Chapter 2. Developing a New Interpretative Framework

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Perhaps the most important characteristic of the framework and the consequent toolkit we have created for FLAME is that it focusses on detecting and quantifying *change over time* and *differences over space* in the archaeological record. In our case, the key elements in the archaeological record are the metal objects themselves, and our aim is therefore to produce a toolkit which reveals observable changes in these objects over time and space. Our entry point to identifying these changes is via the chemical and isotopic composition of the objects themselves, but such changes can only be meaningfully interpreted when contextualized by their typology, decoration, archaeological context, and manufacturing technology. The ultimate aim of FLAME is to use the changes revealed by a comparison of the chemical and isotopic data to infer human action and intention. It is this focus on ‘change’, and the explicit intention to interpret such change in terms of human action, that distinguishes our philosophy from the more limited ambitions of some of the previous analytical projects reviewed in Chapter 1, focussing primarily on ‘provenance’.

Such inferences, however, cannot meaningfully be made on the basis of individual analyses on isolated objects. These analyses give no sense of what is ‘normal’ or ‘expected’ for a particular object type in a specific time and place, and therefore lack any comparative context—this is effectively the same argument as that made by Pittioni (1957) when challenging the work of Otto and Witter (1952), as discussed in the previous chapter. Observations of change and difference have to be made on the basis of *group properties*, which should be determined on as large a number of objects as possible. We term such a set of objects an *assemblage*. A variety of views on the meaning of the term ‘assemblage’ have recently been published in a special issue of the *Cambridge Archaeological Journal* (2017(1)), where, as with many commonly-used archaeological terms, one finds that the concept itself is fluid. As discussed further below, we see an assemblage essentially as a thematically-defined group, the nature of which is not fixed but depends on the specific question being asked. In our case, an assemblage could be all the metal
artefacts from a particular tomb, or all the metal objects belonging to a particular archaeological culture, or all the bronze daggers of a particular shape from across Eurasia. The toolbox described in the next chapters is designed to reveal changes in chemical and isotopic composition through a comparison of such assemblages.

One other key point to note is that our attention is intentionally focussed on objects, or more strictly on assemblages of objects, as opposed to other sources of metallurgical data, and our methodologies have been developed accordingly. That is not to say that we are not interested in these other sources of evidence relevant to metal artefacts, such as the mineralogy and chemistry of known ancient mining sites (as provided by, for example, O’Brien 2015), or the chemical metallurgy of the smelting process, or the metallographic structure of the objects themselves. However, we regard these as independent sources of information, to be subsequently compared with the results of the analysis of the objects themselves. Thus, if we identify a particular region as being dominated by objects made from a particular type of copper (see Chapter 4) in a specific time period, then this offers us a starting point to postulate that a mine or mines operating at that time and producing such copper should exist within that particular region. The identification of a mine capable of doing so then provides independent evidence that such copper was being locally produced. It is however worth noting that our mapping approach for different types of copper can also suggest the geographical extent of the use of such copper, which is information not immediately obtainable from the examination of the mining area itself. Conversely, the absence of such a suitable production area within a particular region would strongly suggest the importation of metal from another area. The use of a GIS database allows for the overlaying of several such independent sources of information, thereby facilitating the combination of these multiple strands of evidence.

Building a new conceptual framework: ‘Form and Flow’

Our conceptual framework is the major feature that distinguishes our approach from those of many previous workers, but to some it may at first glance appear unnecessarily abstract. In our view, however, it provides a powerful new framework which allows us to combine data from many different sources, and in particular to link chemical and isotopic data to human behaviour (Bray et al. 2015). As such, it has been very helpful in guiding the development of the tools and ideas discussed below. Rather than focussing on specific metal objects, the central concept is one of metal ‘flowing’ over time through society, and being chemically and isotopically modified by a series of human interventions, which
will in turn influence the composition of new objects produced from that flow. Such interventions might include:

- the mixing of ore or smelted copper from more than one mining source;
- deliberately alloying copper with significant quantities of another metal, such as tin or lead, to create a new material;
- re-working an object into a new shape, possibly with re-alloying and/or the addition of other metal, or recycling objects to create new objects.

We can see that many such factors can combine in a wide variety of ways to produce a complex dynamic system which affects the composition of the flow of metal and the metal artefacts made from it. Our aim has been to develop a quantitative methodology to follow and disentangle this system. It should be immediately obvious that it automatically includes the traditional concept of provenance, if the situation is simple enough to do so, but is also capable of dealing with more complex scenarios.

**Metal flow**

The concept of metal flow in archaeology has been emphasized by several scholars (e.g., Bradley 1988; Needham 1998; Jin 2008; Pollard 2009), often in the context of attempting to model trading networks and technological pathways, or to express the life cycle of an object as it is made, used, and deposited. An example of the latter is illustrated in Figure 1, from Ottaway (2001), in which the metal is seen to go around a cycle starting with mining and smelting, through the manufacture and use of the object, and ultimately back to an oxidised form through corrosion. It is effectively a thermodynamic cycle in which energy is consumed in converting the ore to the metal, and entropy eventually causes it to revert to its mineral state. Such a cycle is a useful representation of the practical cycling of metal, but our ‘flow’, dealing with the underlying metal, is more abstract than this (Bray and Pollard 2012). Essentially it is a theoretical construct which enables us to separate the lives of individual objects from that of the metal from which they are made, and ultimately to link together the data from mines and smelted metals to objects.
In creating this model, we have relied heavily on the theoretical construct of the ‘biography’ of an object (Gosden and Marshall 1999). The concept of a person’s biography is well understood and well established. It is a record of a person’s birth, life, deeds and death. It examines the way in which a person interacted with the world, and the way that the world interacted with them. Just as every person has their own unique biography, so too does every object. At the heart of this notion of object biography are questions about the links between people and things: about the ways that meanings and values are accumulated and transformed. Biography is relational, and an object biography consists of the sum of the relationships from which it is created. As an object goes through the course of its functional life it interacts with people. Such objects do not simply set the stage for human action, they are integral to it. In our case, however, we need to think about the distinction between the biography of a single object and that of the underlying metal flow. A specific object may have only a relatively brief existence, but the metal flow from which it is made, and to which it might be returned if it is recycled, may have a much longer existence. In many ways this concept is similar to that of prosopography, familiar to historians. This describes the situation where each individual within a defined group, such as all the bakers in Medieval Nottingham, might have left a relatively sparse biography (e.g., birth date, marriage date, location of bakery, etc.). However, when all these sparse records are assembled and integrated, we may get a good picture of the life of bakers in Medieval Nottingham—not of any
particular individual, but an average of the lives of this *assemblage* of bakers. Our metal flow is in some ways equivalent to the assemblage of bakers’ lives—an *object prosopography*.

**Simple linear biographies**

The biography of a single object may be conceptually very simple—it could be made, used for a short period, and deposited, to be later found by archaeologists. We term such an object biography a *simple or linear trajectory*. As a trivial example, we may imagine that a member of the elite demands a particular object be made using primary copper from a specific source. We use the term ‘primary’ here to denote copper fresh from the smelter or refinery, and not mixed with copper from any other source. This primary unit of copper is probably then alloyed with tin and perhaps lead to give certain desired physical or visual properties. The object is made from this metal stock and performs a specific function for a period of time in the elite household, and is then buried within the tomb of the person, probably only a few years or decades after manufacture. In this simple scenario, the object then sits in the tomb until it is excavated, conserved, chemically analysed, and perhaps put on display in a museum. Although from a theoretical perspective we must also consider the period in the tomb and on museum display to be part of the object’s biography (van der Stok-Nienhuis 2017), in terms of our flow model the object is only part of the flow of metal for the period when it is in active use, from manufacture to deposition. After that, it is effectively ‘out of circulation’ and not able to contribute to, or be affected by, the flow. Moreover, even when it is ‘in circulation’, in this particular case it undergoes no significant changes—after it has been smelted, alloyed, and manufactured, neither its composition, form nor decorative features are altered until after it is removed from circulation. Essentially it carries the same information into the grave as it had when it was first made. In this case, it is an instantiation of the composition of the metal flow available to the metalworkers at the time it was made. For objects which follow such a pathway, the traditional chemical and isotopic approaches to provenance are likely to be feasible, and possibly successful (*Figure 2*). Any ‘fingerprint’ inherited from the ore source is highly likely to be preserved within the object. The traditional ‘provenance’ models using chemical and isotopic data appear to have generally assumed (often only implicitly) that *all* archaeological copper alloy objects more or less follow such simple (linear) paths. Our view is that this may be the case, but the onus is on the archaeologist and analyst to explicitly demonstrate that this is true *before* moving to undertake provenance studies.
**Figure 2:**
Linear and complex object biographies.

**Complex biographies**

Although such a simple short biographical pathway between origin and deposition is of course possible, it is obviously not the only trajectory that we might imagine. For example, instead of being buried in the elite tomb, the object could have been passed on to succeeding generations, either as a practical object for further use, or as a memento, or an heirloom, to be buried some time later with a descendant of the original elite person. It might thus remain in use for several generations, being inherited, curated, and passed along repeatedly. This scenario simply extends the active life of the object. Following burial, however, it might have been looted and re-used in its original form, but in another time and, possibly, place. This too would lengthen the ‘active’ life of the object, which would then have had an ‘interrupted’ life history, both in time and perhaps also in space, if it is transported some distance after looting. All of these possible combinations of scenarios simply extend the ‘active’ life of the object, but do not of themselves physically change the object, nor the chemical information contained within it. As in the previous
example, it still carries to the tomb the same information that it had on creation, and is still an instantiation of the flow of copper at the time it was made. If, however, it was looted from a tomb, or passed on into a new social context by some other mechanism, such as trade, exchange or gift-giving, it may no longer have had the meaning that it did in its original context, and might have been melted down to create one or more new objects. The original object, in this new social context, may have been seen more as an ingot containing a convenient supply of raw material rather than as an object containing significant symbolic capital. At this point it may simply have become ‘scrap metal’, to be mixed with other unvalued object forms, and potentially reworked into other completely unrelated forms. We may imagine that such processes could continue in this way for some time, until the object is finally lost or deposited. We would term such a life history a branched or complex biography. The mutability of copper and its relative resistance to corrosion lends itself to such long and complex lifetimes, although perhaps not to the same extent as gold and silver, or possibly even glass.

But, in this last scenario, to which object or objects are we actually attaching this biography? It cannot be to the original object, unless we choose to see such a chain of events as being composed of a sequence of related objects, each with their own biographies. This might be appropriate for a particular set of events, where a single object is re-made at intervals, but with no addition of new metal. However, at each re-melting event in such a chain, there is the potential for the metal from one object to be divided between many objects, or for many objects to be amalgamated into one object, or new metal from a different source to be added. Under such circumstances, we suggest that it is better to switch our focus from the biography of individual objects or a sequence of objects to the biography of the metal contained within these objects, since it is this metal which is actually being manipulated by human agency. This is our conceptual flow of metal. It ‘flows’ through the objects, but its composition can change over time, as new sources of metal are added to the flow, even though the composition of each individual object within the flow may not change over its own lifetime. Moreover, we can conceive of a metal flow which can change composition over time without objects being recycled, simply by a new stock of metal being injected into the flow. This new stock may come from a new mine source being added to an existing flow of metal from the original mine, causing a significant change in the composition of the flow. It could also be that the flow is interrupted—metal from one mining region becomes no longer available, and is simply replaced with material from another source, with no continuity between the two. Hence the flow model is not predicated solely on the recycling of objects, but takes into account the multiplicity of events which might befall the metal flow.
To aid the explanation of this model, in a previous paper (Bray et al. 2015) we likened the flow of copper to that of a river, but this analogy is perhaps unhelpful if taken too literally. There are certain features which work, such as the idea that objects can be ‘scooped out’ of the metal flow like water in a bucket, and returned to the river if recycled. The concept of tributaries joining together is also a useful analogy for multiple mines providing metal to the flow, but the fact that rivers tend to grow in volume from source to sea does not necessarily apply to metal flow. It is more likely that the flow is greatest nearer to the source(s). In that paper, we also placed great emphasis on the role of recycling of individual objects or groups of objects in changing the composition of the flow. This was perhaps useful in the context of the Early Bronze Age in Western Europe, where we think that down-the-line trade and recycling may have been part of the dominant mode of metal transport, as a consequence of objects being passed between groups of people over relatively short distances, and re-modelled to fit local expectations of shape. More generally, however, we feel that in many cases this process is likely to have been a minor contributory factor compared to the greater volumes of raw metal being injected into the flow from new mining and smelting sites. We therefore see this hypothetical ‘flow’ of metal as being a useful tool for linking the composition of metal flowing from many mines, as well as being a mechanism for handling the possibility of the large-scale recycling of objects. It is almost certain that the balance between the influences of these two mechanisms will vary over space and time, as well as by the form of the object (perhaps weapons being treated differently to more mundane objects), and also the social status of the potential users of the objects. Nevertheless, by developing a series of tools which allows us to detect change in the flow of this metal, we believe we provided a practical framework for identifying and untangling the complex nature of the interaction between humans and metal.

**Flow and provenance**

It is worth reflecting at this point what the differences are between a dynamic ‘flow’ model as described here, and other more traditional scenarios, since this is a key distinguishing feature of the FLAME project. In the case of an object with a simple linear biography, or any linear biography in which the original object remains intact, then the conventional ‘provenance hypothesis’ as first enunciated by Damour (1865, 6) and summarised by Wilson and Pollard (2001) clearly applies. There is likely to be some characteristic of the ore that, after allowing for the changes which can occur in smelting and manufacture, is carried through into the object. This can be measured and, after comparison with appropriate ore data, or some other material of known origin, can be used to assign an object to...
an ore source. Strictly speaking, of course, such a procedure can only eliminate sources from which the object could not have come, rather than prove the metal to have come from a particular site. Nevertheless, the ambition of provenance can in principle be achieved. But what of the second scenario? If metal from many ore sources is mixed, as might be necessary in large-scale bronze production, or if several objects are recycled to make something new, then the simple link between a single ore source and the object is gradually destroyed. Ultimately, an object ceases to have a single source, and the simple ‘provenance hypothesis’ becomes meaningless.

**Figure 3** shows a series of schematic interpretations of some of these scenarios. The first sketch shows a set of objects recovered at different times, and a series of inputs, which probably represent different mining sites. Between them is the hypothetical metal flow, which consists of all the objects (plus scrap metal, ingots, etc.) that exist at a particular time and place. The composition of this flow is of course unknown, both in terms of the total population and typology of the objects, and also its range of chemistries. The second sketch illustrates how we can use the chemistry of an assemblage (the recovered and analysed sample) to approximate the chemistry of the metal flow at that time, providing we can be satisfied that the assemblage is sufficiently representative of the parent population—the flow. The third suggests how separate metal flows might co-exist—in this example, an elite flow and a common flow, each drawing on different sources of metal, and giving rise to different assemblages. This sketch also indicates a fracture in the metal flow caused by a culture change, which we hypothesise, changes the metal supply systems, such that the composition of the flow changes. There is, however, the possibility of some continuity across the transition, if the later culture robbed or reused metal that was in circulation before the change.

A key question, and one which we may never be able to answer satisfactorily, is ‘*how many archaeological copper objects conform to the single source hypothesis, and how many are too complex for this to be a meaningful question?*’ We can postulate some general answers to such a question, which may or may not be helpful. In regions close to a single large mining source, where fresh metal supply is plentiful, we might expect there to be little mixing or recycling, and therefore the provenance hypothesis is likely to be valid. Further, we may expect the degree of mixing/recycling to increase with distance from such a source (although distance need not be a linear measure, but may be directional, and depend on factors such as ease of river transport, etc.). Such a simple linear relationship might also apply but in a different way to a highly organised complex society, where the means and resources exist to transport large quantities of metal from very specific sources
Figure 3: Hypothetical illustrations of metal flow.
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over considerable distances. The reverse could, however, also be true—highly organised complex societies might have the resources to draw in metal from many sources, and mix them at the foundry sites, thus negating the provenance hypothesis. In metal-consuming regions which are remote from metal sources, where the supply may be difficult or discontinuous, we may expect a far higher degree of mixing and recycling. Geography may not, of course, be the only factor. Political interventions (or, indeed, natural disasters) might disrupt the supply from a particular region, causing a switch of the inputs into the flow. Societies in terminal collapse, where central control has diminished and they no longer have the capacity to control the metal circulation, may also see a rapid change in the balance between the use of fresh metal and recycled metal. We see just such a situation at the end of the Roman occupation of Britain, where we have postulated that by the end of the Early Saxon period, some 250 years after the collapse of Roman Britain, at least 75% of the copper alloy in circulation was still recycled Roman (Pollard et al. 2015).

However, under the flow model, all is not lost in these more complex scenarios, even when mixing and/or recycling may become significant. In such situations, we must switch to a stronger focus on thinking about detecting change in the flow of archaeological metal using the appropriate tools, rather than simple provenance. This means that the traditional question of provenance has to take a back seat, although it is not forgotten altogether. It merely becomes one of a number of possible explanations for the observed chemical changes in the metal flow. In other words, the cause of these changes may not be a simple switch in ore source, but might reflect many other factors, such as a massive input of looted metal, or a change in smelting practice, or a general increase in recycling. Nevertheless, we suggest that the observation of such changes within the metal supply is still archaeologically meaningful. In fact, we might argue that the ability to detect such changes is more archaeologically meaningful, and possibly more interesting, than simply thinking about changes in ore source. Put more philosophically, we might argue that our model attempts to deal with the general case of human interaction with metal, whereas provenance is an example of a specific case, sitting within the more general and potentially more complex situation.

Operationalizing the framework

Several groups of researchers have articulated frameworks for understanding metal circulation which are similar in many respects to that described above (in particular, Chernykh (1992) and Ottaway (1982)). Our model differs primarily
by explicitly separating the biography of the individual objects from the conceptualised biography of the underlying flow of metal. But what in reality is this ‘flow’ of copper? It consists of a series of snapshots of the stock of copper (or copper alloy) available at any particular time and place, and the ‘flow’ reflects how this stock changes over time and space. The stock is made up of all the available copper alloy resources at that time and place, including all objects, plus fresh metal ‘ingots’ and other ‘scrap’, and the chemical and isotopic composition of the stock is therefore the average of that in all of its components. However, its precise composition is, of course, generally unknown, and largely unknowable, to us. We can, however, tentatively make the assumption that the composition of those objects that are available to us (i.e., all the chemical and isotopic analyses of objects from that particular time and place, which is one definition of an assemblage) is a representative sample of the composition of the stock. This allows us to reconstruct the chemical and isotopic composition of the metal in circulation at that time and place, and, hence, to compare the metal in circulation at different times or places. This assumption is of course only true providing the data available to us are an unbiased sample. As is inherent in all aspects of archaeology, this is unlikely to be completely true, perhaps through the vagaries of sample preservation, or excavation strategy, or through biases in the selection of samples for analysis (arising from museum sampling constraints, interests of the analyst, etc.). The issue of sample bias is addressed in more detail below.

The toolkit: the “Oxford system”

Based on the model developed above, we have devised a system (sometimes referred to as ‘the Oxford system’), which is based on a set of three separate but interlinked groups of tools:

- **trace element composition or ‘Copper Groups’**, which focusses on information derived primarily from the copper ore source(s), but which may potentially be altered by subsequent human manipulation of the metal,

- **alloy composition (‘Alloy type’)**, which is defined to be the result of intentional action, as craftspeople choose to add metals to modify the characteristics of the material (fluidity in casting, colour, hardness, etc., or perhaps to give additional symbolic significance), but subsequent mixing and recycling might move the assemblage away from the originally-designed alloy compositions,

- **lead isotope composition**, which can give information about the source of copper, or the added lead, but is also susceptible to alteration due to anthropogenic mixing.
These tools are based on the intrinsic properties of the objects (i.e., on their chemical and isotopic compositions), to which we add at least one more intrinsic property, that of **form** (as described by typology), which is imposed by humans and reflects the socio-technological context of production, amongst other things. We can of course elaborate on this, by considering form to be a complex variable incorporating decoration, manufacturing technology, the ‘technological style’ of Lechtman (1977), etc. There is a fifth (extrinsic) property, namely ‘**context**’, which frames the life history of each object, and allows us to situate its intrinsic attributes within the wider physical and social world.

It is important to note that, in general, and if the data support it, we would normally attempt to use all three of these toolkits together to address a particular archaeological question. Frequently this is not possible because we cannot get a full set of major and trace element data, plus isotopic measurements, on the same objects. If it is possible, however, then it is generally worth doing because each toolkit provides a specific perspective on different aspects of human behaviour, and it is only by piecing them all together that we can hope to obtain a realistic answer. In general, the trace elements contain information about the source (or sources) of the copper, and might provide some evidence for the manipulation and recycling of the metal. The alloying data gives us a picture of the desired alloy composition, if it is a deliberate alloy, or allows us to demonstrate that the assemblage represents a set of objects which have no common target composition, which might be indicative of extensive recycling. The toolkit is therefore deliberately designed to consider the identity of the copper in circulation separately from any alloying processes. This separation is a unique and powerful feature of the Flow model. Alloying can be a deliberate choice, aimed at producing a metal with specific physical or aesthetic properties, but equally it may be a series of deliberate choices, where a particular alloy may be **re-alloyed** sometime during its lifetime, perhaps by adding more tin to change the colour, or by adding lead to increase the fluidity of the melt, or to dilute and extend the stock of metal. We do not therefore see alloying as necessarily being a single unique event in the life of the flow of metal. Thus, neither the percentage of the alloying elements present in an object, nor the consequent ‘alloy type’, is a fixed property within the metal flow.

In modern foundry practice, and presumably also in ancient practice, it is not unusual to sort alloys before recycling, so that the composition of the final product can still be controlled to some extent. However, in a situation where recycling is extensive and/or not very selective, we may also envisage that the make-up of the alloy becomes increasingly less controlled, and ultimately results in metal where the alloying elements are present at more-or-less random levels, which may be below the levels at which the alloying elements exert much influence on the physical and
aesthetic properties. In contrast to the modern (engineering) definitions of alloys, our approach is specifically designed to highlight such situations, and distinguish between intentional ‘primary’ alloying and less intentional ‘secondary’ alloys.

In particular, we can consider circumstances where some copper from a specific source (or mixture of sources) is circulated in an unalloyed form, whereas some of the same copper is alloyed and then circulated in the alloyed form. By conceptually separating the processes of producing the copper and producing the alloy, we can therefore begin to ask questions about the form in which the metal was circulated—perhaps as separate ingots of copper, tin and lead, to be subsequently mixed to order at the foundry, or as preformed ingots of copper with tin (or lead) already added. The practice of recycling would suggest that the raw material at the foundry might also include objects which have no specific significance or value. This in turn prompts a discussion of what the commonly-used term ingot actually means. Normally it is defined as a block of raw single metals (i.e., ingots of copper, tin and lead) transported specifically to be used at a foundry to create objects. We believe that we must allow for the possibility of ingots consisting of pre-alloyed metals, but also that, in some circumstances, an unwanted object may simply be regarded as an ingot of raw material. In other words, one person’s axe might become another person’s ‘ingot’, and this might be an important mode of trade and exchange in some contexts. It does not require much imagination to see that in some circumstances recycling other people’s metal objects is likely to be far easier than mining, smelting and transporting fresh metal. This leads to the introduction in Chapter 5 of the idea of regional alloying practice, where we might look for regional patterns in how alloys were designed and produced.

In Chapter 6, we present new ways of presenting lead isotope data, which differ from the conventional approach of plotting a scattergram of two sets of isotope ratios. The purpose of this is, however, more than simply to explore new presentational techniques: it represents a fundamental re-think of the use of lead isotopes in archaeology (Pollard and Bray 2015). The conventional approach simply represents the adoption of the interpretational techniques developed in lead isotope geochemistry, the original purpose of which was to provide a graphical means for calculating the geological age of particular lead deposits. Although useful in some circumstances, we suggest that the interpretation of lead isotopes in archaeological objects is different from that in geological ores, primarily because of human action—the possibility of mixing lead from different sources, the addition of lead to copper objects, or the recycling of objects containing lead from one source into the flow of metal which might contain lead from other sources. In other words, there is an additional layer of complexity in archaeological objects which is not easily accounted for in the conventional geological approach. Using
the techniques described in Chapter 6, we can distinguish between objects where
the lead is low and the lead isotopes are likely to reflect the source of the copper,
and those objects containing more lead, probably deliberately added, where it is
the source of the lead that is being identified by the isotopic data. Since such
diagrams also show mixing lines between different isotopic sources of lead, we
can begin to see patterns where the same source of copper is mixed with lead of
two or more isotopic values, potentially reflecting two or more different sources
of lead. Equally, we can see the reverse—the same lead being mixed with two
different sources of copper. These examples simply serve to show the complexity
of the possible metal flow patterns that might occur within and between different
societies, but also that the methods described here can begin to unravel this
complexity.

We can now re-visit the idea of an assemblage, introduced above as being the
totality of the objects from a particular place and time for which we have chemical
and/or isotopic data. We use such an assemblage as the best possible proxy for
characterizing the metal available at a particular place and time. We must, of
course, always remember that our assemblage is, at best, a biased sample drawn
from a biased sample of a biased sample of an unknown and unknowable parent
population! The three sources of bias referred to here are i) the bias introduced
by the original choice of objects to be deposited into archaeologically accessible
contexts, ii) the bias of archaeological recovery in terms of the contexts selected for
excavation, and iii) the bias in selecting excavated objects to analyse chemically
and isotopically. As explained in Chapter 3, it requires a strong focus on typology
and archaeological context when interpreting the data from such analysed objects
to minimise the effect of these biases.

Whilst this is one way of using the term assemblage, we can sometimes be more
specific, which might also be helpful in countering some of the biases discussed
above. It is essentially a scalable parameter which needs to be specifically defined
for each question being asked. For example, it could be all the metal objects from
a single tomb, which then allows us to compare the characteristics of the metal
in this tomb with those from other tombs, or with the general pattern of metal in
circulation. Within the excavation of a single site, it could be all the metal objects
from a particular phase of occupation, which would allow us to look at changes
over time by comparing the metal assemblage between phases at that particular
site. Scaling up, we can equally define an assemblage as being all the metal from
a particular cultural group, which allows us to compare between groups—thereby
addressing questions of the degree of interaction between adjacent cultures, or
the degree of continuity between successive cultures. On the other hand, we
may choose to classify all the objects of a particular type as an assemblage,
irrespective of where they were found, thus allowing questions of the relationship between typology, function and metal use to be considered (such as ‘were personal ornaments made from the same copper, and alloyed in the same way, as weapons’?). In each of these cases, the assemblage is selected specifically to represent the class of objects necessary to answer the question being asked. When combined with *ubiquity analysis* (the percentage of a particular assemblage made up of a particular type of copper or alloy) and *profile analysis* (the distribution of a particular element in all of the objects in the assemblage) we can use spatial and temporal mapping to follow these subtle chemical shifts caused by human interventions through space and time.

Taken together these tools offer an integrated methodology which combines: i) a model for the chemical changes in copper-alloys caused by human and technological processes, with ii) a re-definition of the terminology for alloy composition, which does not implicitly assume deliberate alloy design, and iii) a new way of interpreting lead isotope data that is more sensitive to anthropogenic mixing. One strong feature of this system is that it is both *scalable* and *universal*. It is *scalable* in the sense that it can be applied to assemblages representing the contents of a single grave or hoard, up to a particular type of object which is distributed across all of Eurasia. It is *universal* in the sense that the basic methodology can be applied anywhere, and used to compare assemblages from widely separated places and times. That is not to say that it can be applied anywhere in a mechanical fashion, with guaranteed outcomes—although the *processes* we have developed are universally applicable, the interpretation of the observed changes will be radically different, depending if one is dealing with a set of relatively small-scale loosely organized societies, such as those found on the Steppe, or a highly organized and centralized state such as Dynastic China or the Roman Empire. Nor can it be assumed that by simply applying the prescribed methodology to any archaeological situation, all questions will be answered! It does mean, however, that data from, say, Eastern Europe can be directly compared with that from southern Siberia. This avoids the limitation seen when classifications taken from earlier studies are compared, since most of these classifications are derived from internally defined parameters, making them specific to that dataset. Thus the outcomes of the SAM programme cannot be directly compared with those of Chernykh, whereas using our methodology the results can be directly compared across all of Eurasia. Our assertion is that the methodological tools described here can be used as a starting point for any archaeological interpretation, but specific questions might require a different set of subsequent approaches.
Sample bias

Above we raised the issue of the potential bias between the objects for which we have chemical analyses, and the totality of the metal produced in a particular region. This is a serious issue, and one that is rarely discussed in traditional approaches to archaeometallurgy, particularly in provenance studies. One conventional aspect of sample bias is to consider how well the average analysis of the assemblage (the sample) represents that of the (unknown) parent population (the flow). We can of course calculate the average composition of the objects in the assemblage available to us, and produce a mean and standard deviation for each element (e.g., Cu = 64.5 ± 1.2 %, etc.), providing that we think the distribution of each element is approximately normal within the assemblage. Sampling theory, however, tells us that although the average is the best available estimate for the mean of the population, the standard deviation of the sample (the analysed assemblage) is not the standard deviation of the population (i.e., the stock of metal), and also that the calculated standard deviation for the assemblage is invariably smaller than that of the parent population (Miller and Miller 1984, 41–44). The latter can be calculated from that of the sample, provided we know the sizes of the sample and the population, as illustrated in Figure 4. We know the size of the sample, but that of the population is unknown, and is likely to be much greater than that of the sample. If the sample size is large compared to the assumed size of the parent population (e.g., if we have analysed most of the objects in a tomb), then the difference will be minimal, but for small samples, where we might only have analysed 200 objects from an area which is likely to have produced millions, then the difference will be very large. Most archaeometallurgical studies, however, do not take this into account, and simply take the parameters of the sample to be those of the parent population, and then use these data to perform further numerical calculations.

A more significant issue in the context of FLAME is the potential bias arising from the typological mismatch between the sample and the parent population. As shown in Figure 5, if the hypothesised parent population contains a number of different typologies, but the proportions in each segment are unknown, then we have to assume that the totality of known objects (i.e., those which have been archaeologically recovered) represents faithfully the divisions in the unknown parent population. In this hypothetical example the recovered population consists of 25% axes, 35% daggers, 10% swords and 30% pins by number. If we assume that each of these categories has a different chemical composition, then the analysed sample will be biased if it does not contain the same proportion of object
types. This becomes an important consideration when looking at regional alloying practices in Chapter 5, and is discussed further there.

In the light of the difficulties of predicting the chemical properties of an unknown parent population from an inevitably biased sample of those objects which have been excavated and chemically analysed, we might be tempted to give up, although all archaeological research in one way or another has to learn to deal with such challenges. In fact, one of the characteristic features of archaeology is that it has to come to terms with data that are far from ideal in the statistical sense. It generally does this by recognizing the limitations of the data (often, however, implicitly) and devising ways of overcoming them. Mathematically speaking, a good start is often provided by switching from parametric to non-parametric statistics—i.e., away from using means and standard deviations to characterize the data, and using medians, interquartile ranges and order statistics instead. The methods we describe here are essentially non-parametric and do not rely on using descriptions based on means and standard deviations, with the concomitant assumptions of normality. They are therefore inherently better suited to dealing with the sort of data that we routinely encounter. They are also reasonably robust with respect to errors in the actual measurements, as described in the next chapter. In short, we argue that the approach described here is not only conceptually more useful when considering the role of metal within human society, but, given the nature of the data, is also mathematically more appropriate.

![Diagram](image.png)

**Figure 4:** Relationship between the sample (assemblage of analysed objects) and the parent population (the stock of metal) if the sample is unbiased.
Figure 5:
Relationship between a more complex parent population (stock of metal) and the assemblage.