these items. Figure 36 shows that axes have clusters with high percentages of arsenic in the north-west, and clusters with low levels in the north-east: this latter is the same region where clusters with low levels are manifest when undertaking the analysis using the entire assemblage. Finally, ornaments do not have any spatial clusters with high or low percentages of arsenic.

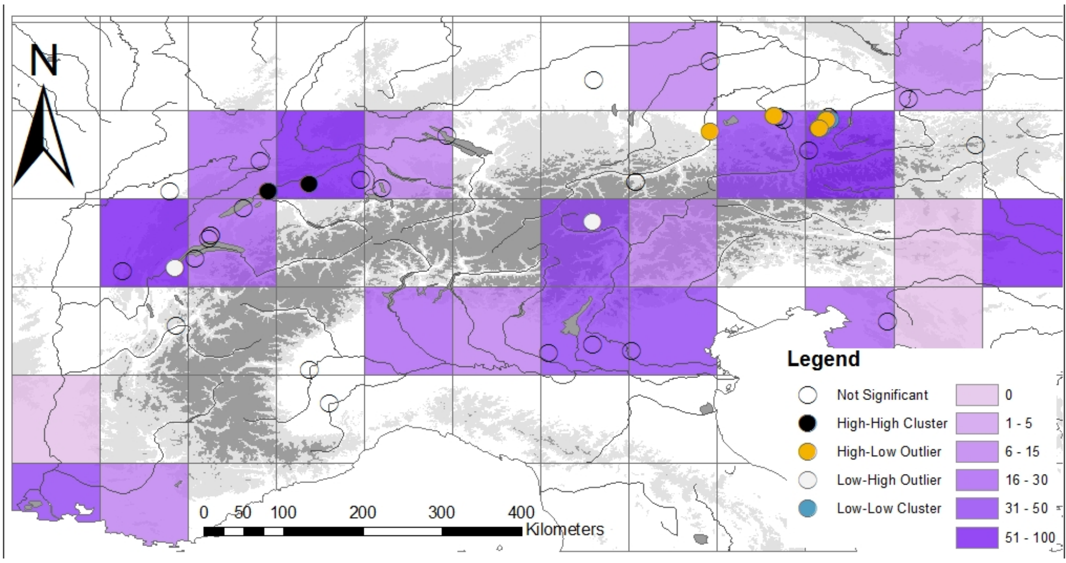

Figure 36: comparison between the percentages of axes made with Copper Group 2 per zone and the result of spatial analysis on arsenic level in objects.

Figure 37 compares the level of arsenic for each category of artefact. The difference between axes and ornaments on the one hand and daggers on the other is clear: the first group has peaks at lower levels of arsenic, with a significant switch to the lowest in the case of the ornaments, and daggers have a peak in the highest concentration. Halberds are not even inserted into the graph because their peak in the last bin was so high (66%) that it was off scale.

Axes have a specific high arsenic spatial cluster in the western region and clusters of low levels of arsenic in the east. It can be argued that artefacts which show a depletion in arsenic levels may be testifying to the effects of metal reworking which increases from the western to the eastern region of Europe.

Finally, ornaments have very low levels of arsenic, which are not spatially clustered. Most of these artefacts were simple beads and perhaps (because of the low arsenic) they may be considered as being produced from heavily recycled and remixed material.

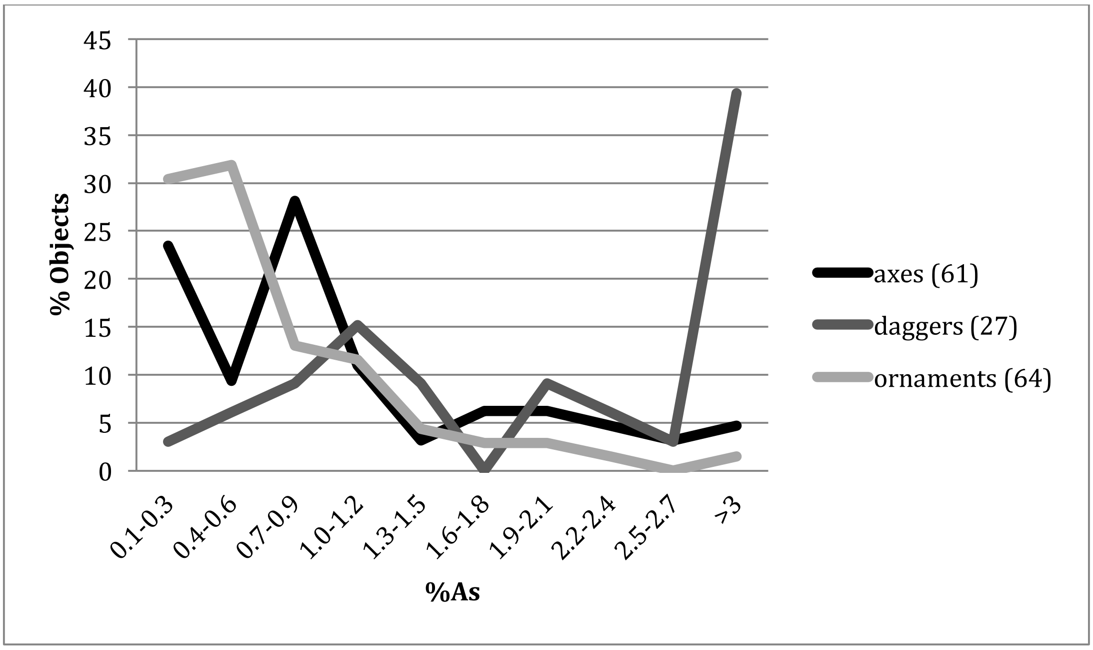

Figure 37: percentages of objects made of Group2 per level of arsenic in the Copper Age.

9.2 Copper Group 5 (Copper with Ni)

Group 5, characterized by the presence of only nickel as a trace element, is typical of Switzerland, and of the Corded-Auvenier culture (see Figure 38). In the Copper age there were three axes, nine daggers, 18 ornaments and eight awls made of this composition. The same kind of composition is found also in the southern part of the Alps, in the Copper Age cemetery at Sabbione (Pearce 2007, 85) (Berzero 18 and 19 in Appendix II).

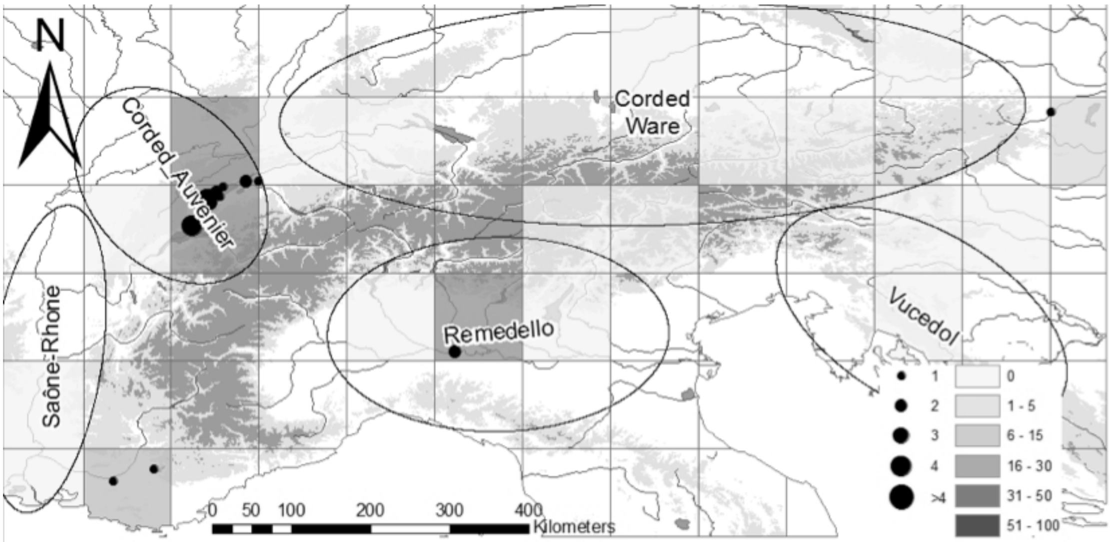

Figure 38: percentages of objects made of Copper Group 5 (nickel only) per zone in the Copper Age, as in Figure 32. The group has a clear focus in Switzerland, but with examples also in the southern part of the Alps.

9.3 Copper Group 7 (Copper with Sb and Ag)

Group 7, made of copper, antimony and silver, has a similar major concentration in the western part of the study area, with a correspondence to the Auvenier

Corded and the Saône-Rhône cultures. Within this group 13 axes, three daggers, five ornaments and two awls may be counted.

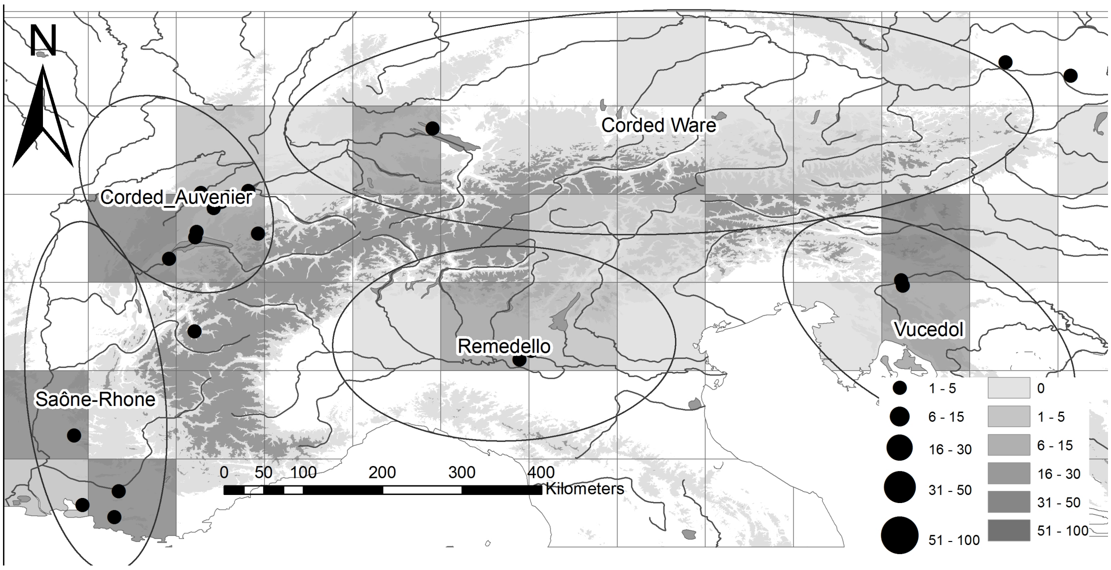

Figure 39: percentages of objects made of Copper Group 7 per zone in the Copper Age. Map symbols are explained in the caption of Figure 32. The group is clearly more present in the western part.

The categories of the artefacts show important differences for this chemical signature. In south-western France this composition is mainly linked to ornaments, in particular beads found in burial in dolmens (such as Dolmen des Cudières) and in caves (e.g. Le Baume de Lan). The few objects found with this composition in Slovenia are awls (SAM 1049 and SAM 1066 in Appendix II), which might be related to the Beaker culture.

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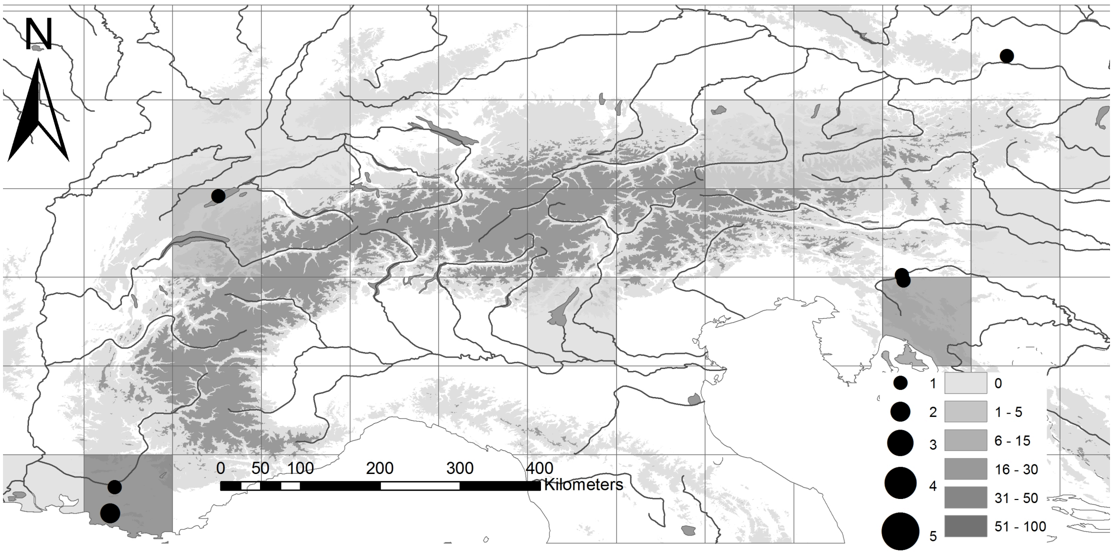


Figure 40: percentages of ornaments and awls made of Copper Group 7 per zone in the Copper Age. The map symbols are explained in the caption of Figure 32. There is a focus in the south-western part of France.

In Switzerland, on the other hand, this composition is more closely linked to axes, as in the example of La Graviers (SAM 22268), Vallamand (SAM 2785), Treytel (BAR66) and Vinelz (SAM 2787). In Italy there is an axe from Fiesse, a burial considered as belonging to the Beaker culture (de Marinis 1994; Montanari 2001)(SAM 20390).

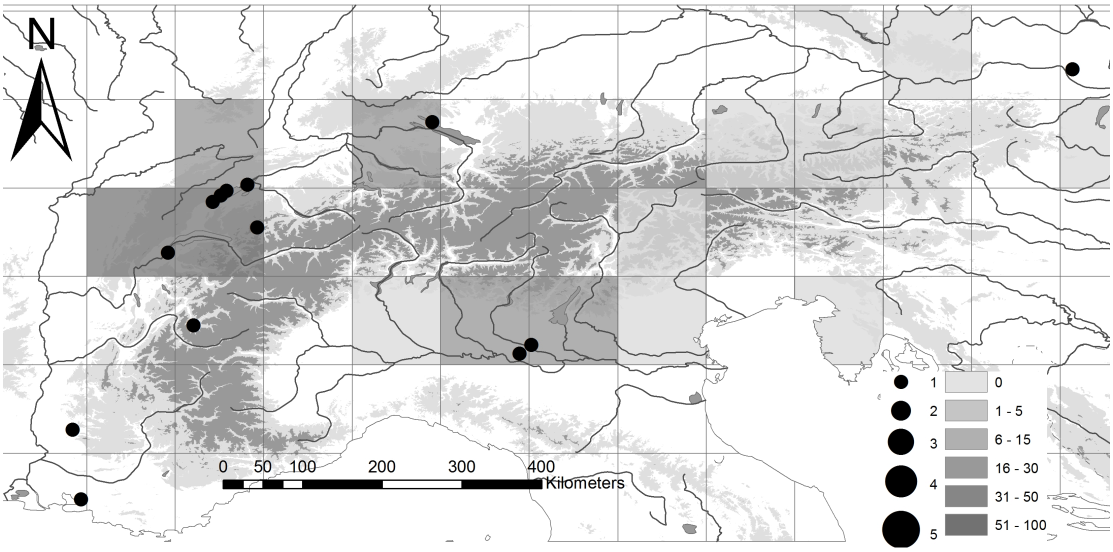


Figure 41: percentages of axes made of Copper Group 7 per zone in the Copper Age. The map symbols are explained in the caption of Figure 32. There is a distribution focus in Switzerland.

This group has no arsenic, but, antimony can be considered as a volatile element, even thought not as volatile as arsenic. Geostatistical analyses have been undertook on log(10) transformed antimony, but the result indicates a spatially random distribution. This, of course, may be due to the fact that antimony responds less strongly than arsenic to cycles of reheating and re-melting .

9.4 Copper Group 9 (Copper with As and Ag)

Group 9, silver and arsenic as minor elements, is an eastern group (see Figure 42). In the Copper Age there were 44 objects with this composition: 13 axes, six daggers, 19 ornaments and four awls. Most of the axes and daggers of the Remedello cemetery have this kind of composition, in particular Remedello type daggers, whereas the Beaker type dagger (O-W 369) found in the same cemetery is made of arsenical copper (Group 2). Many objects from Trentino are made of copper belonging to Group 9, for example beads and an awl from La Rocca di Manerba (MS1, MS15, MS21), Frana del Bersaglio (TNS12), Riparo Gaban (TNS15), Arco (TNS2, TNS5), and the axe from Col del Buson (AA 150). In the northern zone of the Alps, this composition is mainly found related to flat axes of the Corded Ware culture, as in the cases of Lieferind (Kienlin 504402), Attersee (Kienlin 504404), Rainberg (O-W 335), and Mondsee (SAM4348).

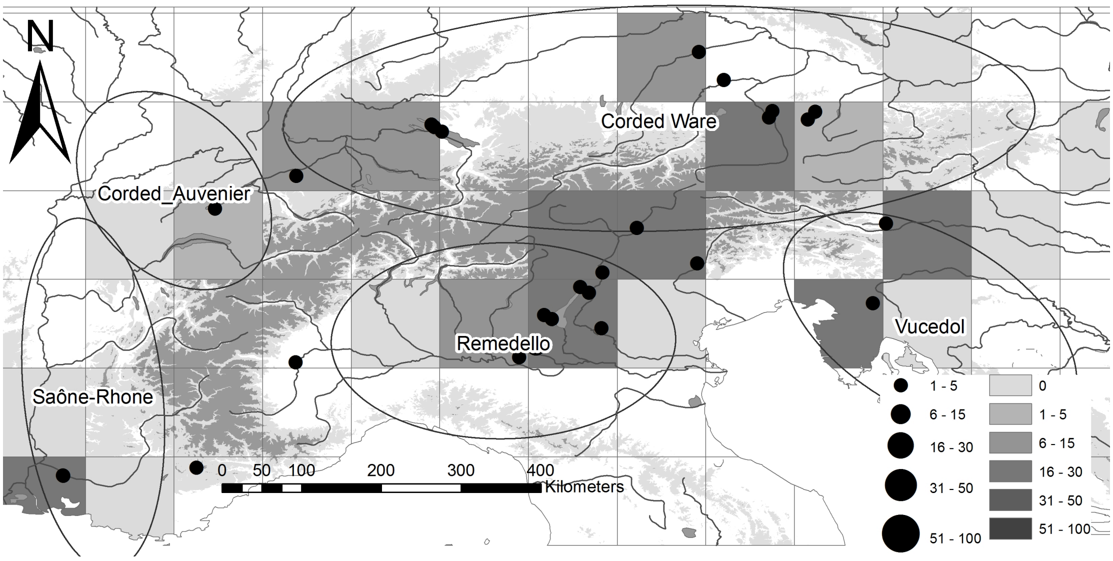


Figure 42: percentages of objects made of Copper Group 9 per zone in the Copper Age. The map symbols are explained in the caption of Figure 32. The group is clearly more present in the east.

As with Group 2, the log(10) of arsenic was calculated to obtain a distribution more similar to a normal distribution. In this case, the spatial distribution of different percentages of arsenic is random.

The graph of percentage silver of Group 9 and Group 2 confirms that this is a specific copper group and not just the tail of Group 2, as a result of setting the limit of presence of 0.1% to define copper groups. This was already suggested by the fact that this group has a specific location whereas Group 2 was spread throughout the Alps.

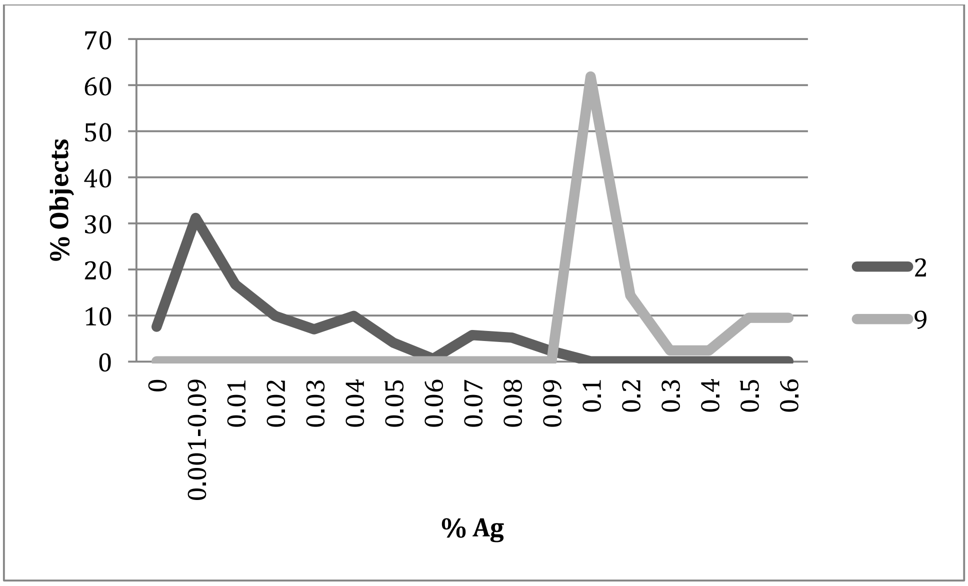


Figure 43: percentages of objects made of Copper Group 2 and Group 9 per level of silver in the Copper Age. See Figure 30 for the different scale unit used for Copper Group 9 and Group 1.

The graph of the percentage of arsenic per category gives interesting results (Figure 44). It is, indeed, very similar to the one for Group 2, with axes and ornaments having more objects with a percentage of arsenic below 1% and daggers that have a peak corresponds to three or more percent of arsenic.

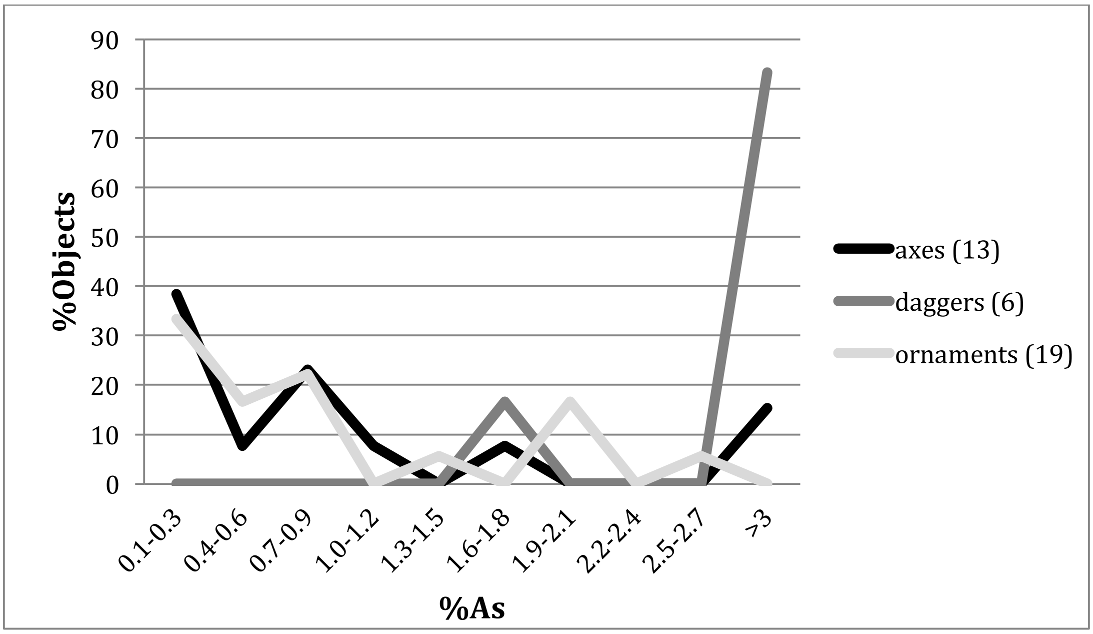


Figure 44: percentages of objects made of Group 9 metal per level of arsenic in the Copper Age.

This is important to understand the nature of arsenical copper (Group 2). In Italy all the daggers have a high percentage of arsenic: both the ones that have only arsenic as a trace element and also those that have arsenic and silver. There were objects with pure copper, or copper with silver, but none of them were daggers or halberds. In the northern part of the Alps, on the other hand, there were documented cases of daggers that have no arsenic, but were made of copper with nickel (in particular in Switzerland) or copper with silver (in the north-east region). The most interesting case is Group 4, namely metal made of copper and silver because this composition was present both in the north and in the south of the Alps, but only in the northern part were daggers made of this composition. This is discussed in more detail in Section 9.6.

9.5 Copper Group 4 (Copper with Ag)

Group 4, made of copper and silver, has clear western distribution (Figure 45). In the north-east of Italy it is particularly abundant, and the percentage of Group 4 objects is even greater than pure copper (Group 1) and arsenic copper (Group 2), contrary to the general pattern of the Circum-Alpine region (Figure 31). In this group there are 16 axes, nine daggers, 10 ornaments, and three awls.

This chemical signature is particularly common in axes of “Bocca Lorenza” Type, a form common in the northern-west part of Italy. This type includes, besides the axes from the burial in cave of Bocca Lorenza, one axe from Merendole (PD) and one in Tormičeva cave in San Canziano (TS) (Pearce 2007, 45). In the northern zone of the Alps this compositional group is found in grip-tongue daggers, a type related to the Bell Beakers groups. This is the case for daggers found in Kircheim (FMZ 388 in Appendix II), Wolfarshauser (O-W 189), and Moosinning (O-W 190).

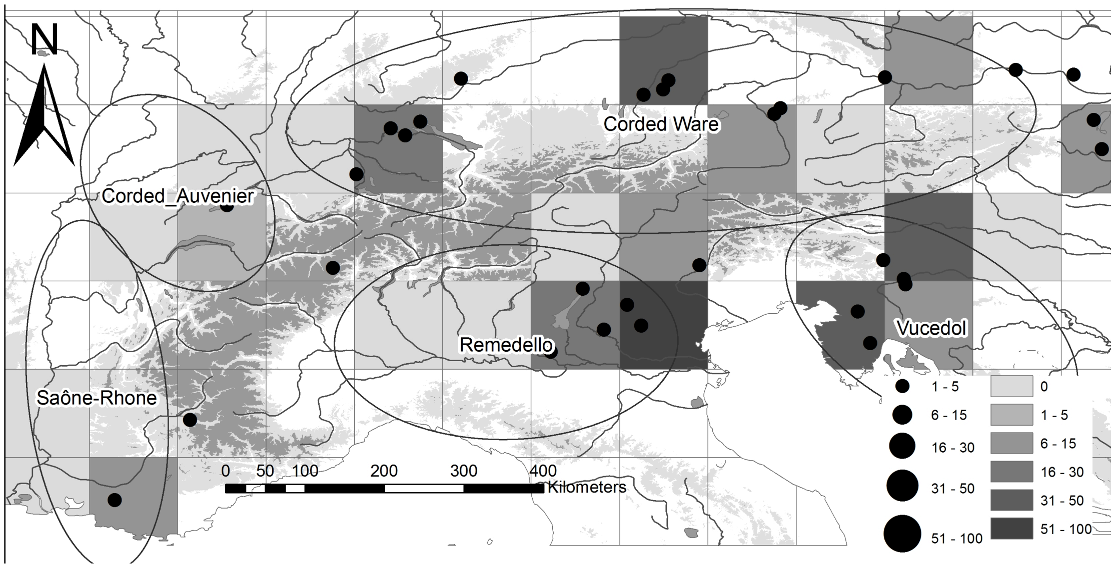


Figure 45: percentages of objects made of Group 4 per zone in the Copper Age. The map symbols are explained in the caption of Figure 32. The group is clearly more present in the east.

In this case the graph of arsenic distribution shows a peak in correspondence of the 0.1% of arsenic. This fact may lead to the hypothesis that this group is actually part of Group 9 – in other words, Group 4 (Cu with silver) is, at least partially, the result of heavy recycling of Group 9 metal (Cu with silver and arsenic), since the arsenic is more easily removed. This is also supported by the same geographical distribution of the two groups.

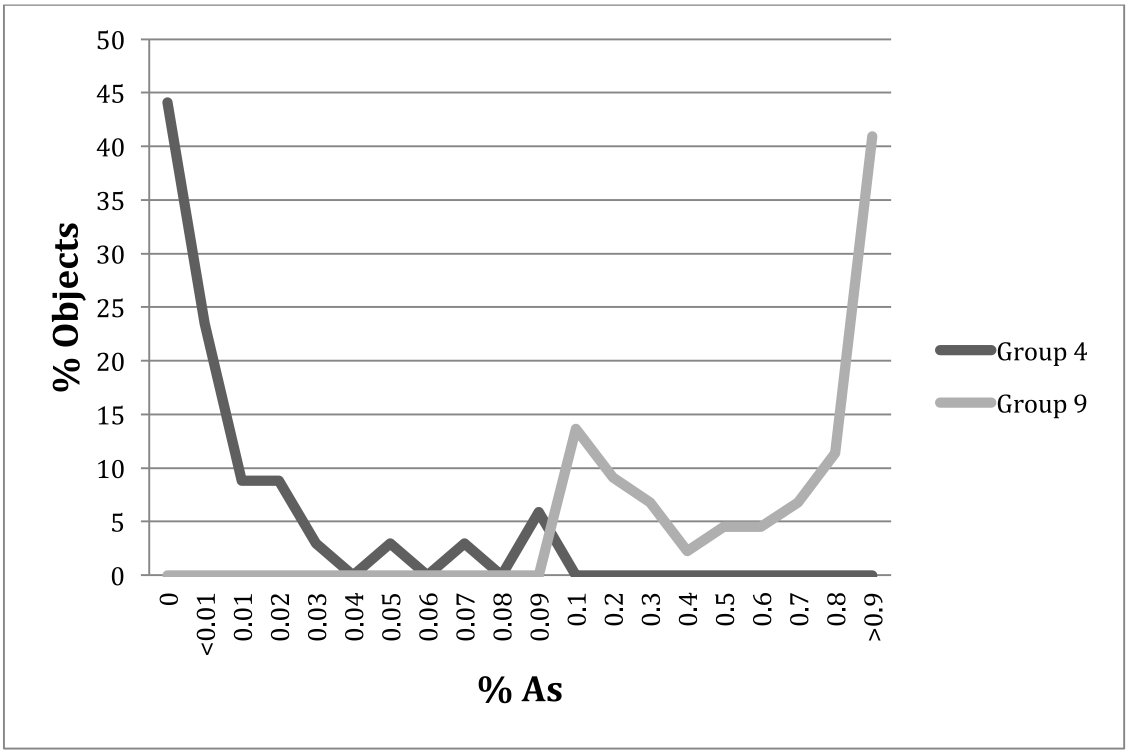


Figure 46: percentages of objects made of Copper Group 4 and Group 9 per level of arsenic in the Copper Age. See Figure 30 for the different scale unit used for Copper Group 9 and Group 1.

Finally, Group 16 (Cu with As, Sb, Ni and Ag) is present only in two hotspots in western Switzerland and northern Italy (in Brescia province) but does not show a clear pattern of distribution. It may be hypothesized to be the result of mixing metal from more than one copper source.

All of the previous discussion is based on the chronology proposed by Krause (2003). As discussed above, a further two different chronologies (de Marinis and David-Elbiali) have been proposed for northern Italy and Switzerland. In the Copper Age, however, both the chronologies of de Marinis and David-Elbiali lead to approximately the same conclusions as the Krause chronology (Figure 47). The most relevant difference is in relation to the central part of northern Italy. Here, instead of the presence of many different copper groups with a predominance of arsenical copper (Figure 31) there is a phase where arsenical copper is the only group. In the northeast region Group 9 is more common than group 4. But, in general, even considering a slightly different chronology, the same metal groups stand out as significant.

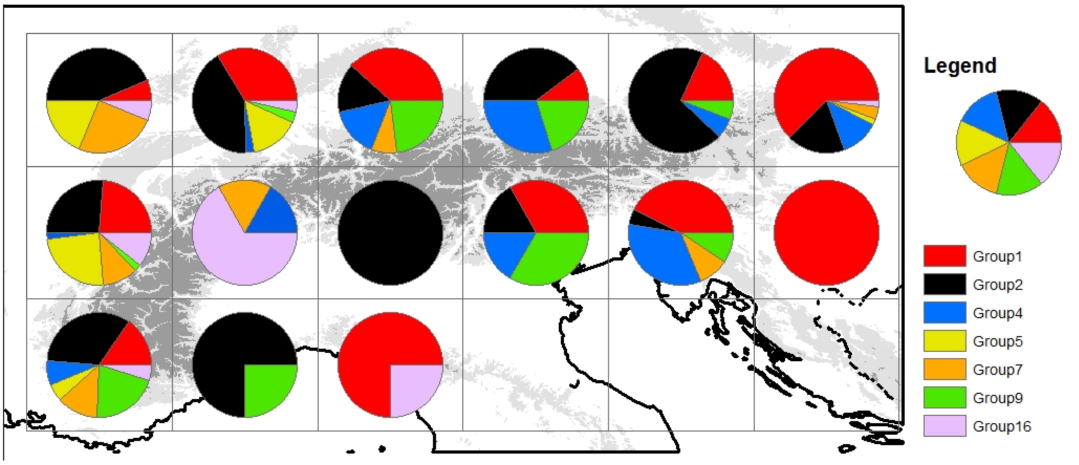


Figure 47: pie charts showing the percentages of objects made with different compositional groups in different zones in the Copper Age using the chronology proposed by de Marinis and David-Elbiali.

9.6 Discussion

From the above analysis, we can propose that the Copper Age in the Alps is characterized by two big flows of metal and a number of minor, localised metal groups. The two big flows are those of pure copper (Group 1) and arsenical copper (Group 2).

9.6.1 Hypothesis of production of pure copper and arsenical copper

Group 1 (pure copper) is mostly related to the eastern zone, and in particular to the Vučedol culture (see Section 7.1.6). This culture is related to the Balkans cultures where metallurgical activities are well known since the fifth millennium. Indeed the metal produced by the Balkans cultures is a very clean copper but it still debated if it derives from native copper or the smelting of copper carbonate minerals (Kienlin 2010, 18–19). This flow arrives at least to Austria, as is also proved by lead isotopic analysis (Höppner *et al.* 2005). There is also a high percentage of artefacts made from this metal in Switzerland. This may be due to the same flow, but, considering also that during the entire Early Bronze Age in this region a high percentage of objects were made with a clean type of copper (see Section 3.2.2), local metal production cannot be excluded, although it is not proved at this time (see Section 5.2). The possibility that this clean copper flow is the result of remelting and reheating of material from Copper Group 2 seems unlikely, because most of the artefacts do not have any arsenic at all.

The origin of the Group 2 metal in central Europe has previously been suggested to be the Iberian peninsula (Bray & Pollard 2012; Hartmann & Sangmeister 1972), which is known for the highest percentage of objects made of arsenical copper in the Copper Age. The key role of the Iberian peninsula in the emergence of metallurgy in Italy is also a hypothesis supported by Pearce (Pearce 2007). Geostatistical analysis of the entire Copper Age assemblage cannot help to understand whether this may be true, because of the exceptional high peak of arsenic in northern Italy due to data from halberds and daggers that would hide a signal of decreasing arsenic from the west to the east. But the results of the analysis on axes alone highlight a spatial cluster of high levels of arsenic in the western zone and low levels in the eastern zone of the Alps, supporting a movement of metal from the west with a series of re-melting or recycling processes that would contribute to reduced levels of arsenic.

Apart from these two main groups there are a number of more localised groups. Their distribution is *not* dependant on the presence of the Alps. They are primarily present in the western or in the eastern zone, but are equally distributed north and south of the Alps. The transalpine contacts in the Copper Age, that are often claimed through singular "iconic" case study, such as Ötzi moving from the north-Tyrol to south-Tyrol, or the Hornstaad disc, which is claimed to have a south-eastern kind of metal (Klassen 2010), appear to be confirmed by this more general study. This contradicts the idea of Barker (1971) of a "Remedello metal" in the Copper Age (see Section 2.7.1), but also contradicts the view that all the metal in Italy was coming from Germany. Italy was never separated from the north Alpine flows of metal, neither in the case of the "main flows" (pure copper, arsenical copper), nor with small "local" flows. Some of the minor compositional groups were reasonably from north Alpine ores, some others from Italy, as discussed in detail below.

9.6.2 Hypothesis of copper production in the western zone

In the western zone the main "local" copper groups are Groups 5 and 7. The article published by Cattin *et al.* in 2009 (see Section 2.8.1) confirms the presence of the groups here mentioned, in particular pure copper, arsenical copper, and copper with nickel. There are also a number of "antimony coppers" that are not recorded in this database, but this may be a problem of definition of the threshold to determine the presence of an element. In any case, their analysis may help us to better understand the flows of metal in the western zone of the Alps during the Copper Age. They recognised two chronological phases: a first phase (corresponding to the Lüscherz culture) and a second phase corresponding to the Auvernier Corded Ware.

In the first phase there was pure copper and copper with nickel, corresponding to Copper group 1 and 5 in this thesis. The local nature of copper Group 5 (copper with nickel) has been repeatedly claimed. It corresponds to the group FC of Junghans *et al.* (Junghans *et al.* 1960, 1968b, 1974). Its locally restricted distribution was recognised by the Stuttgart group, and also, more recently, by Matuschik (2004) and Cattin (2008). Strahm hypothesized a west-Alpine source and claims its presence also in France (Strahm 1994, 29, 2005, 32), whereas lead isotopic analysis seems to point to a mineralization in the Rhine Massif. In the southern zone of the Alps this composition is related to a Beaker cemetery (Sabbione).

The situation of the lead isotopes in the second phase, corresponding to the Auvernier Corded Ware, is more complex, and many isotopic signals are recognised both from the Central Europe (Austrian mineralizations and the Rhine Massif), the Mediterrean (pointing to the Cabrières mine, whose use was well known since the fifth millennium), and Sardinia, as well, cannot be excluded. In this phase arsenical copper became more common, together with antimony copper and arsenic and antimony copper, corresponding to Group 7 in this thesis. Ambert (2001) linked this kind of copper to the Cabrières mine (see Section 7.1.3), and this hypothesis was also supported by Cattin *et al*., in particular for the biconical beads whose shape is frequent in the south of France. Indeed, this thesis recognises a difference in the distribution of Group 7 according to the type of objects: it is more frequent in ornaments in France and in axes in Switzerland. If we accept the hypothesis of the movement of this group from the Cabrières mine to the east, with its eastern limit in the Rhine valley, it is likely that in the zone where it originated it was used for very typical local types of objects, namely beads. In gradually moving from the centre of production, metal could have been reused and recycled, to create new types of objects such as, for instance, axes. An alternative, but not supported by the lead isotopes analysis, is that there were two differences sources: Cabrières in France and a local source in Switzerland.

9.6.3 Hypothesis of copper production in the eastern zone

In the eastern zone the two local groups are copper with arsenic and silver (Group 9) and copper with silver (Group 4). The graph of silver in Group 2 and

Group 9 (Figure 43) demonstrates that they are two independent groups. Conversely, the graph of arsenic of Group 9 and Group 4 (Figure 46) may lead to the hypothesis that these two are actually one group. In this case, it seems reasonable to think that Group 4 is the result of re-melting metal of Group 9. A similar pattern has also been observed by Bray in the case of a group of Irish metal artefacts (Bray & Pollard 2012). The hypothesis that these groups are the product of the exploitation of a local resource seems also very reasonable because it is set in a zone where metal production in prehistory has much evidence. As discussed in Section 5.2 the exploitation of the Austrian mineralizations is not proved in the Copper Age, but radiocarbon dates in Trentino suggest the development of the entire *chaîne opératoire.*

Another topic that requires attention is the role of arsenic in daggers and halberds in north-eastern Italy. In the Copper Age in the north of Italy axes were made from almost pure copper, daggers and halberds were made of arsenical copper (see also: Pearce 1998, 54; Steiniger 2005, 253). The huge difference in terms of percentage of arsenic per category of artefact as shown in Figure 35 is only present in this time period: in all the other metal groups the difference of the level of arsenic among different categories is much more limited. The reason implied in this difference is food for thought.

Pearce, as a first instance, suggested that causality was an unlikely reason. It is not linked to the artefacts' productions: both daggers/halberds and axes have been cast in one piece open mould (Pearce 2007, 84). The pattern is too constant and, moreover, copper bearing minerals and arsenical copper minerals have different colours, and this could not have been unnoticed by ancient smelters (Pearce 2007, 86). But, if intentionality has been established, the reasons for this choice are still not clear. Pearce does not exclude that "it might reflect functional considerations, such as the need for axes to withstand repeated blows against trees, whilst the daggers need primarily to keep their edge" (Pearce 1998, 55). But, it has to be noticed that, if people were well aware of these mechanical differences between copper and copper alloys, so that they were deliberately choosing different metals for different uses of the artefacts, then the reason why, at the beginning of the Bronze Ages, they then decided to ignore these differences, producing all the artefacts with bronze, remains unexplained. Pearce repeatedly suggested that the reason for this different choice of metal for different artefacts may be the pursuit of a specific colour (Pearce 1998, 55–57; 2007, 84). This suggestion was accepted by Keates (2002). He noticed that daggers and halberds were found only in male burials, and represented in "*statue stelea*" with male attributes (namely, the ones without pendants/breast but with daggers and solar symbols). Hence, he hypothesized a cultural connection between masculinity, virility, whiteness and luminosity, suggesting that daggers might have been phallic symbol, where the colour might have evoked the semen (Keates 2002, 112–113). On the other hand, it should be noted that the arguments about colour are questionable: arsenic segregates through time and therefore the silverish surface that may be seen now may not be original (Nothover, personal communication).

In any case, daggers and, particularly, halberds were considered to be high-status and possibly ceremonial objects. This view is supported by the study of use-wear on some objects in Italy, on which few use wear traces were found, especially for halberds (Dolfini 2011). This is different to what has been observed, for example, in Ireland (O'Flaherty *et al.* 2011). The supposedly high social value of halberds and the high levels of arsenic within the objects may lead us to think that these objects were subjected to very little recycling or remixing, if any.

The analysis of this thesis highlighted a very high percentage of arsenic for this category of artefacts: the highest of the entire database. This is true for both Group 2 (arsenical copper) and Group 9. Group 2 may be considered as part of a bigger flow that was in the entire Circum-Alpine region, whereas Group 9 is a local production. As explained in Section 6.2 there are three possibilities to produce arsenical copper: co-smelting of arsenic and copper bearing minerals, addition of arsenic bearing mineral to copper metal or copper ore, and addition of *speiss* to copper ore or metal. The use of ferrous arsenic *speiss* is not witnessed in prehistoric times outside Iran (Rehren *et al.* 2012; Thornton *et al.* 2009). But the high percentage of arsenic in the daggers and halberds from north-eastern Italy indicates that this is a very "fresh" metal that was not subjected to multiple cycles of re-melting. The difference between the content of arsenic in axes and daggers made of Group 9 could be easily explained with a selective use of different minerals (easily recognisable for their difference of colour – see Section 6.2) to produce objects with low or very high content of arsenic. But the presence daggers and halberds made of Group 2 with a much higher level of arsenic than any other region in the Alps poses some issues. There are three possible explanations:

- north-east of Italy was a "closed" system, without import of metal from outside. But archaeological evidence denies this (see Section 7.1), and also, evidence from the other copper groups, as explained in this Chapter.
- There was metal coming from outside, but it was not recognised as "acceptable" material from which to make daggers or halberds (possibly, it did not have the "right" colour), and this imported metal was only used to make other (less important?) objects. Most likely these were ornaments, because there are ornaments from this region with arsenic in range of 0.5-2%, but only three axes have arsenic. Daggers and halberds were only made from local mines with high levels of arsenic.
- Object from outside were not recognised as "acceptable" and if they were remelted into daggers or halberd, there was an addition of arsenic bearing minerals to the copper metal.

At the moment there are no data to completely exclude either of the last two hypotheses. It would be interesting to have data about lead isotopes and verify if they may suggest a mixture from more than one ore.

9.6.4 Movement of metal: some considerations

Some observation may be made on the movement of metal and how this movement is linked to the Bell Beaker culture. In the above analysis of the distribution of objects, a number of examples have been found of objects with a composition that is typical of another zone. This is the case for the awls of Ljubljanica river and Ljubljana Marsh in Slovenia made of copper with antimony and silver, which is typical of the western Circum-Alpine zone. The burial of Sabbione, considered as a Bell Beaker cemetery, has objects made of copper with nickel, which many authors have recognised as a very typical composition of Switzerland. Daggers made of copper with silver may also be included into this category. As said in Section 9.6.3, this composition is likely to be the result of many cycles of remelting copper with arsenic and silver, which is probably produced in the south Tyrol. In the zone of production of this kind of copper there are no daggers that do not have arsenic. Conversely, daggers are present in the northern part of the Alps, and have a shape linked to the Bell Beaker culture (grip-tongue dagger), but have a composition that shows no arsenic. The compositional link between the two is only made if it is accepted that arsenic, present in the south Tyrol, is lost on recycling. This connection would not be made if cluster analysis were employed.

The role of the Bell Beaker Culture as innovators in metal-production has been claimed for other European regions (e.g. O'Brien 2001), but the idea was rejected in central Europe. Ambert (2001) noticed that the so called "Bell Beaker objects" or objects that are typically correlated to the Bell Beaker culture (such as awls or grip-tongue daggers) in southern France have a typical local composition, namely copper with arsenic and antimony, that was linked to the Cabrières mine. He hypothesized a local imitation of a shape that was "trending" in Europe. The principal component and cluster analysis undertaken by Merkl (2011, 2010) have not highlighted any specific "Bell Beaker-cluster" and led the author to suggest that the Bell Beaker Cultures were actually using local sources.

Our analysis has highlighted the importance of spatial analysis to understand the role of the Bell Beakers. In fact, it is true that if data from all the metal objects are analysed together no differences emerge from Bell Beaker objects and objects produced by local communities. The main differences are connected to the spread of metal linked to the Bell Beakers. It has been suggested with strontium analysis that Bell Beaker people travelled as small groups, or even as individuals. Evidences for this are also found in Central Europe (Price *et al.* 2004). While travelling they were producing metal with local resources, or re-melting their objects with local metal, and later on, travelling again, depositing metal objects with a chemical signature that is not local. This deposited metal is, however, not coming from thousands of kilometres away (for instance, from the Iberian peninsula), but from hundreds of kilometres, such as the cases mentioned in this thesis. To conclude, the attempt to find a specific "Bell Beaker" metal signature in Europe is useless but the role of the Bell Beaker people in the movement of metal should be acknowledged. This role could only be perceived if analytical data are considered within their spatial distribution, with a scale capable of capturing trans-regional differences (such as the entire Circum-Alpine region).

However, it is argued in this thesis that beside the movement of the Beaker people, metal was also moving in other ways. The two main flows of metal (pure copper and arsenical copper) acknowledged the existence of this movement that, however, is more "gradual" than that hypothesised for the Beaker people. It does not therefore create hotspots of "alien" composition. In those cases the idea of local exchange of metal through neighbouring cultures is more likely. The complex picture of lead isotopic signal drawn by Cattin *et al.*, indeed, seems to lead to a hypothesis of mixing metal from different sources. There were also a number of local mines, producing identifiably different copper. Local mines may well also have existed producing pure copper and arsenical copper, but whose signal has been lost in the two main flows. In the case of the more localised sources, a series of exchanges between neighbours seems to be more likely. The distribution of metal groups and in particular of the minor groups seems to highlight two different zones within which contacts were more frequent: an eastern zone and a western zone. So on the one hand there were contacts among the Corded Ware and the Remedello Culture, on the other the distinction between Corded Ware and Swiss local facies (Auvernier Corded Ware) is confirmed, and the latter has connections with the French Mediterrean world whose influences may be found also in the western part of the northern Italy.

10 The Flow Model in the Early Bronze Age

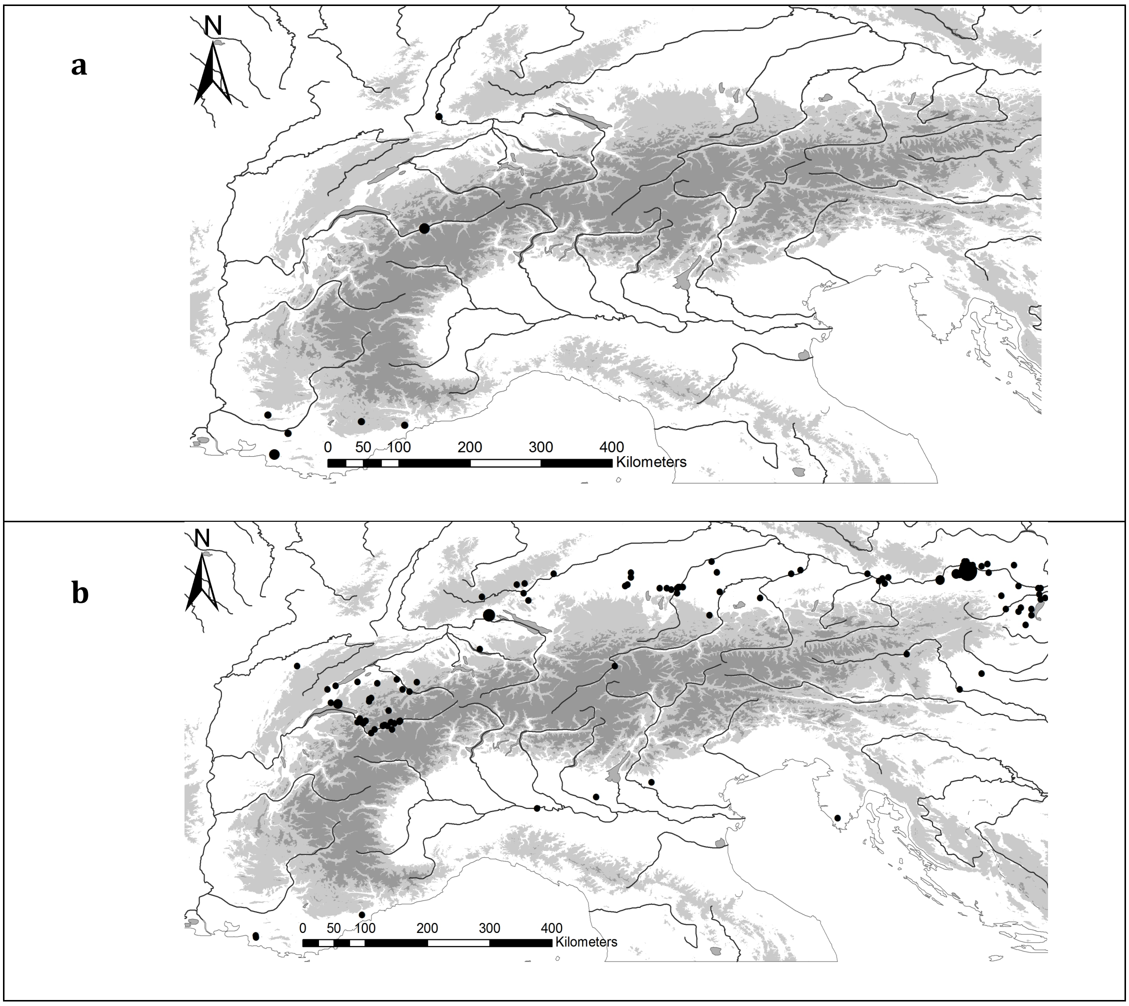
As in the previous Chapter, here a series of maps of the compositional groups are provided, as well as the results of the geostatistical analysis, using the tools created for this thesis.

The Early Bronze Age has been divided into three sub-periods (see Section 7.2). First a general overview of the distribution of the major Copper Groups through each of these periods is provided. Subsequently, for each Copper Group the results of the ubiquity analysis and of the geostatistical analysis are given and discussed. Moreover, the evolution in time of each compositional group that contains arsenic is analysed, because a decreasing level of arsenic is another hint of a recycling activity (Bray *et al.* 2015). Finally, a general overview is given, with a specific attention to the movement of metal.

In Section 7.2.1 some chronological issue have been mentioned. In particular there are some discordances between the dates of the objects in the database of Krause (2003) on the one hand, and the ones proposed by David-Elbiali (2000) and de Marinis (de Marinis 2005, 2006a; 2006b) on the other. In this Chapter the comparisons between the results obtainable with these two chronological frameworks are provided to check that the results are not significantly affected by the choice of chronology.

10.1 A brief excursus of the main copper Groups in the different phases of the Early Bronze Age

As with the Copper Age, the distribution of metal objects reflects cultural differences. Figure 48 shows burial in caves, burial in graveyards, hoards, and settlements in the Early Bronze Age. In the western zone there is continuity from the previous period of deposition in caves. Most of the metal artefacts in the north Circum-Alpine region are related to single burials or hoards, whereas in Italy, in correspondence to the Polada culture, metal is mainly found in settlements.



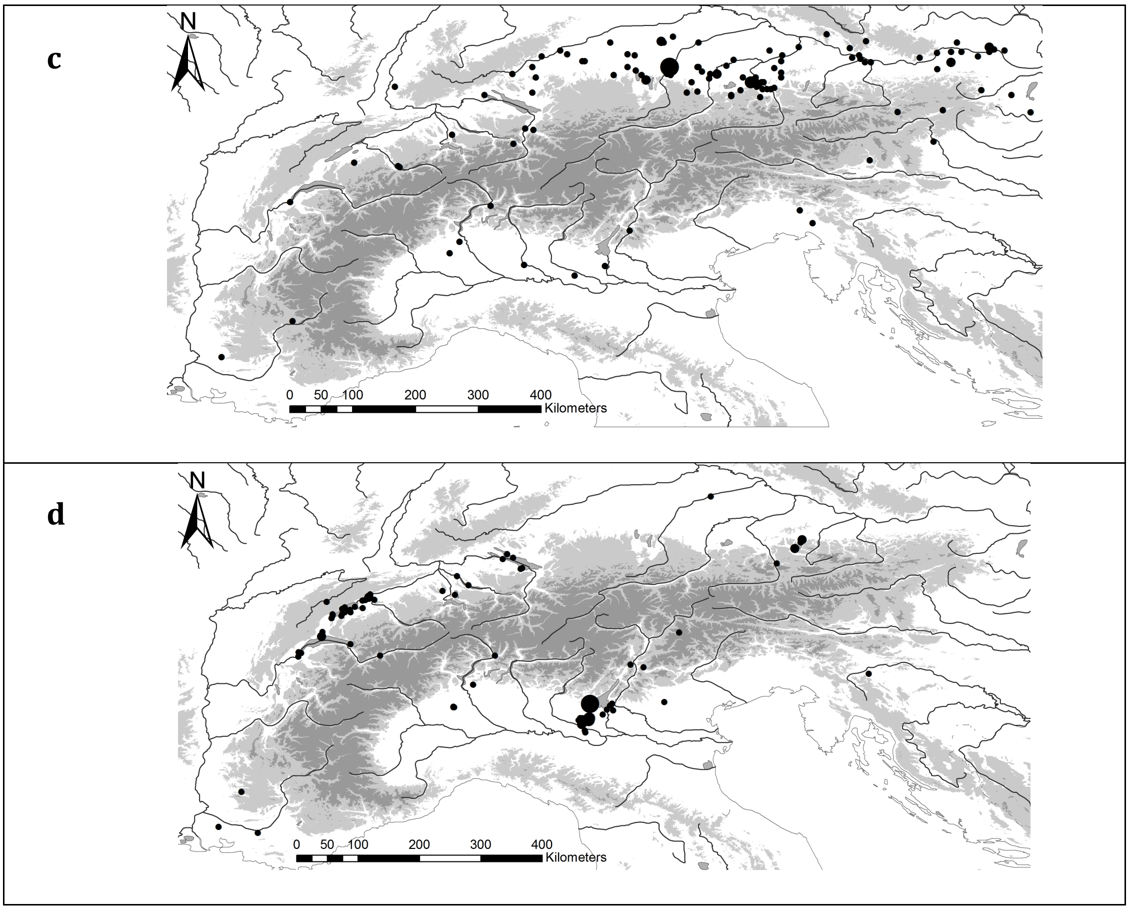


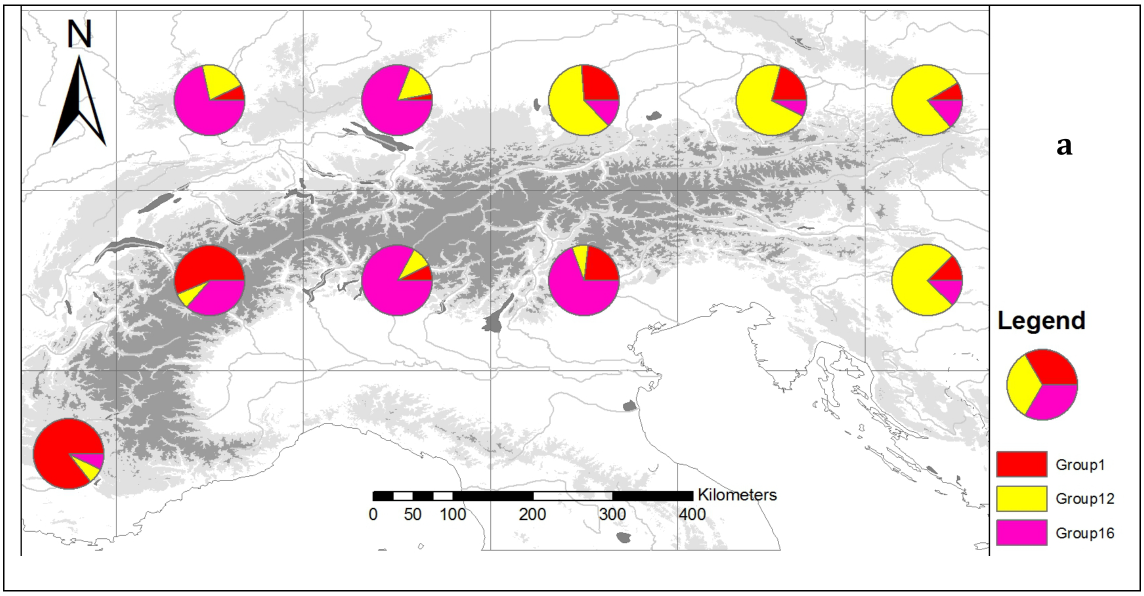
Figure 48: from above: (a) map of burials in cave, (b) burials in graveyard, (c) hoards and (d) settlements in the Early Bronze Age. The size of dots is proportional to the number of metal objects.

The transition from the Copper Age to Early Bronze Age 1 (2200-2000 B.C.) signals a change where the trace element composition of the artefacts becomes more consistent across the study area. This possibly suggests the growth of a small number of larger-scale trading patterns (Krause 2003). Almost 80% of all the artefacts of this period (A1) fall into just Groups 12, 16 or 1 (Table 11).

Group1	Group2	Group3	Group4	Group5	Group6	Group7	Group8
315 (15%)	38 (1.8%)	21 (1.0%)	19 (0.9%)	20 (0.9%)	13 (0.6%)	54 (2.6%)	3 (0.1%)
Group9	**Group10**	**Group11**	**Group12**	**Group13**	**Group14**	**Group15**	**Group16**
8 (0.4%)	4 (0.2%)	21 (1.0%)	999 (49%)	27 (1.3%)	37 (1.8%)	5 (0.2%)	450 (22%)

Table 11: number and percentages of objects per Copper Group (see Table 2) in the Early Bronze Age A1.

Group 12 is more common in the eastern part, Group 16 in the central area and Group 1 in the west.



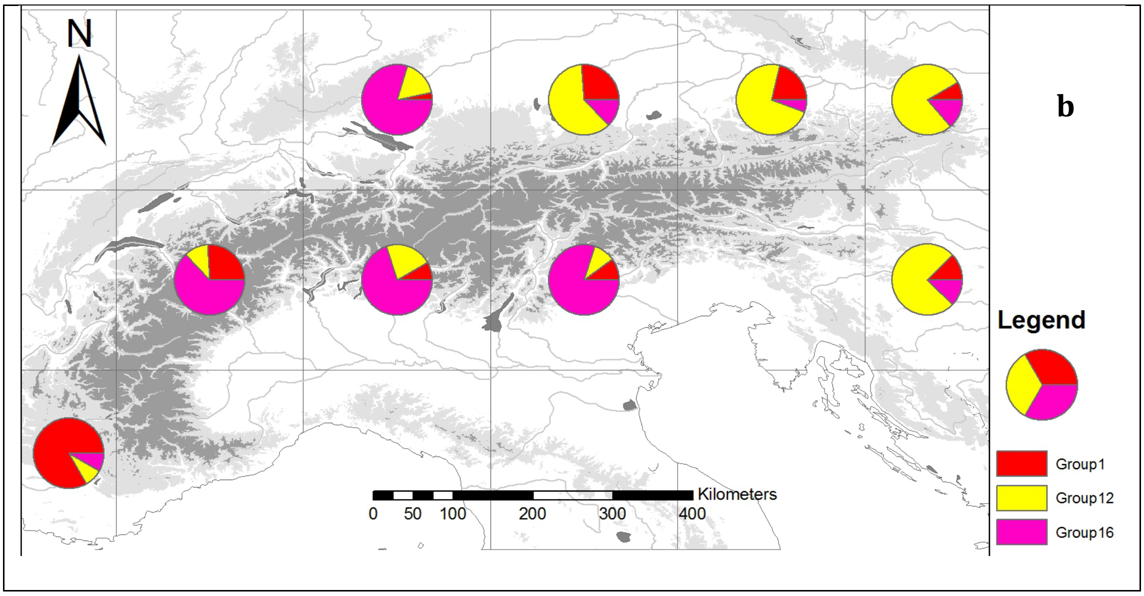


Figure 49: pie charts with different compositions per zone in the Early Bronze Age A1, using the chronology proposed by (a) Krause and (b) de Marinis and David-Elbiali. Each square is represented at least by four objects.

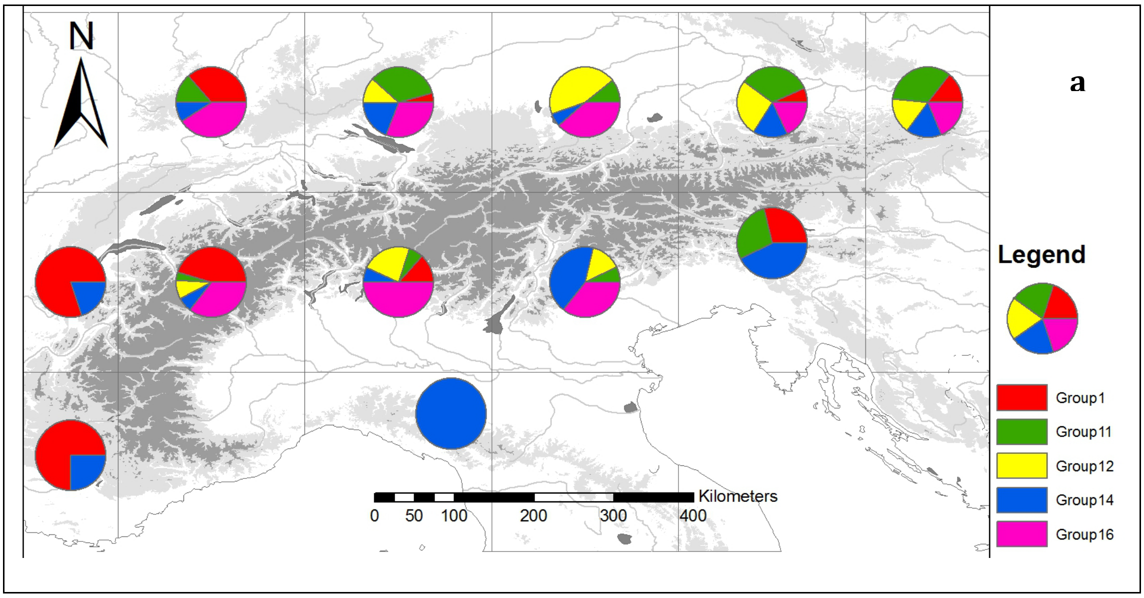
As has been underlined for the Copper Age, the use of the chronologies proposed by David-Elbiali and de Marinis does not change the conclusions for these Early Bronze Age 1 contexts. The main difference is the significant reduction in the number of artefacts dated to the Early Bronze Age A1 in western Switzerland. Apart from this specific disagreement, the picture of the distribution of different groups of copper in the Circum-Alpine Early Bronze Age, in general, does not depend on which chronological system is used.

In the second phase of the Early Bronze Age (A2a) there is the introduction of two new metal groups into the system: Groups 11 and Group 14 (Table 12). The importance of Group 12 decreases, while Group 16 and Group 1 are more stable.

Group1	Group2	Group3	Group4	Group5	Group6	Group7	Group8
127 (8.1%)	39 (2.5%)	24 (1.5%)	9 (0.6%)	60 (3.9%)	16 (1.0%)	8 (0.5%)	5 (0.3%)
Group9	**Group10**	**Group11**	**Group12**	**Group13**	**Group14**	**Group15**	**Group16**
4 (0.3%)	7 (0.5%)	237 (15%)	415 (26%)	7 (0.5%)	149 (9.6%)	12 (0.7%)	437 (28%)

Table 12: number and percentages of objects per composition in the Early Bronze Age A2a.

Group 16 is now more widely spread, especially in the northern part of the area.



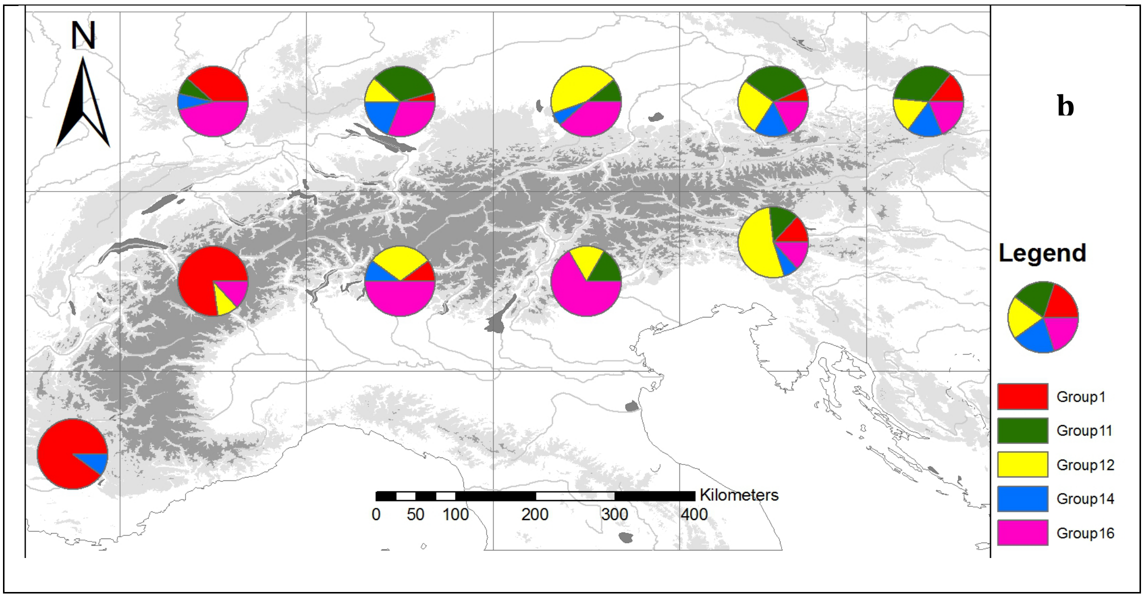


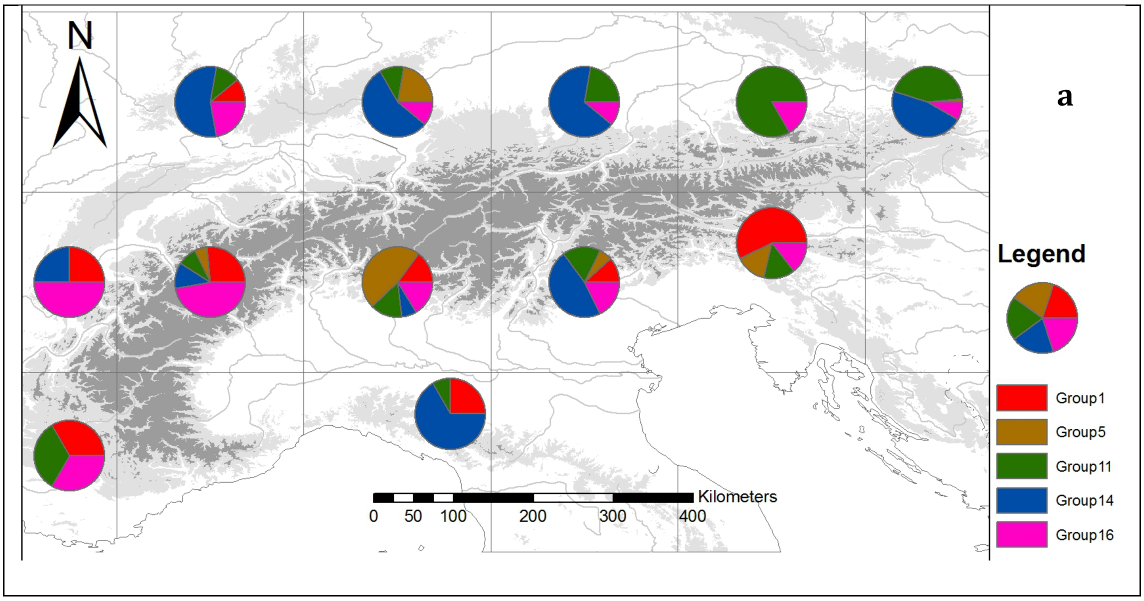
Figure 50: pie charts showing the different compositions per zone in the Early Bronze Age A2a using the chronology proposed by (a) Krause and (b) de Marinis and David-Elbiali. Each square is represented at least by four objects.

Using the chronology proposed by de Marinis and David-Elbiali the main difference is the increasing major importance of group 16 and group 1 in the southwest and the absence of group 14 in the south of the Po valley, but, once again, the general picture does not change significantly.

In the last phase of the Early Bronze Age (A2b) the trends of the previous period (A2a) continue. The decline of Group 12 continues to a point where it becomes a minor group. On the other hand, some groups that made their first appearance in the Early Bronze Age 2a re-appear, as in the case of Group 11 and Group 14. Meanwhile, Groups 1 and 16 remain stable in their importance (Table 13).

Group1	Group2	Group3	Group4	Group5	Group6	Group7	Group8
31 (11%)	12 (4.3%)	4 (1.4%)	0 (0.0%)	36 (13%)	8 (2.8%)	5 (1.8%)	5 (1.8%)
Group9	**Group10**	**Group11**	**Group12**	**Group13**	**Group14**	**Group15**	**Group16**
1 (0.4%)	2 (0.7%)	53 (19%)	7 (2.5%)	2 (0.7%)	69 (25%)	2 (0.7%)	43 (15%)

Table 13: percentages of objects per compositional group in the Early Bronze Age A2b.



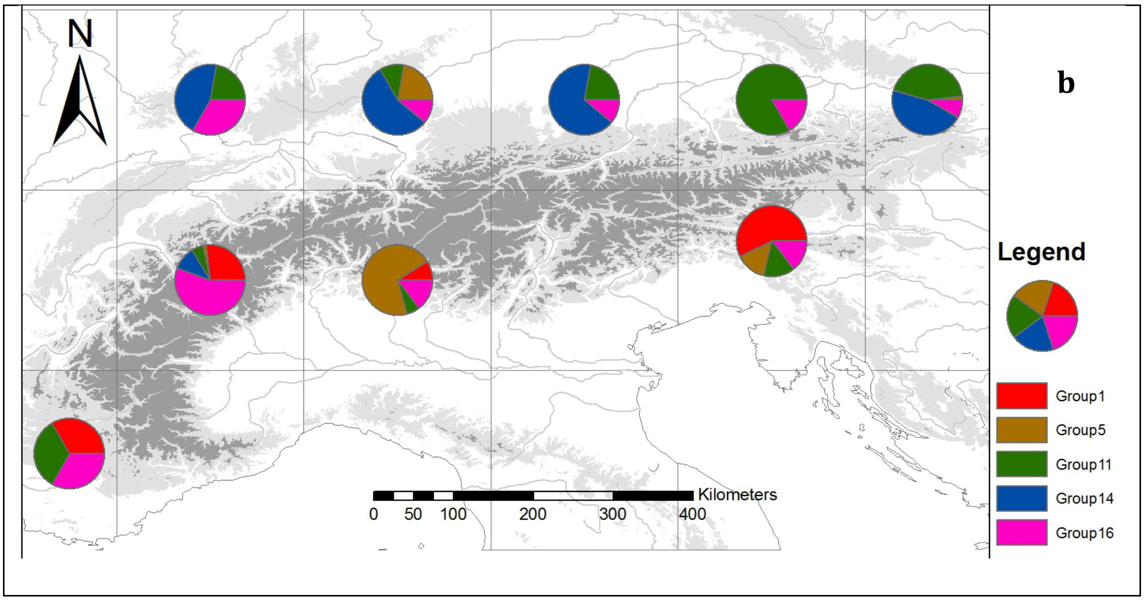


Figure 51: pie charts showing the percentages of objects made with different compositional groups in different zones in the Early Bronze Age A2b using the chronology proposed by (a) Krause and (b) de Marinis and David-Elbiali. Each square is represented at least by four objects.

Adopting the chronology of de Marinis and David-Elbiali, the importance of Group 1, 11, 14, 5 and 16 is confirmed, as noted above in the previous periods of the Early Bronze Age.

10.2 Copper Group 1

10.2.1 Period A1

Group 1 –clean copper[10]- is well represented in all the phases of the Early Bronze Age. In the first phase (A1) Group 1 is the third most important composition (approximately 15% of the assemblage). Its distribution is more related to the western part of the study area, corresponding to the Rhône (Figure 52). In particular, it is the main compositional group for the Saône-Rhône and the southern France cultural groups.

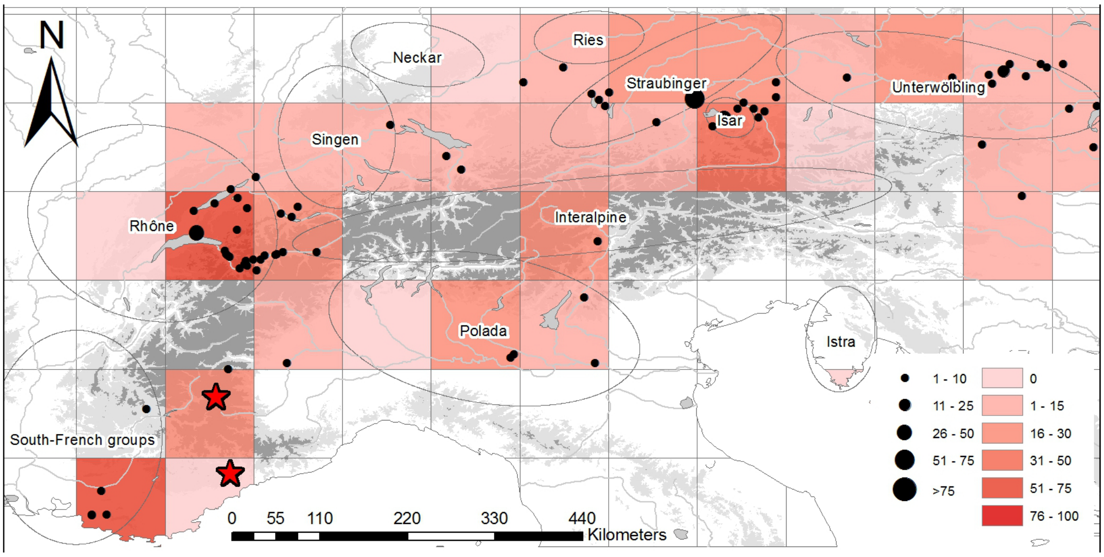


Figure 52: percentage of objects made with Copper Group 1 metal per zone in the Early Bronze Age A1. Map symbols are as in Figure 32. The stars indicate the possible mines (Saint Véran and Clue de Roua).

[10] This refers to the copper base of the objects. It means that copper has not trace elements such as As, Sb, Ni and Ag. There might be an alloying element, such as tin. Tin flows will be discussed in Chapter 11

In the eastern part of the Alps Group 1 copper was mainly related to *Ösenringe* deposited in hoards, such as the cases of Sirndorf, Stockerau, Bergen, Eiselfing. So there is a possibility of a material with a composition typical of a distant region (the west) used to make objects typical of the local zone (the east). It is also possible, in principle, that this clean copper could be recycled copper from the previous period, which was common in this region, even if it was not mined there (see Chapter 9). Another possibility is that this might be fresh clean copper from the Balkans, but the percentage of clean copper in the further east (1-15%) does not suggest a flow of clean copper from the Balkans, in this time period. Similarly, in northern Italy this composition is mainly related to a few hoards made of axes, such as Remedello Sotto and Serravalle. The type of hoard (consisting only of axes) and also the typology of these axes are more related to the western zone of the Alps, because they are similar to the Neyruz Type (Tecchiati 1992).

10.2.2 Period A2a

Copper Group 1 maintains the same distribution as in the Early Bronze Age 1, being more focused in the western region and related to the Saône-Rhône and the south-French cultural groups, and with a halo effect. We use the term 'halo' to indicate that the importance of this metal group decreases with distance. There are thus more objects of this metal type found close to the possible centre of production. From this proximal area, there is a gradual decline in ubiquity with distance, to a point where only a small percentage of the assemblage has the composition of the particular Copper Group. In EBA A2a there are several specific assemblages that show a Group 1 signature, for example *Ösenringe*, found only in the north-east (as in A1). There are, in particular, a high number of axes made with this composition, mainly in the western region, in particular the axes of Neyruz type. These axes could be found in burials, settlements and hoards indiscriminately.

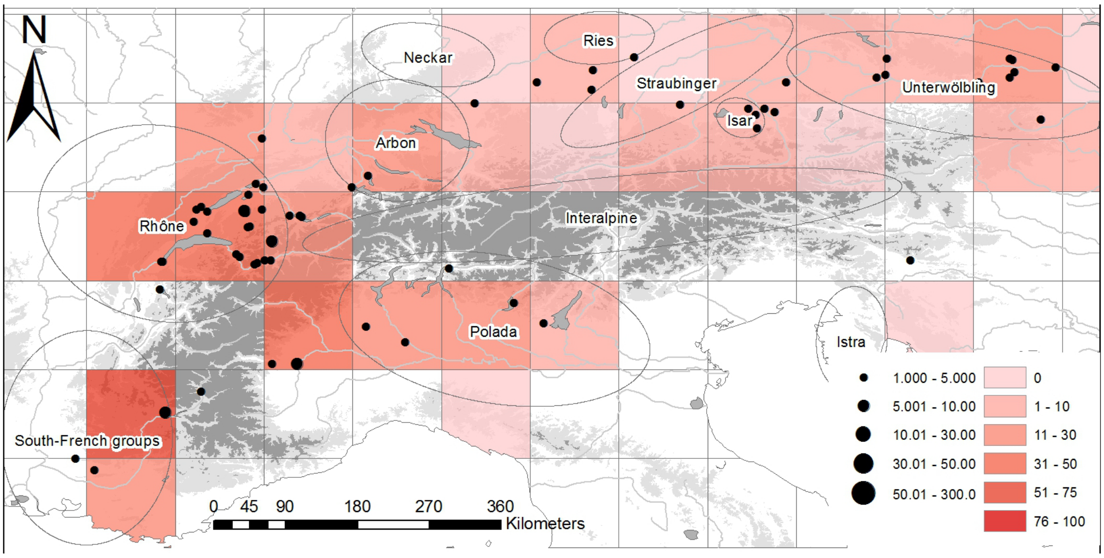


Figure 53: percentage of objects made with Copper Group 1 per zone in the Early Bronze Age 2a. Map symbols are as in Figure 32.

10.2.3 Period A2b

In the final phase Copper Group 1 maintains its previous distribution, being more focused in the western zone, but in this phase it penetrates more consistently into the Polada culture in northern Italy, instead of being limited to the Rhône regions. Following the pattern of the Early Bronze Age 2a, Group 1 in the west is not generally limited to a specific category of object or site, apart from a hot spot of this composition in southern Austria. This is due to the composition of the axes of the Nieder hoard, in Osterwitz (O-W 1200-1203). These axes are described by Otto and Witter as “flat axes made of raw material, just cast” (Otto & Witter 1952) and this leads to an hypothesis of a “metallurgical hoard” comprising of unfinished artefacts. The analysis presented here suggests that the origin of this hoard might be far from the deposition point, most likely in the western zone of the Alps, where this composition was more common.

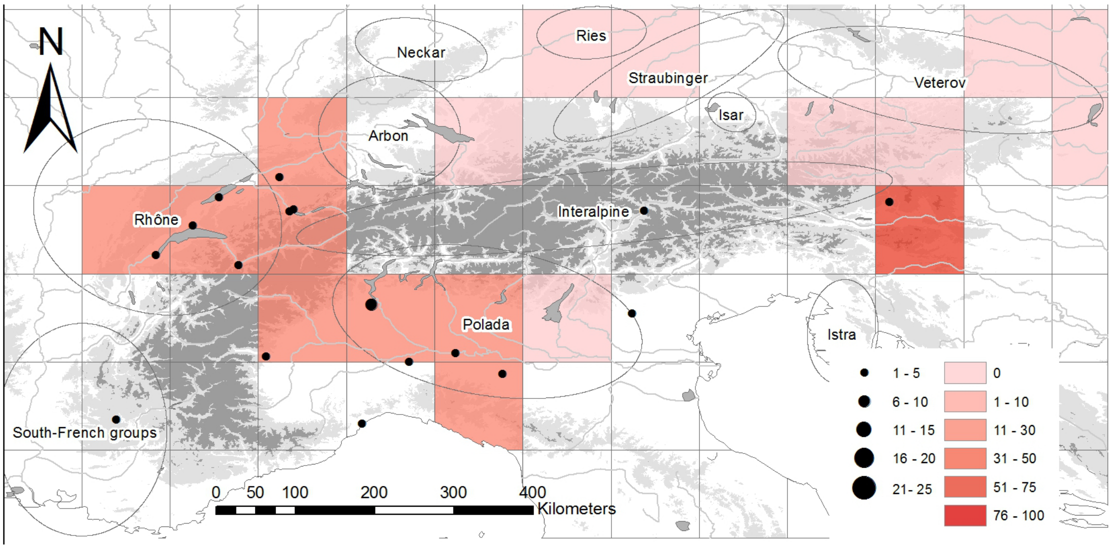


Figure 54: percentage of objects made of Copper Group 1 metal per zone in the Early Bronze Age A2b. Map symbols are as in Figure 32.

10.2.4 Discussion on Copper Group 1

As explained in Chapter 3.2 the Flow Model is based on a two-step analysis: ubiquity analysis and the analysis of the most volatile elements in space and time. Group 1 allows only the first step, since it consists only of clean copper. But, as mentioned, the ubiquity analysis highlights a region with a high percentage of objects made of this composition that corresponds to the possible ore source. The zone where this Group is more common includes the mine of Saint Véran, in which is verified the presence of the entire *chaîne opératoire* for copper production, functional in 2300-1750 B.C. (see Section 5.2); and Clue de Roua, functional in 2200-1800 B.C.. From Saint Véran bornite was extracted, from which copper without impurities could potentially be smelted. From Clue de Roua there is evidence for exploitation of native copper (Section 5.2). Therefore, it seems possible that the primary centres of production of this Copper Group are Saint Véran and Clue de Roua.

The typical pattern of the "halo effect" is indicated as a "fall off in frequency or abundance with distance from the source" by Renfrew. It is a pattern that indicates uniform loss or deposition and absence of highly organised, directional, preferential exchange (Renfrew 1977, 72). This kind of distribution is more likely to be related to short step exchange: if the distribution of metal were through established long distance trade-routes, the percentage of objects would show a preferential direction where the percentage remains higher for a greater distance. A final note, discussed in detail in Chapter 11, is that in most cases objects made of Copper Group 1 in the western zone have had an addition of tin, but not in the east.

10.3 Copper Group 12

10.3.1 Period A1

Almost half of all the artefacts dated to A1 belong to Group 12 (copper with As, Sb and Ag). Only eight axes were made with this composition, and 16 daggers against 272 ornaments, 697 ingots and nine awls. This Copper Group was mostly distributed in the northeast of the Alps (Figure 55). Surrounding this hotspot is a halo of zones with lower percentages of objects made with this composition. Its distribution corresponds roughly with the Straubinger, Isar and Unterwölbling cultural groups.

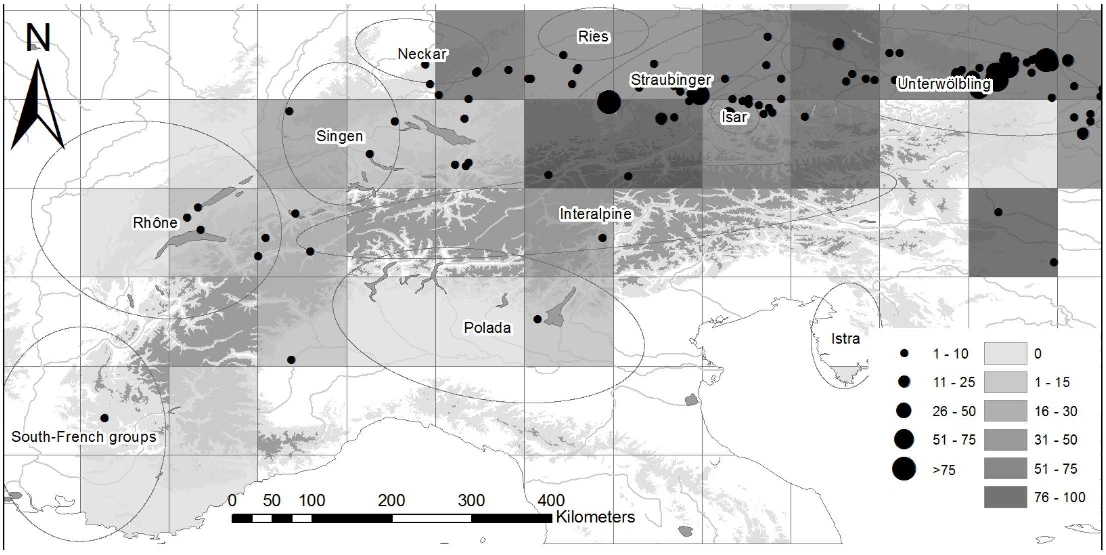


Figure 55: percentage of objects made with Copper Group 12 per zone in the Early Bronze Age A1. Map symbols are as in Figure 32.

The composition of Group 12 (copper with arsenic, antimony and silver) is related to a particular kind of artefact: namely the *Ösenringe*. In Italy artefacts with this kind of composition are found mainly in Ledro: two spectacle spirals (Te 24 and Te38), an *Ösenring* and an awl. Another *Ösenring* was found in south Tyrol, but only a fragment of a spiral with this composition was found in the western zone, in Piedmont. In the north-east zone the percentage of the other categories of artefacts made with Copper Group 12 is still high, but other groups are also present. For instance, axes made of group 16 are well represented in the north-east.

For Copper Group 12 we can also study the spatial distribution of arsenic, which was not the case for Group 1. The spatial correlation analysis (Global Moran's I) demonstrated that the geographical distribution of arsenic in objects classified as Copper Group 12 is not random with a $p<0.01$. The Anselin Local Moran's I analysis pinpoints that the location of spatial clusters of high levels of arsenic reflects the distribution of objects: objects with high concentration of arsenic are in correspondence to the zone where most of the objects have this composition (Figure 56).

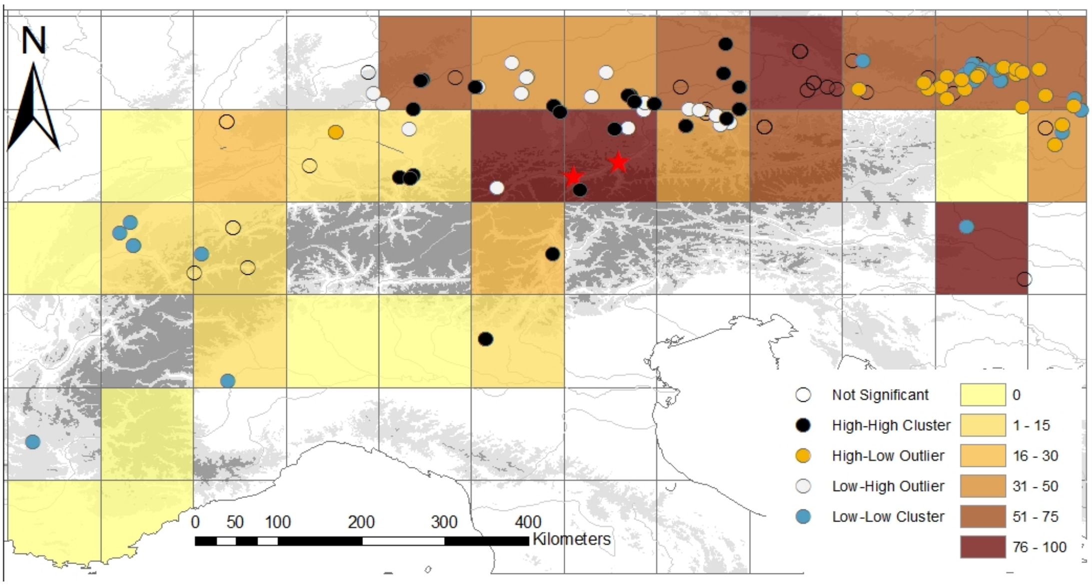


Figure 56: comparison between the percentages of objects made with Copper Group 12 per zone and the result of spatial cluster analysis on arsenic level in objects. The red stars indicate the location of Schwaz-Brixlegg district, the possible source of this kind of material.

There is a halo effect of depletion of both the concentration of artefacts and of the level of arsenic from the zone that may be the production centre (see below). From this central zone there are zones where the level of arsenic is average and, furthest from the centre, zones where there are clusters of low levels of arsenic.

This distribution of clusters is due, in particular, to the distribution of ingots (*Ösenringe)* that, as mentioned, are the most represented category of artefacts with this Copper Group composition. Although *Ösenringe* generally contain high levels of arsenic, the Local Anselin Moran's I analysis indicates that arsenic pattern in ingots are highly spatially clustered, showing that the arsenic levels in *Ösenringe* tend to fall off with distance from the possible source. This reflects the picture already shown when considering the entire assemblage. However, the spatial distribution of the levels of arsenic in ornaments is quite different, because in this case it does not reflect the distribution of objects: namely spatial clusters of high levels of arsenic are not in correspondence to the areas where most of the ornaments made of Group 12 are found (Figure 57). These clusters are due to a specific category of artefacts: rings found in burials (e.g. Unterwölbling, Gemeinlebarn) that are concentrated in the furthest northeast zone.

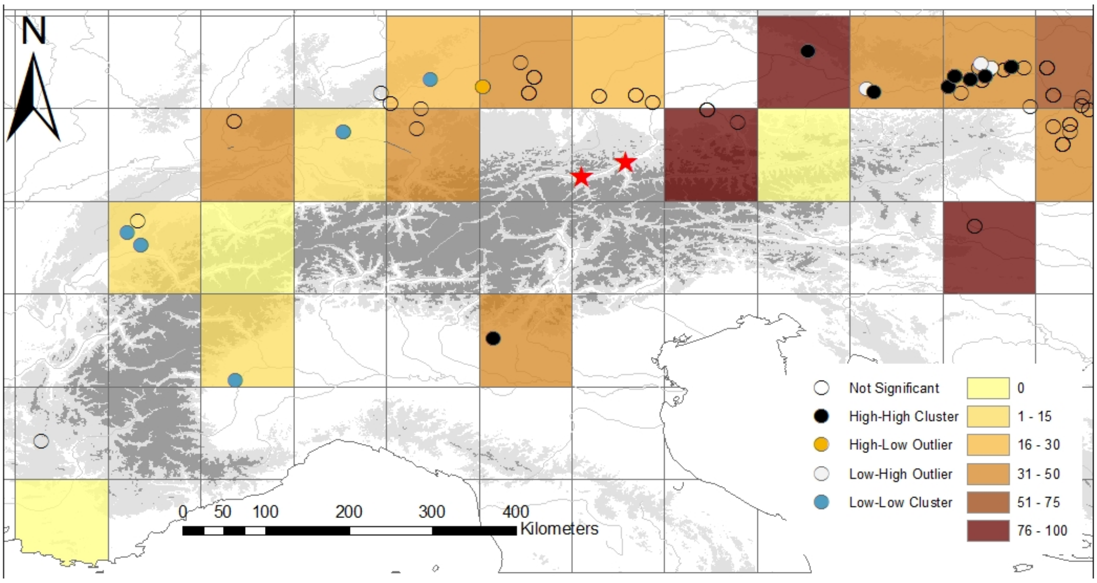


Figure 57: comparison between the percentages of ornaments made with Copper Group 12 per zone and the result of spatial cluster analysis on their arsenic levels. The red stars indicate the location of the possible source of this kind of material.

The graphs of the amount of arsenic show the important difference between ingots on one hand and the other categories on the other. In fact, axes, daggers and ornaments have the peak in the lower level of arsenic content. Axes show also a peak at about 2% of arsenic but it has to be observed that there are only few axes, and one or two objects are enough to cause a significant peak. Ingots have a distribution that is similar to a normal distribution with a peak around

1.5% (Figure 57). The implications of the different arsenic distribution in ingots are further discussed in Section 13.3.

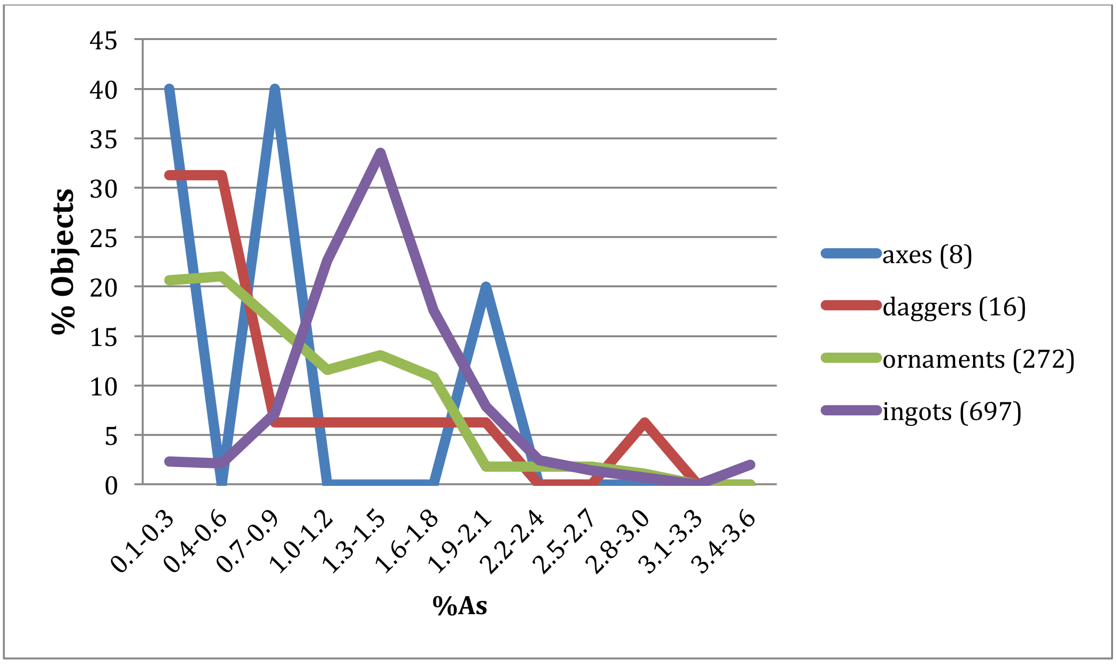


Figure 58: percentages of objects made of Copper Group 12 per level of arsenic in the Early Bronze Age A1.

10.3.2 Period A2a

In the second phase Copper Group 12 decreases in ubiquity, so that now only 27% of the artefacts are made with this composition, almost half of its presence in the Early Bronze Age A1. Ingots are still the most represented category, but the number of axes increases (22), daggers remains mostly unaltered (10), while ornaments decrease very significantly (20).

The spatial and cultural distribution is similar to the previous phase, but some differences should be highlighted. The north-west area has still the highest percentage of objects with this composition, but this percentage is decreased: in the previous period it was 75-100% and in this period it is 31-50%. From this zone there is a halo effect that involves a larger area, to western Switzerland (Figure 59). Again, Group 12 copper is particularly related to what Krause classifies as "ingots" found in hoards, but in this phase, beside *Ösenring*, a new category of ingot appears: *Spangenbarren* (rib ingots). In north-east, apart from ingots, Group 12 is found in ornaments, in particular the ones from the Stockerau hoard.

Conversely, in the other zones of the Alps, the Group 12 composition is more common in axes or daggers. In northern Italy it is particularly related to types of objects whose spatial distribution is very localised to the eastern zone, for example in a dagger of Barche di Solferino, which have a shape typical of the eastern zone of northern Italy (Bianco Peroni 1994, 27), a dagger of Maraschina (Bianco Peroni 1994, 24) and the pins of Ponti (Carancini 1975, 95).

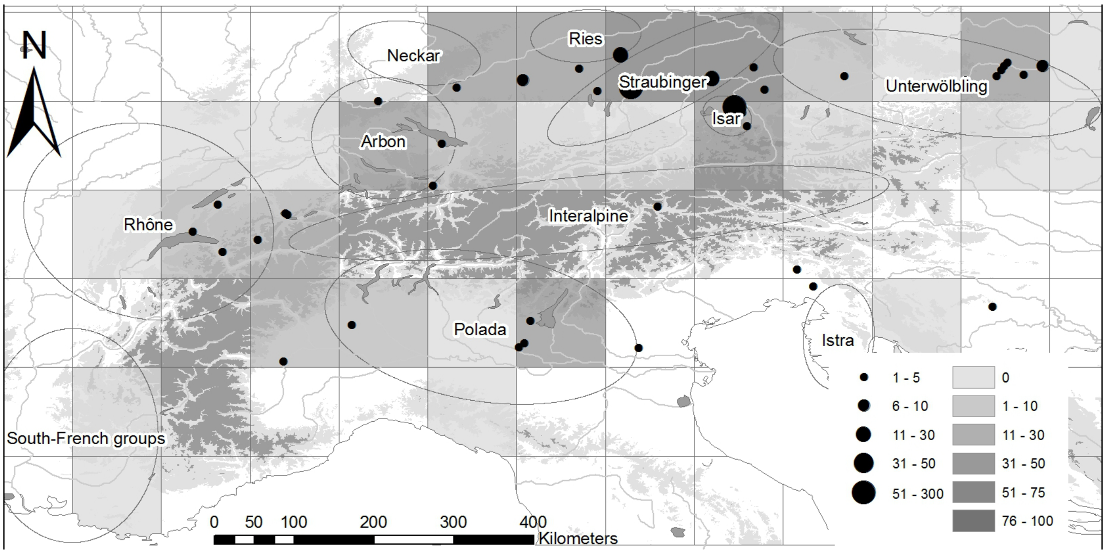


Figure 59: percentage of objects made with Copper Group 12 per zone in the Early Bronze Age A2a. Map symbols are as in Figure 32.

The spatial distribution of the clusters with high levels of arsenic does not change significantly from the previous period and there is still a coincidence between the zones with a high percentage of objects made of this composition and the position of spatial clusters with high levels of arsenic, throughout the Inn valley. From this zone, there is a halo effect, with a zone that has a lower percentage of objects made of this composition and with spatial clusters containing low levels of arsenic.

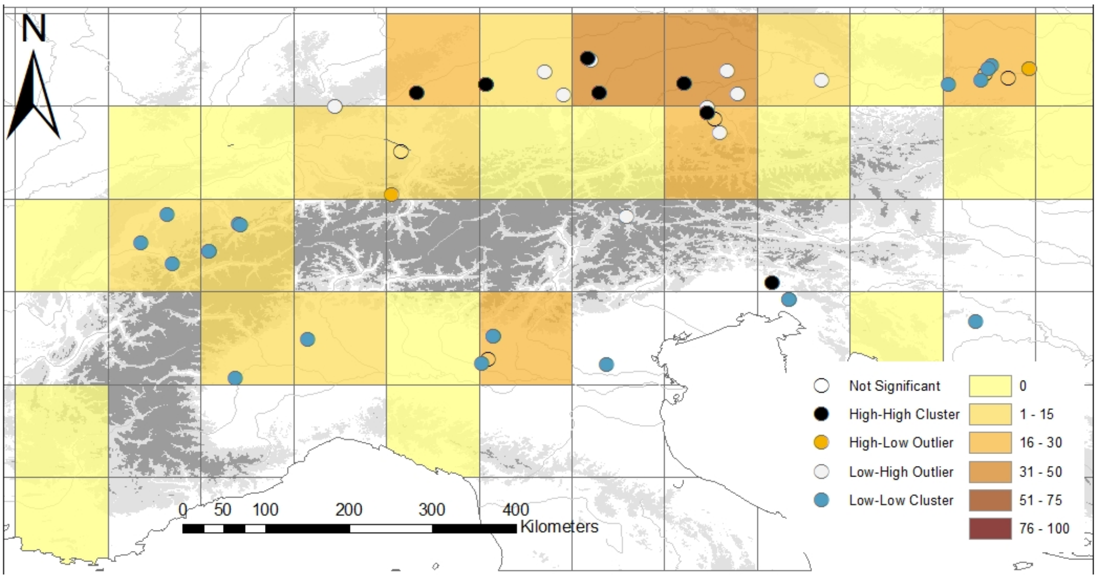


Figure 60: comparison between the percentages of objects made with Copper Group 12 per zone and the result of spatial cluster analysis on arsenic level in objects in the Early Bronze Age A2a.

The clusters with high levels of arsenic are influenced by the presence of ingots, which, as mentioned above, are solely distributed in that region. Ingots, as mentioned below, have a higher percentage of arsenic than the other categories and have a clustered distribution, even though the Local Anselin Moran's I analysis has not be able to pinpoint specific locations of clusters of high values of arsenic. However, the Global Moran's I analysis indicates that the entire assemblage –ingots excluded- is still clustered. Local Anselin Moran's pinpoint at least a cluster of low level of arsenic in the western region. On the other hand, considering each category of artefacts, axes, daggers and ornaments have random spatial distribution of arsenic, but the analysis may be invalidated by the low number of objects (Table 14).

The pattern of the level of arsenic for each category of object is similar to the one already explained for the previous period: in particular the different pattern of ingots with respect to the other categories, because ingots have a distinct maximum at about 1.5% of arsenic whereas the peak of frequencies for the other categories are at lower levels (Figure 61). This is further discussed in Section 13.3.

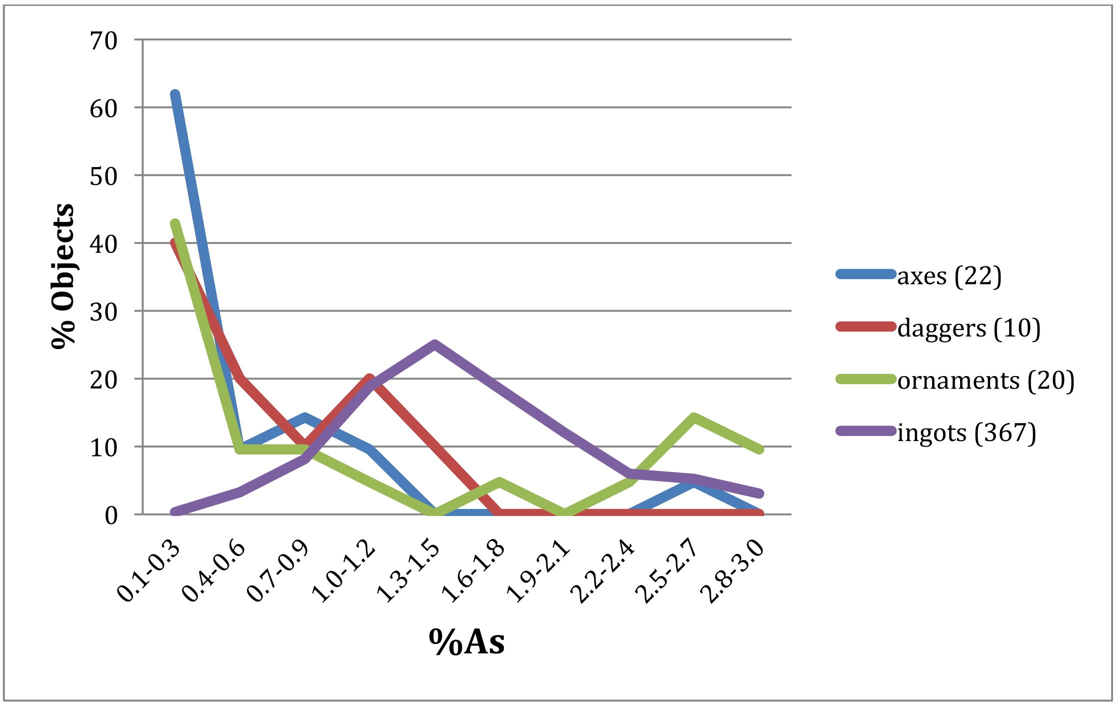


Figure 61: percentages of objects made of Copper Group 12 per level of arsenic in the Early Bronze Age A2a.

10.3.3 The analysis of arsenic in Group 12 through time

The next graphs highlight the changes of arsenic through time for each category of artefacts. There are hints of a reduction of arsenic through time in axes and ornaments (Figure 62). In the case of ingots, the percentage of objects in the highest peak has a significant reduction in the second phase of the Early Bronze

Age. The patterns of ingots are obviously very different from the ones of the other artefacts and this is further discussed in Chapter 13.

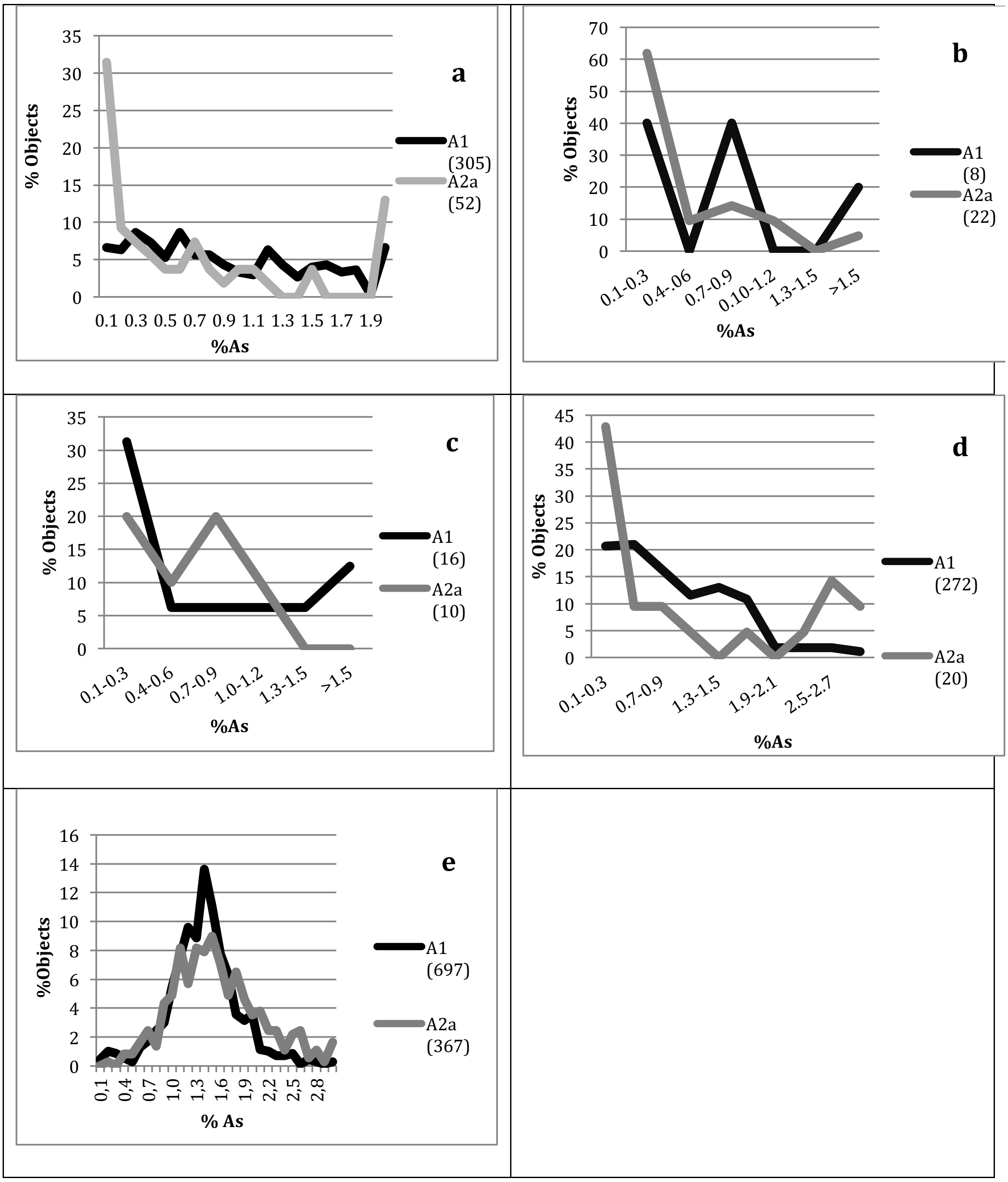


Figure 62: percentages of (a) the entire assemblages, (b) axes, (c) daggers, (d) ornaments and (e) ingots made of Copper Group 12 per level of arsenic through time.

10.3.4 Discussion on Copper Group 12

According to Höppner *et al.* (2005), the supposed sources for *Fahlerz* with As, Sb and Ag (Group 12) are the Schwaz-Brixlegg mines. As explained in Section 5.2 the activity of those mines is not totally certain, but, taking into account the above evidence of both ubiquity and geostatistical analysis (Figure 56), it seems probable. From the Schwaz-Brixlegg area there is a halo effect in the distribution of objects. The level of arsenic constantly decreases through time, both overall and within single categories of artefacts. These patterns are a clear evidence of movement of metal through short steps and of a recycling activity. Moreover, the decreasing number of artefacts (both absolute and relative) may suggest that the main production of this kind of metal is in the first phase of the Early Bronze Age; in the second phase the production was reduced if not stopped, and metal finds are solely the result of recycling of the primary production in the previous phase. As a matter of fact, the lower levels of arsenic in objects indicate a major recycling activity that creates a kind of “secondary” metal.

10.4 Copper Group 16

10.4.1 Period A1

Another important composition - roughly 22% of the artefacts dated to EBA A1 - is Group 16, defined by the presence of Cu containing As, Sb, Ag, and Ni. This group seems to be more common in the central regions, with a particular focus on the Rhine, Oglio and Adda rivers (Figure 63), corresponding to the Singen and the Polada cultural groups.

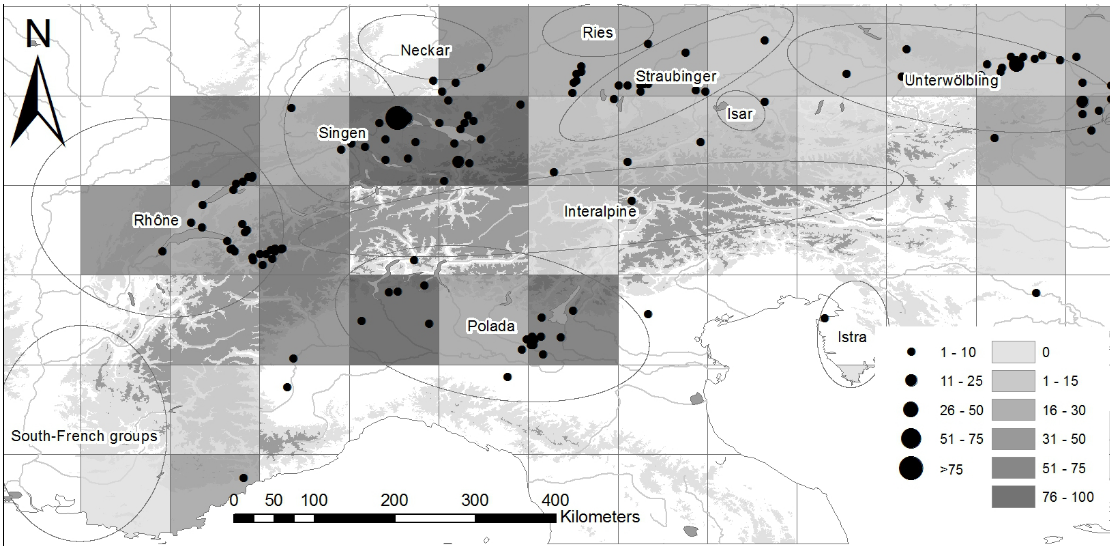


Figure 63: percentage of objects made with Copper Group16 per zone in the Early Bronze Age A1. Map symbols are as in Figure 32.

Axes, daggers and ornaments are well represented in Group 16: there are 113 axes, 62 daggers, 260 ornaments, nine awls and six ingots. Group 16 is an important group for all kinds of artefact and is less related to a specific category, as with group 12 for the *Ösenringe*. It has to be noted, though, that, as is well established, moving from east to west the number of hoards made of *Ösenringe* decrease and, in a symmetrical way, the number of hoards composed of axes increase. These axes have mainly the composition of group 16. Axes made of group 16 are well represented in the north-east, due mainly to large axe-hoards such as the example from Wolnzach. These axes are reported to be Saxon type (SAM 15320-15325), and this typology is typical of the north-east zone of the Alps (Kienlin 2010, 137; Kienlin *et al.* 2006, 462). Hence here there is a case of artefacts made of a composition typical of another region but with the typology of the local zone.

The Spatial Correlation Analysis undertaken on arsenic –previously transformed with the log(10) function – on all the objects dated A1 shows that this is not a random geographical distribution with a $p<0.01$. Once again, there is a substantial correspondence between the zones that have the highest percentage of objects with this composition and the highest values of arsenic, and also, at the same time, between the zones that have less artefacts and the lowest levels of arsenic, creating a "halo" effect (Figure 64).

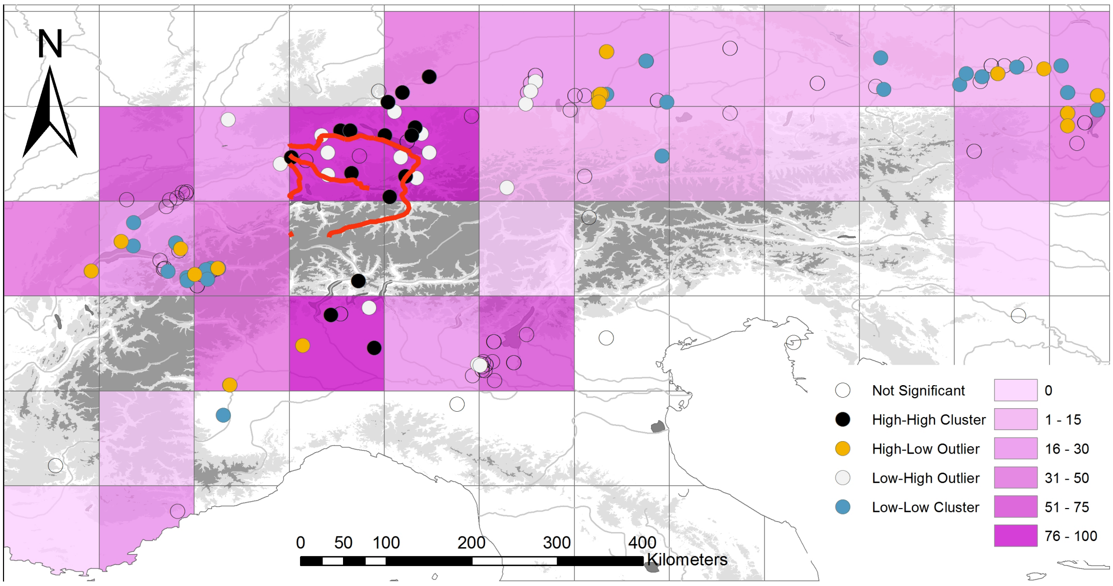


Figure 64: comparison between the percentages of objects made with Copper Group 16 per zone and the result of spatial cluster analysis on arsenic level in objects. In red the possible zone of the source of this metal.

The clustering effect depends on the category of the artefacts. In particular, the cluster of high levels of arsenic focussed in the central region is due to the presence of axes with high levels of arsenic. Axes, in general, have a higher level of arsenic than the other categories (Figure 65). They can be divided into two groups: there is a group of 58 axes that have a level of arsenic>1% by weight, that are mainly from hoards and mainly located where there is a higher concentration of artefacts made of this composition. Axes with less than 1% of arsenic are more broadly spread across the entire Circum-Alpine region and may be founds in hoards, but also in settlements and as single finds. We note that the Shapiro Wilk test indicates that the hypothesis that the first group of axes (the ones that have more than 1% in weight of arsenic) has a normal distribution of arsenic cannot be rejected, with a p value of 0.99. The mean arsenic in this group is 2.18%. This suggests that these axes may be primary metal, and the hypothesis that they may have been functioned as ingots is dealt in Chapter 13.

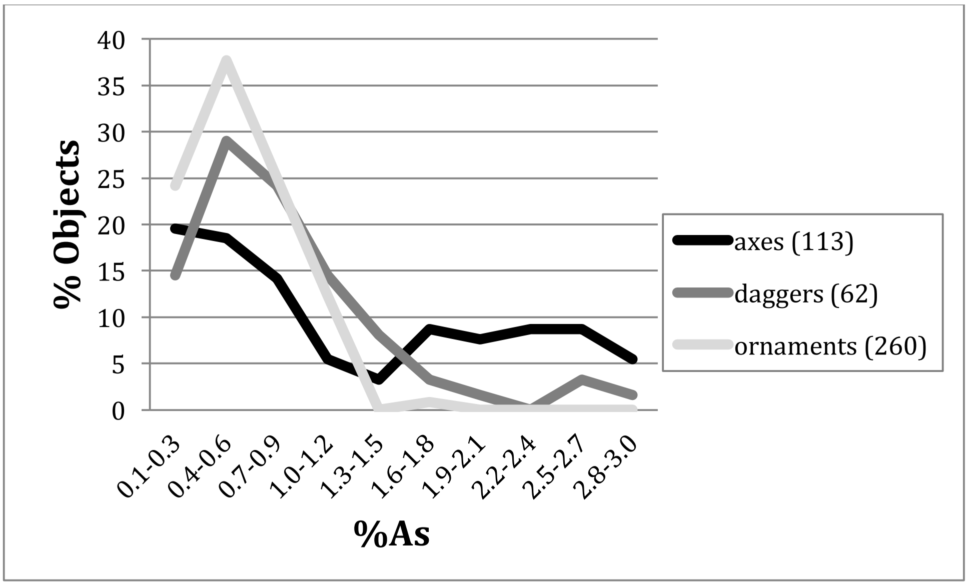


Figure 65: percentages of objects made of Copper Group 16 per level of arsenic in the Early Bronze Age A1.

10.4.2 Period A2a

In a second phase of the Early Bronze Age the most relevant difference in terms of representation of artefacts is the appearance of *Spangenbarren* ingots, which embody almost ¾ of the entire assemblage of artefacts made with the composition of Group16 (435 in total). There were also 51 axes, 28 daggers, 46 ornaments, and three awls.

In this chronological phase Group 16 has more centres of concentration compared to its earlier distribution. Apart from the area where it is predominant in the first phase of the Early Bronze Age, it also acquires a major importance in the eastern region.

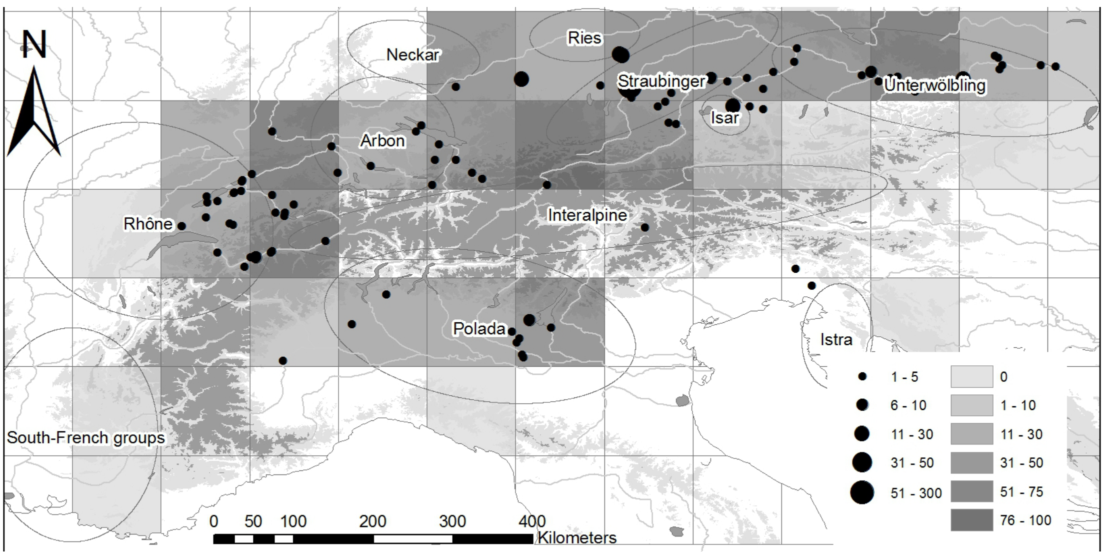


Figure 66: percentage of objects made with Copper Group 16 per zone in the Early Bronze Age A2a. Map symbols are as in Figure 32.

As shown below (Figure 70) the trend for the level of arsenic in ingots is once again different from the ones for axes, daggers and ornaments, so two spatial cluster analyses have been undertaken, because for *Spangenbarren* ingots the log(10) transformation of arsenic is not necessary to obtain a distribution similar to a normal distribution.

Spangenbarren ingots are mainly present in the northeast region, but this is true in general for all the ingots, not only for the ones made of this kind of composition. Once again, they are spatially cluster distributed (Figure 67).

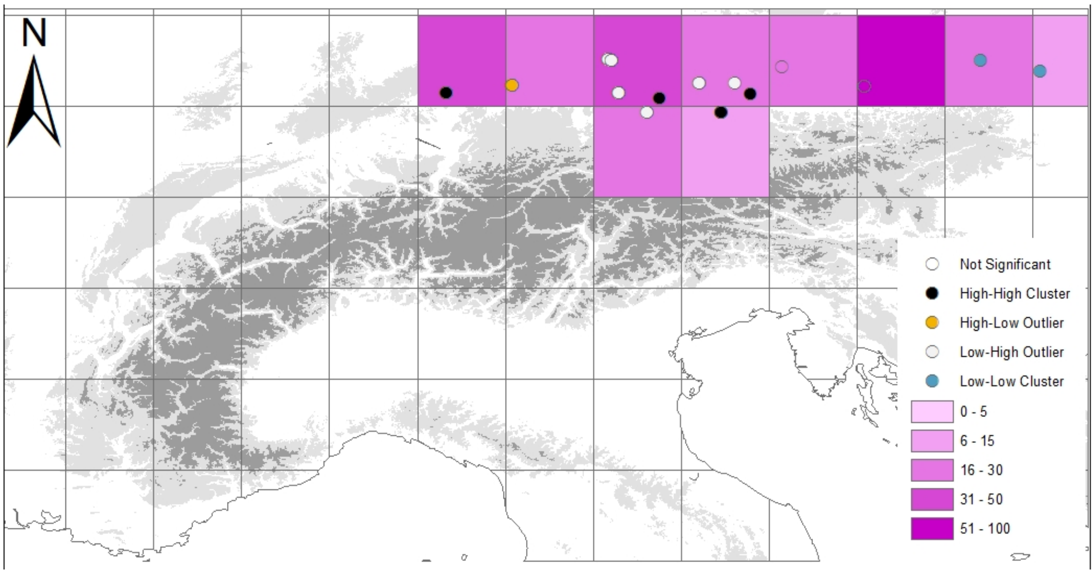


Figure 67: comparison between the percentages of ingots made with Copper Group 16 per zone and the result of spatial cluster analysis on arsenic levels in objects.

The other objects (Figure 68) are more equally distributed thorough the Circum-Alpine region with two main foci: one in the northeast, like the ingots, and the other in the central western zone, as in the previous period. The farthest western zone, corresponding to the low Rhône valley, is the zone where copper of Group

16 is less common. The spatial clusters of high percentages of arsenic are located similarly to the ones for the ingots, namely in the northeast zone and no longer in the centre-west, where there are spatial clusters of low levels of arsenic.

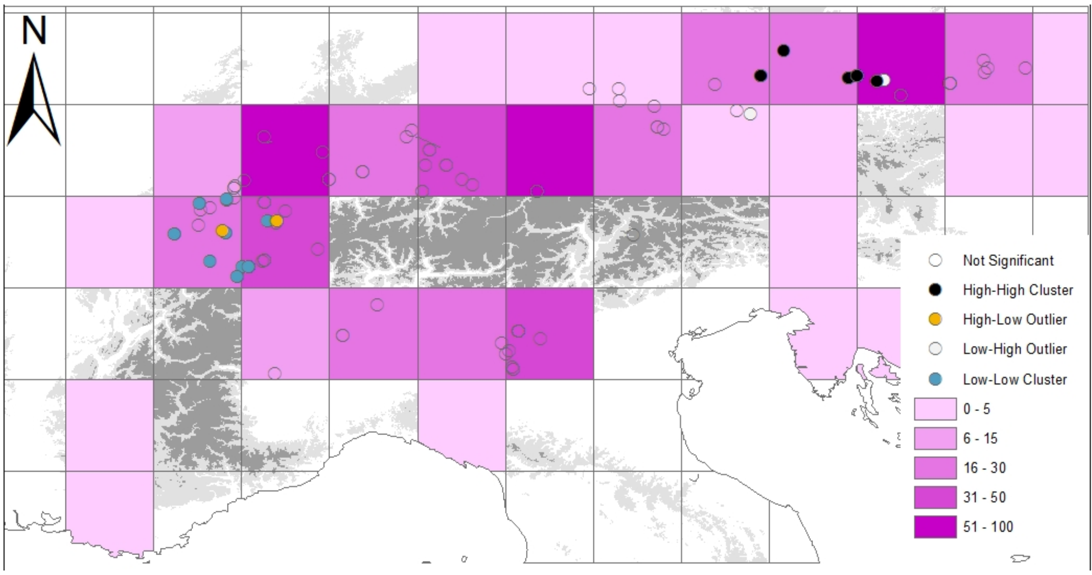


Figure 68: comparison between the percentages of objects (ingots excluded) made with Copper Group 16 per zone and the result of spatial cluster analysis on arsenic levels in objects.

Looking at the different categories of artefacts there are some differences. Ornaments and axes show a distribution of arsenic in space similar to the one seen when considering the entire assemblage. On the other hand, daggers have clusters of high levels of arsenic in Italy, and clusters of low levels of arsenic in Switzerland (Figure 69). The daggers responsible for the clusters of high levels of arsenic are three daggers from Ca'de Cioss, Lagazzi and Peschiera (although the one from Lagazzi has been dated to the Early Bronze Age A2b by de Marinis). Clusters with low levels of arsenic are, similar to the other artefacts, in the west.

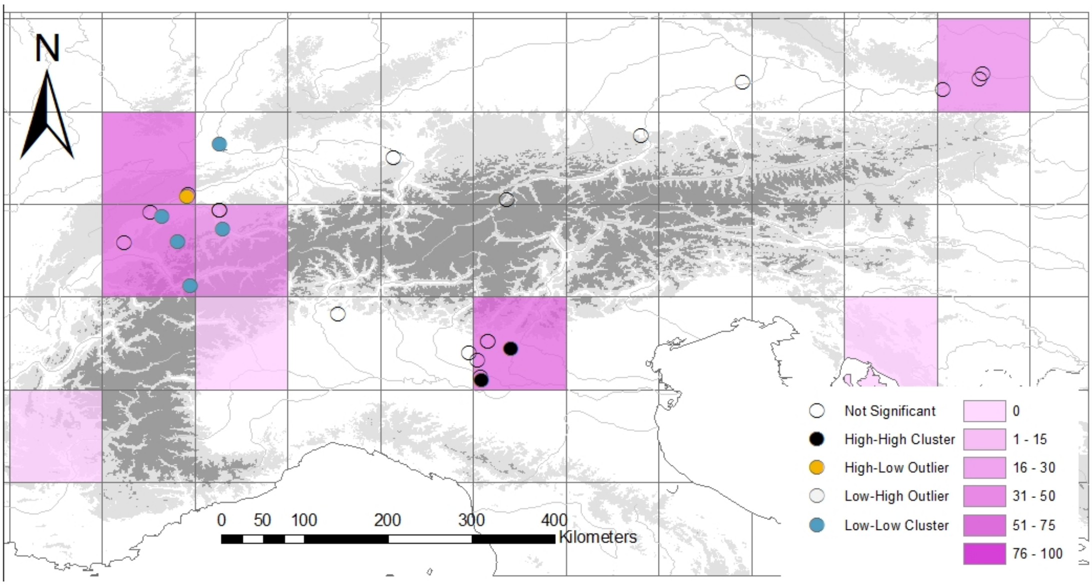


Figure 69: comparison between the percentages of daggers made with Copper Group 16 per zone and the result of cluster analysis on arsenic levels in daggers.

The trends of the levels of arsenic in the artefacts (Figure 70) are very similar to the ones of the previous period. As with the previous period, there is a group of axes with a significantly higher percentage of arsenic, and those axes are from hoards, such as Wilhering and Griesbach in Austria, and Sigriswil-Ringoldswil in Switzerland. The pattern of *Spangenbarren* ingots is significantly different and has the modal peak at 1.4% of arsenic, and this is similar to the pattern of ingots in Group 12, both in the Early Bronze Age A1, and in A2a.

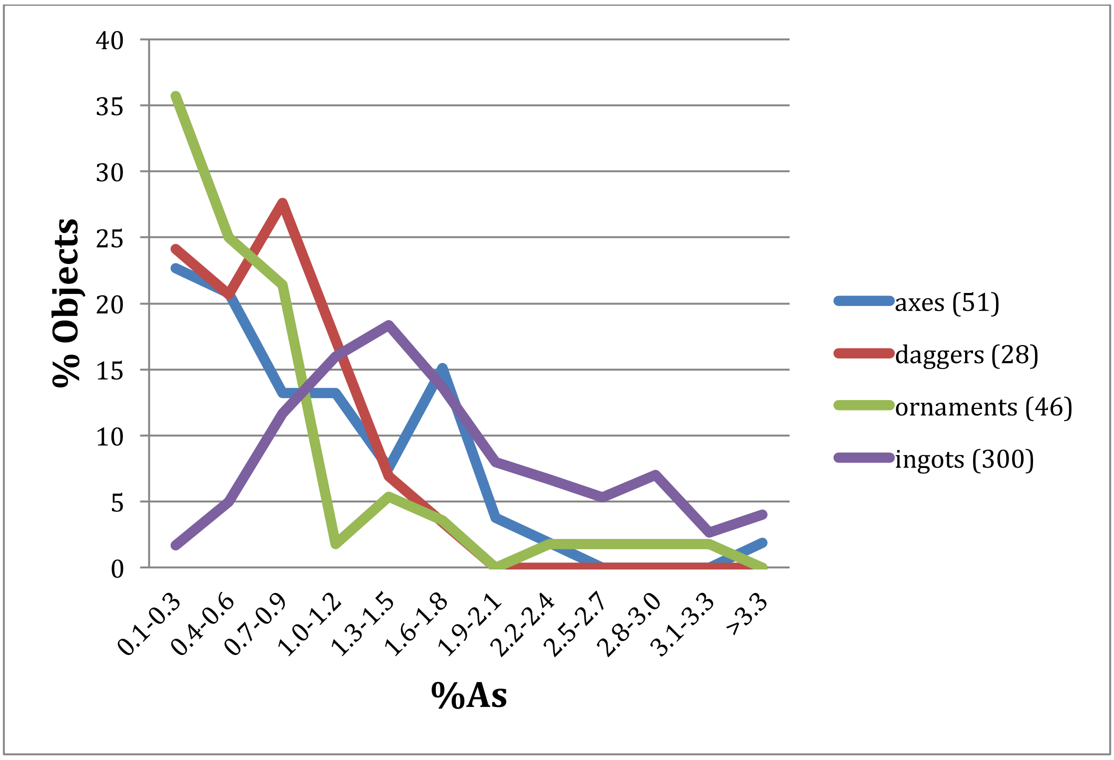


Figure 70: percentage objects made of Copper Group 16 per level of arsenic in the Early Bronze Age A2a, divided by category.

10.4.3 Period A2b

In the last phase of the Early Bronze Age, the number of objects decreases significantly. There are only 45 artefacts made with the composition of Group 16: 26 axes, eight daggers, 10 ornaments and one awl. This reflects a decrease in the percentage of Group 16 objects to 15.5%. Group 16 is mainly distributed in the western part, in the Arbon and Polada cultural zones. From there, it spreads with a halo effect. On the other hand, there is a hotspot further north-east, with its own little halo. This time the hotspot is not due to a hoard, but mainly to ornaments from burials, such as the pins found at Regelsbrunn (SAM 5012, 5013) or Geimenlebarn (SAM 5609).

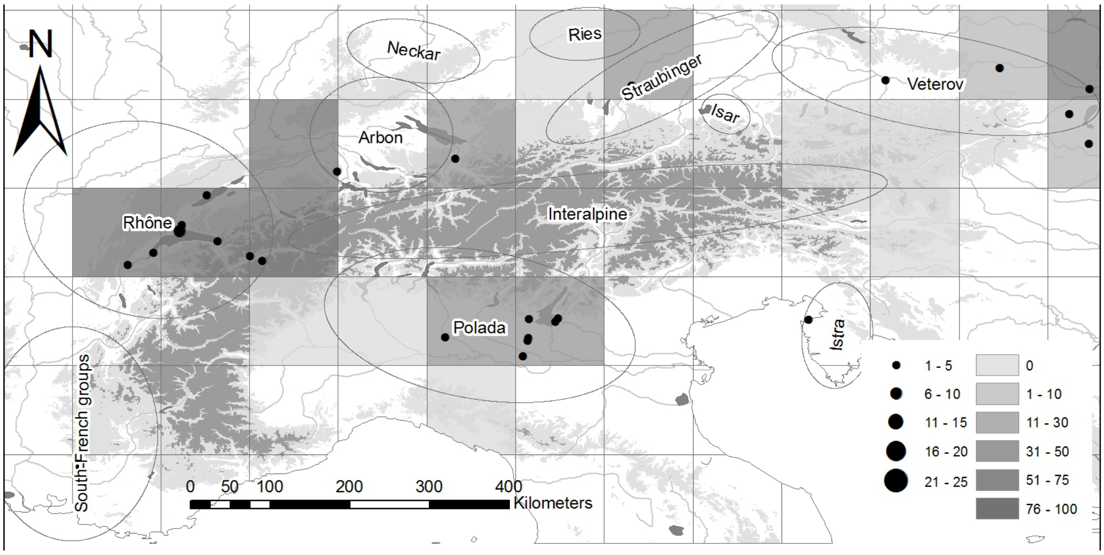


Figure 71: percentages of objects made of Copper Group 16 metal per zone in the Early Bronze Age A2b. Map symbols are as in Figure 32.

In this period the distribution of arsenic does not highlight spatial clusters of high or low levels of arsenic. Moreover, ingots with this kind of composition are no longer recorded, and this fits with the fact that, in general, very few ingots are dated to the Early Bronze Age 2b, and these are completely different from the ones of the previous phase (cakes instead of *Ösenringe* and *Spangenbarren*).

In this phase, the trends in the arsenic distribution of all the represented categories are more similar and this is demonstrated also by Kruskal Wallis analysis, which reports a p=0.5.

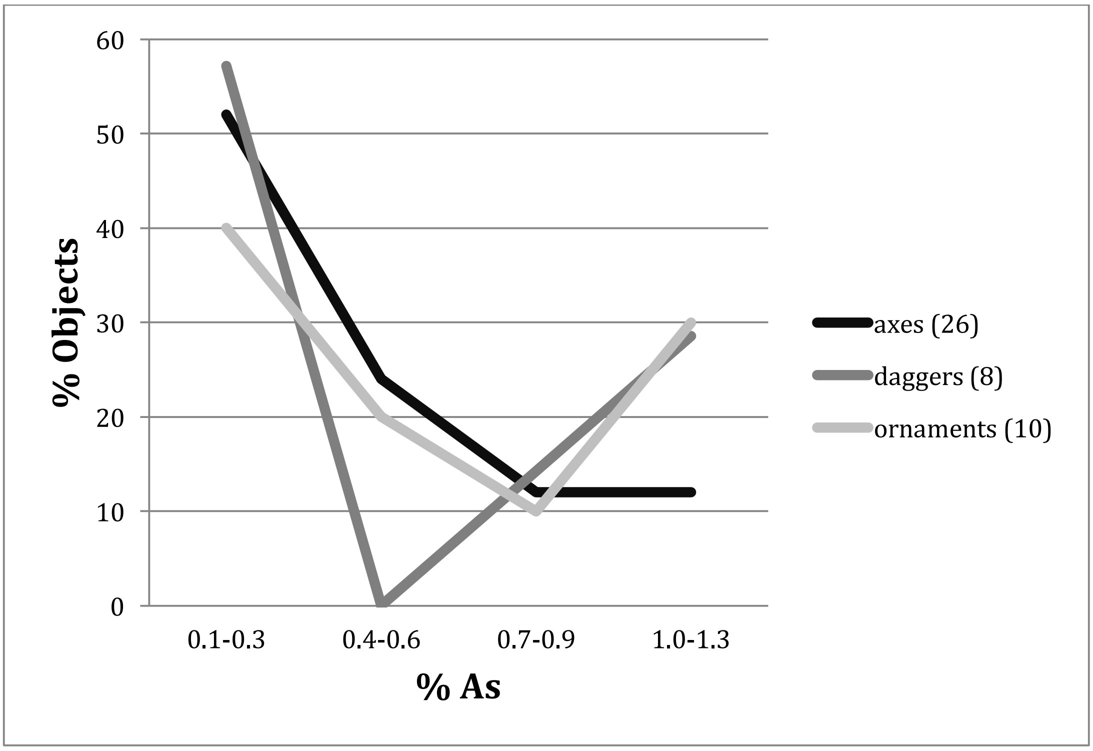


Figure 72: percentages of objects made of Copper Group 16 per level of arsenic in the Early Bronze Age A2b.

10.4.4 The analysis of arsenic in Group 16 through time

Figure 73 compares the trends of arsenic by category through time. This, of course, is not possible for ingots, present only in the Early Bronze Age 2a. The graphs show that the loss of arsenic is apparent in the last phase but not so evident between the first and the second phase, at least as regards axes and daggers.

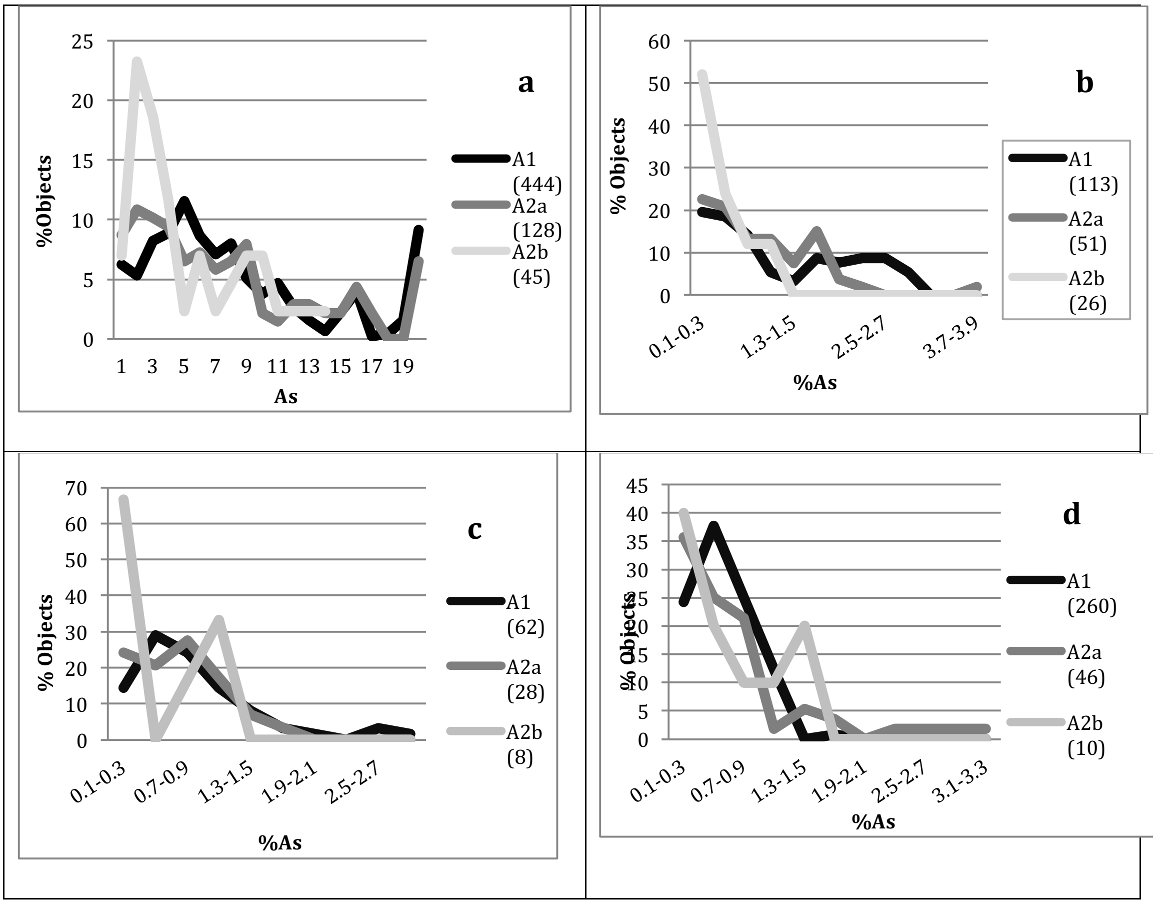


Figure 73: percentages of (a) the entire assemblage (ingots excuded), (b) axes, (c) daggers, and (d) ornaments made of Copper Group 16 per level of arsenic through the three phases of the Early Bronze Age.

Another factor that should be taken into consideration is that the proportions of arsenic, antimony, nickel and silver within the Group 16 metal category changed over time. In the first phase of the Early Bronze Age, almost all the artefacts are made with a trace element composition dominated by antimony (Figure 74).

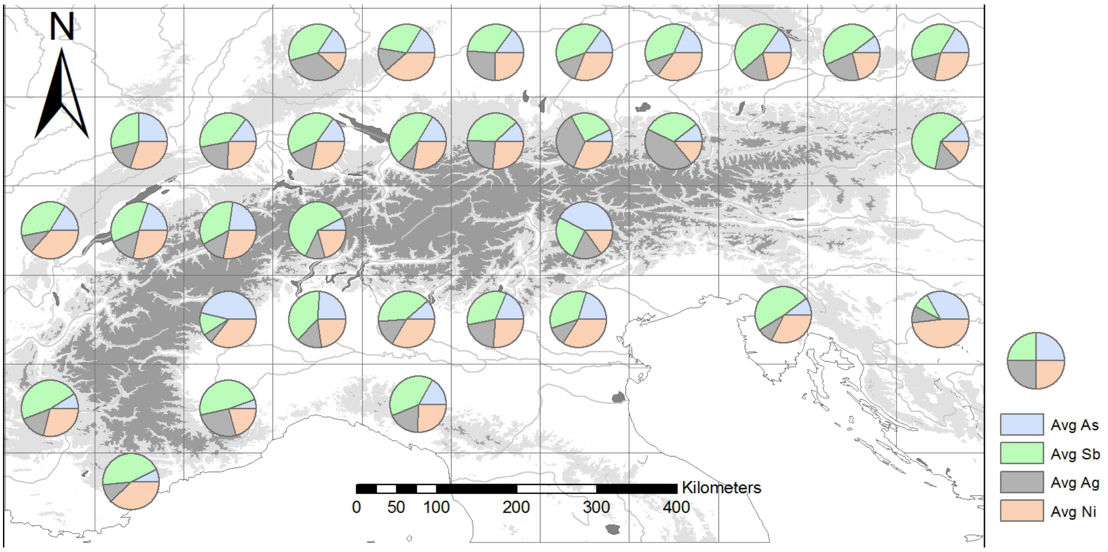


Figure 74: pie charts showing the proportion of arsenic, antimony, silver and nickel in Copper Group 16 in the Early Bronze Age A1. The majority of the artefacts have antimony as main trace element.

In a second phase in the eastern zone there are more artefacts made with arsenic dominating (Figure 75).

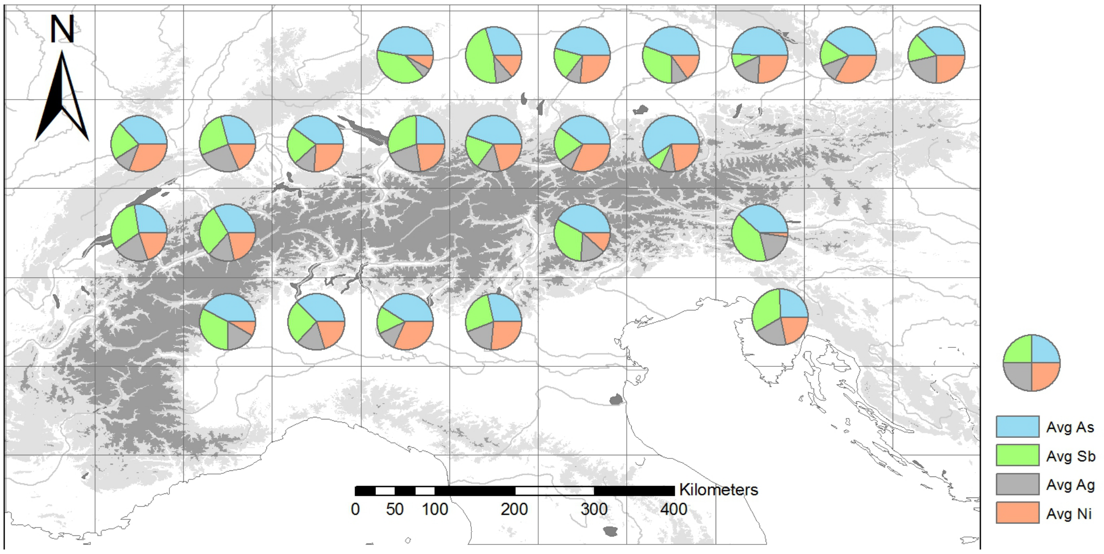


Figure 75: pie charts showing the proportion of arsenic, antimony, silver and nickel Copper Group 16 in the Early Bronze Age A2a. The majority of the artefacts have arsenic as main trace element.

Finally, in the last phase most of the artefacts contain As and Ni as principal impurities (Figure 76).

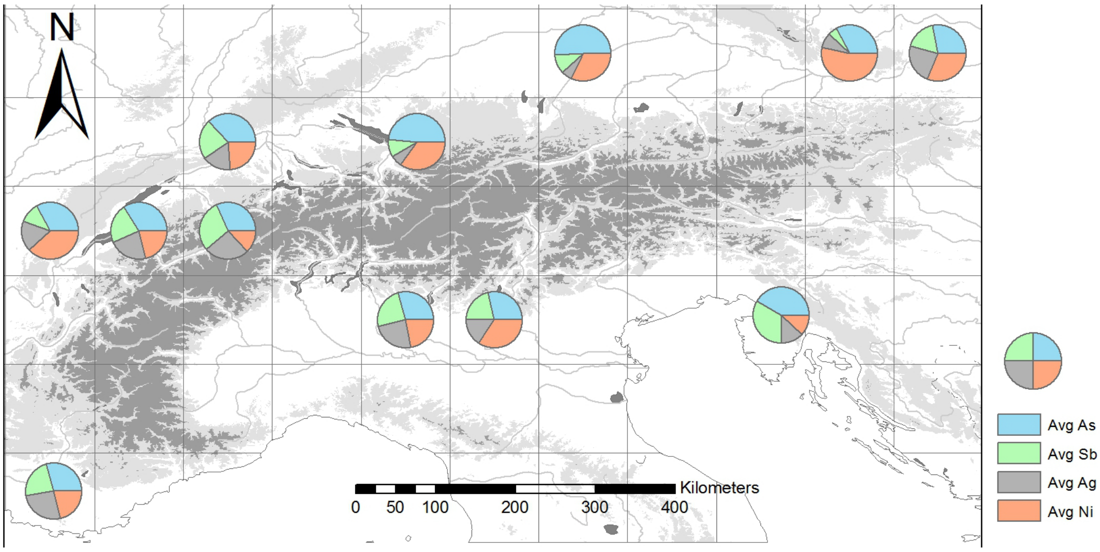


Figure 76: pie charts showing the proportion of arsenic, antimony, silver and nickel in each object made of Copper Group 16 in the Early Bronze Age A2b.

These patterns of changes of the elements through time cannot be explained simply with a recycling model, and are discussed below.

10.4.5 Discussion on Copper Group 16

The origin of copper with arsenic, antimony, silver and nickel in the Early Bronze Age A1 is still debated. The hypothesis of a mine in the upper Rhine valley has been proposed (Kienlin 2010, 176; Krause 2002), but no evidence of mining activity or metal production has been found (see Section 5.2). But the presence of objects, even dated to the final phase of the Copper Age, that have lead isotope ratios compatible with the Rhine massif, supports the possibility of mine exploitation in this area (Cattin *et al.* 2009). Another possible origin for Copper Group 16 is a mine in Lombardy recently studied by Giardino (Giardino 2006), and claimed to be exploited in prehistoric times. Unfortunately, there are no data on the composition of the minerals inside this mine, so it is not possible to know if it is compatible with the composition of Group 16. We note, however, that Group 16 can also be the result of mixing materials from multiple sources.

In the first phase of the Early Bronze Age (A1) there is, in general, a good correspondence between the zones where most of the artefacts were made and clusters with high percentages of arsenic, and also a halo effect in the distribution of objects. This is highly compatible with the idea of a single centre of production and a zone of exchange where objects were more heavily re-melted, losing some percentage in weight of arsenic in the process. Figure 64 would suggest that this centre is the Rhine Valley.

In the second phase of the Early Bronze Age (A2a), the artefacts made with the metal composition of Group 16 are distributed, besides the zone already highlighted for the Early Bronze Age A1, in the north-east. This zone also shows the presence of clusters with higher levels of arsenic and, furthermore, it possibly represents a different kind of metal, with arsenic dominating the four trace elements, instead of antimony. Moreover, spatial clusters of low level of arsenic are present in the central area, where reasonably there still was some "old" metal from the previous period that was subject to re-melting activity. These patterns, in addition to the fact that overall the average level of arsenic within this metal group in the entire Circum-Alpine region is higher than the previous period, leads to the hypothesis that there is a new impulse of metal from the east, whose composition belongs to Group 16. This supports Krause's statement that in the second phase of the Early Bronze Age there is an “eastern Alpine copper” (Krause 2003, 166-169). Proof of exploitation in the Mitterberg dates from the Middle Bronze Age, but an earlier exploitation could also be hypothesized. The fact that this area has ores containing nickel-bearing minerals (such as gersdorffite and millerite, see Section 6.3) supports this theory. This new type of metal could be linked to the presence of a new kind of ingot with this composition: *Spangenbarren.*

Finally, in the last phase of the Early Bronze Age (A2b) the level of arsenic in the artefacts is geographically randomly distributed. On the other hand, the overall level of arsenic is significantly lower than those of the previous periods. Hence, this pattern could be explained with the hypothesis that the metal of this phase is the result of heavy manipulation of metal, with re-melting and possibly mixing processes.

10.5 Group 11

10.5.1 Period A2a

Group 11, made of copper, arsenic and nickel, makes its first appearance in this phase and is more common in the east with the Isar, Straubinger and Ries cultures. Overall, 234 artefacts had this kind of composition: 22 axes, eight daggers, 18 ornaments and 186 ingots. The Global Moran's I test on the level of arsenic on artefacts (transformed with the log(10) function) indicates that the spatial distribution of arsenic was not random with a $p<<0.01$. The Anselin Local Moran's analysis on the overall artefacts, as Figure 77 shows, demonstrates that there is a correspondence of high percentage of objects made with this composition and high levels of arsenic in the northeast zone, in the Inn Valley.

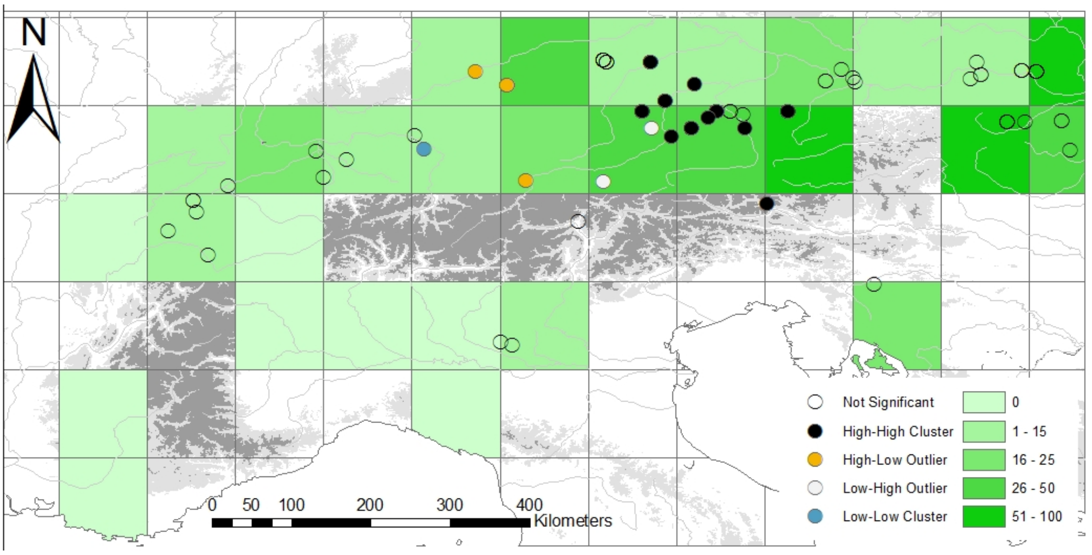


Figure 77: comparison between the percentages of objects made with Copper Group 11 per zone and the result of spatial cluster analysis on arsenic level in ingots in the Early Bronze Age A2a.

This distribution is due to the ingots, but in this case not because ingots have a higher level of arsenic. In fact, Figure 78 shows that, unlike the other copper Groups, the distribution of arsenic in ingots is similar to the other types of objects and cannot be ascribed to a normal distribution. The spatial clusters shown in Figure 77 are due to the fact that ingots are spatially clustered, whereas axes, daggers and ornaments have a spatially random distribution of arsenic.

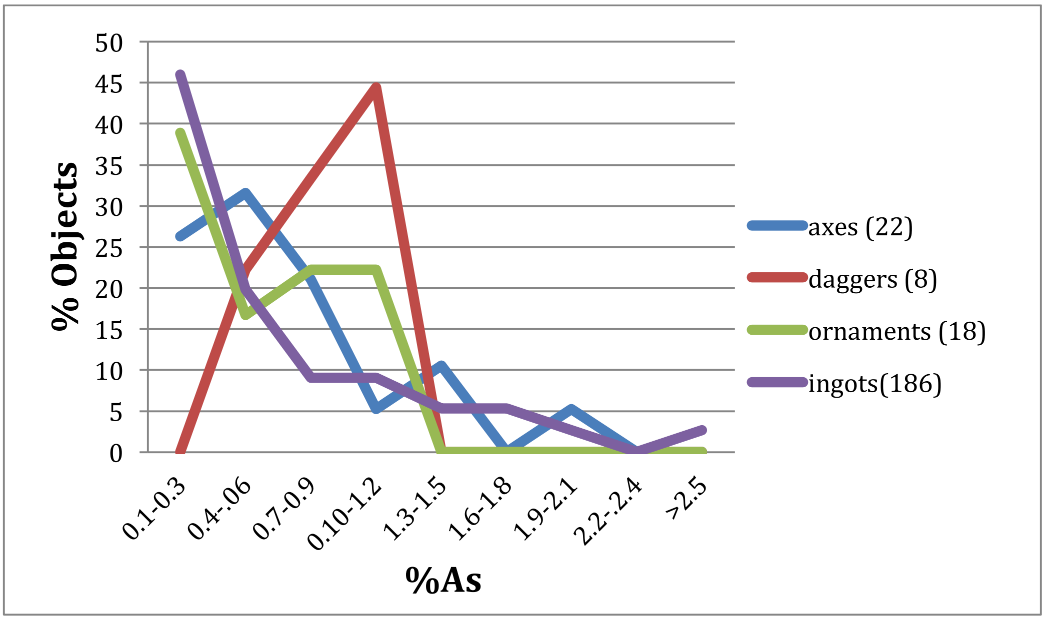


Figure 78: percentages of objects made of Copper Group 11 per level of arsenic in the Early Bronze Age A2a.

10.5.2 Period A2b

From this phase there are a total of 54 artefacts: 13 axes, 10 daggers, 27 ornaments and four sickles. There are not significant differences in the patterns of this group, both in the overall distribution of the assemblage, and in the characteristic of specific types of artefacts (Figure 79).

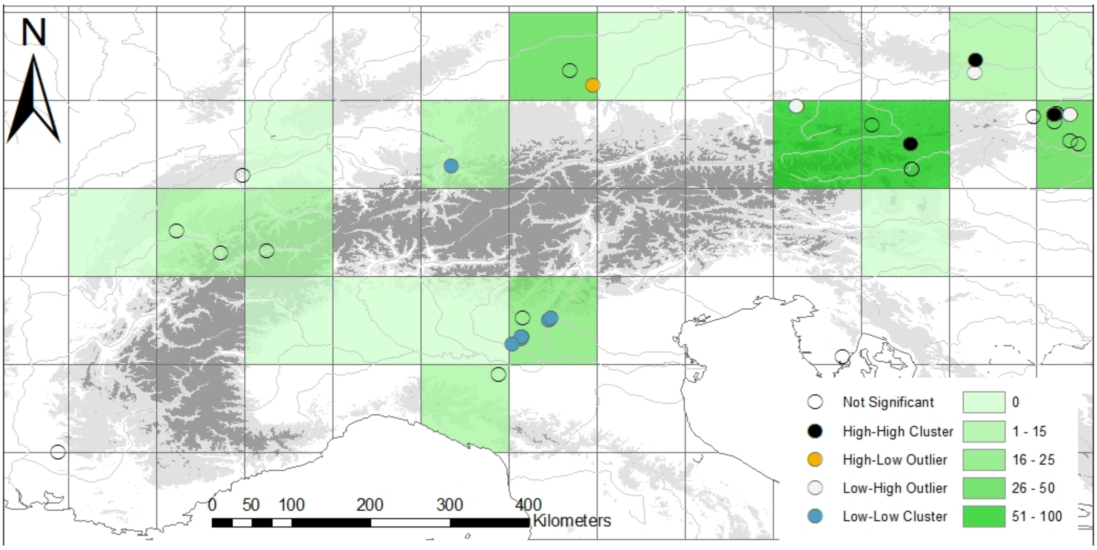


Figure 79: comparison between the percentages of objects made with Copper Group 11 per zone and the result of cluster analysis on arsenic level in object in the Early Bronze Age A2b.

10.5.3 The analysis of arsenic in Group 11 through time

The general trend indicates a slight loss of arsenic through time. However, if the single categories are taken into consideration, only daggers show a significant decreasing level of arsenic. Axes have a slight increase of percentage of objects with the lowest level of arsenic; in both ornaments and axes, there is slight a reduction in the percentage of objects with the highest levels of arsenic (more than 1% of weight) (Figure 80).

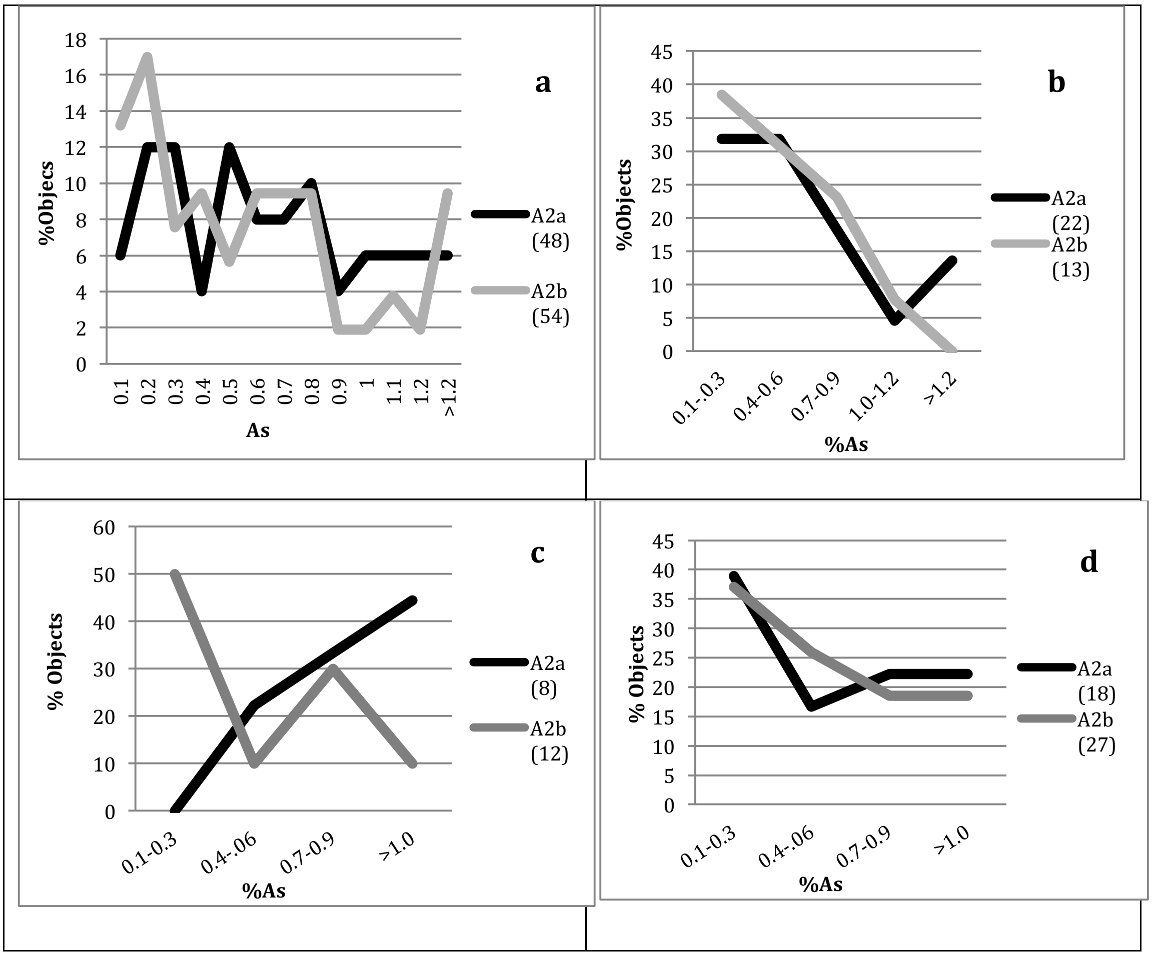


Figure 80: percentages of (a) axes, (b) daggers and (c) ornaments made of Copper Group11 per level of arsenic from the Early Bronze Age 2a to the Early Bronze Age 2b.

10.5.4 Discussion on Copper Group 11

The geographical distribution of the objects and of spatial cluster analysis leads to the hypothesis that this Copper Group is part of the "Eastern Alpine Copper", already discussed as one of the two flows for Copper Group 16. The behaviour of arsenic in Group 11 is similar to Group 12: a constant picture containing spatial clusters of high levels of arsenic corresponding to those regions where a higher percentage of objects are made of metal with those compositions. From these regions the distribution of objects shows a halo effect. The depletion of arsenic is less evident and this indicates that, beside the manipulation of metal orginated in A2a there was a continuous production of new metal also in A2b.

10.6 Group 14

10.6.1 Period A2a

Group 14, with arsenic, antimony and nickel as trace elements, also first appears in the Early Bronze Age 2a. Ingots represent the most predominant category, with 87 artefacts in a total of 146. There were only 27 axes, 14 ornaments, 15 daggers and three awls. Its distribution is unusual, because its ubiquity ranged from 1 to 30 % almost everywhere in the Alps, with the exception of a very high peak in Italy, which relates to the furthest west range of Emilia Romagna, at the edge of the Polada culture.

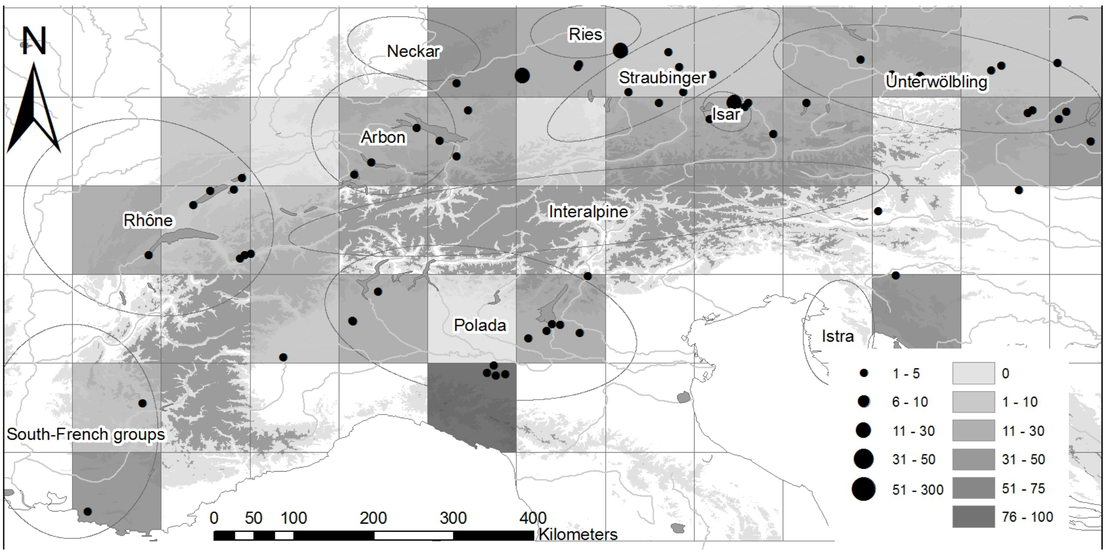


Figure 81: percentage of objects made of Copper Group 14 metal per zone in the Early Bronze Age A2a. Map symbols are as in Figure 32.

The log(10) of arsenic is used to undertake Global Moran's I analysis: the results are spatially clustered. The geographical distribution is peculiar because, contrary to all the other groups, spatial clusters of high levels of arsenic are not in correspondence to the zone where most of the artefacts had this composition (Figure 82).

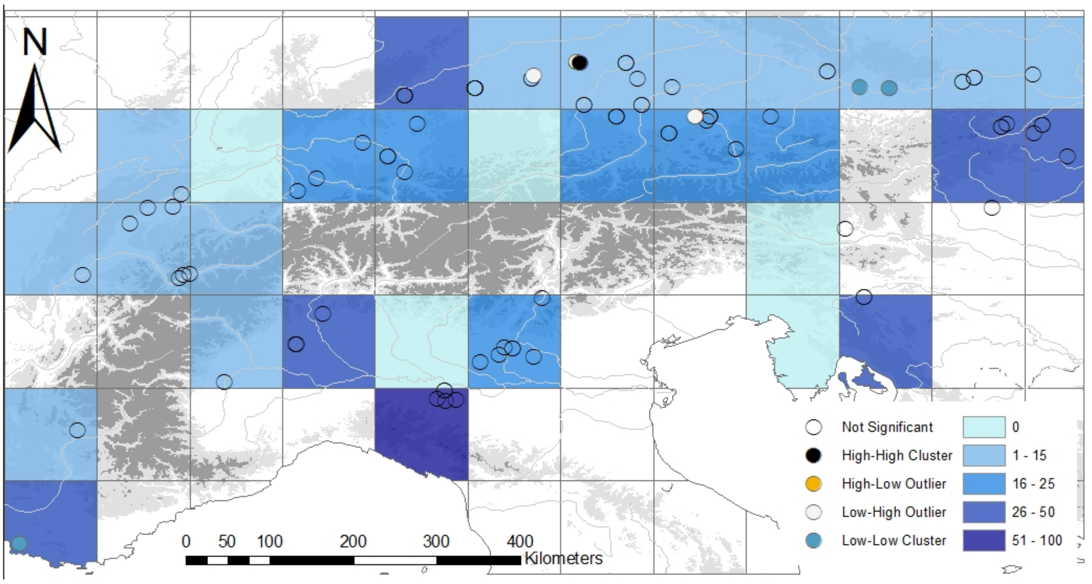


Figure 82: comparison between the percentages of objects made with Copper Group 14 per zone and the result of cluster analysis on arsenic level in object in the Early Bronze Age A2a.

The spatial clusters in that region, though, are due to the presence of ingots, which were distributed only in the northeast. Ingots have, in general, a higher percentage of arsenic (Figure 83). But, in this case, the spatial distribution of arsenic is random.

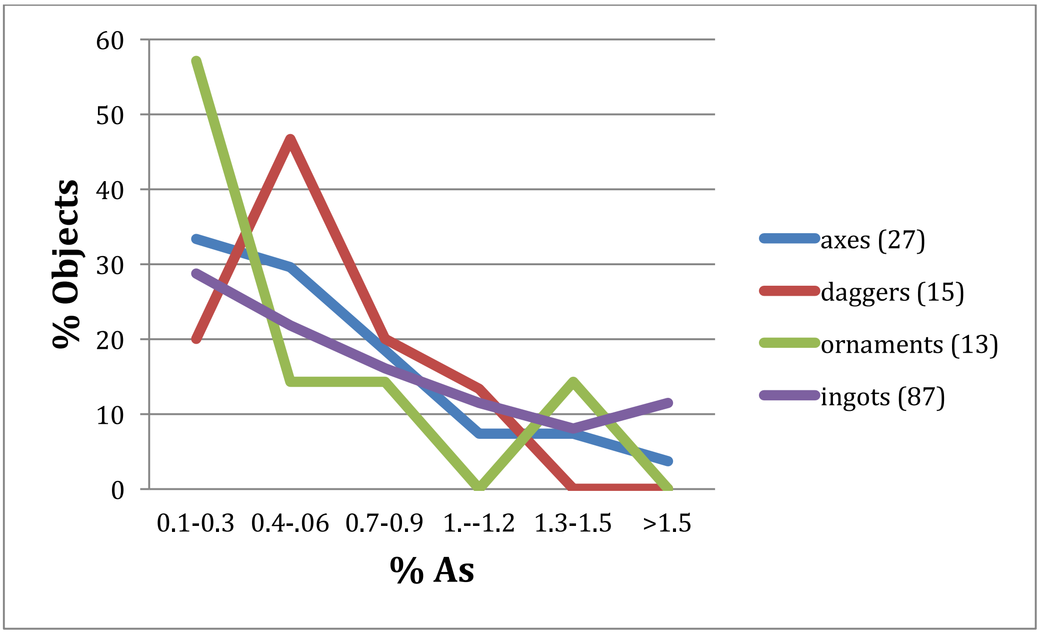


Figure 83: percentages of objects made of Copper Group 14 per level of arsenic in the Early Bronze Age A2a.

10.6.2 Period A2b

In the last phase of the Early Bronze Age this group becomes the most important, with ¼ of the entire assemblage made of this kind of metal. There are a total of 72 artefacts: 19 axes, 31 ornaments, 19 daggers, one copper cake, and two sickles.

The distribution of the Group 14 (copper with arsenic, antimony and nickel) is still unusual, characterised by the presence of different foci. It is interesting to note that the spatial cluster analysis pinpoints the presence of spatial clusters of low arsenic in the zone where this Group was more common in the previous period (Figure 84).

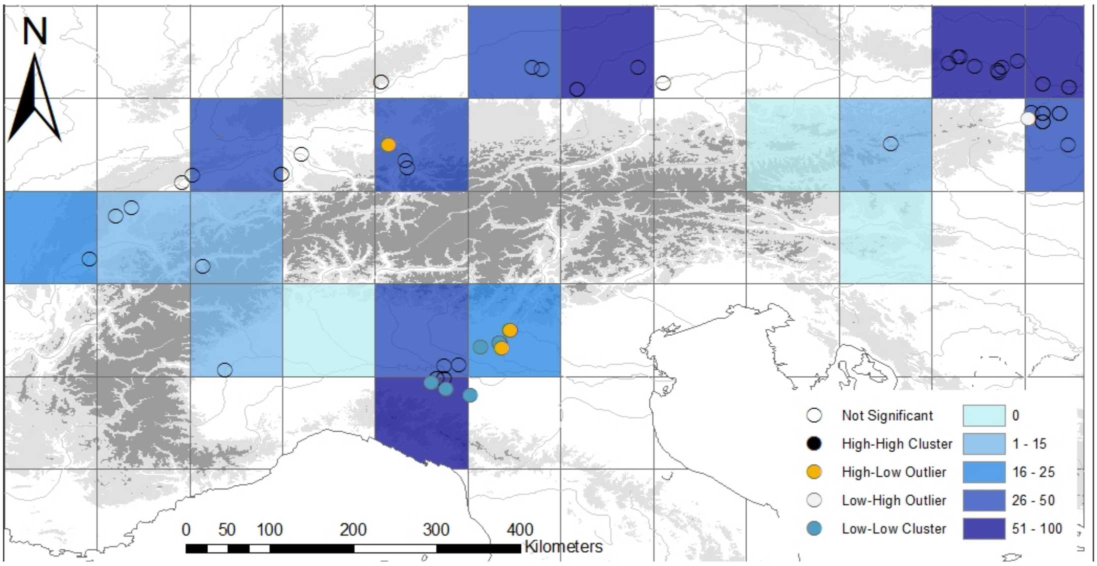


Figure 84: comparison between the percentages of objects made with Copper Group 14 per zone and the result of cluster analysis on arsenic level in objects in the Early Bronze Age A2b.

The trends of the levels of arsenic per category, in this phase, are quite different from the previous phase: in this phase artefacts do not have peaks of high frequency in the lowest levels of arsenic.

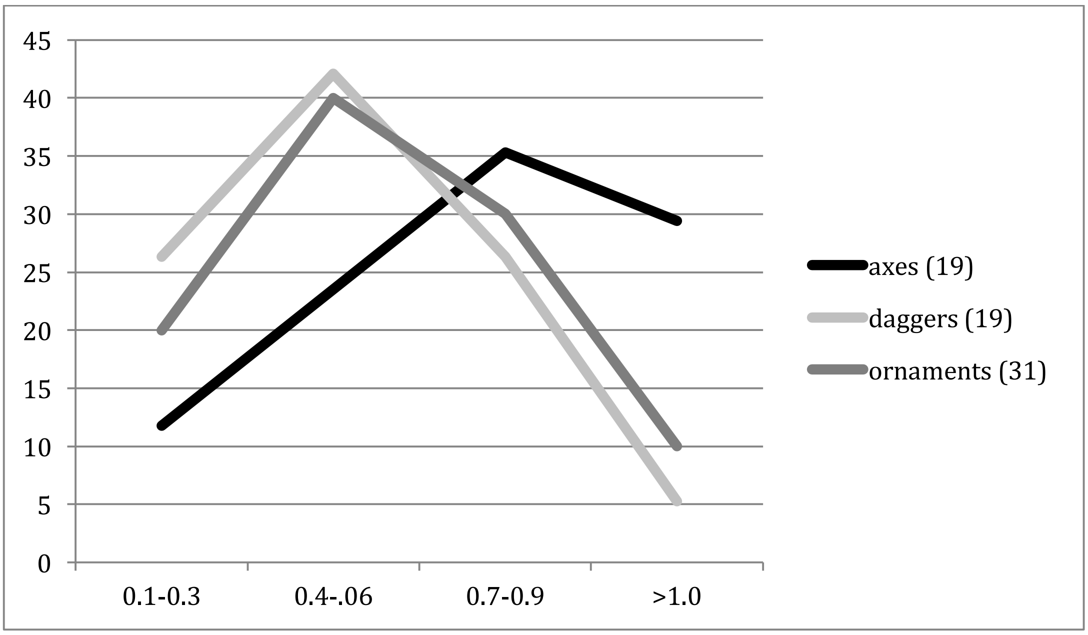


Figure 85: percentages of objects made of Copper Group 14 per level of arsenic in the Early Bronze Age A2b.

10.6.3 The analysis of arsenic in Group 14 through time

The graphs that show the distribution of arsenic through time demonstrate the peculiarity of this group. Overall, in A2a there were at least two importan peaks in the distribution of arsenic, and this is a further suggestion for the presence of more than one source for this group. In A2b the distribution of arsenic is more omogeneous within 0.1 and 1%. It is possible that such a distribution indicates the contemporaneous presence of remelting activity and new material. In the case of this compositional Group the level of arsenic tends to increase through time, in particular, for the axes and ornaments (Figure 86).

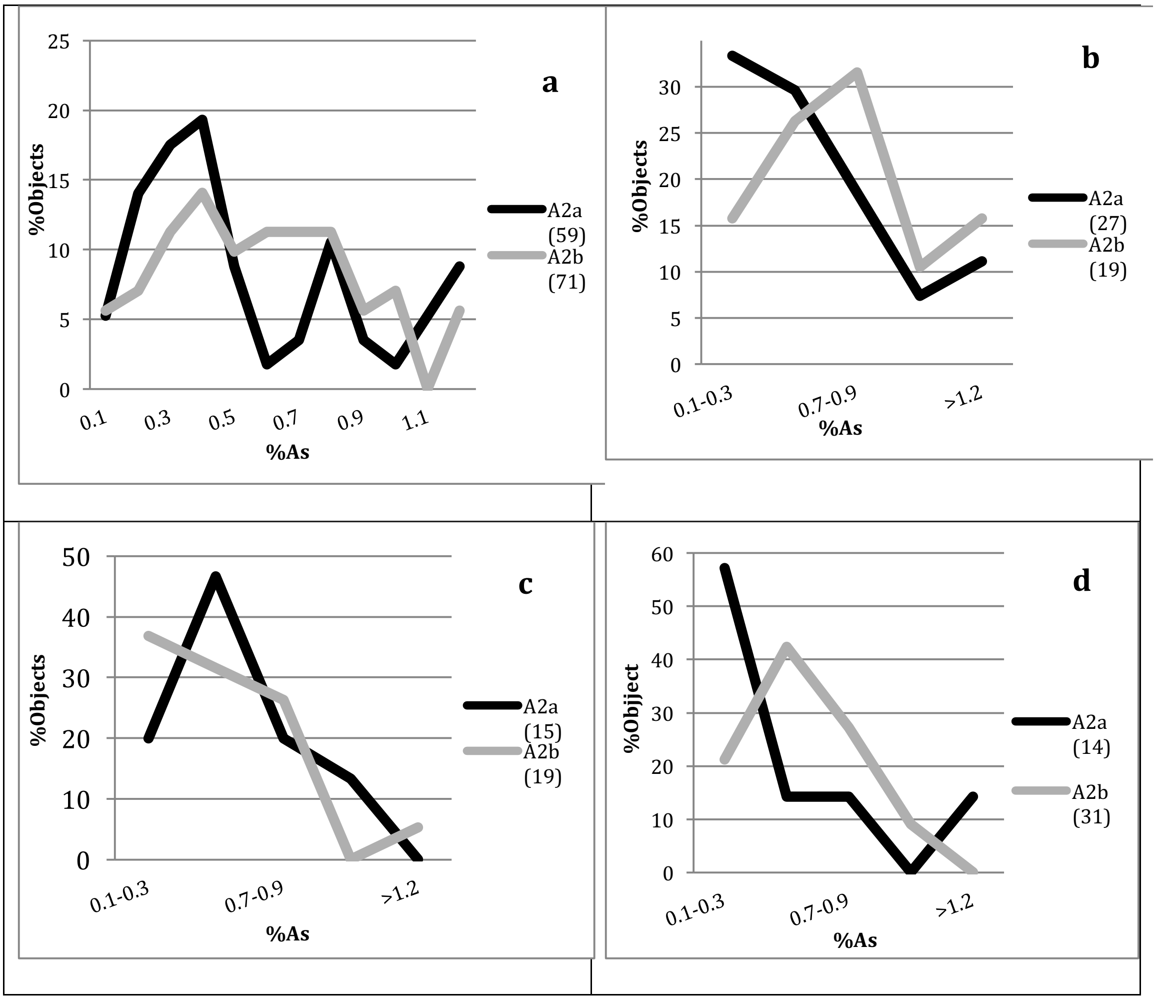


Figure 86: percentages of (a) the entire assemblage (ingots excluded), (b) axes, (c) daggers, and (d) ornaments made of Copper Group 14 per level of arsenic in the Early Bronze A2a and Early Bronze A2b.

10.6.4 Discussion on Copper Group 14

The interpretation of Group 14 is more problematic. It does not look like a flow of metal and perhaps it is just the result of exploitation of some local mines. This is particularly possible in the case of the hotspot close to Modena, where some metal production activities are hypothesized (Giovannini *et al.* 2005). If true, that would mean that in the second phase of the Early Bronze Age there is the exploitation of more local ores, similar to the Copper Age (see Chapter 9).

Another possible explanation is that this Group is the result of mixing material, in particular Copper Group 16 with Copper Group 1. The element that is less present in Copper Group 16 is silver (see Figure 74Figure 75Figure 76). So, the addition of a clean type of copper would produce copper with arsenic, antimony and nickel. But, *contra* this hypothesis, there is the distribution of Copper Group 1, which seems to be relegated to the western zone for the entire Copper Age.

In the second phase (A2b), among the hotspots in the Po valley, in the north–east, there is a zone with a high percentage of objects made of this composition that corresponds to the presence of spatial clusters of high levels of arsenic, whereas the zones that already had this kind of composition (i.e. around Modena) have spatial clusters with low levels of arsenic. This leads to the hypothesis that in this second phase there was a group of metal being part of the "eastern Alpine flows" with this composition. Conversely, there is evidence for heavy recycling activity around Modena, suggested also by the decreasing arsenic levels in this zone.

10.7 Group 5 in Period A2b

Group 5 (copper with nickel) reappears in the final phase of the Early Bronze Age in the western part of the study area (Figure 87). The axes of Pieve Albignola represent the highest number of artefacts that have this composition. Few other artefacts have this composition, including a copper cake from a hoard in Feldkirch, Amberg, in western Austria, an axe in the hoard of Nieder, a couple of axes from Switzerland (SAM 2968, SAM 3052) and some objects from the Garda region, from recent analysis led by Pernicka and Salzani (Pernicka & Salzani 2011) (073050, 073072, 091763, 091764, 091769).

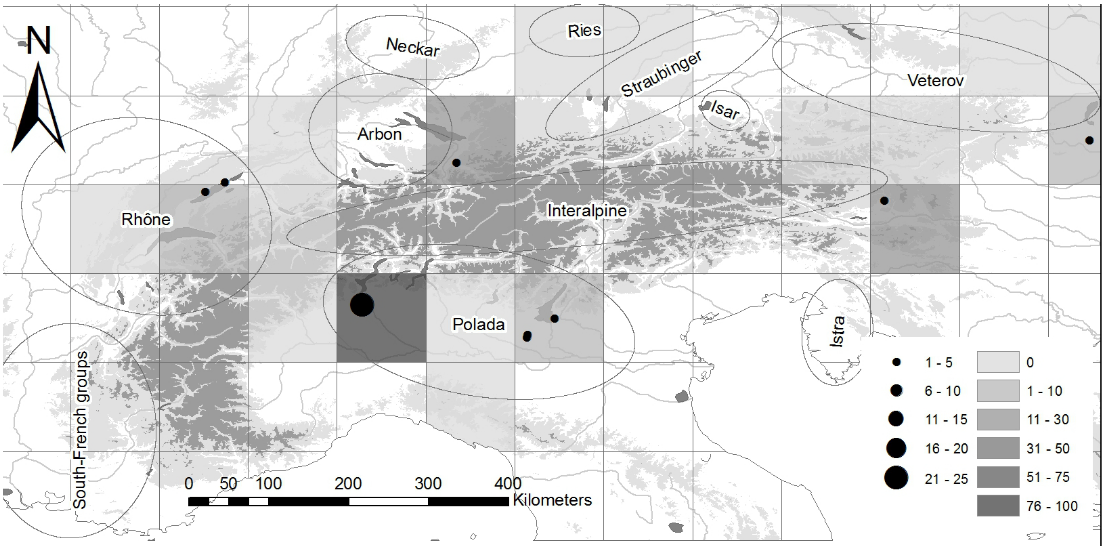


Figure 87: percentages of objects made of Copper Group 5 metal per zone in the Early Bronze Age A2b. Map symbols are as in Figure 32.

Looking at the distribution of this Group, it is possible that the same mine that was active in Switzerland in the Copper Age (see Section 9.2) was re-opened. Most of the objects that have this composition are reported as ingots by the original authors. In addition to the copper cake, there is also the case of Pieve Albignola, considered to to be a 'metallurgical hoard', with unfinished axes that still had casting flashes (de Marinis 2006a; Pearce 2007). These axes, according to the authors, are a clear example of the use of axes as ingots in antiquity. Similarly, the unfinished axe in the hoard of Nieder has been reported by Krause (2003) as part of a 'metallurgical hoard'. However, if this is the composition of ingot material then it has to be noted that not many artefacts, apart from these ingots, actually have this composition. This may lead us to think that the fact that there are few finished artefacts made of copper with nickel is due to a gap in our knowledge. On the other hand, even within this recent set of analysis, other groups, which contain nickel alongside other trace elements, are more represented, in particular Group 11 (11 artefacts) and Group 16 (seven artefacts). Given this mismatch, it is reasonable that the question of the nature "ingots" in the Early Bronze Age should be reconsidered. This is partially done at the end of this Chapter and in more detail in Chapter 13.

10.8 Dependency of these patterns on different chronological frameworks

As a final note, it may be observed that the use of different chronological frameworks, or coarser chronological frameworks, does not influence the broader results. Undertaking geostatistical analysis on the Copper Groups in the entire Early Bronze Age integrating, were possible, the chronologies proposed by David-Elbiali and de Marinis, leads to similar conclusions. Group 12 has spatial clusters of high levels of arsenic corresponding to the mines of the Inn valley. Group 16 manifests spatial clusters in the northern Circum-Alpine region, which may be the result of more than one flow of metal. Group 11 has a pattern compatible with an eastern provenance. Group 14 is more controversial, with different spots in different zones, possibly as the result of different flows or of local exploitation.

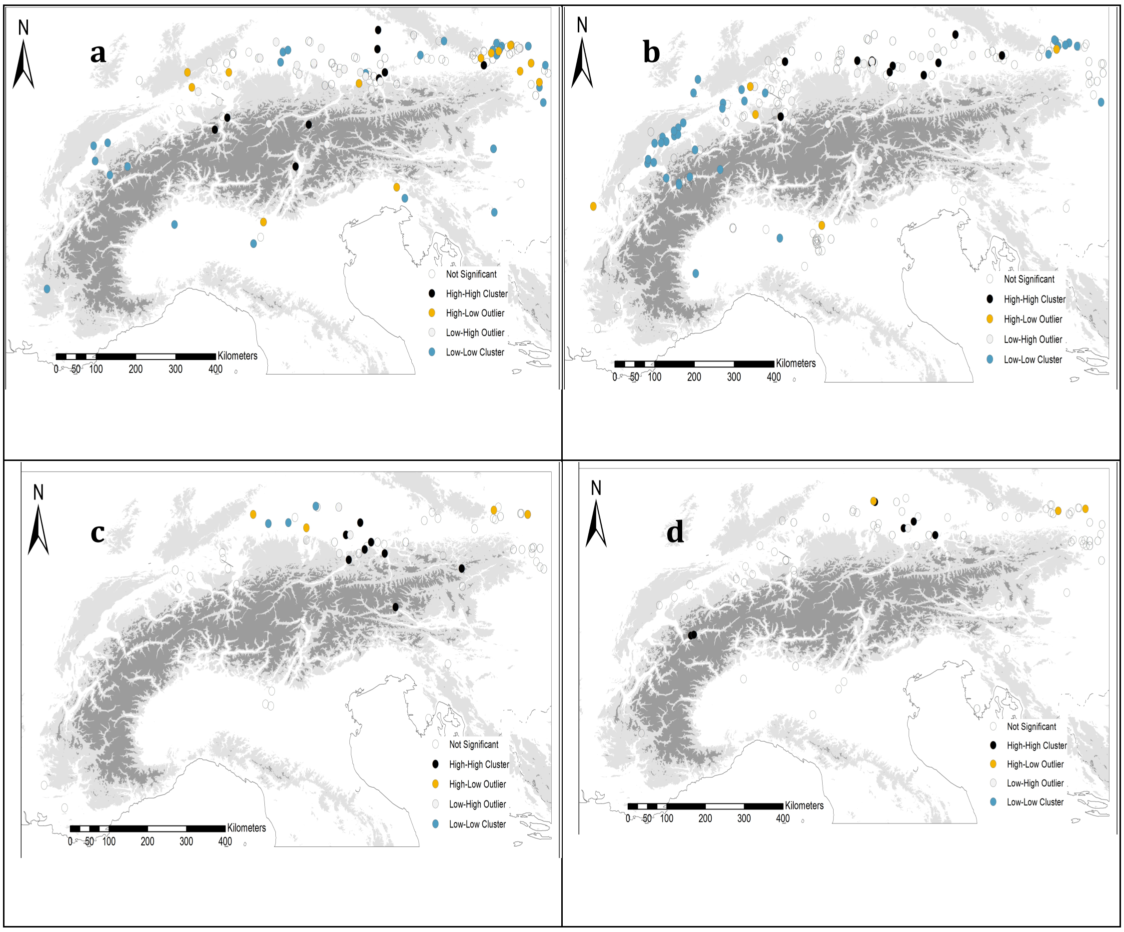


Figure 88: geostatistical analysis undertaken on Groups of Copper in the entire Early Bronze Age, using, where possible, the chronologies proposed by de Marinis and David-Elbiali. From the upper left: (a) Copper Group 12, (b) Copper Group 16, (c) Copper Group 11 and (d) Copper Group 14.

10.9 An overview of the main patterns emerging from the analysis of Copper Groups in the Early Bronze Age

In the transition from the Copper Age (Chapter 9) to the Early Bronze Age broader flows of metal appeared. On the one hand there was a dramatic increase in the number of metal artefacts found, on the other hand the number of copper groups represented decreased (see Table 17). However, as the Early Bronze Age progresses there seems to be a trend of decreasing numbers of metal artefacts

(Table 14 and Table 17). In reality this is mainly due to hoards of ingots in A1 and A2a that are not present in A2b. As mentioned in Section 7.2.1 and also by Krause (2003), these ingots are hard to date because there are no available radiocarbon data from hoards. The sequence that indicates *Ösenringe* as earlier than *Spangenbarren* seems to be confirmed by the analysis in this thesis. *Spangenbarren* have a composition coherent with the second phase of the Early Bronze Age (A2a), but, we may not completely exclude the possibility that some *Spangenbarren* indicated as "A2a" by Krause are, in reality, from the last phase of the Early Bronze Age (A2b).

Copper Group	Period	Type of object	Number of objects	Presence of spatial clusters
Group 16				
	A1			
		Overall	450	Yes
		Axes	113	Yes
		Daggers	62	No
		Ornaments	260	Yes
	A2a			
		Overall	428	Yes
		Axes	51	Yes
		Daggers	28	No (?)
		Ornaments	46	Yes
		Ingots	300	Yes
	A2b			
		Overall	45	No
		Axes	26	No (?)
		Daggers	8	No (?)
		Ornaments	10	No (?)
Group 12				
	A1			
		Overall	1002	Yes
		Axes	8	No (?)
		Daggers	16	No (?)
		Ornaments	272	Yes
		Ingots	697	Yes
	A2a			

		Overall	419	Yes
		Axes	22	No (?)
		Daggers	10	No (?)
		Ornaments	20	No (?)
		Ingots	367	Yes
Group 11				
	A2a			
		Overall	234	Yes
		Axes	22	No (?)
		Daggers	8	No (?)
		Ornaments	18	No (?)
		Ingots	186	Yes
	A2b			
		Overall	54	Yes
		Axes	13	No (?)
		Daggers	10	No (?)
		Ornaments	27	No (?)
Group 14				
	A2a			
		Overall	146	Yes
		Axes	27	Yes (?)
		Daggers	15	No (?)
		Ornaments	14	Yes (?)
		Ingots	87	No
	A2b			
		Overall	72	Yes
		Axes	19	Yes (?)
		Daggers	19	No (?)
		Ornaments	31	Yes

Table 14: table showing for each Copper Group the categories that were spatially clustered in arsenic and the ones that were random through the Bronze Age. A question mark indicates that the low number of the sample may prejudice the analysis.

The general trend is a situation where the percentage of arsenic is geographically clustered (Table 14) and where there is a good correspondence between the clusters of high levels of arsenic and the zones with a higher percentage of artefacts made with a specific composition. These trends are in accordance with a theory of re-melting activity, that causes a depletion of arsenic through time, and with distance from the possible source of metal, as explained in Section 3.2.

Consequently, the observed patterns can provide information about both the primary centres of production and the movement of metal to its final deposition. In the Sections of this Chapter this has been separately discussed for each Group of metal. Some general reflections are added here, in particular about the movement of metal.

As with the Copper Age (see Section 9.6), it should be observed that the Alpine mountain range was never a solid barrier to the movement of metal. However, the distribution of the different chemical signatures is uneven. Most of them show a preferential distribution in either the eastern or western part (Figure 89), rather than northern-southern, throughout the entire time span taken into consideration. This is also reflected in the equally uneven distribution of tin when it appears, and further observations on this phenomenon are dealt with in Chapter 13. The possible role of the mountains as a barrier is tested with a series of GIS analyses in Section 12.2.

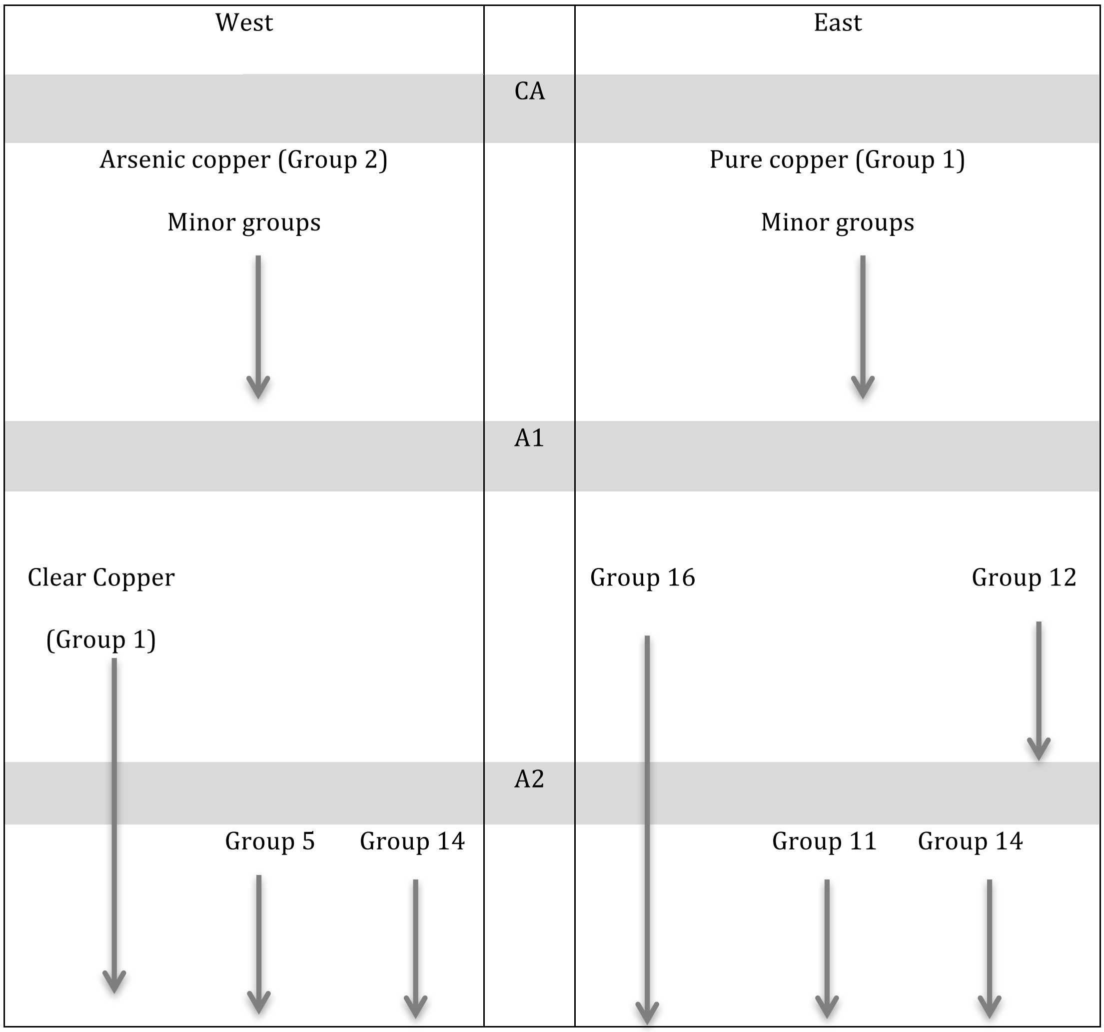


Figure 89: distribution of the main copper groups in the eastern and western zone of the Alps.

The results of ubiquity analysis and the depletion of arsenic already discussed for each Copper Group indicates the general pattern of recycling activity in the Early Bronze Age. The depletion of arsenic through time for each category of artefact observed in some cases (Figure 62Figure 73 Figure 80) is potentially compatible with a recycling model in which each category of artefacts (i.e. daggers, axes and ornaments) is remixed and re-melted independently from the others. This has been suggested by Bray and Pollard in the British Isles (2012) and may be linked to the concept of cultural acceptance of imported shapes (Derevenski & Sørensen 2002; Gosden 2005). However, first it must be observed that this loss per categories is not always present. Moreover, the patterns of arsenic in the different categories (besides "ingots", which are discussed in Chapter 13) are usually very similar, hence the mixing of different kinds of objects cannot be excluded. Furthermore, the distribution of the artefacts with the same copper composition varies highly according to the cultures. For example Copper Group 12 is very common in the Straubinger culture, which is well known for the presence of hoards of *Ösenringe* and *Spangenbarren* and, as a matter of fact, in this area most of the artefacts made of Group 12 are *Ösenringe* and *Spangenbarren*. But, in other cultures there are other types of artefacts made of this composition: for example daggers in the Polada culture or ornaments in the Unterwöbling culture. So, it is likely that metal was remelted to produce different objects, in the passage from one culture to another. This observation introduces also the topic of how different cultural groups perceived metal.

In the Rhône culture, especially in southern France, there was a *continuum* from the Copper Age cultures, which is reflected particularly in the high frequency of ornaments, generally related to burials, from the Copper Age to the Bronze Age. Those ornaments were usually made of clean copper (Group 1), which may be alloyed with tin (see Chapter 11). In the north Circum-Alpine Bronze Age there was the Blechkreis cultural zone that had internal differences marked by hoards and burials (see Section 7.2.3). In particular, in the western part there are fewer hoards (with fewer objects, mostly axes) and fewer cemeteries, but with a higher number of burials. In the eastern zone there are more hoards, made of more objects (*Ösenringe* in the first phase and *Spangenbarren* in the second), and more cemeteries, but with fewer burials and also fewer metal objects used as goods. In the western zone the copper was mainly group 16, whereas in the east it was first group 12 and then the "eastern Alpine groups", such as Group 16, 11 and perhaps 14. In general, in the north Circum-Alpine region the cultural areas are closer to the primary centres of production, so there are cultures that have a "more typical" kind of metal. But this does not mean that in each culture there is only one kind of metal. A certain level of circulation of metal was always present.

In the south of the Alps, the use of metal is less selective. An interesting case is the Polada culture. It does not seem to be a metal producing culture. Conversely, it was certainly a metal using culture, as also testified by the crucibles and moulds found (Marzatico 2011). What is notable is that archaeologists observed strong links with the Danube cultures, so that even a movement of people from this region has been hypothesised (Nicolis 2013). But, objects were made both with metal coming from a central zone (Group 16 in the first phase of the Early Bronze Age is, indeed, the most represented Group) and metal coming from the northeast. The Brenner pass seems to have been used, as testified by some objects such as two bars (TBC1, TBC3) and a flanged axe (TBC2) in Val di Non; an axe in Aldeno (O-W1029), an axe in Nonsberg (O-W 1158), an axe in Penserjoch (O-W 976). It is possible that there was more metal coming from the east but the signal has been lost in the mixing with Group 16, which contains all the trace elements. Moreover this region has many fewer hoards than the north Circum-Alpine region, which have a "habit" that is more similar to the one in the central region: in fact, they were made not of *Ösenringe* (typical of the north-east), but of axes (e.g. Remedello Sopra, Pieve Albignola, Isola di Varese). Polada seems to be an "open" culture, which welcomes differences from different regions.

The habit of hoarding, and if the objects in found in hoards (more specifically *Ösenringe*, *Spangenbarren* and axes of Salez type) may be related to the movement of metal - namely if they were, as often claimed "ingots" (e.g. de Marinis 2006a; Krause 2003) - is more fully discussed in Chapter 13. A final thought is dedicated to the fact that, apparently, the use of different chronological systems does not affect significantly the results of the analysis. The chronology that mostly differs from the one proposed by Krause (2003) is that of David-Elbiali (2000) for western Switzerland. As explained in this Chapter, and further discussed in Chapters 11 and 13, the western zone of the Alps shows patterns that are almost separate and independent from the eastern zone. Moreover, in the western zone there was a predominance of Copper Group 1 through the entire Bronze Age. So, there is the presence of some big patterns of metal that are not affected by the dating of some single artefacts.

11 The Appearance of Tin

The Flow Model is an approach that attempts to perceive the movement of metal, in the case of this thesis, in the Alps. In the last two Chapters we considered the movement of copper in the Copper Age and the Early Bronze Age. However, in the Early Bronze Age there was also the movement of another metal: tin, alloyed with copper to form bronze.

In this Chapter the Flow Model is applied to try to discuss some specific questions about bronze:

- When and from where was the production of bronze introduced into the Alps?
- Why did people decide to use bronze?
- Was tin coming into the Alps as cassiterite, tin ingots, or was there an importation of already alloyed objects?

This Chapter analyses the spatial pattern of objects containing tin in the Early Bronze Age. In a similar approach to Chapters 9 and 10, ubiquity analysis has been used to investigate the presence of tin in different areas of the Circum-Alpine region. The analysis was undertaken using the tool "Percentage Element" of Appendix VII, as explained in Section 8.2. In this Chapter the element chosen is tin and the threshold of presence is taken to be 1%, in order to exclude classifying as deliberately alloyed tin bronzes objects which might contain traces of tin from mixed sulphide ores. The spatial distribution of alloys with tin can give us a range of insights: it can help us to identify the possible routes of tin movement, the possible provenance zone for the tin itself, and it can highlight which of the Circum-Alpine Cultures were more receptive to the adoption of the copper-tin alloy.

11.1 The systematic adoption of tin as alloying element in the Alps: similarities and differences according to the chronological system used.

The discussion about the introduction and the use of tin in the Circum-Alpine region is as yet far from being conclusive. The idea of a general spread of the use of copper-tin alloy from the Near East and Anatolia into Europe has been long debated (among others: Pare (2000); and Roberts *et al.* (2009)). However, the early use of tin in the western part of the Alps has already been noted (Krause 1989) and may reflect a tradition of the systematic production of bronze coming from the west. A possible source of this tradition may be the British Isles (Primas 2003). Primas, without denying the underlying Eastward-spreading model, highlighted an interesting point: in the south-east of the Europe tin alloying was contemporary with lead alloying, whereas in central Europe tin alloying was absolutely predominant and lead was not used regularly until the Late Bronze Age, although there were sources of lead available. In Europe there are sporadic objects with tin as alloy from the end of the fourth millennium, such as the knife with 7.62% of tin from Velika Gruda in Montenegro. The burial has been dated 4335±80 bp (3340-2700 cal B.C.). But there are also sporadic uses of lead as an alloying element, such as some beads, made of copper, lead or gold, from the Copper Age graves in Fontbouisse, France. From the database of this thesis there are some examples of objects made with at least 1% of lead: a hammer axe from Lieli (O-W 186); a double axe from Biel Lake (Rennes 72023); an armlet from Frana del Basaglio (Northover TSN 12), and there is a bead completely made of lead from Chateaurenard (FR 397/24). These uses of tin or lead as alloying element were however sporadic. The preference for tin-containing alloy was developed by the Bell Beakers in Western Europe and first spread into Central Europe with the production of some few selected objects. Krause signalled the presence of a few bronze objects from Central Europe, dated to the Copper Age, in Bell Beaker and Corded Ware contexts (Krause 2003, 212). From Switzerland there are a few bronzes from the Corded Ware Culture such as a dagger and an axe from Saint Blaise that have respectively 3.3% and 2.3% of tin (BAR60, BAR61). In a second phase, tin alloying, perhaps from the British Isles, became a "standardized technique" or "standardized production", and the systematic use of tin subsequently spread to Central Europe, across the old "communication channels" formed by the Bell-Beaker Culture (Primas 2003).

A hint that supports this model is the case of the cemetery of Singen (Krause 1989). The cemetery has been dated with ^{14}C (Table 15). In this cemetery four daggers containing tin were found. These daggers are made with Copper Group 2, which is different from the "typical Singen metal" (Group 16) and is generally related to the Atlantic region (Krause 1989). The daggers also have an "Atlantic" shape – Armorico–British. Interestingly, they have been decorated with a local V-shape motive. Although, as said, the blades contain tin (in a range of 5-9%), their rivets were made of pure copper. Unfortunately, there are no radiocarbon data available for the graves where the daggers were found, but typochronological observations led Krause to claim that the cemetery has objects of only one phase, namely the beginning of the Early Bronze Age (A1). He claimed that the Armorico-British daggers were the first secure evidence for contact with an external technology that was systematically using bronze. The "Atlantic" origin of these daggers may be related to the movement of the Bell Beaker people from the Atlantic region.

Grave	Sample n.	Measurement	Cal BC (95% CI)
7	HD 8972-9116	3680±45	2199-1943
19	HD 8973-9117	3760±50	2343-2026
6	HD 10807-10692	3655±35	2139-1938
65	HD 8974-9155	3850±45	2466-2200
68	HD 8975-9146	3650±45	2141-1900
70	HD 8978-9157	3770±40	2306-2037
74	HD 8976-9129	3640±45	2137-1899
79	HD 8971-9115	3680±45	2199-1943
80	HD 8970-9147	3690±45	2201-1951
82	HD 10806-10691	3730±40	2281-1985

Table 15: radiocarbon dates available from the Singen cemetery, from Krause (1989). Dates calibrated using OxCal version 4.2 with Intcal 2013.

However, more recently Krause has tended to emphasize the role of the Únêtice Culture in the first bronze production of Central Europe (Krause 2003; Müller &

van Willingen 2001), for two main reasons. On the one hand this Culture was set in a zone where there is the important tin source of the Erzgebirge. On the other hand, radiocarbon dates indicate an early bronze production, before 2000 B.C., even with complex forms, such as halberds and metal-hilted daggers, whose manufacture requires knowledge of the lost wax casting technique. From the area of the Únêtice Culture these new techniques –lost wax casting and tin copper alloying- spread into western Switzerland. This model has its issues. First, the exploitation of the Erzgebirge mine is still not demonstrated, mainly because all the prehistoric evidence was destroyed by Medieval activity (Krause 2003, 207). More importantly, recently Schwenzer (2004) started the hypothesis that the origin of the solid-hilted daggers was in Italy and western Switzerland rather than in the Únêtice Culture, and therefore that the first bronzes exploited an as yet unknown tin source in Tuscany. This suggestion is supported by the existence in Italy of the "precursor" of the metal hilted dagger, with the hilt made of bone (Figure 90). So, a new model has been proposed, which invokes a key role of the western Alps in the early production of tin bronzes (see Kienlin 2010, fig. 6.14, fig. 6.16 to compare the Únêtice and western Alps models).

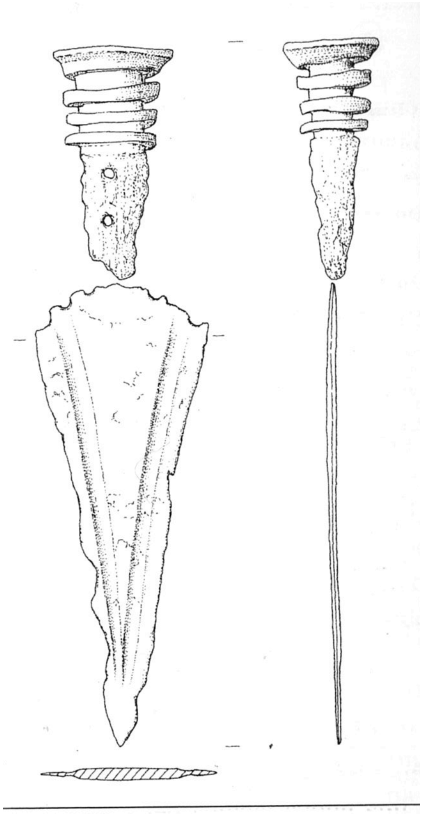


Figure 90: metal dagger with bone hilt, from de Marinis (2000).

The problem of the introduction of the systematic use of tin in the Alps is obviously connected with the problem of the chronology that can be summed up as a lack of radiocarbon dates for metal objects and as a still open debate about the relative chronology of the metal objects. Figure 91 shows a map of the mean percentage of tin per site in the first phase of the Early Bronze Age 1, using the chronology presented in Krause 2003. The focus here is on "finished objects". Objects classified archaeologically as ingots (Ö*senringenbarren* and *Spangenbarren)* and which tended to contain only copper were excluded from this analysis, because if they were used as copper ingots, then their overwhelming presence in the eastern region would have significantly underestimated the presence of tin. A further reasonable exclusion from this experiment was the data on hoards, because they were made of objects that might have been considered as ingots, in particular the hoards made of dozens of axes in western Switzerland.

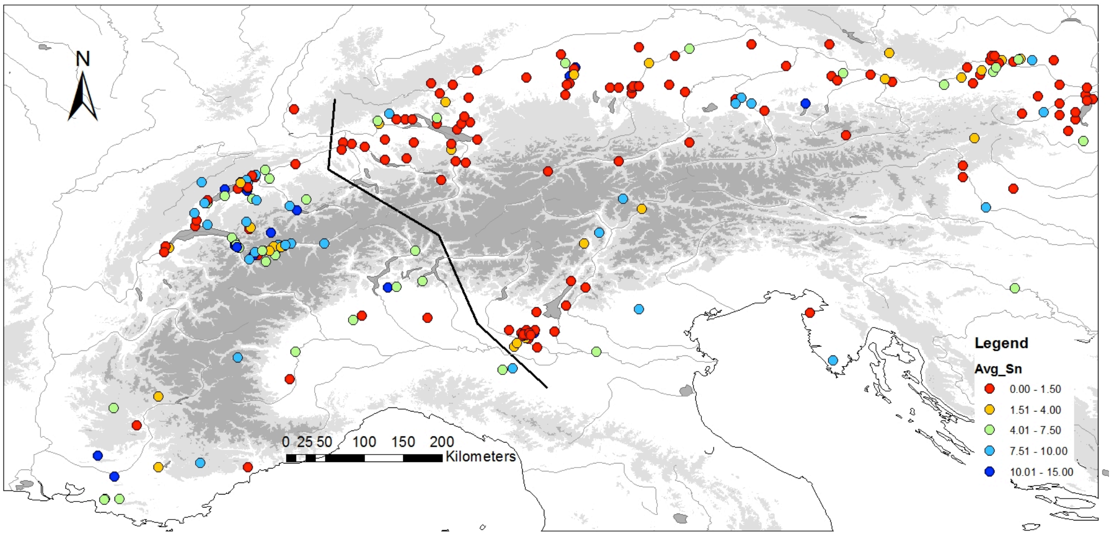


Figure 91: Distribution of the mean percentage of tin for sites in the Circum-Alpine region at the beginning of the Early Bronze Age. Each dot represents a site and the colour indicates the mean percentage of tin in the objects at that site.

It is clear from Figure 91 that there was a preferential use of tin bronze in the western zone of the Alps, and not only the western Switzerland. The mountains were not a barrier to the north-south distribution of tin, but there was a strong cultural barrier, a “tin line”, which divided the western part of the Alps, where tin was used to alloy with copper, from the east, where it was not.

If the chronologies of David-Elbiali and de Marinis are integrated in western Switzerland and northern Italy, then the “tin line” is not evident in the first phase of the Early Bronze Age (A1): it simply represents a division between the eastern zone, rich in artefacts, and the western one, which is numerically very poor (Figure 92).

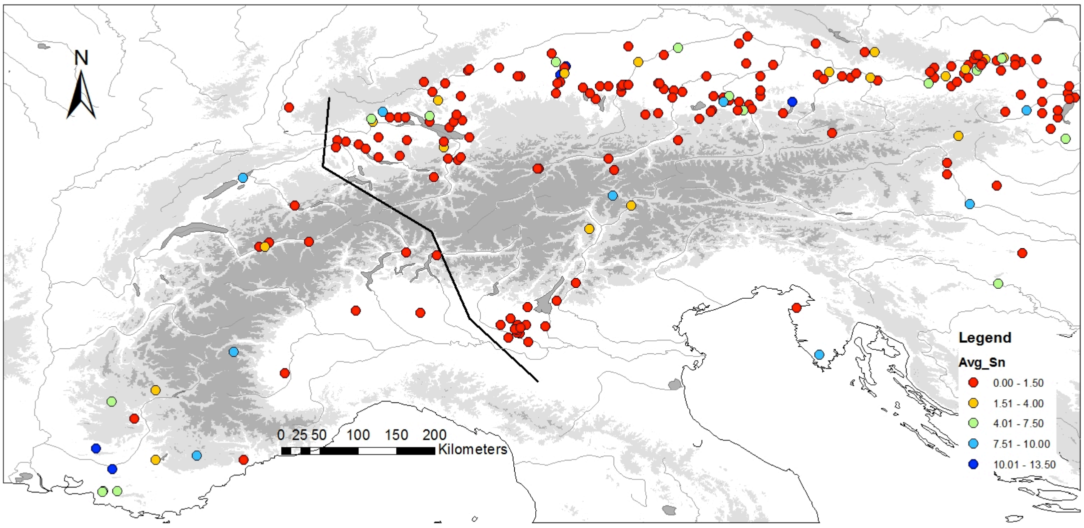


Figure 92: Distribution of tin in the Circum-Alpine region at the beginning of the Early Bronze Age (A1) according to the chronology proposed by de Marinis and David-Elbiali.

Nevertheless, the diagrams of the presence of tin in the eastern and western part in the Early Bronze Age A1, using the chronology proposed by David-Elbiali and de Marinis, indicates a more major presence of bronze objects in the western part than in the eastern. In fact, in the western zone, apart from a major peak of unalloyed objects, there are also small peaks corresponding to 4% and 8% of tin.

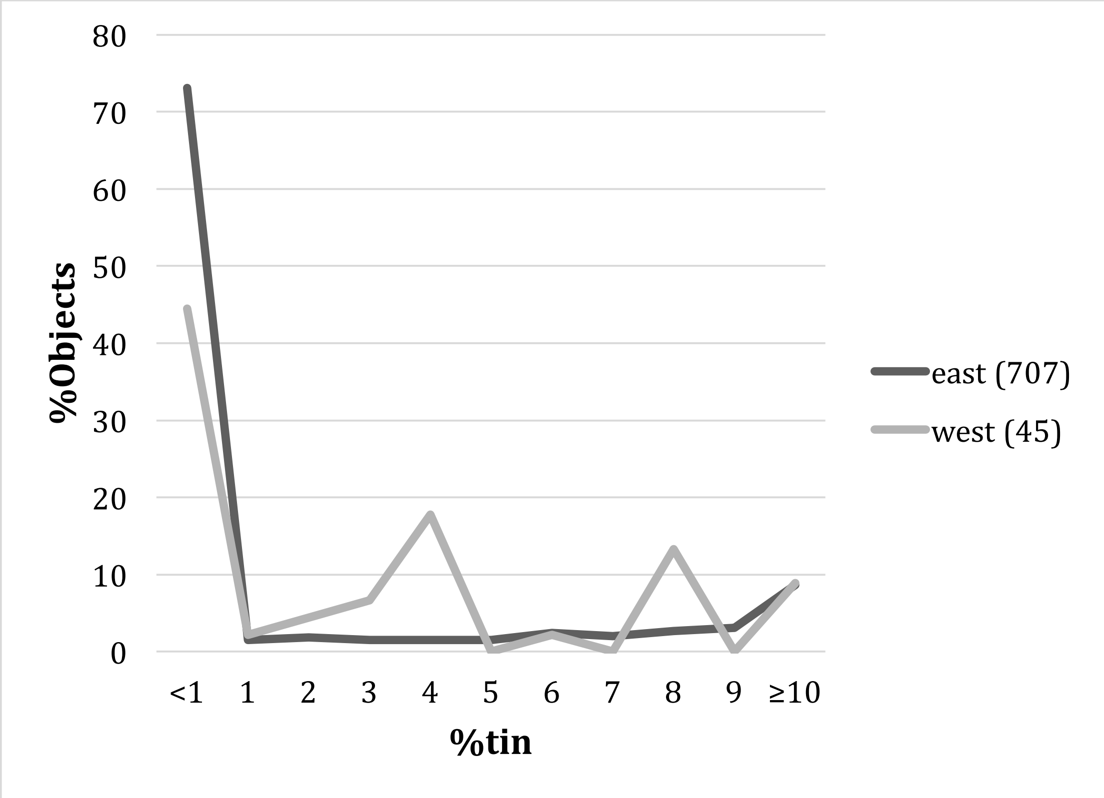


Figure 93: percentage of objects vs. different percentages of tin in the western and eastern part of the Alps in the Early Bronze Age A1, using the chronology proposed by David-Elbiali and de Marinis.

The picture is clearer if the internal subdivisions of the Early Bronze Age are ignored (since this removes the differences between the various chronologies) and a map with the percentage of objects that have at least 1% of tin in the entire Early Bronze Age is built up (Figure 94).

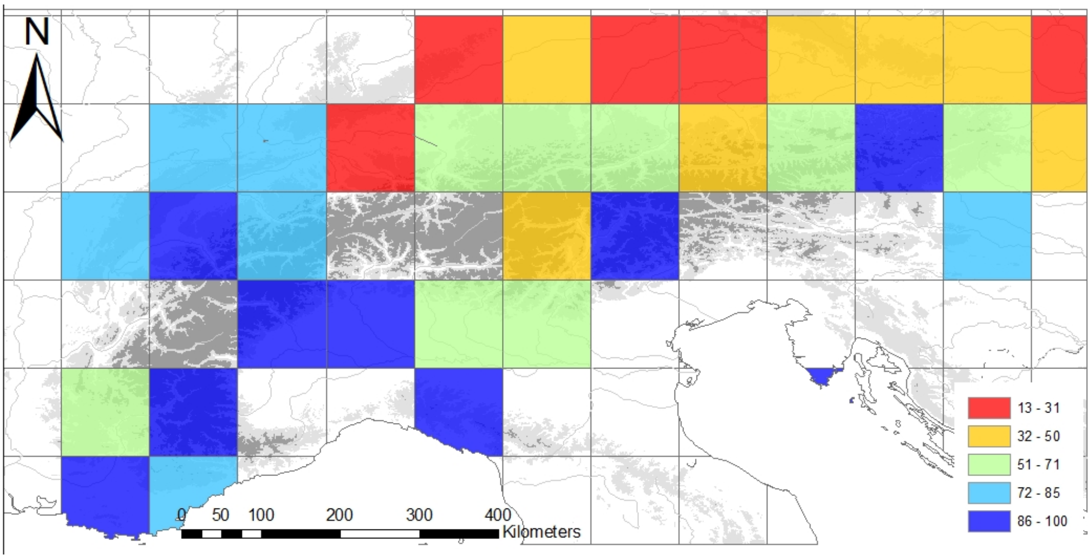


Figure 94: percentages of objects made with at least 1% of tin per zone in the entire Early Bronze Age.

This gives a clear picture where most of the artefacts in the western part of the study area were alloyed with tin, whereas in the east the majority of artefacts had lower tin, but with a few 'hot spots' of higher tin. This suggests that in the eastern zone there was a stronger continuity of copper use into the Early Bronze Age. The analysis in this thesis seems to confirm a model in which the introduction of systematic bronze production in the Alps occurred from the west, as suggested by Primas (2003)

11.2 Considerations about the reason behind the choice of bronze

The adoption of bronze has generally been related to the search for improved hardness (e.g. Hook 2007), in particular for daggers. Krause (2003) has linked the development of bronze production to the improvement of casting techniques such as the lost-wax technique and the production of metal hilted daggers. It may be reasonable that the predominant use of bronze in the western zone of the Alps may be due to the quality of copper. In fact, in Chapter 10 we have hypothesized that the cultural barrier dictated that in the western zone pure copper was available, but in the east *Falherz*. It is certainly true that *Falherz* copper has desirable mechanical properties, in particular hardness (Chapter 6) whereas clean (Group 1) copper is inherently softer and would require alloying with tin to give a similar hardness.

However, as shown in Figure 95 and Table 16, the ornaments show a particularly strong division between coherent areas of tin-bronze use compared to the continuation of copper use. Tin would give a brighter and more highly-polished object, emphasizing the shiny effect of decorative ornaments, and this supports the concept that display and colour, rather than mechanical properties, influenced the adoption and use of tin-bronze. This suggests that a new technology might be accepted and adopted in one zone and in one Culture (the Saône-Rhône Culture), possibly for the shining colour of the finished objects, whereas it is almost rejected in other zones.

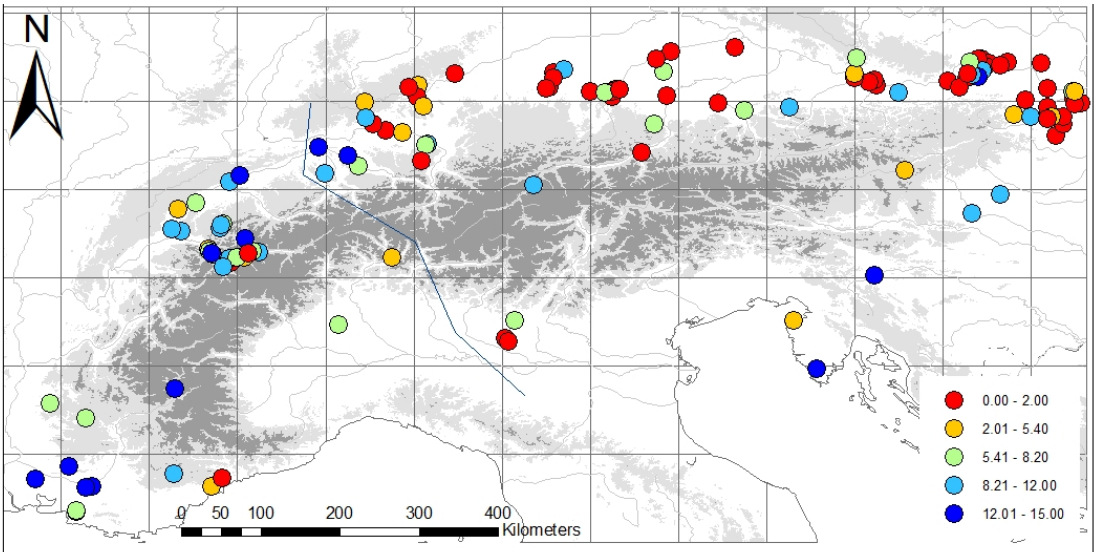


Figure 95: distribution of average tin content in the ornaments in the Early Bronze Age.

Axes		Daggers		Ornaments	
West	East	West	East	West	East
85%	57%	94%	65%	84%	38%

Table 16: percentage of objects with at least 1% of tin

It may also be noticed that in the case of ornaments there is also a significant presence of objects with tin in eastern Switzerland, so in the eastern part of the 'tin line'. This may indicate that the search for a brighter colour is advocated in a larger area specifically for ornaments than for other categories of artefacts. In any case, we should highlight here that even though we are talking of "cultural barriers" the movement of metal from the eastern to the western area was not completely blocked. It rather indicates that there was more metal exchange within the western and the eastern area.

Interesting observations may also be deduced from the analyses of Kienlin *et al.* on Neyruz and Saxon axes (Kienlin *et al.* 2006). Only some of these axes have tin, and in variable amounts. First, it may be questioned if the presence of tin was intentional or if it was the result of mixing activity of copper with some other bronzes, such as ornaments. But what is interesting is that metallography has highlighted that the presence of tin does not have any effect on the final work. Axes have variable amounts of final cold work, which is not dependent on the presence or absence of tin. Consequently, the idea of the initial adoption of tin to increase hardness has to be rejected.

11.3 Considerations about bronze production

In the Alps there are no known tin sources (Chapter 3), so there is a general idea of the knowledge of bronze production travelling from an external area to the Alps together with the raw material (tin or cassiterite) or finished objects containing tin. It has been claimed that if metallic tin is added to liquid copper there is an expectation of *circa* 10% of tin in the final objects, whereas the addition of cassiterite produce bronzes with *circa* 2-6% of bronze (Ottaway 1994, 138–140; Pernicka 1998). Conversely, experiments show that it is possible to obtain objects with high levels of tin also using cassiterite (Herdits *et al.* 1995). Ingots of tin from the Early Bronze Age have not been found, but some objects which may be interpreted as precursors of tin ingots, such as, for example, some tin beads in Holland (Krause 2003, 208) have been found. Indeed, some beads made of tin are found also in northern Italy, in a later phase (Middle Bronze Age) (Salzani 2011, 60).

Figure 96 shows the percentages of objects with different amounts of tin for the main Copper Groups (see Chapter 10). It should be noticed that old OES analysis did not quantitatively measure tin over 10%, simply labelling it “>10%”. Hence, it is not possible to show the distribution of tin for objects over 10%. Even considering this bias, the graph of Copper Group 1, typical of the western zone (see Section 10.2) seems to contain higher levels of tin than groups 12 and 16, whereas objects made of Group 12 and 16 are mainly made of unalloyed copper.

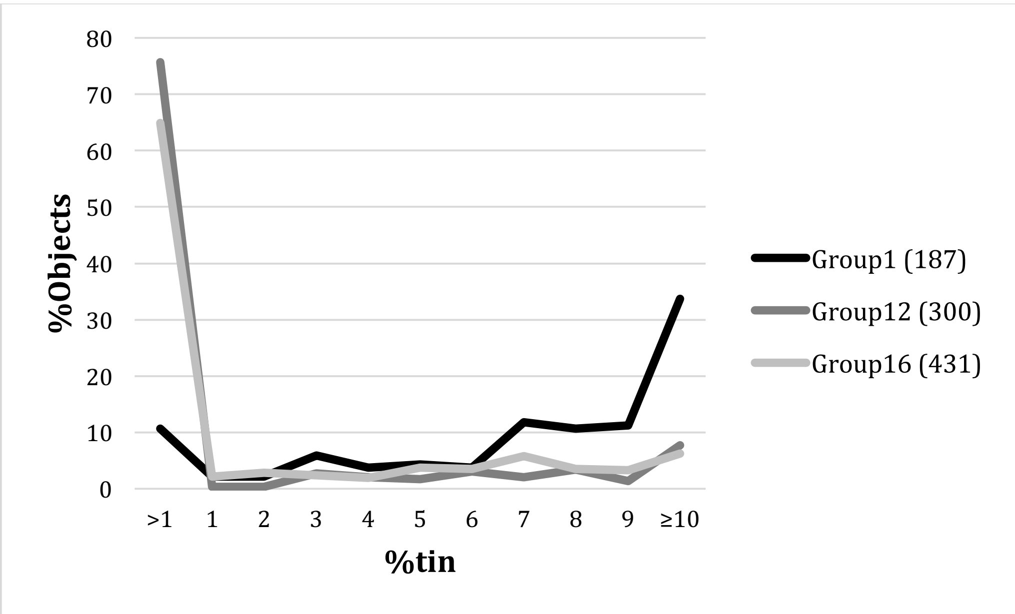


Figure 96: percentage of objects vs. different percentages of tin content in different Copper Groups. The graph includes the entire Circum-Alpine region, in the entire Early Bronze Age. Ingots and data on hoards are excluded.

This pattern could be biased by the fact that tin was more common in the western zone, where also Group 1 was more common. So a further graph has been created, focusing only on the western zone (Figure 97). Even in this graph Group 1 – clean copper - is the one that was preferentially alloyed with tin. Group 12 and 16 have a more significant peak corresponding to 5-7% of tin. It may be argued that these smaller peaks may be the result of mixing material with a percentage of tin ≥ 10% with material without tin.

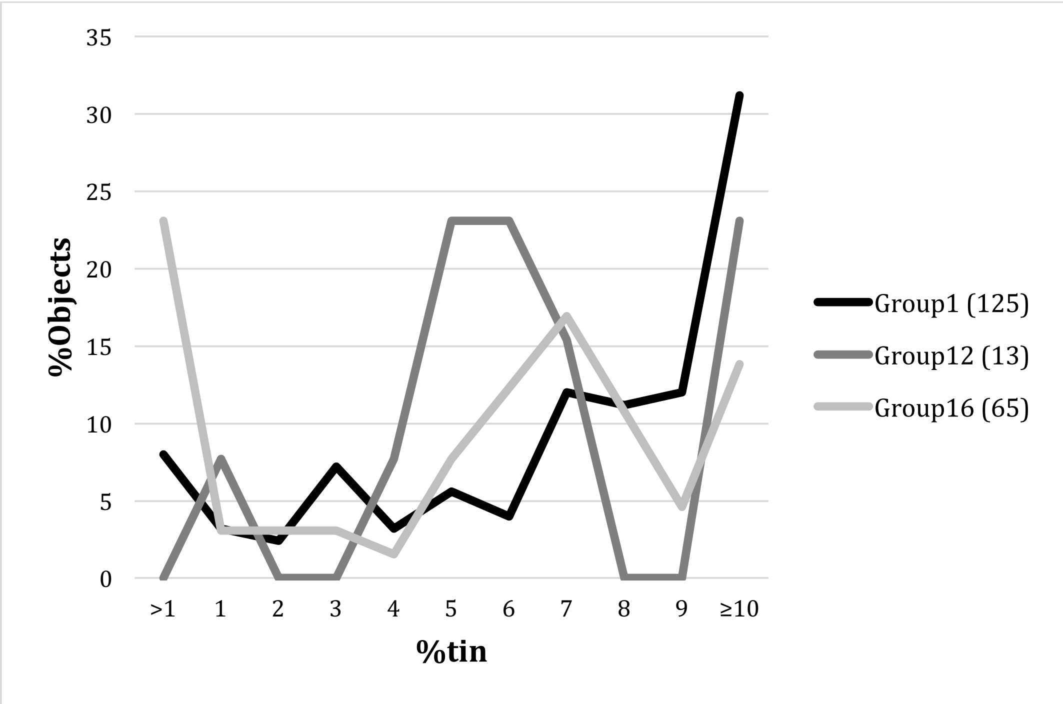


Figure 97: percentage of objects vs. different percentages of tin content in different Copper Groups. The graph includes the western zone of the Alps, in the entire Early Bronze Age. Ingots and data on hoards are excluded.

The question remains if bronzes with 10% or more of tin are a local production with the addition of solid tin or cassiterite, or if they were produced in zones that have tin – the British Isles or the Erzgebirge - and moved through Europe undergoing passages of re-melting. The fact that bronzes in the western Alps are typically made of copper of Group 1 tends to support the hypothesis of a local addition. In fact, in the British Isles and in the Erzgebirge region there was a different kind of copper, with characteristic impurities (Bray & Pollard 2012; Krause 2003), whereas Group 1 is compatible with the local mines of Saint Véran and Clue de Roua that were in use in the Early Bronze Age (Barge *et al.* 1998; Bourgarit *et al.* 2010; Rostan & Mari 2005). But it cannot be completely excluded that the absence of trace elements is the result of a dilution effect caused by some mixing of local (Group 1) copper with metal imported from the British Isles or the Erzgebirge. Moreover, at the moment there is no evidence of a possible exploitation of tin sources in France and in Tuscany at the transition from the Copper Age to the Early Bronze Age, but should be noted that, however, Tuscan copper typically contains traces of arsenic and antimony.

11.4 An overview on the introduction and use of tin in the Circum-Alpine region

To conclude, our analysis cannot say the final word about the introduction of the use of tin in the Alps, but some useful considerations may be suggested. It is possible that the approach to the topic about the introduction of bronze has been too deterministic. On the one hand a link has often been suggested between the use of bronze and advanced casting techniques (e.g. Krause 2003), reviving the old theory of technological determinism (relating bronze as an 'advanced material' to 'advanced casting technologies') as discussed in Section 3.1.1. On the other hand, it seems as if there is a predetermination in the use of bronze: once one cultural group has adopted tin bronze, this must inevitably spread to its neighbours, as in a revival of the diffusionist theories of Childe. Hence, one new early radiocarbon date can change completely the history of bronze production in Central Europe. This approach does not take into consideration why people may really have chosen to use bronze.

Our data suggests the introduction of tin into the Circum-Alpine zone from the west. But, more importantly, it shows a constant, preferential choice of tin bronze in the western zone of the Alps through the entire Early Bronze Age. This specific cultural choice does not change even if some individual bronze objects dated to an early stage are found, in future, in the eastern zone of the Alps. Moreover, we suggest that this choice of tin bronze is neither linked to some advanced casting techniques, nor to the demand for a harder material, but rather to the search for some specific colour. This is implied by the preferential choice of bronzes in ornaments.

The use of bronze is the expression of the choice of a specific cultural group (or groups) that lived in the western part of the Alps. This is also suggested by the presence of peaks in correspondence to 5-8% of tin in Figure 96Figure 97, in copper Groups different from Copper Group 1. This occurs in particular in the in the eastern part of the Alps and may suggest that this presence of tin is not the result of a specific choice for bronze, but simply the result of some mixing activities between bronze objects coming from the west and local objects that do not contain tin.

12 The Flow Model through the Landscape: the role of topography

12.1 Relationship to river drainage systems

As described above, the distribution of different groups of metal is not random, but shows a series of clear geographical patterns over time. In this Chapter, this line of reasoning is pushed beyond the concept of two-dimensional geography to deal with topography.

Using GIS the hypothesis that different metal groups are likely to follow the flow of different rivers is tested. In ArcGIS it is possible to calculate the upslope area that contributes water flows to a common outlet using watershed tools (ArcToolbox>> Spatial Analyst Tools>> Hydrology >> Watersheds). This can be used to calculate the watersheds (and hence, basins) of a river system from a DEM (Digital Elevation Model). The DEM used here is downloaded from the site http://srtm.csi.cgiar.org/ and has a spatial resolution of 90 m, which, considering the large scale of this thesis, is considered sufficiently precise.

The first step is calculating the direction of flows of water in a DEM through the tool ArcToolbox>> Spatial Analyst Tools>> Hydrology >> Flow Direction. This tool calculates for each cell of the DEM which neighbour has the steepest slope. The result of this calculation can be then be used to calculate the flow accumulation (ArcToolbox>> Spatial Analyst Tools>> Hydrology >> Flow Accumulation). This tool takes into consideration the flows of water and creates a raster in which each cell has a number that is bigger as more flows are converging into it. This information is used to identify the individual flow segments and the source points with the tool ArcToolbox>> Spatial Analyst Tools>> Hydrology >> Stream Link.

The combination of the information about the flow direction and the source points is finally used to calculate the watersheds. The tool calculates watersheds that refer not only to the main rivers, but also to their tributaries. Another step is to reclassify the watersheds so that only the ones that delimit the main river basins are maintained.

Each object in the database is linked to a site and, ultimately, to a precise geographical position, so it is possible to create a spatial join between each artefact and the basin to which it belongs. Thus, for each artefact, two kinds of information are provided: the metal compositional group and the basin to which it belongs. Therefore, it is possible to undertake a statistical analysis to evaluate the correlation between basins and compositional groups. The resulting chi-square test suggests that the distribution of different Copper groups is not random with respect to basins, neither in the Copper Age nor in all the phases of the Early Bronze Age, with a $p<<0.005$ in all the cases. Figure 98Figure 99,Figure 100Figure 101 show through pie charts how the distribution of the major copper groups differs according to river basin for different time periods.

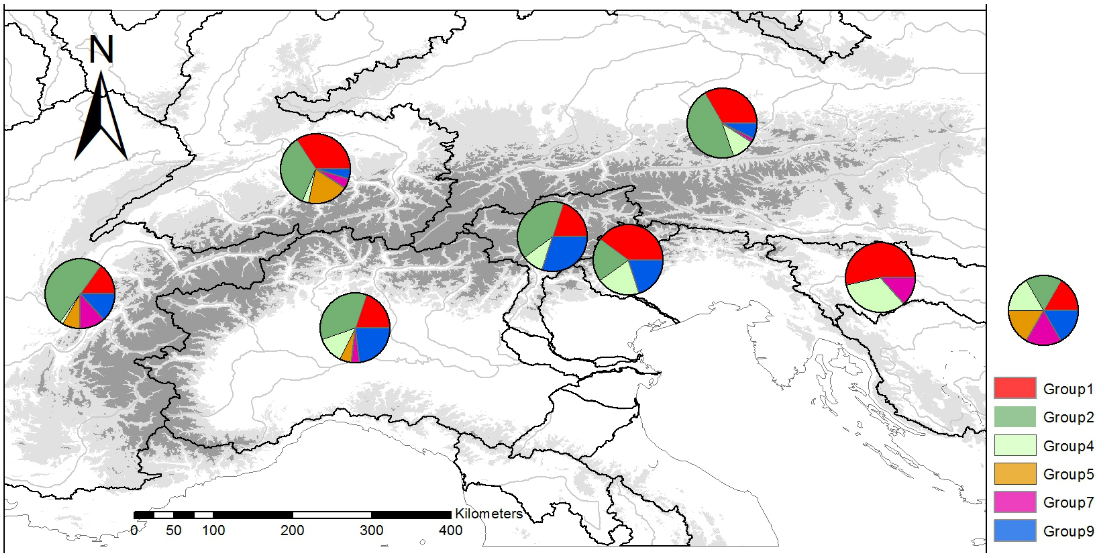


Figure 98: map of the river basins and relative distribution of different copper groups in the CA. The pie charts indicate the percentage presence of each metal group per river basin.

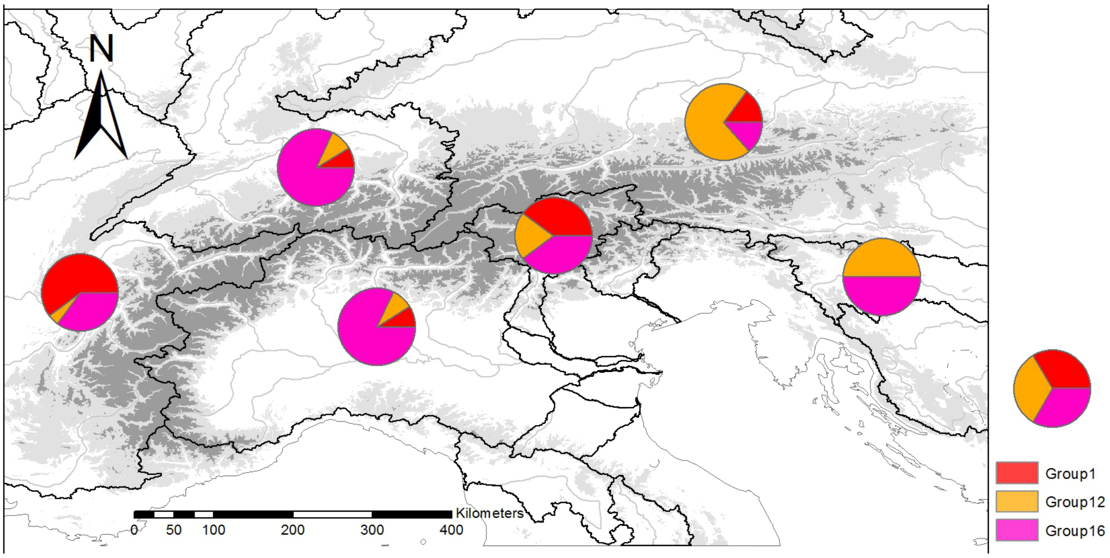


Figure 99: map of the river basins and relative distribution of different copper groups in the A1. The pie charts indicate the percentage presence of each metal group per river basin.

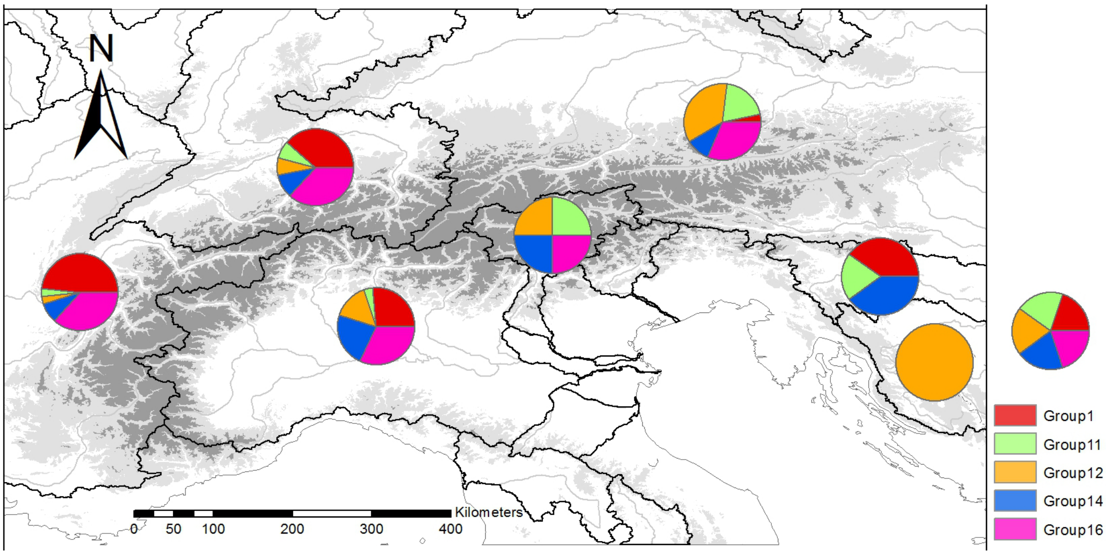


Figure 100: map of the river basins and relative distribution of different copper groups in the A2a. The pie charts indicate the percentage presence of each metal group per riverbasin.

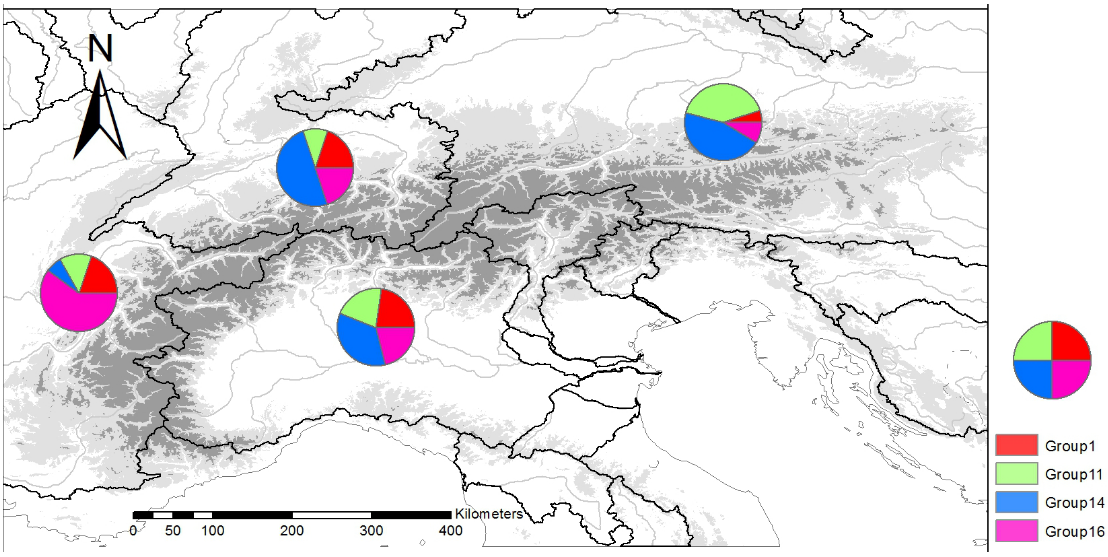


Figure 101: map of the river basins and relative distribution of different copper groups in the A2b. The pie charts indicate the percentage presence of each metal group per river basin.

12.1.1 Copper Age

Using the tool developed in this thesis (see Appendix VI), as explained in Section 8.2 it is also possible to analyse the ubiquity of single copper groups by basin rather than a 1^0 grid, as was done in Chapters 9 and 10. This enables a comparison of the information obtained using different definitions of area. This partially addresses the issue of MAUP (mappable area unit problem), as discussed in Chapter 4.

As summarised in Figure 102, in the Copper Age the Rhône basin is characterised by a dominance of arsenical copper (Group 2); the Adige and Po rivers have similar levels of pure copper (Group 1), but they differ in the percentage of Groups 5, 7 and 9. The Rhine, Danube and Piave basins have a significantly higher level of pure copper than the ones of the Rhône, Adige and Po. Two points should be highlighted: the specific presence of group 5 (copper with Ni) in the Rhine and the high values of group 9 (copper with As and Ag) in the Piave, which, combined with the percentages in Po and Adige, reflect the previously-mentioned importance of this group in the north-east of Italy.

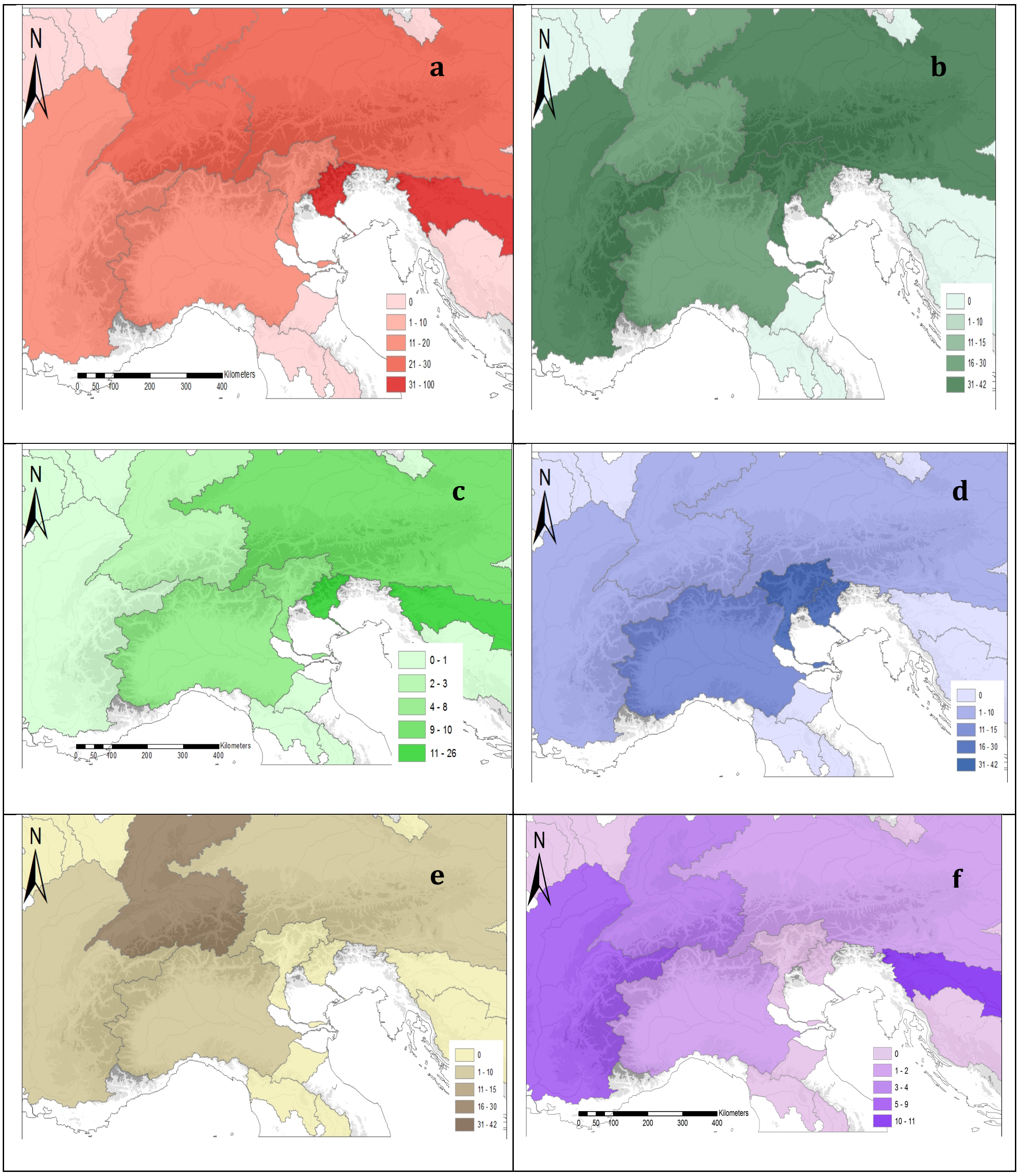


Figure 102: distribution of copper groups in different basins in the Copper Age. (a) Group 1, (b) Group 2, (c) Group 4, (d) Group 9, (e) Group 5, (f) Group 7.

12.1.2 The Early Bronze Age 1 (A1)

In the Early Bronze Age 1 (Figure 103), the specific presence of different copper groups per basin becomes more evident. The importance of copper without impurities (Group 1) in the Rhône region is confirmed, whereas the Danube has a predominance of Group 12 (As, Sb, Ag). The Po and Rhine have similar patterns, with Group 16 (As, Sb, Ag, Ni) dominating, with a slightly higher presence in the Rhine (Figure 103).

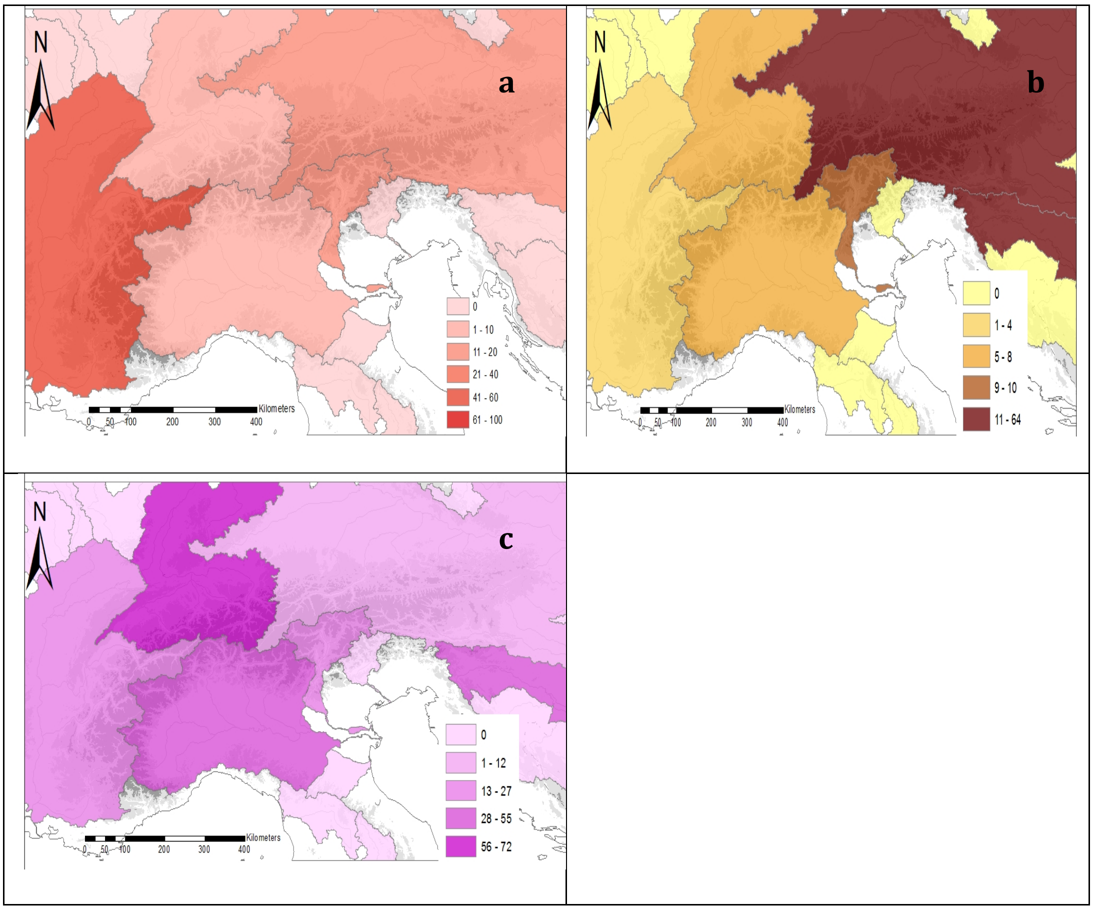


Figure 103: distribution of copper groups in different basins in the Copper Age.: (a) Group 1, (b) 12 (, (c) 16.

12.1.3 The Early Bronze Age A2a

In the second phase of the Early Bronze Age, the distribution of Groups 12 and Groups 1 remains unaltered. Two new groups (Group 11, with arsenic and nickel, and Group 14, with arsenic, antimony and nickel) are distributed respectively in the Piave and the Danube basins and in the Piave and the Po basins (Figure 104).

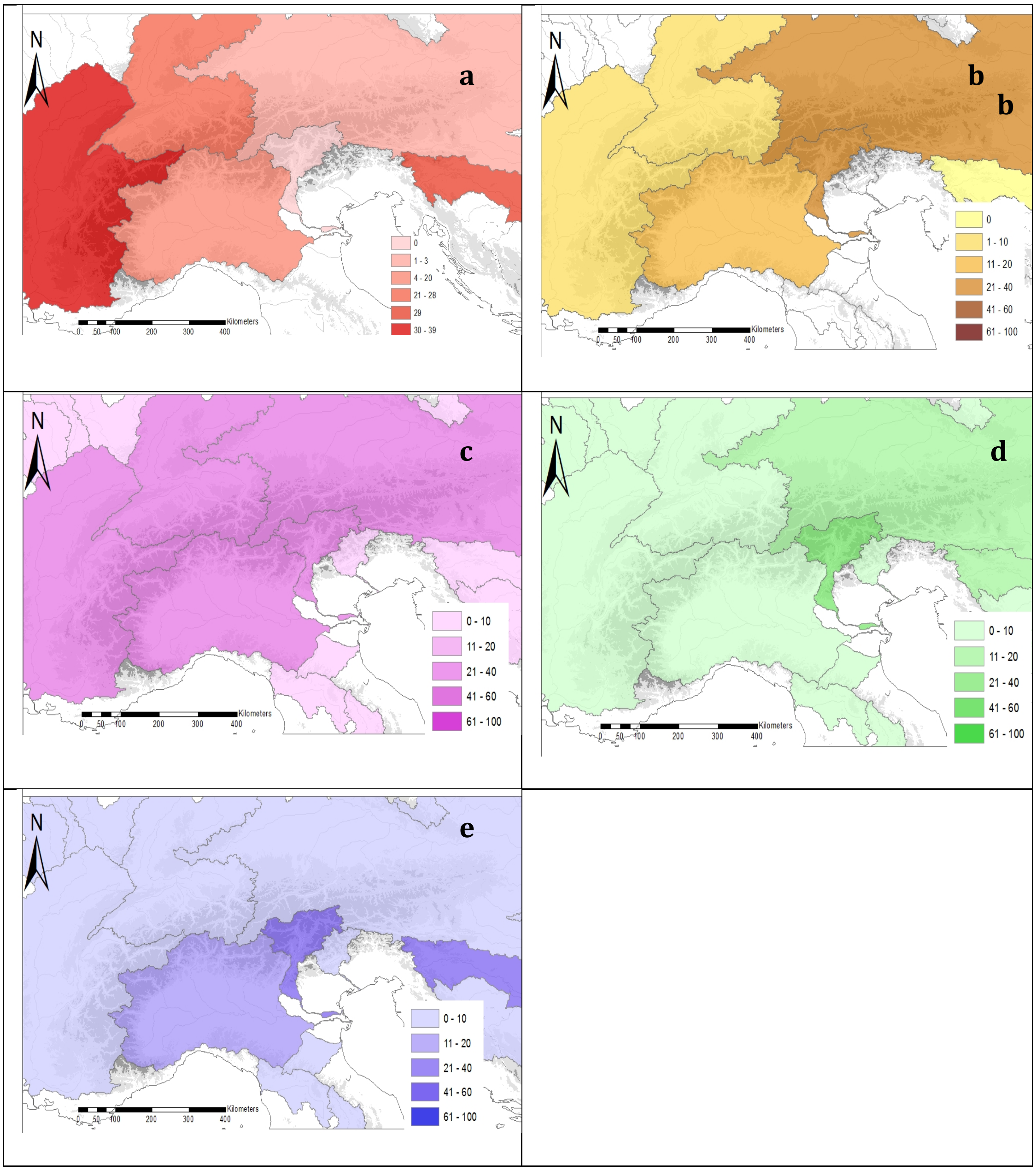


Figure 104: distribution of copper groups in different basins in the Copper Age.: (a) Group 1, (b) 12, (c) 16, (d) 11, (e) 14.

12.1.4 The Early Bronze Age A2b

In the final phase of the Early Bronze Age, the Rhône valley still has an important presence of Group 1, but also of Group 16. The distribution of Groups 1 and 16 are similar for the Rhône and the Po. The Danube and the Rhine, on the other hand, have a mutually similar pattern with a predominance of group 14 (Figure 105).

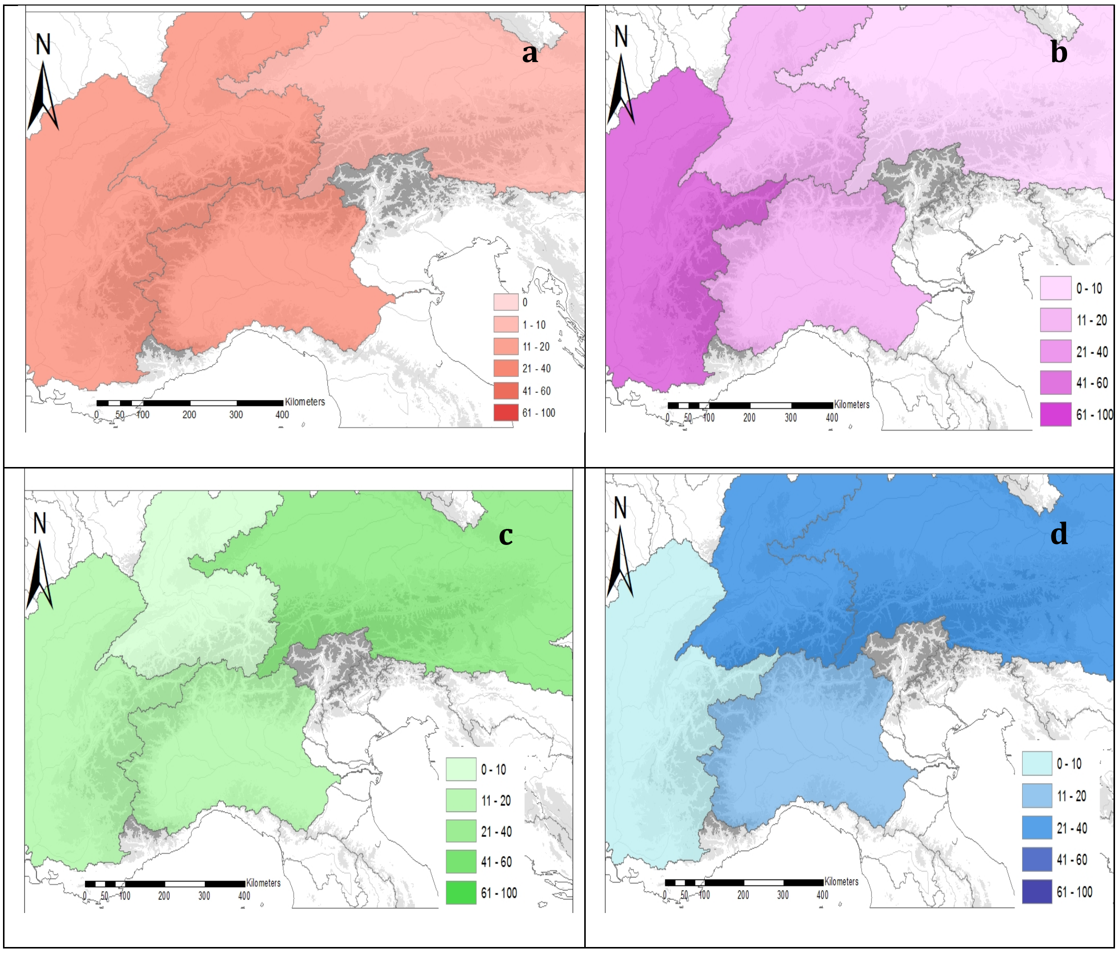


Figure 105: distribution of copper groups in different basins in the Copper Age. (a) Group 1, (b) 16, (c) 11, (d) 14.

12.1.5 Discussion

In Section 4.1 it has been mentioned that one of the reasons why GIS should be considered an important tool for archaeometallurgical study is that can include the topographic variable in the discussion about the movement of metal, as demonstrated above. Rivers may reasonably be described as the "highways of the continent" in prehistory (Cunliffe 2008, 38–47). Large rivers, such as the Danube, Rhine, Rhône and Po would have been easy to navigate, even upstream, especially with the help of sails or human and animal traction (see Section 5.3). As Van de Noort claims "There is no doubting that the earliest boats in Europe were built for use on rivers and lakes, and that the types of craft that enable riverine traffic include hide- and skin-covered boats and logboats" (Van de Noort 2013, 390). The oldest logboat from Italy is from Lake Bracciano, Central Italy, and is dated to the sixth millennium BC (Fugazzola & Mineo 1995). However, most of the logboats found in Italy are from the north, from both lakes and rivers, and some of them have been dated to the Early Bronze Age. Logboats have also been found in the main northern Circum-Alpine lakes (Menotti 2001, 145). Unfortunately, there is a general lack of research on the chronology of these crafts as well as on their social role and technological development throughout the Bronze Age (Ravasi & Barbaglio 2008). But even if they were not navigated, the importance of rivers is hardly diminished: for terrestrial travel, rivers work perfectly as reference points and as a secure marker of the path, and as a reliable source of potable water. The key role of rivers increases in the Circum-Alpine region, where glacial river valleys work as corridors between mountains. The analysis of basins confirms the patterns highlighted in Chapter 9 and 10, and the hypothesis that the distribution of different copper groups is, at least partially, dependent on the river system.

Some differences occur, however, where the patterns are independent of rivers. The analyses of the distribution of tin (Chapter 11) and of different copper groups, both in the Copper Age (Chapter 9) and in the Early Bronze Age (Chapter 10) suggest the presence of a cultural barrier that divided the Alps into two zones: east and west. In the north this line can be imagined as the barrier that divided the Rhine and the Rhône but in the south of the Alps this barrier cuts across the Po basin. In this case, using the basins as an aggregating system, this does not become apparent. This is an excellent example of the importance of the flexibility given by GIS that allows the investigation of the MAUP problem (see Chapter 4). In fact, it demonstrates that with two different aggregating systems, at two different scales, there is the possibility to acquire two pieces of important information: the presence of a cultural barrier that runs through the Alps dividing them into an eastern and western zone, and the importance of the river system as a means of transport.

12.2 Cost Surface Analysis

GIS also allows the calculation and presentation of an accumulated cost surface from a given point. This analysis creates a raster map in which a value indicating the "cost" necessary to reach each particular cell from a given starting point is assigned. This can be interpreted as showing accessibility from a given point. The value of the cost could be due to many different causes. Llobera (2000) grouped them into two main categories: topographic cost and landscape feature cost.

Topographic cost depends upon physical features, mainly the slope of the surface, but other factors, such as soil type, could be included. Landscape feature cost includes vegetation, natural features seen as barriers or means of transport (e.g. a river that can be seen as a means of transport or as a barrier to crossing) and artificial features such as monuments or tombs. In this category cultural choices can have a major weight: there are elements (physical or anthropological) that can be seen as taboos and elements that are seen as attractive for a particular group of people.

In this work only the first category is taken into consideration, namely the topographic cost. Unlike the "classical" use of the cost surface, however, here there is no attempt to determine the most plausible path. This use is, at least, controversial and extensively debated (Herzog 2014). Moreover the choice of an individual person in choosing the next step of a route is possibly simultaneously the most significant and the least predictable parameter to determine the real routes used in the past (Lock & Pouncett 2010). Consequently, in order to try to guess the possible paths, the most fruitful procedure would be a survey campaign in the Alpine passes in order to locate the ones that have the most archaeological remains, as the work of Della Casa has demonstrated (Casa 2007). The aim of this analysis, instead, is to provide a map of the topographic accessibility of the Circum-Alpine zone and investigate how this accessibility reflects the distribution of the objects. This may allow some conclusions about the importance of topography in the movement of the people that were bringing metal artefacts. Therefore, the resulting maps of this analysis are compared to the maps of cultures and to the distribution maps of the different metallurgical groups. For this reason cultural factors should not be considered as factors in the analysis, but should be used to verify the predicted relationships between the physical factors and the reality of the archaeological record.

The starting point for the analysis is the same DEM (Digital Elevation Model) downloaded from the site http://srtm.csi.cgiar.org/ as was used above. From this file a raster map with the values of slopes is created using ArcGIS tool Spatial Analyst Tools >> Surface >>Slope. This tool calculates for each cell of a raster the maximum rate of change in value from that cell to its neighbours. This file can be used for the cost surface analysis, but Bell and Lock (2000) have underlined how this approach is too simplistic. For example, a linear correlation between slope and cost would lead to the conclusion that climbing a vertical slope of 90° is only ninety times as difficult as walking on the level. They propose a calculation of cost based on the ratio between the tangent of the angle of slope with the tangent of 1° (Bell & Lock 2000).

The ratio between the cost of walking on a flat surface and on a slope can be imagined as proportional to the ratio between the potential energy at the flat surface and the altitude that has to be reached when walking on a slope:

$C = mgy_0/mgy_1$

where m = mass, g = aceleration due to gravity, y_0 = the starting height and y_1 is the height attained. If y is the difference between y_0 and y_1, then:

$y= x\tan\theta$

and x is the horizontal distance between starting and finishing point.

The relative cost of going from an altitude of y_0 and y_1 over a distance x is $\tan\theta/\tan 0°$. To avoid the fact that $\tan 0°$ is ∞, this ratio is calculated with a small angle as denominator, i.e. 1°. The resulting graph of the function gives a more realistic relationship between cost and angle, in which low slopes do not significantly affect the cost, whereas higher slopes increase the cost dramatically. It has to be noted that, since the formula is a ratio, the result is a relative cost and does not have a measurement unit, but is an absolute number.

In order to create a cost map with this calculation there is the ArcGIS tool Spatial Analyst Tools >> Map Algebra >>Raster Calculator, which assigns for each cell of a new raster (the output) the values obtained from the above expression. The result of this calculation gives the cost of moving from one cell to its neighbour across the entire surface. It can be read as the "potential energy" map. Usually we want to measure the cost of moving from a specific point to all other possible points, such as when calculating the cost associated with specific flows of metal.

In order to do this, the ArcGIS tool Spatial Analyst Tools >> Distance >>Path Distance is used. This tool considers each cell of a raster as node and all the nodes are linked together with lines. Each of these lines has a value of "impendance" that is determined by the cost (the value of the input raster) and the direction of the movement. The origin has a cost 0. From the origin the cost of all the neighbours (C1) is given, and so on. Effectively, the map represents the accumulated cost Cx=C1+C2+C3+…. In the analysis it was also possible to consider a horizontal and vertical influences to the movement (e.g. assign a higher "impendace" if the movement is uphill or downhill).

In this thesis, as an example of the possibility of this analysis, the situation of the Early Bronze Age A1 is considered. As explained in Section 10.1, in this period in the Alps there were only three main flows of metal, whose composition is clean copper (Group 1), copper with arsenic, antimony, silver and nickel (Group 16) and copper with arsenic, antimony and silver (Group 12). For all of these three groups a hypothesis of the possible ore source was given, taking into consideration information about the mines whose exploitation is demonstrated during the relevant time period (Section 5.2), the mineralization of these mines (Section 5.2), and the results of ubiquity analysis and geostatistical analysis (Section 12.2). The copper mines found in the Inn valley, the upper Rhine, Saint Véranand and Clue de Roua are therefore considered as possible sources respectively for copper of groups 12, 16 and 1 in the Early Bronze Age 1.

The resulting map for the first case (Figure 112) indicates that from the Inn valley the Danube Valley can be reached with least cost, followed by the Rhine valley, the upper Rhône and then, finally, the Po, Adige, Piave and lower Rhône valleys. The peaks of the Alps were, obviously, the most difficult zones to reach. It is interesting to note that the actual distribution of the copper of Group 12, or "*Ösenring* copper", is not completely as predicted by the cost surface. The majority of zones with the highest ubiquity of Group 12 metal are distributed in the Danube basin, as predicted by the cost surface, but there is only a weak relationship between cost and the less ubiquitous sites.

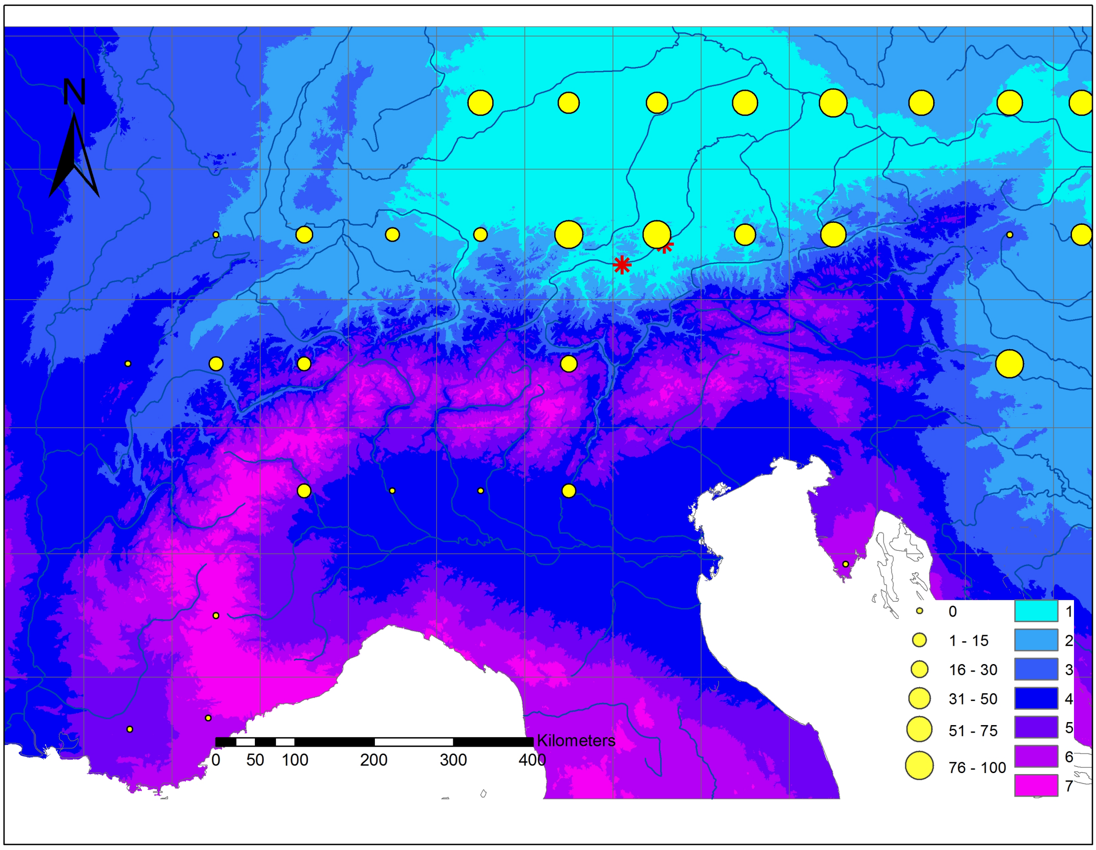


Figure 106: cost surface from the Inn valley mines (red stars). Light blue indicates zones more easily reachable, violet the hardest. The size of the dots indicates the percentage of objects with composition of Copper Group 12 per zone.

A similar analysis is shown for the second most common group in the Early Bronze Age, Group 16. In this case the possible ore source is unknown, but Krause has suggested it could be a mine in the mountains surrounding the upper Rhine (Krause 2002). The geostatistical analysis supports this hypothesis (see Chapter 9), so the upper Rhine has been used as a starting point.

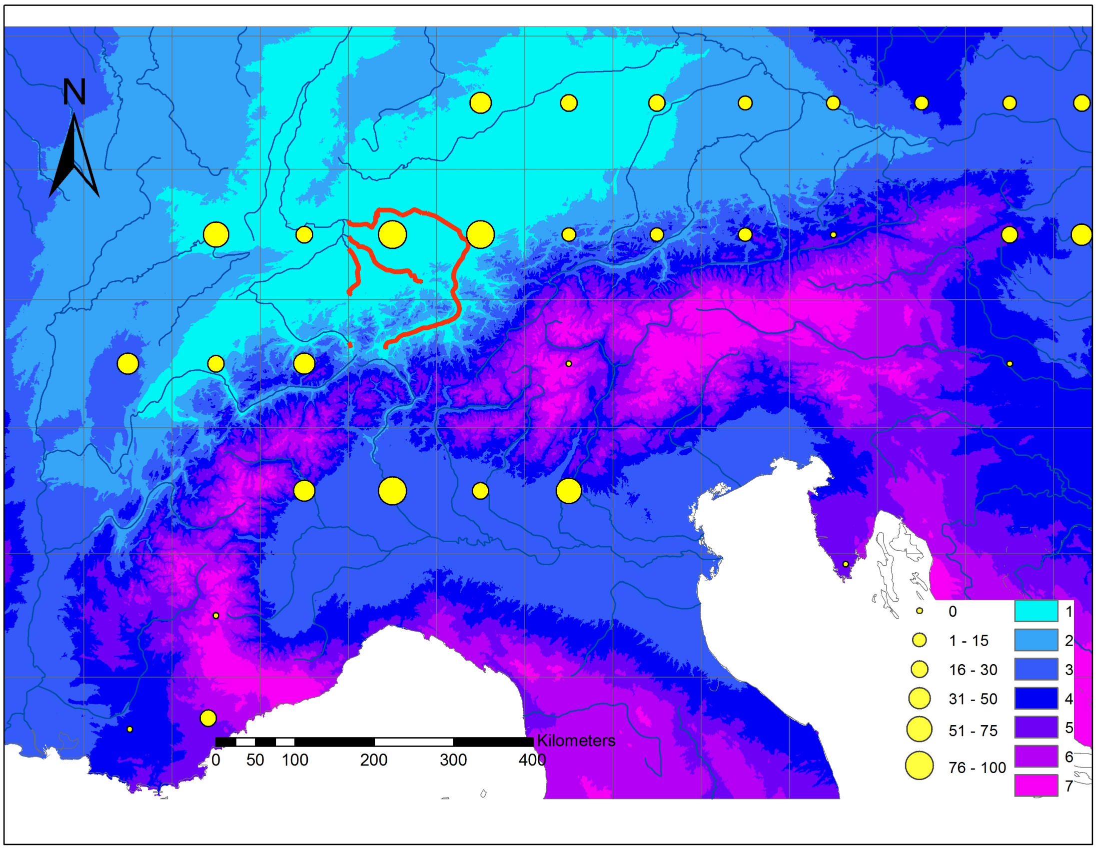


Figure 107: cost surface from the Upper Rhine (red lines). Light blue indicates zones more easily reachable, violet the hardest. The size of the dots indicates the percentage of objects with composition of Copper Group 16 per zone.

In this case the least cost zone corresponds to the Rhine and the upper Danube, a second grade of cost is given to the upper Rhône, the Danube and, interestingly, the upper Ticino valley. Finally, the lower Rhône, lower Danube and Po valleys have the highest cost. As with the previous case, there is in general a good correspondence between the lowest levels of cost surface and the distribution of objects with this kind of composition, but there are also significant differences. In particular, the upper Danube, which has a very low cost, does not have the highest percentage of objects made of Group 16. On the other hand, one of the zones that has the highest presence of this metal is the Ticino valley, which corresponds to a zone with a second level of cost, the same as the Danube, which has no or very few objects made of this composition. This confirms the importance of the St. Gotthard pass and its close bypass routes (see Section 5.3).

Finally, the third group taken into consideration is Group 1, made of clean copper. In this case, the most probable ore source is the mines of Saint Véran and Clue de Roua (see Section 5.2).

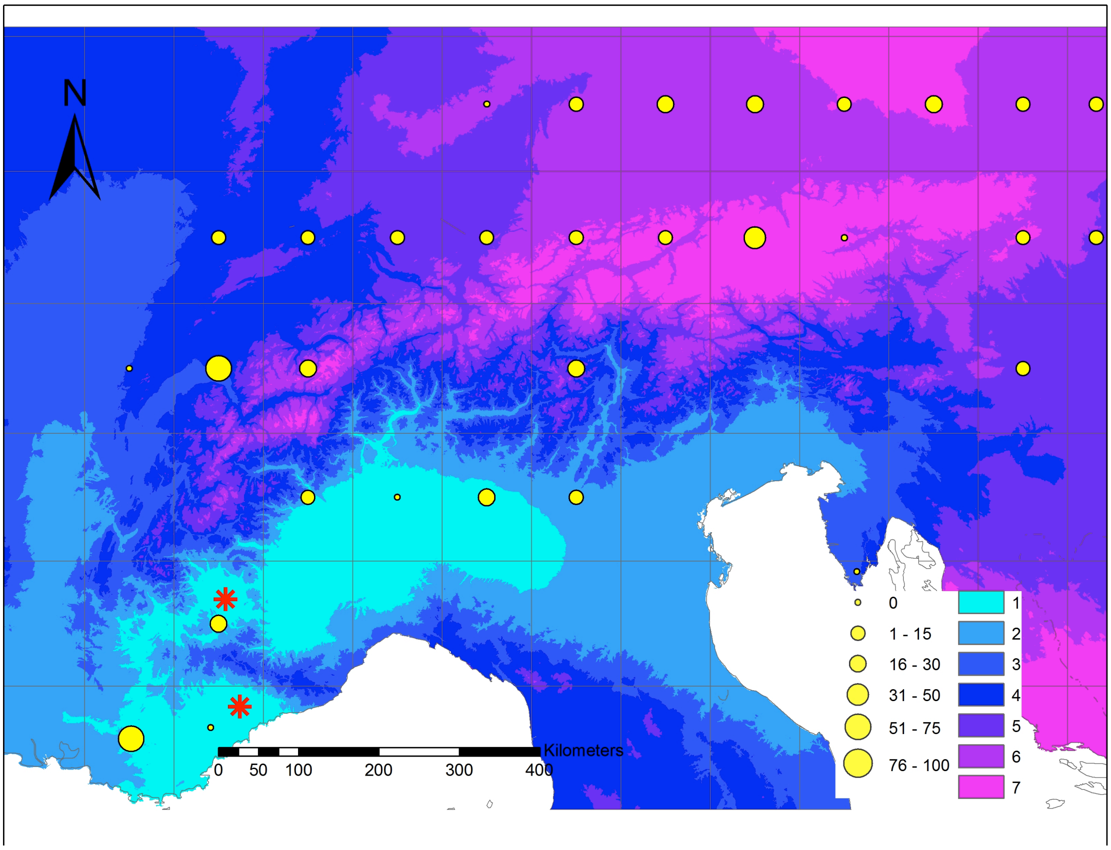


Figure 108: cost surface from Saint Véran and Clue de Roua mines (red stars). Light blue indicates zones more easily reachable, violet the hardest. The size of the dots indicates the percentage of objects with composition of Copper Group 1 per zone.

In this case the difference between the distribution of the objects and the cost surface is more evident. The entire Po valley is very easily reachable, and this is confirmed by the presence of numerous passes in this region (see Figure 12). It is true that the climate in this region is less favourable to the movement through the Alps, but the beginning of the Bronze Age witnessed generally better conditions (Section 5.3), as proved by the exploitation of the mine, set at the high altitude.

The predominance of cultural choices over the topography is more evident when the cost surface is taken into consideration. As explained in Chapter 5, the recent formation of the Alps made them sharp and difficult to climb. The cost surface analysis reiterated this difficulty, especially in the cases of the mines in the Inn and Rhine valleys. Nevertheless, the distribution of the objects denies the role of the Alps as a barrier and reiterates that the Alpine passes were used both in the eastern and in the western zone. On the other hand the analyses highlighted that zones that could have been easily reached do not necessarily have artefacts with similar copper composition. This is particularly true in the case of the mine Saint Véran and the distribution of the associated copper Group 1 (Figure 108).

As mentioned in Chapter 4, Gaffney and van Leusen warned that the use of GIS could lead to a deterministic model that emphasises the mappable features and underestimates the culture, rituality and choices (Gaffney & van Leusen 1995, 374–377). As Llobera underlined, though, the risk of determinism is not dependent on the information managed in a GIS but by the use and interpretation of this information. In his words "a study which incorporates environmental information is not condemned to determinism" (Llobera 2001). Taking into consideration the concepts of structures by Giddens (1984) and affordances by Gibson (1986), Llobera proposed a new interpretational model of the environment that includes such concepts as structure and affordances. Structure is the sum of the material resources and the human habits. Affordances are the properties of the environment as perceived by an agent in practical action. The link between the two concepts is practise: a group of individuals who share the same structure produce and reproduce the same practise that leads them to a specific perception of the environment. According to Llobera the existence of particular affordances may be explored via GIS by relating the distribution of different material evidence with some mappable characteristic. The suggestion of Llobera has been followed in this work. The use and distribution of the metal objects has been compared firstly to river basins and then to topography. The use of the cost surface, in particular, did not focus on the "typical" use (to calculate "the most probable path") but rather tried to evaluate the "structure" of the different zones. This "humanistic use of GIS" allows the use of the topographical feature to obtain more information about the cultural choices and the perception of the environment in the Early Bronze Age. It is possible to conclude that cultural factors were more important than topographical factors. On the one hand, the mountain range was not a barrier. On the other hand, it may be noticed that, even though rivers were used as connecting factor, the "cultural factor" that divided the Po into two zones was more determining. Another way to see it is that ancient people took advantage of topographical elements (i.e. rivers) to perform a movement based on cultural motives. Those cultural reasons were also stronger than potential topographical barriers (i.e. mountains).

13 General Discussion

In Chapter 2 it has been explained how the perspectives of researchers on the ancient metallurgy in the Alps have often been limited to extrapolating information about technology and provenance, dedicating much less attention to how metal was perceived and used in society. Moreover, it has been underlined that there are some simplifications that can often be seen in the perception of ancient metallurgy by archaeologists. For example, there is a recurrent idea of changing composition as a marker for improved technology and, in turn, for a chronological series (e.g. David-Elbiali, de Marinis; see Chapter 7 for a discussion of this assumption). The picture is complicated by the fact that in the Circum-Alpine region there is also a lack of chronological and archaeological synthesis, as explained in Chapter 7, and consequentially that new data can modify decades old certainties (Dolfini 2014b).

The contribution of this thesis in the complex topic of ancient metallurgy in the Circum-Alpine region is to give a synthetic perspective of the entire region, focusing, in particular on how GIS may help to understand the relationship between humankind, materiality and space. In Chapter 9 it has been discussed how this methodology may help to understand the circulation and use of copper in the Circum-Alpine Copper Age, and in Chapter 10 in the Early Bronze Age. Chapter 11 is focused on the introduction and use of tin bronze in the Circum-Alpine region, and Chapter 12 is dedicated to the role of topography in the flow of metal. In this final Chapter we would like to show how a new interpretative model may contribute to some open debates about the beginning of the Metal Age in the Alps, in particular focusing on some "hot-topics" such as the change of use and perception of metal from the Copper Age to the Bronze Age, and the hoarding habits in the Early Bronze Age. This new model emphasises the importance of using the "biography of metal" approach in the Alps in the Copper Age and Early Bronze Age, with a specific attention on the movement of metal and the role of the environment.

13.1 Metal production

Numerous possible mines are present in the Alps and some of them have a verified exploitation from the fourth millennium B.C. (Section 5.2). In Chapter 2 it has been highlighted how the topic of provenance has influenced centuries of research. Despite the failures of this approach, even recently many authors have attempted to pinpoint the exact provenance of a single artefact, and advocate new analyses on objects and on mines (e.g. Salzani 2011, see Section 2.7.5). The Flow Model demonstrates that if there were the presence of flows of metal that were recycled and remixed, it would be virtually (and, as many failed attempts demonstrate, practically) impossible to pinpoint the provenance of a single metal object because it is not made from a single batch of metal. Nevertheless, by combining the results of ubiquity analysis and geostatistical analysis it is possible to determine the zones that were probable centres of primary metal production. In the Circum-Alpine region these centres often correspond to known mining regions (Section 5.2), but also indicate some other zones where there are no known mines. In all these cases, however, the presence of mines has already been independently hypothesized, such as the Rhine valley in the case of Copper Group 16 (Krause 2003), and western Switzerland in the case of Copper Group 5 (Cattin *et al.* 2011). These results show the value of not including data on mining sites in the initial spatial analysis. By following the procedure demonstrated here it is possible to subsequently use the location of known or suspected mines as corroborative evidence, backing up the conclusions drawn from the spatial analysis of the objects on their own.

There is some evidence for a change in the pattern of metal production in the transition from the Copper Age to the Early Bronze Age (Table 17). The scale of production appears to dramatically increase. The evidence for this is not only the increased number of artefacts and moulds that have been recovered in the Early Bronze Age, but also the wider distribution of moulds, frequently found in valley settlements away from the primary mining zones (see Chapter 7). This increase is reflected in the number of analysis available on metal artefacts. In the Copper Age, in *circa* 1400 years there are 533 analysed artefacts; in the Early Bronze Age, covering 800 years, more than 4000 artefacts have been analysed.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16
CA	127 (24%)	170 (32%)	10 (1.9%)	34 (6.4%)	40 (7.5%)	9 (1.7%)	23 (4.3%)	5 (1%)	42 (8%)	1 (0.2%)	18 (3.8%)	11 (2.1%)	4 (0.8%)	8 (1.5%)	7 (1.3%)	24 (4.5%)
A1	315 (15%)	38 (1.8%)	21 (1.0%)	19 (0.9%)	20 (0.9%)	13 (0.6%)	54 (2.6%)	3 (0.1%)	8 (0.4%)	4 (0.2%)	21 (1.0%)	999 (49%)	27 (1.3%)	37 (1.8%)	5 (0.2%)	450 (22%)
A2a	127 (8.1%)	39 (2.5%)	24 (1.5%)	9 (0.6%)	60 (3.9%)	16 (1.0%)	8 (0.5%)	5 (0.3%)	4 (0.3%)	7 (0.5%)	237 (15%)	415 (26%)	7 (0.5%)	149 (9.6%)	12 (0.7%)	437 (28%)
A2b	31 (11%)	12 (4.3%)	4 (1.4%)	0 (0.0%)	36 (13%)	8 (2.8%)	5 (1.8%)	5 (1.8%)	1 (0.4%)	2 (0.7%)	53 (19%)	7 (2.5%)	2 (0.7%)	69 (25%)	2 (0.7%)	43 (15%)

Table 17: overall table of the number and percentage of objects for each compositional group in the different chronological phases considered in this thesis

The increased number of analysed metal artefacts combined with a decreasing variety in the types of copper, and the presence of northCircum-Alpine cemeteries with grave goods composed by many metal objects (Section 10.1) contributed to the development of a theory according to which in the passage from the Copper Age to the Early Bronze Age some elite-groups arised. These groups controlled three main mining districts in the Alps and the distribution of metal through some ingots: *Ösenringe* and *Spangenbarren* in the east, Salez type axes in the central region, and Neyruz type axes in the west (Krause 2003) (Figure 109). This model explains the colonization of the highlands of the Alps as a consequence of the search for metal sources. Moreover, the appereance of the elites is linked to the idea of increasing of social complexity, also proved by technological improvements, possibly acquired from the nearby Únětice culture, both in smelting techniques (in particular to smelt *Fahlerz*) and also in production techniques, namely with the appearance of tin-copper alloy and lost-wax casting.

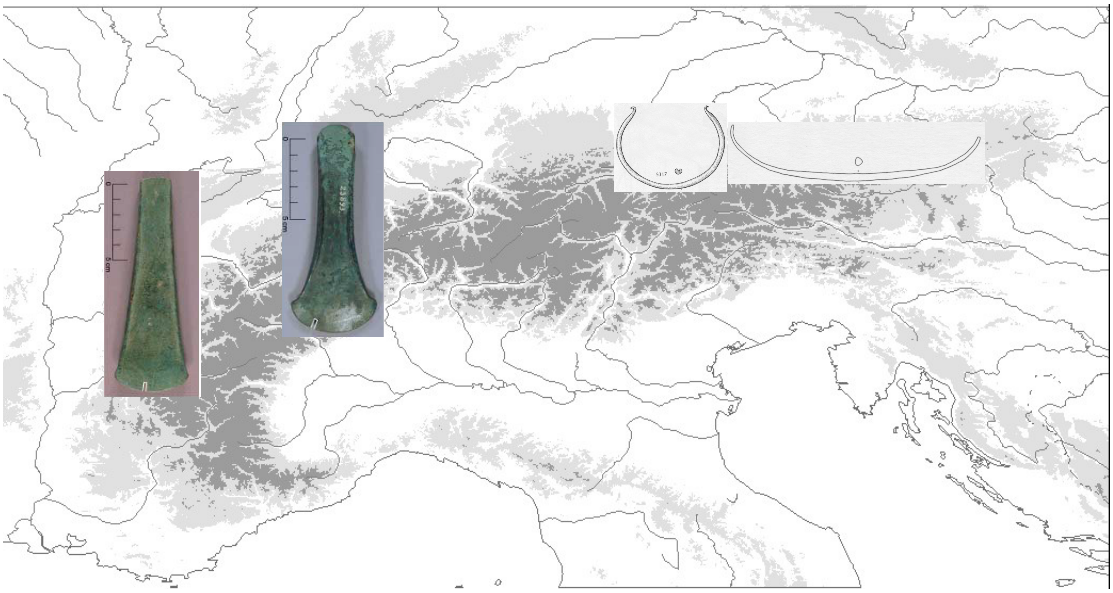


Figure 109: from the right, *Spangenbarren, Ösenringe*, axes Salez type and axes Neyruz type. According to Krause (2003) these objects were ingots, used in the Early Bronze Age distribution of metal in, respectively, Austria, southern Germany and Switzerland.

In contrast, according to Kienlin (2010), the increase in metal production does not necessitate elite control. He sees the exploitation of the mines in the Early Bronze Age taking place through small-scale activities organised on seasonal basis (see Section 2.8.2). In support of his theory, Kienlin also pinpointed that there are very few permanent settlements found in the highlands, despite the large scale of production of metal. Human activity in the highlands has been known since the Neolithic (Del Lucchese 1998; Del Lucchese & Odetti 1996, see Section 5.3) when the mountains were quarried for flint or greenstones. In the Early Bronze Age there is evidence for small settlements in the highlands both in the north and south of the Alps (see Section 7.2.3 and 7.2.4), especially in the south-west (see Section 7.2.5). These were interpreted as being impermanent, related to pastoralist activities, and possibly mining. The presence of these small settlements on both the sides of the Alps may suggest seasonal activities of more than one group of people, rather than the permanent exploitation of mines by a centralized society dominated by elites. It is possible that people from both sides of the Alps met and exchanged material in the highlands (including also pottery, salt, stones; see Harding (2013)).

In this thesis the increased production of metal in the transition from the Copper Age to the Early Bronze Age is, indeed, confirmed (Table 17). Moreover, in the Copper Age at least 50% of copper (Groups 1 and 2) has here been interpreted as coming from outside the Circum-Alpine region (Chapter 9), with a number of minor Copper Groups, still well represented, having a local distribution. In the Early Bronze Age the patterns of metal production suggest that it almost totally originates within the Alps (Chapter 10). New sources were exploited, some of which possibly were only available because of an improvement in the climatic conditions that raised the permanent snow-line (Section 5.3). Nevertheless, it has to be noted that in the course of the Early Bronze Age copper production changed from an absolute predominance of only three Copper Groups (1, 12 and 16) in the first phase (A1), to a situation where minor local production seems to have re-started, such as Copper Groups 14 and 5. This local production is similar to the situation in the Copper Age, and in the case of Copper Group 5, the re-opening of an old mine can be hypothesized. So although we see a change from a dispersed production pattern in the Copper Age to a more restricted pattern in the Early Bronze Age A1, and then a reversion to a more distributed pattern in A2, this does not necessarily demonstrate the appearance of elite control in A1.

The transition from the Copper Age to the Early Bronze Age is also often seen as a moment of important technological innovation in metal production. One of these is the smelting of sulphide ores or *Fahlores* (de Marinis 2006a; Krause 2003), because it has been hypothesized that their smelting requires a slagging process (see Section 6.5). As mentioned in Chapter 3 the idea of technological improvement as the motor for the choice of metal can be traced back to Childe (1944), and is recurrent in the history of archaeometallurgical research in the Alps (e.g. de Marinis 2005; Hook 2003, 2007; Salzani 2011; Trampuž Orel 1995). But recent experiment has verified that copper could be extracted from these minerals also using a simple, non-slagging process, without the addition of flux (Kienlin 2013; O'Brien 2013, see Section 6.5). And this is also supported in the work presented here by the fact that the smelting of copper of Group 16 in the Early Bronze Age 1 left so few traces that a secure location of the smelting site is not possible. Moreover, recent radiocarbon dates suggest the production of *Fahlerz* from the Copper Age (Dolfini 2014b), and from Trentino there is also evidence of slag *prior* to the Bronze Age (Marzatico 2011; Pearce 2007; Pedrotti 2001). In this thesis the presence of copper with impurities characteristic of *Fahlerz* has been noted from the Copper Age and, in particular, copper from Trentino has a clear signal of *Fahlore*, with arsenic and silver (see Chapter 9.4). This all suggests that the transition from the Copper Age to the Early Bronze Age was not accompanied by a simple change in technology, as has been generally assumed.

An important innovation in metal production in the Bronze Age is however the introduction of systematic intentional alloying with tin and more sophisticated casting techniques, such as the lost wax technique. These two aspects, according to Krause, went together and were imported into the Alps from the close-by Únětice Culture (Krause 2003). As mentioned in Chapter 9.6, it cannot be completely excluded that there was intentional alloying with arsenic, in particular in the north-east of Italy, close to the Trentino mining district, during the Copper Age. In fact, it is well known that some alloying experiments may have occurred even in the Copper Age (Primas 2003). Moreover, the introduction of the lost wax technique from the Únětice Culture is called into question by a new model that has been proposed for the origin of the lost wax process in the western Alps (Schwenzer 2004).

More significantly, this thesis demonstrates the inconsistency of the proposed link between tin addition, improved casting techniques and improved hardness of the finished objects, as has been repeatedly claimed by, amongst others, Ottaway (1982) and de Marinis (2005). This theory has been adopted despite numerous hints indicating the preferential use of tin in ornaments (such as Garagnani *et al.* (1997); see Section 2.7.3). The evidence presented here suggests that the use of bronze was the choice of a specific cultural group (the Saône-Rhône group), probably due to an appreciation of the colour, or of the shininess, as witnessed by its frequency in ornaments (see Chapter 11). From metallography, it would seem that the hardness of bronze was properly appreciated and sought only in the final phase of the Early Bronze Age (A2b) (Kienlin *et al.* 2006).

13.2 Movement of metal

This thesis has demonstrated that the distribution of the copper groups and also of bronze artefacts was not blocked by the presence of the Alps (i.e. there was not a separation between the northern and southern area). As explained in Chapter 5 in the western zone of the Alps there are several possible transalpine passages and some of them have prehistoric archaeological remains. The eastern zone is more difficult to cross, because the Alps are divided into more than a single chain, each of them with a number of ridges. The most important pass is the Brenner, which also connects the mining zone of Trentino with the ones in the Inn valley. This was probably a preferential route for seasonal travel in the highlands, and, in fact, some metal finds have been found close to this route.

On the other hand this theses has hypothesised the presence of a cultural barrier that ran through the Alpine chain dividing it into an eastern and western zone (Chapter 12). This division appeared in the distribution of different copper groups, both in the Copper Age (Chapter 9) and in the Early Bronze Age (Chapter 10). It is evident also in the distribution of bronze artefacts (Chapter 11). Although this division comes here from a fresh analysis of the metal data, it mirrors well-known cultural boundaries and contact networks. In the north Circum-Alpine region this division corresponds well to the boundary between the Early Bronze Age Rhône Culture in the west and the Blechkreis Culture in the east (Merkl, 2011, fig. 4.8).

Even more interesting is the fact that this division continues to the south of the Alps, as explained in Perucchetti *et al.* (2015). In contrast with the river system model for the north of the Alps, it cuts the River Po, which is navigable, into two. This may mark the expression of cultural differences that have a number of parallels in the prehistory of the Po Valley. In 1989, Peroni stated: "It is like, indifferent to the Alpine barrier, and more important than it, a cultural barrier [...] cut northern Italy transversely from north to south." (Peroni 1989, 364–365). He was referring to the Middle and Recent Bronze Age, and in particular to metallurgy, from a typological perspective. Since then, the idea of a cultural barrier has appeared constantly in Italian studies from the Middle Bronze Age onwards.

De Marinis, also looking at the typology of metal artefacts – in particular of the Middle and Final Bronze Age, mentions the barrier that divides northern Italy from north-western to central eastern Italy, and states that both of these parts "gravitate one to north-west and the other to north-east" (de Marinis 2006a, 1311). Gambari also highlighted the importance of transalpine contacts, in particular from the Middle Bronze Age, and, conversely, the low level of interactions between the eastern and the western part of the Po valley (Gambari 1998, 66–71). In 2008, Baioni noted that between the Adda and Oglio rivers there was a cultural barrier from the Middle Bronze Age onwards, with "proto-Golasecca" Culture in the Bronze Age and "Golasecca" Culture in the Final Bronze Age on the western part, and "Polada" Culture in the Bronze Age of the eastern part. This division endured for centuries, so that it was even a boundary between two different Augustan regions in the Roman period, but it has never been the subject of serious research (Baioni 2008, 63–64). It may also reflect more ancient networks or cultural areas, dating to the Neolithic. The zone that includes the Rhône basin, Piedmont and Liguria was indeed the location of the Neolithic network of polished stone axes (Barfield & Broglio 1966, 63–65; Bouard 1993; Bouard & Fedele 1993; Venturino Gambari *et al.* 1996). Contacts between Piedmont and France and Switzerland were hypothesized also in the Copper Age, witnessed by exchanges of primary resources, such as quartz, and influences in pottery decoration and shape (Venturino Gambari 1998, 52–56). There is therefore evidence for a cultural divide both before and after the Early Bronze Age. The analysis of metal distribution presented here seems to cover this time-gap and suggests a long history for a cultural division across the Po.

In the model proposed by Krause (2003) the movement of metal was controlled by elites and occurred by long distance transport of objects considered as ingots, typically found in hoards (Figure 109). Here we define a hoard as a group of concealed metal objects, typically occurring in pits. In this context, an ingot is taken to be a large mass of raw material from which objects can be manufactured in a secondary production process. As a matter of fact, the real function or meaning of a hoard is still not clear. What is clear is that their distribution is not coincident with the distribution of the settlements, neither on a large scale (Wengrow 2011, 138) nor on a small scale (Barfield 1994, 132). They are usually interpreted as stock-in-trade of merchants or itinerant smiths (Clarke 1968, 264), or as a ritual sacrifice of goods (Bradley 2013; Wengrow 2011, 141).

In the Early Bronze Age the hoards are very common in the Circum-Alpine region, in particular in the northeast, and they are linked to the Straubinger culture. During the first phase of the Early Bronze Age, in this zone hoards are mainly made up of several dozens of *Ösenringe,* usually with the composition of Group 12, and in a second phase *Ösenringe* are substituted by *Spangenbarren*, made of both Group 12 and Group 16. *Ösenringe* and *Spangenbarren* are, often uncritically considered as ingots by archaeologists (see, among others, Carancini 1996; Heyd 2013; Jirán *et al.* 2013). In the north-west of the Alps and in northern Italy some axes in hoards have also been considered as ingots, such as the Salez type axes, made of copper of Group 16, and the Neyruz type axes, made of copper Group 1 (de Marinis 2006a, 1289–1295; Krause 2003). Another type of axes that are occasionally considered as ingots are unfinished axes found in hoards of fewer pieces of metal (typically about 10 axes), such as the case of Pieve Albignola or Nieder in the Early Bronze Age 2b. (de Marinis 2006a; Pearce 1998, 2007).

This thesis has shown patterns of metal movement in the Copper Age and Early Bronze Age that suggest a network of exchange that was probably made of short distance exchanges between close-by communities. Chapters 9 and 10 have discussed the interpretation of what we have termed the 'halo effect', which shows decreasing ubiquity and reduced arsenic levels with distance from the supposed centres of production. The existence of such a 'halo zone' is an indication of the movement of metal through short steps of exchange rather than long trade-ways through some preferential routes. Metal objects, as they moved, were subjected to cycles of re-melting and remixing to conform to local ideas of typology. Especially in the Bronze Age there are clear patterns of recycling from both ubiquity analysis and the spatial distribution of arsenic (Chapter 10). The importance of a local dense network may be indicated by the fact that the location of settlements is within visibility range (Primas & Schmid-Sikimić 1997).

This is also an hint supporting this interpretation which goes against the idea, based on Gordon Childe (1957), of the specialist metallurgist as a free agent moving between different communities and marketing their skills on a commercial basis. This perception of the metallurgist constantly re-occurs in the debates of archaeometallurgy (e.g. Charles (1985) and, more recently, Heyd (2013), who presents the metallurgist as a specialised figure forming part of a complex, hierarchical society). This idea has partly been contested by Budd and Taylor, who proposed the idea of metal production as part of a magical and social ritual (1995), but still involving itinerant specialist. From this work, it seems more likely that each community was recycling and reshaping metal locally according to its own ideas of what shape a metal object should have to be acceptable.

13.3 Some observations on hoards and ingots

Recycling, remixing and reshaping also pose some questions about the nature of hoards and what are considered as ingots. In this paragraph first the role of

Ösenringe and *Spangenbrarren* is discussed, and then a contribution to the debate on the function of axes in hoards follows.

13.3.1 *Ösenringe* and *Spangenbrarren*

In the Straubinger culture *Ösenringe* are not only found in hoards, but also in burials (Section 7.2.4). Using logarithmic As/Sb bivariate diagrams, Krause claims that the ones in the hoards are a very homogeneous group, whose composition is different from the ones found in burials. Consequently, Krause distinguishes two categories of *Ösenringe,* according to the mode of deposition: ingots in hoards, and ornaments in burials (Krause 2003, 160–166). Additionally, Krause claims that the composition of the *Ösenringe* in hoards is, indeed, similar to other artefacts, such as socket hilted daggers. Hence, he concludes that they were actually used as ingots (Krause 2003, 188-189), in particular in a zone now corresponding to Austria.

The analysis proposed in this thesis demonstrates that the distribution and percentages of arsenic in the so-called ingots (*Ösenringe* in hoards and *Spangenbrarren*) indicates some peculiarities in this category of artefacts. The distribution of arsenic in axes, daggers and ornaments has peaks in the lower values of arsenic, whereas *Ösenringe* and *Spangenbrarren* have a distribution similar to a normal distribution, with a level of arsenic significantly higher than the other artefacts (Figure 62Figure 73Figure 80). This anomalous distribution of arsenic levels within ingots might indicate a standardized production model. It probably also indicates that the ingots are made with "fresh" material and are not recycled from other objects, because in that case there would have been a depletion of arsenic. This is in accordance with the concept of ingots as a "primary stock of metal". On the other hand, the "classical" notion of ingots sees them as being distributed over a long distance, where they are used to produce objects. Geostatistical analysis of the spatial distribution of arsenic in ingots showed geographical clustering, which indicates some form of recycling activity. This is not only discordant with the classical idea of ingots (Clarke 1968; de Marinis 2006a; Pearce 1998), but it does not even fit with the hypothesis of "ritual" deposition of objects, if this is considered as a one-off action made with fresh metal (Bradley 2013; Wengrow 2011).

The apparent contradiction may be in the modern perception that tends to separate the value of objects into two worlds: on one hand the economic, utilitarian perspective, on the other the "magical" and "ritual" world. It is possible that ingots may have values in both worlds. According to Wengrow and Bradley ingots were part of a metal production "sacrified" when that metal was produced. In Bradley's words "A specific selection of raw material had to be deposited in the ground when other artefacts were melted down" (Bradley 2013, 129). Here we have shown that some ingots were deposited hundreds of kilometres away from the likely ore source, and during this movement they appear to have been remelted (as evidence by the spatial decrease in arsenic levels). It is possible that the movement of metal happened in two simultaneous processes. There was a circulation of axes, daggers and ornaments, through short steps, that were continuously recycled (mainly remelted, but possibly also mixed together). At the same time there was also the circulation of metal through ingots that were *less* recycled. The production of new objects was mainly done using the first group of finished objects, but ingots were occasionally used, especially in the case of some particular categories of objects considered as "high status", such as metal-hilted daggers (Krause 2003, 188-189), or at a special time of the year. If an ingot was used there could have been a ritual re-melting and redeposition. A remixing of some "old" metal may also be hypothesized as part of the rite to make new metal. This mix would not be sufficient to change completely the chemical signature, but it would be enough to determine a reduction in the content of arsenic through re-melting. This may explain why the arsenic level of ingots decreases in respect to the levels in ores, but not so dramatically as the level of arsenic in the other objects. Moreover, in the transition from the first Bronze Age A1 to A2a the shape of ingots changes: from *Ösenringe* to *Spangenbrarren.* It might be reasonable to think that some *Ösenringe* were remelted to create the new "socially accepted" shape (Derevenski & Sørensen 2002), namely *Spangenbrarren.* But, once the metal is in circulation within other categories of objects, it has already been heavily remelted, remixed and manipulated.

13.3.2 The case of Salez and Neyruz type axes

Another interesting case study is that of Salez axes. The use of axes as ingots in southern Germany and Switzerland has been suggested by different authors (among others de Marinis (2006); Pearce (2007)). The analysis of Krause demonstrated that axes in the Early Bronze Age are chemically a very heterogeneous category, which is not in accordance with the idea of ingots. On the other hand, he identified a specific type of axes that had a very homogeneous composition: axes of Salez type. For this specific category Krause proposed the interpretation of axes as ingots (Krause 2003, 188-189).

Kienlin rejected the interpretation of Krause (Kienlin 2010, 181). Firstly, he noted that if it is true that the logarithmic diagram of As versus Sb (used by Krause) suggests homogeneity within the Salez type group of axes, the linear diagram of As vs. Sb highlights some differences. In particular the axes from hoards in the north of the Alps (Hildenwagen, Sennwald, Stockach, Ravensburg) and Torbole Casaglia in the south, which de Marinis previousy claimed to be a "metallurgist's" hoard (de Marinis 2006a), have a higher percentage of trace elements in comparison to similar axes found in settlements or burials. Secondly, metallographic analyses indicate another difference between axes in hoards and axes found outside hoards: the former show very few or no signs of cold work, whereas the latter have been cold worked. According to Kienlin, this cold work is proof that those axes are not ingots, because refining objects that would be used only as source of metal makes no sense. Kienlin also claims that the difference in the production of the two groups of axes is due to the awareness of the hardness of metal: axes in hoards are not cold-worked because the high level of trace elements already makes them hard enough to not necessitate any further cold work. However, Kienlin seems to contradict himself, because in the same article he claimed that the awareness of the amount of cold work necessary to obtain the maximum hardness according to the chemical composition is noticible only in the final phase of the Early Bronze Age (A2b).

The analysis of this thesis demonstrates that the composition of Salez type axes in hoards has some similarity with that of *Ösenringe* and *Spangenbarren,* even though they belong to different compositional groups (Group 12 for *Ösenringe* and Group 16 for Salez type axes). In fact, as with *Ösenringe* and *Spangenbarren*, the distribution of arsenic in Salez type axes has a peak in arsenic at about 2.5% and the hypothesis that it also has a normal distribution cannot be rejected (Shapiro Wilk test = 0.099). As noted above, such high values of arsenic and a distribution that could be normal are hints of objects made of “fresh” metal that was not recycled, as with *Ösenringe* and *Spangenbarren*.

The observation of Kienlin about the significance of the use of a linear plot of As vs. Sb to show the different composition of axes in hoards, settlements and burials is important, but it does not explain why axes in hoards should be chemically different from the same axes from other contexts. However, this thesis has suggested that axes in hoards are chemically similar to *Ösenringe* and *Spangenbarren*, which leads to the conclusion that they were, indeed, ingots, in the sense proposed in this thesis. They are objects made with “fresh”, not recycled, material and they are given a shape that is socially accepted. They experienced a lower number of recycles than the other objects “in circulation”, and they are probably part of a ritual deposition of metal. In contrast, the axes not in hoards were part of a more general circulation of metal, and are therefore chemically different from their hoard counterparts.

In the Circum-Alpine region there was another type of axe that also may have been considered as an ingot, namely the Neyruz type. In this case, the metal used to make the artefacts was clean copper, so it is not possible to produce arsenic spatial distribution maps, or to test whether they are made from primary metal, as was possible with Salez type axes. It has to be noted that the amount of cold work applied to the Neyruz type axes was higher (Kienlin *et al.* 2006). Nevertheless, this is not necessarily in contradiction with the hypothesis proposed here of fresh metal that was given an acceptable shape to be ritually deposited in the ground.

13.3.3 Other cases of hoards

The last category of hoards taken into consideration is the one made up of objects whose composition does not fit the typical composition of the objects in that zone. This is the case of the so called "metallurgist hoards" made of unfinished axes. Pieve Albignola in particular has been repeatedly claimed to be a metallurgist's hoard (Berzero *et al.* 1991; de Marinis 2006; Pearce 2007). The analysis and interpretation of the Pieve Albignola by Pearce is specifically explained in Section 2.7.2. Here it is recalled that Pearce used this hoard to create the concept of "*aes formatum*": "ingots that acquired their value by being visibly sufficient metal for the manufacture of a given artefact" (Pearce 1998, 58). According to this author, metal in prehistory was exchanged through ingots, whose shape indicated that there was an acceptable quantity of metal. *Contra*

Pearce, Kienlin pointed out that only a few hoards have unfinished axes, with flashing, that might be "ingot-axes": for example only one hoard with this characteristic has been found in northern Italy. This is not the pattern that one might have expected if this was indeed the usual, typical way to exchange metal, in a situation of established trade-routes with the axes forming a precursory currency (Kienlin 2010, 181). Moreover, he claimed that the picture drawn by Pearce seemed to be "a transfer of modern economical concepts to prehistoric societies" (Kienlin 2010, 175).

One observation that this thesis can add to this discussion is that Pieve Albignola is one of those cases of a hoard made of objects with a different composition from that of the surrounding objects. In the case of Pieve Albignola, the axes are made of Copper Group 5, namely copper with only nickel as trace element. In the hoard some finished and some unfinished axes are present. But both of them have a shape that is local. Conversely, the kind of composition of these axes is typical of Switzerland and which have been repeatedly claimed to be the result of local Swiss production. In northern Italy there are very few other objects contemporary to the Pieve Albignola hoard made of Group 5 copper, whereas more examples are present in Switzerland. This suggests that these axes may have come from Swirtzerland.

There are other cases similar to the Pieve Albignola hoard in the Early Bronze Age. The hoard of Nieder, in Osterwitz, found in Austria and dated to the Early Bronze Age 2b, is a very similar example because it is made of unfinished axes whose composition is typical of the western zone (Group 1, clean copper). Other examples may be found in the Early Bronze Age 1 in the north-eastern hoards of Sirndorf, Stockerau, Bergen, Eiselfing that have some *Ösenringe* made of Group 1, also typical of the western zone. Similarly, in the Early Bronze Age 2a there are some *Spangenbarren* made of Group 1 copper, such as in hoards Wimmern, Waging, and Krumbach. The hoard Wolnzach, in eastern Austria, dated Early Bronze Age 2a, has a content made of axes of Saxon type (a local type) made of Group 16 copper. In this case the peculiarity is also due to the fact that in this zone hoards usually were not made of axes: hoards composed of axes is a typical western habit. In northern Italy, Group 1 has been found in the hoards Remedello Sotto and Serravalle, both made of axes of local typology.

All the examples above indicate an occasional movement of metal over a long distance, similar to what happened in the Copper Age with the Bell Beaker objects (see Section 9.6). This could lead to the idea of a continuation of the figure of the "single traveller" or of travelling groups (echoing the views of Budd and Taylor (1995)) and of the concept of "travel as a rite of passage" (Sheridan 2014) hypothesized for the Copper Age, but it may also indicate the exchange of some metal with a different colour as a precious exchange of goods. The exchange of some metal artefacts as status-symbol through different cultures of the Circum-Alpine region has been recognised by archaeologists (e.g. de Marinis (2006a) about the circulation of daggers of Bois type). Here it could be suggested that some metal could be exchanged and perceived as particularly prestigious even if it was not in a finished form. In any case, it is clear that the receiving culture does not consider these objects as "ingots", or "*aes formatum*", in the sense of raw material to produce objects, because the assemblages have a composition different from that of the surrounding objects. This strengthens the idea of "ingots" or "objects in hoards" as stored goods, only occasionally used.

To conclude, from the evidence of this thesis the statement of long-distance movement of metal through ingots is only partially supported. Other forms of movement of metal, particularly short distance exchange, are also shown to be important. In fact, not only is there evidence for recycling activity in the other kinds of artefacts, but also that even ingots were subjected to some level of manipulation. Bradley's (2013) interpretation of hoards as a ritual deposition linked to metal production seems plausible in this context. Hoarding might be imagined as a ritual recycling and re-melting of "ingots" (*Ösenringe*, *Spangenbarren*, some types of axes) or a previous mixing of new material with "old" material as part of the rite to make new metal. This mixing is not sufficient to change completely the chemical signature, but it would be enough to cause a reduction in the content of arsenic.

14 Conclusions and Recommendations for Further work

The stated aim of this thesis was to reconsider the archaeometallurgy of the prehistoric Alps in the light of new concepts, perceptions, and ideas. Chapter 3 explained some theoretical criticisms of the approach taken in previous archaeometrical studies and illustrated a new model, the Flow Model. In particular, this thesis represents an attempt to include space and the environment in the narrative of the Flow Model, with the use of GIS.

A significant issue with traditional methodologies is that they can – at their best - provide "static snapshots" of the chemical composition of objects and the distribution of those in space and time. The Otto and Witter and SAM projects were explicitly attempts to identify the provenance of metal and there was the claim of a direct link between each derived chemical cluster and the metal ore source. This approach was quickly criticized (Slater & Charles 1970) and limitations were soon admitted (Ottaway (1982) declared the failure of some provenance methodologies). Nowadays authors are much more cautious on the linkage between chemical clusters and ores. It is recognised that the chemistry of metal objects can be the result of recycling, or different working processes, but still there is the tendency to ignore these problems as "background noise" and to continue to treat chemical clusters as independent groups of metal (Krause 2003, 145). This static approach is reflected also by the geographical representation of chemical clusters. With simple distribution maps such as those used in SAM or by Krause (Section 4.1) it is possible to identify where a specific kind of metal was present. Some speculation about contacts can be made (Krause 2003) but not much can be said about the direction of movement of the metal and how the metal moved. Moreover, the big missing element in these maps is the real 3D world.

The Flow Model represents an alternative, holistic approach to the study of metal that is not limited to questions about the provenance of metal or the technology used to produce metal. It argues that how metal was used and perceived in society also had effects in the chemistry of the objects, and that these effects may be detected by analysing a large database of chemical analyses. The basis of the Flow Model is that if metal was used and recycled its chemistry would change, and that this change is visible in space and time. The use of ubiquity analysis (Bray *et al.* 2006) in GIS, the use of key trace elements to undertake geostatistical analysis, and the study of the variation of arsenic in time and space can help to understand the perception and use of metal in society. Moreover GIS may also be used to include the topography into the narrative of the use of metal.

This thesis has demonstrated that the use of GIS in archaeometallurgy is extremely promising. Ubiquity analysis and geostatistical analysis are two independent analyses that, when combined, allow the pinpointing of possible centres of primary metal production, even when the exploited sources are not yet known.

It is true that in some cases the geostatistical analysis simply highlights those zones where specific categories of artefacts have a higher percentage of arsenic, and might therefore be seen simply as a more complicated way of mapping the distribution of those categories of high-arsenic objects. So, for example, in the Copper Age geostatistical analysis of arsenical copper (Group 2) indicates the zones where there were more daggers and halberds (which are on average higher in arsenic), and in the Early Bronze Age zones where *Ösenringe* and *Spangenbarren* (also high in arsenic) were more common. This is why it is important to repeat the analysis separately for each category of object and verify if the results for each category are similar to the overall pattern. Clearly, if one category dominates the assemblage, then the results from that category will 'match' the overall pattern, but what is important here is to check if the patterns for the minor categories follow the same pattern. If they do, then we can assume that there is a common flow of metal through all object categories. If they do not, then different object categories are being treated differently. The distribution of objects containing arsenical copper (Group 2) in the Copper Age, for example, shows differences between the spatial patterning of daggers and axes (Section 9.1). Axes have been interpreted as possibly part of a flow of metal from the west to the east, whereas daggers show the local intentionality of producing daggers with very high levels of arsenic.

In the Alps there are a good number of mines that could have possibly been exploited in prehistoric time and for some of them evidence of exploitation is available (see Section 5.2). This information in the literature is generally in agreement with the independent analyses carried out in this thesis. But the potentiality of this method is that it can also be applied to areas where less information is available about the possible mines. Moreover, this methodology can detect when one of the Copper Groups (defined as in Section 3.2.2) includes two or more flows of metal (e.g. Group 16 in the Early Bronze Age 2a, see Section 10.4). In this case, even though we initially characterise this metal as Group 16, by mapping and undertaking spatial analysis we can see that there is more than one source represented. This is a very clear example of the difference between our "open" methodology and the methodology proposed by previous authors, where Copper Groups (or in their terminology, clusters) are seen as the *result* of the analysis and considered to be *closed* and *fixed* (see Section 3.2). Conversely, we see our Groups as mutable and as the starting point of further analysis.

To obtain this information a large number of compositional analyses are required. This, in Europe, is already provided mainly by the works of SAM and Otto and Witter, plus a number of smaller, local projects (for the Circum-Alpine region see Chapter 2). The depth of this previous work makes it possible to obtain information without the necessity for new analysis on objects or on possible ore sources. This is in strong contrast to other authors, who claim that no further progress is possible without more data, especially on ore sources (for example Garagnani *et al.* 1997; Ottaway 1982; Salzani 2011). New analysis, such as lead isotope analysis would certainly be useful, especially in assessing the degree of mixing which might be taking place (Pollard and Bray in press), as has been done by Cattin (2009) on Copper Age artefacts from Switzerland. Lead isotope analyses would be particularly important, as mentioned in Chapter 9, to help to understand whether there was intentional alloying of arsenic in the northern Italian Copper Age. Unfortunately, as yet lead isotope data for the Circum-Alpine region are sporadic: apart from the above-mentioned work of

Cattin (which presents about 100 sets of Pb isotope data, but which are not accompanied by chemical analysis), ten other objects have been analysed by Cattin (2011) and 12 from the Garda region by Pernicka (2011). The last two sources have been included in the database (Appendix II) since they have accompanying chemical data. When more data becomes available it can however be easily incorporated into the framework established here. This is, undoubtedly, a further advantage of this methodology.

The Flow Model has demonstrated that large databases of analysis are still, when used judiciously, a precious source of information, although the analysis are frequently old and some detailed information about the objects is often lacking. This also contradicts the views of some other authors (such as Cattin 2011 or Salzani 2011) who decided to use only recent data. This is an understandable and laudable position, but this does not as yet provide enough data to carry out large-scale analyses.

The combination of the Flow Model with GIS technology allows also a more detailed understanding of how metal moved. In this thesis it has been suggested that metal mainly moved through short steps and there was probably recycling and remixing of material. This implies short contacts and exchanges of material through adjacent communities, rather than long-distance trades of raw material or finished objects. But, the possibility of using different scales of analysis allowed us to both understand the big patterns of flows of metal and to pinpoint specific cases of metal with a composition that differs from the surrounding objects. This combination of levels of analysis has often been missed by previous authors. For example, Merkl (2011) was not able to recognise that Bell Beaker metal had some specific patterns (see Section 9.6.4).

The use of GIS has also allowed for an evaluation of the impact of topographical features on the movement of metal. From the evidence of this thesis, topographic elements were not a critical factor: the Alps were not a barrier to movement. It is true that there was a positive correlation between different copper groups and different river basin, so that it is reasonable to think that rivers were used as a means of transport. But there was actually a cultural barrier that divided the Alps into an eastern and western zone that cut across even navigable rivers, such as the Po. Cost surface analysis better clarifies that the distribution of metal was not determined by the “accessibility” of different geographical regions.

This thesis’ application of GIS to a large-scale archaeometrical study, which is not limited to just producing distribution maps of objects, is innovative and GIS can be demonstrated to be a valuable tool to understand metal production, exchange and use in the Circum-Alpine Copper Age and Early Bronze Age.

14.1 Suggestions for Further Work

The systematic use of novel GIS tools, while extremely useful, also poses a series of new theoretical and practical problems. As mentioned in Chapter 4 there are three main issues in the use of GIS: representation of time, the MAUP problem and the risk of geographical determinism. The theoretical framework used in this thesis tried to avoid determinism as much as possible (see Chapter 12). The two other aspects have a similar background issue: the necessity of a compromise between precision and the scale of the analysis. Within the database there are some data that have not been used because their precision was less than the time or space scale of this research (e.g. objects generically dated "second millennium B.C."). Some other data were considered as useful for some parts of the analysis but not for others. For example a generic chronological attribution to the "Early Bronze Age" was useful to produce the tin distribution shown in Figure 94, but not for the analysis of the depletion of arsenic.

The MAUP problem has been empirically solved by exploiting the flexibility of the program (ArcGIS) and deciding which unit area would be most useful for the analysis (in this case, using ubiquity analysis). More sophisticated solutions could be applied, which take into account the uneven distribution of objects in space, and use different areal units for different regions. This would require further development with python scripts.

As regards the time dimension a further issue is raised by its representation in a map. In this work time is given as a series of maps, each one representing a specific time period. Within each single map, the progression of time can be seen in the recycling patterns. For example, spatial clusters with a low percentage of arsenic indicate a zone with metal that has been in circulation for a long period, and that has undergone several cycles of remelting. But it may be useful to develop a proper tGIS (time-Geographical Information Systems) by combining GIS with Bayesian modelled radiocarbon dates (where available) (Green 2011).

Of course, this means that the homogeneous availability of radiocarbon dates in the entire zone is required, which is currently far from the reality in the Circum-Alpine region.

In fact, a very practical problem encountered in this work is the use of different chronological framework in different regions of the Alps. This thesis has attempted to take into consideration these differences and the results have been discussed in the light of different chronologies. It has been demonstrated that the patterns highlighted here were so solid that they emerged even using different chronological systems. Nevertheless, in order to properly understand the importance of metal in different chronological phases and cultural groups, there is the need to create a new synthetic homogeneous chronological framework for the entire Circum-Alpine region. This should transgress the limits of the current countries and schools of research, and where possible be based on increasing the number of absolute dates, not only on samples from the context but also directly from organics adhering to the metal objects, following the British example (Needham *et al.* 1997).

Another technical issue regarding the geostatistical analyses is that they are currently parametric, which might not be statistically appropriate. In section 8.2 it has been explained that not all data have a normal distribution. In some cases a log(10) transformation has been necessary to produce quasi-normal data, but this solution is not ideal because the data themselves may not actually have a log-normal distribution. A better solution would be to develop non-parametric tests with the use of python, so that instead of the mean, the median can be used.

Much other information about metal production can be obtained with metallography, but traditionally such evidence is visual. If the results can be "quantified", following the example of Northover (1980), they could be more easily used in a numerical database. For the Circum-Alpine region some metallographic descriptions are available (see Appendix II), but they are as yet too few to undertake proper statistical analysis. Less than 100 artefacts have been analysed, mainly from the north Circum-Alpine region, from the works of Kienlin (2006) and Budd (1991). From the north of Italy there are some sporadic data from Artioli (2007). But it has to be noted that Artioli used neutron diffraction instead of optical microscopy and the comparability of these two techniques has been questioned (Dolfini 2015).

It would also be ultimately important to integrate this metallurgical database with other databases on other materials or with data on human mobility (stable isotopes). In central Europe some skeletons from what are considered as "Bell Beakers burials" have been analysed to determine the Sr isotope ratios that can give some hints about the mobility of people (Grupe *et al.* 1997; Price *et al.* 2004). It would be desirable to have more data about what are considered "local people" on both the northern and the southern zones of the Alps to speculate about the range of transalpine movement of people and the range of movement of goods through short step exchanges. This would help to distinguish between the movement of people and ideas.

To conclude, it is important to emphasise the potential universality of the methodology used here. What is important to underline is that the methodology proposed has an open grouping system that does not require brand new statistical analysis for each region or period of study, unlike cluster analysis (see Section 3.4.1). It is also important to stress the importance of including geographical and topographical analysis in the archaeometallurgical study to properly understand the movement of metal in the real world. Some further work can be done to adapt this method from the Circum-Alpine region to some other regions where the searoutes should be included. In any case, it is important not to indulge in the temptation of attributing human behaviour to being a mere response to the environment.

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Appendix IV: Code "Normalise"

```
#Name: normalise.py
#Description: Normalise percentage after subtracting tin
#Author: Laura Perucchetti

#Import arcpy module
import arcpy

#Script arguments
Artefacts_normalize = arcpy.GetParameterAsText(0)
if Artefacts_normalize == '#' or not Artefacts_normalize:
Artefacts_normalize = "Artefacts_normalize" # provide a default value if
unspecified

FeN_calculated = arcpy.GetParameterAsText(1)
if FeN_calculated == '#' or not FeN_calculated:
FeN_calculated = "Artefacts_normalize" # provide a default value if unspecified

#Local variables:
Cu1_added = Artefacts_normalize
Cu1_calculated = Cu1_added
TotN_added = Cu1_calculated
TotN_calculated = TotN_added
Cu1N_added = TotN_calculated
Cu1N_calculated = Cu1N_added
PbN_added = Cu1N_calculated
PbN_calculated = PbN_added
AsN_added = PbN_calculated
AsN_calculated = AsN_added
SbN_added = AsN_calculated
SbN_calculated = SbN_added
AgN_added = SbN_calculated
Ag_calculated = AgN_added
NiN_added = Ag_calculated
NiN_calculated = NiN_added
BiN_added = NiN_calculated
BiN_calculated = BiN_added
AuN_added = BiN_calculated
AuN_calculated = AuN_added
ZnN_added = AuN_calculated
```

```
ZnN_calculated = ZnN_added
CoN_added = ZnN_calculated
CoN_calculated = CoN_added
FeN_added = CoN_calculated

#This adds a field "Cu1"
arcpy.AddField_management(Artefacts_normalize, "Cu1", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This sets a value for Cu1. If Cu has a value copies that value, otherwise it
calculates Cu1 subtracting from 100 the total of the values of the other
elements
arcpy.CalculateField_management(Cu1_added, "Cu1", "value( !Cu! , !Sn! , !Pb! ,
!Arsenic! , !Sb!, !Ag!, !Ni! , !Bi! , !Au! , !Zn! , !Co! , !Fe! )", "PYTHON_9.3", "def
value( Cu, Sn, Pb, Arsenic, Sb, Ag, Ni, Bi, Au, Zn, Co, Fe ):\\n if Cu>=0:\\n return
Cu\\n else:\\n return 100- ( Sn + Pb + Arsenic + Sb + Ag + Ni + Bi + Au + Zn +
Co + Fe)")

#This adds a field TotN
arcpy.AddField_management(Cu1_calculated, "TotN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates TotN as sum of the values of all the elements but Sn (Cu taken
form Cu1 instead of Cu)
arcpy.CalculateField_management(TotN_added, "TotN", "[Pb] + [Arsenic] + [Sb]
+ [Ag] + [Ni] + [Bi] + [Au] + [Zn] + [Co] + [Fe] + [Cu1]", "VB", "")

#This adds Cu1N as Normalization of Cu1 after the subtraction of tin
arcpy.AddField_management(TotN_calculated, "Cu1N", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates Cu1N as normalization of Cu1 after the subtraction of tin
arcpy.CalculateField_management(Cu1N_added, "Cu1N", "[Cu1] * 100 /
[TotN]", "VB", "")

#This adds PbN
arcpy.AddField_management(Cu1N_calculated, "PbN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates PbN
arcpy.CalculateField_management(PbN_added, "PbN", "[Pb] * 100 / [TotN]",
```

```
"VB", "")

#This adds AsN_
arcpy.AddField_management(PbN_calculated, "AsN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates AsN_
arcpy.CalculateField_management(AsN_added, "AsN", "[Arsenic] * 100 /
[TotN]", "VB", "")

#This adds SbN
arcpy.AddField_management(AsN_calculated, "SbN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates SbN
arcpy.CalculateField_management(SbN_added, "SbN", "[Sb] * 100 / [TotN]",
"VB", "")

#This adds AgN
arcpy.AddField_management(SbN_calculated, "AgN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates AgN
arcpy.CalculateField_management(AgN_added, "AgN", "[Ag] * 100 / [TotN]",
"VB", "")

#This adds NiN
arcpy.AddField_management(Ag_calculated, "NiN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates NiN
arcpy.CalculateField_management(NiN_added, "NiN", "[Ni] * 100 / [TotN]",
"VB", "")

#This adds BiN
arcpy.AddField_management(NiN_calculated, "BiN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates BiN
arcpy.CalculateField_management(BiN_added, "BiN", "[Bi] * 100 / [TotN]",
"VB", "")
```

```
#This adds AuN
arcpy.AddField_management(BiN_calculated, "AuN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates AuN
arcpy.CalculateField_management(AuN_added, "AuN", "[Au] * 100 / [TotN]",
"VB", "")

#This adds ZnN
arcpy.AddField_management(AuN_calculated, "ZnZ", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates ZnN
arcpy.CalculateField_management(ZnN_added, "ZnZ", "[Zn] * 100 / [TotN]",
"VB", "")

#This adds CoN
arcpy.AddField_management(ZnN_calculated, "CoN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates CoN
arcpy.CalculateField_management(CoN_added, "CoN", "[Co] * 100 / [TotN]",
"VB", "")

#This adds FeN
arcpy.AddField_management(CoN_calculated, "FeN", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

#This calculates FeN
arcpy.CalculateField_management(FeN_added, "FeN", "[Fe] * 100 / [TotN]",
"VB", "")
```

Appendix V: Code "Grouping"

```
#Name: Grouping.py
#Description: It creates a series of maps selecting the objects according to their
compositional groups and dates
#Author: Laura Perucchetti

#Import System Modules
import shutil
import os
import arcpy
from arcpy import env
env.overwriteOutput = 1 #1 I overwrite 0 I don't overwrite


#It sets variables for input dataset
file = arcpy.GetParameterAsText(0)

#Set variables for input attributes
limitAs = arcpy.GetParameter(1)
limitSb = arcpy.GetParameter(2)
limitAg = arcpy.GetParameter(3)
limitNi = arcpy.GetParameter(4)


#This creates four fields with the thresholds for As, Sb, Ag and Ni
arcpy.AddField_management(file, "limitAs", "FLOAT")
arcpy.CalculateField_management(file, "limitAs", limitAs, "VB")

arcpy.AddField_management(file, 'limitSb', "FLOAT")
arcpy.CalculateField_management(file, "limitSb", limitSb, "VB")

arcpy.AddField_management(file, 'limitAg', "FLOAT")
arcpy.CalculateField_management(file, "limitAg", limitAg, "VB")

arcpy.AddField_management(file, 'limitNi', "FLOAT")
arcpy.CalculateField_management(file, "limitNi", limitNi, "VB")

#IThis adds a new field that will be populated with the compositional group to
which each object belongs.
arcpy.AddField_management(file, 'group_', "TEXT", 5, "", "", "", "", "")

#This codes "expression" that is used to calculate the field 'group_'
expression = 'value (!AsN!, !SbN!, !AgN!, !NiN!, !limitAs!, !limitSb!, !limitAg!,
!limitNi!)'
codeblock = """def value(AsN,SbN,AgN,NiN, limitAs, limitSb, limitAg, limitNi):
```

```
if AsN < limitAs and SbN < limitSb and AgN < limitAg and NiN < limitNi:
return 'NNNN'
if AsN < limitAs and SbN < limitSb and AgN < limitAg and NiN >= limitNi:
return "NNNY"
if AsN < limitAs and SbN < limitSb and AgN >= limitAg and NiN < limitNi:
return "NNYN"
if AsN < limitAs and SbN < limitSb and AgN >= limitAg and NiN >= limitNi:
return "NNYY"
if AsN < limitAs and SbN >= limitSb and AgN < limitAg and NiN < limitNi:
return "NYNN"
if AsN < limitAs and SbN >= limitSb and AgN < limitAg and NiN >= limitNi:
return "NYNY"
if AsN < limitAs and SbN >= limitSb and AgN >= limitAg and NiN < limitNi:
return "NYYN"
if AsN < limitAs and SbN >= limitSb and AgN >= limitAg and NiN >= limitNi:
return "NYYY"
if AsN >= limitAs and SbN < limitSb and AgN < limitAg and NiN < limitNi:
return "YNNN"
if AsN >= limitAs and SbN < limitSb and AgN < limitAg and NiN >= limitNi:
return "YNNY"
if AsN >= limitAs and SbN < limitSb and AgN >= limitAg and NiN < limitNi:
return "YNYN"
if AsN >= limitAs and SbN < limitSb and AgN >= limitAg and NiN >= limitNi:
return "YNYY"
if AsN >= limitAs and SbN >= limitSb and AgN < limitAg and NiN < limitNi:
return "YYNN"
if AsN >= limitAs and SbN >= limitSb and AgN < limitAg and NiN >= limitNi:
return "YYNY"
if AsN >= limitAs and SbN >= limitSb and AgN >= limitAg and NiN < limitNi:
return "YYYN"
if AsN >= limitAs and SbN >= limitSb and AgN >= limitAg and NiN >= limitNi:
return "YYYY"
else:
return 'WRONG'"""


#This calculates the field "Group" according to the code called "expression"
arcpy.CalculateField_management(file, "group_", expression, "PYTHON_9.3",
codeblock)

#This adds a new field that will have the information about the compositional
group and the age to which the object belongs
arcpy.AddField_management(file, 'age_group', "TEXT", 10, "", "", "", "", "")

#This codes "expression1" that is used to calculate the field 'group_'
expression1 = 'value1 (!Age_1! , !group_!)'
codeblock = """def value1(Age_1,group_):
if (Age_1 == "P1" ) and (group_ == "NNNN" ) :
```

```
return "P1_NNNN"
if (Age_1 == "P1" ) and (group_ == "NNNY" ) :
return "P1_NNNY"
if (Age_1 == "P1" ) and (group_ == "NNYN" ) :
return "P1_NNYN"
if (Age_1 == "P1" ) and (group_ == "NNYY" ) :
return "P1_NNYY"
if (Age_1 == "P1" ) and (group_ == "NYNN" ) :
return "P1_NYNN"
if (Age_1 == "P1" ) and (group_ == "NYNY" ) :
return "P1_NYNY"
if (Age_1 == "P1" ) and (group_ == "NYYN" ) :
return "P1_NYYN"
if (Age_1 == "P1" ) and (group_ == "NYYY" ) :
return "P1_NYYY"
if (Age_1 == "P1" ) and (group_ == "YNNN" ) :
return "P1_YNNN"
if (Age_1 == "P1" ) and (group_ == "YNNY" ) :
return "P1_YNNY"
if (Age_1 == "P1" ) and (group_ == "YNYN" ) :
return "P1_YNYN"
if (Age_1 == "P1" ) and (group_ == "YNYY" ) :
return "P1_YNYY"
if (Age_1 == "P1" ) and (group_ == "YYNN" ) :
return "P1_YYNN"
if (Age_1 == "P1" ) and (group_ == "YYNY" ) :
return "P1_YYNY"
if (Age_1 == "P1" ) and (group_ == "YYYN" ) :
return "P1_YYYN"
if (Age_1 == "P1" ) and (group_ == "YYYY" ) :
return "P1_YYYY"

if (Age_1 == "P2" ) and (group_ == "NNNN" ) :
return "P2_NNNN"
if (Age_1 == "P2" ) and (group_ == "NNNY" ) :
return "P2_NNNY"
if (Age_1 == "P2" ) and (group_ == "NNYN" ) :
return "P2_NNYN"
if (Age_1 == "P2" ) and (group_ == "NNYY" ) :
return "P2_NNYY"
if (Age_1 == "P2" ) and (group_ == "NYNN" ) :
return "P2_NYNN"
if (Age_1 == "P2" ) and (group_ == "NYNY" ) :
return "P2_NYNY"
if (Age_1 == "P2" ) and (group_ == "NYYN" ) :
return "P2_NYYN"
if (Age_1 == "P2" ) and (group_ == "NYYY" ) :
return "P2_NYYY"
if (Age_1 == "P2" ) and (group_ == "YNNN" ) :
```

```
return "P2_YNNN"
if (Age_1 == "P2" ) and (group_ == "YNNY" ) :
return "P2_YNNY"
if (Age_1 == "P2" ) and (group_ == "YNYN" ) :
return "P2_YNYN"
if (Age_1 == "P2" ) and (group_ == "YNYY" ) :
return "P2_YNYY"
if (Age_1 == "P2" ) and (group_ == "YYNN" ) :
return "P2_YYNN"
if (Age_1 == "P2" ) and (group_ == "YYNY" ) :
return "P2_YYNY"
if (Age_1 == "P2" ) and (group_ == "YYYN" ) :
return "P2_YYYN"
if (Age_1 == "P2" ) and (group_ == "YYYY" ) :
return "P2_YYYY"

if (Age_1 == "P3" ) and (group_ == "NNNN" ) :
return "P3_NNNN"
if (Age_1 == "P3" ) and (group_ == "NNNY" ) :
return "P3_NNNY"
if (Age_1 == "P3" ) and (group_ == "NNYN" ) :
return "P3_NNYN"
if (Age_1 == "P3" ) and (group_ == "NNYY" ) :
return "P3_NNYY"
if (Age_1 == "P3" ) and (group_ == "NYNN" ) :
return "P3_NYNN"
if (Age_1 == "P3" ) and (group_ == "NYNY" ) :
return "P3_NYNY"
if (Age_1 == "P3" ) and (group_ == "NYYN" ) :
return "P3_NYYN"
if (Age_1 == "P3" ) and (group_ == "NYYY" ) :
return "P3_NYYY"
if (Age_1 == "P3" ) and (group_ == "YNNN" ) :
return "P3_YNNN"
if (Age_1 == "P3" ) and (group_ == "YNNY" ) :
return "P3_YNNY"
if (Age_1 == "P3" ) and (group_ == "YNYN" ) :
return "P3_YNYN"
if (Age_1 == "P3" ) and (group_ == "YNYY" ) :
return "P3_YNYY"
if (Age_1 == "P3" ) and (group_ == "YYNN" ) :
return "P3_YYNN"
if (Age_1 == "P3" ) and (group_ == "YYNY" ) :
return "P3_YYNY"
if (Age_1 == "P3" ) and (group_ == "YYYN" ) :
return "P3_YYYN"
if (Age_1 == "P3" ) and (group_ == "YYYY" ) :
return "P3_YYYY"
```

```
if (Age_1 == "P4" ) and (group_ == "NNNN" ) :
return "P4_NNNN"
if (Age_1 == "P4" ) and (group_ == "NNNY" ) :
return "P4_NNNY"
if (Age_1 == "P4" ) and (group_ == "NNYN" ) :
return "P4_NNYN"
if (Age_1 == "P4" ) and (group_ == "NNYY" ) :
return "P4_NNYY"
if (Age_1 == "P4" ) and (group_ == "NYNN" ) :
return "P4_NYNN"
if (Age_1 == "P4" ) and (group_ == "NYNY" ) :
return "P4_NYNY"
if (Age_1 == "P4" ) and (group_ == "NYYN" ) :
return "P4_NYYN"
if (Age_1 == "P4" ) and (group_ == "NYYY" ) :
return "P4_NYYY"
if (Age_1 == "P4" ) and (group_ == "YNNN" ) :
return "P4_YNNN"
if (Age_1 == "P4" ) and (group_ == "YNNY" ) :
return "P4_YNNY"
if (Age_1 == "P4" ) and (group_ == "YNYN" ) :
return "P4_YNYN"
if (Age_1 == "P4" ) and (group_ == "YNYY" ) :
return "P4_YNYY"
if (Age_1 == "P4" ) and (group_ == "YYNN" ) :
return "P4_YYNN"
if (Age_1 == "P4" ) and (group_ == "YYNY" ) :
return "P4_YYNY"
if (Age_1 == "P4" ) and (group_ == "YYYN" ) :
return "P4_YYYN"
if (Age_1 == "P4" ) and (group_ == "YYYY" ) :
return "P4_YYYY"
else:
return 'else'"""

#This populates the field "Group_Age" according to the code called
"expression1"
arcpy.CalculateField_management(file, "age_group", expression1,
"PYTHON_9.3", codeblock)

#It creates a series shape_files: one per each combination of age_group

#This set the variables that will be used to select
Group1 = 'NNNN'
Group2 = 'YNNN'
Group3 = 'NYNN'
Group4 = 'NNYN'
Group5 = 'NNNY'
Group6 = 'YYNN'
```

```
Group7 = 'NYYN'
Group8 = 'NNYY'
Group9 = 'YNYN'
Group10 = 'NYNY'
Group11 = 'YNNY'
Group12 = 'YYYN'
Group13 = 'NYYY'
Group14 = 'YYNY'
Group15 = 'YNYY'
Group16 = 'YYYY'
Age1 = 'P1'
Age2 = 'P2'
Age3 = 'P3'
Age4 = 'P4'
Age5 = 'P5'
Age6 = 'P6'
Age7 = 'P7'

#This creates a List of Variables according to the Age
AgeList = [Age1, Age2, Age3, Age4, Age5, Age6, Age7]

#This create a List of Variables according to the Compositional Group
GroupList = [Group1, Group2, Group3, Group4, Group5, Group6, Group7,
Group8, Group9, Group10, Group11, Group12, Group13, Group14, Group15,
Group16]

#This creates a new folder called Age
##os.makedirs (mypathAge)

#This sets the variable for output directory
mypath = arcpy.GetParameterAsText(5) + '/'

#This creates a series of folder in the directory of the output. There will be a
folder per each age in the list "AgeList"
for age in AgeList:
os.makedirs(mypath+age)


#This creates the list for output
AgeGroup = []

#This concatenates Age with Groups and puts the results in AgeGroup list
for age in AgeList:
for group in GroupList:
AgeGroup.append (age+ '_'+group)

#For each element in the AgeGroup list, a new shapefile is created.This selects
the records from the input file that have the agegroup field equal to the AgeList
variable, and it populates the new shapefile with them. The output will be in
```

```
the folder of the according Age
for x in AgeGroup:
if x.startswith(Age1):
arcpy.Select_analysis (file, mypath + Age1+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age2):
arcpy.Select_analysis (file, mypath + Age2+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age3):
arcpy.Select_analysis (file, mypath + Age3+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age4):
arcpy.Select_analysis (file, mypath + Age4+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age5):
arcpy.Select_analysis (file, mypath + Age5+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age6):
arcpy.Select_analysis (file, mypath + Age6+'/' + x,"age_group = '%s'" %x)
if x.startswith(Age7):
arcpy.Select_analysis (file, mypath + Age7+'/' + x,"age_group = '%s'" %x)


#Overwrite files with the same name
arcpy.env.overwriteOutput = True
```

Appendix VI: Code "Percentage P1"

```
#Name: Percentage P1.py
#Description: It creates a series of maps selecting the objects according to their
compositional groups and dates
#Author: Laura Perucchetti

#Import System Modules

import arcpy
import os

from arcpy import env

#1 overwrites 0 does not overwrite

env.overwriteOutput = 1

#Insert variables

Group1 = 'NNNN'
Group2 = 'YNNN'
Group3 = 'NYNN'
Group4 = 'NNYN'
Group5 = 'NNNY'
Group6 = 'YYNN'
Group7 = 'NYYN'
Group8 = 'NNYY'
Group9 = 'YNYN'
Group10 = 'NYNY'
Group11 = 'YNNY'
Group12 = 'YYYN'
Group13 = 'NYYY'
Group14 = 'YYNY'
Group15 = 'YNYY'
Group16 = 'YYYY'

Age1 = 'P1'
Age2 = 'P2'
Age3 = 'P3'
Age4 = 'P4'
Age5 = 'P5'
Age6 = 'P6'
Age7 = 'P7'

#List variables

#This creates a List of Variables from the Age
```

```
AgeList = [Age1, Age2, Age3, Age4, Age5, Age6, Age7]

#This creates a List of Variables from the Compositional Group
GroupList = [Group1, Group2, Group3, Group4, Group5, Group6, Group7,
Group8, Group9, Group10, Group11, Group12, Group13, Group14, Group15,
Group16]

#This creates a list for output
AgeGroup = []

#This concatenates Age with Groups and puts the results in the AgeGroup list
for group in GroupList:
AgeGroup.append (age+ '_'+group)

#This sets a variable for the input net that is going to be joined
target_features = arcpy.GetParameterAsText(0)

#This sets a variable for the output path
mypath = arcpy.GetParameterAsText(1)+'/'

#For each element of the AgeGroup list a new join with the input net is created
in a new folder (the output path)
##output = os.makedirs(mypath+'/fishnet/')
for x in AgeGroup:
join_features = x
out_feature_class = (mypath + x)
arcpy.SpatialJoin_analysis(target_features, join_features, out_feature_class)
##JOIN_ONE_TO_ONE}, {KEEP_ALL}, {CONTAINS})

#It creates a file copy of the input fishnet, called join_tot
arcpy.CopyFeatures_management(target_features, mypath+"join_tot.shp")
y= (mypath+"join_tot.shp")

#It joins join_tot with each result of the spatial join between the input map and
the input net
for x in AgeGroup:
join_features = x
arcpy.JoinField_management(y, "FID", mypath + x+ '.shp', "FID", ["Join_Count"])


#Overwrite files with the same name


arcpy.env.overwriteOutput = True


#For each group a new field is created, each with the name of the group. For
each compositional group the result of the count of the spatial join is copied in
the field with the corresponding group name
```

```
arcpy.AddField_management(y, 'Group1', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group1', '!Join_Count!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group2', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group2', '!Join_Cou_1!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group3', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group3', '!Join_Cou_2!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group4', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group4', '!Join_Cou_3!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group5', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group5', '!Join_Cou_4!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group6', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group6', '!Join_Cou_5!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group7', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group7', '!Join_Cou_6!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group8', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group8', '!Join_Cou_7!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group9', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group9', '!Join_Cou_8!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group10', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group10', '!Join_Cou_9!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group11', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group11', '!Join_Co_10!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group12', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group12', '!Join_Co_11!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group13', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group13', '!Join_Co_12!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group14', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group14', '!Join_Co_13!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group15', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group15', '!Join_Co_14!', "PYTHON_9.3")

arcpy.AddField_management(y, 'Group16', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'Group16', '!Join_Co_15!', "PYTHON_9.3")

#This deletes the original fields with the counts
```

```
arcpy.DeleteField_management(y, ["Join_Count", "Join_Cou_1", "Join_Cou_2",
"Join_Cou_3", "Join_Cou_4", "Join_Cou_5", "Join_Cou_6", "Join_Cou_7",
"Join_Cou_8", "Join_Cou_9", "Join_Co_10", "Join_Co_11", "Join_Co_12",
"Join_Co_13", "Join_Co_14", "Join_Co_15"])


#This adds a field called TOT
arcpy.AddField_management(y, 'TOT', "FLOAT", 10, "", "", "", "", "")
#Calculate the total number of object per each polygon of the net
arcpy.CalculateField_management( y, 'TOT',
'!Group1!+!Group2!+!Group3!+!Group4!+!Group5!+!Group6!+!Group7!+!Group
8!+!Group9!+!Group10!+!Group11!+!Group12!+!Group13!+!Group14!+!Group1
5!+!Group16!', "PYTHON_9.3")

#For each compositional group:

#It defines the expression used to calculate the percentage of presence of the
group in each polygon of the input net:

expression1 = 'prop (!TOT!, !Group1!)'
codeblock1 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""
#Add a field that will contain the information about the percentage
arcpy.AddField_management(y, 'P_Group1', "FLOAT", 10, "", "", "", "", "")
#Calculate the percentage according to the expression defined
arcpy.CalculateField_management( y, 'P_Group1',expression1, "PYTHON_9.3",
codeblock1)

expression2 = 'prop (!TOT!, !Group2!)'
codeblock2 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_Group2', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group2',expression2, "PYTHON_9.3",
codeblock2)

expression3 = 'prop (!TOT!, !Group3!)'
codeblock3 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""
```

```
arcpy.AddField_management(y, 'P_Group3', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group3',expression3, "PYTHON_9.3",
codeblock3)

expression4 = 'prop (!TOT!, !Group4!)'
codeblock4 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_Group4', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group4',expression4, "PYTHON_9.3",
codeblock4)

expression5 = 'prop (!TOT!, !Group5!)'
codeblock5 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_Group5', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group5',expression5, "PYTHON_9.3",
codeblock5)

expression6 = 'prop (!TOT!, !Group6!)'
codeblock6 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_Group6', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group6',expression6, "PYTHON_9.3",
codeblock6)

expression7 = 'prop (!TOT!, !Group7!)'
codeblock7 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""
```

```
arcpy.AddField_management(y, 'P_Group7', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group7',expression7, "PYTHON_9.3",
codeblock7)


expression8 = 'prop (!TOT!, !Group8!)'
codeblock8 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group8', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group8',expression8, "PYTHON_9.3",
codeblock8)


expression9 = 'prop (!TOT!, !Group9!)'
codeblock9 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group9', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group9',expression9, "PYTHON_9.3",
codeblock9)

expression10 = 'prop (!TOT!, !Group10!)'
codeblock10 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group10', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group10',expression10,
"PYTHON_9.3", codeblock10)

expression11 = 'prop (!TOT!, !Group11!)'
codeblock11 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group11', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group11',expression11,
```

```
"PYTHON_9.3", codeblock11)

expression12 = 'prop (!TOT!, !Group12!)'
codeblock12 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group12', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group12',expression12,
"PYTHON_9.3", codeblock12)

expression13 = 'prop (!TOT!, !Group13!)'
codeblock13 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group13', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group13',expression13,
"PYTHON_9.3", codeblock13)

expression14 = 'prop (!TOT!, !Group14!)'
codeblock14 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group14', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group14',expression14,
"PYTHON_9.3", codeblock14)

expression15 = 'prop (!TOT!, !Group15!)'
codeblock15 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group15', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group15',expression15,
"PYTHON_9.3", codeblock15)

expression16 = 'prop (!TOT!, !Group16!)'
codeblock16 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
```

```
return 100 * IC1 / IC
else :
return 0"""

arcpy.AddField_management(y, 'P_Group16', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_Group16',expression16,
"PYTHON_9.3", codeblock16)
```

Appendix VII: Code "Percentage Element"

```
#Name: Percentage Element.py
#Description: It creates a series of maps selecting the objects according to their
compositional groups and dates
#Author: Laura Perucchetti

#Import System Modules

import arcpy
import os

from arcpy import env

#1 I overwrite 0 I does not overwrite

env.overwriteOutput = 1

#Insert variables
input=arcpy.GetParameterAsText(0)

#This sets a variable for the input net that is going to be joined
target_features = arcpy.GetParameterAsText(3)

#This creates a variable for the output
mypath = arcpy.GetParameterAsText(4)+'/'

#This sets the element chosen to calculate the percentage of presence
element = arcpy.GetParameterAsText(1)
##field = "!" + element + "!"

#This sets the threshold of "presence"
threshold= arcpy.GetParameterAsText(2)

arcpy.AddField_management(input, "threshold", "FLOAT")
arcpy.CalculateField_management(input, "threshold", threshold, "VB")

#This creates a new field that indicates which objects have the element chosen
over the threshold, and which does not have it
#expression = 'value (element)
expression = 'value (!%s!, !threshold!)' %element
codeblock = """def value(element, threshold):
if element > threshold:
return 'YES'
else:
return 'NO'"""

#This creates two maps: one with the element over the threshold, and the
```

```
other that have the element under the threshold
arcpy.AddField_management(input, 'PRESENCE', "TEXT", "", "", "", "", "", "")
arcpy.CalculateField_management(input, 'PRESENCE', expression,
"PYTHON_9.3", codeblock)

arcpy.Select_analysis (input, mypath + 'YES.shp',"PRESENCE = 'YES'")
arcpy.Select_analysis (input, mypath + 'NO.shp',"PRESENCE = 'NO'")


#For both the maps with presence and absence of the element, a new join with
the input net is created in a new folder (the output path)

JOIN_YES = arcpy.SpatialJoin_analysis(target_features, mypath + 'YES.shp',
mypath + 'JOIN_YES')
JOIN_NO = arcpy.SpatialJoin_analysis(target_features, mypath + 'NO.shp',
mypath + 'JOIN_NO')

#It creates a file copy of the input fishnet, called join_tot
arcpy.CopyFeatures_management(target_features, mypath+"join_tot.shp")
y= (mypath+"join_tot.shp")

#create a list of possibilities (YES or NO)
##List = [JOIN_YES, JOIN_NO]

#It joins join_tot with each result of the spatial join between the input map and
the input net
##for x in List:
## join_features = x
arcpy.JoinField_management(y, "FID", mypath + 'JOIN_YES.shp', "FID",
["Join_Count"])
arcpy.JoinField_management(y, "FID", mypath + 'JOIN_NO.shp', "FID",
["Join_Count"])


#Overwrite files with the same name

arcpy.env.overwriteOutput = True

# This creates two new fields "YES" and "NO". In each field the result of the
count of the spatial join is copied.
arcpy.AddField_management(y, 'YES', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'YES', '!Join_Count!', "PYTHON_9.3")

arcpy.AddField_management(y, 'NO', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'NO', '!Join_Cou_1!', "PYTHON_9.3")

#It deletes the original fields with the counts
arcpy.DeleteField_management(y, ["Join_Count", "Join_Cou_1"])
```

```
#For YES and NO
#It adds a field that will contain the information about the percentage of
presence
#It defines formula to calculate the percentage of presence

arcpy.AddField_management(y, 'TOT', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'TOT', '!YES!+!NO!', "PYTHON_9.3")

#calculate percentage
expression1 = 'prop (!TOT!, !YES!)'
codeblock1 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_YES', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_YES',expression1, "PYTHON_9.3",
codeblock1)

expression2 = 'prop (!TOT!, !NO!)'
codeblock2 = """def prop(IC, IC1) :
if IC1 >= 0 and IC >0:
return 100 * IC1 / IC
else :
return 0"""


arcpy.AddField_management(y, 'P_NO', "FLOAT", 10, "", "", "", "", "")
arcpy.CalculateField_management( y, 'P_NO',expression2, "PYTHON_9.3",
codeblock2)

#This deletes the fields YES and NO in the original table
arcpy.DeleteField_management (input, "threshold")
arcpy.DeleteField_management (input, "PRESENCE")
```