

Craft Practice and Resource Perception in the Southern Urals During the Middle Bronze Age

Derek Pitman

PhD Archaeology

The Department of Archaeology

The University of Sheffield

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Abstract

The thesis characterises metallurgical production at two Middle Bronze Age, Sintashta communities in the Southern Urals and presents a new model for the organisation of metal production in the region. Current models argue for intensive and centralised production that contributed to social complexity and the development of long-range exchange networks. Middle Bronze Age groups are characterised as complex warrior chiefdoms or even proto-states. The thesis examines these interpretations through the detailed characterisation of metallurgical debris. Particular attention is given to the identification of local practices at two Sintashta settlements and to characterising specific technological choices. An integrated methodology is employed, which incorporates fieldwork, an extensive study of metallurgical debris and a programme of experimental archaeology.

The results demonstrate that the scale and organisation of primary copper metallurgy is greatly misrepresented in the published literature. While some aspects of production practice were shared among communities, specifically smelting technique, other aspects, such as the procurement of resources, were locally articulated. This has important implications for interpreting the organisation of Sintashta groups and their role in wider Eurasian society. The thesis argues that the persistent use of metallurgy as an indicator of complexity is inappropriate when craft practice is considered in its social context. The conclusion is that Middle Bronze Age communities in the Southern Urals were not complex hierarchies or proto-states that controlled production and access to resources. They were locally distinct groups that maintained a collective direction through a restriction and mediation of production practices.

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Chapter 1

Introduction

The archaeology of how things are produced and consumed is an inquiry into how people made their world, and in doing so, how they organised and maintained their relationships and identity within the wider community (Ingold 2000: 312). To make is to be concerned with how the material world performs, but since production requires access to resources, the acquisition of skills, the negotiation, organisation and maintenance of social relationships, it is also simultaneously concerned with politics and power; it is therefore foremost a social phenomenon (Pfaffenberger 1998). Producing both materials and things draws together the acts of individual agents and the wider social group in a meaningful and creative process (Dobres 2000; Pfaffenberger 1998). It is the strategies by which such diverse aspects were drawn together by Middle Bronze Age Sintashta communities that are the primary concern of this thesis.

The emergence of Sintashta type settlements at the end of the third millennium BC in the Southern Urals is held to be a critical development on two counts. First, it is viewed as the region's first truly complex cultural development, and secondly the associated economic development is seen to be the impetus for establishing structured and extensive long range relationships which facilitated the transmission of cultural knowledge, and, crucially, the exchange of significant quantities of commodities (see discussions in Anthony 2009; Frachetti 2008; Hanks 2010a; Kohl 2007). The Sintashta phenomena is notable not only for the development of highly organised settlement structures but also the establishment of Kurgan cemeteries, which many archaeologists have looked to as repositories of complex composite artefacts such as chariots and metalwork, especially in the form of ornate items of personal adornment. It is argued that copper metallurgy is a central aspect of the Sintashta cultural development (Anthony 2009; Grigor'yev 2002) and copper metal is often cited as the main commodity to be traded with far-off communities (Anthony 2009). Sintashta settlements are often seen as host to specialised mining and metal producing communities and it is this characterisation of Sintashta communities that is addressed by this thesis. Specifically, how metallurgical production was practiced and organised among the Middle Bronze Age communities of the Southern Ural steppe and whether, in light of new evidence, such existing understandings can be sustained.

1.1 Aims and Objectives

It is therefore, the aim of this thesis to develop a critical understanding of the "*Sintashta metallurgical process*" through the characterisation of metallurgical production debris from two sites, and to use this to examine the role of metallurgy in existing models of production. This will be achieved through the following objectives:

- The formal and scientific characterisation of archaeometallurgical material from the two Sintashta settlements, Stepnoye and Ust'ye, in order to identify various technological choices and production practices.

- A programme of experimental reconstruction to explore practical and materials aspects of the metallurgical process as understood from the results of the analytical programme.

- A constructive critical evaluation of existing models of Sintashta metallurgical production through the integration of new results with existing literature of Eurasian prehistory and craft production.

The focus on the technological choices involved in the Sintashta metallurgical process is of central importance as craft production and its organisation have long held a key place in characterising social organisation and in identifying complex societies (Binford 1962; Childe 1947; Andrews and Doonan 2003: 51; Renfrew 1974; Trigger 1989; Service 1971; Freidman 1974). The concept of complexity stems from cultural evolutionary paradigms which see societies move from simple bands (such as hunters and gatherers) through increasingly 'complex' stages until they are considered fully complex. This model of social development is widely used by archaeologists (Pluciennik 2005; Renfrew and Bahn 2012) and is drawn from Service's social evolutionary classification of band—tribe—chiefdom—state (Service 1971). Within this paradigm, complexity is more synonymous with inequality in as much as it is tied to concepts of state development and how specific groups develop increasing control and power over labour, material resources and the wider economy, often using superficially unrelated means such as religion and cult practice. In almost all models for social complexity, the organisation of craft production is considered a key marker of development (Rowlands 1995).

It is because of the importance given to social complexity in the study of the Eurasian Bronze Age (Anthony 2009; Epimakhov 2002; Frachetti 2012; Hanks 2009; Zdanovich 2002), that the characterisation of craft practice, specifically metallurgy, has implications for how the organisation of Sintashta society is understood (Hanks and Doonan 2009). Indeed, the characterisation of metallurgy has been frequently cited as evidence for Sintashta complexity, yet the evidence, which is rather scant, has yet to be considered from a perspective that seeks to integrate rigorous laboratory characterisation, contextual and archaeological detail, and experimental reconstruction. As such this approach is the basis of this thesis.

Concomitant with its use as an index of social development, Bronze Age metallurgy has been afforded a central role in stimulating and sustaining extensive networks of cultural, economic and social interaction, which together have been termed a 'world system' (Anthony 2009; Chernykh 1992; Kohl 2007; Kuzmina 2008). The widespread and apparent shared

tradition of metallurgy in the Southern Urals at this time has been explained as the outcome of centralised coordination by a polity which established far reaching and diverse political and economic relations (Hanks and Doonan 2009; Zdanovich and Zdanovich 2002: 253).

These types of discussion have typically resulted in models which feature pan-regional interactions covering an expansive region of the steppe, or which assert a 'highly developed' level of social complexity (cf. Anthony 2009; Frachetti 2008; Hanks 2010a; Kuzmina 2008). It is perhaps due to the extended geographic range of the steppe terrain and the prevalence of pastoral nomadism in later periods, coupled with a desire to explain east-west cultural transmission (See Frachetti 2012), that these kinds of large-scale models have become the accepted norm in studies of the region (Kohl 1996; Kristiansen 1999; Koryakova 1996). However, with very few settlement excavations published the assertion that their occupants engaged in such intense and unified metallurgical practice has been drawn primarily from the secondary literature and the work of a select few specialists (Degtyareva 2010; Grigor'yev 2000; Zaykov et al. 2005).

Due to the weight given to a shared tradition it is appropriate that the metallurgical production process and its organisation receive adequate academic scrutiny, rather than simply being accepted uncritically. Issues of scale and technological variability are key considerations in assessing the degree of cultural complexity amongst Steppe communities and their relations with wider systems (Hanks 2009). Understanding the nature of these relationships and the varying pathways through which communities engaged with craft practice is more than just a proxy for complexity; it is a means to understand how groups acted within their world and how different aspects of the community interacted and related to each other in the wider context of day-to-day life. Therefore this thesis will explore the concept of a shared tradition through a detailed study of metallurgical practice at two sites in the Southern Urals; Stepnoye and Ust'ye (Figure 1.1).

1.2 Project Development

This doctoral project was developed within the wider '*Sintashta Collaborative Archaeological Research Project*' (SCARP), led by Bryan Hanks and Roger Doonan, which sought to investigate the evidence for copper metallurgy as practised by the Middle Bronze Age communities of the Southern Urals through understanding the social and spatial characteristics of metallurgical production (Hanks 2009). This was undertaken through a significant programme of fieldwork and analysis which included; large-scale pedestrian survey, geochemical and geophysical survey, excavation and materials analysis (Hanks and Doonan 2009; Doonan et al. 2014).

From the outset the project intended to integrate aspects of archaeological practice that have often worked in isolation from one another, especially around the division of what is considered an excavation and a post-excavation task (Hanks and Doonan 2009; Hanks 2011). With this in mind all specialists spent time in the field leading aspects of fieldwork and material sampling.

The outcome of such an approach is a greater integration between discrete pieces of work, and in turn an epistemological dependency between what in other projects might be



Figure 1.1 Map showing the main study area and the locations of the two main sites

seen as discrete studies. The reflexive nature of this research promoted the integration of scientific methodologies and survey techniques within the wider fieldwork process. The SCARP project has been the foundation of numerous PhD projects, including large-scale pedestrian surveys (Johnson 2014), mortuary studies (Ventresca-Miller 2013) and archaeobotanical analysis.

It was within this framework this program of PhD research was initiated. The foundations for this study was the author's Masters Project which sought to characterise resource procurement in the immediate vicinity of Stepnoye (see chapter 5). In addition, aspects of the SCARP project presented a significant backdrop for the work presented in this thesis and can be found throughout the following chapters. It was the early results of SCARP highlighted the need for a wider, comparative project which allowed resource procurement and technological choices to be explored at multiple sites (Hanks et al. 2015).

1.3 Thesis Outline

Archaeology in Russia developed along a unique trajectory which may not be familiar to many archaeologists working in the West, yet it has important implications for how the problem that this thesis addresses has been framed, as well as the type of methodologies used. It is with this in mind that Chapter 2 begins with a historical background to archaeology in Russia, with specific reference to how this has influenced scholarship in the Southern Urals. The archaeology of the Southern Urals shows a clear relationship with the development of Soviet archaeology, which operated within a strong culture-historical framework. The chapter then presents a detailed outline of what constitutes Sintashta

archaeology and the types of site and material that are typically used to characterise these communities. The chapter concludes with a critical reflection on the current debate surrounding the development of social complexity in the Southern Urals, detailing the arguments of scholars both inside and outside Russia.

Chapter 3 focusses the archaeology of metals and how metallurgy has had an enduring history of being intertwined with arguments of complexity and social development (Childe 1930, 1944; Wertime 1964, 1973). It presents a background as to how this relationship developed from some of the earliest studies of ancient metallurgy, through the development of 'archaeometallurgy' to an understanding of metallurgical practice as a fully social phenomenon. The chapter then presents a detailed discussion as to how metallurgical production may be better understood through an approach that integrates concepts such as temporality and technological choices.

Building on the themes outlined in chapter 2 and the broad chronology of chapter 3, Chapter 4 details what is currently understood as the Sintashta metallurgical process; from procurement, through primary and secondary production, to the consumption patterns of metallurgical artefacts, as well as the wider understanding of Bronze Age metallurgy in the region.

Following these three background chapters, Chapter 5 introduces the study area of this project; beginning with the Southern Urals in general before presenting a detailed outline of the two main areas of focus and the sites that produced the materials analysed in this thesis.

Chapter 6 presents the detailed results of the analytical phase of this thesis. The materials analysed include metallurgical debris such as slag, copper minerals and metallurgical ceramics. Chapter 7 presents the results of the experimental phase of this project.

Chapter 8 draws together the results of the previous chapters into a two part discussion. In the first part new evidence is used to critically evaluate existing models of Sintashta metallurgy, and in turn, social complexity. This is followed by a new proposal as to how Sintashta metallurgy might be better understood and what alternative research agendas might be adopted.

The final chapter, Chapter 9, presents conclusions regarding the role of metallurgy in Sintashta communities. Specifically the way in which its close association with complexity has, perhaps, drawn focus away from more interesting issues such as how production practice is articulated on a local scale and the implications of this within the wider day-to-day lives of the occupants of these sites. The chapter ends with a discussion of what is needed from future work. It will also consider how the methodology and results of this thesis can be expanded and built upon to fully address some of the wider questions of the development, organisation, and modes of production of Middle Bronze Age communities and their place within wider historical narratives.

Chapter 2

The Archaeology of the Southern Urals

The Eurasian landmass, characterised by both forest and grassland steppe, has been the focus of archaeological investigation since the 18th century (Trigger 1989: 207). The apparent monotony of the terrain coupled with the nomadic traditions of its more recent historical communities has resulted in archaeologists conceptualising this expanse as a space which needs to be understood in terms of groups moving through or from it. In effect, the archaeology of the steppe has become an archaeology of long range communication and movement, rather than one which seeks to understand steppe communities in their own right. Archaeology in the Southern Urals could in many ways be parodied as the archaeology of migrations and interactions (Anthony 2006; Frachetti 2009; Kuzmina 2008; White and Hamilton 2009). However, when considered as a distinct archaeological region that played host to an inhabited landscape featuring various subsistence strategies and life-ways, it becomes possible to understand Central Eurasia not just as a meeting point between East and West, but a region worthy of study in its own right.

Central Eurasia, and the Southern Urals in particular, mark the epicentre of the Eurasian steppe; where east meets west in the narrowest zone of the "*steppe corridor*" (Kristiansen and Larsson 2005: 181; Shnirelman 1998). However, the role of the Southern Urals in archaeological scholarship is not simply a product of the region's distinct geographical character but also of the fluctuating academic traditions which have been applied to the region in the last two centuries. Therefore the first part of this chapter aims to outline the history of archaeological scholarship in Russia; highlighting the influence that this has had on the development of archaeological and historical interpretation in the Southern Urals. The second part outlines a chronology for the region which attempts to incorporate aspects of the culture-historical framework with absolute dates and some of the wider chronological discussions. This is followed by a detailed introduction to the main subject area of this thesis; this Middle Bronze Age Sintashta archaeological complex. The final part of this chapter focuses on the role that the Southern Urals have played in wider discussions of 'social complexity' and long distance interaction.

2.1 The Development of Eurasian Archaeology

The history of archaeological thinking in Central Eurasia has been informed by a variety of epistemological frameworks from cultural history, through Marxism to World Systems Theory (Kohl 1996; Wallerstein 1974; Yablonsky 2000). The most significant development in recent times has been the opening up of geographic and political borders; only three decades ago the region's archaeology was all but unknown in Britain, Europe and America, with few, if any scholars having contact with those practicing archaeology within the former Soviet Union (Anthony 2006; Frachetti 2008). This means that for most of the 20th century the history of archaeology in Central Eurasia was divided between those working in the region, and those commenting from outside (Anthony 2006: 40).

The formative phases of archaeology began in tsarist Russia, like elsewhere in 18th century Europe, as an antiquarian pursuit (Trigger 1989: 207) focused on the unsystematic excavation of kurgans (round barrows). However, by the turn of the 20th century Russian archaeology had begun to develop its own field methods and interpretive frameworks. The most significant development in this period was the construction by Aleksander Gorodstov of the sequence of cultural horizons that would become the basis for Bronze Age phasing in the region that consisted of; Yamnaya (or pit-grave), Katacombnaya (catacomb-grave), and Srubnaya (timber-grave, Gorodtsov 1907; Shishlina 2008: 8).

While initially continuing along the same trajectory the early Soviet period saw Marxist doctrine began to be applied to archaeological discourse; although by no means in a completely coherent Marxist manner (Miller 1956: 46; Trigger 1989: 214; Platonova 2010: 309; Klejn 1993). A core Marxist principle held that social interaction, development, and organisation were all dependent on the means of production (Gregory and Stuart 2004). This would suggest that a Marxist archaeology would place the organisation of production at its forefront, developing a nuanced understanding of how things were made and the wider implications that this would have had on the social organisation of ancient peoples. However, this does not seem to have been the case. Technology is discussed in the early Soviet literature, however, it was only done so in broad historical terms; with the presence of technological change (i.e. the introduction of metallurgy) seen as proxy for wide-ranging societal development (Trigger 1989). Indeed, another core principle of early Marxist archaeology, perhaps one adhered to more closely, was archaeology's alignment with history, focusing on macro-scale events which could be seen reflected in broad changes in modes of production. This was at the expense of more localised studies which would seek to understand the detailed organisation of production (Klejn 1993, 2006; Trigger 1989). Archaeologists working within the Soviet Union and outside suggest that the archaeology of the early Soviet Union could only claim to draw on selected Marxist principles, rather than being a full 'Marxist archaeology' (Klejn 2012).

Under Stalin the system of archaeology, now under direct control, continued to be focused on the wider aims of the State. At this time contact between Soviet and foreign scholars was forbidden and many prominent archaeologists of the previous era lost their posts and were in some cases exiled or imprisoned. A central tenant behind this change was to fully bring cultural policy in line with Marxist-Leninist philosophy (Trigger 1989: 223). Despite the valuable consequence of an increased interest in the way people lived, Stalin-era archaeology was subject to severe conceptual restrictions based around the unilinial evolutionary scheme developed by Engels (1902: 255).

This system of hierarchy in social organisation increasingly informed archaeological interpretation and the focus of discussion shifted, at least in part, from the cultural histories of multiple ethnic groups to the history of a single people, cumulating in the communist state. This approach avoided external determinism, stressing the socially conditioned internal development of this evolution (Shnirelman 1995: 123; Trigger 1989: 226). Ultimately though, within the eras of Lenin and Stalin, "*Marxism was what the management said*" (Klejn 2012: 152). Embracing Marxism potentially provided an opportunity for archaeology to place the analysis of production at the centre of archaeological discourse, something the West was reticent to do until relatively recently. However the opportunity was missed, passed over in favour of an archaeology which served the wider ambitions of the State in much more immediate and, perhaps in some ways, narrower terms.

Following the death of Stalin in 1953 there was a gradual loosening of the adherence to Marxist theory, which led to archaeology following a more explicitly objective framework (Bulkin et al 1982). In this period the bulk of scholars centred on a highly empirical approach, one which Klijn describes as relying on "*common sense*" and "*built on shaky methodological foundations*" (2012: 55). This 'theory-free' approach can be seen in much of the Soviet literature of the 1960s and 70s. However, a minority of archaeologists perused a "*spectrum of trends*" that drew on numerous disciplines and theoretical frameworks. Bulkin et al (1982) suggest that, outside of the dominant empirical framework, Soviet archaeology followed three trends that they term; Archaeological History, Archaeological Ethno-genesis and Archaeological Sociology (Shnirelman 1998; Zdanovich and Gaiduchenko. 2002; Zdanovich and Kirillov 2002). While each approach had its own conceptual frameworks they were united in their rejection of a need for a 'specifically archaeological theory', instead suggesting theory could be appropriated from other disciplines. In the Southern Urals ethno-genesis became particularly dominant toward the end of the 1980s, partly due to the aim of legitimising borders and forming administrative units and republics (Tishkov 1994).

This had a significant impact on Central Eurasia, where archaeological evidence seemed to suggest a series of defined frontiers and horizons. Perhaps the most significant of which, in terms of the central Eurasian Bronze Age, was the 'Andronovo Horizon' (2000- 1500BC) which was identified at sites from the Urals to the Altai (Figure 2.1, Frachetti 2008: 43; Hanks et al. 2007; Koryakova and Epimakhov 2007: 128). The materials from these sites share a number of common attributes that some authors see as indications of cultural/ideological/political commonality such as the 'Andronovo Horizon' (Frachetti 2008: 32; Sorkin and Gryaznov 1966: 5). By the end of the 20th century the increasing pace of archaeological discoveries and the integration of novel analytical approaches began to render the idea of a single monolithic culture difficult to maintain (Koryakova and Epimakhov 2007). It is now clear that regional differences were significant, not only in terms of typology, but in the way in which communities were organised.

Originally excavated in the 1970s, the settlement site of Sintashta and its associated necropolis were originally attributed to the Andronovo Horizon. At the time of excavation the site was unique in the region, being characterised by a formalised internal structure, large fortifications, and reports of 'substantial' evidence for metallurgy (Gening et al. 1992). Later in the 1980s the site of Arkaim, located 46km to the west of Sintashta, was identified during plans to dam and flood a river valley (Zdanovich 2002). Excavations

revealed a settlement with a similar structure and a comparable range of material culture. Together these two sites formed the basis of what became known as the 'Sintashta Culture'. In parallel to these discoveries the geologist I. Batanina, who was attempting to identify mineral resources in the area, identified more than 20 similar sites in an area of 200 by 400 square km from declassified aerial and satellite photographs (Batanina and Hanks 2012). This area became known as the 'Country of Towns' (Zdanovich and Batanina 2007; Zdanovich and Zdanovich 2002).

The identification of the 'Country of Towns' coincided with the collapse of the Soviet Union, and this significant political change created a new kind of academic freedom. This period also saw an increase in the attention of foreign scholars who wanted to explore broad, pan-regional models using World Systems Theory, and who were looking to link the, previously disarticulated, archaeologies of Europe and the Far East (Kohl 2007; Linduff 2004; White and Hamilton 2009).

2.1.1 Archaeology after the USSR: integrating Russian and Western approaches

While the collapse of the Soviet Union presented an opportunity for archaeologists from Russia and the West to collaborate fully for the first time in nearly a century, academic isolation meant that the West was largely ignorant of the discoveries and data which had emerged during the Soviet era. In turn, many Russian archaeologists continued to work within a culture historical framework underpinned by an evolutionary Marxist approach (Anthony 2006; Trigger 1989: 207). At their most traditional culture historical approaches to archaeology rely on two assumptions, that "*artefacts are expressions of cultural norms" and that "those norms define what 'culture' is*" (Johnson 2010: 16). This approach essentially uses a characteristic suite of material traits to define an archaeological culture which is then equated with a human culture. However, as Johnson argues there is "*no guarantee that the archaeological 'cultures' so lovingly produced by culture historians had any relationship to real human communities*" (Johnson 2010: 22). The rejection of this culture history in western archaeology was one of the uniting principles of new/processual archaeology. Both Binford and Clarke rejected the descriptive, unscientific and un-anthropological aspects of culture histories (Binford 1962; Clarke 1973). Clarke was scathing in his description of an approach that *"takes all the running you can do, to keep the same place"* (The Queen to Alice, Through the Looking-Glass, Lewis Carol, Clarke 1978: 3), asserting that more data and the continued acquisition and description of archaeological material does not give a better understanding of the past (Johnson 2010:13; Clarke 1978: 3).

Modern Russian culture-history has its roots in early 20th century western archaeology and the Soviet/Marxist empirical approach favoured in the latter decades of the 20th century (Klejn 2012). While in some ways it remains explicitly formalist there is much more of a tendency in Russian archaeology to equate archaeological cultures with ethno-linguistic and even genetic groups, subjects which are treated with greater caution by Western scholars (Anthony 2006: 43; Frachetti 2008: 34; Shnirelman 1995). However, like western culture-historical approaches, the framework practiced in Russia struggles to explain change in cultural groups beyond the restricted themes of migrations and diffusion (Johnson 2010, Trigger, 1989).



Figure 2.1 Distribution of sites originally attributed to the Andronovo horizon (adapted from Koryakova and Epimakhov 2007: 125).

Anthony argues that this is more than just a consequence of differing academic traditions and is related to the broader history of the Russian experience, where extreme cultural frontiers were more commonplace in the relatively recent past (Anthony 2006: 44). While many Russian archaeologists consider archaeological cultures to be useful shorthand for specific and regularly repeated sets of cultural materials, they are often more willing to give interpretive weight to these cultural frontiers even when prehistoric material is internally varied. It has been argued that such cultural groups are contrivances constructed with little critical reflection or concern for the complex theoretical issues which attend to equating things with peoples (Clarke 1968; 1973; Shanks and Tilley 1993). Yet there remains a logic to their development when considering the scale of archaeology in Russia; where, for example, in Britain comparatively large amounts of archaeological fieldwork is conducted within restricted geographic boundaries, in Russia problems extend over large geographic regions with relatively few excavations. So it could be argued that culture historical frameworks still have a use in Russia, albeit detached from some of their rigidity and ethnic connotations (Hommel, pers. com.).

For many of the same reasons, migrationist explanations of cultural change have also remained common in central Eurasian archaeology (Anthony 2006: 45). Scholars, like Gamkrelidze and colleagues (1995), have tended to treat changes in material assemblages simply as the reflection of the movement and expansion of different ethnic groups; while, Western scholars such as Renfrew, have looked more to changes in internal social dynamics to explain observed change (Gamkrelidze et al. 1995; Renfrew 1987). Anthony argues that; *"migration is under-used by western archaeologists as an explanation for cultural change, and is over-used by soviet and post-soviet archaeologists"* (Anthony 2006). In the past two

decades a number of larger scale international conferences have taken place with the aim of promoting a synthesis between Russian and Western archaeologists and there is little doubt that these issues are slowly being addressed (Boyle et al. 2002; Hanks and Linduff 2009; Jones-Bley and Zdanovich 2002; Levine et al. 2003; Peterson et al. 2006b). A series of large-scale collaborative projects have been on-going, with the results permeating both Russian and overseas academies; examples being the Samara project, which links scholars from the USA and Russia, and recent work at Kargaly, which drew researchers from Spain (Diaz del Rio et al. 2006; Peterson et al. 2006a). Although some of the problems persist, it is clear that the once detached disciplines of Soviet and Western archaeology are now moving together through integrative fieldwork and closer academic collaboration.

2.2 Regional Chronology

The existing chronological framework for the Southern Urals, and more broadly, Central Eurasia, builds upon foundations laid down at the very beginning of Russian archaeology (Gorodstov 1907). The framework of early, middle and late (or Yamnaya, Catacomb-grave, and Srubnaya) is still visible in the culture historical framework which is commonplace today. While the complex periodisation formed around the culture historical framework is frequently used by Russian and a selection Western scholars, others have tended to work within a more general periodisation and, more recently, C14 chronologies (cf. Gei 1999; Kohl 2007; Koryakova and Epimakhov 2007; Kuzmina 2008; Hanks et al. 2007).

The Central Eurasian Bronze Age extends over two and a half thousand years, between 3500 BC to approximately 900 BC (Table 2.1). This is typically broken down into Early, Middle, Late and Final Bronze Ages. According to Koryakova and Epimakhov (2007), the Early Bronze Age covers 600 years, from 3500-2900, the Middle Bronze Age a period of 900 years (2800-1900), the Late Bronze Age a period of 400 years (1800-1400) and the final Bronze Age a period of 400 years (1300-900). However, within this outline there are numerous sub-phases based on individual cultural groupings which appear to give a greater chronological resolution.

A breakdown of the cultural chronology for the Southern Urals can be seen in Table 2.1. Although this chronology is useful, it does not acknowledge the spatial relationships of these groups beyond broad geographical regions. Indeed this is one of the major problems with the way in which archaeological cultures are presented; individual groups tend to be expressed as discrete entities shown on separate maps, giving few points of reference as to how the different groups related to each other geographically or chronologically (such as Koryakova and Epimakov 2007 Figures 2.1 and 2.2 and Kuzmina 2008 maps 9 and 13). In a similar manner to the way in which nation states are today asserted through the production of national maps, the production of individual maps for entities such as "*the Petrovka culture*" or "*the Andronovo culture*" implies that a level of unity exists within these groups, and greater disparity between them. Figures 2.3 and 2.4 show a distribution of the Bronze Age cultural grouping in wider Central Eurasia. These have been compiled from both comparative maps, which seem to show very little overlap, and individual maps of site distributions, which have been overlaid to try to express the extent that these groups overlap. They show that while some patterns appear to be geographically restricted others cover a significant region. They also show that there is considerably more spatial overlap

between 'cultures' than is typically expressed (Anthony 2006; Koryakova and Epimakhov 2007).

In contrast to this fragmenting approach some archaeologists, most notably Evgenii Chernykh (1992), produced larger scale synthesis based on technological zones, some of which cover much of northern Eurasia and parts of Europe and Eastern Asia. Rather than fixing his focus on the identification of cultural boundaries through diagnostic differences in material remains, Chernykh (1992) aimed to explore the mechanisms through which similarities and shared attributes existed over a significant area (Chernykh 1992; 2008; 2009; Kohl 1992). As a result Chernykh has outlined a series of 'metallurgical provinces' and charted their expansion and contraction through time (Chernykh 1992; 2008; 2009). This work is significant as it incorporates radiocarbon dates into existing culture-historical chronologies. What is produced is a vast, but necessarily low resolution chronological outline which covers Central Asia to Mesopotamia and extends from around 8000-600 BC (Chernykh 1992: 13).

Recently there have been several programs that aimed to produce a more refined chronology for the region which could incorporate both radiocarbon dates and the culture-historical framework (Hanks et al. 2007). The radiocarbon dates suggest that there is a significant chronological overlap between sites attributed to the Middle and Late Bronze Age, with the biggest chronological boundary falling between the late and Final Bronze Age (Figure 2.2). However the dates do reflect the overall periodisation of the relative chronology; albeit in most cases being slightly earlier (Epimakhov et al. 2005; Hanks et al. 2007).

While it is clearly beyond the scope of this project to produce a fully integrated chronology for the region, it is important to understand the chronological and geographic setting in which it is situated. While it has been necessary to incorporate the widely accepted culture-historical vernacular, it should be noted that this thesis has attempted, where possible, to treat these boundaries with caution.

2.2.1 Early Bronze Age of the Southern Urals

In the Southern Urals the Early Bronze Age consists primarily of sites attributed to the Yamnaya cultural group (Gimbutas 1958; Gimbutas et al. 1997; Koryakova and Epimakhov 2007). Early discussions presented Yamnaya communities as *"militant kurgan people"* who conquered and destroyed existing Eneolithic Balkan groups (Koryakova and Epimakhov 2007). Yamnaya period kurgans form the basis of Gimbutas's 'Kurgan Hypothesis' which charted the expansion of groups of horse riding pastoralists from Central Eurasia to a region that extended from Western Europe to the Middle East (Gimbutas et al. 1997). It is argued that both the spread of metallurgy and the spread of Proto-Indo-European languages were facilitated by the migrations of Yamnaya groups (Anthony 2007; Gimbutas et al. 1997; Lahelma et al. 2012). More recently archaeologists have abandoned the concept of a unified Yamnaya group in favour of a more localised approach, with the term Yamnaya used as a expression for a number of groups who shared in common a certain set of archaeological characteristics, but which were in other ways more varied (Koryakova and Epimakhov 2007).

Sites attributed to, what in Russian is now usually termed, "*the Yamnaya cultural and historical intercommunity*" are spread over a vast area of Eurasia from the Black Sea to the

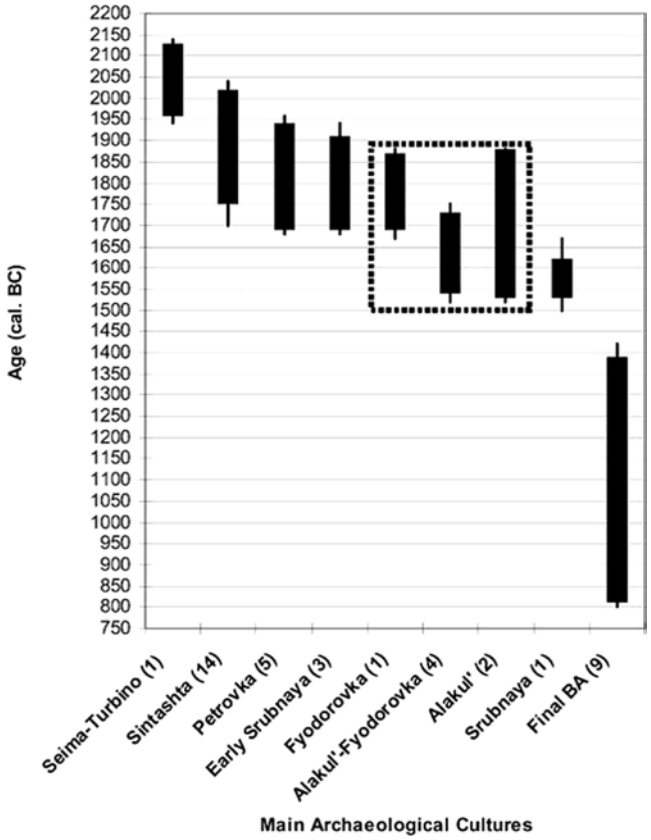


Figure 2. 2 Absolute dates from Bronze Age cultural groups in Central Eurasia (after Hanks et. al. 2007)

western fringe of Siberia (Figure 2.3). The Southern Trans-Ural region is the most easterly area to feature frequent Yamnaya sites (Figure 2.5). Yamnaya sites are typically represented by kurgans located near rivers featuring rectangular inhumation burials with individuals placed on their back or right hand side (Bogdanov 2000; Koryakova and Epimakhov 2007). With the exception of some sites near the Caspian where Yamnaya type pottery has been found, Yamnaya settlements are not identified archaeologically, and it is often argued that Yamnaya groups were seasonally mobile (Bogdanov 2000; Koryakova and Epimakhov 2007). The spread of kurgans along the steppe, which is often considered unsuitable for agriculture, and the lack of agricultural tools recovered from archaeological sites, have been used to argue that the economy was reliant on pastoral stock breeding (Morgunova 2000). Indeed it has been suggested that Yamnaya groups transmigrated in a north-south direction, with winter camps in the south (Koryakova and Epimakhov 2007).

2.2.2 Middle Bronze Age of the Southern Urals

The Middle Bronze Age (2800 and 1900 BC) of the Southern Urals contains sites attributed to three different cultural groups; Abashevo, Sintashta and Petrovka. In absolute terms these sites are broadly contemporary, as can be seen in Figure 2.6 (Chernykh 2008, 2009; Hanks et al. 2007). This period also falls within the early (formation) phase of Chernykh's Eurasian Metallurgical Province (EAMP), which extends from the Pontic-Caspian steppe to the eastern Urals (2008, 2009). Indeed, while the general culture-historical framework cites these cultural units as discrete (Koryakova and Epimakhov 2007, Kuzmina 2008), Chernykh argues that there is little, particularly in terms of material culture, to differentiate

Table 2.1 Chronology for the Southern Ural Bronze Age, after Koryakova & Epimakhov 2007:9.

		Cis-Urals		Trans-Urals	
Period	Date (BCE)	Steppe	Forest Steppe	Steppe	Forest Steppe
Early	3200		Early	Tersek	Surtandy
	3100		Bronze Age	|	|
	3000			|	|
	2900	Yamnaya	Cultures	|	|
Middle	2800	|		|	|
	2700	|		Yamnaya	|
	2600	|		Poltavka?	|
	2500	|			|
	2400	?			
	2300			|	
	2200			|	
	2100		Abashevo	|	
	2000	Sintashta		Sintashta	
	1900	Petrovka	|	Petrovka	|
Late	1800	Alakul'	Srubnaya	Alakul'	Petrovka
	1700	Srubnaya	Alakul'	Fyodorovo	Alakul'
	1600	Fyodorovo			Fyodorovo
	1500	|		Sargary	
	1400	|	Mezhovka	|	Cherkaskul
Final	1300	Sargary	|	|	Mezhovka
	1200	|			|
	1100				|
	1000				
	900	|	|	|	|

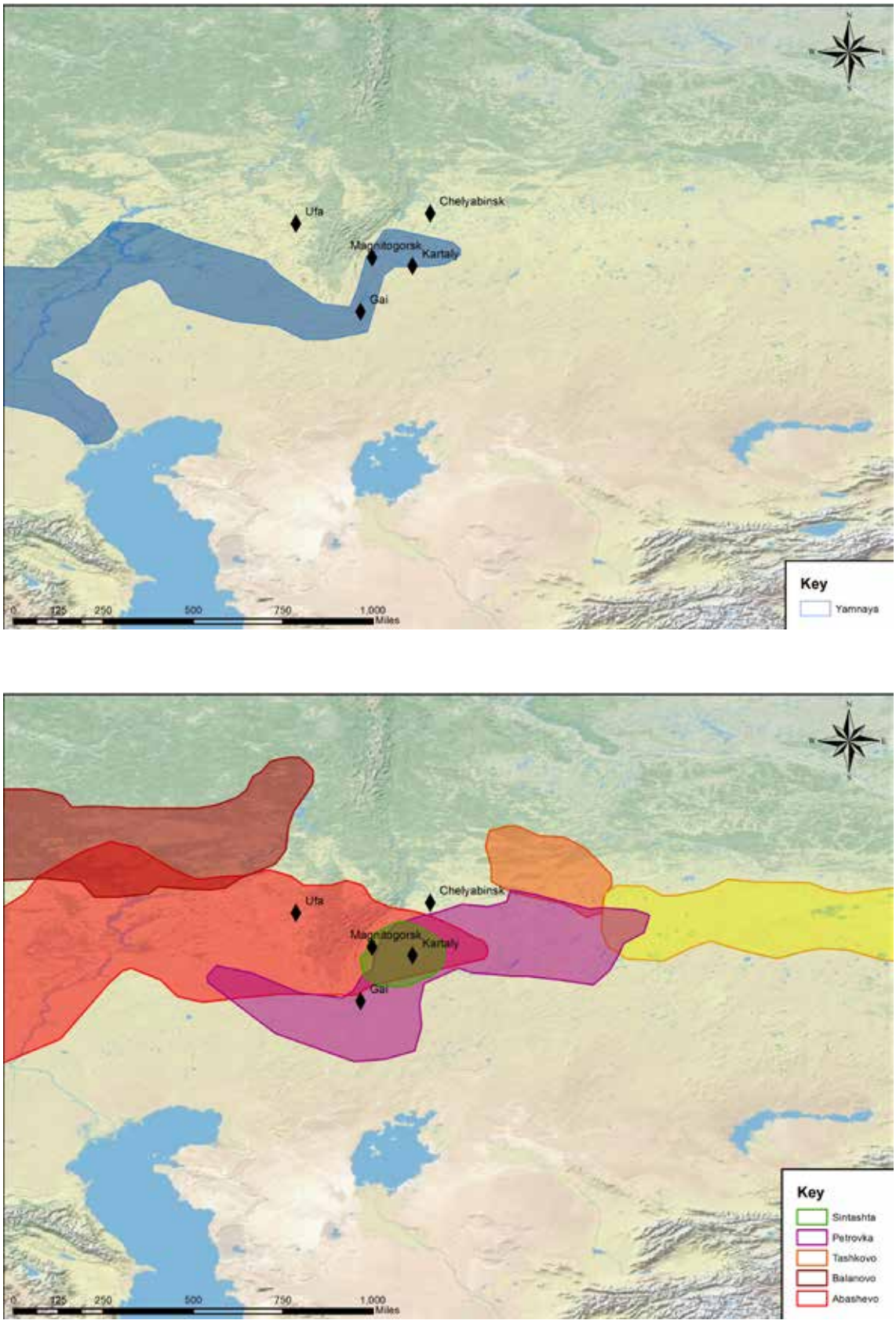


Figure 2. 3 The spatial extent of typically accepted Early Bronze Age (top) and Middle Bronze age cultural groups in Central Eurasia (adapted from Hanks et. al. 2007 and Koryakova and Epimakhov 2007: 58)

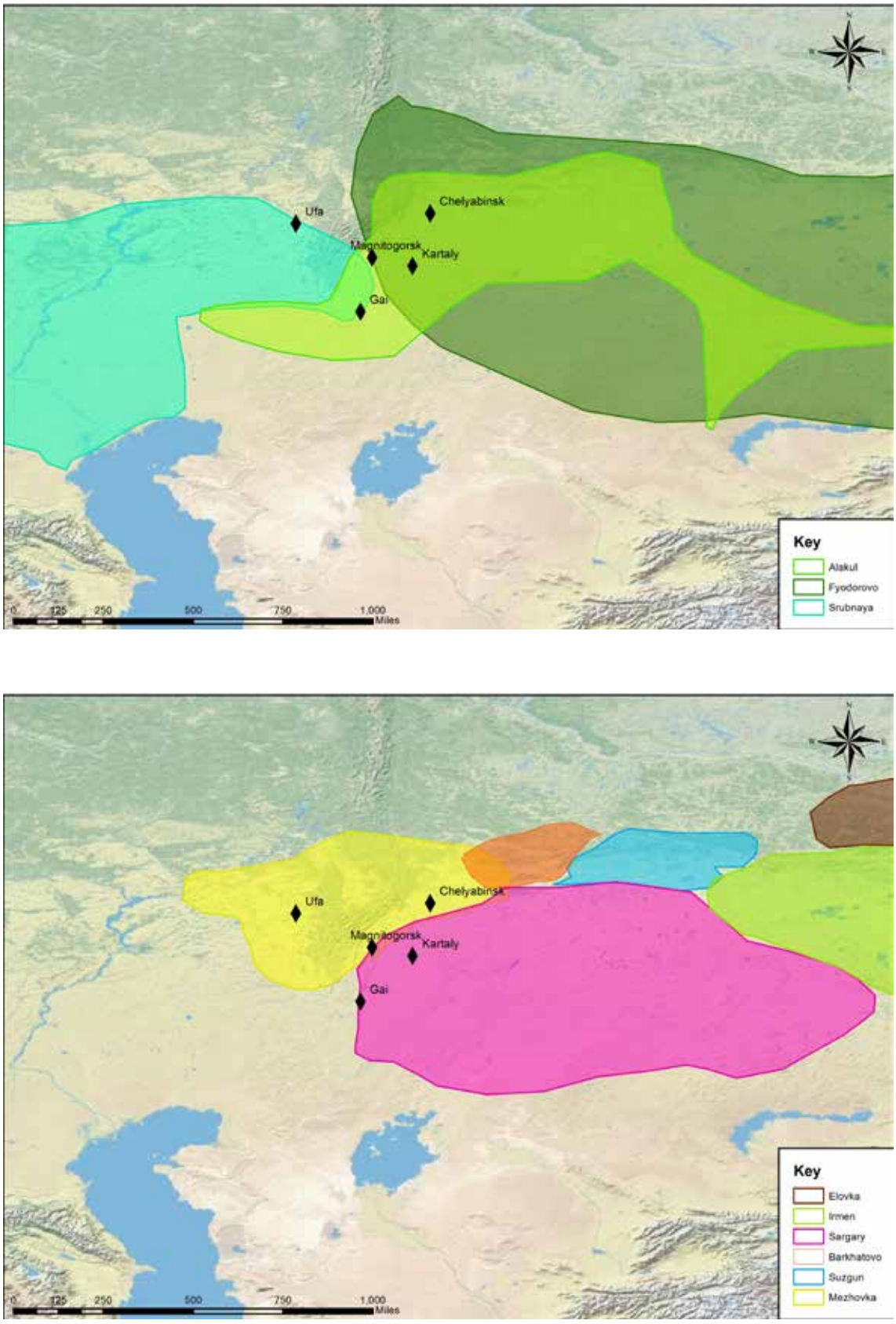


Figure 2. 4 The spatial extent of the typically accepted Late Bronze Age (top) and Final Bronze age cultural groups in Central Eurasia (adapted from Hanks et.al.2007 and Koryakova and Epimakhov 2007)

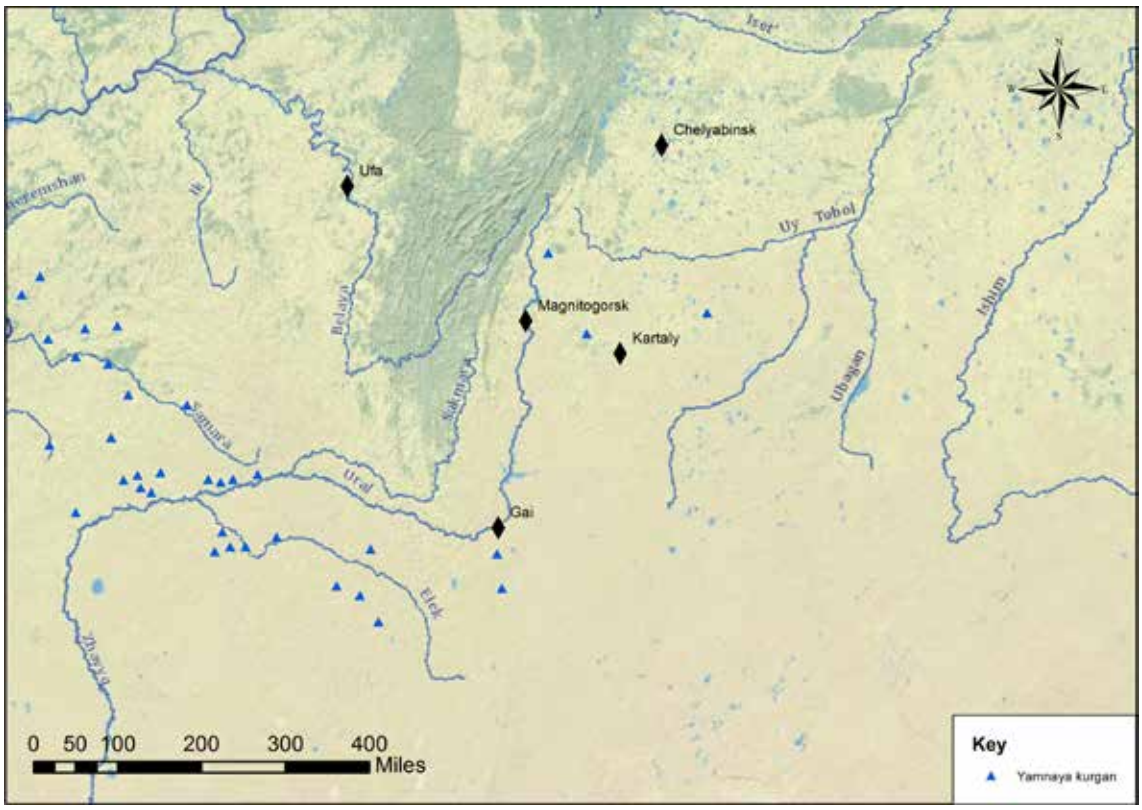


Figure 2.5 Distribution of Yamnaya sites in the Southern Urals (redrawn from Koryakova and Epimakov 2007)

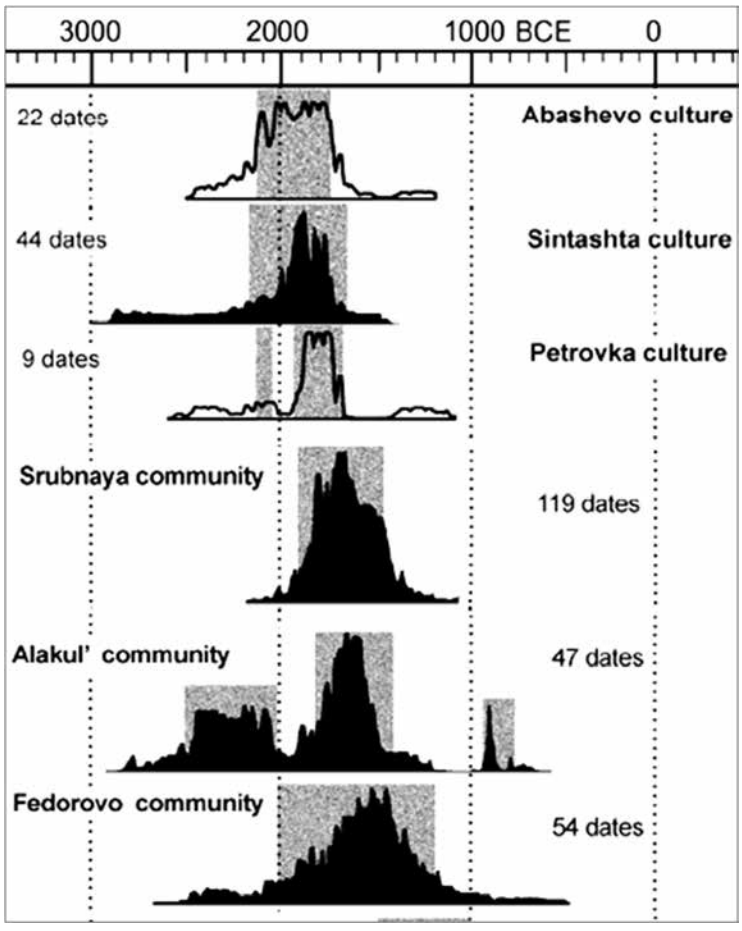


Figure 2.6 Collection of radiocarbon dates by Chernykh 2009

them. Rather, he sees this period as a formative, and wide reaching, metallurgical phase featuring "*swift waves of population movements…[and] expressive but, at the same time, amazingly contrasting essential features*" (1992: 132). He suggests that these phases began with Abashevo-Sintashta-Petrovka peoples expanding in a west-east direction, creating what he terms a 'cultural continuity' covering an expansive region. This was followed by the first appearance of Seima-Turbino materials, which he sees as an east-west migration from the Altai all the way to Finland (see the following section).

In relative terms the earliest of the Middle Bronze Age sites in the Southern Urals are attributed to the Abashevo community that, despite significant chronological overlap, were probably formed before the Sintashta groups (See Hanks et al 2007 for discussion). In absolute terms the earliest dates for Abashevo sites extends beyond Sintashta dates on both sides (Figure 2.7) (Chernykh 2008, 2009).

In many publications Sintashta and Petrovka groups are often considered to be part of the same cultural unit. Indeed they are often conflated into the 'Sintashta-Petrovka culture' (Anthony 2007). Archaeologically, most material is similar between the two groups, although some Petrovka ceramics are distinct from Sintashta ceramics. However, the key difference between the two patterns is their settlement morphology. In contrast to the three types of settlement that characterise the Country of Towns (discussed in more detail in the next section), Petrovka settlements generally have a linear layout of house structures with far less elaborate enclosures (Anthony 2007: 443; Koryakova and Epimakhov 2007: 82).

Stratigraphically, where Sintashta materials and settlements have been found in a direct association with Petrovka remains the Petrovka artefacts overlie the Sintashta material (Anthony 2007: 443; Vinogradov 2004). Therefore, despite the significant overlap in absolute dates (Figure 2.6) it seems that in some areas Petrovka communities developed later than Sintashta communities, while other may have been coeval. As the sites explored in this thesis have been attributed to the Sintashta phase the full characteristics and attributes which have been used to define it will be discussed in greater detail in the final part of this section.

Unlike the other 'cultures' attributed to the Middle Bronze Age, the term Seima-Turbino does not represent a distinct group, rather a collection of sites which feature characteristic metal and worked stone artefacts. What is special about these collections is the geographic range of the sites. The main Seima-Turbino find-spots, shown in Figure 2.8, cover an area from the Altai to Finland and occur in regions, and in some cases on the same sites, as material of other cultural groupings (Chernykh 1992: 215). Because of these factors Chernykh has termed it the "*Seima-Turbino trans-cultural phenomenon*", suggesting that is somehow exists outside of what is traditionally understood as an archaeological culture (Chernykh 1992: 215, 2009).

The chronological scope of Seima-Turbino sites is unclear. While absolute dates, although few in number, suggest that the sites could be as early as 2100cal.BCE (Hanks et al. 2007), most literature, particularly older articles, consider Seima-Turbino archaeological materials to be a distinctly Late Bronze Age development. This may be a due to the appearance of tin-bronze artefacts, which are traditionally seen as indicative of Late Bronze Age traditions

(Grigor'yev 2002). Interpretations as to what these sites actually represent is a contentious issue in the region, with some suggesting the sites are the result of diffusing technological traditions (Koryakova and Epimakhov 2007) while others (Chernykh 1992: 217; Kuzmina 2008) suggest that the sites resulted from migrations of highly skilled metallurgists and/or a warrior elite migrating west from the Altai region. The dominant argument seems to be that the spread of distinctive, and complex, metalwork is indicative of either a rapid diffusion of an advanced technological system (Figure 2.9, White and Hamilton 2009) or an invasion/migration of Seima-Turbino populations (Chernykh 1992: 215). White and Hamilton assert that the rapid spread of Seima-Turbino type metalwork could not have been due to the movement of materials alone, but rather required the movements of skilled craftspeople. Conversely, Chernykh is clear in his assertions that the sites represent an invading force, both conquering and oppressing local peoples. He suggests that the sites in which both Seima-Turbino material and other cultural types are found alongside each other prove the presence of an oppressive, elite force (Chernykh 1992: 215). Though Koryakova and Epimakhov suggest that the movement/migration/transmission of Seima-Turbino metalwork had little impact on the steppe groups, suggesting that the existing technological traditions were sufficient to repel Seima-Turbino groups (Koryakova and Epimakhov 2007).

There is no doubt about the presence of such distinct metalwork over such an expansive region, but interpretations often seems laboured, particularly given the relative paucity of finds and the lack of chronological resolution (White and Hamilton 2009). The migration/invasion theory seems to place a great deal of weight on a comparatively few artefacts. Seima-Turbino metalwork makes up only 1% of Chernykh's corpus of Bronze Age material (1992: 215), yet is argued to be the product of a vast geographical spread of population. The suggestion that it must represent the movement of craftspeople rather than trade alone also seems overly simplistic. Even the most basic chronology for the region shows numerous examples of local and micro-regional dynamics (Koryakova and Epimakhov 2007), yet to feverishly join point A to point B on a map belittles the significance of these artefacts. There is nothing to suggest that the incorporation of Seima-Turbino types into local production systems did not occur, indeed the use of local ore types in many of the regions in which the metalwork is found beyond the Altai suggests that this was the case (Chernykh 2008, 2009). Even if all of the artefacts were produced by a small number of Seima-Turbino smiths there is no reason to suggest that they did not move through local trade and exchange networks so as to account for their wide coverage, perhaps with some of the finest pieces reserved for certain aspects of the community. It is possible that this distribution was followed by the production of local copies, with the same taboos on ownership maintained, leading to the apparent segregated distribution of the metalwork.

2.2.3 Late Bronze Age of the Southern Urals

The Late Bronze Age of the Southern Urals features the Fyodorovo, Alakul' and Srubnaya cultural groups (Figure 2.10). However, there is not a particularly distinct cultural horizon between the Middle and Late Bronze Age. Indeed, Petrovka sites in particular have often been attributed to the Late Bronze Age, while the absolute dates (shown in Figures 2.2 and 2.6) also indicate little diachronic difference between Middle and Late Bronze age groups (Chernykh 2008, 2009; Hanks et al. 2007).

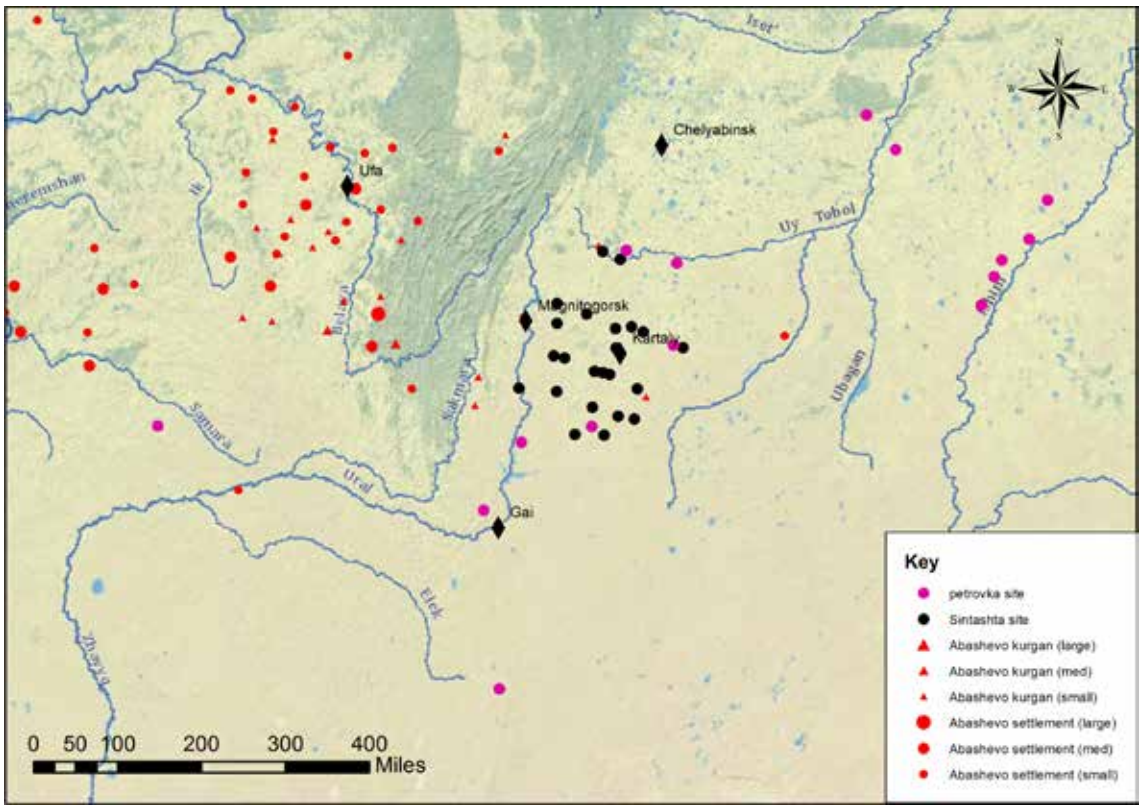


Figure 2.7 Distribution of Middle Bronze Age sites in the Southern Urals (redrawn from Koryakova and Epimakov 2007).

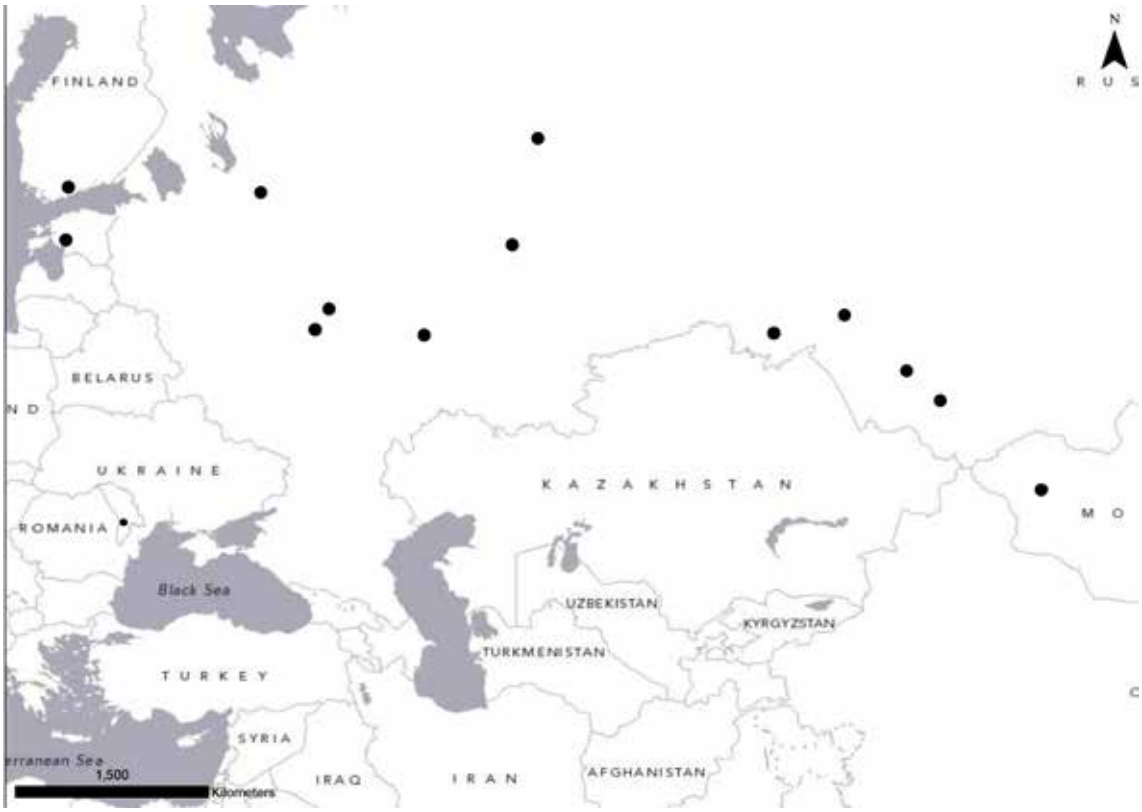


Figure 2.8 Location of Seima-Turbino find sites, Redrawn from Chernekh (1992, basemap ESRI)

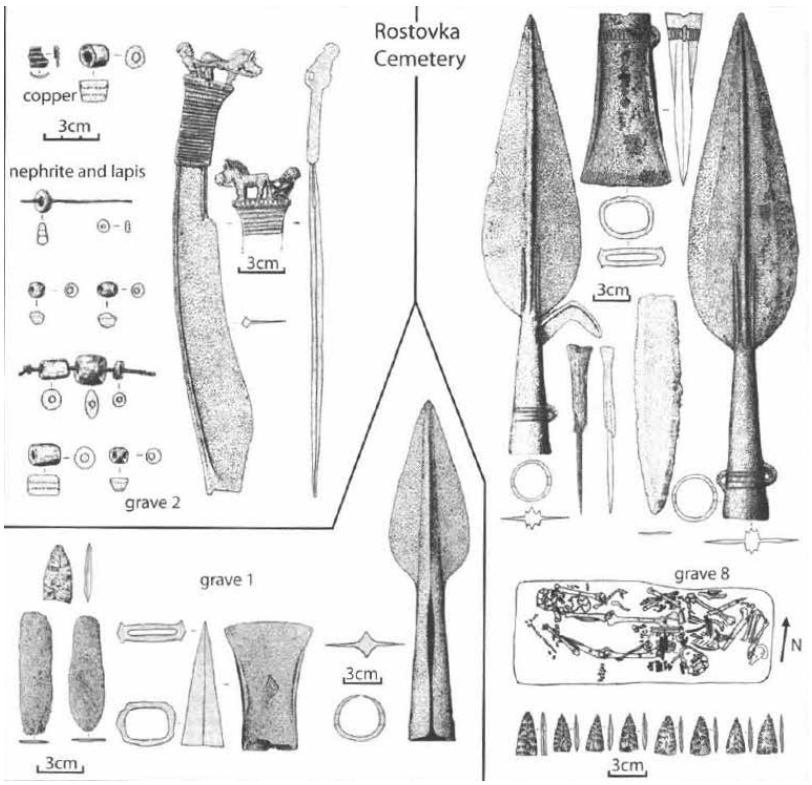


Figure 2. 9 Seima-Turbino metalwork from the Rostovka cemetery (Anthony 2009: 446).

The absolute dates presented by Hanks and colleagues suggest that Alakul', Fyodorovo and Early Srubnaya sites emerged at a similar time, with Alakul'-Fyodorovo and late Srubnaya sites developing later (Figure 2.2, Hanks et al. 2007). However, Chernykh's phasing contains an earlier set of Alakul' dates which fall before any of his Middle Bronze Age dates (Figure 2.6, Chernykh 2008, 2009). This trend is also noted in the relative chronology, where there is no direct linear relationship between the groups, with different sequences emerging in different sub-regions (Koryakova and Epimakhov 2007).

To the east of the Urals these groups are considered to be part of the Andronovo horizon, which incorporated both Alakul and Fyodorovo sites (Anthony 2007). What these terms actually represent is, however, not particularly clear, and Anthony (2007) suggests that there are only minor artefactual differences between these groups and supposedly earlier Petrovka and Sintashta communities. However, at some key sites Alakul styles of ceramic have been identified stratigraphically below Fyodorovo styles, so it is possible that there is a chronological difference (Anthony 2007: 448).

These late Bronze Age communities form the stabilised phase of Chernykh's EAMP. This is characterised by what he describes as a "*stabilisation of steppe belt cultures and communities*" which extends from the Pontic-Caspian to the borders of his East Asian Metallurgical Province. This "*pattern of cultural continuity*", he argues, was the direct result of the Middle Bronze Age dominance of the Sintashta and Petrovka groups at the expense of Seima-Turbino groups in the region (2008, 2009).

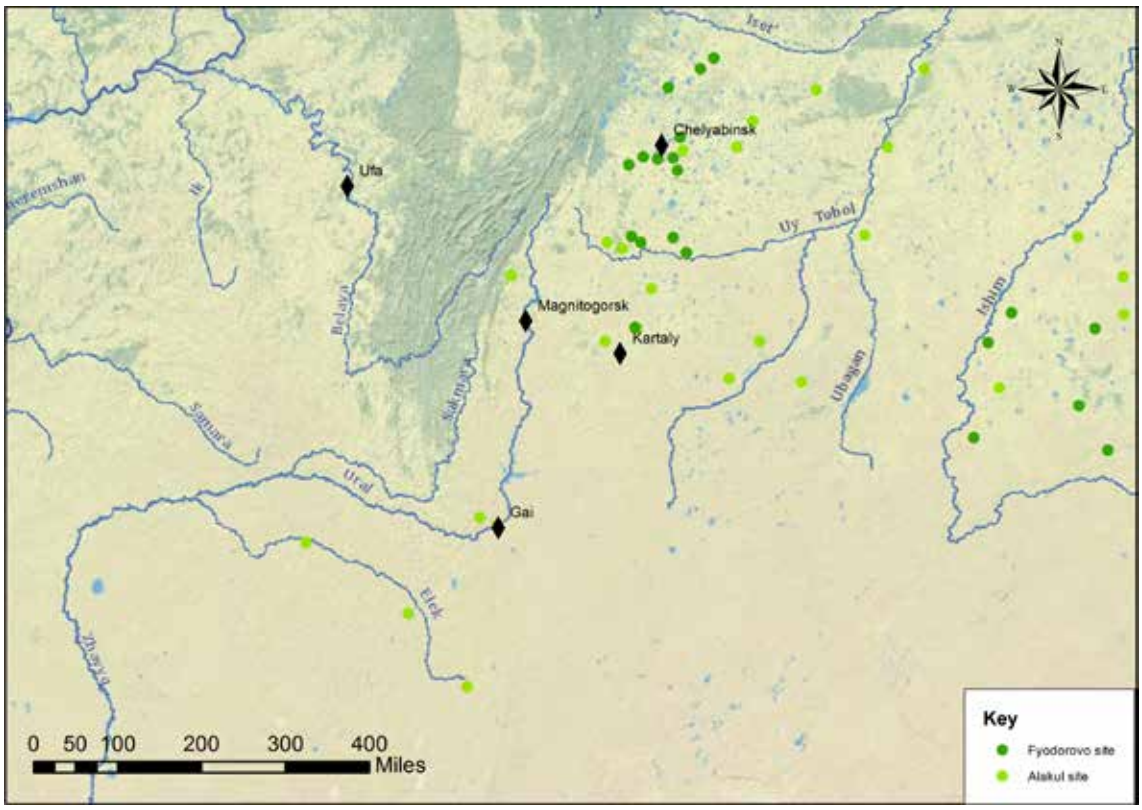


Figure 2.10 Distribution of Late Bronze Age sites in the Southern Urals (redrawn from Koryakova and Epimakov 2007).

2.3 The Sintashta Complex

The previous sections have outlined the main chronological patterns in the Southern Urals. In order to understand the significance placed on aspects of the Middle Bronze Age this section will present a detailed outline of the Sintashta complex. It will include a discussion of settlement typology and an outline of the common suite of material remains and burial practices which have been used to define the Sintashta cultural unit. It will also consider some of the similarities and differences, both geographically and chronologically, between Sintashta patterns and those of neighbouring groups.

2.3.1 The Country of Towns

Twenty-three settlements are known within the Country of Towns. The majority of these sites were identified using aerial photography and topographic survey (Batanina and Hanks 2012; Gening et al. 1992; Hanks and Doonan 2009; Zdanovich and Batanina 2007). Zdanovich and Batanina (2007) have suggested a broad typo-chronological sequence based primarily on the sites' shape in plan. In this scheme, oval settlements, such as Alandskoe, Bersaut, Isinei I, Kizilskoye and Rodniki are considered to be from the earliest phase, followed by circular settlements, such as Arkaim, Sintashta, Sarym-Sakly, Kuisak, Olgino, and Zhurumbai, with finally square settlements, such as Stepnoye, Chekatai, Konopotyanka, Andreevskoe, Chernorech'ye, Sintashta II, Ust'ye, Bakhta, Karnysty and Sarachnaya (Zdanovich & Batanina 2007). However, recent work at the site of Olgino (Kamennyi Ambar), which was previously understood to be a round settlement, showed that it was in fact a small sub-circular settlement with a secondary, more rectangular extension (Batanina and Hanks 2013; Merrony et al. 2009). The authors suggest that

some of the formal differences may have more to do with settlement growth, rather than changing attitudes towards enclosure architecture (Merrony et al. 2009).

2.3.2 Sintashta settlements

Excavated settlements are characterised by a large earthwork enclosure (inner bank and outer ditch) surrounding a wooden palisade or a wall (Figure 2.11), typically enclosing an area of between 6,000 and 35,000 square metres. The excavations at Arkaim revealed the ditches to be between 2 and 4 meters wide and 1.5m deep. Koryakova and Epimakhov (2007: 70) suggest that the palisade wall may have stood up to six meters high. The settlements are typically located 40 – 70 km apart and occupy flat, dry ground, often near the confluence of two rivers or streams (Zdanovich and Batanina 2007). Geologically the sites seem to fall on, or near to, contact zones of schist and granite (see chapter 5 for detailed geological background).

The interior of the enclosures are structured by a series of sectional 'housing blocks' with mudbrick walls and a floor space of between 100 and 250 square metres. It is often stated that all of the housing blocks had a standard floor plan featuring a divided living and economic area which included furnaces for metal working (Koryakova and Epimakhov 2007: 72). However, this conclusion was largely drawn from a small number of excavated examples and geophysical surveys. There has been little focus on a detailed analysis of the likely activities which took place in the structures.

Cemeteries of this period were generally paired with settlements, typically with some form of water barrier between the two, such as a river or a lake (Gening et al. 1992: 72; Koryakova and Epimakhov 2007). As in other periods of the Bronze Age in the Southern Urals, the burial grounds in the Country of Towns have typically been identified by their kurgan mounds, though the flat grave cemeteries have also been identified, most notably at the eponymous site of Sintashta (Gening et al. 1992).

2.3.3 Material remains

The previous sections have outlined the dominant architectural and monumental structures that are indicative of Sintashta sites which together constitute the Country of Towns. It could be argued that, with the initial discoveries of Sintashta and Arkaim, settlement typology was the most distinctive feature of Sintashta archaeology. However in the subsequent years, following excavations of both settlements and mortuary sites, it became apparent that there was a rich suite of materials which, when viewed in combination, could be broadly seen as being discrete.

Metallurgy has been one of the defining characteristic of the Sintashta phenomenon, particularly the use of copper and copper alloy, although gold and silver are also found in burial contexts (Koryakova and Epimakhov 2007). Metal artefacts have been identified at both enclosures and mortuary sites, with the latter producing the bulk of known material (Hanks et al. 2014). The majority of Sintashta metalwork fits a fairly standard package; one which includes weapons – in the form of socketed axes, spearheads and knife/daggers (although the latter could be considered more utilitarian or multi-functional) – tools, such as chisels, adzes, awls and sickles (Figure 2.12), and jewellery including hair ornaments (Figure 2.13), rings and bracelets (Grigor'yev 2002).

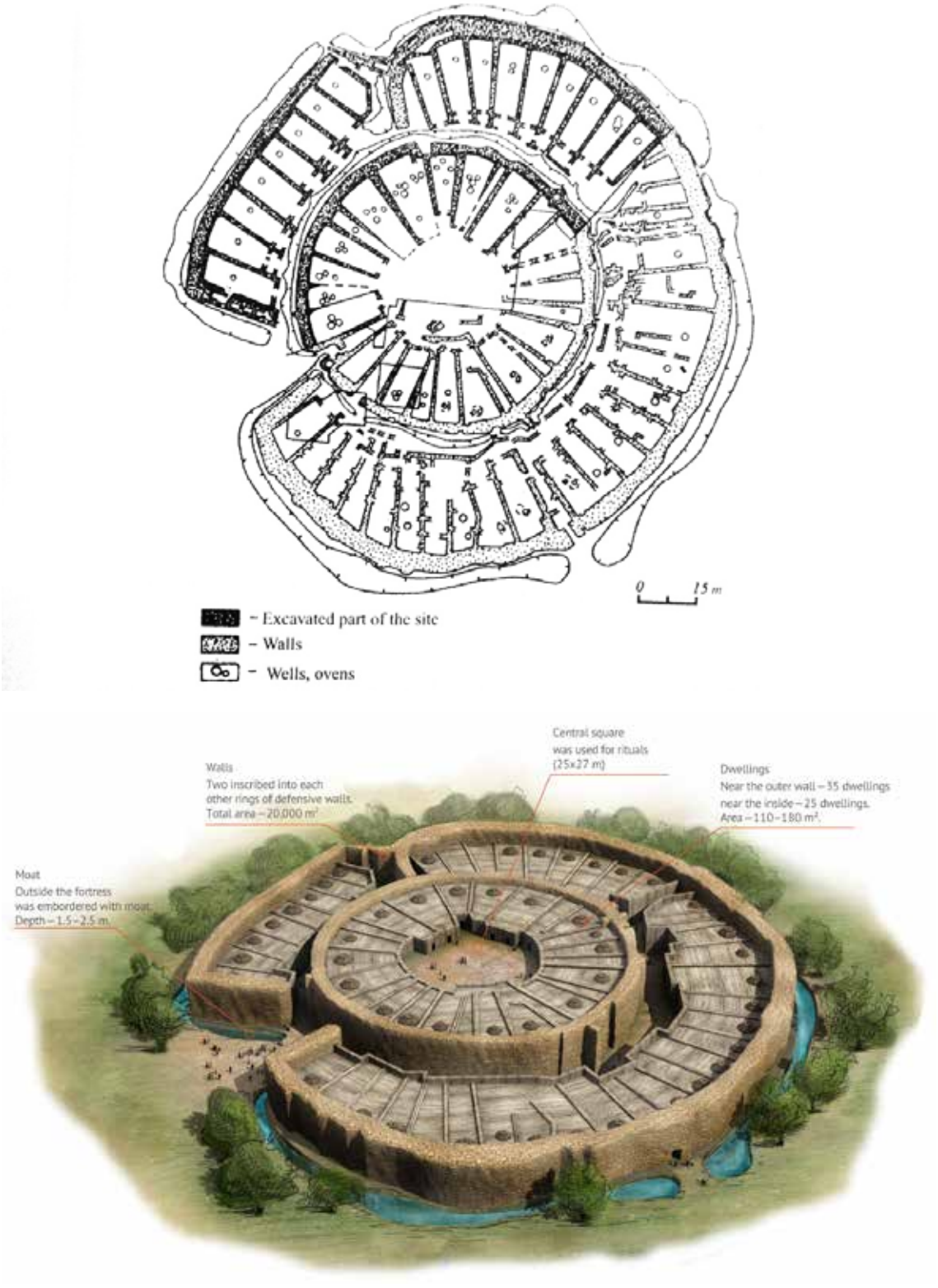


Figure 2.11 Plan of Arkaim, (top, after Zdanovich 1997) and reconstruction and interpretation of Arkaim by the Russian Ministry of culture (bottom, culture.ru)

In addition the most abundant find type in Sintashta period excavations is ceramic (Figure 2.14). There are two main types of ceramic found on Sintashta sites; pots/vessels and metallurgical ceramics. Vessels have been found in a variety of sizes, ranging from small (less then 5cm in diameter) to large; over 20% of the pots found at Arkaim were between 16 and 50 litres in capacity (Koryakova and Epimakhov 2007: 84). The composition of the ceramic varies, and very little petrographic analysis has been carried out on ceramic assemblages, but, based on visual characterisation, talc and silica seem to dominate. Many of the vessels excavated contained fabric impressions on their interior surface. It is typically suggested that this was the result of a forming technique in which the main body section of the pot was formed around a fabric former, either containing sand, a wooden blank or even a smaller pot (Koryakova and Epimakhov 2007: 74; Vinogradov 2013). The latter technique is also evident in a smaller selection of vessels which have positive decorations on their interior which some have suggested resulted from their formation around an uncovered pot base (Vinogradov 2013). A characteristic found frequently with Sintashta pots is evidence of repair, in some cases extensively so (Degtyareva 2010; Vinogradov 2013). This is found in the form of metal pot clasps and staples which typically straddle a fault, some of which were more severe than others.

The other, less common group of ceramics found at Sintashta sites are typically associated with metallurgy. Very little work has been carried out on metallurgical ceramics in the Southern Urals (see chapter 6 for analysis of the metallurgical ceramics from Stepnoye and Ust'ye). These ceramics associated with metallurgy have fallen into two groups; those artefacts seen as tuyéres or blow pipes and those seen as crucibles (Koryakova and Epimakhov 2007). The tuyéres/blow pipes are typically less than 10cm in length and have

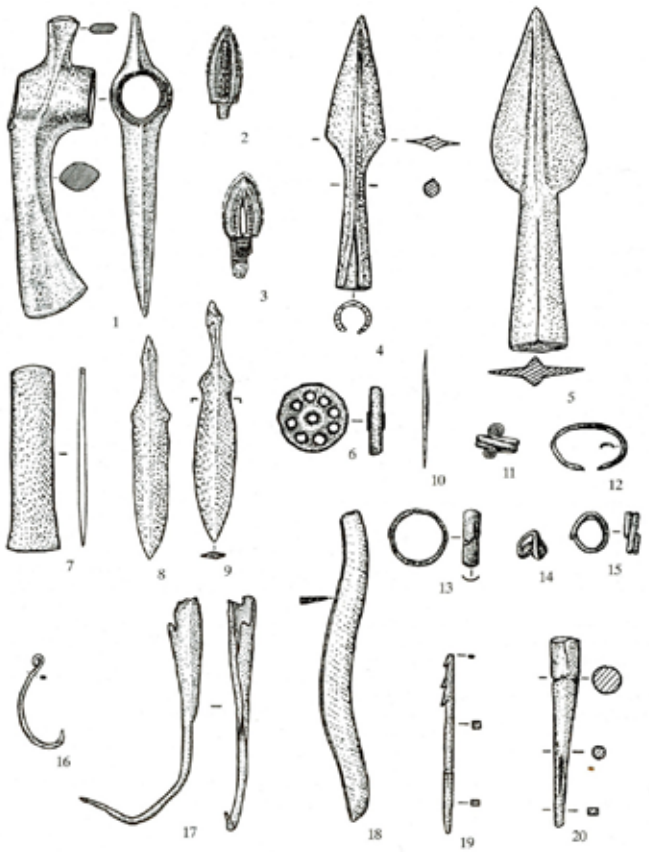


Figure 2.12 Selection of typical metal artefacts from the "Country of Towns" region. 1, 2, 3, 7-9, 11, 12, 14-16; Sintashta cemetery, 5, 18; Kammennyi Ambar V, 4, 6, 10, 13, 19, 20; Bolshekaraganski, 17; Arkaim (Grigor'yev 2002)

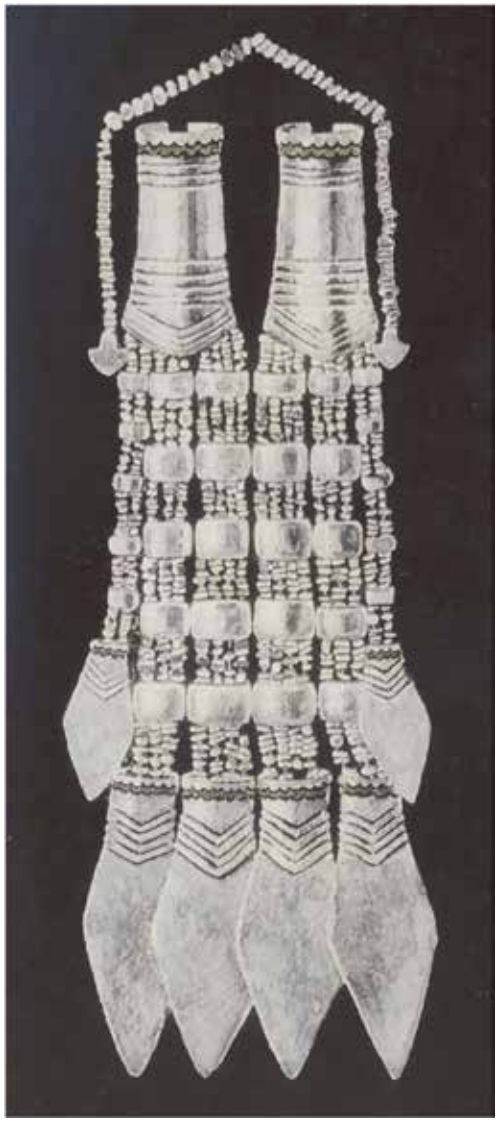


Figure 2.13 Silver Sintashta plait ornament (Grigor'yev 2000: 291)

an internal bore of 0.5-2cm; all have shown evidence of decoration. Very few crucibles have been found in the region, but those which have been identified are typically highly vitrified and amorphous or are open plate-like vessels, similar to the contemporary Abashevo type crucibles found to the west of the Urals (Koryakova and Epimakhov 2007; Vinogradov 2013).

The final material remains that are seen as a defining characteristic of the Sintashta package is the chariot (Figure 2.15). Chariots, although composite artefacts, seem to have been made almost entirely from wood. There are just 16 known chariot burials present in nine excavated cemeteries. Those found have two wheels 1-1.2 metres in diameter with 10-12 spokes (Anthony 2007: 387). The gauge of the chariots has led some to argue that the smaller examples were too narrow to be functional and were purely for ritual or parade (Anthony and Vinogradov 1995; Gening et al. 1992; Vinogradov 2003; Zdanovich 1995). However, Anthony (2007) argues that because they were accompanied by adult males who were adorned with a plethora of weapons, especially 'javelin' points and that their appearance coincided with a new kind of cheek piece, presumably intended to increase the control over the horses used to drive them, that the narrow gauge would not hinder their functionality.

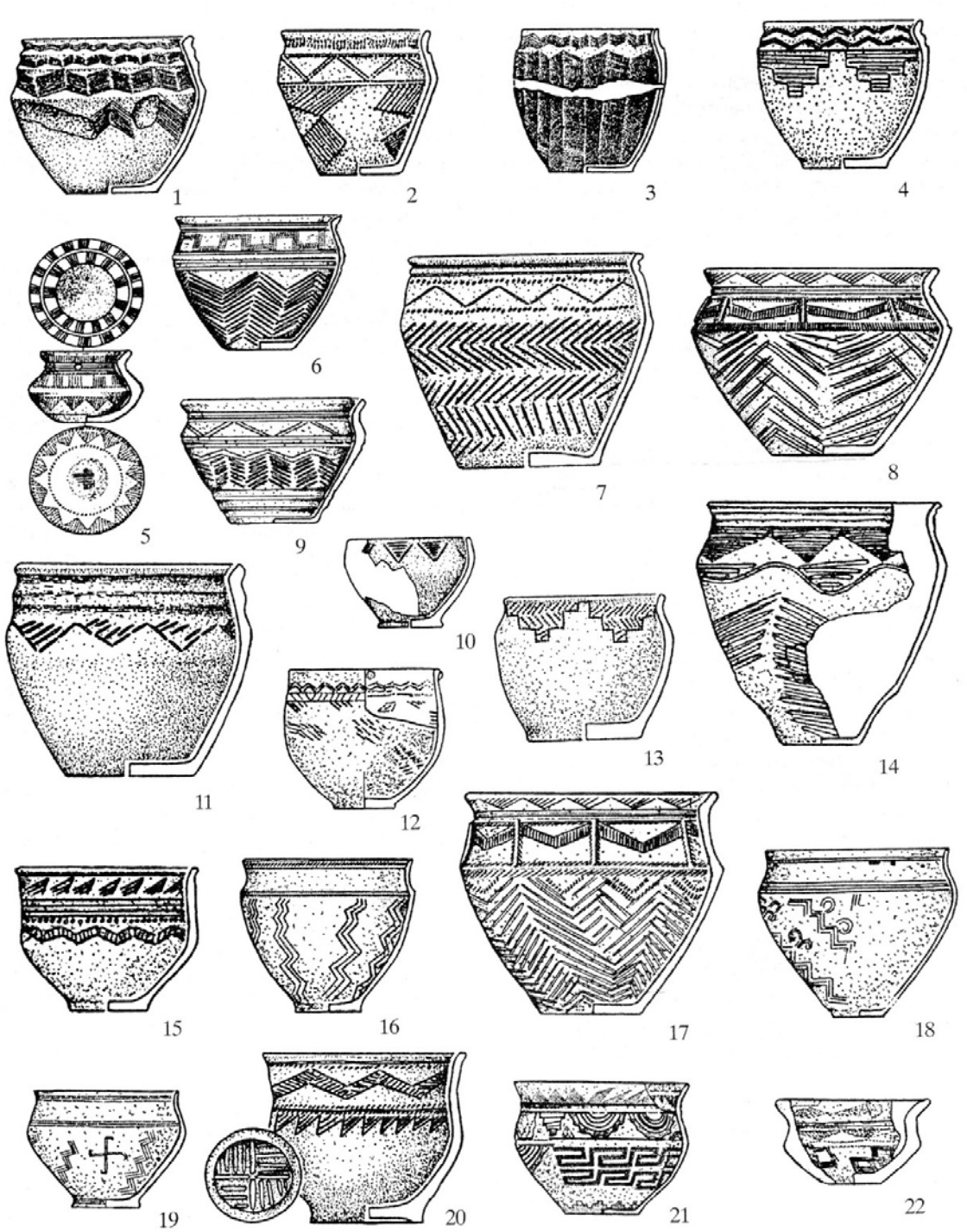


Figure 2.14 Sintashta period ceramics. 1-4, 7, 10, 11, 13, 15, 20; from the Bolshekaraganski cemetery (Arkaim), 5, 6, 8, 9, 16-19, 21, 22; Sintashta cemetery, 12; Kamennyi Ambar V, 14; Arkaim settlement (Grigor'yev 2002)

While the above are often the most discussed aspects of the Sintashta material panoply the settlements and cemeteries are rich with the products of other crafts, such as; ceramics, stone, worked bone and wood, with each material group containing a range of artefacts (Grigor'yev 2002). It is important to note that much of the material culture found on Sintashta sites is not unique to the Sintashta complex; the very fact that it does not respect the supposed boundaries of this area may suggest a great deal more interaction in the region than is implied by the typical culture-historical chronology. As Chernykh (2009: 133) has recently argued, it should be impossible to draw a border between the 'cultures' of the Middle Bronze Age based on material evidence alone.

2.3.4 Burial Practices

In contrast to the scarcity of published settlement excavation data, a large number of Sintashta period burial sites have been excavated and many excavation reports been published, including the cemeteries associated with Arkaim (Bolshoikurgan), Sintashta, Olgino (Kammenyi Ambar) and Chernorech'ye (Krivoe Ozero, Vinogradov 2003, 2005). The bulk of the artefacts discussed above were recovered from these excavations. It is important to note however, that kurgans, the dominant form of Sintashta burial, likely only represented a small portion of the population, with some suggesting that they could represent as little as one third of the settlement inhabitants (Epimakhov 2002; Koryakova and Epimakhov 2007: 93).

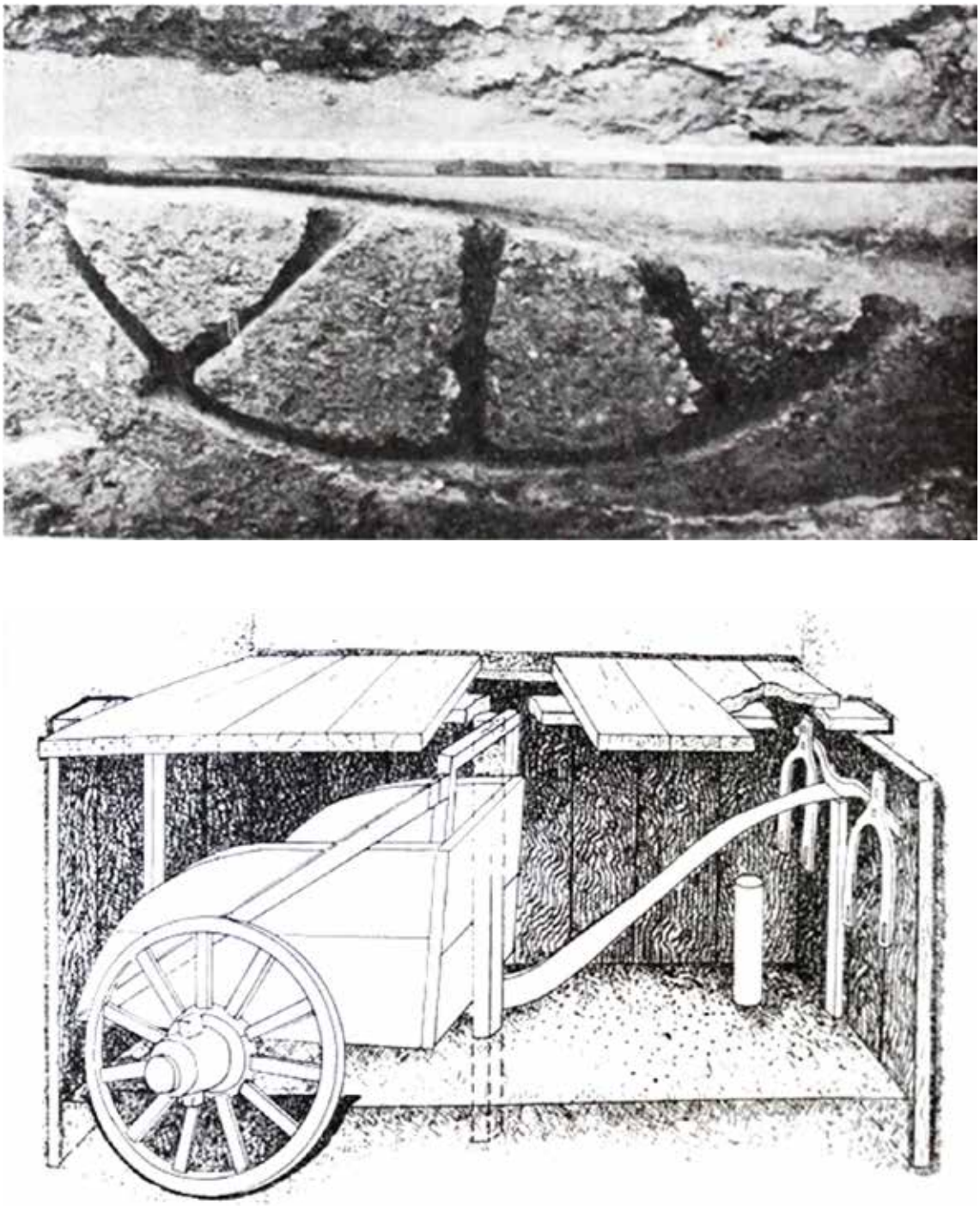


Figure 2.15 Spoked wheel impression excavated at the Sintashta cemetery (top) and a reconstruction of a Sintashta type chariot (bottom, after Gening et al. 1992).

Cemeteries featuring Sintashta kurgans are overwhelmingly located near to settlement enclosures. In the most part, each enclosure is paired with a cemetery and many have been excavated. It is fairly typical, with only two exceptions, for the cemeteries to be located within a kilometre of the enclosure, separated by some form of waterway, either a lake, spring or river (Hanks 2009). It should be remembered though, that while the cemeteries are located near to Middle Bronze Age enclosures they typically span a much broader timeframe, with many including kurgans from the early, late and final Bronze Ages. In fact, some even contain later Iron Age and historic burials, with a few, despite being located many kilometres from modern settlements, still in use today (Doonan et al. 2015).

The structure and arrangement of burial sites is broadly similar over the whole Country of Towns. Most known burial sites appear visibly in the landscape, marked by a kurgan, which is a type of burial mound similar to a barrow/tumuli. Excavated grave pits often feature wooden rectangular structures, sometimes on multiple levels (Figure 2.16). Sintashta period kurgans also feature numerous secondary burials, where a body has been allowed to decompose elsewhere and has then been interred into the kurgan, resulting in the absence of many of the smaller bones (Grigor'yev 2002).

Archaeologically, it is difficult to outline a defined 'Sintashta' burial rite because there are a number of traits that spread far beyond the borders of the Country of Towns and; "*the Sintashta funeral rite is distinguished by its high variability when compared with the background of other Ural Bronze Age cultures*" (Koryakova and Epimakov 2007: 80). However, there are some broad similarities which are used, more generally, to characterise Middle Bronze Age burial. They often featured large numbers of domestic animals, both whole and disarticulated. Horse, cattle, sheep, and canines were all frequently interred. (Zdanovich and Gaiduchenko 2002). The frequency of animal burials, particularly the large fauna, such as horse and cattle, have been used to suggest that the funerals were accompanied by feasting on a competitive scale (Anthony 2009).

A rare, but significant aspect of Sintashta burial practice is the presence of chariots. While very few of the excavated burials contained chariots this has nevertheless been seen as an important aspect of the Sintashta burial rite and their presence is often seen as a key indicator of a chiefly or warrior class. This has led some to suggest that Sintashta communities were structured as a 'warrior aristocracy' (Kristiansen 1999). However with the function of these chariots often questioned, others have been more cautious and suggested that they were perhaps specialist ritual vehicles used to transport the dead to the afterlife (Kuzmina 2000). However despite these grand assertions there remain very few (comparatively) chariot burials and their wider associations with other material classes and burial types are varied and poorly understood.

Middle Bronze Age burials, specifically those attributed to Sintashta groups, are seen by many as clear evidence that the Southern Urals was the place of origin of Indo-Iranian/ Aryan ritual practices as described in the Rig Veda and Avesta (Anthony 2009; Kuzmina and Mallory 2007: 192). Passages such as; "*...and may they bury Death beneath this hill" (Rig Veda 10.18-4), "...let the Fathers keep this pillar firm for thee...*" (Rig Veda 10.18-13), and "*... let a thousand clods remain above him*" (Rig Veda 10.18-12) have found parallel in Sintashta burial practices (Anthony 2007: 409; Kuzmina and Mallory 2007: 192). Although it seems far from the "*precise description*" of Sintashta burial pits, kurgans and supporting pillars that

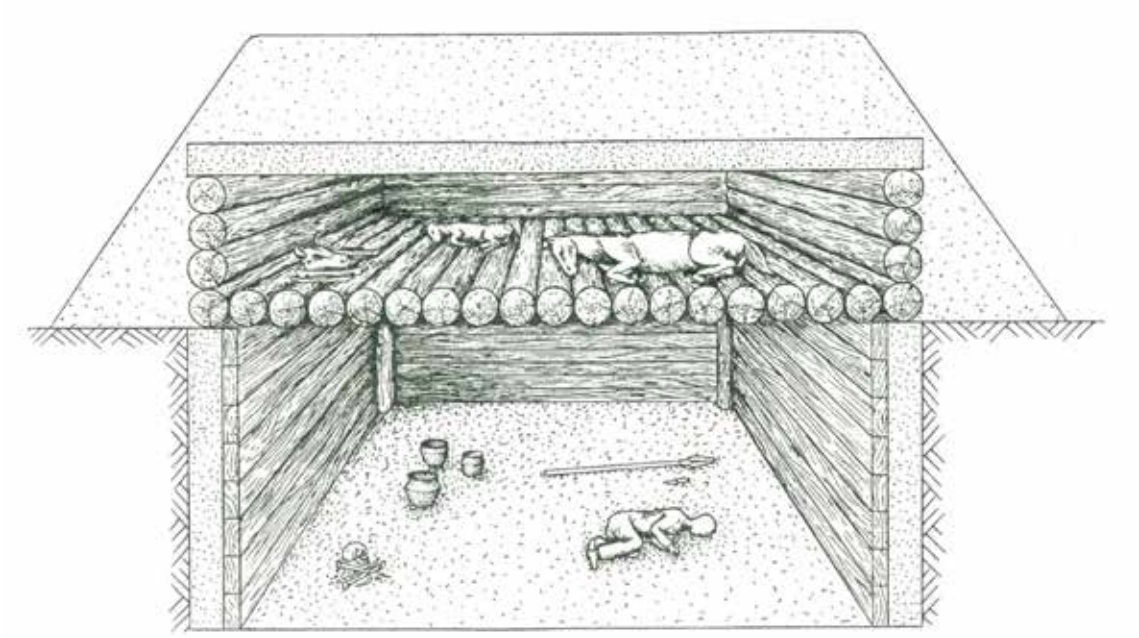


Figure 2.16 Reconstruction of a Sintashta burial, along with whole horse sacrifice, secondary burial and a package of material culture (Grigor'yev 2002)

Anthony proposes there are arguably some parallels, particularly in terms of the mound structures (Anthony 2007: 409).

Metallurgical burials

Often found alongside chariot burials, either within the same cemetery or sometimes the same kurgan, were burials which featured primary copper production waste, ore and tools (Epimakhov 1996; Gening et al. 1992; Kaliyeva and Logvin 2009; Vinogradov 2003). These burials, which many have interpreted as being of copper producers, are identified at many of the excavated cemeteries in the Middle Bronze Age, including Krivoe Ozero, Stepnoye, Arkaim, Sintashta and Solntse II. Beyond the presence of metallurgical debris, the organisation of these graves and their association with other aspects of the community are not uniform. For example, the burials at Krivoye Ozero, Sintashta, Solntse II and Bestamak all featured metallurgical debris, and yet their association with other burial types were different. At Sintashta the burial contained a single interment which was alone in a spatially dislocated kurgan, yet which was accompanied by the long bones and skulls of at least four other individuals which had been 'cleaned of soft tissue' prior to inhumation (Gening et al. 1992). The burial at Sintashta is perhaps the most spectacular case of metallurgical material being given special significance in death in the Country of Towns region.

At Krivoe Ozero, the burial was in a large, multi-interment kurgan, which contained the remains of an elderly male with signs of severe acromegaly (skull deformations and bone scarring) possibly caused by a pituitary problem (Vinogradov 2003). The same Kurgan featured what has been termed 'ritual specialists' in the form of a 'face to face' burial and numerous foetal and juvenile internments. The individual was buried alongside a typical male toolkit featuring a bronze knife and a selection of vessels, as well as a cache of metallurgical debris (Rykushina 2003). The example from Bestamak, a site not within the Country of Towns region but often attributed to the Sintashta cultural group, also contained the burial of an elderly male alongside metallurgical debris, although in this case the individual was buried with typically female-gendered adornments (Kaliyeva and

Logvin 2009). Unlike the other sites, Solntse II contained multiple burials interred with metallurgical debris. Three of the 17 excavated inhumations contained metallurgical debris, two of which also contained chariots, with the third buried in the same kurgan as a chariot burial (Epimakhov 1996). What is clear from these examples is that the relationship between individuals interred with metallurgical debris and with other aspects of the community, in death at least, was by no means uniform at Sintashta period sites, and that the relationship between metallurgy and death was considerably varied.

Middle Bronze Age burials in the Southern Urals do seem to have made an effort to express specific gender identities, with many biologically male interments accompanied by weaponry/tools and biologically female interments accompanied by elaborate jewellery, with the latter more prevalent in later examples (Hanks et al. 2014; Kupriyanova 2008). However, while there do, in material terms, seem to be at least two distinct gender identities, the relationship between gender and biological sex does not seem to be completely fixed. There are a small but significant number of burials attributed to the Middle Bronze Age (both Sintashta and Petrovka types) that include biologically male skeletons accompanied by what are more routinely seen as female adornments. This elaborate expression of gender may also have been associated with aspects of wealth and/or status; it is important to acknowledge their meaning would have been manipulated by the living during the mortuary event (Doonan et al. 2015).

2.4 Sintashta: Recent models and syntheses

The characteristics outlined above, and the unique chronological developments in the Southern Urals, have drawn a significant amount of international attention to the region. This has led to the development of models and discussions which seek to draw wide ranging syntheses, particularly on the part of those who wish to understand the development of 'social complexity' (Anthony 2009; Epimakhov 2002; Frachetti 2012; Hanks and Linduff 2009; Jones-Bley and Zdanovich 2002). Sintashta groups and Middle Bronze Age communities more generally have been seen as an ideal case study for the development and understanding of complex communities within prehistoric archaeology in the Eurasian steppe region (Hanks 2009); while aspects of material culture, burial practices and architecture of these groups feature in numerous discussions which seek to better understand how complex communities developed and interacted on a continental scale, it is metallurgy which seems to command a special significance in these discussions (Anthony 2009; Hanks and Doonan 2009; Epimakhov 2002; Zdanovich 1997).

In many ways, the archaeology of the Bronze Age Southern Urals could be considered a study of social complexity (Hanks 2009). As seen earlier, concepts of social complexity are drawn from an evolutionary model which sees societies develop from 'simple' bands through to complex states (Service 1971). However, the term can be problematic as it carries certain epistemological connotations which assume that there is an inevitability to progress, inequality and 'complexity' (Chapman 2003). While recent work has begun to move away from singular trajectories (Drennan et al. 2011) there is still a tendency to see metallurgy (and craft specialisation generally) as simply an index of complexity, rather than as a socially embedded practice which can be studied to reveal the conditions under which such practices become meaningful.

The apparent rapidity of the move from mobile pastoralism to seemingly sedentary communities means that it is no surprise that the issues of social complexity are foregrounded in the Southern Urals (Anthony 2009; Epimakhov 2002; Frachetti 2012; Hanks and Linduff 2009; Jones-Bley and Zdanovich 2002). Superficially the Middle Bronze Age communities in the Southern Urals exhibit many characteristics which could be seen to represent emerging social complexes that may have been subject to a centrally controlling hierarchy (Anthony 2007; 2009; Grigor'yev 2002; Kohl 2007). The assumed rise in craft specialisation, the nucleation and increased permanence of settlements and the monumental funerary practises afforded to only certain aspects of the community could all be seen as symptomatic of such complexity. The role of metallurgy is central to this assertion; intensive metallurgy is held as indicative of this complexity and in turn, metalwork, and control over its production/access to necessary resources is used as a measure of wealth, status and power (Grigor'yev 2002; Hanks 2009). Simply put, the ubiquitous, large-scale, developed metallurgical practises suggested for the region are one of the critical pillars that support the arguments for complexity.

Complexity then is closely tied to the archaeology of the Southern Urals, in terms of both how archaeology is interpreted and in terms of the questions asked. This though is as much due to the history of the study of archaeology in the region as it is to the geographic scope and international significance of the region. It is within such a framework that many of the wider models and discussions which include the Southern Urals are constructed; such as the origin of Sintashta communities and their links with wider Eurasia.

2.4.1 The Origin of Sintashta patterns

A fundamental theme drawn from discussions of complexity in Central Eurasia is the perceived differences between archaeological patterns and the attribution of causal mechanisms. The discussions have tended to fall into two categories: arguments concerning migrations and invasion and those which emphasise internal social and economic development (Anthony 2009). These arguments are particularly significant when examining the Middle Bronze Age Sintashta patterns, as the (supposedly) sudden appearance and subsequent abandonment of significant settlements is without parallel (Koryakova and Epimakhov 2007: 66). It is the 'proto-urban', hierarchical character of these settlements that has attracted such intense discussion regarding their formation (Zdanovich 1995; cf Johnson and Hanks 2012).

In attempts to outline the development of these proto-urban centres Kuzmina argues that Sintashta communities were not only characterised by metallurgy, but that it was fundamental in their development (Kuzmina 2000, 2008). Beginning with the collapse of Chernykh's 'Carpathian Metallurgical Centre' to the south east of the region, Kuzmina argues that Early Bronze Age communities, such as the Yamnaya, had first developed metallurgy which led to the early Sintashta developments (Chernykh 1992: 48; Kuzmina 2000: 119). She argues that this, coupled with a rise in warfare, were the driving factors behind proto-urban development in the region suggesting that;

> *"The struggle for ore deposits in the Urals resulted in the construction of fortresses in areas where large-scale metalworking took place" (Kuzmina 2000: 119).*

Anthony (2009: 47) proposes, in contrast to Kuzmina, that a number of factors led to the development of Sintashta patterns including: competition for valuable grazing land, increased warfare, and contact with Central Asian markets. However, like Kuzmina, Anthony argues that a large increase in the value of metal was a central factor in the formation of Sintashta patterns (Anthony 2009: 67). He uses the location of Sintashta type settlements, on the flood terraces of rivers and streams, to argue that the control of what he sees as ever- decreasing grazing areas was a driving factor in the decision to become more settled and to build large, fortified settlements. This, he argues, was due to environmental pressure, particularly dryer conditions caused by a change in climate (Anthony 2007). Increased warfare is noted in Abashevo groups, and Anthony argues that a merging of this community with the more mobile Poltavka community in the east led to the development of Sintashta patterns in the face of continued and increased warfare (Anthony 2009: 52).

An increase in warfare is one of the factors that Anthony suggests caused the increase in demand for metals, stimulating an inter-regional demand for valuables. Another factor, he argues, was the establishing of relations with the 'Bactria–Margiana Archaeological Complex' (BMAC) which connected the Country of Towns region with a 'bottomless market' for metal. This, in conjunction with a continuation in warfare, the development of the chariot, and aggrandising feasting is central to Anthony's hypothesis. With Anthony arguing;

> *"The geographic position of Sintashta societies at the eastern border of the Pontic-Caspian steppe world exposed them to many new cultures, from foragers to urban civilisations. Contact with the latter probably was most responsible for the escalation in metal production, funeral sacrifices, and warfare that characterised the Sintashta culture." (Anthony 2009).*

Both Kuzmina and Anthony suggest that climatic change was a causal factor in the development of Middle Bronze Age groups; however it is the rise in demand and subsequent production of metal that, they argue, drives, and crucially, sustains, these developments. Others (Grigor'yev 2002; Chernykh 1992) have proposed that the formation of Sintashta communities focused more on migrations than internal development; some even attempt to trace the roots of Indo-European speaking peoples (Grigor'yev 2002). Grigor'yev has argued that the formation of Sintashta groups was a direct result of migrations of Indo-European speaking peoples from the near east, particularly the Anatolian area (Grigor'yev 2002). Like Anthony and Kuzmina, Grigor'yev uses metallurgy to support his hypothesis, arguing that the use of arsenical bronzes was a technology brought from the south of Chernykh's 'Circumpontic Metallurgical Province' (Chernykh 1992).

Both the internal development and migration arguments are underpinned by the perceived increase in complexity that the Sintashta phenomenon is seen to represent. The models of development see the sites as indicative of an increase in inequality through increased centralisation of power, while the migration models see the shift from seemingly more simple, mobile communities, to complex settlements as evidence of the arrival of more complex communities from outside of the region (Anthony 2007; Griogor'yev 2002). In both cases the complexity of Middle Bronze Age groups seemingly facilitated their place in wide-ranging contact and exchange networks which characterise the Southern Urals as a hub between east and west (Anthony, 2009; Kristiansen and Larsson 2005; Kristiansen 2011).

2.4.2 Large-scale interactions

Central Eurasia is an expansive area unparalleled in many of the regions which shaped the development of 'Old World' archaeology; it lacks boundaries both geographically and epistemologically. Regional syntheses therefore need to confront the lack of geographic boundaries, such as water or mountains, that so often contain regions that feature strongly in European archaeology, such as the Aegean, the Alpine region or even continental Europe itself (Hanks 2009; Kuzmina 2008) and perhaps think more in terms of social boundaries. The difficulty in defining what a region might look like is magnified by the conceptualisation of the region as a monotonous continuum forming a neutral environmental backdrop for social processes (cf. Ingold 1993b). The apparent neutrality of 'environment' has, to some extent, given free range to theories of social change and model building where cultural datasets are rapidly collated unhindered into broad syntheses.

The most extensive of these models are those that develop a 'World Systems' type approach. 'World systems' approaches stemmed from the work of Immanuel Wallerstein in the 1970s and 1980s. Wallerstein attempted to provide a framework through which to understand the disproportionate relationships that has shaped the modern 'world system', from its roots in the 16th century to the present day. His 'world system' was based on a; "*social system, one that has boundaries, structures, member groups rules of legitimisation and coherence*" (Wallerstein 1974: 347). A central theme in his model was the core/periphery relationship, wherein different interregional groups who were operating at different scales were interdependent of each other. However, his World Systems Theory goes further than this, extending beyond specific polities and communities and incorporating social, economic and ideological systems. To the extent that economy is seen to dominate ideology and cannot be reduced to it, it could be argued that World Systems Theory draws on aspects of Marxism. However World Systems Theory operates on a large scale through both space and time, and therefore it is difficult to understand how social interaction on a human scale could be meaningfully accommodated (Kohl 1996). The use of World Systems Theory has been exploited by archaeologies, both in the Old and New World, with scholars attempting to utilise it far beyond its originally intended scope in regions as diverse as Mesoamerica and Eastern Europe (Blanton and Feinman 1984; Kohl 1996; Sherratt 1993; Wallerstein 1974).

For the Middle Bronze Age, Koryakova has proposed a model, inspired by World Systems Theory, in which she attempts to explain the disparity in archaeological remains and long term structural change (Frachetti 2009: 23; Koryakova 2002). Koryakova suggests that uneven economic and technological developments, in particular metallurgy between the population occupying fortified Sintashta sites and those more 'clan-tribal' groups who occupied neighbouring areas, led to a variety of core-periphery relationships (Koryakova 2002: 103). The extent to which such models are congruent with World Systems Theory is debated. Frachetti claims that such models are not explicitly World Systems Theory according to the terms that Wallerstein and later Kohl set out (Frachetti 2009: 23), stating that communities did not, despite some sites acting as a focal point for social and political cohesion, demonstrate the capacity to maintain necessary influence over the surrounding periphery in terms of resource control (Frachetti 2009: 23; Kohl 1996; Wallerstein 1974). Similarly Kohl rejects some of the more regimented aspects of World Systems Theory, particularly the idea that the network of interconnections in Bronze Age Eurasia constituted a single, interdependent yet closed unit (1996; 2007: 246).

Andre Gunder Frank took a much more global stance on applying World Systems Theory to the Bronze Age. In 1993 he wrote a challenging article suggesting that much of the Old World existed in a single world system, encompassing the near east and Central Eurasia for much of the Bronze Age and operating in cycles of expansion and contraction. Frank used aspects of Chernykh's metallurgical provinces to argue for much of Eurasia's inclusion in his models, particularly stating the idea that; "*the development of metallurgy was an increasingly interconnected and shared process throughout most of Eurasia*" (Frank 1993: 391). Frank's article proved both thought-provoking and contentious, as can be seen in the debate which followed, which features arguments for and against the application of the theory to prehistory (see reply by Muhly and Kohl in Frank 1993).

More recently, and presented as distinct from World Systems Theory by its author, Frachetti has developed a theory of Non-uniform Complexity. 'Non-uniform complexity' and, more recently, 'non-uniform institutional complexity' are terms he has used in his attempt to create a theoretical model for Central Eurasia which incorporates the disparity between large-scale similarities in archaeological evidence with the often diverse archaeological structures which are visible on the local scale (Frachetti 2009). Where World Systems Theory relies on the application of certain parallels with Wallerstein's model, Frachetti has attempted to; "*describe a condition of scalar transformation of various general institutional forces that shape the social interactions around differentiated local communities*" (2009: 24).

The term 'institutional forces' in Frachetti's theory include institutions such as burial form, settlement conventions, ideology, economic and political organisation (2009: 22); the non-uniformity occurs where some of these institutions are shared among diverse groups but where others are locally distinct (Frachetti 2012). Relying heavily on Chernykh's work and the large-scale metallurgical provinces he describes, Frachetti argues that metallurgy is one of these uniform institutions. In Central Eurasia this equates to a system where many ideological and basic subsistence patterns are variable, but production, particularly metallurgy, features widespread similarities. The regional and pan-regional models outlined here all rely heavily on an understanding of metallurgy drawn from Chernykh's early work (1992). However, even Chernykh concedes that while shared morphological traits are visible, our understanding of the social organisation of mining and metallurgy and how this changes through time is still limited (1992: 309). It will become clear in the following chapters that the conceptualisation of metallurgy is problematic, and that metallurgical practice was far from uniform in the Bronze Age.

2.5 Summary

This chapter has covered a range of subjects related to the archaeology of the Southern Urals. In outlining the history of Eurasian archaeological discourse it has sought to illustrate how unique and diverse theoretical and methodological conditions have shaped our understandings of this region to date. Much of the framework which is evident today, from the three Bronze Age phases which have their roots with Gorodstov's burial typology, to the rapid shift in practice during the early Soviet period, can be traced back to specific historical developments. It was in the early Soviet period that the character of Russian archaeology diverged in style from its European, antiquarian, foundations and developed into the more formalised 'Soviet archaeology' of the mid-20th century.

The developments witnessed during the Soviet period saw archaeology follow aspects of Marxist doctrine which heavily influenced much of the structure which is still visible today. The focus on historical narratives, cultural groupings, and social evolution all drew on Marxism and Marxist-Leninism. Even though this began to lead academic policy only certain aspects of Marxist writings were adopted; despite a focus on the outcome of means of production, the actual organisation of production was generally assumed to follow the wider evolutionary narrative; metal artefacts were evidence that production systems had developed to a certain level, the systems themselves drawing little attention. Ultimately thought, it was not the work of Marx and Engels which had the biggest influence on archaeology during this period, but the wider aims and ambitions of the State (Klejn 2012).

With the death of Stalin, the influence of State ideology on the development of Russian archaeology diminished, and ideas beyond State doctrine began to be employed by Russian archaeologists. Nationalism, regional identity and New Age ideology all began to influence wider archaeological interpretations. It was within this more liberal academic framework that Sintashta, Arkaim and subsequently the 'Country of Towns' were discovered and conceptualised. The wide range of new ideologies and academic frameworks can be seen in some of the interpretations proposed during this period, from the homeland of the Slavs to the origin of Indo-Iranian mythology. In short, the early developments and direction of Sintashta archaeology was a direct product of nearly 100 years of wider Russian political history, framed within an established framework but drawing on new and diverse ideas.

In the years which followed wider political events would continue to influence the development on Southern Ural archaeology; the rapid breakup of the Soviet Union, and loosening of borders opened Russian archaeology to a wider international audience. In turn this allowed Western scholars to begin to incorporate the vast corpus of Russian data into their interpretations. For the first time interpretations and models did not arbitrarily end at the Iron Curtain.

The implications of this sudden opening were profound. A huge interpretive and geographic space needed to be filled, a space which seemed to demand big ideas and big models. While collaboration between Western and Russian scholars could only be considered favourably, the initial tendency was to focus on large-scale problems rather than more local questions. These large-scale approaches are clearly evident in the chronological framework for the region. Structures and horizons such as the Andronovo or Seima-Turbino show vast groups covering distances on scale inconceivable in other regions. It is perhaps because of the multiple scales of chronologies, from defined and discrete cultural entities though techno-typological provinces to trans-cultural phenomenon, that Russian archaeology can be difficult to contextualise. This situation is only made more complicated by the radiocarbon chronologies that are beginning to show much more crossover and overlap between different groups that previously suspected. While some of the boundaries between cultural groups and horizons can at times seem somewhat arbitrary, there are clear characteristics which suggest a great deal of local and regional variation in the way that communities were organised at any one time.

While Sintashta archaeology has featured heavily in these large-scale models it also provides an ideal case study to explore variation over a seemingly homogeneous landscape. Its distinct settlement structures, funerary rituals and production practises create an ideal

circumstance to explore the validity of the wider models which assume homogeneity. To date the prevailing academic models seem intent on contextualising the Middle Bronze Age groups who lived in the Southern Urals within wider continental Eurasia. However inquiry on this scale can serve to obscure the local and regional dynamic and life-ways which make such communities so important to study. In exploring how groups lived, adapted, and acted in such a distinct manner in a period of, arguably, fluctuating climate, it becomes possible to reveal, in detail, the conditions under which the Sintashta phenomena became manifest. The very formation of Sintashta archaeological sites and materials seem tied to concepts of progress, evolution and complexity. Yet the variation and dynamics which are described in this chapter, in terms of archaeological remains, and in the next chapters, in terms of metallurgical practice, suggest that these notions are inadequate when dealing with past social practice. The underlying assumptions that underpin these developmental discussions rely heavily on our understanding of production practice. The following chapters will explore this subject in greater detail.

Chapter 3

Approaches to Metallurgy in Archaeology

The study of ancient metals and the emergence of metallurgy are arguably some of the most enduring themes in prehistoric archaeology (Chernykh 2009; Killick and Fenn 2012; Ottaway 2001). Metallurgy has played a special role in archaeological research since the discipline emerged from its antiquarian roots into the more systematic discipline that we recognise today (Doonan and Day 2007; Goodway 1990; Rehren and Pernicka 2008). While the products of metallurgy have often been afforded a central position in archaeological discussions, the study of metallurgical production, until comparatively recently, has been the purview of scientists and metallurgists, who have tended to focus on the chemical and technical pathways of production at the expense of its social and cultural aspects (Doonan and Day 2007; Doonan 1999). As Goodway (1990) has highlighted, the development of processual approaches saw a widening interest among archaeometallurgists in production evidence. Although Goodway does not develop this observation further it was likely the result of the New Archaeology conceiving society as a system made up of a number of sub-systems (Clarke 1968, 1973). In the economic sub-system production was held as being particularly influential and therefore centres of production, as inferred from production evidence, were given increasing attention by archaeologists. More recently the study of production remains have become central to anthropological studies of technology, with a focus on technological choice and integrated social approaches which have emphasised the interplay between people and things, material and ideas (Dobres 2000). It is clear then that current approaches to the study of metallurgy have changed considerably in a relatively short period.

This chapter presents a background to the study of metallurgy which leads into a discussion the main theoretical framework through which this project was enacted, drawing on a combination of archaeological science and an appreciation of the socially constructed nature of technology. The chapter concludes with a summary of some of the key technological choices in the metallurgical process, their wider implications and how they might be understood archaeologically and experimentally.

3.1 Studying Ancient Metallurgy

Metals found interpretive prominence in the study of prehistory when C. J. Thomsen, in the early 19th century, used the chronological relationship between the use of stone, bronze and iron as the basis for his catalogue of Danish antiquities (Thomsen et al. 1836). The three age system that Thomsen employed was drawn from earlier works by the French antiquarians Nontfautcon and Mahudel, but its application to the Danish national collection provided an empirical basis which saw the 'three age system' become widely adopted (Trigger 1989: 75).

Technologies and, more appropriately typologies, continued to form the basis of chronologies well into the 20th century, with Childe publishing 'Archaeological ages as technological stages' in 1944, wherein he gave metallurgy a special significance drawn from what he saw as its technical sophistication (Budd et al. 1994; Childe 1944). Childe drew on selected Marxist principles, specifically the relationship between production and social development, which emphasised the economic significance of metallurgy, and suggested that it was a fundamental index of the development of social elites and complex societies (Childe 1930, 1935). The elevated status that Childe afforded to metallurgy has had an enduring effect on archaeological discourse, but is particularly visible in the archaeology of central Eurasia.

3.1.1 The development of 'archaeometallurgy'

Parallel to the early interpretive emphasis placed on metallurgy at the beginning of the 20th century, the materials themselves were beginning to be routinely analysed by this time; pioneering metallurgists such as William Gowland began to study ancient metallurgical processes in considerable detail (Gowland 1899). Despite this interest in metallurgical processes, the bulk of early analytical work was being applied to finished objects, with the aim of authentication; by the end of the 1960s some of the largest museums in the world, including the British museum and the Louvre, had dedicated analytical laboratories for such purposes (Goodway 1990: 706).

The post-war period in Britain and America witnessed substantial developments in instrumental scientific techniques (Clarke 1973). In archaeology this facilitated a marked increase in the ability to study ancient artefacts with quantifiable scientific rigor. However, this produced more than just an increased ability to classify archaeological remains; it provoked significant developments in archaeological theory which attempted to situate archaeology as a firmly scientific discipline. David Clarke in particular saw this period as a 'loss of innocence' during which archaeology attained a 'critical self- conscience'. He argued that;

> *"What first appeared to be merely a period of technical re-equipment has produced profound practice, theoretical and philosophical problems to which new archaeologies have responded with diverse new methods, new observations, new paradigms and new theory" (Clarke 1973).*

In the study of ancient metallurgy, this new scientific arsenal allowed artefacts which had escaped the purview of traditional archaeological approaches to be studied in detail

for the first time. This had particular relevance to production waste, and it is against this backdrop that the study of ancient metallurgy developed into what would later be termed 'Archaeometallurgy' (Goodway 1990).

The term archaeometallurgy itself was first formally established in 1973 when B. Rothenberg founded the institute for Archaeo-Metallurgical studies at University College London, although, like much nomenclature, the term was undoubtedly in use earlier (Goodway 1990; Rehren and Pernicka 2008, Doonan and Day 2007). The effect that the advent of New Archaeology had on the development of this sub-discipline was profound; New Archaeology created a scientifically rich and optimistic environment which actively encouraged empirical and technologically advanced studies (Doonan and Day 2007).

It was within this paradigm that many seminal projects incorporating large analytical datasets using newly developed techniques, such as trace element and lead-isotope analysis, were carried out (Gale and Stos-Gale 1991; Gale 1989). Projects such as the Studienzu den Anfängen der Metallurgie (SAM) analysed several thousand bronze artefacts using the best scientific equipment available (Junghans et al. 1974). Their aims were rooted in the more processual aspects of archaeometallurgy, in that they sought to explore the networks of bronze movement across an extended region.

While the analysis of artefacts was primarily carried out by chemists, the study of production debris was left to metallurgists and geologists. In the 1960s and 70s former metallurgists such as Ronald Tylecote and Han-Gert Bachman both published extensively on the subject of archaeometallurgy; producing some of the most enduring syntheses about the history of metallurgy and its study. The former is noted as one of the founders of the discipline (Bray and Pollard 2012; Rehren and Pernicka 2008).

The underlying theoretical framework which features so heavily in the main developments of archaeometallurgy was drawn primarily from positivist reasoning, which shares many values with the natural sciences. Within this framework objects are seen as static, inanimate and existing prior to their description by animate subjects, whereas the subjects themselves have the ability to act within, and describe the world of objects (Jones 2002: 8). Central to this framework is the ability of subjects to adequately describe the world of objects from a fully detached perspective; objects can be touched, experienced and recorded; their attributes are considered to exist a priori and just need to be empirically observed (Jones 2002; Trigger 1989).

This framework is one half of what Jones refers to as the 'two cultures' of archaeology. The other 'culture' being subjectivism, in which the qualities and attributes of objects are not universally determined, but are only understood through culturally contingent values and metaphors (Dobres and Robb 2005; Hodder 1992; Jones 2002). The implication of this is that it cannot be assumed that one cultural group will experience and categorise the same object in the same way as another group, with words only having an arbitrary relationship with the things they describe (Jones 2002: 5; Saussure 1983). These two 'cultures' have had an effect, to varying degrees, on the way in which archaeological metallurgy has been studied and interpreted, and is reflected in other dichotomies, for example; history versus science, rationalism versus relativism, physical versus textural, practical versus cultural reason (Dobres 2010; Jones 2002; Trigger 1989: 373). Although it could be argued that

these dichotomies are largely superfluous there are subtle conceptual differences which underpin differing approaches to ancient metallurgy. For example, some would argue that the material properties of an object, be it a finished artefact or metallurgical debris, are the product of standard, knowable and predictable processes which were encoded and recorded in the material properties of the object under study; which were then locked away, only to be decoded by the scientist (Goodway 1990; Killick and Fenn 2012). This essentialist outlook is clear in the following quote by Craddock;

> *"The composition of materials can give far more unambiguous information on the technology of the process that produced them than on the society that used them." (Craddock 1995: 2)*

The extensive use of this framework in the study of ancient metallurgy has been due, in part, to the image of the ancient metallurgist as an early experimenter, a proto-scientist (Budd and Taylor 1995). The strength of the enduring image of a male metallurgist, experimenting and discovering was formalised by Childe who saw metallurgy as a 'proto-science' and a victory of rational man over superstition, developing a 'true' objective understanding of the world (Budd and Taylor 1995: 136; McNairn 1980; Trigger 1989). Childe then, saw the development of metallurgy and an objective understanding of the world as one and the same. This theme is also evident in later work by Theodore Wertime, who saw the early developments in metallurgy as the result of 'feverish experimentation' which involved a 'tangled web of discovery' (Wertime 1964: 1261–1266). This attitude gave metallurgy, and by association ancient metallurgists, an elevated significance when compared to other ancient crafts such as basketry and potting, which were seen as 'unscientific' (Budd and Taylor 1995). The dichotomy evident in this view is reminiscent of the opposition which Jones sees between objective and subjective; the objective, male proto-scientists were busy experimenting with metallurgy while the, presumably unscientific (at least in the language of the day), women were left to make pots for cooking and baskets for gathering food (Budd and Taylor 1995). Of course, these views are unlikely to be expressed by the majority of archaeometallurgists, but there still exists a tacit impression that the more complex aspects of ancient metallurgy and mining were dominated by men, with women playing a merely supportive role (O'Brien 2004; Wager 2009).

In understanding metallurgy as a knowable process questions which were 'answerable' though scientific processes have dominated the subject, which has tended to focus on large scale models to produce generalisations following linear developmental trajectories (Trigger 1989: 373). These have included questions of exchange and the movement of artefacts over large areas, such as the previously mentioned Stuttgart project, and questions that emphasise the linear development and evolution of technology (Childe 1944; McNairn 1980; Wertime 1964, 1973). This latter tendency is clearly visible in archaeometallurgy, where an attribute of the development of ancient metallurgy is the concept of linear technological evolution, where technology progressively develops without any external societal motivation (cf. Pfaffenberger 1992). Applying evolutionary logic to technology has allowed those who study it to predict the outcome of knowable developmental pathways, and it thus becomes definable by scientific laws.

3.1.2 Archaeometallurgy and post-processualism

The development of post-processualism in the late 20th century led to these science driven approaches receiving less attention, in favour of discussions which focused on contextual relationships (Goodway 1990). Early post-processual approaches marginalised the study of production, as it was often seen to be strongly linked to the New Archaeology agenda, instead choosing to focus on the metaphor and meaning encoded into artefacts (Goodway 1990; Hosler 1995). The proponents of New Archaeology emphasised that any interpretation must be based on some form of theoretical reasoning, even if that reasoning is only tacitly applied (Hodder 1995). Therefore, while earlier approaches had a continued influence on the physical study of ancient metallurgical remains, the broader interpretation of the objects themselves has been integrated into post-processual approaches. This has led to an interpretive gulf developing between those who studied the physical properties of ancient material and those who drew more strongly on contextual analysis;

> *"This is because, for theoreticians, the material qualities of artefacts do not necessarily determine their meaning while, for science-based archaeologists, the material properties of the archaeological record form the meat and drink of their studies"(Jones 2004).*

At their core, early post-processual approaches were at odds with the study of ancient production, because archaeometallurgy, as a discipline, was established within processual theory and was allied with the development of New Archaeology which emphasised the importance of production as part of the economic sub-system. When post-processual studies did engage with production, the choices made during the production process were seen to be determined by what was reduced to something pertaining to the finished object, not the practice itself (Hosler 1995). So while in objective reasoning, technologies developed through their own agency, in early post-processual works the production of objects was dictated by their usage upon consumption. There was also a change in nomenclature; while objectivists would refer to ancient metallurgists as scientists and technicians, subjectivists would use terms such as artisan and craftworker (Budd and Taylor 1995; Hosler 1995). So in subjective reasoning ancient metallurgy was no longer the result of proto-scientists who were attempting to obtain dominion over nature, but the result of artisans expressing themselves and their social relationships through the making of things and the taking advantage of a seemingly limitless range of material choices (Budd and Taylor 1995).

While production studies were rarely in the foreground at this time; the early 1990s saw the mushrooming of a movement which formed, in part, from early post-processual philosophies, but drew far more from parallel developments in anthropology which endorsed technology as a fully social phenomenon (Bijker et al. 1987; Ingold 1988; Lemonnier 1992). This movement saw production not as something that affects culture and society, driving its development though the results of 'feverish experimentations' and technologically driven endeavours, or as a way in which human groups communicate through the making and using of artefacts, but as a fully integrated social act (Lemonnier 1993: 3).

3.2 Exploring Metallurgy as a Social Phenomenon

> *"……..looking at technology by no means rules out an appreciation of the human and social dimensions of community life, but, on the contrary, makes a fuller appreciation more possible." (Pfaffenberger 1998: 299)*

To some degree, approaching production as a fully social phenomenon can be characterised as a post-processual approach (Dobres and Hoffman 1994; Shanks and Hodder 2007). In recent years, however, it has become clear that these approaches go beyond the processualist/post-processualist and objective/subjective dialectic as they emphasise the interplay between social forces and the constraints and facilities of the material world. Therefore it becomes possible to accept that objects may have a priori properties which affect the way in which they were understood and used, and in turn, societal forces mediate the choices through which these interactions took place (Dobres and Robb 2005; Ingold 2007; Jones 2004). There exists a group of complementary methodologies and conceptual frameworks which facilitate the study of metallurgical production and ancient crafts as fully social phenomena without asserting either an exclusively objective or subjective ontology; specifically concepts of technological choice, chaîne opératoire, time-geography and habitus.

Central to these approaches is the concept of agency, in that they rely on an understanding that humans or other entities act within a culturally specific and inter-subjective world (Barrett 2001). In other words; "*societies are created and recreated through the active involvement of knowledgeable and active human subjects*" (Jones 2002: 20). Adopting an agent-centred approach allows a focus on the "*relationships between material conditions and human practice*" (Barrett 2001). Giddens has argued that the actions of agents are guided by the social structures within which they are placed, while simultaneously producing and sustaining these structures (Giddens 1984: 25). In other words; it is the interaction between people and the world, agents and things which simultaneously constrains, mediates and recreates the world in which people live across space and time (Giddens 1984: 25).

While an agent-centred approach to understanding production is of considerable value to this thesis, there has been significant debate surrounding the nature of human-material interaction. Central to this discussion is the level of influence the materials themselves have within the relationship. It has been suggested that many of the early social constructivist approaches to technology placed too much emphasis, at the expense of material conditions, on the social conditions which drove production (Knappett 2008; 2012). This has stimulated a movement which has attempted to reassert the importance of the material's role in the relationship. In a recent publication entitled 'material agency' Knappett and Malafouris (2008) have proposed that we consider materials as an active and influential agent within the engagement. This position draws parallels with actor-network-theory (ANT) which asserts that humans and things are engaged within a social network which gives an equal distribution of influence, assuring a collective response between human and non-human agents (Ingold 2008). Malafouris, drawing on aspects of material agency and ANT has suggested that in the act of throwing a pot the potter and the clay are symmetrical, equal partners entwined in a 'dance of agency' (2008). However, in the same volume Ingold points out that the potter and clay are by no means equal in the relationship. He suggests that the material qualities of the clay are important, but they



Figure 3.1 The varying outcomes of skilled practice and perception-response on copper ore

facilitate interaction, rather than being an 'interactant' (Ingold 2008). This is a significant point as it highlights the principal weakness in the concept of material agency; that non-human factors are an equal and active participant in the relationship. Latour (1994) uses the example of the combination of a gun and man to highlight the supposed equality of the relationship, creating a 'gunman'. In such an equal partnership neither the gun nor man can shoot independently of each other, and he therefore argues that the relationship is equal. However, from Ingold's perspective the gun simply facilitates the (gun)man's ability to act, and it is in the skilled and embodied response to the material abilities of the gun where the action/agency resides.

Ingold (2008) satirises the underpinnings of ANT through the presentation of an alternative arthropod; the SPIDER (Skilled Practice Involves Developmentally Embodied Responsiveness). Central to Ingold's argument is that agency is reliant on the ability to perceive and respond to the facilitating material qualities. The way that the agent responds depends on a combination of bodily skill, choice and intentionality. This perception–response is central to what can be described as a necessarily unbalanced relationship.

In the context of metallurgy this position is particularly significant. In a mutually recursive relationship, where the material plays an equal role, the element of choice seems to be divorced from its social context. Whereas when skilled practice is emphasised, choice becomes fundamentally important. For example copper ore, when imbued with equal agency, would presumably drive a predefined outcome, while in reality it is the skilled response to the material which guides the ultimate outcome. For a stone worker the copper ore could be crafted into an ornate bead, whereas, for a metallurgist it could be transformed to a metal knife (Figure 3.1). It is a combination of choice, embodied skill and knowledgeable practice which drives the different outcomes, the material attributes of the copper facilitate this; or as Ingold would say, acts as the "*ground upon which the action takes*

place" (2008).
It is an appreciation of the perception and response to material attributes that allows us to simultaneously explore the role of both individuals and groups in the production process so as to understand how craft practice is enacted. Through this lens concepts such as technological choices and chaîne opératoire can be seen as both methodologies through which to apply an agent-based approach in an archaeological context, and as conceptual frameworks through which to understand past practice (Dobres 2009). To some degree they could be thought of as 'middle range' approaches which serve as a methodological and conceptual bridge between the abstracted concept of agency and the practice of archaeology (Dobres and Robb 2005). However this definition is inadequate as they are more than simply a way of 'doing agency'; they present an opportunity to scrutinise the interaction between people, materials/objects/environment, through acts of production/use/inhabitation in terms of a complex set of interrelated conditions rather than by describing a number of static remains (Dobres 1999, 2000: 166; Binford and Sablov 1982).

3.2.1 Technological choice

In many ways technological choice forms the basic building block of recent approaches to craft production; it could be considered the fundamental 'unit' of knowledge that any study seeks to establish. Initially led only by anthropologists and sociologists (Van der Leeuw and Papousek 1992; Lemonnier 1993; Leroi-Gourhan 1945), the realisation that there were typically multiple ways to conduct any task and the choices made are as much related to social, economic and ideological frameworks as to material and functional considerations opened the material to a far wider field of analysis (Sillar and Tite 2000). As Lemmonier argues;

> *"the identification, location and deciphering of technological choices correspond to a series of crucial questions regarding how, and in what respect, technologies are a mediation (as well as a compromise) between universal physical laws and the unbounded inventiveness if cultures."(Lemonnier 1993: 10)*

This is an important realisation in archaeology because the study of production has tended to focus only on the choices actually made, rather than giving any consideration to choices which were rejected (Van der Leeuw 1993: 241). Central to the concept of technological choice is what goes beyond the physical, that is; the mental processes which dictate production choices which are fully embedded in a broader, social, political and symbolic system (Lemonnier 1993: 3). However, it is impossible to remove any technological choice from the material, the environmental or the social world.

Technological choices can, sometimes, be conscious and intentional (Van der Leeuw 1993) while at other times tacit and routine (Ingold 1993a), in both cases they can imbue ideas of self, identity and social relations (Wager 2002). In primary metallurgical production these choices are numerous; choices such as the type of mineral smelted, the type of furnace, the location of a smelt and the production pathway are all identifiable archaeologically. Obviously these choices are affected to different degrees by the physicality of the materials involved, and many of the choices can be significantly affected by the outcome of choices, but there is not one that exists in isolation from social, political and ideological contexts. Encapsulated within choices are aspects of technique, movement, temporality, geography,

human/material and human/environment interactions through which things come into being. There exists a tacit and cyclical relationship between the concept of technological choice and these themes. However, they each draw on different, but complementary, theoretical frameworks.

3.2.2 The Chaîne opératoire

Chaîne opératoire translates literally as 'operational sequence' and is drawn from the work of French anthropologists Marcel Mauss and Andre Leroi-Gourhan, who considered technology as a "*total social phenomenon*" asserting that technology is "constituted within an influential social and historical context" (Leroi-Gourhan 1945; Martinón-Torres; Mauss 1927:120; 2002; Schlanger 2004). They emphasise that technology was a fully social act, placing the actions of the human body as central to its study (Darvill 2008). Bodily habits and posture are central to exploring chaîne opératoire, with a sequence of bodily movements forming the basis of a technique which can be expanded to incorporate cognitive and didactic elements (Schlanger 2004, Walls in press). Chaînes opératoires could be seen as the first chapter in a series of wider studies of object biographies which seek to explore the long-term relationship between people and objects, from the 'birth' (production) of an artefact through to its 'death' (Joy 2009). However, while the terms are sometimes confused within the literature (cf. Driscol 2010, Piquette 2010) chaîne opératoire remains distinct in that it is solely focused on the various human-material relationships at the production stage.

The term chaîne opératoire has come to encapsulate both the chaîne opératoire as an object of study and as a methodological approach (Martinón-Torres 2002). As an object of study, the chaîne opératoire is at its most simple definition, a "*series of technical operations which transforms a raw material into a usable product*" (Cresswell 1990; Martinón-Torres 2002). Even this simple definition moves the objective of a technological study from the static accumulation of physical processes to the dynamic study of the acts of production. As an approach, the chaîne opératoire expands on this further; rather than being the object of a technological study, it becomes the way through which past production practice is interrogated and understood, affecting the aims, methods and enacting of archaeological endeavour (Dobres and Robb 2005). This focus on the making of material culture, rather than just its physical state, allows a dynamic past to be re-imagined through the study of static archaeological remains. Where technological choices primarily focus on how socially embedded an individual choice is, the chaîne opératoire presents a tangible structure through which these choices are enacted through physical techniques (Van der Leeuw 1993: 240).

Recently the term has been significantly extended to incorporate a broader methodology for the empirical investigation of the "*step-by-step physical actions and material procedures by which ancient technicians procured, prepared, modified, altered, shaped, used, repaired, reworked, recycled, and ultimately discarded their material culture*" (Dobres 2000: 167). This expansion allows those who employ a chaîne opératoire-based approach to study ancient production practices as; *"integrated webs weaving skill, knowledge dexterity, values, functional needs and goals, attitudes, traditions, power relations, material constraints and end products together with agency, artifice and social relations of technicians"* (Dobres 1999: 12). In the study of metallurgical production then, a chaîne opératoire based approach extends from resource procurement, though processing, smelting, casting, use, re-use and recycling of metals; procurement includes not just the mineral resources but the full panoply of necessary resources including fuel, clay and flux; it

also incorporates a broad array of skills and techniques.
Transformative metallurgy draws on a broad range of choices, skills, and techniques in addition to materials and resources, which, when presented in schematic form resemble more of a web than a chain of events. Indeed chaînes opératoires are often illustrated as either complex flow diagrams displaying production steps in a dry and sequential fashion, or more imaginative illustrations depicting actions linked by a web of arrows (cf. Leroi-Gourhan 1945; Sillar and Tite 2000). However neither method of illustration seems to capture the full suite of acts and engagements which constitute the panoply of production, something which is particularly true with regard to copper metallurgy. This is perhaps because illustrating a truly exhaustive metallurgical chaîne opératoire is problematic; by their very nature, chaîne opératoires are fully interwoven into the wider acts of the community and other spheres of production and consumption. Indeed, as Dobres points out, the chaîne opératoire is focused on performance, and is therefore body-centred (Dobres 1999).

It may then, be better to view a chaîne opératoire as a meshwork of interwoven lines/ pathways which represent the flow of people though time and space while engaging in the many acts of production (Ingold 1993b). The full interconnectedness of such acts are highlighted when attempting to simply identify the beginning of the metallurgical chain; mining, which is often seen as the first step (Ottaway 2001), can only be enacted following the identification of a suitable source, the procurement of adequate tools, and the acquisition of the necessary skill set to remove ore from the host rock. So then, it maybe that the chain could begin with the construction of mining tools; but, in the case of antler picks the animal would first need to be hunted, killed and processed, which itself requires a full range of tools, skills, and knowledge (and the use of copper tools only serves to exacerbate the issue). Therefore the study of metallurgy becomes the study of craft people, and how they enacted metallurgical production with their wider community.

In adopting a chaîne opératoire approach it becomes possible to incorporate what could be considered incompatible aspects of archaeology in a way thatgoes beyond the sum of their parts. Materials science, when enacted through the aims of a chaîne opératoire approach, can form the tangible basis through which an array of choices, tasks and configurations can be elucidated and understood. However, this is merely one aspect of an integrated study of production; to move closer to a full understanding of the social role of a chaîne opératoire and the technological choices it involves it is necessary to explore the context in which the chaîne opératoire is located (Ingold 1997; Wager 2002: 62). This requires consideration of how the chaîne opératoire was situated within space and time and how the physical attributes of the materials and spaces involved affected choices and actions.

3.2.3 Production in time and space

Through an awareness of technological choices and the chaîne opératoire it becomes clear that metallurgical production contains an array of possible configurations which have vastly different implications regarding how the choices and steps are organised in time and space. A chaîne opératoire approach, in emphasising the role of time and space, means that context and landscape are no longer passive backdrops in which the many acts of production and technological choices took place, but a "*record of – and testimony to – the life and work of past generations who have dwelt within it, and in doing so, have left there something of themselves*" (Ingold 1993a). This is the basis for what Ingold describes as his "*dwelling*

perspective" though which he develops the concept of a 'taskscape' (Ingold 1997).
Ingold sees taskscapes as analogous with landscapes; as landscapes are an array of related features, a taskscape is an array of related activities (Ingold 1993b: 158). He describes it as "*qualitative and heterogeneous*", and that a "*taskscape is to labour what the landscape is to land*" (ibid). A benefit to this approach is that it shifts the focus from abstract, imprecise and necessarily broad chronological timescales where craft production can be thought of as a dissipated or dislocated phenomenon, to more generational timescales where the day to day, seasonal, and more deeply rooted practices that structure life are given an immanency in the recovery of archaeological material and data. While these do not preclude what Merton calls "*astronomical time*", which is the uniform, homogenous and quantitative flow of time, they do emphasise the importance of "*social time*" which is formed through the doing of things and is *"tied to the particular circumstances of place and people"* (Ingold 1997). The concept of a taskscape then is of particular relevance to ancient production, as it allows a focus on the broader character and rhythm of the interrelated day to day activities of life, the more seasonal endeavours as well as exceptional activities (Edmonds 1997).

Metallurgy, like other forms of production, is not limited to a single spatial configuration. As with the varying choices and chaîne opératoire open to primary metallurgy, the way in which it was situated within time and space can also significantly vary. Therefore the temporal and spatial context of metallurgical production is a central consideration when attempting to explore the specific organisation of production as well as the scale of production within a community.

3.2.4 Engaging in production

The core aspect of all of the concepts outlined above is an understanding of production not as a process, but a practice; an interconnected web of the acts and engagements which are temporally, spatially and socially embedded. It is the very embodiment of craft then, which allows these concepts to be integrated into a framework for the study of ancient metallurgy. Through themes such as skill and theories of material engagement which focus on the nature of human/material interactions in terms of both constraints/freedoms afforded by a material as well as the physical acts of engagement with the material world, the role of the craftsperson can be incorporated into discussions of production (Dobres and Robb 2005).

Concepts of embodiment should be at the heart of any chaîne opératoire approach, as it focuses on the bodily engagement that is central to each production act (Leroi-Gourhan 1945). Through an understanding of embodiment it is possible to more fully incorporate disparate methodologies such as landscape survey, chemical analysis and experimental archaeology, into a more integrative programme. The doing of things removes the boundary between people and the world around them. Most compellingly outlined by Ingold, this creates an understanding of the world where people and things are not seen as discrete points connected by arrows, but as a "*trail along which life is lived*".

To some, engagement with materials can be seen as contingent on both the physical acts of production, the bodily engagement with materials, and the materials themselves. The relationship between these two aspects is termed 'materiality' (Jones 2004; Knappett 2008; 2012).It was Gosden who first used the term in this context (1982:82) suggesting that it refers to 'human relations with the world' (Gosden 1994: 82 and see Knappett

2013: 189). However, Jones has since expanded the term to act as a bridge between archaeologicaltheory and archaeological science, linking the material understandings generated through archaeological science to the social relations covered by archaeological theory. Knappett takes this a step further and suggests that the approaches outlined above, most notably the chaîne opératoire are useful means through which to understand materiality in Gosden's sense of the word (2012).However, use of the term materiality is not without its problems. The term is often used without clear definition and is often couched in the "*equal relationship*" terms discussed earlier and, while seeking to understand human relations with the world is undoubtedly an important aspect of exploring production, attempting to condense those relations into a single term could be seen as unnecessary. It is then, perhaps more useful to explore the outcome of material engagements from the perspective of skilled interaction with material and the bodily aspects of craft practice.

Central to the bodily aspect of material engagements is what Mauss and Bourdieu term "*habitus*", which, at its most basic relates to the repertoire of "*techniques of the body*" which are drawn from "*culturally patterned postures and gestures to be found in any particular society*" (Bourdieu 1979; Ingold 2000: 427; Mauss 1979: 101). The importance of habitus to the study of metallurgical production is clear; with metallurgy being a complex collection of physical acts which requires both learned knowledge and embodied skills brought to bear through numerous technological choices and culturally specific chaîne opératoire and taskscapes, it impossible to consider metallurgy as a single process. Although habitus gives focus to the physical engagement of the human body with regard to the production process, it is of course influenced by the physical properties of the materials in use. This can influence the nature of engagements with things and how they are perceived (Jones 2004). As noted earlier, this is not to say that material attributes dominate the engagement with them, but that the physical qualities of any material can be felt and understood, albeit in different ways. Jones argues that "*the meaning of pottery is not arbitrary, but is at least partly determined by its material qualities*" (Jones 2004). However, this assumes that material qualities are always understood in the same way, but, as Ingold contests, the way in which the material qualities were manifest, perceived and acted upon were fluid (Ingold 2007).

Material attributes do not necessarily dictate a specific technological choice, but they can influence innovations and solutions in interesting ways. For example; the use of a sulphide ore in the copper smelting process prevents following some technological pathways which would be effective with other minerals, and yet the ways in which craftspeople overcame this material issue are numerous and diverse. Therefore an understanding of the attributes of materials by the archaeologist is essential as it allows these innovations and choices to be placed with the wider context of choice.

3.2.5 Contextualising production

The concepts outlined above allow human-material interaction and production generally to be understood at the scale of individual agents, and to some degree, groups of craft practitioners, but it is important to explore role of production at a community scale. Two concepts are particularly useful in a wider contextualisation of production; Marx's modes of production and Bourdieu's social fields.

A mode of production is central to Marx's historical materialism and can be defined as

a combination of productive forces and the social relationships of power (Gosden 1989; Hindness and Hurst 1975: 10). In an archaeological context modes of production can be broken down into elements which include raw materials, labour, technology and output. Situating chaîne opératoire and the range of technological choices within production modes allows the incorporation of individual scale concepts with more macro scale narratives which include the relationships between different groups. Each element can be subdivided further to incorporate aspects of scale, variability and organisation (Andrews 1997). In structuring a mode of production and outlining likely archaeological characteristics, like those presented by Andrews for ceramic production (1997), it is possible to draw together the relationships between metallurgists, other craftspeople and further aspects of the community.

This approach is complimented by Bourdieu's concept of social fields. The 'field' is the other half of his practice theory, in that it includes habitus on the human scale, and fields on a larger, societal scale. He defines fields as the setting in which an agent operates and functions, drawing on social, economic and cultural aspects, rather than a simple class division (Hilgers and Mangez 2014). Social fields are particularly useful in a prehistoric context as they do not predispose a class-based hierarchy; different aspects of the community can interact and compete in different ways giving scope for a wider range of interrelations. Central to Bourdieu's concept of the field is that they are relational; there exist numerous fields which relate to each other on numerous levels and each field contains a series of relations dedicated to a specific activity or practice. This relational approach has clear parallels with Marxist principals, yet offers the freedom to expand beyond economic class and to incorporate many types of community. This is especially useful in the context of production: where Marx would see the value of a product as a sum of the labour process, Bourdieu argues that it is not necessarily the creator(s) alone who imbue value, but (in the context of art) the wider relationship between those who display, promote and consume an object (Bourdieu 1993: 76). It is this relational approach that allows wider issues such as social organisation, power structures and hierarchies to be better understood, or as Brückand Fontijn state; "*agency (the power to act or to have an effect of the world) is a product of relationships…*" (2013: 204).

3.2.6 Characterising communities: an integrative approach

Drawing together the approaches outlined in the previous sections it becomes possible to propose a framework through which the characterisation of metallurgical practice can be used to explore the organisation of Sintashta communities. Rather than being aligned to one specific theory, this would better be described and an integrative approach, i.e. one which draws together complimenting concepts from both archaeological science and archaeological theory to explore the practice of metallurgy and the role of production within the wider community. Through adopting a firmly anthropocentric, agent-based approach which places practice within its landscape, temporal and social contexts, it becomes possible to better explore the scale, character, significance and organisation of production.

The first way in which this thesis integrates these themes is through a combination of a literature review which combines the wider archaeological narrative (outlined in the previous chapter) and the specific metallurgical background (presented in the following chapter). Rather than simply being a technical summary, the following synthesis attempts

to view the published literature through the lens of the concepts outlined in this chapter, breaking down production practice temporally, spatially and by production sequence. In addition, the basis for the geography of production is presented in Chapter 5, which outlines the landscape and resources within which technological choices were enacted.

The second aspect of enacting this methodology is the detailed analysis and characterisation of metallurgical debris (outlined in Chapter 6). Throughout the programme of analysis the process of interpretation was front-loaded; materials were analysed with the specific aim of identifying characteristic choices, and aspects of the chaîne opératoire that could be situated within their taskscape. This is perhaps where Jones' integration of archaeological practice and theory is most visible. Rather than the gathering of abstracted analytical data which was subsequently fed into a theoretical model, the process of interpretation was ongoing; from excavation to the final record. The framework outlined here was not an afterthought, but central to the analytical process. The third aspect of an integrative framework is the experimental engagement with the production process. This draws on many of the themes outlined above, and can give an awareness of the role of the producer and what is possible for the material to facilitate in terms of action.

Finally, in order to expand the study of production to help elucidate wider societal issues it is important to move beyond the individual producers themselves and examine their role within the community. By defining social fields archaeologically and allowancing the relationship between those who participate in production and the field(s) that that they operate within/with it is possible to explore higher resolution modes of production. So rather than just exploring how production was organised we can explore where it was situated in ancient communities.

3.3 Choices in Primary Metal Production

In adopting a methodology within which these aspects are a central theme, the scope of study can move beyond the physical and chemical transformations from ore to metal to one which addresses the full interconnectivity of events and interactions within the wider sphere of everyday life (Dobres 1999; Ingold 2011: 63). However, it is necessary, to some degree, to draw an arbitrary boundary between what can be considered the core aspects of metallurgy such as resource procurement, ore processing, smelting, casting/forging and finishing (Doonan 1996; Ottaway 2001). To do so does not remove them from the wider range of associated acts, but presents a more manageable unit of analysis.

3.3.1 Resource procurement

Studies of resource procurement in ancient metallurgy typically focus on the acquisition of a suitable mineral (Ottaway 2001). However it is important to note that the resources required for primary copper metallurgy extend far beyond just the mineral, and include clay for furnaces and crucibles, a fuel for the furnace, tools for processing the ore, which may consist of lithics, antler and fabric; and particularly secondary minerals which were used as fluxes (Craddock 1995). The choices made in the acquisition of all of these resources have implications relating to how metallurgy was practiced. The study of some of these aspects, in the context of metallurgy, have been termed a "*cross craft approach*" (Thornton

and Rehren 2009). This term, though, still gives the tacit impression that each craft is ultimately discrete, excluding the possibility of broadly skilled 'craftspeople'. Resource procurement, perhaps more than any other aspect of production, tends to exist within the widest geographic range, and, as such the widest temporal range. Therefore the taskscape of resource procurement is of central consideration.

Mineral procurement

In the procurement of a mineral the first step presumes a familiarity with a locale, or at least the conditions that define a suitable locale. In cases where there are only limited resources this is a simple choice between mining the known, available mineral and not mining at all. However, in areas where numerous mineral outcrops were available, the decision to select one source over another is significant. This decision may have been based on the availability of extraction techniques, the location of an outcrop (including attitudes to it), the knowledge of how to smelt a particular ore, or even the knowledge that the metal produced has specific qualities (Doonan et al. 2007).

When a viable mineral resource is identified there are numerous techniques available to remove the ore from the host rock. These may depend on the type of mineralogy but are drawn from the knowledge and skill set of the miners and could include open pits or trenches which remove only mineral bearing rocks, large open cast mines that remove large areas of ore and host rock, or even more ephemeral picking of surface outcroppings (Barnatt 2002; Chernykh and Lebedeva 2002; Crew and Crew 1990; Timberlake 2001). The skills, techniques and resources required would vary significantly depending on the type of extraction method; a knowledge and familiarity with a particular toolkit and its associated technique may have influenced the choice of mine. However, even the simplest form of mining would have required knowledge of ore mineralogy, the difference between a suitable and unsuitable ore, as well as basic extraction skills. Accordingly, more complex mining techniques would require a mixture of bodily skill in order to articulate the mining tools and even, in the case of firesetting, an understanding of pyrotechnology (Crew 1990; Timberlake 1990b).

Mining is typically seen as the act of removing minerals from the earth through the act of tunnelling or digging (Simpson and Weiner 1989). The term tends to evoke an image of specialist, subsurface activity on an industrial scale. However, this presents a potentially disproportionate caricature when dealing with some of the earliest and more ephemeral ore procurements. Although this is only a small semantic distinction, it is important in the context of the Southern Urals, because surface depsoits of ore minerals were likely commonplace, and ultimately the act of recovering ore from a surface outcrop is significantly different to tunnelling deep into the earth.

Fuel procurement

Fuel procurement is an integral aspect of ancient metallurgy, but often remains ignored (Ottaway 2001). There are two broad types of fuel in ancient pyrotechnic terms; long flame fuels and short flame fuels (Tylecote 1986: 223). Long flame fuels, such as wood, produce an oxidising atmosphere and are relatively rapid burning, whereas short flame fuels, such as charcoal, produce a high temperature, reducing atmosphere and burn much more slowly (ibid). It is typically assumed that the former was used for roasting ores and the latter for smelting oxide and carbonate ores (Ottaway 2001). The identification of

fuel procurement strategies, particularly in prehistoric contexts is difficult, as the process can leave little trace in terms of both the acquisition of the resource and its processing; however, when production is intense and sustained there are certain observable factors, such as a decrease in biodiversity, which may be noted in the pollen record of charcoal burning structures (Hillebrecht 1989). The total amount of fuel necessary in prehistoric smelting is difficult to quantify. Some experiments have shown that considerable volumes of charcoal are necessary for the most basic of smelting practices (Merkel 1982; Timberlake 2013), however, the skill of the modern experimenter is likely much less refined than that of a prehistoric craftsperson.

Ceramic procurement

The procurement of a suitable ceramic is perhaps as important as the procurement of ore. Even the earliest known smelting seems to have relied heavily on a strong understanding of the properties of ceramic and the manipulation of clay (Rothenberg 1990). In copper metallurgy, ceramics are often used in the construction of the furnace, crucibles, tuyères and moulds, with each type requiring different properties. Furnaces needed to resist high temperatures while maintaining their structural integrity; crucibles were often exposed to the highest temperatures of the smelt and needed to contain a liquid charge; likewise, tuyères had to withstand the highest of temperatures at their tip, while moulds needed to resist thermal shock while maintaining their shape. Good clay combined with suitable tempering materials and knowledge of ceramic production were all beneficial to a successful smelt.

Ceramic procurement choices in metallurgy is an interesting area of study as it presents the possibility of a relationship between two crafts. For example it may be that metallurgical ceramics were procured from those who routinely produced other ceramics, which would suggest a certain level of specialisation with the community. Conversely the technical requirements of metallurgy may have necessitated a specific understanding of clay and temper properties and therefore may have been produced directly by metallurgists. Understanding the relationship between potters and metallurgists makes it possible to understand how metallurgists engaged with other aspects of the community.

3.3.2 Ore processing

The choices made during the ore processing stage can have significant implications regarding how production was organised, both within the community and within the landscape of time and space. The most common aspects of ore processing are related to beneficiation, which is the knowledgeable selection of mineral from other un-used (known as gangue) minerals. It has been shown in other studies that choices made during the beneficiation stage can influence the properties of the finished product (Doonan 1994).

Modern day beneficiation practice employs complex chemical floatation techniques (Davenport et al. 2002) whereas prehistoric beneficiation is typically seen as a more physical task, which involved crushing, hand sorting and sometimes washing (Doonan 1994). Indeed beneficiation requires a considerable amount of physical dexterity in order to adequately separate good ore from gangue. The principle choices at the beneficiation stage are the location of ore processing and the way in which processing is enacted. In many prehistoric examples beneficiation is noted at the place of extraction, such as Ross

Island in Ireland, or Batan Grande in Peru (Merkel et al. 1994). However, in these cases the procurement is closely associated, geographically, with primary smelting. Conversely, in examples where smelting took place away from the mine, the location of processing can elucidate how the various acts of production were distributed throughout the community.

3.3.3 Smelting

Smelting is the stage at which ore is transformed to metal though a combination of high temperature and controlled atmosphere. The choice of smelting technique is dependant, to varying extents, on the type of ore, the production of a successful metallurgical ceramic and the ability to create and maintain a controlled atmosphere.

In broad chemical terms there are four types of copper smelting processes identified in prehistory; direct reduction, roasting and reduction, co-smelting and matte conversion (for a summary of smelting pathways see Table 3.1). In terms of techniques these different pathways present different problems; a reduction smelt may require more of an enclosed superstructure than an oxidising smelt, and the bellowing/blowing regime may also be different. Knowledge of the type of ore used is also essential, as to attempt a matte conversion on a carbonate ore would produce very little of use. The difference between a single step process and a multistep process is also significant as the latter may allow the production of a copper metal to be carried out over numerous locales and times. It is not uncommon in prehistoric crafts to find intermediary products moving instead of either the raw materials or finished artefact (Doonan and Day 2007; Pulak 2001).

Beyond the background chemical processes there are numerous choices which can affect the way in which ancient craftspeople smelted. Normally these choices can be best understood through analysis of metallurgical slag. In addition, Doonan (1999) has shown that an analysis of technological architecture can facilitate an understanding of group size and pyrotechnical dynamics. The way in which air is induced into the furnace, the way in which the copper is removed from the furnace and how the charge is placed within the furnace are all aspects of a process which can, in ideal circumstances, be recovered archaeologically.

3.4 Identifying Choice

The incorporation of social approaches to the study of past production practices have been significant because they place choice at the centre of discussions. Many approaches and themes incorporate choice as an underlying assumption, albeit not always in the same vocabulary examples being: chaîne opératoire, materiality and taskscape (Dobres 1999; Ingold 2000; Jones 2004). What unifies many social approaches is the understanding that past groups or individuals had the ability to accept or reject an option based within the social/cultural context in which the decision was made (either tacitly or explicitly).

In ancient metallurgy the choices are vast and this section by no means presented an exhaustive list; they are, however, those which have most bearing on this thesis. They all have significant implications on how production was organised and how craft producers were situated within the wider community. There are numerous ways though which to identify choice. However the most important starting point is a strong archaeological

Table 3.1 Typical pathways in the copper smelting process (after Rostoker et al. 1989; Hanks and Doonan 2009)

Pathway	Ore type	Chemical process	Notes
Direct reduction	Oxide/ carbonate	$2CuO + CO \rightarrow Cu_2O + CO_2$ or $Cu_2O + CO \rightarrow 2Cu + CO_2$ or $Cu_2CO_3(OH)_2 + 500^oC \rightarrow 2CuO_2 + CO_2 + H_2O$	Typically applied to oxide and carbonate ores through the removal of oxygen with the addition of excess carbon monoxide. Slag is produced primarily from the gangue minerals and any flux which was added to facilitate their removal
Roasting and reduction	Sulphide	$CuFeS_2 + 3O_2 \rightarrow CuO + FeO + 2SO_2$ or $2CuFeS_2 + 3O_2 \rightarrow CuO + FeO + CuS + FeS + 2SO_2$ then reduce	Associated with the smelting of sulphide ores. Chemically there are two pathways which fall under this category; full roasting followed by reduction smelt or partial roasting followed by a co-smelt. The resultant mixture is then co-smelted in a mildly oxidising/reducing atmosphere to produce copper metal as described in the next section.
Co-smelt	Oxide/ carbonate and sulphide	$3CuO + FeS \rightarrow FeO + SO_2 + 3Cu$ or $3Cu_2O + FeS \rightarrow FeO + SO_2 + 6\ Cu$ or $5CuO + CuFeS_2 \rightarrow FeO + 2SO_2 + 6Cu$	A mixture of oxide and sulphide ore is smelted in a mildly reducing/oxidising furnace. The sulphur acts as an additional reducing agent in the absence of excess CO.
Matte conversion	Sulphide	$CuFeS_2 + O_2 \rightarrow CuFeS + SO_2$ then $2CuFeS + O_2 \rightarrow CuS + FeS + FeO$ then $CuS + 3FeS + 5O_2 \rightarrow CuS + Fe_3O_4 + 3SO_2$ once all the iron is removed $CuS + O_2 \rightarrow Cu + SO_2$	Begins with an enrichment phase where the copper ore is heated under oxidising conditions to drive off excess sulphur before it is subjected to repeated oxidising smelts to remove the subsequent sulphur. Once all of the iron is removed, the copper can be released from the sulphur by oxidation.

question (Andrews and Doonan 2003). There is an ever-increasing list of techniques and methods available for the study and analyse of archaeological materials, and yet without a strong rationale these result in little more than the accumulation of data in the hope that meaning or explanation might reveal itself.

Identifying ore procurement strategies can be achieved in numerous ways which draw on both field work and laboratory analysis. Field surveys in the vicinity of production sites and of known mineral rich areas can provide a range of potential resource choices which can be explored through detailed analysis (Doonan 1999; Hanks and Doonan 2009; O'Brien 2004; Timberlake 1990a; Wager 2002). This, coupled with the identification of unused ore fragments among archaeological assemblages, can suggest the type of ore body exploited. This is significant as sourcing studies have typically been situated in the laboratory in the guise of trace element or lead isotope analysis. In situating the study of mineral procurement in the field, as has been done by the SCARP program (Hanks et al 2014), procurement studies can be enacted though an archaeological rationale rather than one situated primarily in chemistry. Of course, the analysis of metallurgical debris can hint at the type of ore used when field-based programmes are unsuitable (Bachmann 1982; Hauptmann 2007; Weeks 2003). Indeed many archaeometallurgical projects have attempted, in what can been termed consumption led inquiry,to infer ore source, and thus a likely production pathway, through the chemical and isotopic analysis of copper/bronze artefacts (see Chernykh 1992; Northover 1989; Rohl and Needham 1998);although these techniques have been met with some criticism (Budd et al. 1996).

The most direct way to explore choices made at the smelting stage is through analysis of metallurgical debris; such as slag, metallurgical ceramics, unused mineral and other debris. The type of atmosphere employed, furnace type, minerals used, the recipe, smelting regime, and even how aspects of production were organised, can all be understood through the characterisation or metallurgical debris (Bachmann 1982; Doonan 1996; Hauptmann 2007). This could be considered as practice-led inquiry; that is to assume that the enacting of technological choices leave a characteristic and observable physical residue which is indicative of more than just the underlying process (Eldridge 2014). Through an understanding of technological choices, and by working within the frameworks outlined above, it is possible to approach the study of metallurgy as more than just a technical process. The extent to which this approach has been applied in the southern Urals is limited. Many of the studies of metallurgy follow a more objectivist framework; with Russian archaeology more generally considered a scientific discipline, many of the studies which have focused on metallurgy have aimed to quantify and catalogue, rather than discuss metallurgy as a social practice.

3.5 Experimenting with Choice

Experiment has a long tradition in the study of archaeological metals, with some scholars using experimentation as early as the late 19th century (Gowland 1899) to test ideas about metal fabrication. Since the 1970s it has been used more regularly as the end point in studies to test proposed theoretical models based on the analysis of excavated materials and structures (Merkel 1982; Tylecote 1962). It is the inability of analytical studies on their own to resolve the myriad choices regarding materials, technique and process which has attracted researchers to use experiments. The practical engagement in such activities

acts as a sobering check on the more fanciful theoretical proposals. While there is a strong community which uses experiment, it should be remembered that experiment rarely proves anything; rather it is best used in the negative to dismiss models. As Coles (1979) highlights, it is more capable of disproving theories as when something "*works*"; it is likely one of many solutions and thus remains a possibility rather than a definite proof.

More recently, many experimental practitioners have realised the potential for such studies to be used as outreach activities and to augment living history events, which has led to some strong opinions being published concerning what exactly experiment is and how it best be defined (Doonan and Dungworth 2013: 2). Some have chosen to restrict definitions of experiment to strict protocols which strongly mirror scientific practice (Outram 2008; Reynolds 1999), while others, taking their lead from post-modernist insights, have sought a more liberal definition, and one that extends to include the experiences of practitioners, what some have chosen to call an experiential approach (Mathieu 2002; Townend 2002).

There is, no doubt, value in the many aspects of reconstructing materials, structures, processes and practices, and the possibility of adopting a sensory approach to such activities promises to be an area which will develop seriously in the near future, as frameworks for engagement in such issues emerge (Doonan and Dungworth 2013; Hamilakis et al. 2002). For this study, however, the pressing concerns are perhaps more prosaic, as many aspects of material identification and how these material elements are assembled in to a working whole are yet to be established. That said, the value of experimenting is by no means limited to this. Experimental engagement can be a means through which the concepts outlined above can be explored beyond the hypothetical. Though enacting production practice, no matter in how contrived a way, it is inevitable that aspects of the relationship between practitioner and material will be better understood. This is a fundamental benefit of adopting Ingold's perspective of skilled practice, perception and response; even a relatively unskilled 'craftsperson' (or even archaeologist) will begin to better understand the ability/constrains of materials, as well the temporality and spatial articulation of production.

This chapter has presented both a background to the study of metallurgy and a framework through which past production practice can be used to understand the actions of ancient craft practitioners and groups. In outlining such a framework it becomes possible to move beyond an understanding of technical process to a position in which the role of production within the community can be understood. It becomes possible, when the products of skilled practice can be understood through survey, materials analysis and experiment, to not only understand the role of the craftsperson in their community, but also how they relate to other social fields, indeed how they relate to the wider community. By looking beyond metallurgists to exploring their relationships to other craftspeople and other societal fields it becomes possible to better explore these potentially diverse communities.

The following chapter draws on the concepts outlined here to present the current state of our understanding regarding metallurgy in the Southern Urals. Rather than being a simple synthesis of literature, the chapter attempts to, where possible, to channel existing knowledge into production steps and discrete technological choices.

Chapter 4

Metallurgy in Bronze Age Central Eurasia

This chapter presents a summary of the current understanding of Bronze Age metallurgical production in the Central Eurasia with particular emphasis on practices in the Southern Ural region. The Southern Urals have, in various periods, had a strong relationship with metallurgy from the Bronze Age to the present day. The two major modern cities in the Country of Towns region, Chelyabinsk and Magnitogorsk, are both major industrial centres, with metallurgy making the most significant contribution to the economy (Prokhorov 1982). To some extent, this modern association with metallurgy accounts for the enthusiasm of some scholars who see the Bronze Age of the region as the origin of this tradition (Grigor'yev 2000; Zdanovich 1995).

To date the most extensive and influential study of metallurgy in the region has been conducted by Chernykh (1992), wherein he undertook a pan-regional study of metallurgical forms alongside a more limited investigation of composition. Central to Chernykh's work is the concept of a 'metallurgical province' which can be defined as:

> *"[a] large continuous region (a 'federation' of similar and related production centres, 'the largest historical production system operating in antiquity') linked through its shared utilization and morphologically defined metallurgical ornaments, tools and weapons; a common technology of metallurgical production; and availability of or access to the same metallurgical sources" (Kohl 1992: xv)*

Chernykh's three main provinces consisted of the Carpatho-Balkan Metallurgical Province, the Circumpontic Metallurgical Province and the Eurasian Metallurgical Province, as well as a number of smaller, regional provinces (Chernykh 1992). The provinces spanned much of the Old World and covered an expansive time frame from the Early Metal Age though to the Late Bronze Age (some 4000 years). Chernykh's work has been seminal in establishing a framework on which more recent studies in the region have built upon, although his primary focus was the finished artefacts, rather than evidence of production (Chernykh 2009; Zhang 2012). Chernykh himself concedes that, while his coverage and corpus of material is extensive, the social organisation of mining, metallurgy and metalworking, and how it changed over time, was beyond the remit of his work (Chernykh 1992).

Despite the fact that finished objects are found across the region and feature frequently in discussions of metallurgy, the evidence for primary, extractive metallurgy in the Bronze Age has been recovered in far fewer contexts and rarely features in detailed discussions (Zhang 2007). Due to considerable inconsistencies in the way in which sites have been excavated and material curated and published there are significant problems when attempting to explore the extent of production evidence in the region. Material associated with Middle Bronze Age sites, for example, has attracted a great deal of international interest, yet very few of the excavations have reached full publication. This has led to a situation where much primary data has been referred to in the secondary literature prior to major publication (see Hanks 2010a for discussion). This is often problematic, for instance in the case of Arkaim (Zdanovich 1995), where secondary accounts of unpublished material have been used to inform broader syntheses of a wider geographic scale. Scholars including Anthony, Kohl and Kuzmina have all used the supposed ubiquity of metallurgy in Sintashta houses to support their theories, doing so based largely on data in the secondary literature (Anthony 2009; Kohl 2007; Kuzmina 2008). It is important to acknowledge this point before outlining a review of the regional evidence, because the unbalanced nature of published evidence can serve to obscure an understanding of the evidence itself. To conduct a full survey of the unpublished evidence from Bronze Age metallurgy in Central Eurasia would require a significant study of archival sources far beyond the scope of this thesis. However, the review presented here does consider the conditions of excavation, the timeliness of publication and, critically, reports from excavation directors and those who have worked on the material.

4.1 Early Bronze Age

Evidence for metallurgy in the Early Bronze Age is predominantly found in burial contexts in two forms; the metal artefacts themselves and a number of tools associated with object production, such as grinding stones, moulds and crucibles (Chernykh 1992). Sites attributed to both Yamnaya and the western Poltavka communities have yielded such evidence (Zhang 2007: 129). Evidence for primary metallurgy and mining is uncommon in the Early Bronze Age; evidence has only been found at two sites: the site of Kargaly, in the form of dated mining deposits, and at the settlement site of Turganik in the form of slag and ore (Chernykh 1996: 85; Zhang 2007: 129).

Kargaly is located to the south west of the region (Figure 4.1) and was subjected to sustained archaeological investigation in the 1990s by E. Chernykh (Chernykh 1996). The majority of the ancient exploitation has been attributed to the Late Bronze Age (see later); however, there is evidence linking the earliest exploitation to the Early Bronze Age. The evidence for EBA exploitation comes from three main sources: chemical analysis of EBA metal artefacts suggesting Kargaly was the likely source of ore used, radiocarbon dating of material from the open cast pit, and a Yamnaya/Poltovka type burial excavated on the site (Chernykh 1996: 85; Diaz et al. 2006; Zhang 2012). The burial, of a young male, contained two axe moulds of the Yamnaya type (Chernykh 2002).

Turganik is a settlement located to the west of Kargaly (Figure 4.1, Zhang 2007: 129) and excavations revealed a number of Yamnaya type objects. Amongst the excavated material were a number of pieces of 'sandstone' ore, similar to that found at Kargaly; slag, crucibles

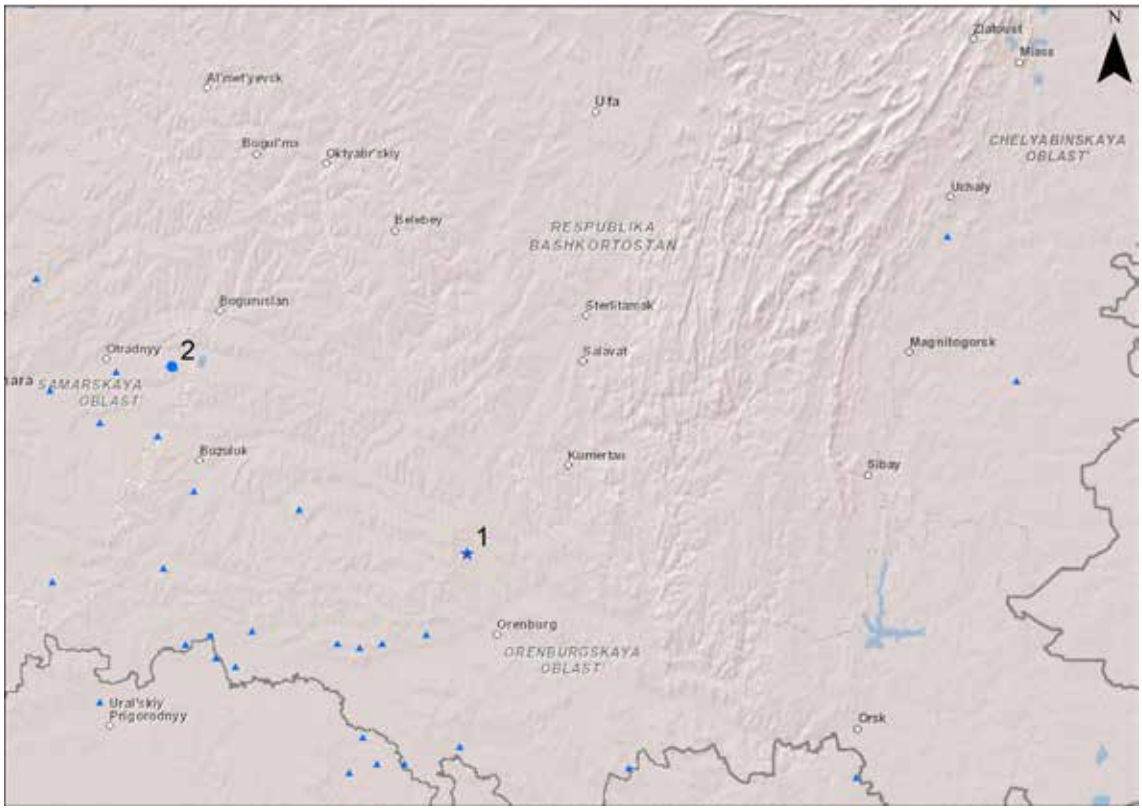


Figure 4.1 Location of the Early Bronze Age sites mentioned in the text. 1; Kargaly, 2; Turganik (After Morgunova and Khokhlova 2006)

said to have used been for smelting, and unfinished awls and chisels (Zhang, 2007, p. 130). It should be noted, however, that the material was not included in the original excavation report (Bogdanov 2004; Morgunova 1984), Zhang was likely given access to unpublished material.

Although not extensive, these two examples do suggest that extractive metallurgy was taking place, at least in the west of the region, during the Early Bronze Age. However, it is impossible to say whether the paucity of evidence can be equated with a low scale of metallurgical production, or is due to the difficulty in locating Early Bronze Age production sites (Koryakova and Epimakhov, 2007, p. 45). While primary metallurgy is not well represented in the Early Bronze Age there are some examples of secondary metallurgy, most notably moulds for socketed axes (Chernykh 1992; 61). These have been found at sites throughout Chernykh's Circumpontic Metallurgical Province.

4.2 Middle Bronze Age

The Middle Bronze age produces considerably more evidence for metallurgy, particularly at Sintashta type sites (Grigor'yev 2000). Beyond Sintashta sites, evidence for extractive metallurgy and artefact production has been found in a number of excavations to the west of the Urals on sites attributed to Abashevo (Koryakova and Epimakhov 2007: 33). The settlement sites of Bergovskoye, Balanbash and Urnak (Figure 4.2) all contain house structures where metallurgical debris, including smelting vessels, crucibles and slag has been recovered. Balanbash is said to be the most significant of these production sites, "*producing copper for a large territory*" (Koryakova and Epimakhov 2007: 34). However,

only 'smelting pots', slag, and finished objects were found on these sites; no metallurgical architecture was identified. Grigory'ev has argued that this was most likely due to the use of very basic furnaces, which would have left little more evidence than an area of burning (Grigor'yev 2000: 513). Although no mines/mineral sources have been directly tied to Abashevo exploitation, there are numerous outcrops of copper-bearing-sandstone to the west of the Urals and it has been suggested that these were exploited widely on a piecemeal basis (Koryakova and Epimakhov 2007: 34).

The majority of Middle Bronze Age metallurgical evidence has been found at Sintashta sites (Koryakova and Epimakhov 2007) and it is no surprise that this area has been a major focus of attention for scholars exploring the wider implications of metallurgical production (Anthony 2009; Hanks 2009; Grigor'yev 2002; Frachetti 2012). Despite the evidence noted at the Middle Bronze age settlements in the region (Grigor'yev 2000) there are still significant uncertainties regarding the scale and intensity of metalworking (Anthony 2009: 47; Hanks et al 2014).

To date, nine sites of the 23 known Sintashta period settlements have been partially excavated, most of which were found to contain at least some metallurgical evidence (Hanks 2009: 148). From publications of subsequent analytical work it is possible to say with certainty that seven settlement sites contained metallurgical debris: Arkaim, Sintashta, Ust'ye, Olgino, Sarym-Sakly, Alandskoye, Rodniki, and Stepnoye (Grigor'yev 2000: 476).

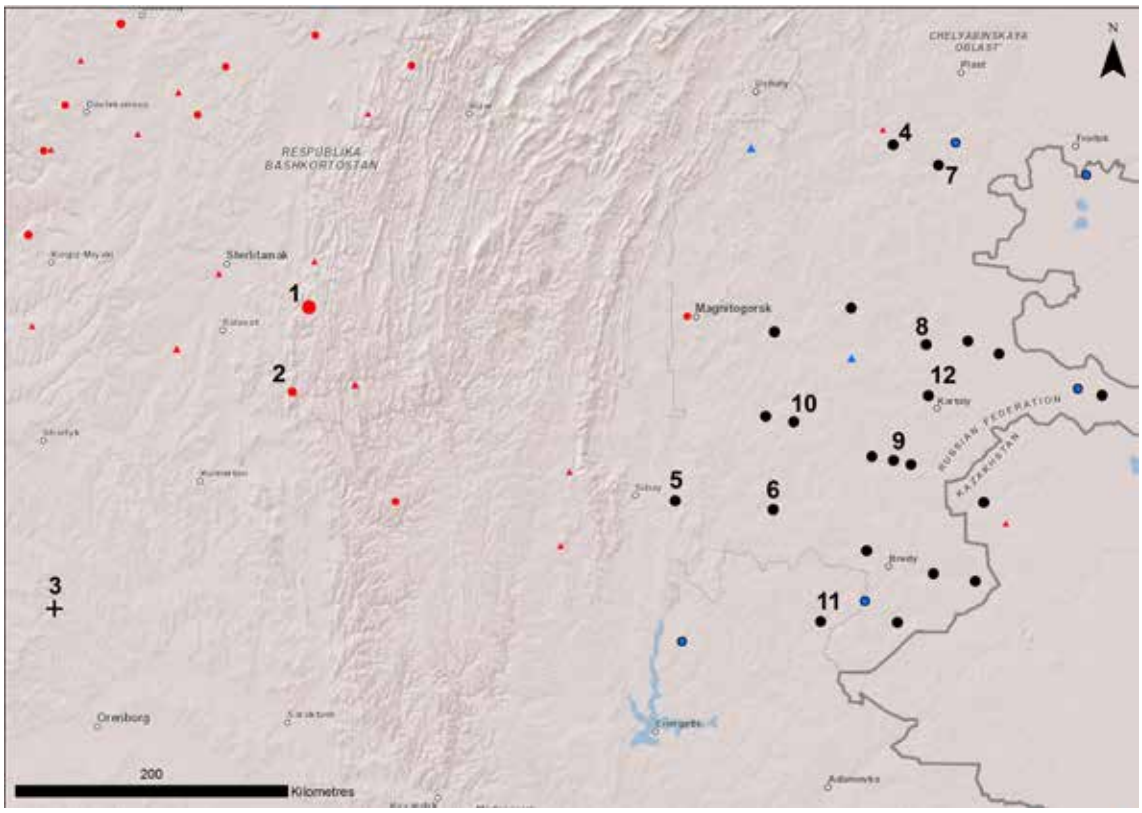


Figure 4.2 The locations of some Middle Bronze Age of the sites referred to in the text: 1 Balanbash, 2 Bergovskoye, 3 Kargaly/ Gorny, 4 Stepnoye, 5 Arkaim, 6 Sintashta, 7 Chernorech'ye, 8 Ustye, 9 Olgin'o (Kamenny Ambar), 10 Sarym- Sakly, 11 Alandskoye, 12 Rodniki (locations taken from Koryakova and Epimakhov, 2007). Red = Abashevo, Blue = Petrovka, Black = Sintashta, Triangles = Kurgans, circles = Settlements.

As well as in settlement contexts, metallurgical debris has also been found in Sintashta period burials. Excavations at the burial grounds associated with Sintashta, Chernorech'ye (Krivoye Ozero), Ust'ye (Solntse II), Arkaim (Bolshekurgansky), Stepnoye and Olgin'o (Kamenny Ambar) all produced at least one burial which included slag fragments and other metallurgical debris (Vinogradov 2004: 270). It is important to note that slag, although significant, was only found in a small percentage of the burials excavated at these sites.
While the process of metallurgy was extensively discussed by Grigoryev and colleagues, the study of mining has been the purview of geologists, particularly Zaykov (Zaykov et al. 2005). This has led to a situation where smelting has been studied as a technological problem, while mining has been seen as a geological one. The following sections outline the current model for Sintashta metallurgy, beginning with mining, before moving through smelting and object production, before finishing with an outline of the consumption patterns of metal objects.

4.2.1 Mining Practice

Attempting to understand the nature and organisation of mining during the Middle Bronze Age in the region is difficult due to the destructive nature of mining itself and the sheer abundance of small, ephemeral mineral outcrops. There are ten mines in the region which were possibly exploited in antiquity (Chernykh 1992; Zaykov et al. 2005). However, only one mine, Voroskaya Yama, has produced any dating evidence from the Bronze Age (Grigor'yev 2002: 84; Zaykov et al. 1995). Five of these potentially ancient mines are located within the Country of Towns regions, with a further two some 50km to the north (Chernykh 1992: 227; Zaykov et al. 2005). The majority have only been dated through geographic association and morphological characteristics (Hanks 2009: 153; Zaykov et

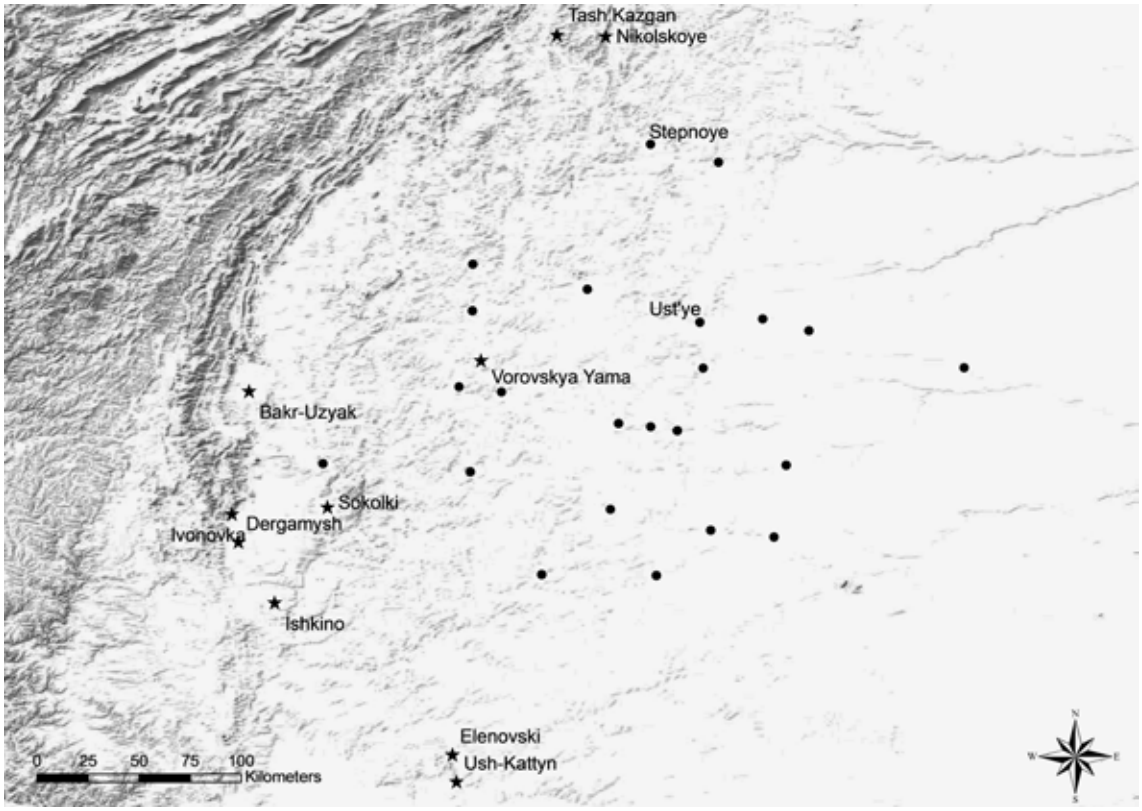


Figure 4. 3 Location of the mines attributed to the Middle Bronze Age in relation to the settlements of the courtly of towns (circles).

al. 2005). It is clear from the distribution of the mines however that there is no specific or uniform association between mines and settlements, with some settlements having a much closer proximity to known mineral resources than others (Figure 4.3).

Dating and morphology of 'ancient' mines

While the presence of these mines is important, their dating remains a significant problem. None of the mines has been convincingly dated to a resolution beyond 'Bronze Age' and the majority are simply termed ancient. This makes any conclusions drawn from their locations and morphology tentative at best, especially as low impact mining was commonplace in the region up until the Soviet period (Yuminov pers com). However, at least one of the mines, Voroskaya Yama, has yielded Bronze Age ceramics, and overall the region is significant in that it lacks any evidence for large-scale, sustained ancient mining comparable to that of Kargaly, to the west of the Urals (Chernykh 2002; Grigor'yev 2002: 84; Zaykov et al. 1995). Due to these problems, discussions regarding mining practice have typically been limited to analytical studies which have attempted to link artefacts, slag and ore through quantitative chemical composition studies which have aimed to identify production centres (Chernykh 1992). Very few studies have directly attempted to outline either the intensity or scale of production or its organisation.

The sites (Figure 4.3) that have been broadly attributed to the Middle Bronze Age have been so largely due to combination of their spatial association with settlement sites, dating evidence from spoil heaps (Voroskaya Yama) and their morphological appearance. They were typically open pits between 20 and 80m in diameter and up to 12m deep (Koryakova and Epimakhov 2007). They were noticeable in the landscape as trenched or as depressions in the ground. Indeed, the name of one of the most discussed mines, Voroskaya Yama, translates as 'thieves pit' which was the name given to it by locals who noted that it was used to hide stolen livestock (Zaykov et al 2005). These mines all exploit near surface outcrops. None of those suggested as dating to the Bronze Age have deep shafts or any major subsurface mining activity (Zaykov et al 2005). So, while the five potentially ancient mines identified in the literature are problematic to date, they show no evidence of highly organised and intensive exploitation in antiquity.

Organization and scale of mining

The organisation of mining in the Country of Towns has been central to many of the discussions of social organisation and complexity in the region, specifically the level of integration/cooperation which was present between the communities (Hanks 2009). For example, Kuzmina has argued that it was the competition for the best mining sites which led to the formation of Sintashta patterns, while other scholars have argued that very few mines were actually exploited and that therefore resources were shared (Grigor'yev 2002; Kuzmina 2008). Indeed, it is clear from Figure 4.3 that there is little direct geographic correlation between the location of known mines and the location of settlements; only Voroskaya Yama falls within the main cluster of known settlements. Unfortunately with such little dating evidence to identify mines that were exploited during the Middle Bronze Age the organisation of mining has primarily been understood through scientific-led ore sourcing projects.

Until fairly recently the principal method for the sourcing of ores in the Southern Urals, and in central Eurasia generally, has been based on the bulk chemical composition of

metalwork, with more limited studies of slag. However, recently, chromite sourcing has become the preferred method for attempting to source ore and metallurgical production in the region (Grigor'yev 2003, 2007; Zaykov et al. 2012). In the Southern Urals sourcing using the composition of chromite spinels is attractive due to the presence of localised serpentinite geology and the relatively unreactive nature of the spinels at typical smelting temperatures. Assuming that spinels in slag can be directly correlated to an ore source, local geologists and archaeologists Zaykov, Yuminov and Grigor'yev have argued that much of the ore smelted in the region was derived from serpentinite deposits, specifically at Voroskaya Yama (Grigor'yev 2003, 2007; Zaykov et al. 2012). The results of their work support the idea of a limited selection of mining sites, namely those in serpentinite zones.

The difficulty in attributing artefacts to contexts of production and to geological deposits, and the lack of focus on the local area around settlement/production sites, means that, at present, it is impossible to adequately appraise the models forwarded by Zaykov et al. (2012). The dominant model then is one which proposes large scale, centralised mining based at Voroskaya Yama with ore minerals being distributed to a large network of smelting centres (Grigor'yev 2003; Koryakova and Epimakhov 2007; Kristiansen and Larsson 2005). Exploring the scale of mining in the Middle Bronze Age is problematic. Attempts have been made to the infer scale of production from the excavation of these sites; for example at Vorovskaya Yama it has been estimated that 6400 tons of copper ore material, with an estimated 2% concentration of copper, could have produced a maximum 128 tons of copper (Zaykov et al. 1995, 2005). However these figures would assume a total reduction, with no copper lost to the slag, and it is not clear how much copper mineral, if any at all, was extracted during the Middle Bronze Age. In addition, 2% seems a comparatively low yeild for a copper ore, particularly given the abundance of high grade copper mineralisation in the Southern Urals.

Mining practice

Evidence for mining practice in the Southern Urals is found typically in the form of tools recovered from settlements. The aim of the excavation of mining sites has been to date the mine and to procure adequate mineral samples (Zaykov et al. 2005), and therefore reports of evidence, tools, structures, architecture etc. in connection with mining in this region have not found prominence. This is in contrast to studies which have taken place in the Cis-Urals, specifically at the mining site of Kargaly, where excavations have produced numerous stone, bone and antler tools which were used in the act of mining (Chernykh et al. 2002). That said, examples of hammer stones have been found at 'ancient' mining sites just to the south of the region in Kazakhstan (Zaykov 2007). These hammer stones had a shallow groove running across the centre which suggests they were hafted and similar to prehistoric examples noted elsewhere in the Old World (Craddock et al. 2002). In addition, other percussion tools are found regularly on settlement sites and in burials (Epimakhov 1996; Gening et al. 1992; Vinogradov 2003, 2004). These are usually interpreted as grinding/crushing stones.

4.2.2 Smelting Practice

Since the earliest Sintashta discoveries, the experimental reconstruction of the Sintashta metallurgical process has been pursued by Stanislav Grigor'yev and colleagues based at the Ural branch of the Russian Academy of Sciences. Grirgor'yev has worked on material

from many of the excavated sites in the region and has produced a number of publications describing his reconstruction of the Sintashta metallurgical process and the 'evolution' of the Sintashta furnace (Grigor'yev 2000). Much of this work was based on experiments conducted by Grigor'yev and Rusanov in the early 1990s. Grigor'yev and Rusanov (1995) embarked on a substantial program of experimental reconstruction with the primary aim of understanding the process found at Arkaim. Grigor'yev proceeded in subsequent articles to apply his experimental findings, based largely on Arkaim, to the interpretation of the Country of Towns as a whole (2002, 2003, 2013).

Accompanying evidence for smelting on Sintashta sites are reports of hearths or furnace structures. These have regularly been identified within Sintashta structures and many of these are interpreted as smelting furnaces or sometimes as multifunction domestic/industrial hearths (Koryakova and Epimakhov 2007: 37). The seemingly ubiquitous presence of furnaces on Sintashta sites has provided the foundation for many of the wider discussions regarding the nature of Sintashta communities (see Hanks 2009 for discussion). The current model suggests that smelting not only took place in every settlement, but in every household (Grigor'yev 2002, 2003; Koryakova and Epimakhov 2007; Kuzmina 2008; Zdanovich 1995). This argument is largely based on the presence of purportedly elaborate furnace structures in many excavated houses (Grigor'yev and Rusanov 1995). It is striking that, despite the assertion that these communities engaged in a unified process, there is significant variation in the morphology of these proposed furnace structures. Where these variations are acknowledged, they are considered stages in an evolutionary scheme, which can be seen in Figure 4.4 (Grigor'yev 2000, 2002, 2003, 2013).

The furnace structures being suggested by Grigor'yev range from relatively simple bowl hearths to the more complex well-tunnel-furnace which is shown in Figure 4.4. While the simpler furnace structures proposed by Grigor'yev are argued to have been powered by bellows, the well-tunnel-furnace has been said to rely on a combination of 'natural' draft accompanied by a forced draft (Grigor'yev 2003). In this model the natural draft was provided by a combination of the horizontal flue, which connected the main furnace chamber to a nearby well, and the vertical flue which rose from a separate horizontal channel at an oblique angle to the main horizontal flue (Figure 4.5). Grigor'yev and Rusanov have proposed that the combination of the cold air in the well and the hot air in the main chamber, coupled with the vertical flue, created a pressure differential which induced a draft (Grigor'yev and Rusanov 1995).

While the well-tunnel-furnace is by far the most common type of furnace discussed in relation to Sintashta metallurgy, it is only seen in its most complicated form in a small number of house structures (Gening et al. 1992; Zdanovich 1995), where there is no compelling evidence for these actually being used in a metallurgical context (Degtyareva 2010: 339; Rusanov 2011). It therefore seems untenable to view them as the archetypal furnace for the region. In fact, there is a significant amount of variation in the little excavation data which has reached publication. Grigoryev, for example, has documented 23 of what he sees as furnace structures from the excavations of Arkaim, Sintashta and Ust'ye, yet only three or four seem to have the complexity of a well-tunnel-furnace, and only half are found in association with a well (2000:464). In addition, recent experimental work has highlighted significant problems associated with the application of these structures in a metallurgical context (Comeau 2012). Despite this, the very complexity of the furnace has become something of a metaphor

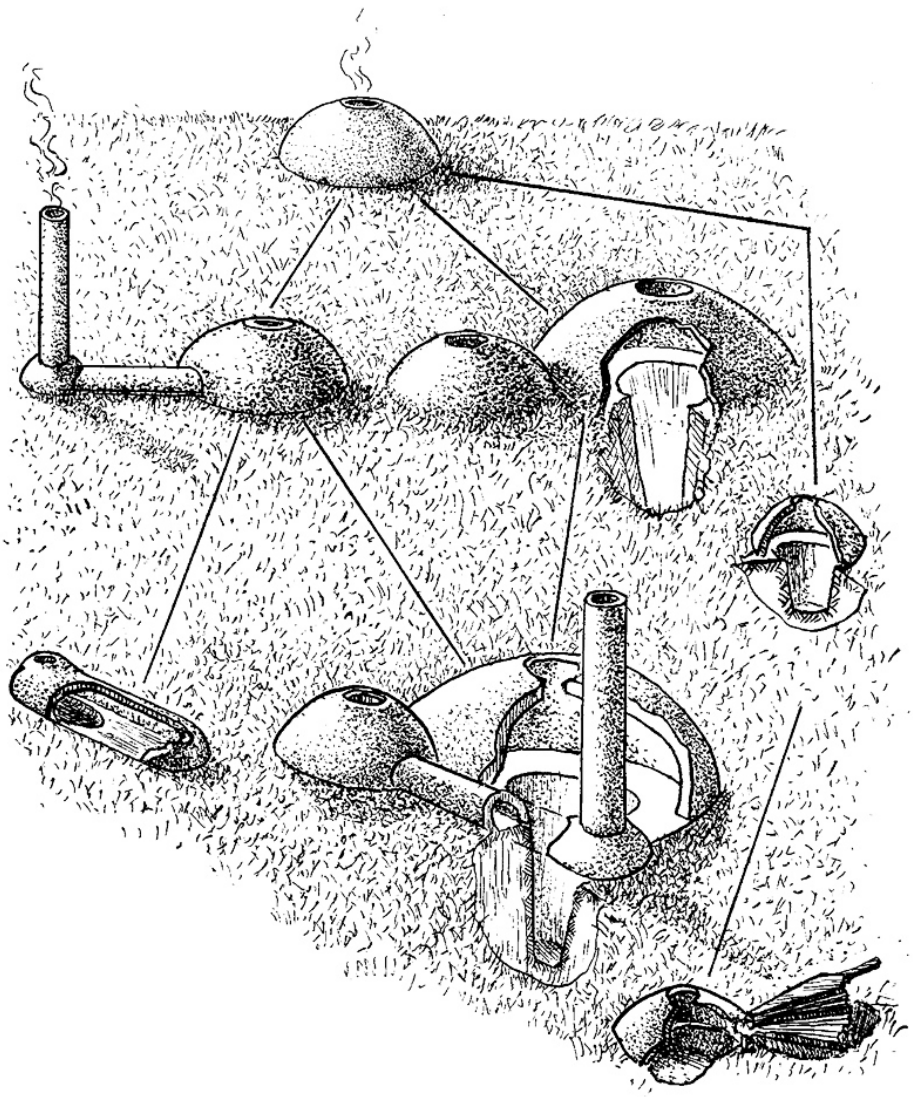


Figure 4.4 Grigor'yev's evolution of the Sintashta furnace (Grigor'yev 2013)

for the complexity and technical superiority of Sintashta metallurgists (Kristiansen and Larsson 2005: 174). A product of this emphasis is that the majority of discussions in the secondary literature exclusively draw on this type of furnace (Anthony 2009; Koryakova and Epimakhov 2007). In many cases the furnace is considered to be multifunctional, used in both a domestic sense for cooking and heating as well as in a metallurgical production context (Grigor'yev 2000). The difficulty with this assertion is that the set of characteristics which may define a metallurgical furnace become obscured. One of the early advocates of the well-tunnel-furnace, Rusanov, has recently revised his interpretations, stating that there were likely two main types of furnace used; both simple bowl types (2011). Rusanov argues that a hearth which contains only a small amount of slag cannot automatically be characterised as a furnace, particularly when slag is found in so many contexts, but that a more rigorous appraisal of the furnace architecture (based largely on his experimental work) is necessary to identify furnaces (2011: 316).

Moving beyond the dominant furnace type, the other features which have been interpreted as furnaces bear much more resemblance to bowl hearths, or are at least easier to reconcile with those elsewhere in Bronze Age contexts (Craddock 1995; Tylecote 1987; Rothenberg 1990: 6). The examples in the Southern Urals are typically small, with a main depression which is usually less than 60cm in diameter, and only consisting of one chamber. These



Figure 4.5 Digital reconstruction of a Grigor'yev style Sintashta furnace (R. Potter).

smaller structures were found lined with burnt clay and sometimes stones (Grigor'yev 2000: 465). One example at Arkaim had a tuyére embedded in the base of the furnace, which suggests a simple bellows/bowl furnace configuration.

It is clear then, even from the very limited available evidence, that there is no single 'Sintashta furnace' and that even within a single settlement there is considerable variation between the likely/suggested smelting structures. While these models might be neat and compelling, the actual evidence suggests something very different.

Organization and scale of smelting

The organisation of production, like many other aspects of Sintashta metallurgy, is drawn from a fragmentary mix of the limited primary data and secondary sources which suggest that metallurgy was practiced in every house unit, with no dedicated production areas within the settlements (Koryakova and Epimakhov 2007). As outlined in the previous section, this ubiquitous spread of metallurgy is seen as central to the character of Sintashta communities. The bulk of the data which forms the basis of these arguments is derived from the excavations at Sintashta and Arkaim (Gening et al. 1992; Zdanovich 1995). While neither site has been published in extensive detail it is possible to explore the locations of likely production contexts from the early Sintashta publications (Gening et al. 1992)

Sintashta was excavated in the 1980s, but due to erosion only half of the site was preserved. Parts of around 29 house structures were identified; radiating like the spokes of a wheel in two concentric circles. However, only nine complete house floors were identified (Gening et al. 1992: 41). In nearly every excavated house structure (where enough of the floor plan was present) a hearth feature was identified. These were often associated with large pits and the structures were subsequently interpreted as complex multi-chambered furnaces (Gening et al. 1992; Zhang 2007: 219). While it is not extensive, the publication by Gening and colleagues does make note of instances where slag was found within excavated features, and therefore it is possible to conduct a broad contextual study of the metallurgical debris found at the site and to contrast this with the interpretation placed on the hearth features. Figure 4.6 shows a plan of the excavation. The coloured areas highlight houses which



Рис. 7. Памятник СП. Общий план

Figure 4.6 Broad distribution of metallurgical debris in the Sintashta settlement. Blue; contains metallurgical slag, green; contains ore minerals, red; contains processing tools (adapted from Gening et al. 1992).

contained metallurgical slag in a secure context, (blue), copper ore (green) and copper spillage/casting debris (red). It is clear that if we limit our definition of a metallurgical feature to one which contains metallurgical debris (as Rusanov would now argue) then significantly fewer houses at Sintashta were engaging in metallurgy than has been suggested. It is possible to expand this argument further, based on the limited recovery of ore and tools, to consider that perhaps different parts of the process were taking place in different structures, perhaps with one family or group beneficiating the ore with another enacting the smelt.

4.2.3 Casting/finishing

Evidence for bronze casting on Sintashta sites is found in two forms; fragments of moulds and copper droplets. A. D. Degtyareva has suggested that casting was typically carried out on settlement sites in moulds made from talc, clay and stone, the latter usually being preheated. Mould fragments have been identified at Sintashta, Arkaim and Oligino (Gening et al. 1992; Koryakova et al. 2011; Kuzmina 2008). However, crucibles specifically for casting have not been identified.

There is considerable evidence that, following casting, copper and copper alloy artefacts were routinely further worked. Abrasives, hammers, whetstones and anvils have all been identified on settlement sites and in burial contexts in association with other metallurgical debris (Degtyareva 2010; Gening et al. 1992; Koryakova et al. 2011; Vinogradov 2004). Evidence for the extent of secondary working of artefacts has been outlined by Degtryeva, who conducted metallography on artefacts from most of the excavated sites in the region. Her results show that only a small quantity of artefacts were left in their as-cast state, with only 2% of artefacts showing no sign of subsequent hot or cold working. The majority of the artefacts Degtyareva analysed had been forged at temperatures above 600°C, with the others being cold worked or annealed. A summary of her results can be found in Figure 4.7. Degtyareva does argue, however, that due to the volatility of arsenic in the alloys the application of higher temperatures was limited when producing artefacts, suggesting that smiths were both aware of the presence of arsenic, and of the effects of its loss to the object (Degtyareva 2010: 141).

4.2.4 Consumption

Metal artefacts have been found at every significant Sintashta period excavation. This is the case in both settlement and burial contexts, although far more have been recovered from the latter (Degtyareva 2010). Metal artefacts are commonplace within Sintashta graves, with over 15 excavated sites producing nearly 600 artefacts (Degtyareva 2010; Vinogradov 2003). Significantly fewer metal artefacts have been found at settlement sites; only 61 such artefacts have been described in the published literature. This figure is likely due to both the paucity of published settlements and the lower numbers, in absolute terms, of excavated sites. On a site by site basis however, there does seem to be more metal artefacts recovered from cemeteries; cemetery sites on average produce double the metal artefacts compared to settlement sites (Table 4.1). A full breakdown of the objects identified from the published literature can be found in Table 4.1. What is interesting is the ratio of tools to weapons found between sites (note, Degtyareva considers knives/daggers as tools, which is not a universal position).

In terms of quantifying consumption trends it would be more useful to survey the mass of metalwork found, however this information is rarely reported. An exception is recent work produced by the Sintashta Collaborative Research Project, which surveyed the metalwork from the Stepnoye cemetery (Doonan et al. 2015). The metalwork was derived from primarily transitional Sintashta and Petrovka contexts in two kurgans. The results are significant because while the point counts suggested that more copper was consumed in tools than weaponry this was not the case in terms of absolute volume. It was interesting that while the tools and ornament values represented numerous artefacts, almost all of the arsenical copper identified was in a single weapon (Table 4.2).

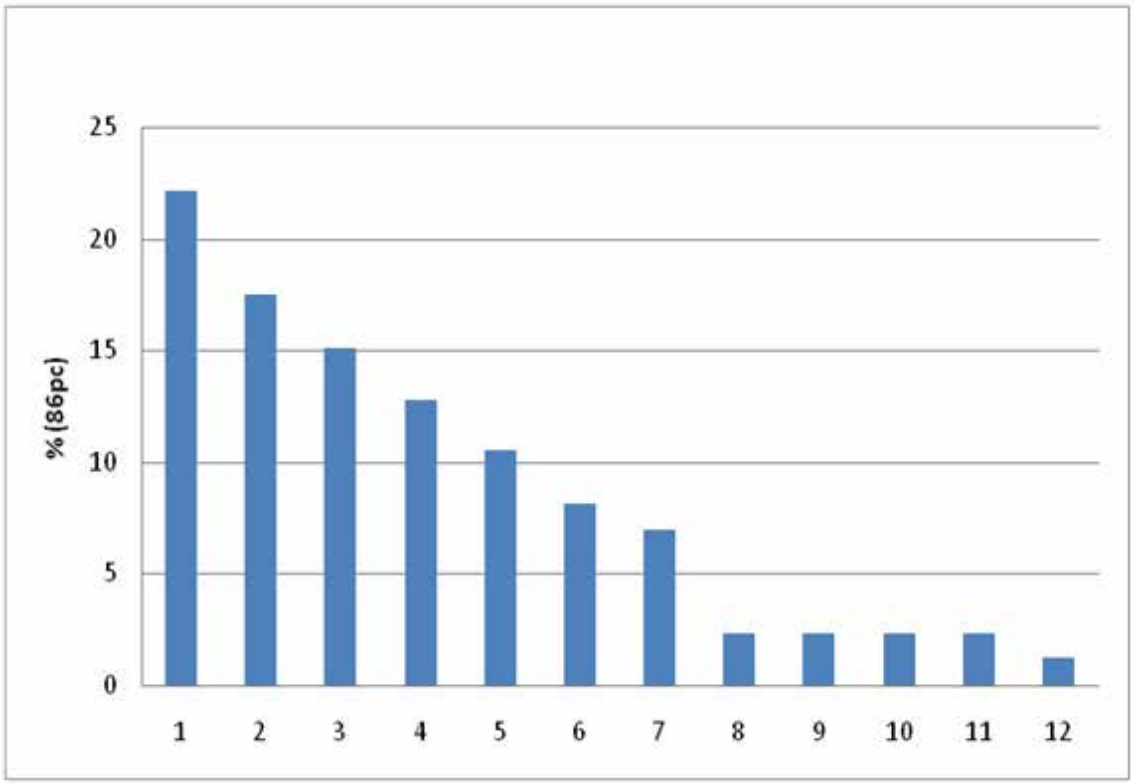


Figure 4.7 Distribution of finishing techniques after Degtyava 2010

1: Heated and forged at 400-500 °C

2: Cast and forged with a compression of 50-60% at 400-500 °C 3: Forged at 600-700 °C

4: Cast and forged at 600-700 °C 5: Cold forged and annealed

6: Cast and cold forged 7: Forged at 600-800 °C

8: Cast with no further working

9: Cold forged with a reduction of 80-90% 10 : Forged and welded at 400-500 °C

11: Forged and welded at 600-700 °C

12: Cold forged, annealed and homogenised.

Table 4.1 Total numbers of metal artefacts found at Sintashta sites (after Degtyareva 2010 and Hanks et al. 2014)

Site	Tools	Weapon	Ornament	Staples/ fastenings	Ingot/ production debris	Total Cu alloy	Total gold	Total silver	Total metal artefacts
				Graves					
Krivoe Ozero (chernorechye)	14	n.p.	93**	14	n.p.	120	1	n.p.	121
Kammeny Ambar (olgino)	35	1	12	18	n.p.	63	2	1	66
Sintashta great kurgan	40	2	68***	36	n.p.	100	6	40	146
Sintashta 1	35	n.p.	7	15	n.p.	57	n.p.	n.p.	57
Sintashta 2	7	7	15	13	n.p.	32	10	n.p.	42
Gerasimovka 2	2	n.p.	n.p.	n.p.	n.p.	2	n.p.	n.p.	2
Berizovski	1	n.p.	n.p.	n.p.	n.p.	1	n.p.	n.p.	1
Malinovski 2	2	n.p.	n.p.	n.p.	n.p.	2	n.p.	n.p.	2
Bolshoi Kurgan (arkaim)	17	1	n.p.	1	n.p.	19	n.p.	n.p.	19
Novokumakski	2	n.p.	n.p.	n.p.	n.p.	2	n.p.	n.p.	2
Tanabergin	37	2	32	20	n.p.	80	5	6	91
U gory Berozovoi	4	n.p.	n.p.	n.p.	n.p.	4	n.p.	n.p.	4
Dzaman-Kargala 1	11	1	5	n.p.	n.p.	17	n.p.	n.p.	17
Obil'kin Lug 3	5	n.p.	n.p.	n.p.	n.p.	5	n.p.	n.p.	5
Total (Grave)	229	14	236	118	n.p.	526	24	47	597
				Settlements					
Stepnoye 4*	17	n.p.	4	1	n.p.	22	n.p.	n.p.	22
Sintashta	9	n.p.	1	2	n.p.	12	n.p.	n.p.	12
Arkaim	11	n.p.	n.p.	1	n.p.	12	n.p.	n.p.	12
Ust'ye*	17	9	6	n.p.	5	37	n.p.	n.p.	37
Total(Settlement)	37	9	7	3	5	61	n.p.	n.p.	61
TOTAL	**320**	**32**	**254**	**125**	**10**	**670**	**24**	**47**	741

*SCARP 2009 n.b Ust'ye count includes LBA material. Others from Degtyareva (2010), ** from 2 bracelets, *** 46 from 2 head pieces

Table 4.2 Mass in grams of metalwork recovered from the Stepnoye cemetery.

Alloy	Ornament	Tool	Weapon	Total
Pure Cu	3.5	199.4	119.1	322
Arsenical copper	12.3	122.6	1153	1287.9
Tin bronze	304	298.3	1378.7	1981
Au	5.9	0	0	5.9
			Total	3596.8

4.2.5 The current model for Sintashta metallurgy

Drawing these arguments together it is clear that the current model for Sintashta metallurgy proposes that resources were mined on a large scale, coordinated by a central polity with metallurgy adhering to a single, ubiquitous tradition, although, somewhat contradictorily, significant development is claimed through time.

Key arguments include;

- Mining and metallurgy conformed to a single tradition, which was shared throughout the Country of Towns
- Metallurgy took place in every settlement
- Metallurgy was ubiquitous across settlements
- Large, complex smelting furnaces were employed
- Mining was carried out only at a only small number of sites
- Ore was derived primarily from deposits in serpentinite geologies, producing the characteristic "*chromite slag*"
- Metallurgy was carried out in every settlement and every household, suggesting that the settlements were specialist metallurgical centres
- Metal was not simply being produced for local consumption, but for large scale, long distance trade and exchange which fuelled large networks and extended over huge areas of Eurasia

These assertions have become closely associated with models which argue for complexity. However, it is already clear from the reappraisal of some of the literature here that some of these assumptions are problematic; most notably the distribution and scale of production, which is contradicted by the primary record. In addition there is little direct evidence for the majority of these assumptions. They will be addressed in more detail in the subsequent chapters.

4.3 Late Bronze Age

The Late Bronze Age is characterised by a marked shift in settlement patterning, and metallurgy too, with the increasing use of tin-bronze, is subject to a considerable change (Koryakova and Epimakhov 2007: 42). There also seems to be an increase in the number of individual sites recorded in the Late Bronze Age, with over 800 known Srubnaya settlement sites, around 8% of which have been excavated (Koryakova and Epimakhov 2007: 113). Although so few of these excavations have been published in detail (Zhang 2012) that it is difficult to accurately assess the distribution of metallurgy over the region, it is still possible to explore the evidence from three of the key sites and to tentatively characterise some broad trends in the metallurgy of the period. The sites discussed here are: Kargaly, a large mining

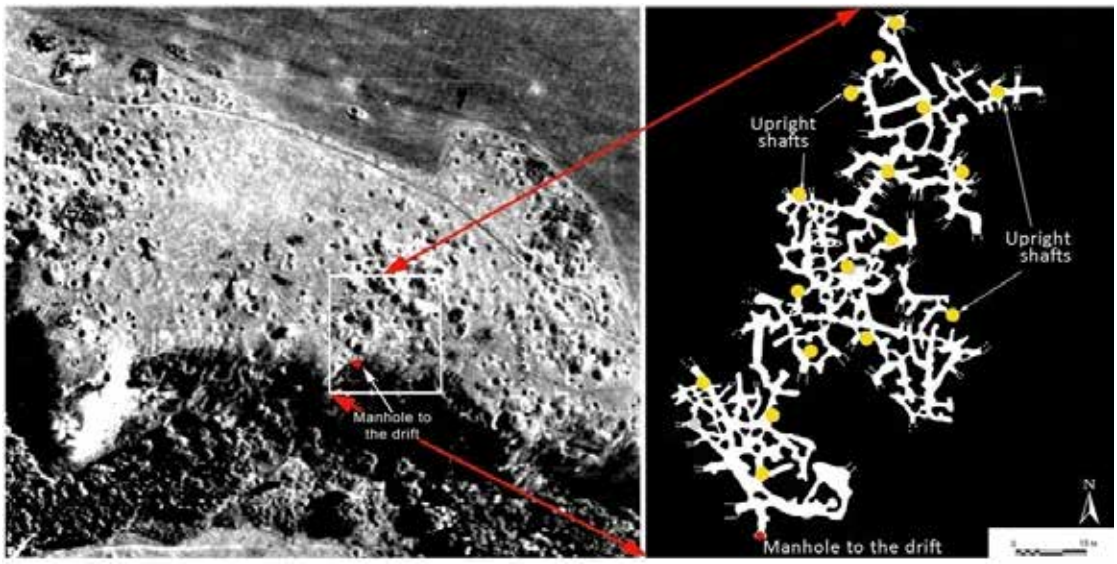


Figure 4.8 Aerial photograph of the surface scars and Kargaly and a plan of the subterranean workings (Evgenij Chernykh 2010).

complex; Gorny, the settlement site associated with Kargaly; and Tiubiak, a more traditional style of Late Bronze Age settlement (Chernykh 2002; Obydennov et al. 2001).

One of the largest Late Bronze Age sites in the region is the 'mining district' of Kargaly and the associated settlement and cemetery of Gorny. These two sites have been used to characterise Late Bronze Age metallurgy as large scale and associated with expansive mining activity (Kohl 2007: 171). The evidence for mining at Kargaly is vast, with 500 sq km of activity and a number of subterranean shafts extending to a depth of up to 40m (Figure 4.9, Vicent et al. 2006). What is particularly remarkable about Kargaly is that it is currently the only developed mining site in the region directly associated with a settlement complex (Diaz et al. 2006). The site seems to have been exploited at multiple periods during the Bronze Age, with evidence for both Early and Late Bronze Age activity. However, no Middle Bronze Age activity has been identified. Whether this is due to a genuine lack of activity, or of only more ephemeral exploitation during this period is debatable, but it is clear that the largest stage of exploitation took place in the Late Bronze Age. This period of exploitation is associated with Srubnaya groups, this being particularly evident in the deposits at the settlement of Gorny, located on a promontory hill and surrounded by the workings (Chernykh and Lebedeva 2002).

Gorny (Figure 4.9) was excavated between 1992 and 1999, but despite such prolonged excavation only a small percentage of the site was exposed (c.35,000m^2). The site has been broadly split into two phases, with the later subdivided into three sub-phases (Zhang 2012). The earliest phase consisted of 'shaft pits', which the excavators have suggested were used both as dwellings and production spaces (Chernykh and Lebedeva 2002: 52). Almost every pit contained smelting remains, including slag, (in the most part crushed to a powder) and copper droplets; however, no furnace structures were identified. During phase B, particularly sub-phase 1, the activity on the site increased significantly with the construction of two large residential and metallurgical complexes. The phase B activity seems to have completely replaced phase A, with a clear horizon between the two (Chernykh and Lebedeva 2002). Complex 1, to the north of the site, contained three 'living quarters' which were also used for smelting and ore sorting. The excavators identified large

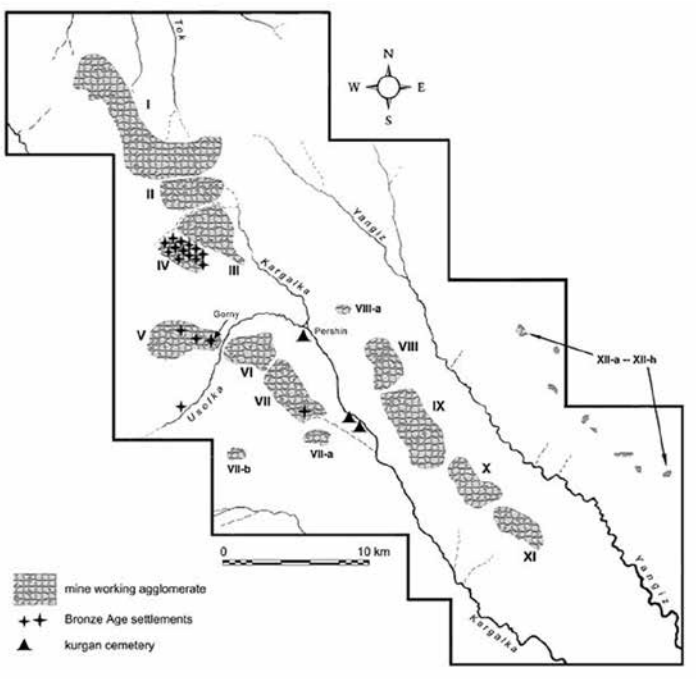


Figure 4.9 Plan of Kargaly showing the locations of the mine workings and the settlement sites, including Gorny (Chernykh 2011).

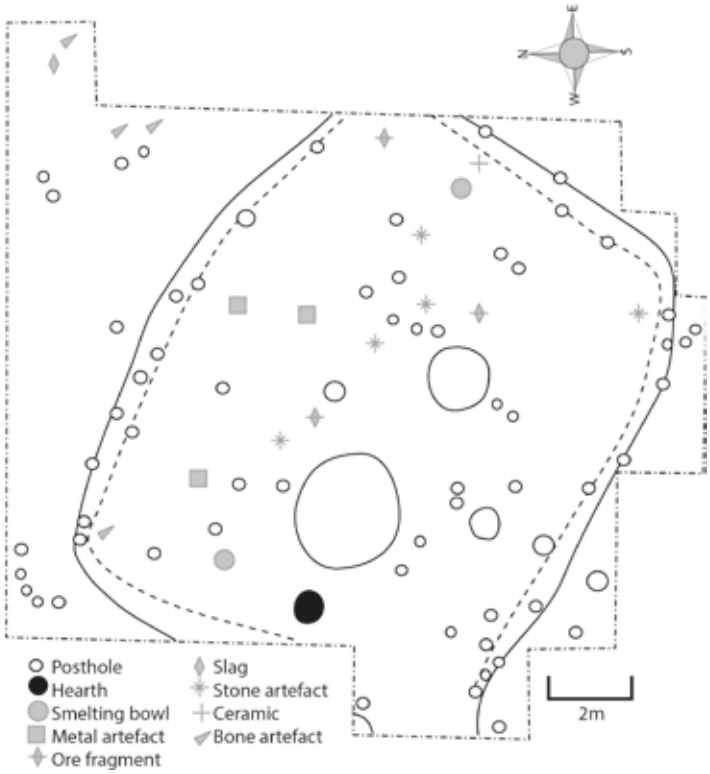


Figure 4.10 Plan of house 4 at Tiabaik (redrawn from Zhang 2007)

hearth features within the buildings (c.150cm in diameter) and an associated rubbish pit which contained crushed slag, copper droplets, and ingots (Chernykh 2002; Chernykh et al. 2002). The rest of complex 1, known as the smelting quarter, also contains a furnace, yet only 46 identifiable pieces of slag were recovered (Zhang 2012).

In contrast to Gorny, the settlement of Tiabaik does not seem to be directly associated with a mining complex. The settlement area covers 18,000m^2, though less than a quarter of this has been excavated. The excavations revealed nine buildings ranging in date from the Middle to Late Bronze Age; six of the buildings have been attributed to the Srubnaya complex (Zhang 2007: 290). The buildings were rectangular and around 12.4 by 9 meters in size, some of which had a porch/gateway. The interior layout of the structures (Figure 4.10) is similar to Middle Bronze Age Sintashta units, with all of the houses containing a large pit/well and hearth structure (Obydennov et al. 2001: 55). The plan of house 4, shown in Figure 4.10, is a good example of this type of house; the detail recorded on the plan shows that evidence for metallurgy was spread throughout the house and into the area outside. The excavations produced a range of material including slag, copper ore, and an ingot. They also produced evidence for leather and stone working, suggesting that this was not a simply a 'metallurgical and metalworking settlement' as Zhang has suggested, but a broader community engaging in a variety of activities (2007: 289).

Clearly, our understanding of metallurgy during the Bronze Age is structured by a number of factors: the relatively low percentage of excavations being published in detail, the ambiguity of what constitutes evidence of metallurgy, and the disproportionate variation in the focus on the archaeology. It is perhaps due to the desire among archaeologists working under the Soviet system to identify modes of production (Trigger 1989) that archaeological inquiry initially tended to focus on those sites with evidence for metallurgy; As Zhang notes; "*... these settlements are all metallurgical and/or metalworking sites, which explains why they have been better investigated than other settlements*" (2007: 286). This approach could have potentially biased the overall representation of the region. The evidence presented above suggests that the nature and scale of mining and metallurgy was not consistent either throughout the Bronze Age or the region. There is no clear evidence for a progressive movement from simple to complex, small scale to large.

4.4 Conclusions

This chapter has presented a background as to what is currently understood about Bronze Age metallurgy in the Southern Urals. While there was a necessarily a more detailed focus on the Middle Bronze Age, the summaries as to what is understood of the Early and Late Bronze Age were aimed to present a flavour of the scale and extent of metallurgy in the two periods. A more exhaustive study of primary sources might have highlighted a greater breadth of evidence, but it is clear from the secondary literature that comparatively little attention has been paid to primary production practice in either period (Koryakova and Epimakhov 2007).

What the evidence does suggest is that, while metals were clearly used by early communities, production practice in the Early Bronze Age was low scale, possibly piecemeal (Grigor'yev 2002). The mobile nature of the communities may have led to a production process which

was carried out only sporadically, with control of production not held by a single groups or class. Conversely, Late Bronze Age metallurgy could be characterised as a large scale, highly specialised practice, with the bulk of production carried out only by select groups. It is tempting then, to draw a line between these two extremes and place the Middle Bronze Age somewhere in-between. Indeed, Middle Bronze age Sintashta groups are often seen as the beginning of an intensification of metallurgy which had its origins in the Early Bronze Age and resulted in the scale of production suggested at Kargaly. However, this it perhaps too simplistic a model, resulting from an anachronistic understanding of the character Middle Bronze Age metallurgy based on what is seen of evidence from later periods.

However, it is clear from the information presented here that mining in the Middle Bronze Age was not comparable with what is seen at Kargaly, and there is no clear evidence that Sintashta communities were an intermediate step in a linear progression from small scale to large scale, or even that the practice evident at Kargaly has any connection to Middle Bronze Age practises. Although little has been written about production practice at Kargaly it is likely that the slag, based on its description as 'crushed to remove prills' (Diaz et al 2006), was drawn from a different process to that which is evident during the Middle Bronze Age. While it may be that the nature of the ore necessitated a different technique, it is likely the process was not directly related to the Middle Bronze Age practices. There is also a disparity in the nature and scale of copper mining. There is nothing seen in the Middle Bronze Age which is in any way comparable to the style of mining seen at Kargaly. All of the mines suggested as belonging to the Middle Bronze Age are comparably smaller and seem to derive from a more informal mining practice.

The development then, of complex Sintashta settlements, is seen as the product of an intensification of metallurgy which witnessed mobile Early Bronze Age groups becoming more organised and territorial, before presumably dispersing and following intense specialisms (at least in terms of mining). But in order to maintain such a role Sintashta communities would in some way need to be centrally controlled, with specific aspects of the communities maintaining some form of arbitration over resources and production. However, what is seen suggests the opposite: both mining and metallurgical practices seem to be discrete, at least between Middle and Late groups.

While the current evidential basis is at best fragmentary, even the reappraisal of the data presented here would suggest that the existing arguments are not sustainable. It is from this perspective that the following chapters attempt to explore these problems through a programme of original research drawing on fieldwork, analysis and experimental engagement. In short, it is hoped that the new data presented in the following chapters will not only reformulate our understanding of Middle Bronze Age metallurgy in the Southern Urals, but also present a research framework through which these wider questions can be resolved.

Chapter 5

Study Area and Sites

The Southern Urals have featured in many archaeological syntheses, yet few if any, have chosen to formulate a coherent archaeology of this region on its own terms. Instead, as discussed previously, the Southern Urals are analysed as a regional unit which connects others and therefore acts to hold together wider-ranging syntheses. There is clearly a current trend to develop syntheses at a continental scale (Kohl 2007; Kristiansen and Larsson 2005) yet this insistence has resulted in very few syntheses that have attempted to deal with the existing evidence in the detail required. The first part of this chapter, therefore, aims to outline the regional characteristics of the Southern Urals, not as periphery between two regions, but as a distinct area of study.

The second part introduces the local areas of study; the Ui valley and the Tuguzak valley. It includes relevant aspects of the Sintashta Collaborative Research Project and how these connect to the aspect of study reported in the main body of the thesis; primary copper metallurgy, and specifically the aspects of landscape and resource survey which enable a contextualisation of the production process. The final part of this chapter draws together previous scholarship regarding the main enclosure sites studied: Stepnoye and Ust'ye. These sites produced a significant amount of the material which is studied in chapter 6 and have been the focus of much of the SCARP programme. Therefore both the previous work and the recent results of the SCARP fieldwork are summarised.

5.1 The Southern Urals

The Southern Urals features a mixture of distinct and diverse topographic, ecological, climatic and geological zones which together have offered a rich and diverse environment for the communities who have lived in the region from prehistory to the present day. Geological variation is particularly profound, which is typical for a mountainous region where variation is expected to be high, but is also the case in the areas of forest and grass steppe. This is, in part, because ecological and climatic zones run in an east-west direction perpendicular to the Ural range.

5.1.1 Topography

There is substantial topographic variation throughout the Southern Urals. The north of the region contains the southern ranges of the Ural Mountains themselves; which form a belt from north to south separating Europe and Asia (Koryakova and Epimakhov 2007; Brown 2008). The orogeny of the Urals produced a north-south range with gently folded foothills to the east.

To the east of the region, in the Trans-Urals, the topography varies from northwest to southeast (Figure 5.1), with considerable undulation in the northwest which slowly levels out to become flatter in the southeast (Chibilyov 2002). This area includes numerous tributaries originating in the Ural foothills, with some (Ui Ayat and Tobal) flowing in an easterly direction, towards the Trans-Ural plain, and some in a westerly direction into the Ural River, eventually flowing into the Caspian Sea. While many parts of the landscape afford an extensive level of visibility, the overall scale is often lost. At times, when moving through the supposedly flat steppe, it is easy to lose all reference points for extended periods. In contrast, the Western Cis-Urals are much flatter and undulations tend to be reserved for river valleys with a topography which is much more typical of a grass steppe (Chibilyov 2002).

5.1.2 Climate and ecology

The climate and ecology of the Southern Ural area are products of both the unique geographical conditions of the Ural mountain range, and the expansive land mass of the Eurasian continent (Christian 1998). These cause extreme fluctuations in temperature throughout the year while producing a consistent ecological system.

The wider Central Eurasian region features longitudinal ecological zones which run in an east-west direction, perpendicular to the temperate mountain range of the Urals. To the north of the region runs a carboniferous forest which, further south becomes temperate continental forest which, in turn, opens into grass steppe before becoming desert steppe (Figure 5.2). The Southern Urals primarily fall on the grass steppe which is at the centre of what is sometimes termed the 'steppe belt' (Frachetti 2008; Kuzmina 2008). This is often seen as a facilitating factor in the aforementioned east-west interactions which connect Europe with Asia (Kuzmina 2000). The openness of the grass steppe is seen in contrast to the other longitudinal zones which flank it to the north and south (Figure 5.2, top); temperate continental forest to the north and desert steppe to the south. Many of the cultural groupings identified during the Bronze Age seemed to fall on the open, grass steppe (Koryakova and Epimakhov 2007).

The southern Trans-Urals currently has a low vegetation density, with only localised woodland (Figure 5.2, bottom). The landscape is dominated by grasses and herbaceous flowering plants (Prikhod'ko et al. 2013; Stobbe and Kalis 2012). The nearest dense forest lies c. 100km to the west on the Ural mountains themselves, or 50km north (of the northerly most settlements) in the main forest steppe (Caroll et al. 2004). While it is difficult to characterise vegetation profiles for the whole Country of Towns region, a small number of recent projects have begun to produce a profiles for the Middle Bronze Age Southern Urals (Prikhod'ko et al. 2013; Stobbe and Kalis 2012). Palaeosoils from Arkaim and river cores from the vicinity of Olgino have shown broad trends in localised vegetation.

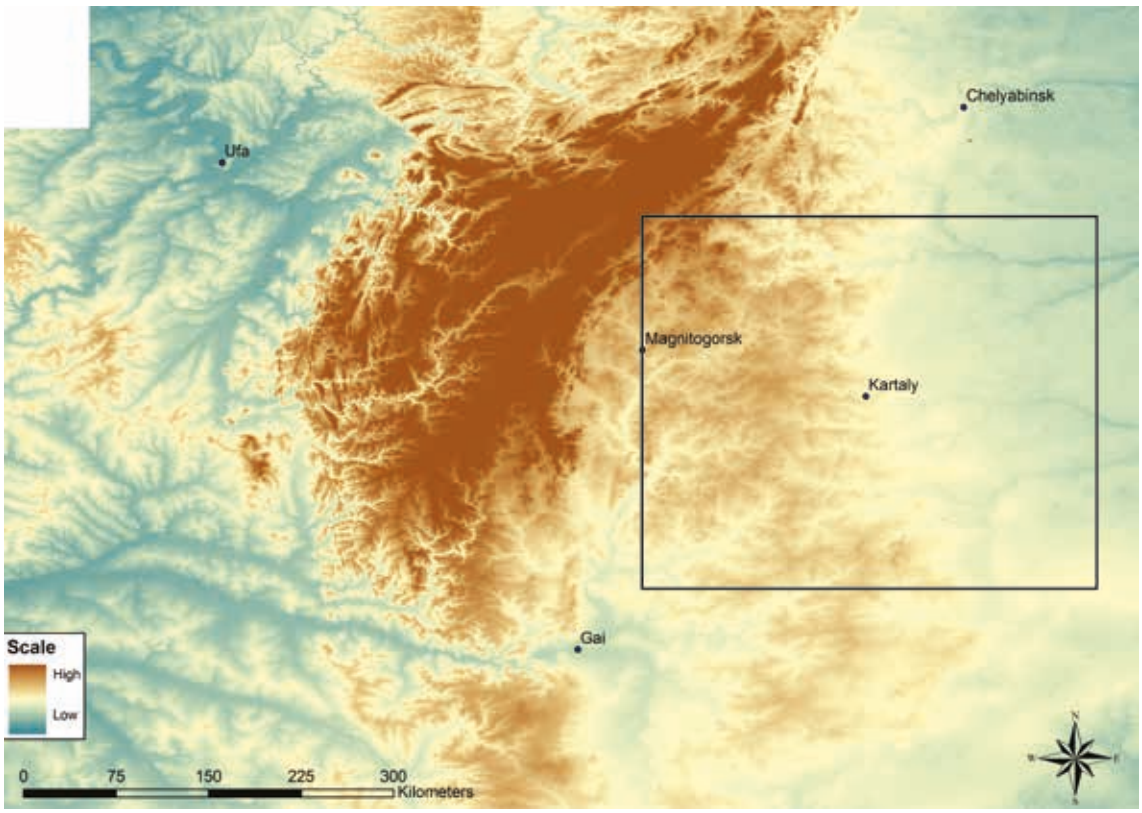
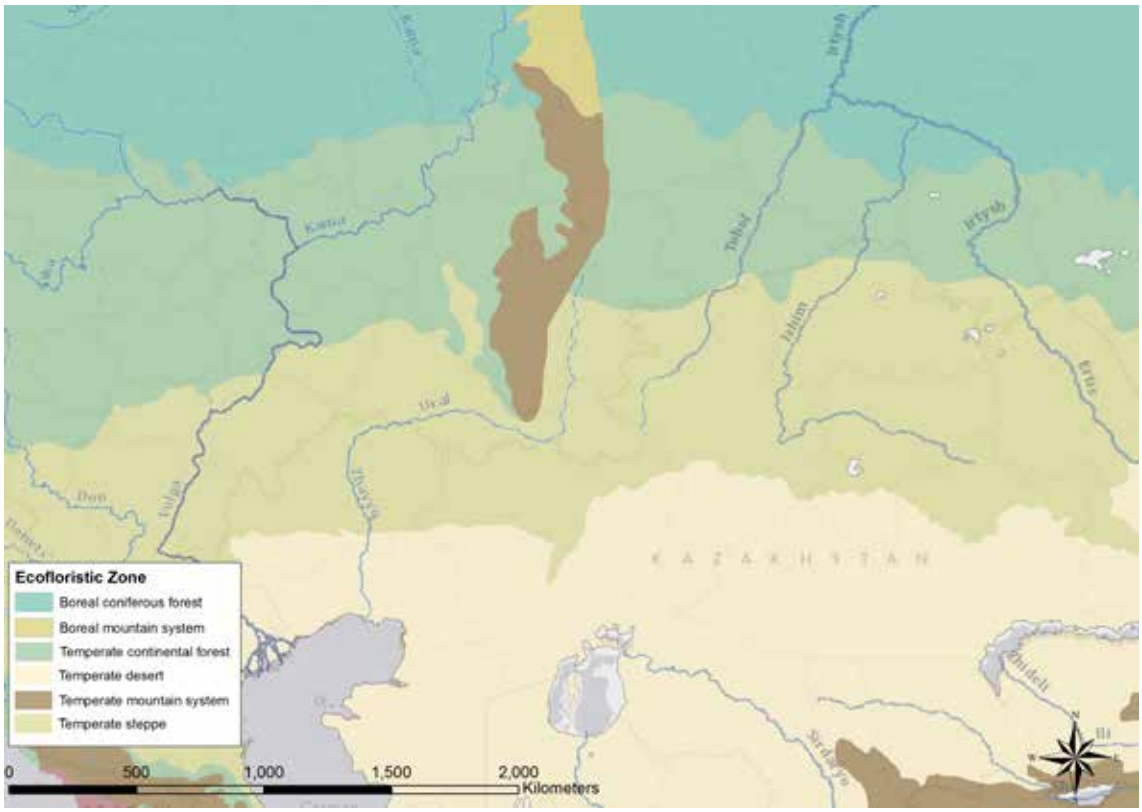


Figure *5.1 Relative topography of the Southern Ural area with the Country of Towns region highlighted (ASTER GDEM is a product of METI and NASA).*

While taking these as a general indicator of vegetation must be treated with caution, they suggest that the overall types of flora in the area of those two sites were largely similar to today, being dominated by grasses with more localised and limited large flora (Stobbe and Kalis 2012; Prikhod'ko et al. 2013).

To the south east of the mountains, on the Trans-Urals, lies the intersection of two major river systems; the Tobal to the east and the Ural to the west. This is the complex web of tributaries on which many of the settlements of the Country of Towns were established. Reconstructions of ecological conditions in the Southern Urals during the Middle Bronze Age are problematic as they have tended to be drawn from pollen cores derived from very few individual sites, and while it is possible to infer some localised climatic conditions, it has, with the current dataset, proven difficult to compile an accepted ecological model for the Southern Urals as a whole. Cores to the west and south of the region, from Orenburg and the Don basin respectively, show that the region was largely stable in the Middle Bronze Age, with the unique exception of rapid deforestation noted in the Kargarly region of Orenburg as being caused by intense charcoal production (Diaz del Rio et al. 2006). However, pollen cores have suggested significant climatic fluctuation in the wider Bronze Age.

To the east of the Urals, cores recovered in the Country of Towns have shown three likely climatic fluctuations during the Bronze Age. These began with the Sub-boreal 1 period, in which temperatures were likely below average, producing more humid conditions before a period of warmer, more arid conditions (Sub-boreal 2), which corresponded with the earliest Sintashta period dates, c. 2000BC (Zdanovich and Zdanovich 2002). The third period, Sub-boreal 3, occurred towards the end of the Middle Bronze Age and again produced cooler,



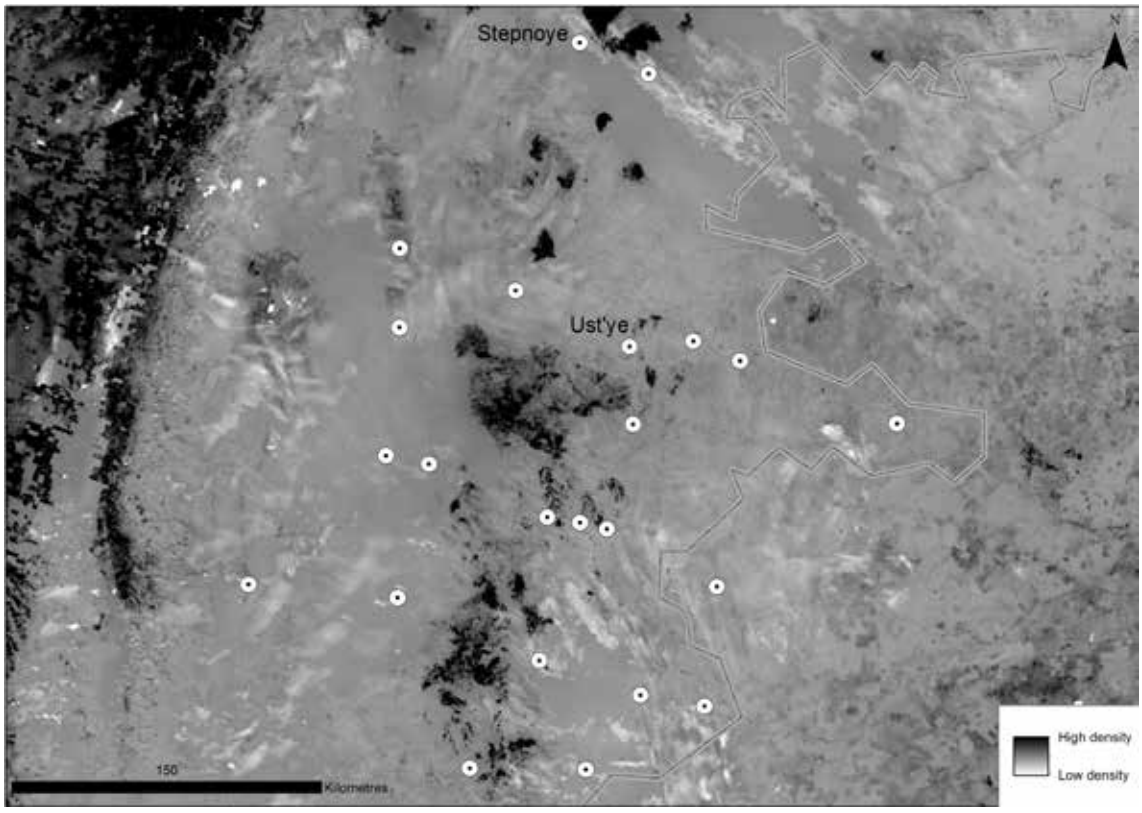


Figure 5.2 Top; eco- zones of Central Eurasia (Aaron and Gibbs 2000). Bottom: MODIS Normalized Difference Vegetation Index of the country of towns region showing the current vegetation density (bottom, Caroll et al. 2004).

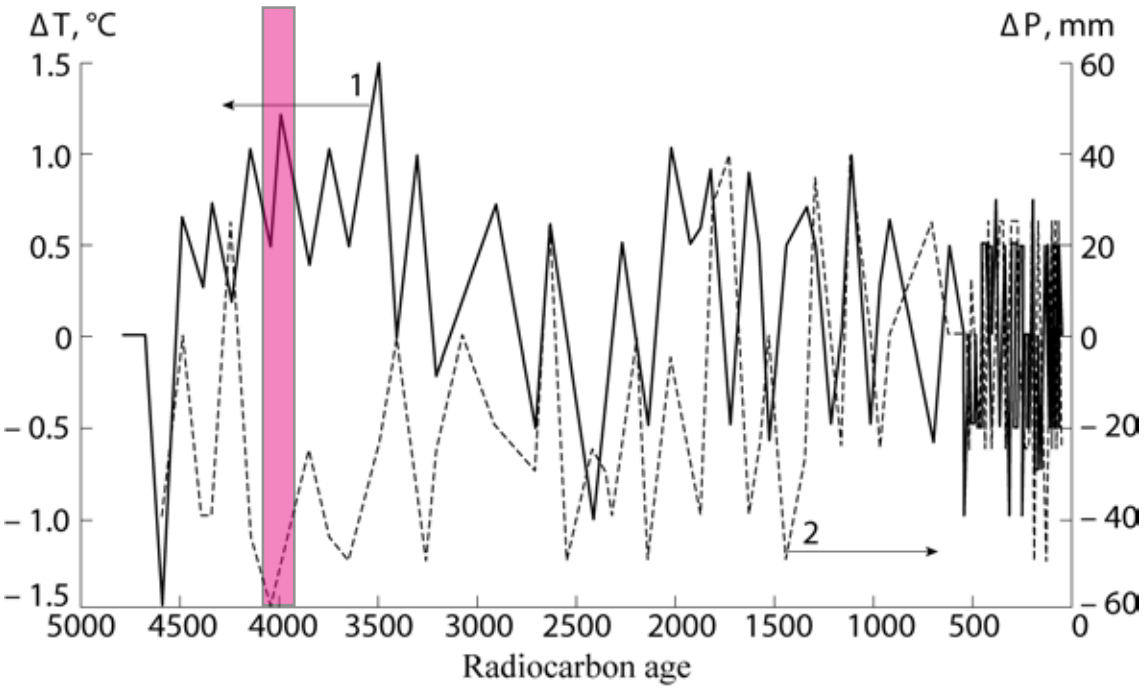


Figure 5.3 Deviation in annual temperature (1) and annual precipitation (2) from the Usvyatskii Mokh peat bog in European Russia (Klimenko et al. 2001) with the main Sintashta period highlighted.

more humid conditions (Lavrushin and Spiridonova 1999). These dates however are not universally accepted and there is some debate as to the exact chronological timeframes of the changes (Kremenetski et al. 1999; Kuzmina 2008: 3). That said, it is typically asserted that the Middle Bronze Age featured a period of warming which correlates with a dip in precipitation (Figure 5.3 Kremenetski 2003; Kremenetski et al. 1999; Zdanovich and Zdanovich 2002). In this is the case then, as the mountains produce a climatic borderline, the rise in aridity would have produced more extreme conditions to the east of the Urals; with more humid conditions to the west and greater aridity to the east. Precipitation to the east of the Urals remains low with c.400mm annually in Chelyabinsk (Kazakov 2013), while in Ufa the annual precipitation is nearly 600mm. This pattern is mirrored in a north-south direction, with southern regions experiencing as little as 150mm of precipitation annually (Kuzmina 2008).

A typical annual weather cycle in the Southern Urals consists of cold winters and hot, rainy summers, with relatively dry springs and autumns (Kazakov 2013). Figure 5.4 highlights the current annual variation in temperature and precipitation. While extreme caution should be used when applying these cycles to a prehistoric context, the continental nature of the weather patterns suggests that the overall trends would have remained the same. However, as total precipitation levels are comparatively low (ibid) then conditions would likely have been significantly harsher in the Middle Bronze Age; with a warm, dry summer flanked by a dry spring and autumn and a cold winter.

Just as recent climatic warming is said to be responsible for more unpredictable and extreme outbursts of weather (Pall et al. 2011) the warming which occurred during the Middle Bronze Age in the Urals potentially produced similar events, so, while the overall trend suggests it was warmer and dryer, individual weather events may have been more

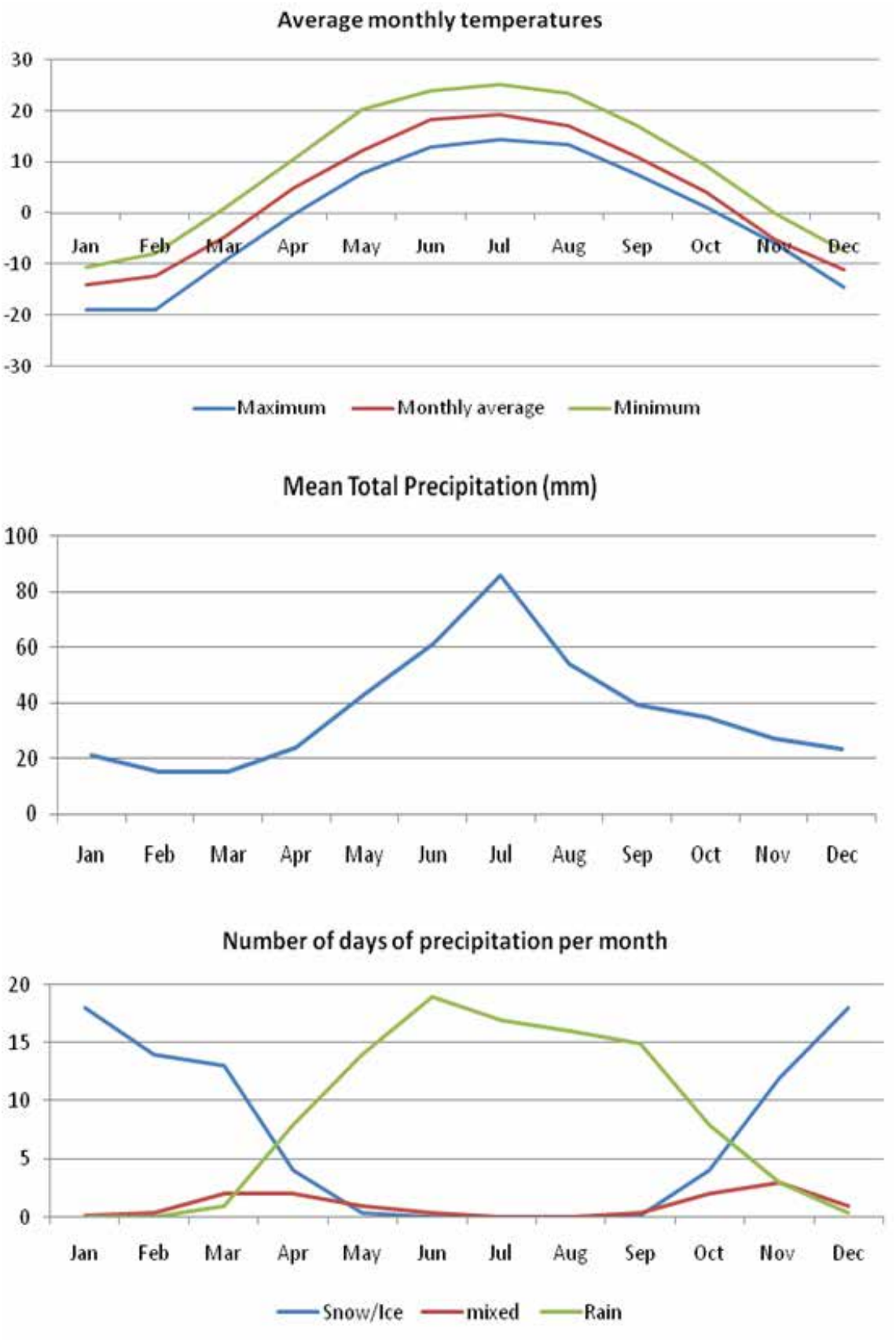


Figure 5.4 Annual weather cycles in the Chelyabinsk oblast (Kazakov 2013).

intense and unpredictable. Therefore, while scholars such as Anthony may be correct in suggesting that the climate of the Bronze Age played a role in the development of complex communities, it would be more reasonable to argue that increasingly unpredictable and intense weather cycles influenced and even constrained the way in which yearly tasks were enacted; perhaps giving rise to the need for more focal points and consistency within the landscape, this being manifested through enclosures. This would impact many aspects of day to day life such as herding cycles, resource procurement and craft practice, as well as more exceptional activities such as funerary practice.

5.1.3 Geology

Geologically the Southern Urals are one of the most varied regions on the planet. The Urals themselves are an example of Palaeozoic arc-continent collision (Brown 2009) which Formed 300 million years ago when the Baltican continental crust collided with the Kazakhstan plate. The subsequent subduction of the Baltican continental crust beneath the Kazakhstan plate was responsible for the diversity in geology which is currently found in the region. This process has left six distinct longitudinal geological zones in the Southern Urals; the Pre-Uralian zone, the West Uralian zone, the Central Uralian zone, the Magnitogorsk-Tagil zone, the East Uralian zone, and the Trans-Uralian zone (Figure 5.5, Brown and Echtler 2005).

The Pre-Uralian, West Uralian and Central Uralian zones all contain late Triassic, early carboniferous sediments which hold numerous sedimentary based ore deposits. The Magnitogorsk-Tagil zone contains two volcanic arcs, the Tagil-Arc in the Middle Urals, and the Magnitogorsk-Arc in the Southern Urals. These regions are primarily composed of Lower to Mid Devonian basalts which are overlain by volcanocalstic (of volcanic origin) sediments. The East Uralian zone features numerous granitoid intrusions which form the 'main granite axis' of the Uralides, while the Trans Uralian zone is composed of volcanic and plutonic deposits overlain by evaporates and oceanic crust (Brown and Echtler 2005; Brown et al. 1998).

The main Sintashta region is located primarily on the East and Trans Uralian zones and seems to correspond well with the zone of igneous intrusives. It was this type of igneous activity that was responsible for much of the ore genesis in the eastern Southern Urals.

Ore formation in the Southern Urals

Ore formation in the Southern Urals occurred in four geological zones: the main Ural rift, which contains ultra-basic, volcanogenic structures; the Magnitogorsk paleo-volcanic arc, which is composed of underwater volcanoes; the East Uralian rift, which contains the remnants of volcanic structures; and the East Uralian zone which consists of large granite massifs (Figure 5.5, bottom, 5.6 and 5.7 (Zaykov et al. 2005). Copper ore was formed in the Southern Urals through three types of process, volcanogenic massive sulphide deposits (VMS), porphyry copper deposits and sedimentary hosted copper (Herrington et al. 2005; Mosier et al. 2009). Each produced characteristic ore structures which would affect the way they were identified and exploited.

Volcanogenic massive sulphide deposits (VMS): Found mainly in the Eastern Urals (Figure 5.6), along the main Uralian fault (Mosier et al. 2009), these deposits were formed during massive volcanic activity in a deep seawater setting. The association of seawater

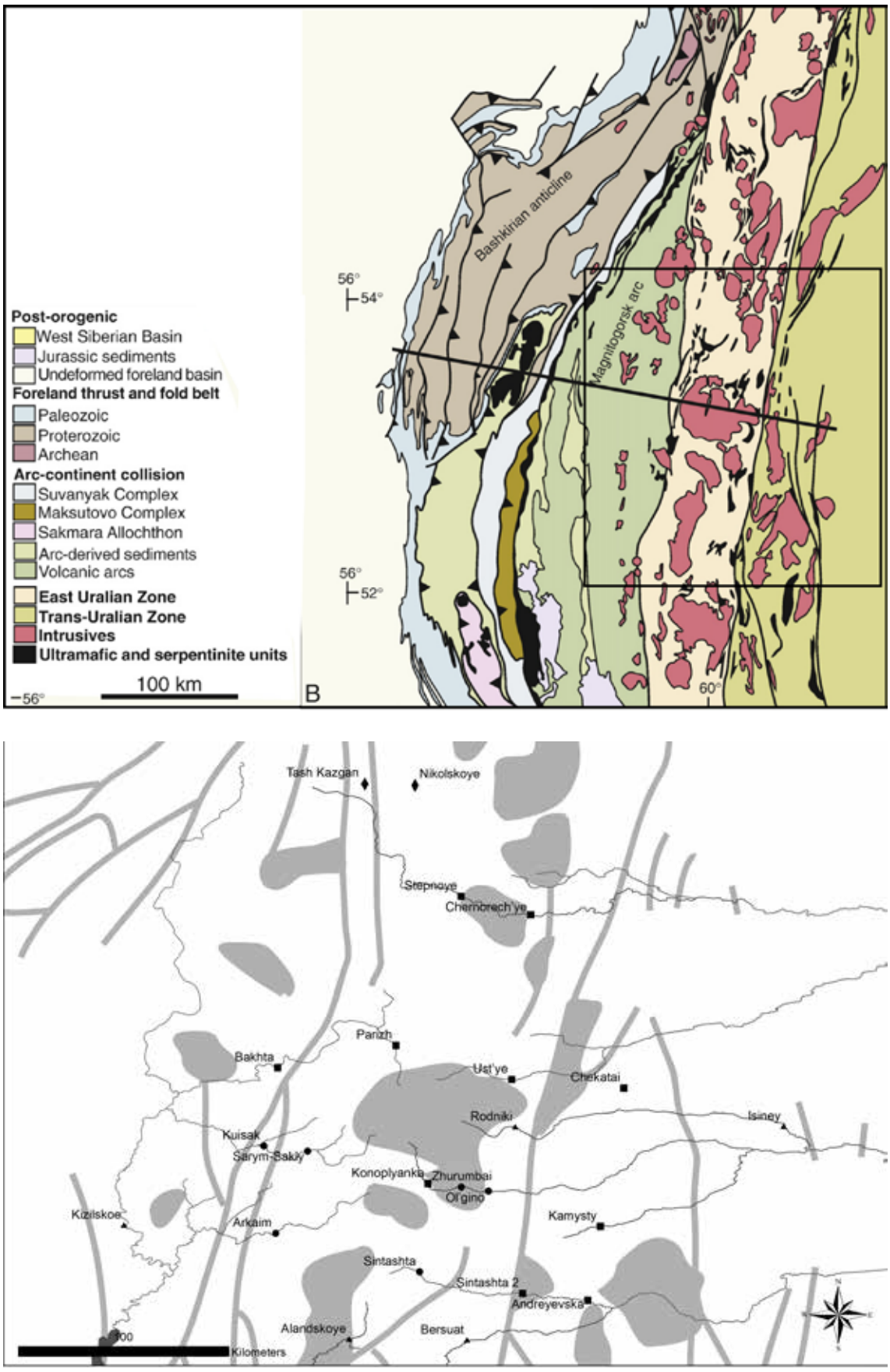


Figure 5.5 Top, geological zones of the Uralides with igneous intrusion in pale red (after Brown et al. 2006), the settlements and suggested mines in the Country of Towns region and the approximate location of of the main zones of igneous intrusion in the Southern Urals (bottom, adapted from Brown 2009).

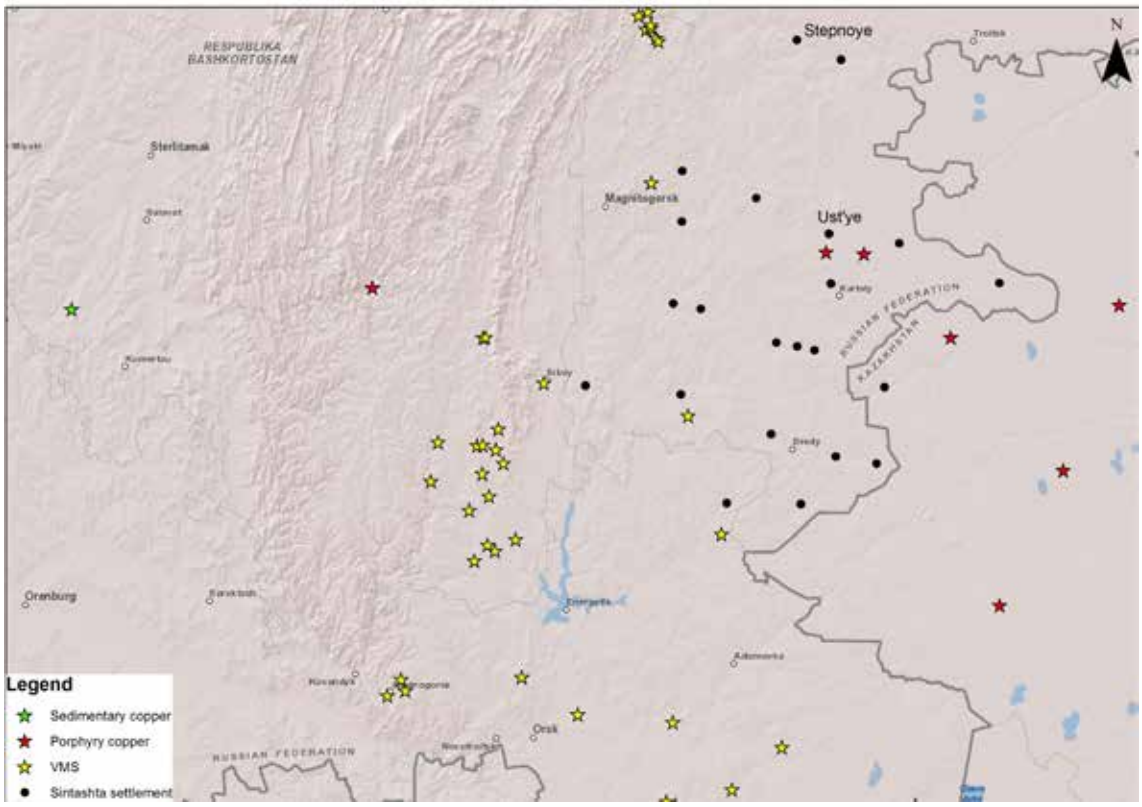


Figure 5.6 Locations of economically viable mineral depositions in the Southern Urals showing the range and extent of mineralisation (Cox et al. 2003; Mosier et al. 2009; Singer et al. 2008).

with igneous activity created hydrothermal convection which caused the formation of a rich hydrothermal fluid from which the ore minerals precipitated (Figure 5.7). The typical formation of VMS deposits consists of a conical mound-like structure overlying a 'stockwork' zone containing vein-like deposits which fed the main formation (Herrington et al. 2005).

Porphyry deposits: porphyry copper deposits form in regions adjacent to porphyrtic igneous intrusions. In the Southern Urals they occur mainly in the south east (red in Figure 5.6). They are formed when mineral-rich hydrothermal fluids are thrust from the body of the igneous intrusion during the cooling process, which are then precipitated in faults and fissures in the host rock (Figure 5.8). This forms a zone of rich mineralisation around the intrusions. The nature of hydrothermal deposition means that porphyry deposits tend to form in vein-like structures (Sillitoe 2010).

Sedimentary hosted copper: This type of formation is found to the west of the Urals, on the un-deformed basin stratum of the main Eurasian plate (Green in Figure 5.6) In this region they are typically associated with 'red bed' deposits which consist of ferrous sandstones and shale (Hitzman et al. 2010; Kirkham 1989). Sedimentary hosted deposits were formed by the movement of oxidised, copper-bearing fluids across a reduction front which resulted in the precipitation of copper sulphides (Hitzman et al. 2010). They tended to form in hydrologically closed basin structures (Figure 5.9). Morphologically they are found in sheet-like, horizontal deposits that range from 3 to 30 meters in depth (Kirkham 1989).

The formation of secondary mineralisation: when these predominantly sulphidic copper deposits are located near to the surface they typically undergo weathering which

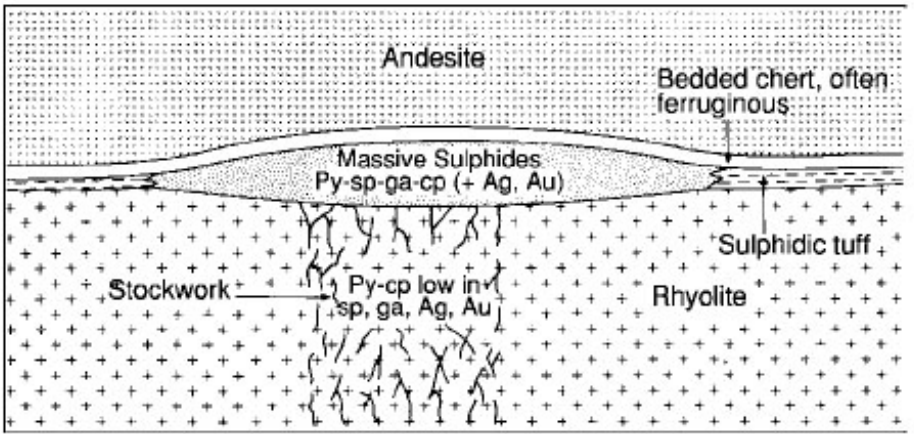


Figure 5.7 The formation of volcanogenic massive sulphide deposits like those to the east of the Urals (Davis 2005).

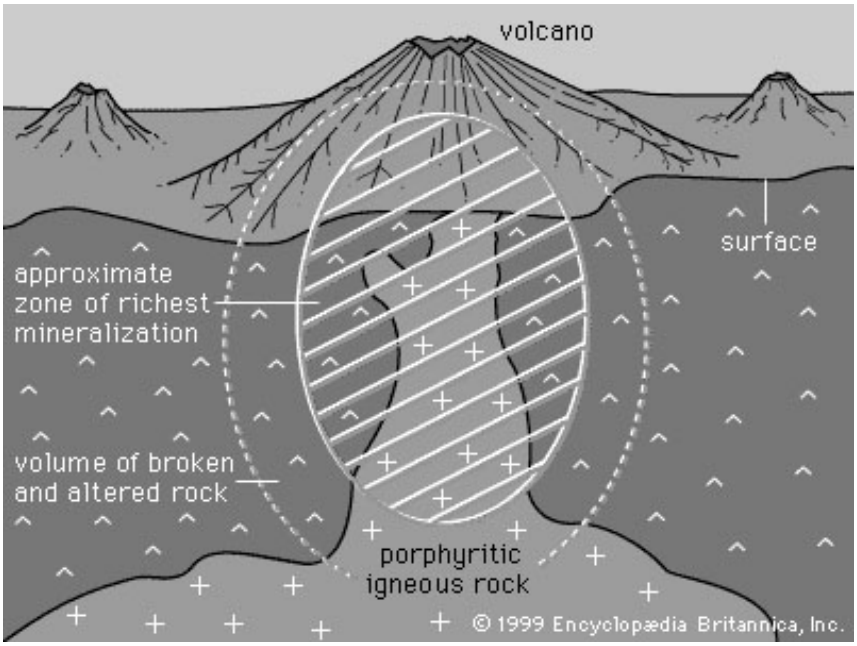


Figure 5.8 The formation of porphyry deposits around an igneous intrusion such as those in the Magnitogorsk paleovolcanic arc, to the south east of the Urals (Encyclopædia Britannica).

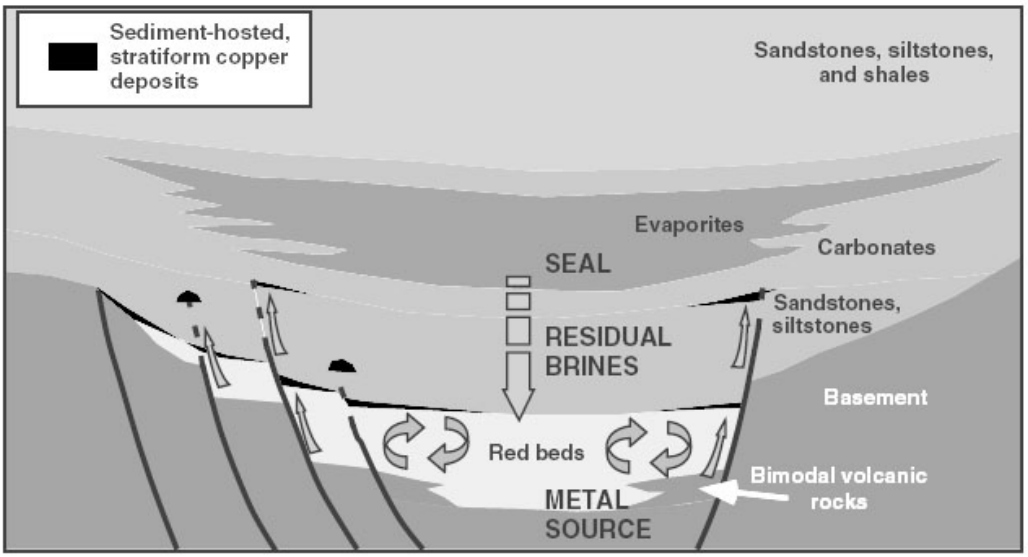


Figure 5.9 The formation of sedimentary hosted copper deposits such as those found to the west of the Urals.

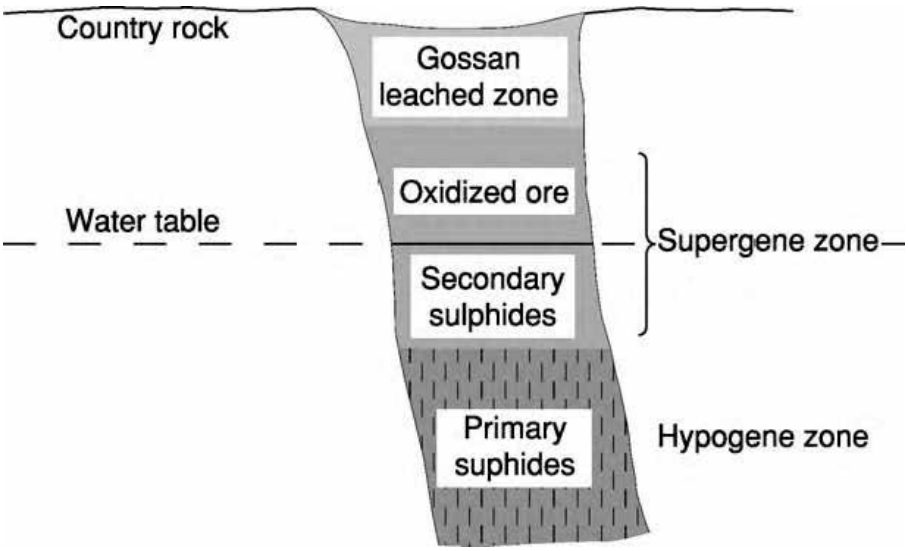


Figure 5.10 Schematic of 'near surface zonation' which forms secondary mineralisation (Davis 2005)

results in 'near surface zonation' (Davis 2005: 489). This causes a characteristic ore body which consists of primary sulphides overlain by enriched secondary sulphites which, in turn, are overlain by secondary oxide and carbonate minerals. Finally the ore body is capped by an iron rich 'gossan' layer which only contains minimal copper mineralogy (Figure 5.10).

Figure 5.6 shows the distribution of these types of copper deposits in the Southern Urals which have been identified recently and deemed economically significant (Cox et al. 2003; Mosier et al. 2009; Singer et al. 2008). The map is only intended to show the range and breadth of ore types across the region, rather than to imply ancient exploitation of these deposits. Smaller deposits have been noted, however, which do seem to have been exploited in antiquity (Zaykov et al. 2005).

The extent of the geological activity in the region has led to significant quantities of smaller deposits throughout the region which are too small to appear on such large scale geological surveys. However, when attempting to understand the nature of ancient exploitation it is vital to consider such smaller deposits. As seen in Chapter 4, Russian geologists have surveyed many potentially ancient mines (ibid), identifying five different types of exploited ore body. Geologically, these feature;

- Zones of oxidized ores formed from pockets of sulphide ore within metasomatic ultrabasic and basic rock, which manifest as veins of malachite and azurite in varying thicknesses and which contain high concentrations of arsenic. These deposits are noted at two ancient mines; Voroskaya Yama and Ush-Kattyn, with the former also being heavily associated with serpentinite geology.

- Oxidised ores which include copper pyrite-bearing ores of volcanic and sedimentary origin which form in lenses up to 30m thick. Zaikov et al suggest that this type of deposit is attractive to modern exploitation and therefore very little ancient exploitation would likely be preserved, with the exception being the Bakr Uzyak mine.

• Zones of oxidized veins and pockets of ore inclusions in granite massifs, which include primary and secondary deposits forming ore bodies which are several kilometres thick, such as the Elenkova mine.

• Pockets of oxidation in veins within extrusive basalt layers, such as the open Sokolki mines.

• Oxidised quartz-based veins in granite massifs and paleo-volcanic arcs which form numerous small deposits which contain metals including gold, silver, tungsten, molybdenum and arsenic, such as at Nikolski and Tash Kazgan in the north of the region.

The Southern Urals then is a topographically diverse, mineral rich and climatically varied region which features numerous resources and environments which ancient communities could have exploited. The next sections move from this wide characterisation to explore the local environs of the two main study areas.

5.2 Local Study Areas

The Southern Ural region is clearly geologically, topographically and ecologically diverse, but the scale and distribution of this variation is extremely localised. Therefore it is essential to consider the region at a local scale, a scale which is appropriate to the archaeological sites under study. This section introduces the main characteristics of the two local study areas in the Ui and Toguzak valleys. This thesis and the SCARP project were centred on these regions. Consequently this section draws heavily on the collaborative work carried out by the wider SCARP programme and acts as a background to the main body of discrete archaometric and experimental research which forms the basis of this thesis as is presented in the chapters which follow.

5.2.1 The Ui Valley

Beginning in the Trans-Urals, the Ui river runs in an east-west direction before flowing towards the river Tobol. Within the study area, shown in Figure 5.11, the river Ui is fed by two major tributaries, the confluences of which play host to the main archaeological features, the enclose sites of Stepnoye and Chernorech'ye, as well as their associated necropolis.

The Ui passes through the northern part of the Country of Towns region and as such is situated in one of the more topographically comparatively varied regions of the study area. To the south, the river valley has considerable undulation caused by a series of underlying igneous intrusions which flank the Ui (Figure 5. 11). This is particularly noticeable to the south of Stepnoye where there are three large hills (in steppe terms) which form the beginning of a nearly unbroken chain of hills and outcrops between the sites of Stepnoye and Chernorech'ye. The land north of the river is, however, much flatter where, with the exception of some localised undulations, the topography remains flat for c. 6km before rising to another chain of granite hills. The hills mark the extent of the horizon to the north. This is in contrast to the south of the river where the horizon feels much closer (Figure 5.12).

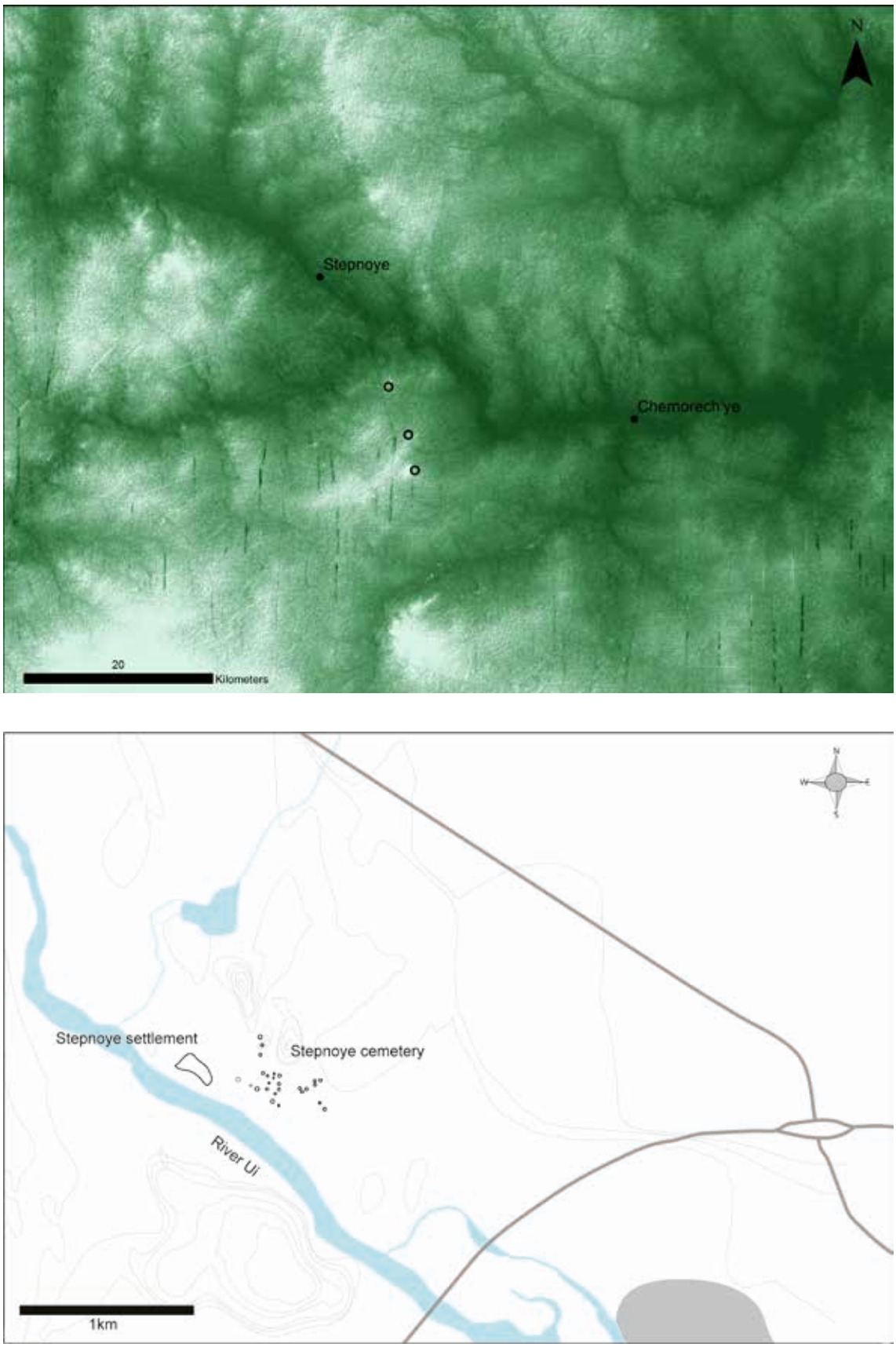


Figure 5.11 Digital elevation map of the Ui river valley (top) with the outcropping igneous intrusives highlighted (hollow circles) and a topographic profile of the area around Stepnoye (bottom).

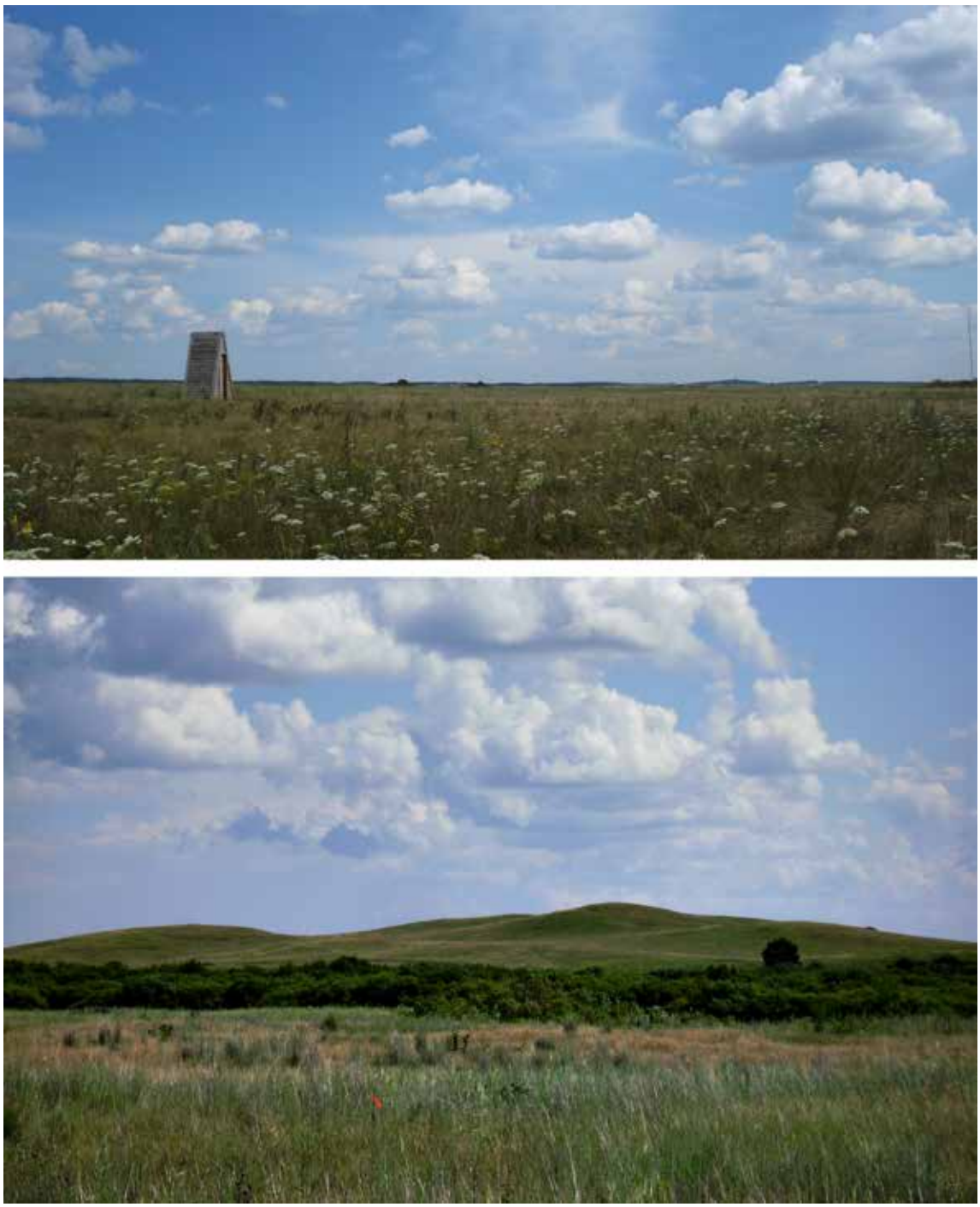


Figure *5.12 Comparison of the north (top) and south (bottom) horizons as seen from the Stepnoye enclosure.*

Between the granite hills the landscape is much more flat, with only sweeping undulations which are barely appreciable at ground level. However in some areas, particularly around 2km from the river, the extent of the undulations become clear and it is easy to lose all point of reference. This means that moving through the landscape becomes more problematic as one travels further away from the river valleys and perhaps, in part, explains the location of the sites. Even subtle undulations in the comparably flat plateau between the enclosure and the cemetery at Stepnoye means that the more distant kurgans become lost within the undulations. However when first constructed the majority of the kurgans would have likely protruded against the horizon to the north-east of the site, perhaps providing a visual reference to the location of the occupation.

Due to the extent of soil build-up the Ui cut into the ground up to three metres in some places. This is notable next to the Stepnoye enclosure, where the meandering path of the river has truncated the southern part of the site. In areas where the river bank is exposed the cutting by the river has revealed soil sequences which consist of a thin layer of humic topsoil overlaying compact steppe sand. In some instances these have formed above a thick layer of compact clay. However, the river Ui itself has a considerable difference in flow between wet and dry seasons; like the Turganik (see later), it is fed by springs located upstream from Stepnoye and near Chernorech'ye.

Geologically the Ui valley cuts through large areas of intrusive igneous activity in the form of granite and syenite zones (Figure 5.13). The igneous intrusions cut into coal measures and Ordovician sediments. The area therefore features numerous igneous-sedimentary contact zones forming areas of contact metamorphism as well as fault lines (Karpinsky

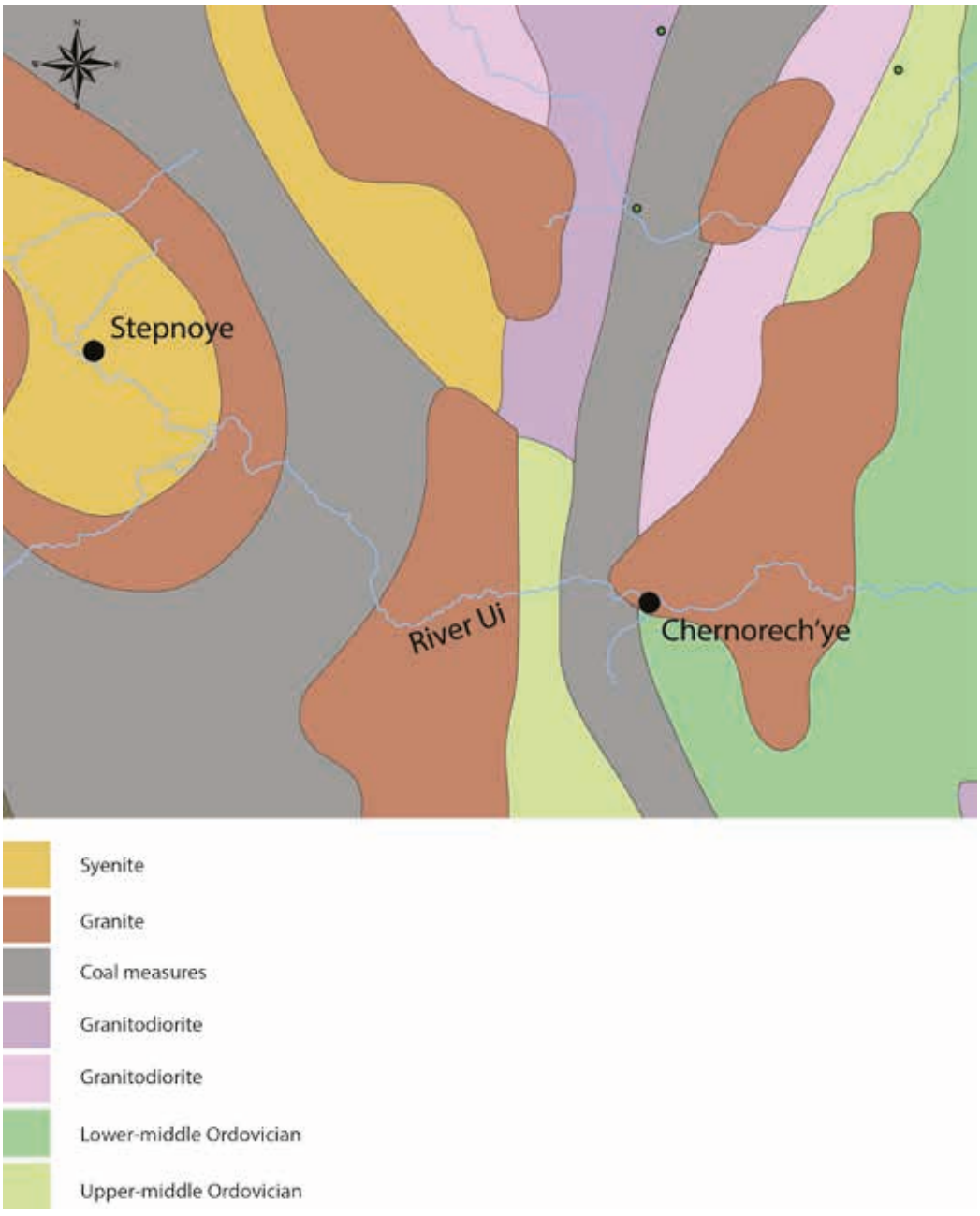


Figure 5.13 Simplified geological scheme for the Ui Valley

2012). In the immediate area of Stepnoye this geological activity is visible as a contact zone between granites and schist which forms outcrops sporadically at the surface. It is in such areas that porphyry copper deposits typically form (Sillitoe 2010).

Resource potential

The resource potential of the Ui valley was explored by SCARP through a programme of small scale catchment surveys in partnership with local historians which focused on the areas in the immediate vicinity of the enclosure sites (Hanks et al 2014). This differed from the previous mining surveys in the region, which predominantly targeted sites through known areas of recent exploitation, geological maps and economically viable mineral sources. Survey work in the Ui valley identified three potential sites of exploitation; Zmeye Yama, Kordon Lenin and Sanarka Dacha A (Figure 5.14, Hanks et al 2014, Pitman 2008).

Zmiye Yama ('snake's pit' in English) consisted of a complex of discrete mining features within a wider landscape of prospection pits. The complex was located 30km to the north-east of Stepnoye and 20km from Chernorech'ye. The site showed little evidence of modern, industrial scale activity, although the presence of timber shoring in the adits would suggest that some of the features were in use comparatively recently. However, just to the north of the complex were three kurgans running perpendicular to the dip of the slope, which suggest that the area was known in antiquity. Kordon-Lenin featured a central mining complex within a forest area surrounded by prospection pits to the south and significant modern exploitation to the north. The main complex was dominated a series of overlapping spoil heaps and mine shafts which covered an area of 100x80m, the extent of which can be seen in Figure 6.18. The shafts were up to 12m wide and 5m deep. Two of the deepest shafts contained timber shored adits similar to those at Zmiye Yama. Some of the spoil heaps contained a large amount of oxide ore in the form of malachite and azurite.

Sanarka Dacha A was located nearest to the settlements, at only 19km from Stepnoye and 17km from Chernorech'ye. The site was morphologically the most compelling identified. It consisted of a series of parallel and perpendicular trenches cut into the weathered granite bedrock and their associated spoil heaps. The features at Sanarka Dacha A were exactly what would be expected from an early mining site, in that there would have been surface outcrops which were removed from the bedrock, with little invasive mining beyond the veins themselves (Figure 5.15). The structures had parallels with dated Bronze Age mines, such as those at Rio Tinto in Spain and the Great Orme in Britain (Andrews 1994; Craddock 1995). The excavations identified a sherd of pottery which was dated broadly to the Bronze Age (Zdanovich pers. Comm.).

The SCARP resource survey of the Ui valley shows clear potential for ancient copper exploitation, with at least three surface outcrops with a 25km radius. In order to fully assess this potential samples were taken from the sites in order to act as a comparison with material excavated from the enclosures. This will be discussed in detail in chapters 6 and 8.

5.2.2 The Toguzak valley

The Toguzak valley, like the Ui valley runs in a west-east direction towards the Tobol before joining the Ob. In the study area the river runs along the base of the slope of a large pronounced ridge parallel to the river (Figure 5.16).

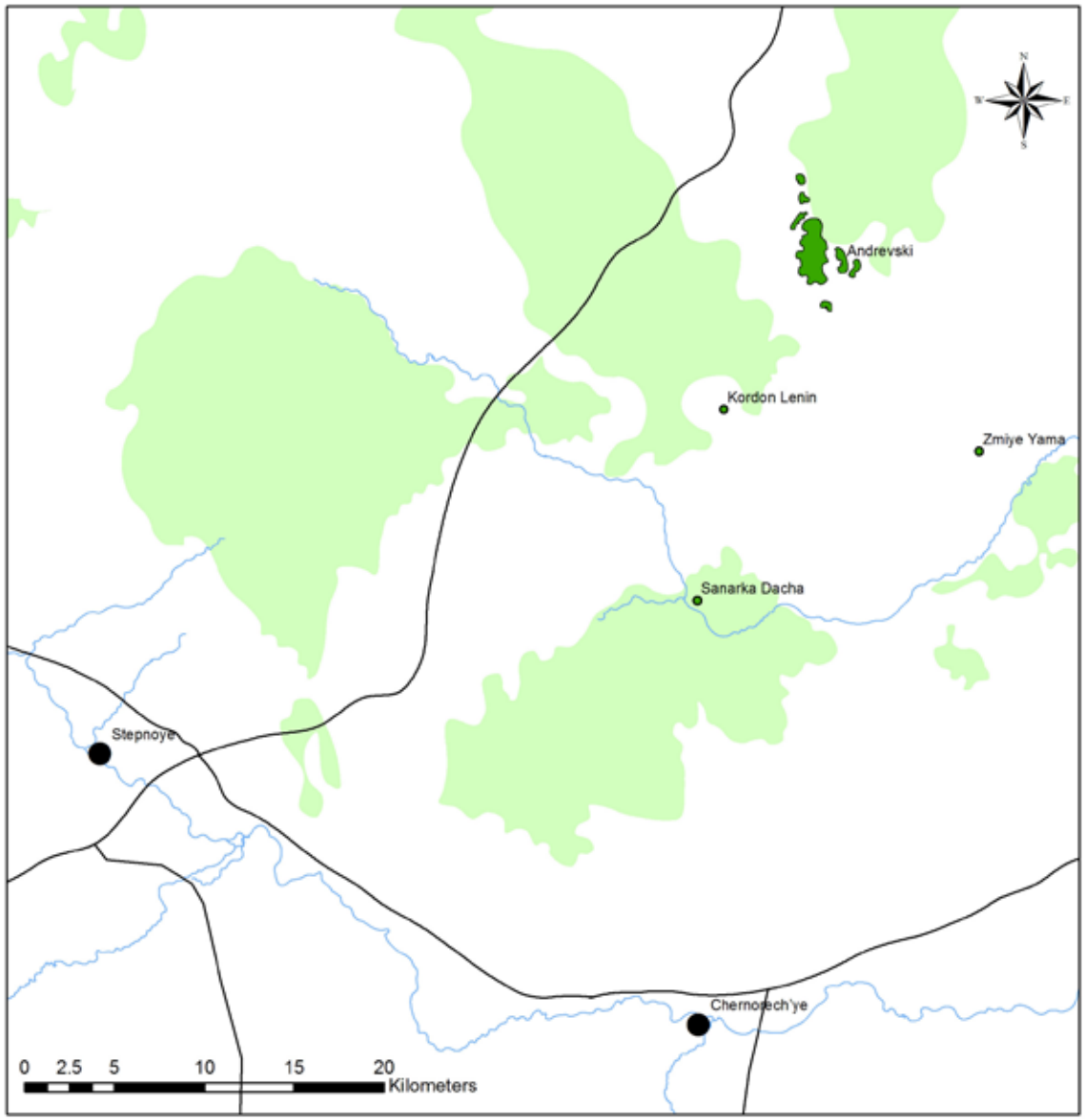


Figure 5.14 Location of Stepnoye and Chernorech'ye in relation to the surveyed mining sites (dark green).

The topography of the Toguzak valley is quite different to that of Stepnoye. The valley itself is visibly more asymmetrical, with a relatively steep rise to the north but an expansive plateau to the south. The northern break of slope is located c. 2km to the north of the site of Ust'ye. The ridge runs from the modern day village of Solntse (4km to the east of Ust'ye) to as far west as the village of Gorny (8km to the west). In contrast, the area to the south of the river is relatively flat and much more of a traditional steppe landscape with no clear topographic feature for over 8km. Like Stepnoye then, the horizon is different on each side of the settlement (Figure 5.17), with views to the north (top) much more restricted than to the south, east and west, although the slope of the Toguzak valley is much more subtle than the protruding hills flanking the Ui. As the river moves east towards the Middle Bronze Age settlement of Sarechnoye the landscape also becomes flatter and more steppe-like (Figure 5.17 top).

Unlike at Stepnoye, where the kurgan cemetery is in part lost to the scale of the landscape, the Kurgans north of the Toguzak at Soltste 2 are clearly visible from the enclosure, and



Figure 5.15 one of the trench features as SDA

vice versa (Figure 5.18). From the enclosure site the cemetery is one of the most clearly identifiably points in the surrounding landscape. The level of visibility in the flat areas is also different to at Stepnoye, with a much greater range of inter-visibility to the south of the river. However, the undulations to the north are much more pronounced and, again, it is easy to lose reference points.

The broad underlying geology in the area of the settlement and to the west is largely composed of igneous and metamorphic type geologies which include basalts and granite structures which abut a limestone ridge (Figure 5.19). Further to the west, and upstream from the settlement, is a band of serpentinite. To the east the geology is more sedimentary, featuring clay, shale and coal measures. Like the Ui valley, the extensive igneous intrusions and faultiness were probably responsible for the mineralisation in the surrounding area.

The ridge immediately north of Ust'ye features numerous fault-lines running perpendicular to the slope.

The Toguzak itself, although technically, as it forms a continuous route, a river, is vastly different in character to the Ui. Where the Ui is a steadily flowing river, albeit lower in the summer season, the Toguzak is more a collection of springs which form a barely moving water course (especially in dry seasons). This is particularly noticeable in the area around Ust'ye, where at least three springs conjoin to form the river. These continually active springs are a product of the same geological conditions which led to the formation of rich minerals in the area; deep, underground fault-lines and cave systems within the igneous ridge allow aquifers to form and water to be channelled to the surface.

Resource potential

The survey of potential resources in the Toguzak valley, although broadly similar to the Ui Valley in terms of aims, was slightly different due to the fact that mineral resources had already been identified within 6km of the settlement during the original excavation (Figure 5.20). Therefore the bulk of the fieldwork took place within the vicinity of the Ust'ye enclosure. The survey identified two sites of interest; Gorny-Toguzak and Ust'ye-North (Doonan et al. forthcoming).

Gorny-Toguzak was located 4km to the east of the Ust'ye enclosure. The site contained a series of spoil heals surrounding a central clay area. The clay area was most likely a shaft which had silted up due to the surrounding hill wash. The spoil heaps appeared to relate to various excavations of this feature, as they seem to orbit the rim of the clay area (Figure 5.21). Two of the spoil heaps contained visible high grade copper ore (WP 98 and 97 on Figure 5.21). Ust'ye North was located only 900m to the north of the main enclosure and just 1km from the kurgan cemetery and was similar in morphology with two re-silted shafts and a series of overlaying spoil heaps (Figure 5.22). Its proximity to the settlement is particularly interesting as, if it were used in antiquity; it would be the closest mineral resource to a Sintashta period settlement. Future work at this site could be extremely fruitful, but like many of the mines visited in these surveys, would require the use of mechanical excavation aids.

All of the ore at both sites was associated with a pure quartz mineral, presumably the hosting vein. Many of the ore minerals identified were in fragmentary form, suggesting that they had been crushed following excavation. As with the Ui valley, there was clear potential for ancient copper exploitation in the Toguzak valley. There are two rich surface/near surface deposits within 5km of Ust'ye. Samples were taken from the mines and were used as a comparison with the material excavated at Ust'ye.

5.3 The Enclosure Sites

The program of SCARP fieldwork explored numerous sites within the two river valleys, including settlement enclosures, Kurgan cemeteries and mining sites. Both of the study areas feature Middle Bronze Age enclosures and cemeteries with Stepnoye, Chernorech'ye and Krivoe Ozero located in the Ui Valley and Ust'ye, Solntse 2 and Sarechnoye located in the Toguzak valley. However, it was at two enclosure sites of Stepnoye and Ust'ye that

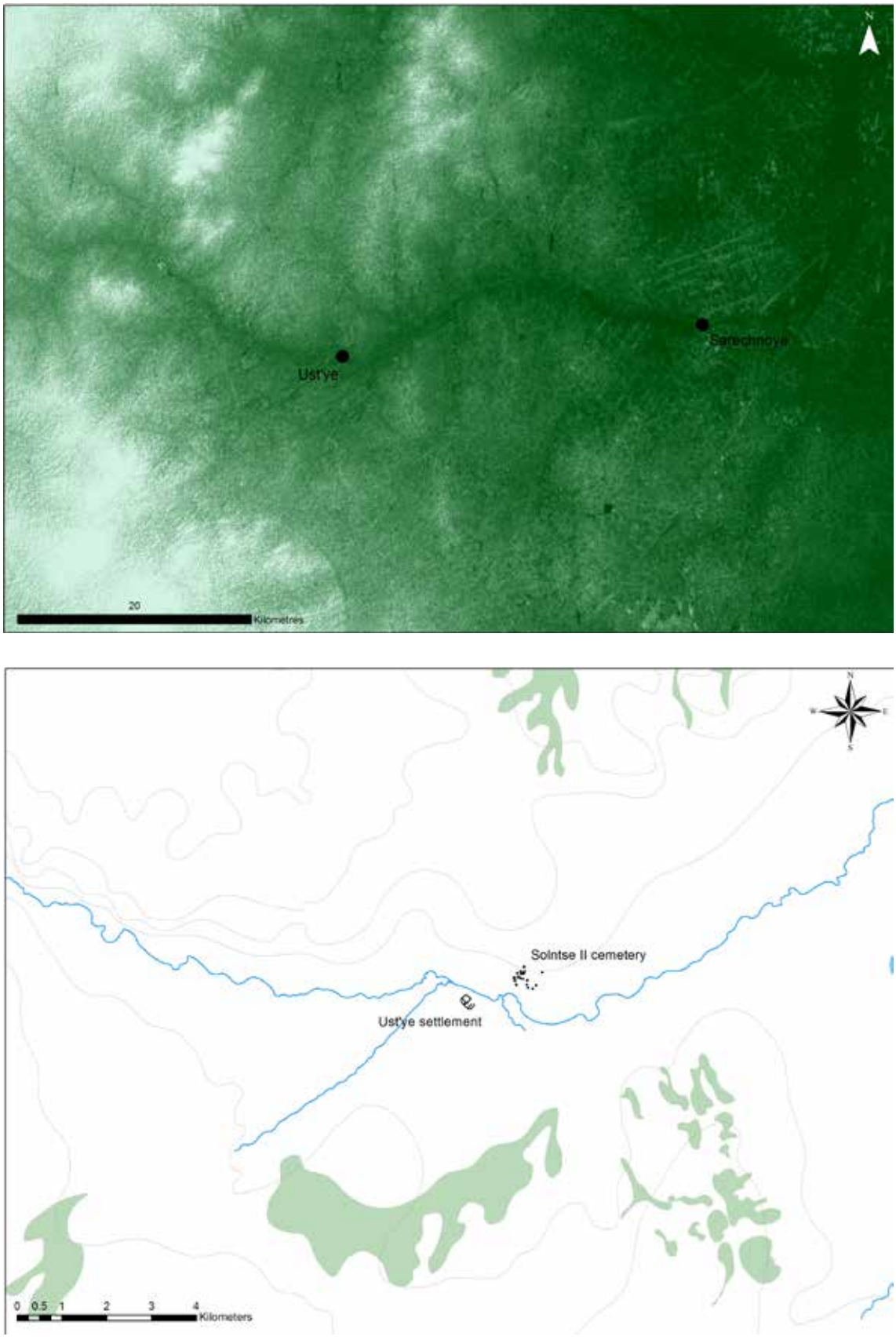


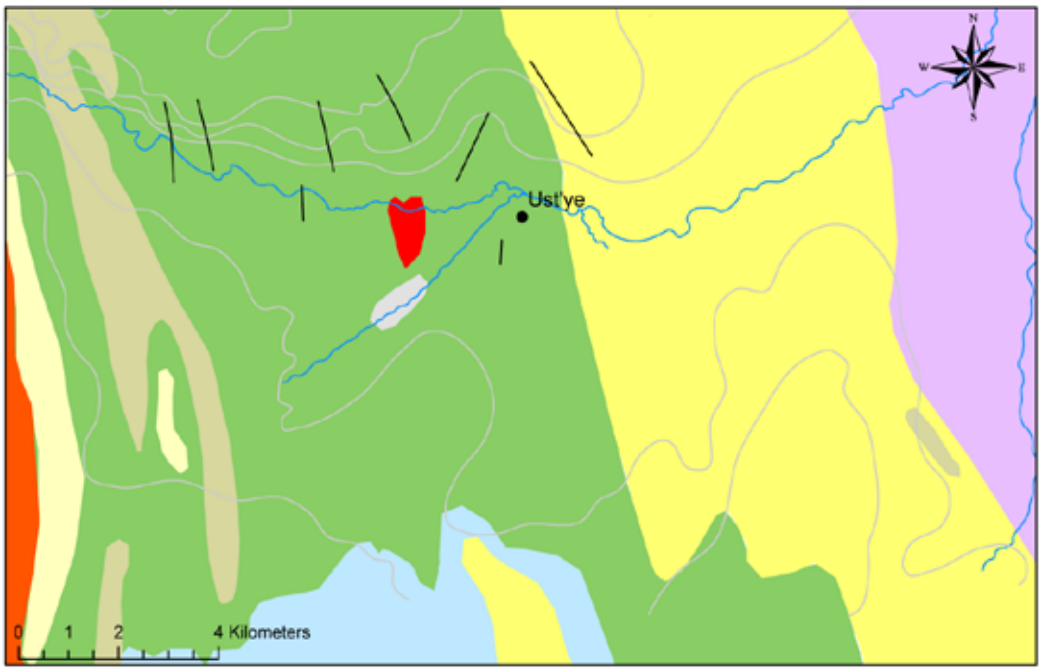
Figure 5. 16 Topography of the Toguzak Valley (top) and the location of Ust'ye and Solntse 2 in the wider river valley (Bottom).



Figure 5.17 Comparisons of the horizons at Ust'ye, the relatively close and restricted horizon to the north (top) and more open to the south-east (bottom). In the northern horizon it is just possible to see the Kurgan cemetery on the slope of the ridge.



Figure 5.18 Oblique aerial photograph from Solntse 2 showing both the main kurgan cemetery (foreground) and the settlement enclosure



Legend

- quartz bearing limestone
- granite intrusive
- granodiorite, granite, and sometimes plagiogranites granosyenites
- serpentinite
- limestones sometimes metamorphosed, locally carbonaceous layers of clay and lime-shale
- coal measures, carbonaceous shale, clay, carbonaceous clay, less graphite, chlorite, phillite with layers and bundles of siltstones, sandstones, conglomerates. Sometimes layers and lenses of anthracite
- Substage Tournaisian stage. diabase, basalt porphyries and their tuffs.
- diabase, porphyrite andesite, basalt, and their tuffs, tuff porphyritic greenschists conglomerates tuffti, rarely quartz porphyry, albitophyre, carbonaceous and siliceous shales
- paragneisses biotite, amphibole and biotite-muscovite, banded, mica schist, sandstone and arkosic polymictic gniss, biotitized, porfiritoidy, amphibolites, marbles

Figure 5. 19 Simplified geological map of the Toguzak valley.

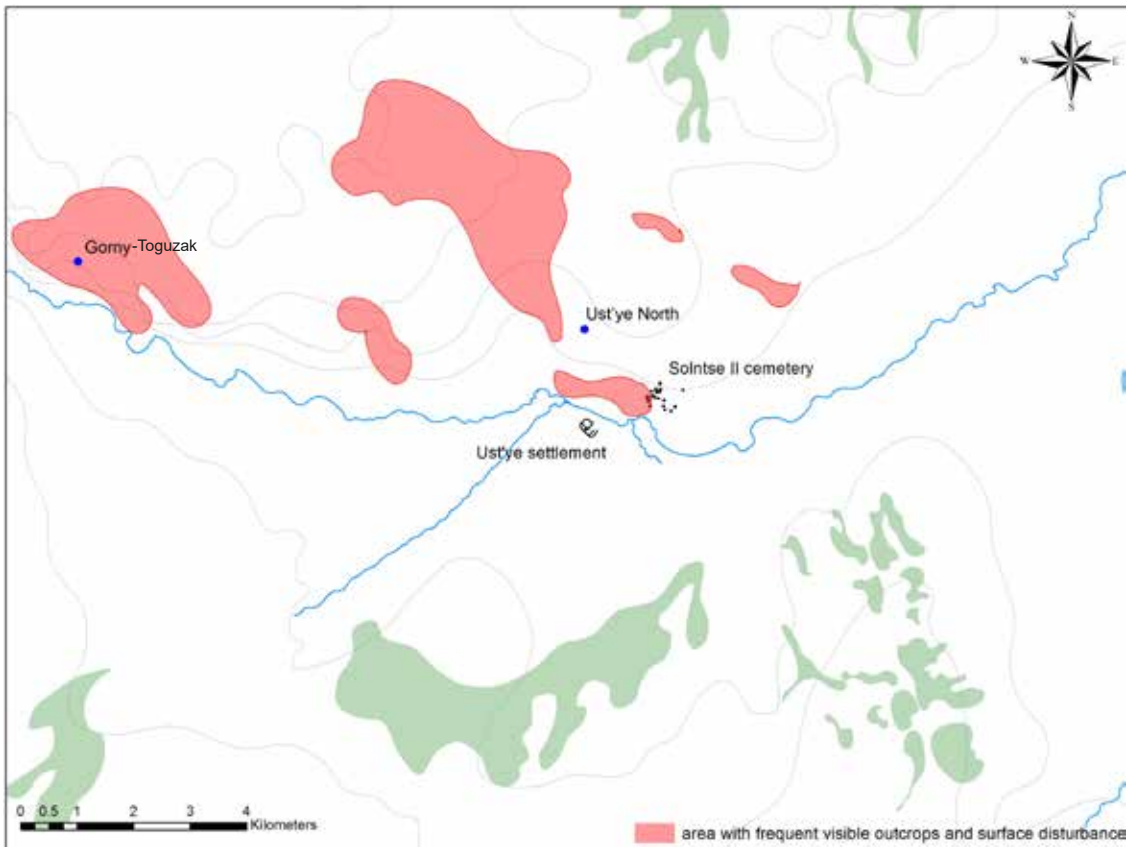


Figure 5.20 Map showing the extent of outcropping mineralogy and surface disturbance to the north of Ust'ye, as visible from satellite imagery (Google Earth 2007).



Figure 5.21 Interpretive sketch plan of Gorny-Toguzak showing the large central clay area surrounding by overlapping spoil heaps.

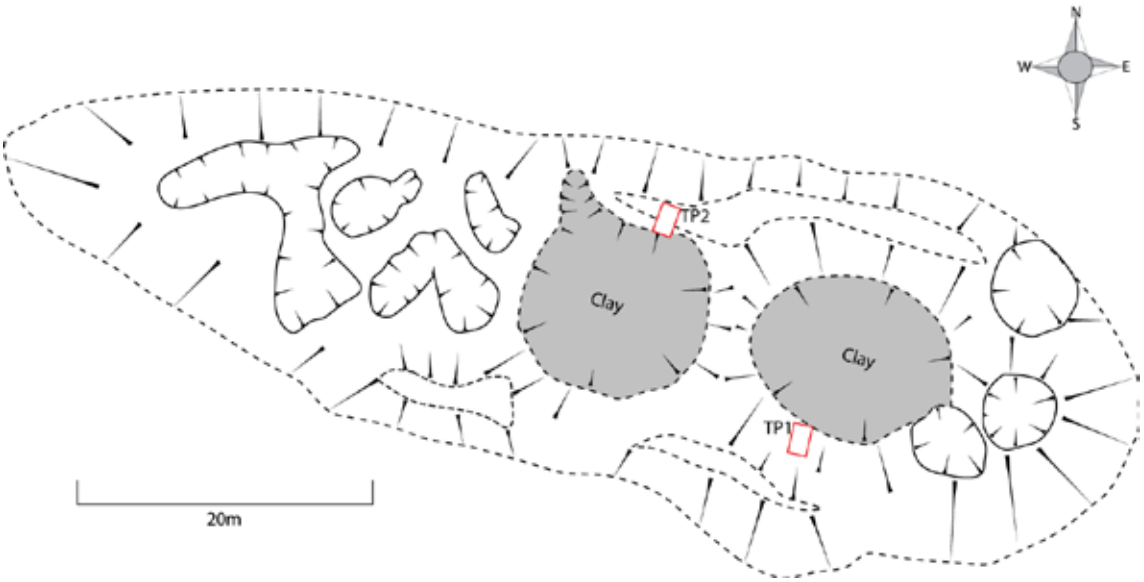


Figure 5.22 Interpretive sketch plan of Ust'ye North showing the location of the two main shafts and associated spoil.

much of the work was centred upon and, in the context of this thesis, the bulk of the metallurgical debris studied was derived from work at these two sites.

The site of Stepnoye, the most northerly Middle Bronze Age complex in the Country of Towns region, consisted of an earthwork enclosure and was located near to an extensive kurgan cemetery (Figure 5.23 and 5.24). The enclosure is typically interpreted as a settlement which, based on the evidence of aerial photography, featured numerous internal divisions and house units (Zdanovich and Batanina 2007). It was first identified in 1950 by the Russian archaeologist Sal'nikov (Batanina and Hanks 2012), with the phasing and layout later drawn from a combination of aerial photography and topographic survey and more recently geophysics (Merrony 2007; Zdanovich and Batanina 2007). The site had a clear rectangular enclosure which included a raised bank with a slight outer ditch. The internal area of the site was partitioned, with a linear internal layout and multiple divisions (See Figure 5.25). Zdanaovich and Batanina have noted, based on the aerial photographs, the remnants of a smaller, oval-shaped enclosure bank. They suggest that this is the oldest phase of the site, which was later embellished by the addition of the rectangular enclosure while still utilising some of the existing architecture (ibid).

The space within the rectangular enclosure was divided into three areas, containing a total of 43 depressions which were visible on the aerial photographs, and were thought to be housing units (Zdanovich and Batanina 2007: 161). These units ranged in size from 6 x 2m to 10 x 15m. The enclosure was eroded on the south side by the meandering of the river. Zdanovich and Batanina noted a series of 'dam structures', perhaps to prevent the river from damaging the settlement during its latest phase of occupation, which suggest that the erosion may have begun while the settlement was still in use. Low altitude aerial photography (Figure 5.25) produced by the SCARP programme clearly showed the extent of the earthworks as well as highlighting the clear modular structure of the eastern area of the site.

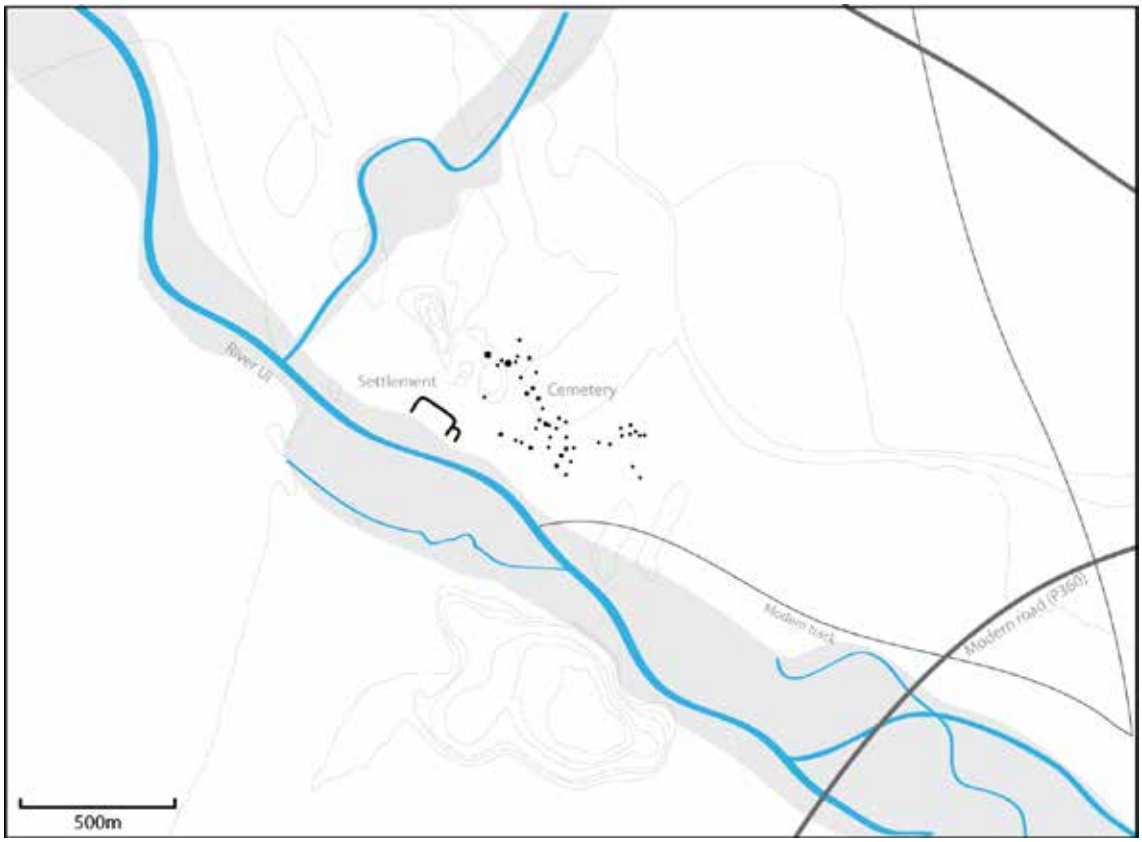


Figure 5.23 Interpretation of the aerial photographs of the Stepnoye enclosure (top, redrawn form Zdanovich and Batanina 2007)

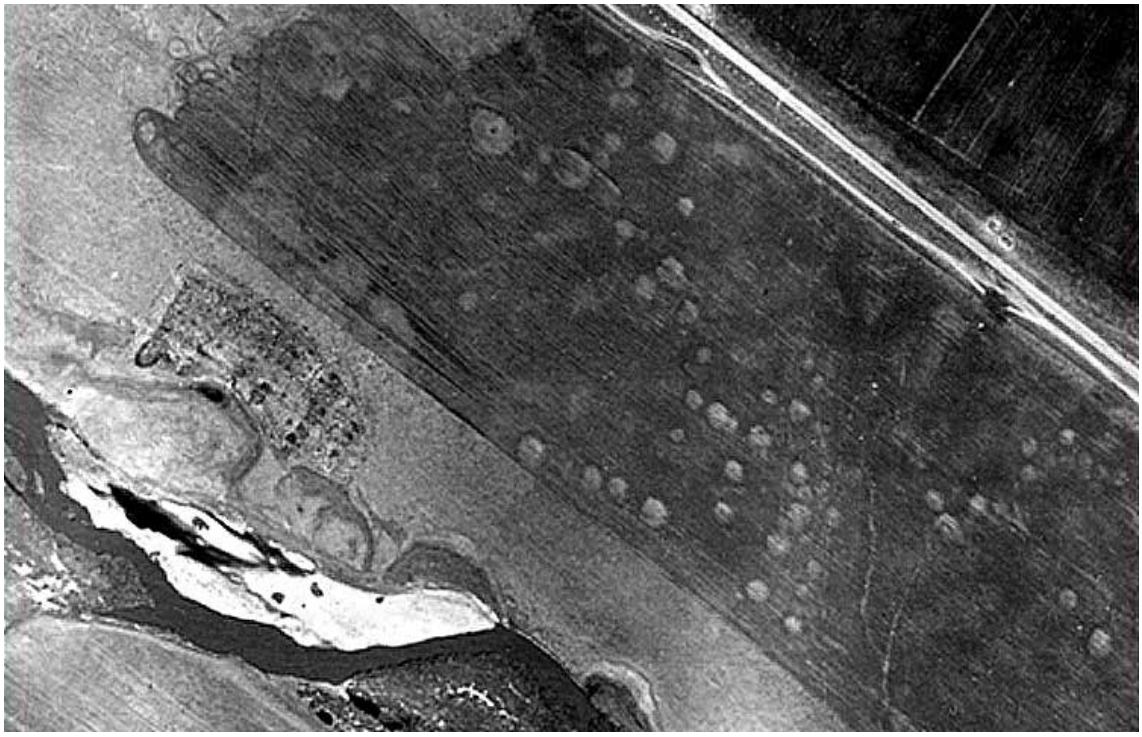


Figure 5.24 Aerial photograph showing enclosure features (left) and the kurgan cemetery.

Both settlement and cemetery were located on the northern flood plain of the river Ui, which, when followed in an easterly direction, is shared by the contemporary sites of Chernorech'ye and Krivoye Ozero (Figure 5.11 an 5.14).

The settlement site of Ust'ye is located on southern bank of the river Toguzak (Figure 5.26 and 5.27). In contrast to Stepnoye, the settlement lies to the south of the river while the cemetery, Solntse 2, is situated on the other side to the northwest. This arrangement, with the settlement and cemetery separated by a body of water such as a river or a lake, is typical of settlements/cemetery complexes in the Country of Towns (Koryakova and Epimakhov 2007). Like Stepnoye, the Ust'ye enclosure was constructed near to the river, on a slightly raised plateau just above the flood plain. The cemetery is situated on a high promontory which overlooks the site.

The settlement complex at Ust'ye was situated on the southern bank of the Toguzak where it meets the river Kisinet (Vinogradov 2013). The name 'Ust'ye' translates from the Russian word for mouth, and is derived from the site's location at the confluence of the two rivers. Like Stepnoye, Ust'ye is in the northern sector of the Country of Towns, but is much closer to the central cluster of settlements (see Figure 1.1). The main enclosure is located on a slightly raised terrace that is around 300 by 250 metres in area and is surrounded by a floodplain. Like the other settlements in the region the site was originally identified from aerial photography. This identified a square-shaped enclosure with evidence of internal divisions running in a linear alignment in parallel with the major axis of the site. Initially the site was considered one of the smaller enclosures in the Country of Towns, at less than 90m in length along its main axis (Figure 5.27).

5.3.1 Geophysical surveys

The two sites were subject to an intensive programme of geophysical survey which included magnetometry (fluxgate and caesium), resistivity and ground penetrating radar. The magnetometry surveys at Stepnoye revealed very little about the underlying structure of the site, with the exception of some ferrous anomalies which were later shown to be modern and intrusive (Merrony 2007). The resistivity survey however did show a

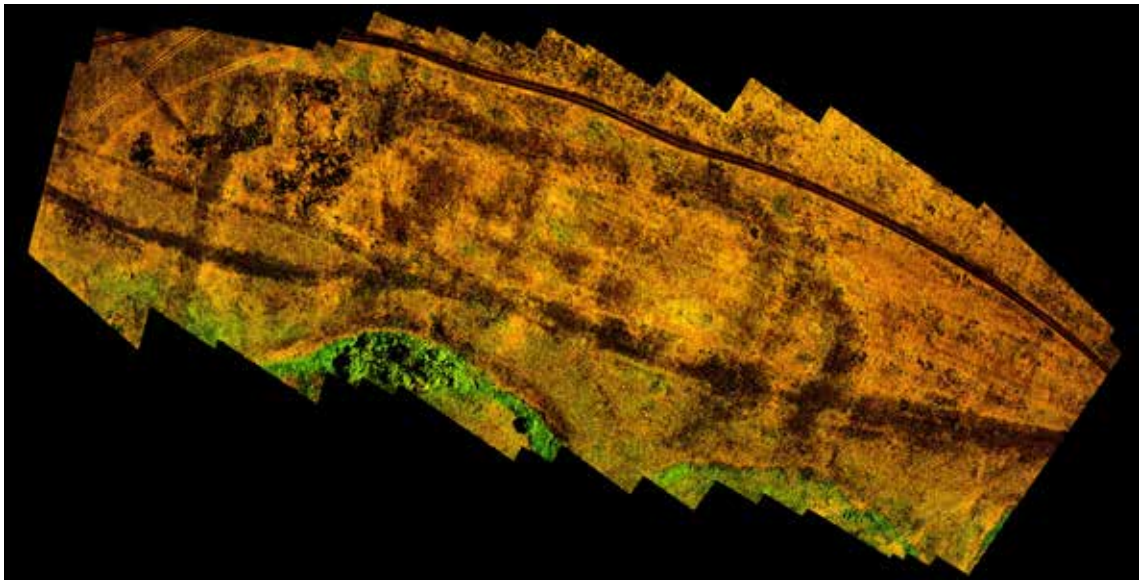


Figure 5.25 A recent low altitude aerial photograph of the site (R. Doonan and D. Pitman).

considerable amount of structured variation (Figure 5.28). The resistivity plot shows the outline of the main enclosure ditch which, according to Merrony, could be interpreted as either a continuous ditch running around the settlement or, more probably, the results of a series of two or even three phases of development. The plot does not show the extensive linear house arrangement which was visible on the aerial photography but it does include some circular/oval features which are approximately the typical size of a Sintashta house (Koryakova and Epimakhov 2007; Merrony 2007).

In contrast magnetometry was particularly successful at Ust'ye. The survey identified that many of the features which are typically identified on Sintashta period sites were clearly visible, including the outer ditch, organised house structures and frequent large pit features. It was suggested that, as with the excavated area, each house in the central enclosure was likely to have contained a well/pit feature, however only a limited number of the structures seemed to contain hearth/burning features (Figure 5.29, round). The original interpretation shows much less regularity in the outer enclosures, which evidenced more linear/partition-like features. The phasing of the site is not immediately clear in the original interpretation; however, in a latter interpretation Hanks et al. (2013) have suggested up to four successive phases of rebuilding. This idea of total reconstruction followed by successive rebuilding is supported to some degree by the original excavation; however the extent of rebuilding, as opposed to extension, is not clear. The alignment of the successive phases/extension does seem to suggest an awareness of the proceeding phase.

5.3.2 Geochemical survey

In addition to geophysical exploration, the sites were subjected to a multi-scalar geochemical survey, resulting in a coverage of c.25ha at each site. The programme, and the subsequent work at Ust'ye, Chernorecheye and Sarachnaya, was the first carried out in the region which aimed to explore how the spatial articulation of production can be understood on the many unexcavated settlements (Doonan et al. 2012).

The surveys primarily consisted of a series of in-situ pXRF analyses over a grid system on resolutions of ten metres and two metres (Doonan et al. Forthcoming). The copper concentrations at each point of analysis were then mapped spatially and overlaid on a site plan. The 10m survey at Stepnoye showed a significant spatial bias in copper concentration towards the east of the site towards the cemetery (Figure 5.30). This spatial trend was also noted in the high resolution (2m) component of the survey which showed that copper concentrations were confined to discrete, structured anomalies in the eastern flank of the site (Figure 5.31). The results suggest that the deposition of copper production debris, and likely copper production was not uniform throughout the site. Subsequent trial trenching suggested that the responses within the settlement are indicative of areas of production, while those on the outside of the settlement are indicative of the distribution of metallurgical waste (Doonan et al. Forthcoming).

The survey at Ustye, much like at Stepnoye, showed an uneven distribution of copper in the soil (Doonan et al. Forthcoming). The copper distribution plot, when overlain with the basic geophysical interpretation, showed that the most intense response was located outside of the settlement to the west, while there were smaller responses within the enclosure (Figure 5.32). This is largely consistent with the results from Stepnoye, which suggest that

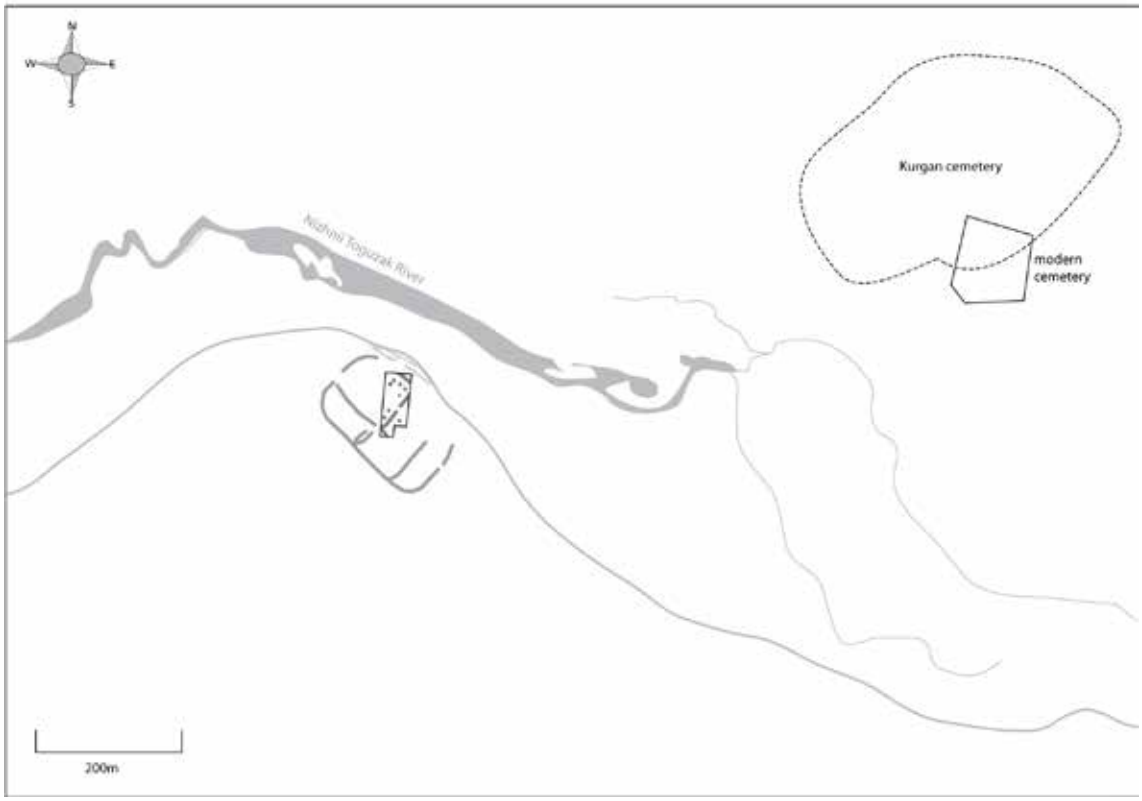


Figure 5.26 Plan showing the locations of the Ust'ye enclosure and the location of the River Toguzak and Solntse 2.

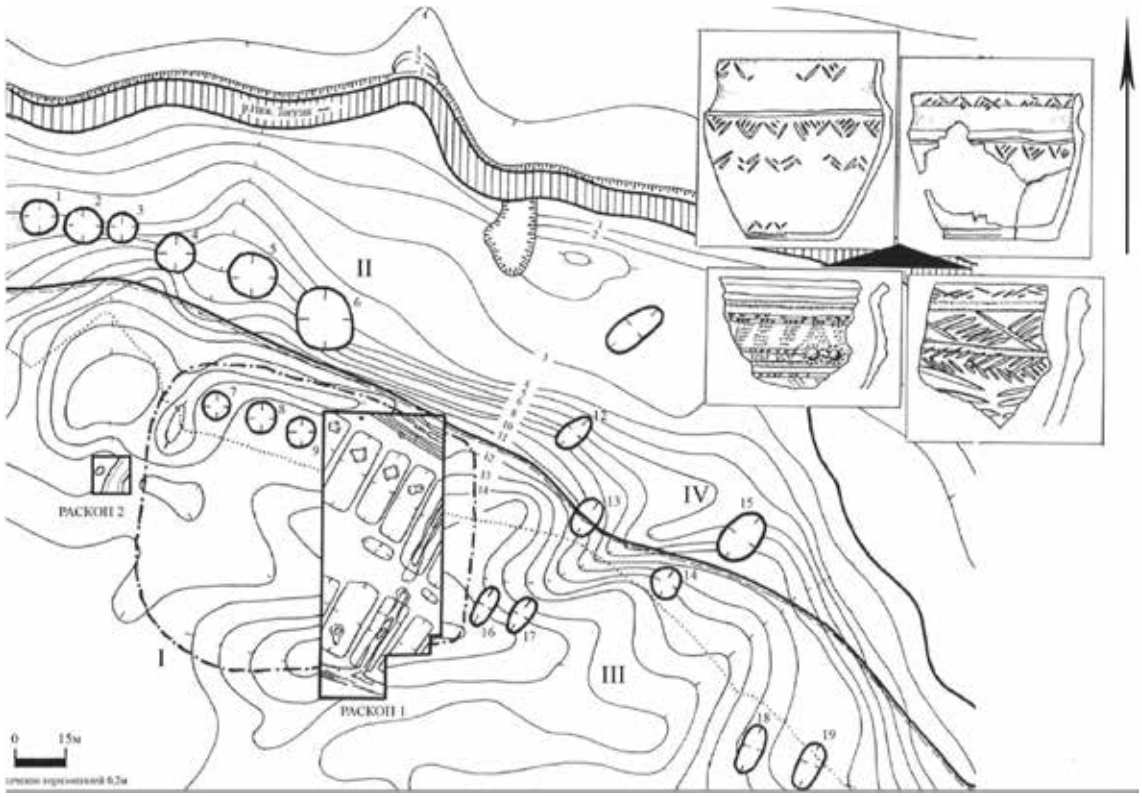


Figure 5.27 Original plan of Ust'ye showing the estimated size of the enclosure (I) and the excavated area (Vinogradov 2013)

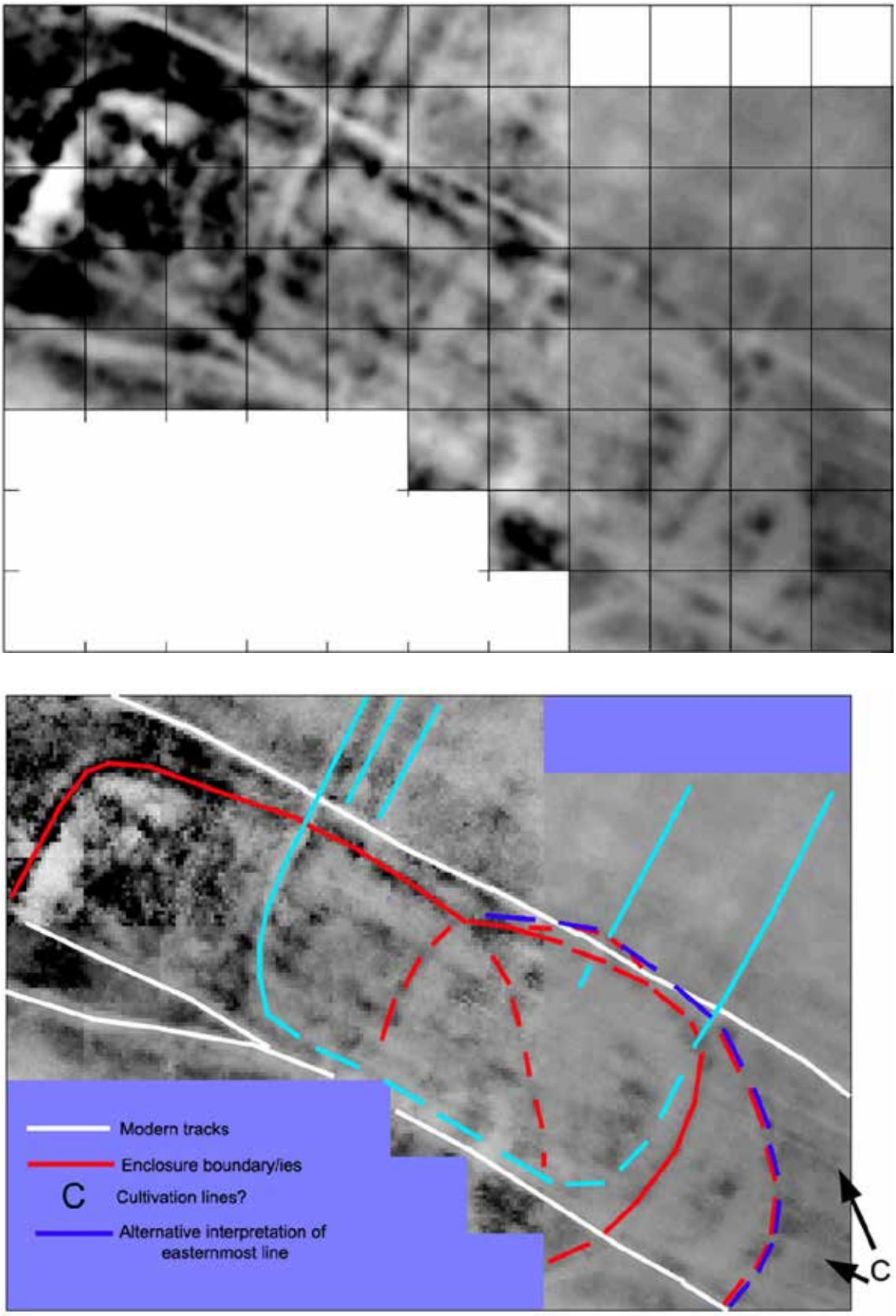


Figure 5.28 Greyscale resistivity plot of the Stepnoye enclose (top) and interpretation (bottom, after Batanina and Hanks 2013; Merrony 2007, square =20x20m)

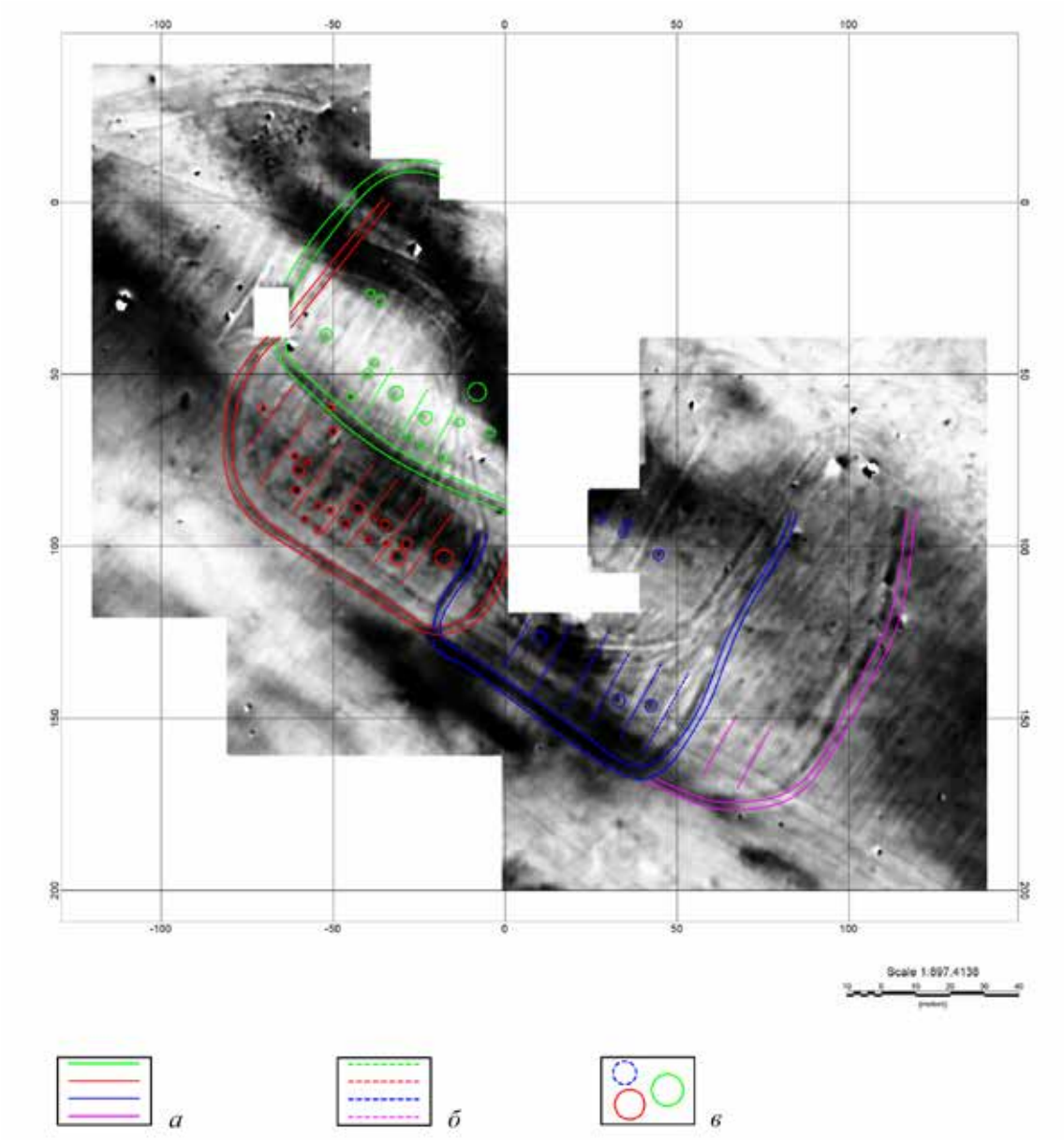


Figure 5.29 Interpretation of the caesium magnetometry including potential phasing (Hanks et al. 2013).

metallurgical practice was not carried out uniformly across the site, with selected areas targeted for deposition.

5.3.3 Excavations

The two sites have been subjected to varying scales of excavation. The enclosure site of Stepnoye, despite being identified in the 1950s, was not excavated until 2008 when SCARP, directed by Bryan Hanks, Dimity Zdanovich and Elena Kupriyanova, began a two year programme of excavation on the western extremity of the site. The trench extended through an outer wall and into a possible housing area. The choice of location for the excavation was driven by a combination of geophysics and topographic survey (Hanks 2009). In contrast, Ust'ye was excavated extensively between 1984 and 1990 by the Chelyabinsk Pedagogical University under the leadership of N. B. Vinogradov, with a smaller programme of excavation carried out by SCARP in 2012.

The main excavation trench at Stepnoye was approximately 34 by 8 meters in an east-west alignment. The first phase of the excavation revealed three ditches and two 'defensive walls', as well as a third, smaller rampart (Hanks 2009). All of the ditches appeared to have a break, which Hanks suggests may have been an entrance to the site. The excavators suggested, based on the quantity of charred wood and ash in the fills of the ditches, that there was a significant quantity of wood used in the construction of the walls (ibid). The

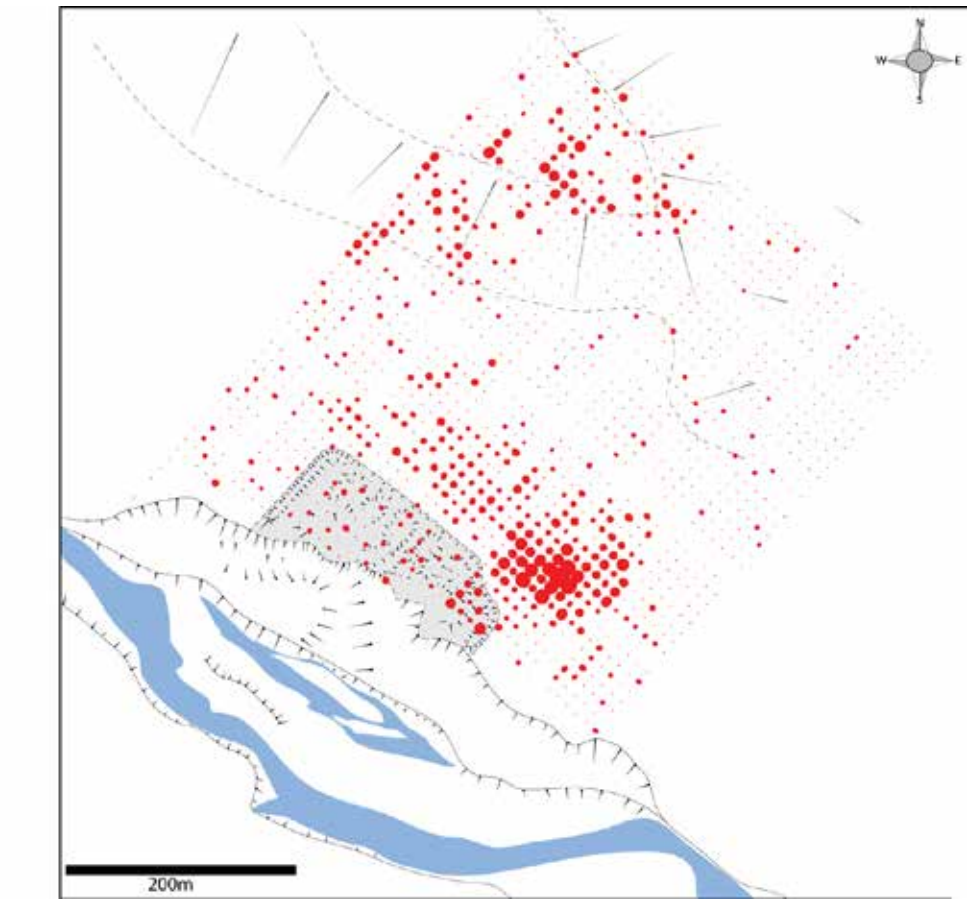


Figure 5.30 Geochemical plot of the Stepnoye survey showing copper concentrations at 10m intervals (Doonan et al forthcoming).

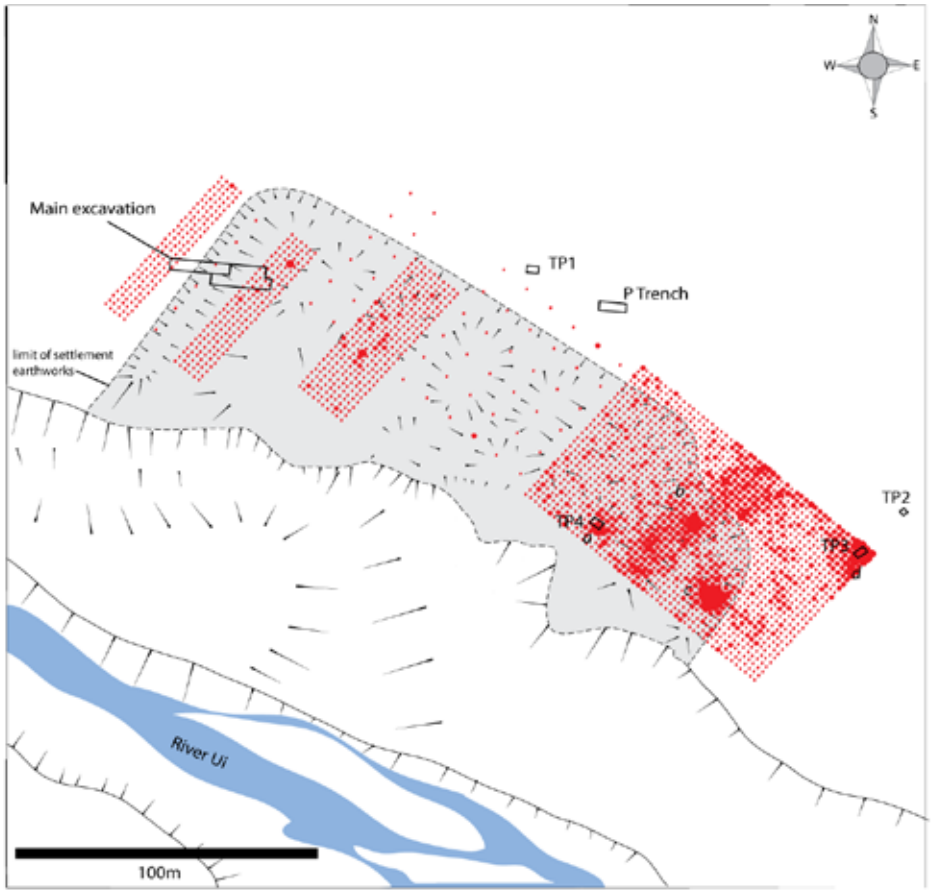


Figure 5.31 Geochemical plot of the Stepnoye survey showing copper concentrations at 2 and 5m intervals (Doonan et al forthcoming).

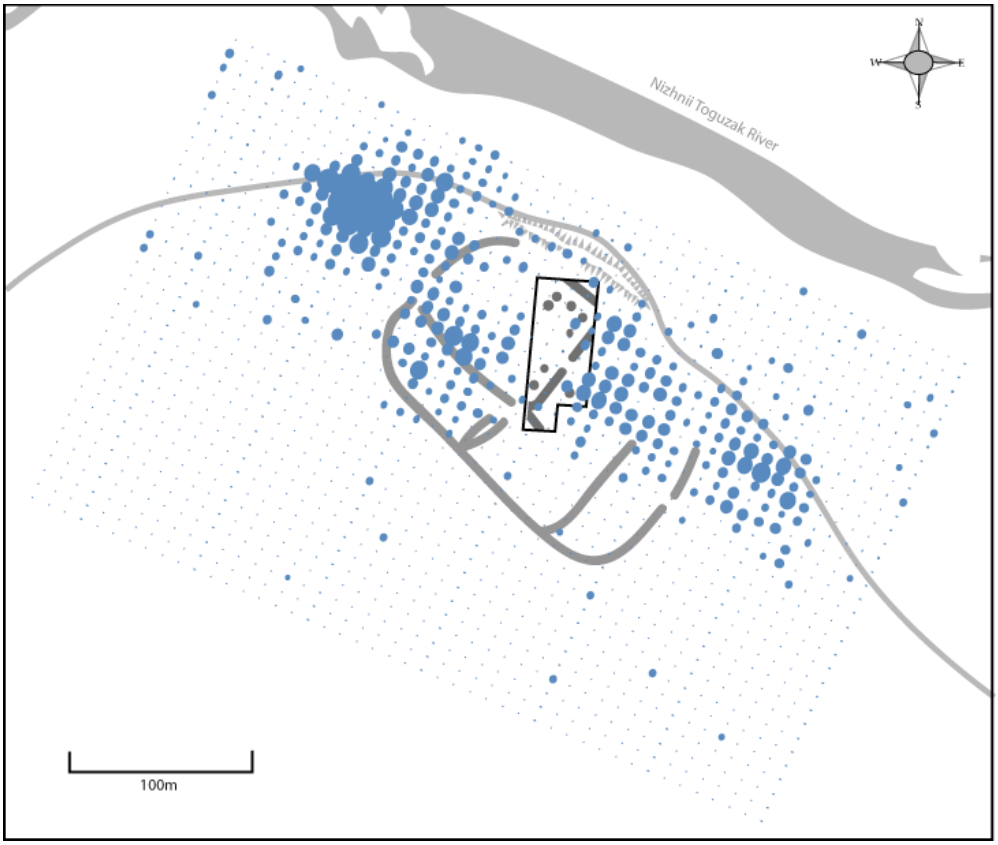


Figure 5.32 Geochemical plot of soil copper levels at 10m intervals overlaid onto a simplified geophysical interpretation (Doonan et al. Forthcoming).

area of excavation within the settlement enclosure revealed parts of two house floors, a courtyard, a midden and a well, and featured two distinct building horizons (Hanks 2010b). Figure 5.33 shows a plan of the excavated area. In total the excavations recovered 1707 ceramic fragments, 1366 which were attributed to the Sintashta phases, and 341 which were later Sargary-Alexseevskym types (FBA), as well as bone spokes, copper awls, needles a sickle and stone abrasives. The excavation also recovered 0.9kg of metallurgical slag.

In addition to the main excavation trench, a smaller trench was located outside of the main enclosure 30 metres to the north, and a series of trial trenches excavated both with the aim to better understand the results of the geochemical and geophysical surveys. The excavations found numerous fragments of metallurgical debris, particularly to the east of the site (see figure 5.34 for distribution map). The uneven distribution of metallurgical debris recovered is even more apparent when the size of excavation in normalised.

The original Ust'ye excavation covered an area of 3,000m^2 in the east of the known settlement area (Figure 5.35, Vinogradov 2013). The settlement was enclosed by a ditch which was up to 3m deep in places, and 4m wide at the top. However, the ditch had been refilled and built on by a later phase of structures. In total the excavation revealed 12 structures and 7 wells. The stratigraphy of the excavation suggested two phases of activity within the excavated area, with Sintashta phases overlain by Petrovka phases. Vinogradov suggested the phases had been separated by a burning event (2004). The majority of the structures are seen to be later Petrovka phase buildings; however, much of the area in between the structures belonged to an earlier phase of construction (Vinogradov 2013). The excavations recovered a significant metallurgical assemblage, including over 1200 fragments of slag, metallurgical ceramics and other debris. The material was recovered from both Sintashta and Petrovka areas of the site.

As with Stepnoye, a test pit was excavated in response to the geochemical survey. This revealed numerous fragments of copper-smelting slag and large quantities of other debris, including ceramic and bone which could be classified as domestic in origin (Table 5.1). The high density of copper slag indicated that the anomaly was undoubtedly related to the dumping of metallurgical debris, but was not limited to it. This would suggest that the disposal of metallurgical debris, and potentially the practice of metallurgy, was not a discrete task.

5.4 Summary

The Southern Ural region features a diverse and varied landscape in terms of both topography and resources. Even the two local study areas have differences in their topographic alignment and proximity to resources, although they also have similarities. Both sites are located near watercourses and even in very dry seasons would likely have, due to the presence of springs, secure access to water. This is important as it has been argued that both access to water and access to minerals were driving forces to Middle bronze Age settlement (Anthony 2009; Kuzmina 2008) and the locations and the conditions through which springs and mineral outcrops form can be the same. Despite some undulations, both study areas feature classic steppe characteristics, especially the abundance of grassland and comparative paucity of trees; however it is a landscape which often affords considerable disorientation over large areas. Even today, aside from rivers and occasional examples of modern infrastructure, the

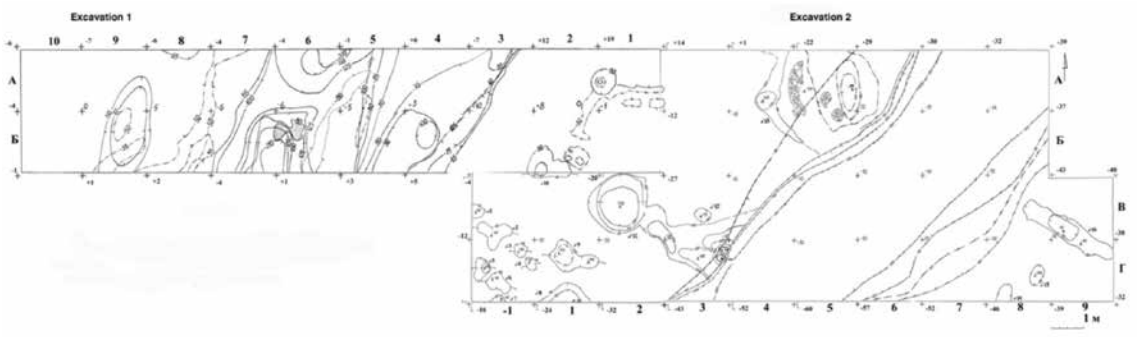


Figure 5.33 Plan of the Stepnoye enclosure excavation (Hanks 2011).

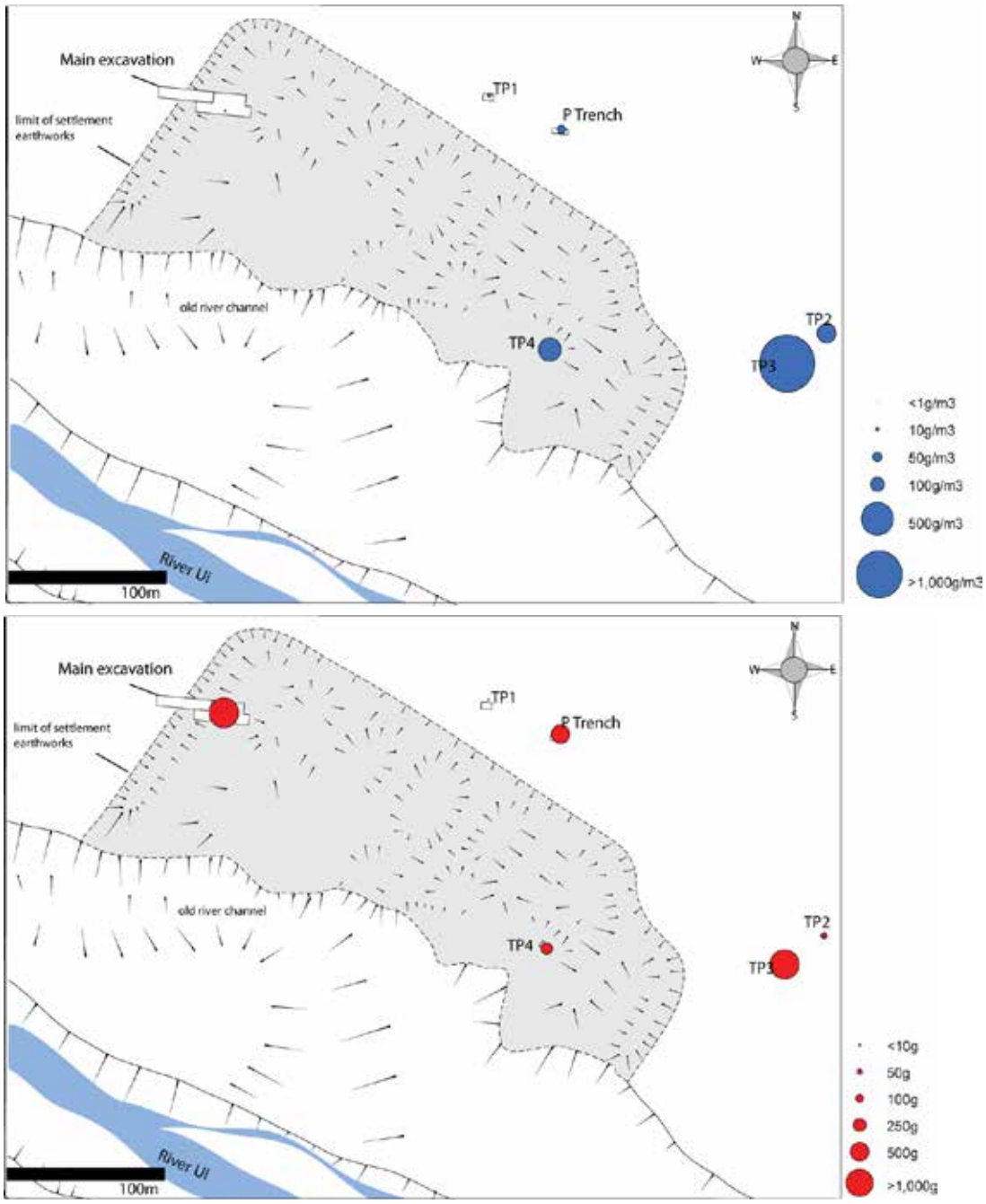


Figure 5.34 Slag per m³ of excavated soil (top) and distribution of slag over the main enclosure displayed as total weight (bottom).

Table 5.1 Finds from the Ust'ye Western Cu Anomaly test pit

	Ceramic		Bone		Stone		Charcoal		Slag	
Context	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
0-2	6	13.9	15	18.4	5	24.6	-	-	12	46.4
2-5	10	32.3	53	55.9	14	84.2	-	-	30	92
5-7	5	11	26	38.8	6	30.1	-	-	2	5.9
7-10	10	22.4	76	137.3	32	142.0	2	0.1	32	87.8
10-15	9	24.6	40	279.3	36	104.0	-	-	34	167.1
102	7	7.2	15	18.7	3	5.5	-	-	-	-
103	3	16.7	36	86.6	23	112.1	8	2.5	13	215
104	1	5.1	2	3.0	3	67.2	-	-	4	37
105	17	86	55	206.9	11	91.6	1	0.1	10	95.3
108	-	-	12	34.3	-	-	-	-	1	69
109	1	15.0	18	51.8	1	0.9	-	-	1	4.8
25-30	-	-	7	5.3	-	-	-	-	4	31.1
30-35	3	39.0	1	26.6	-	-	-	-	2	12.5
Δ101	16	336.0	1	1.2	-	-	-	-	4	36.4
Δ102	7	130.6	7	20.5	-	-	-	-	-	-
Total	**95**	**739.8**	**364**	**984.6**	**134**	**662.2**	**11**	**2.7**	**149**	**900.3**

most notable visual cues in the landscape are kurgan cemeteries. This perhaps serves to highlight their importance in prehistory.

Understanding the climate in the Middle Bronze Age is equally a problematic with some arguing that it was much warmer/dryer (Prikhod'ko et al. 2013) while others suggest it was largely the same (Stobbe and Kalis 2012) as today. Given the importance placed on climate in discussions regarding the development of these communities it is vital that this be better understood. However, even just the exposed nature of the steppe, coupled with a continental climate, presents some harsh and hostile weather conditions and it is important that this is considered when discussing ways of life during the Middle Bronze Age.

Geologically the area is clearly significant. Certainly this is true in modern economic terms, and it is likely that its value was recognized in the past, albeit very differently. Projects investigating ancient exploitation of resources have tended to focus only on what is known geologically, rather than through an engagement with the wider landscape of archaeological sites (cf. Hanks and Doonan 2009). The variety of mineralogy and types of resource bodies would present an ancient metallurgist with a range of choices and pathways through which to exploit and manipulate minerals. However, while minerals were possibly commonplace in the areas of settlements, fuel may have been more difficult to secure. Much more work is needed, but recent environmental data has suggested that trees were present in similar quantities as today while excavations of hearth features identified the use of wood as a fuel. This would likely influence the nature of any metallurgical endeavour and would have significant implications regarding the scale of production. Even the scale of the steppe landscape itself makes archaeology a difficult pursuit; the vast spaces between clearly recognizable sites remain largely unexplored.

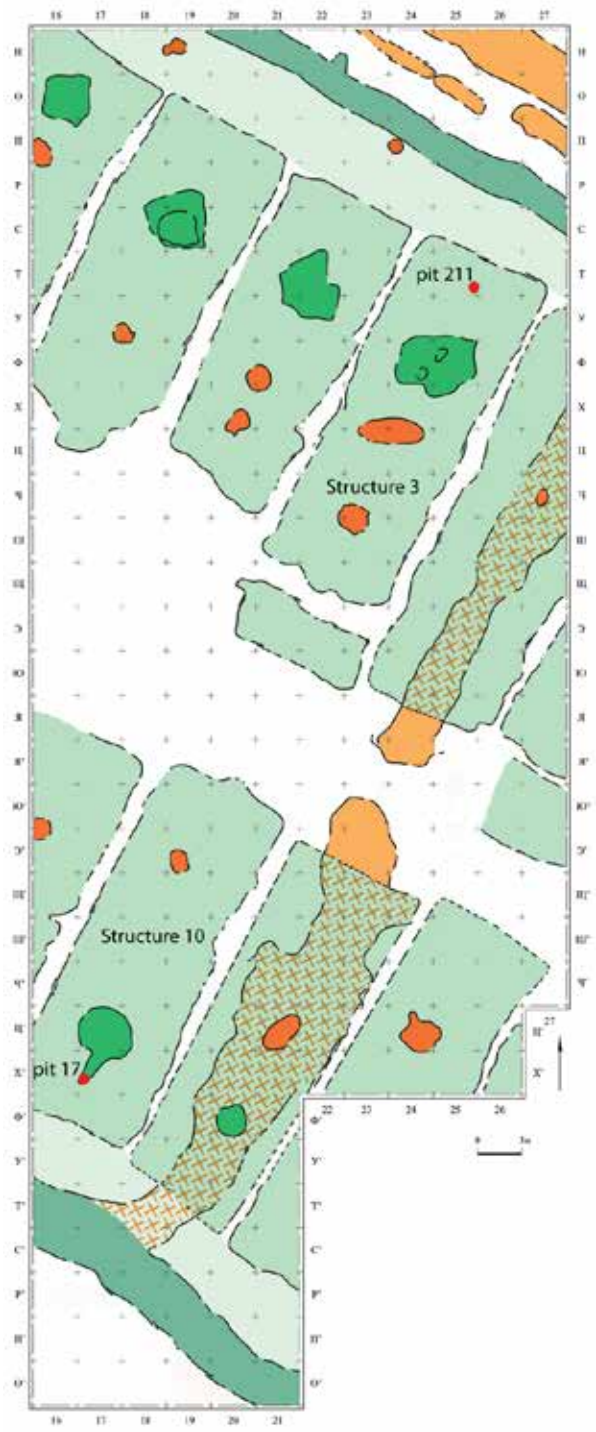


Figure 5.35 Plan of the Ust'ye excavation showing the location of metallurgical features (red) and the Sintashta phase wells and ditches (orange) and the Petrovka phase wells, floors and ditches (green).

On a local scale the SCARP mining surveys have revealed extensive evidence of locally outcropping, small scale mineralogy. In the Ui valley the survey highlighted three areas which may have been exploited in antiquity, and the argument for localised resource procurement at Ust'ye is also convincing, with significant and rich mineralisation noted on numerous occasions within the site's immediate hinterland. While the two sites explored in detail (Gorny-Toguzak and Ust'ye North) were assessed to have the most potential for exploitation, many of the sites visited could have been exploited by the metallurgists at Ust'ye. Both sites lie within a significantly mineral rich area which, before the relatively modern mineral processing left the landscape unrecognisable, would have yielded significant amounts of copper mineral with ease.

At the enclosure sites the SCARP fieldwork has shown that the structure and potential organisation of the sites is far from uniform. What is particularly compelling is both the variation within sites and the differences between them, with clear copper anomalies at Stepnoye and Ust'ye. This will be discussed in more detail following the analysis of material, but the work by SCARP suggests that the organisation and scale of production is by no means uniform between the sites. SCARP has produced an extensive primary dataset in relation to understanding metallurgical practice in its spatial and landscape context. The dataset presented should act as the contextual background for the analysis of work outlined in the next chapter. The excavations of enclosure sites coupled with the resource surveys have produced a range of metallurgical debris in the form or minerals, slag, metallurgical ceramic, copper debris and processing tools. These assemblages will be explored in detail in the next chapter, the beginning of the primary research phase of this thesis, which presents the results of a programme of material characterisation which aimed to establish the extent of variability in production practice at Stepnoye and Ust'ye. Assemblages from the excavation and test pits at Stepnoye, the original excavation at Ust'ye, the 2012 test pits at Ust'ye and the two mining surveys were analysed (methods can be found in appendix A).

Chapter 6

Analysis of the Metallurgical Debris from Stepnoye and Ust'ye

This chapter presents the detailed results of the analytical programme carried out on the metallurgical debris from the settlement sites of Stepnoye and Ust'ye and the minerals collected from associated mining surveys. The metallurgical debris was broadly split into four categories; slag, metallurgical ceramic, ingots/copper waste and ore minerals. The most abundant material class at Stepnoye was slag, other classes of material were poorly represented with only two fragments of metallurgical ceramic, one ingot fragment, one piece of copper waste and 6 small fragments of ore mineral. The assemblage of metallurgical debris from Ust'ye was far more extensive and included a broad suite of metallurgical debris including, slag, ore, crucibles, tuyères and mineral processing tools.

The programme of analysis began with a broad visual characterisation of the materials, before a representative sample of the assemblages was subjected to targeted analysis. The slag assemblages were studied metrically, before being subjected to a programme of optical microscopy, mineralogical analysis and bulk chemical analysis. The aim of the slag analysis was to explore the specific technological choices which produced the material. Metallurgical ceramics were initially subjected to surface analysis, aimed to confirm their use in copper metallurgy, before being sub-sampled for thin section petrography, reflected light microscopy and chemical analysis. A similar suite of techniques was applied to the copper waste using a combination of microscopy and chemical analysis. Mineral samples from both archaeological contexts and the mining surveys were also analysed using this suite of techniques.

6.1 Slag Characterisation

The slag was analysed in both Chelyabinsk and Sheffield. Initially the total assemblage was visually assessed with metric analysis undertaken as outlined in Appendix A. Following this 67 samples were selected for detailed analysis using an integrated analytical protocol that employed optical microscopy and XRF. The results of this analysis were used to inform subsequent sampling strategies for further analysis using SEM-EDS, PGAA and XRD. The analytical strategy aimed to overcome bias results based on a single means of analysis while

also providing a dataset that would allow commentary on a number of material aspects including;

- Bulk chemistry, which addresses issues of technological choice, smelting recipe, race element-analysis, which allows compositional comparison and variation due to technological choice

- Optical/SEM Phase analysis, used addresses aspects of furnace management strategy and comparative analysis through characterisation of individual mineral phases

- Mineral phase analysis through XRD which builds on the phase analysis to characterise non-glassy minerals present in the slag.

Where possible the same suite of analysis was carried out on the Ust'ye slag as was carried out on the Stepnoye material. However, there were exceptions; the metric analysis of Ust'ye slag, due to the extensive assemblage, was carried out on a sub-sample of the material from the main excavation and a total sample from the test pit. In addition, much of the Ust'ye assemblage (over 200 samples) was rapidly analysed using pXRF in Chelyabinsk in order to better select a fully representative sample.

Table 6.1 The presence/absence of key metric traits.

Attribute	Number present	Percentage of recordable fragments
Edge	113	44.4
Ingot impression	77	30.3
Central area	176	69.2
Overspill	111	43.7
Diameter of the plate (Inferred)	34	16.3
Diameter of the ingot (Inferred)	27	13.0
All attributes	21	10.0

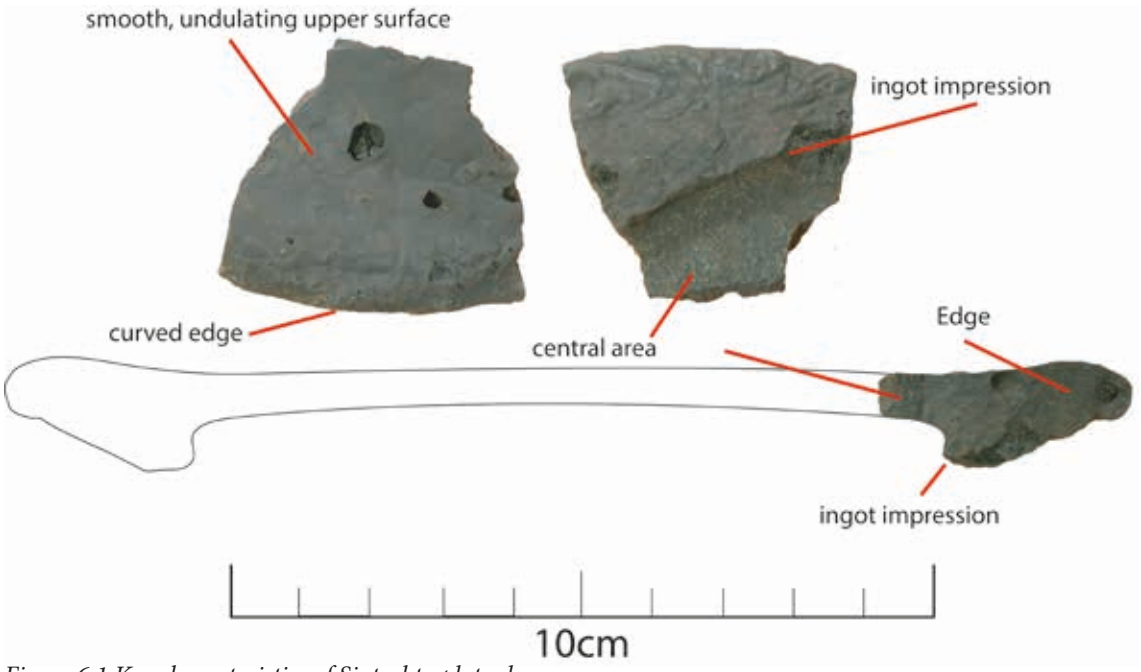


Figure 6.1 Key characteristics of Sintashta plate slag

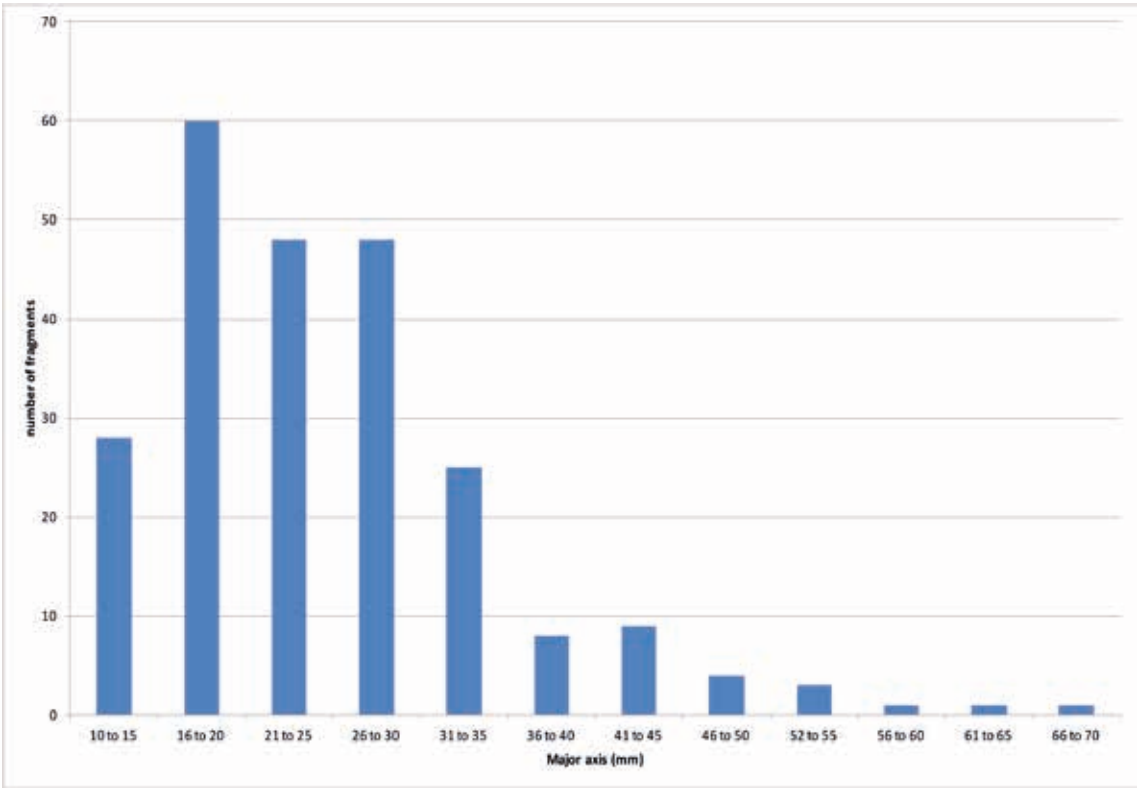


Figure 6.2 Graph showing the frequency of fragment sizes at Stepnoye.

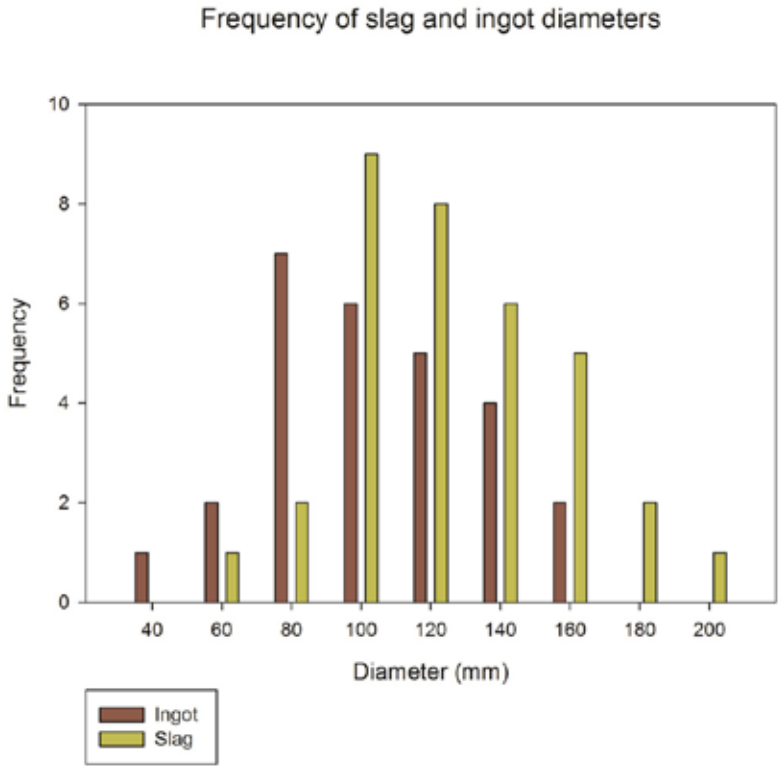


Figure 6.3 The frequency of slag and ingot diameters in the Stepnoye slag.

6.1.2 Metric analysis

In total 2.6kg (236 recordable fragments and 197 <10mm) of material from Stepnoye was studied in the spring of 2010 and the summer of 2011. The material was recovered from the main excavation trench, the phosphorus anomaly excavation, the test pits, the cleaned track surface and Stepnoye 2 (the Kurgan).

All fragments could be broadly classed as plate slag (see Figure 6.1. Table 6.1 shows the presence/absence of these key traits). Diagnostic characteristics were present in all of the fragments, however only a small number of fragments contained all traits. Measurement of the central areas show average between 5 and 9mm in thickness. Plate morphology was established by extrapolating the edge profile with the aid of ceramic curvature charts. Figure 6.3 shows the frequency of the range of inferred sizes. This suggests a typical range of slag plate diameter between 100 and 160mm and an ingot diameter of between 80 and 140mm.

It is possible, based on the average metric characteristics of the Stepnoye slag, to suggest the likely mass of the slag and copper produced during a typical smelting event. The density of the archaeological slag was established on average as ~ 2.8 g/cm^3 . Using density and metric details it is possible to suggest that the amount of slag formed during a typical smelt was 360g (an overall range of 140.84-1055.7g based on the largest and smallest examples).

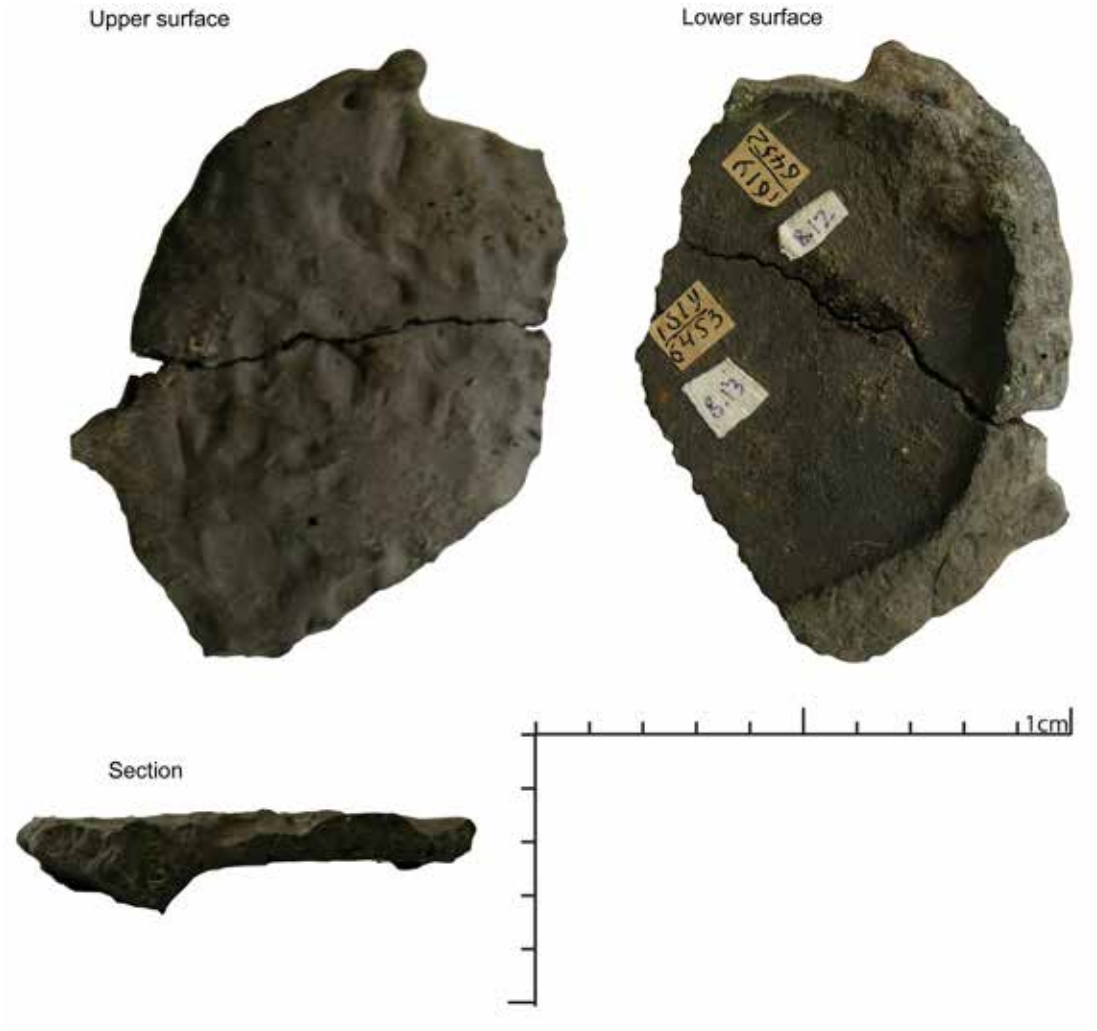


Figure 6.4 The near complete slag plate form Ust'ye

Table 6.2 The samples selected for details analysis by context

Site	Context	Total samples
Stepnoye	Main Exc.	6
	P Trench	6
	Cu TP1	1
	Cu TP2	9
	2007 TP	1
	STEP 2	6
Ust'ye	Main Exc.	14
	2011 TP	11

A plate of 360g, even in a relatively flat bottomed furnace/crucible would have formed an ingot of 378g of copper (a range of 45-988g based on the full range). Of course, a greater curvature would indicate the production of a larger ingot, interestingly the copper ingot fragment found at Stepnoye (see later section for detailed analysis) suggested that it was derived from a ingot of approximately 100mm diameter and would have weighed ~500g.

Overall the assemblage from Ust'ye contained a much greater range of fragment sizes than that from Stepnoye; from small, sub centimetre fragments to near complete slag plates. Although the main range of fragment sizes was similar to that of Stepnoye, there were more exceptional fragments which preserved more of the edge and ingot impression (Figure 6.4). A similar range of thicknesses was observed at Ust'ye as was identified at Stepnoye, with a total range of 5 to 10mm. However many samples did fall into the larger end of this range. Likewise, the extrapolated plate sizes were likely between 10 and 15 cm in diameter. This suggests a similar copper yield at Ust'ye of around 300-500g of copper per smelt.

6.1.2 Microstructural analysis

A total of 29 samples of Stepnoye slag were prepared for optical microscopy with 24 selected from the Ust'ye assemblage. A contextual breakdown of the samples can be seen in table 6.2. A subsample of five sections from Stepnoye and eight from Ust'ye were subsequently selected for scanning election microscopy (SEM-EDS, see Appendix A for methods). The SEM samples were selected based on the programme of optical microscopy in order to confirm and characterise the phases present. The initial slag groups formed first through optical microscopy were therefore further refined following the SEM programme and subsequently re-appraised. The resulting groups emerged from a campaign of analysis that integrated the results of each technique. A sample from each site was also analysed microstruturally using micro x-ray fluorescence.

Optical microscopy

The apparent uniformity noted in the form of the slag was mirrored in the results of microstructural analysis with the majority of samples from Stepnoye conforming to a specific type of microstructure. The samples contained very few pores and, when present, they were usually small (less than 0.1mm). Microstructurally, Stepnoye slags comprised of silicate phases in a glassy matrix with frequent iron oxides, metallic copper, some sulphides and occasional chromite spinels. Ust'ye featured a similar suite of characteristics, with the exception of sulphide inclusions that were largely absent.

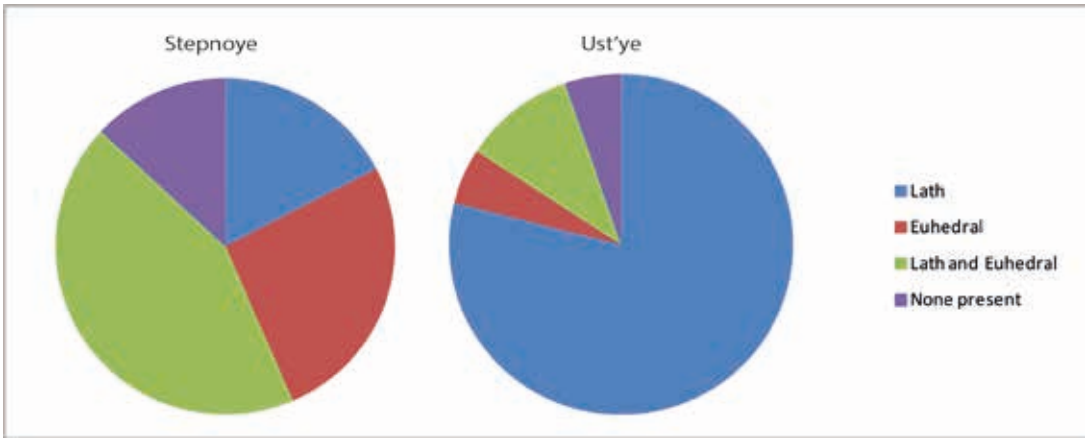


Figure 6.5 Pie chart showing the percentages of different silicate phases in the Stepnoye slag.

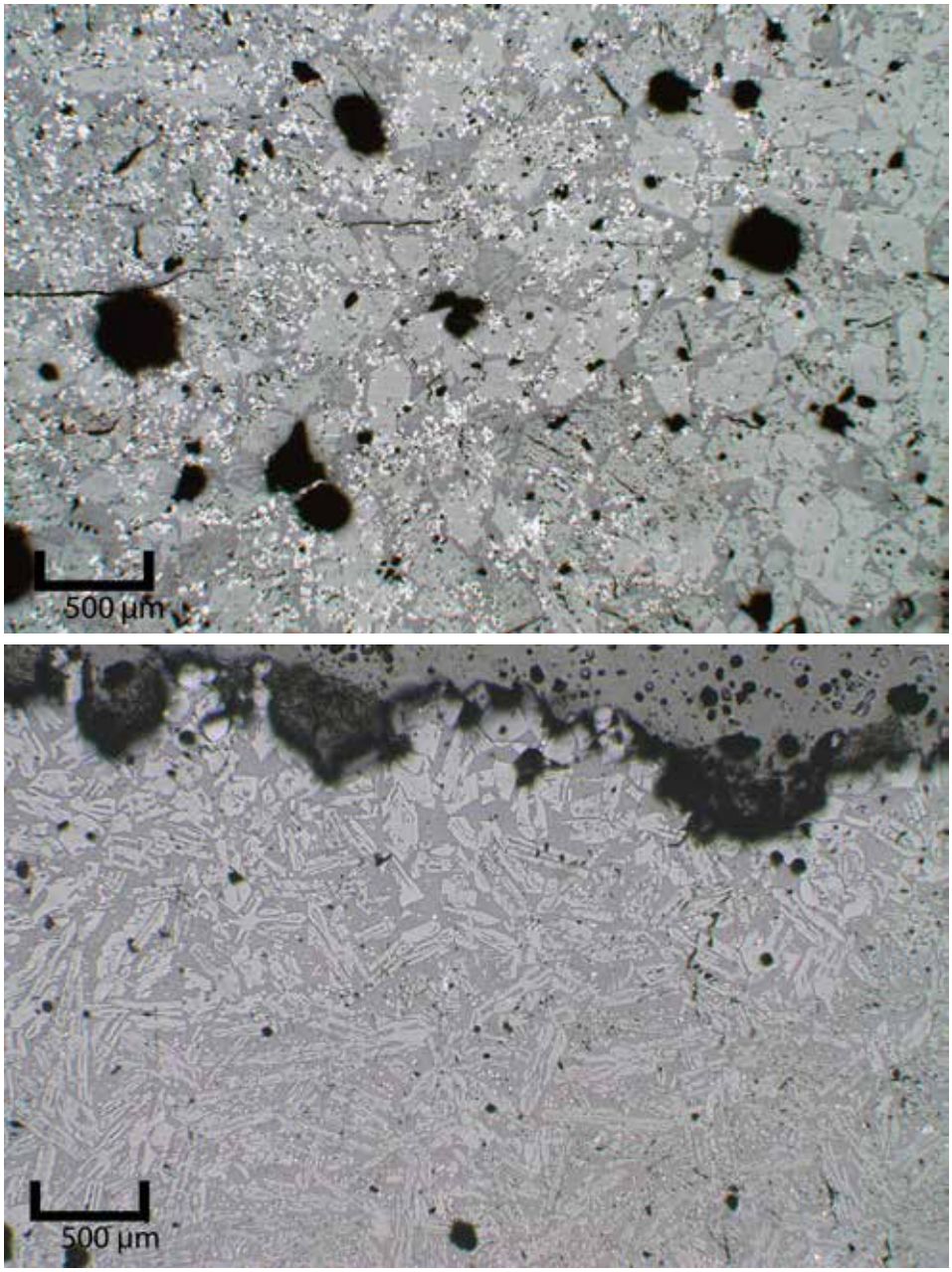


Figure 6.6 Micrograph showing a typical microstructure form Stepnoye (top), showing tabular silicates, dendritic iron oxide and glassy matrix, and Ust'ye (bottom) showing dominant lath-like silicates with frequent free silica inclusions.

The Stepnoye slag contained a mixture of silicate structures in the form of lath-like and Euhedral fayalites (Figure 6.5). Euhedral structures were by far the dominant form with 26% of the Stepnoye assemblage containing exclusively euhedral silicates with a further 44% containing both euhedral and lath like structures; only 17% contained exclusively lath-like structures.

In contrast, 90% of the material analysed from Ust'ye contained lath-like iron silicates, with it being the dominant phase in most samples. Figure 6.6 shows the ratio of silicate phase structures at the two sites. At both sites laths were occasionally noted near the upper surface of the samples and were formed perpendicular to the edge. Hanks and Doonan (2009) suggest that this was caused by the rapid quenching of the slag plate with water.

Nearly all of the Stepnoye samples contained iron oxide in some form, with only 9% of the samples completely devoid of oxide type phases. Indeed over 52% of the assemblage was particularly high in oxides (see Figure 6.7); when present they were found in both dendritic form (wüstite) and spinel form (magnetite), with many samples containing both

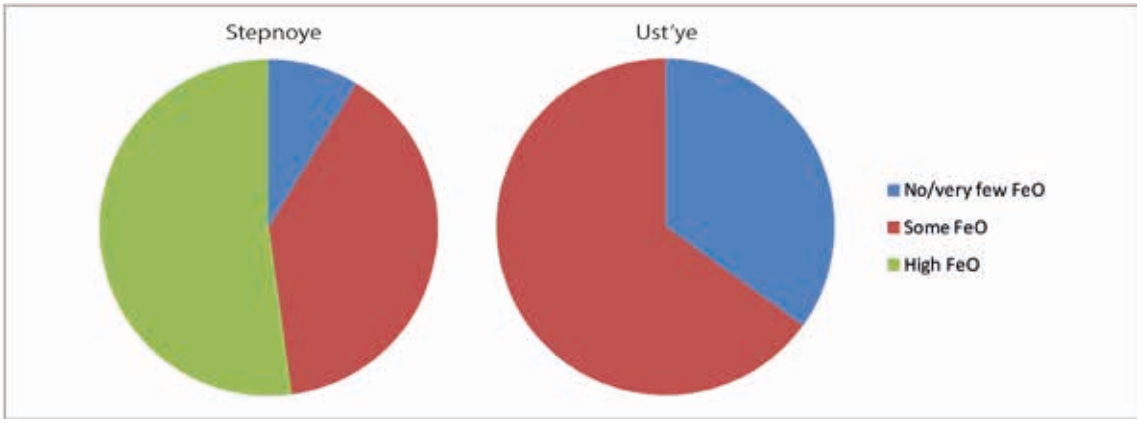


Figure 6.7 The ratios of iron oxide quantities found in the slag assemblages.

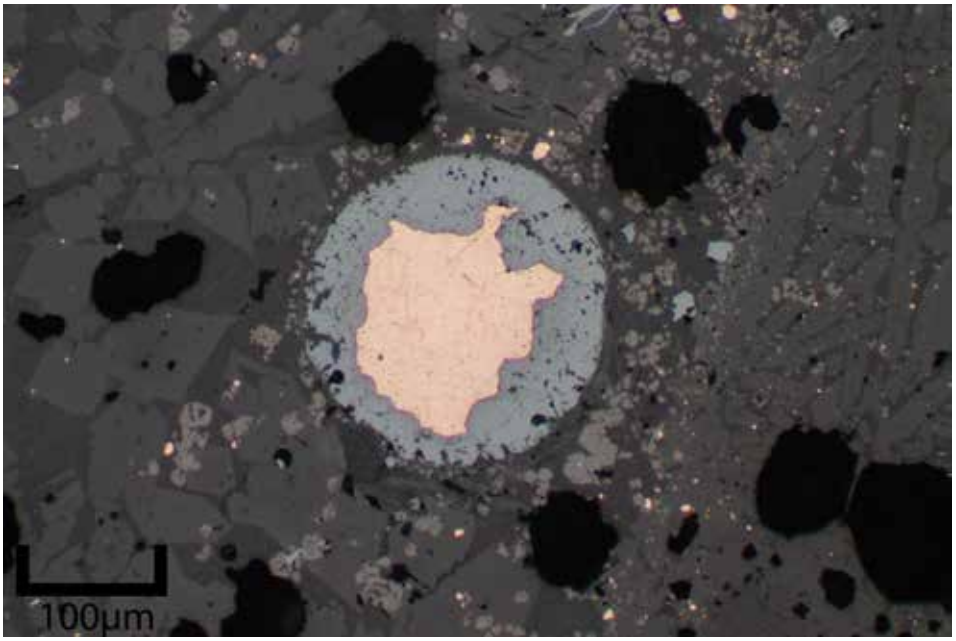


Figure 6.8 Photomicrograph showing a copper prill in association with a sulphide phase in the Stepnoye slag

structures. Overall there were comparably fewer oxide phases in the Ust'ye slag and, when present, they were largely localised and small, spinel like structures (Figure 6.7).

The matrix in the Stepnoye and Ust'ye slags consisted mainly of glass, although some of the samples displayed a micro-phase structure. In most cases the glassy matrix accounted for less than 50% of the samples, with many of the samples containing a matrix of less than 25%.

Over half of the samples from Stepnoye contained copper prills, typically near the underside of the sample. The prills ranged in size from <10μm to >3mm and many of the samples also contained clear sulphide inclusions, some of which were in association with copper prills (Figure 6.8). In the Ust'ye slag, metallic inclusions were present in small quantities in almost all of the fragments analysed, only one sample contained no metallic prills.

Chromites were first identified visually as distinct inclusions which had uneven edges, a lighter halo like zoning and a homogenous core. Figure 6.9 shows the typical appearance of a chromite under reflected light in a sample from Stepnoye alongside magnetite spinels and euhedral fayalite. Chromites, although part of the spinel group of minerals, are both visually and thermodynamically distinct to other spinels. Chromites, high Cr spinels, have fusion temperatures in excess of that achievable in a prehistoric furnace (1700°C) and their presence in slag is often seen as residual from the raw materials of the smelt (Zaikov et al 2005and Grigoryev 2013). In the Stepnoye slag, chromites were only identified in six of the samples whereas they were identified in all of the samples from Ust'ye.

The samples from Stepnoye were notable by their low instance of mineral inclusions with only three samples containing free silica (STEP09-90, 118 and 196) and one copper mineral (STEP09-105.2). The Ust'ye slag however contained frequent free silica inclusions and at least three of the samples contained copper minerals (Figure 6.6).

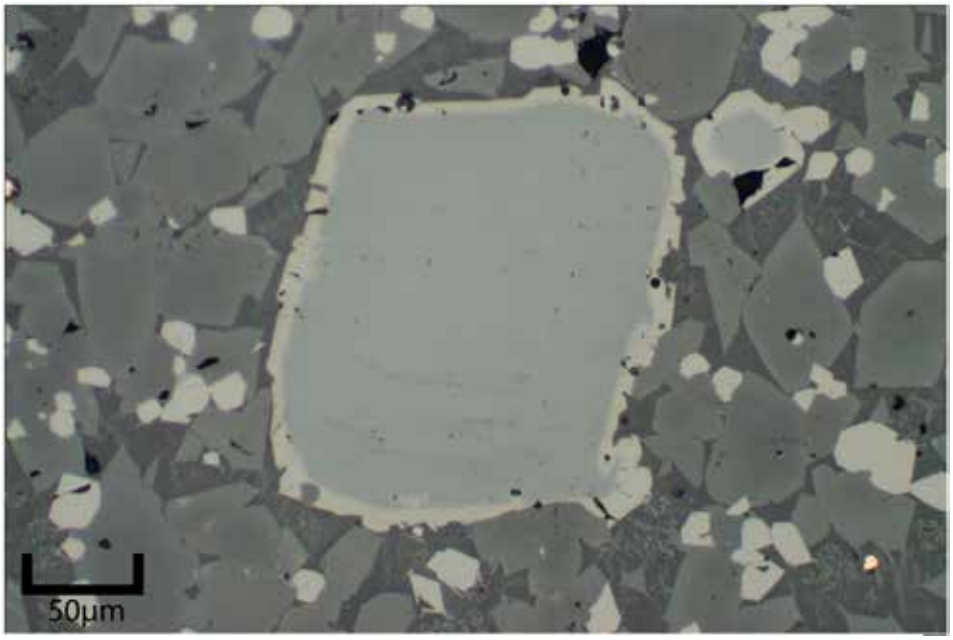


Figure 6.9 Typical appearance of a chromite spinel under reflected light in the Stepnoye slag

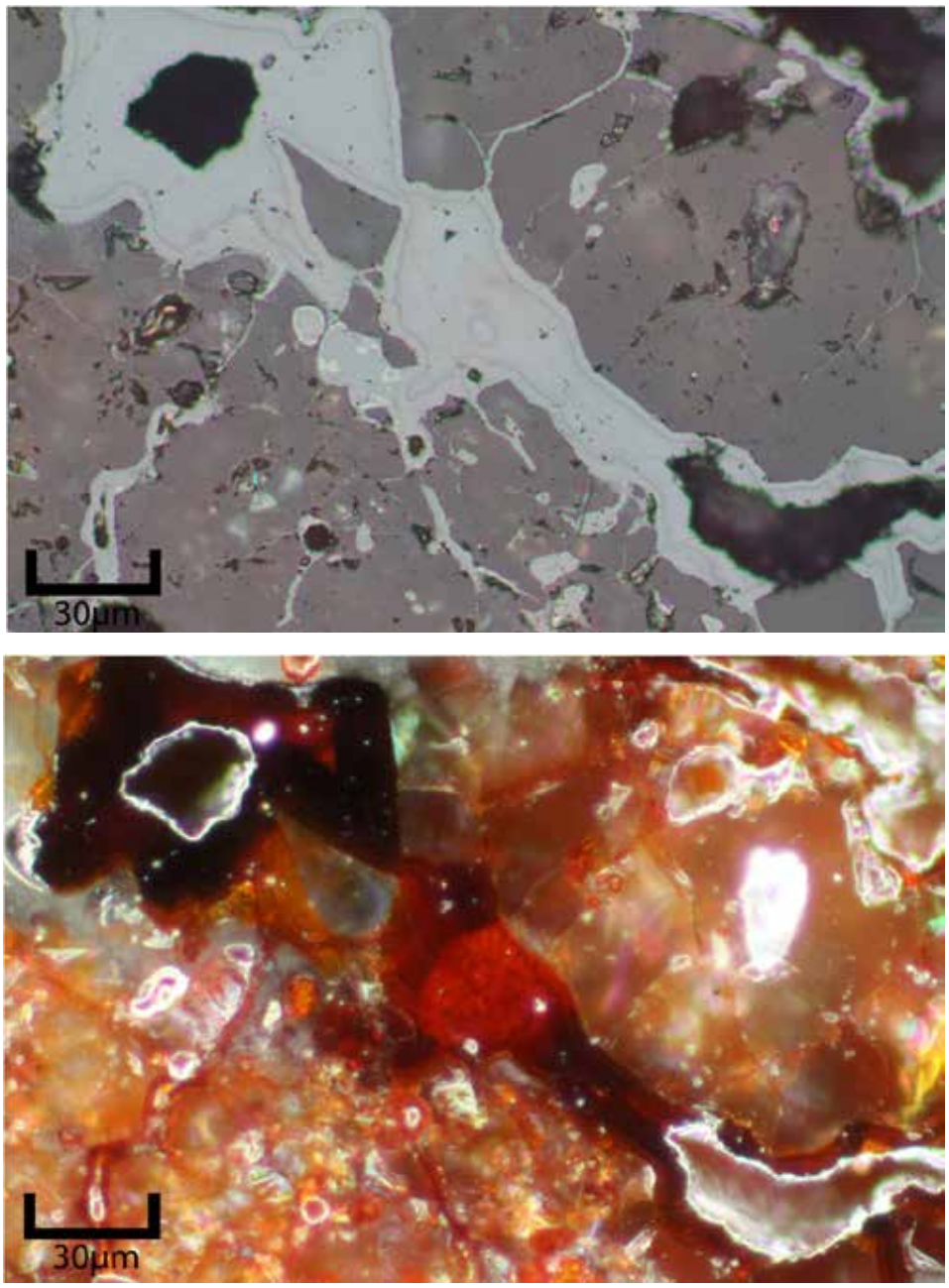


Figure 6.10 Micrograph showing curprite phase in a silica matrix in sample UST11-79 under bright field (top) and darkfield (bottom)

The copper mineral in the Stepnoye slag was structurally very different from the surrounding slag. It contained a matrix of free silica intermixed with iron silicates and frequent copper/iron/sulphide inclusions. It is clear though that some of the inclusions had begun to alter as there were clear euhedral fayalites forming within the inclusion, with more pronounced phases towards the edge. The ore minerals in the Ust'ye slag were optically characterised as cuprite, appearing pale blue under bright field with blood red internal reflections under dark field (Figure 6.10). The samples also had translucent inclusions with strong green internal reflections which are indicative of malachite.

A third mineral type was also identified in both the Stepnoye and Ust'ye slag which appeared platy and foliated. It was preliminarily identified as talc which was confirmed during the programme of SEM-EDS (see below).

The programme of optical microscopy, while showing some similarities between the two assemblages, did highlight significant variation. This was most notable in the frequent presence of sulphide inclusions in the Stepnoye slag which were largely absent in the Ust'ye material. The Stepnoye slag was also higher in iron oxides than Ust'ye and contained more euhedral silicates. The iron oxides are indicative of a mildly oxidising atmosphere while the presence of euhedral formations suggests a slower rate of cooling. In contrast the Ust'ye slags were dominated by the more rapid forming lath-like structures and free silica. This strongly suggests that both the type of ore and smelted process were different between the two sites, with sulphide mineral included in the smelts at Stepnoye while Ust'ye was employed primarily oxide/carbonate minerals; a hypothesis also supported by the possible ore inclusion in the slag. The following programme of scanning electron microscopy was aimed at building on these points.

Scanning Electron Microscopy

Following the initial phase of optical microscopy a sub-sample of slag fragments was analysed from each site. Analyses were carried out on each of the phase types identified optically (Silicates, oxides, metallic inclusions and chromites) in order to fully characterise the slag. Analyses were also undertaken of unusual phases, such as mineral and ceramic inclusions.

Silicates

In total 18 individual silicates were analysed from Stepnoye and a further 29 from Ust'ye. Selected results can be seen in Table 6.3 with full results in Appendix C. At both sites these silicates predominantly contained iron oxide, magnesia and silica. The weight percentages derived from the spot analysis were converted to chemical formula to explore the types of silicates present.

At both sites the silicates were all part of the olivine group. No pyroxene was identified. In the Stepnoye analyses four types of olivine were identified; the iron end member, fayalite (Fe_2SiO_4), and three fayalite/forsterite intermediate compounds $Fe_5MgSi_3O_{12}$, Fe_3MgSiO_8 and the more magnesia rich $FeMgSiO_4$. Over 50% of the Stepnoye silicates fell into the higher magnesia range of compounds which places them in the middle of the fayalite/forsterite system which indicated that they were formed at slightly higher temperatures than pure fayalites (Wood and Kleppa 1981).

The same range of olivine compounds were identified at Ust'ye but it contrast to Stepnoye 90% of the silicates analysed in the Ust'ye slag fell nearer to the fayalite end of the fayalite/forsterite system. Only one sample contained $FeMgSiO_4$. This suggests that, overall the Ust'ye slag formed at slightly lower temperatures than at Stepnoye. The ratio of high magnesia olivines at Stepnoye and Ust'ye correlates well with the ratio of tabular/lath like

Table 6.3 selected SEM-EDS phase analyses from the Stepnoye and Ust'ye slag

Site	Sample	Spec.	Area	MgO	Al_2O_3	SiO_2	P_2O_5	CaO	TiO_2	Cr_2O_3	MnO	FeO
Stepnoye	64	2	Silicate	22	n.d.	34.2	n.d.	0.2	n.d.	n.d.	n.d.	43.2
Stepnoye	x1	3	Oxide	n.d.	14.8	1.0	n.d.	n.d.	0.8	n.d.	n.d.	81.6
Stepnoye	x1	4	Silicate	2.7	0.2	28.9	0.6	0.5	n.d.	n.d.	0.4	65.8
Stepnoye	x1	8(3)	Matrix	n.d.	14.7	39.2	6.3	10.8	n.d.	n.d.	n.d.	26.1
Ust'ye	5076	1	Silicate	4.5	0.8	31.9	0.5	0.3	n.d.	n.d.	0.3	61.5
Ust'ye	6452	1	Oxide	0.4	3.2	1.0	n.d.	0.5	0.5	n.d.	n.d.	94.4
Ust'ye	5076	2	Matrix	n.d.	0.6	17.9	48.5	4.8	3.7	0.7	n.d.	0.1

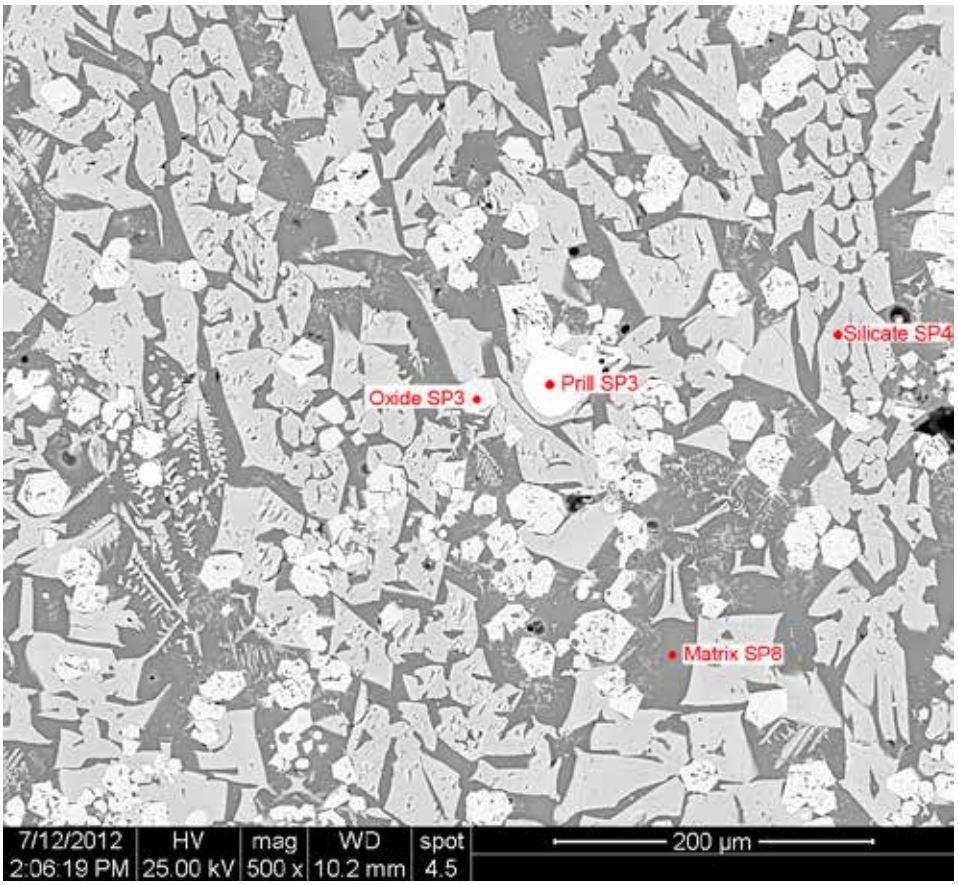


Figure 6.11 Step09 x1 showing locations of analysis and the main slag phases, magnetite (white, angular), fayalite (mid grey) and glassy matrix (dark grey).

structures identified optically. Indeed analysis of the tabular silicates confirmed that they were typically higher in magnesia. This is interesting as the hotter forming, forsterite rich silicates would ordinarily be expected to cool quicker than the fayalites, forming lath-like structures. It is possible that the peak temperature was reduced slower or held for longer at the point of solidification, giving time for the tabular silicates to form.

Iron Oxides

Analysis of oxide phases in the Stepnoye and Ust'ye slag (Appendix C and Table 6.3) showed that the dominant oxide was iron oxide. Many of the phases contained up to 18% Al_2O_3 which was likely substituted with some of the trivalent iron oxide. High instances of Al_2O_3 correlate with spinel forms and were not noted in dendritic oxides (Figure 6.11). This is consistent with the spinel group which is typically the first phase that crystallizes during the smelt (Bachmann 1982). The high quantities of Al_2O_3 substitution, and therefore trivalent structures, supports the results of the optical

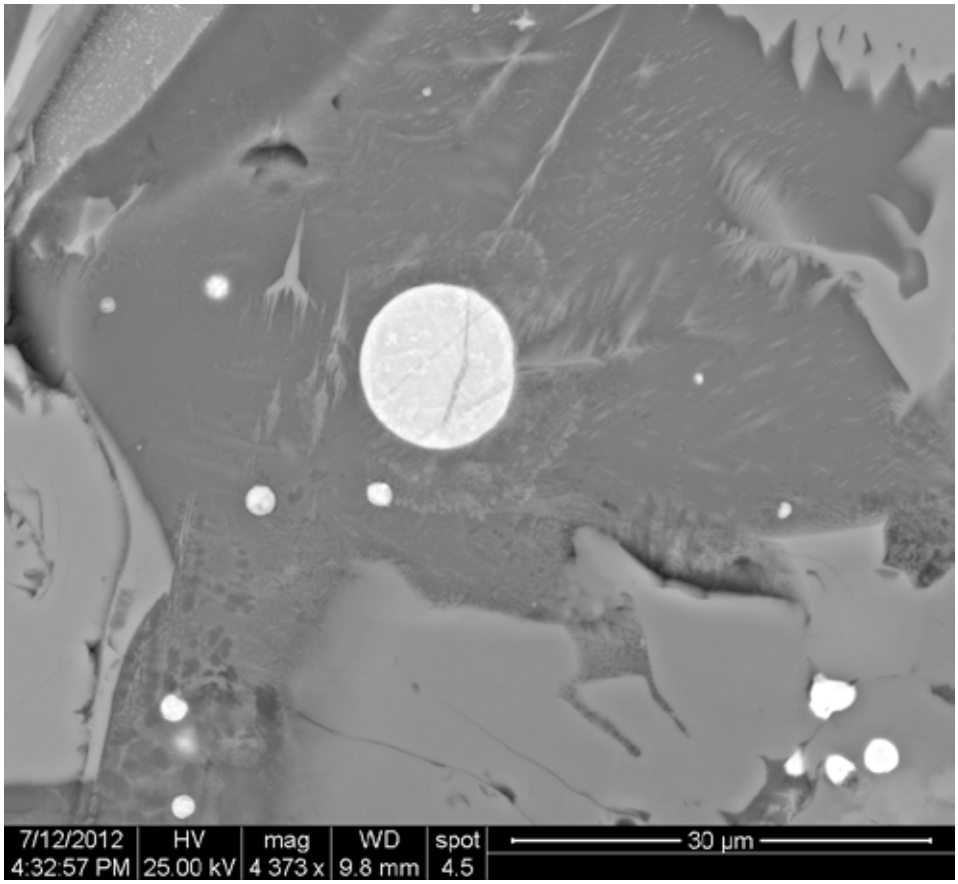


Figure 6.12 SEM Micrograph of a high sulphur copper prill in sample STEP09-1 (spectrum 2).

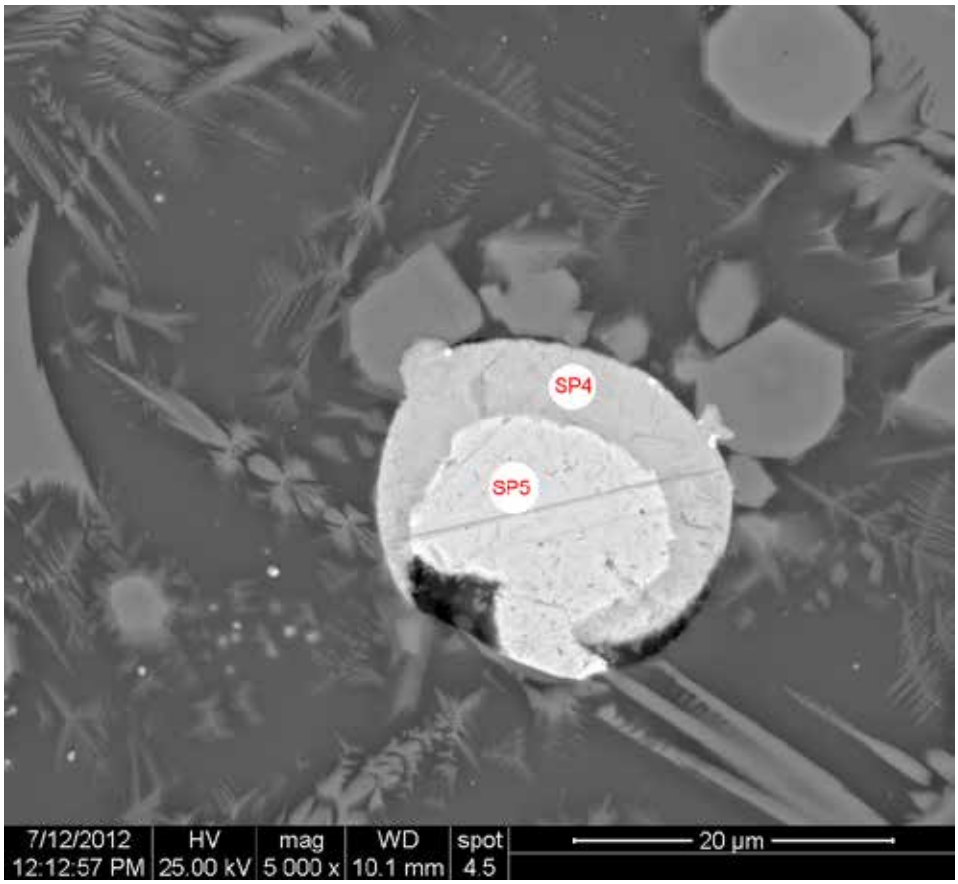


Figure 6.13 Micrograph of a copper prill and associated sulphide halo in sample STEP09 105.2

Table 6.4 selected spot analysis of copper prills

Site	Sample	Spec.	S	Fe	Ni	Cu	As	Sn
Stepnoye	105.2	4	20.6	3.8	n.d.	74.4	0.1	n.d.
Stepnoye	105.2	5	0.2	2.6	0.1	95.6	1.2	n.d.
Ust'ye	3290	1	n.d.	2.7	n.d.	89.2	6.8	n.d.
Ust'ye	6452	1	n.d.	1.1	0.4	91.2	n.d.	7.1
Ust'ye	6452	2	n.d.	3.4	0.3	87.4	n.d.	8.5
Ust'ye	10007	1	0.07	3.9	1.3	94.0	0.5	n.d.
Ust'ye	10007	2	0.3	4.0	2.1	88.4	5.0	n.d.

Table 6.5 SEM-EDS analysis of chromite spinels in the slag (selected elements, %wt normalised)

Site	Sample	Spec.	MgO	Al_2O_3	TiO_2	V_2O_5	Cr_2O_3	FeO
Stepnoye	1	1	8.4	16.5	1	0.4	41.4	31.7
Stepnoye	32	1	0.3	1.7	n.d	0.2	51.5	40.4
Stepnoye	117	1	7.2	13.9	0.3	0.3	50	27.8
Stepnoye	117	2	7.8	14.1	0.2	0.2	49.1	27.3
Stepnoye	117	3	10.8	15.5	0.3	0.3	51.5	21.2
Stepnoye	117	4	7.5	11.6	0.2	0.3	54.8	24.3
Ust'ye	69	1	7.9	13.3	0.4	0.3	47.3	30.2
Ust'ye	69	2	8.7	14.5	0.3	0.4	48.1	28
Ust'ye	83	3	4.4	13.5	0.4	n.d	48.8	31.7
Ust'ye	83	1	9.9	14.6	0.2	n.d	53.4	20.6
Ust'ye	3290	1	12.3	16.8	0.4	0.2	50.6	19.4
Ust'ye	3290	2	8.5	16.5	1	0.4	41.5	31.7
Ust'ye	3290	3	11.3	16.5	0.3	0.2	51.7	19.4

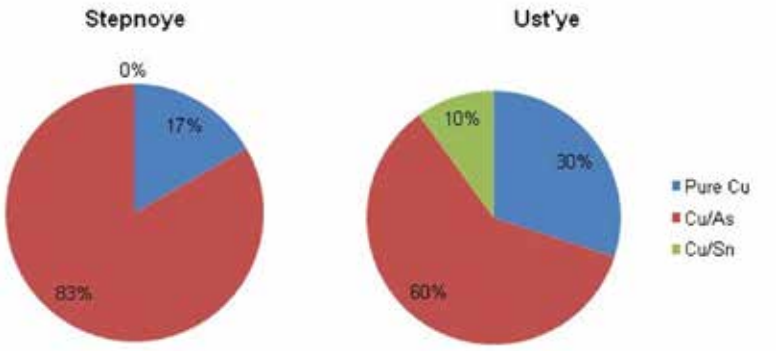


Figure 6.14 Ratios of copper alloy types identified in the analysis of copper prill embedded within slag.

microscopy which suggested the presence of spinel/isometric type phases (trivalent) in many of the samples which form in a mildly oxidising atmosphere and were particularly abundant in the Stepnoye slag.

Metallic inclusions

The typical composition of the metallic inclusions in the Stepnoye slag was 88% copper, 5% iron, 6% sulphur and 0.5% arsenic (Table 6.4). However, there was significant variation in all of the elements, with sulphur ranging from not detected to 20%wt, iron between 2 and 6%wt and arsenic as high as 2%wt. Some of the sulphur rich prills were multi-phased as is shown

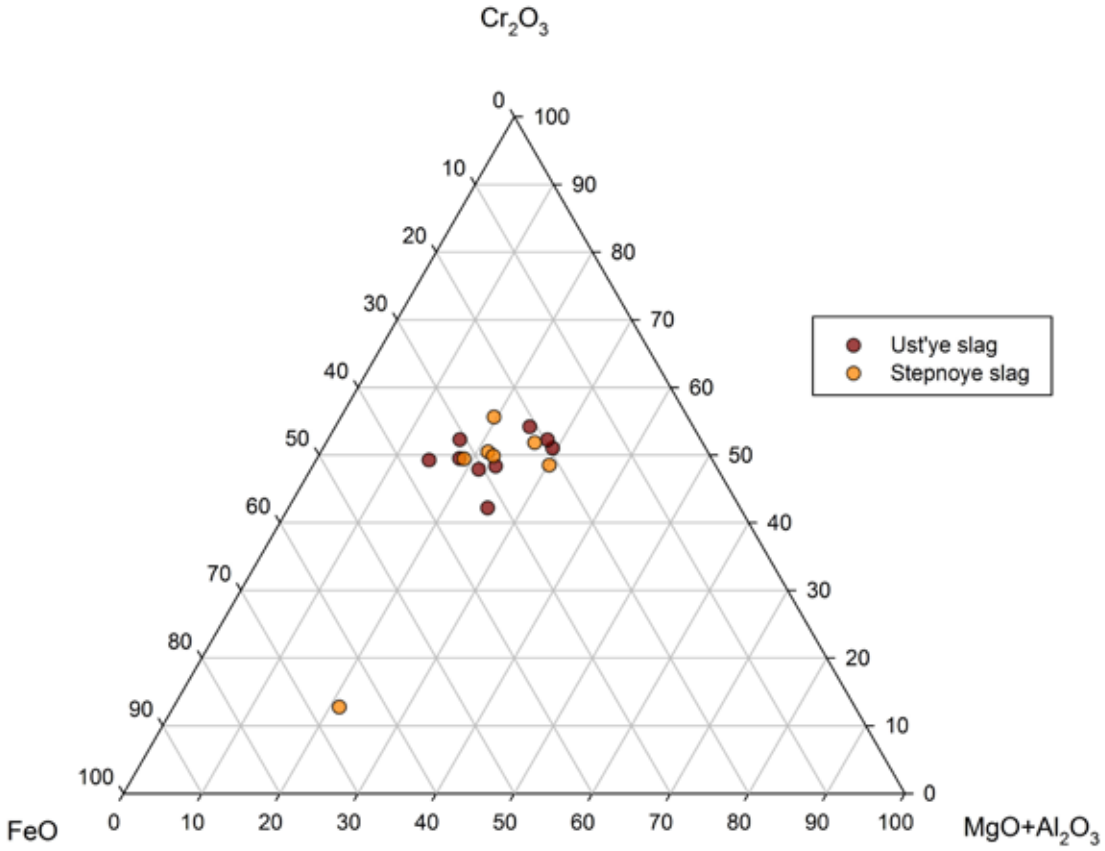


Figure 6.15 Ternary diagram showing the types of chromite spinel identified in the slag

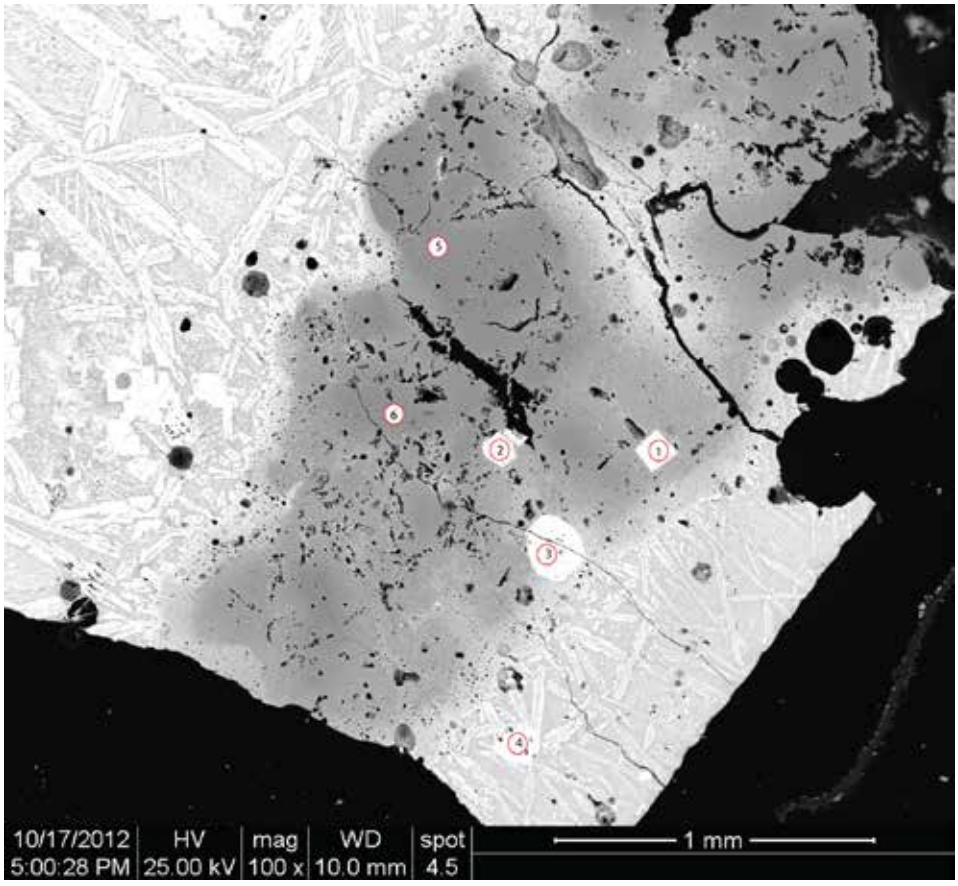


Figure 6.16 Electron micrograph of sample STEP09-117 showing a large talc inclusion and embedded chromite spinels.

Table 6.6 SEM-EDS analysis of the ore inclusions in the Ust'ye slag (%wt normalised)

Site	Sample	Spectrum	Al_2O_3	SiO_2	CaO	FeO	CuO	As_2O_3	FeS	CuS
Stepnoye	105.2	1	0.9	1.8	0.1	n.d.	n.d.	1.4	19.9	76.1
Stepnoye	105.2	2	0.1	0.3	0.0	n.d.	n.d.	0.2	15.8	83.6
Stepnoye	105.2	3	6.7	28.2	1.3	54.1	3.9	1.4	n.d.	n.d.
Stepnoye	105.2	5	7.2	20.9	0.9	63.1	3.9	1.8	n.d.	n.d.
Stepnoye	105.2	6	n.d	0.7	0.1	85.6	5.3	6.5	n.d.	n.d.
Ust'ye	77	1	2.4	3.0	0.1	2.0	91.0	n.d.	n.d.	n.d.
Ust'ye	77	2	26.2	38.8	0.7	13.7	14.5	n.d.	n.d.	n.d.
Ust'ye	77	3	21.7	50.1	0.5	10.2	10.9	n.d.	n.d.	n.d.
Ust'ye	77	4	2.4	2.7	n.d.	0.9	92.2	n.d.	n.d.	n.d.

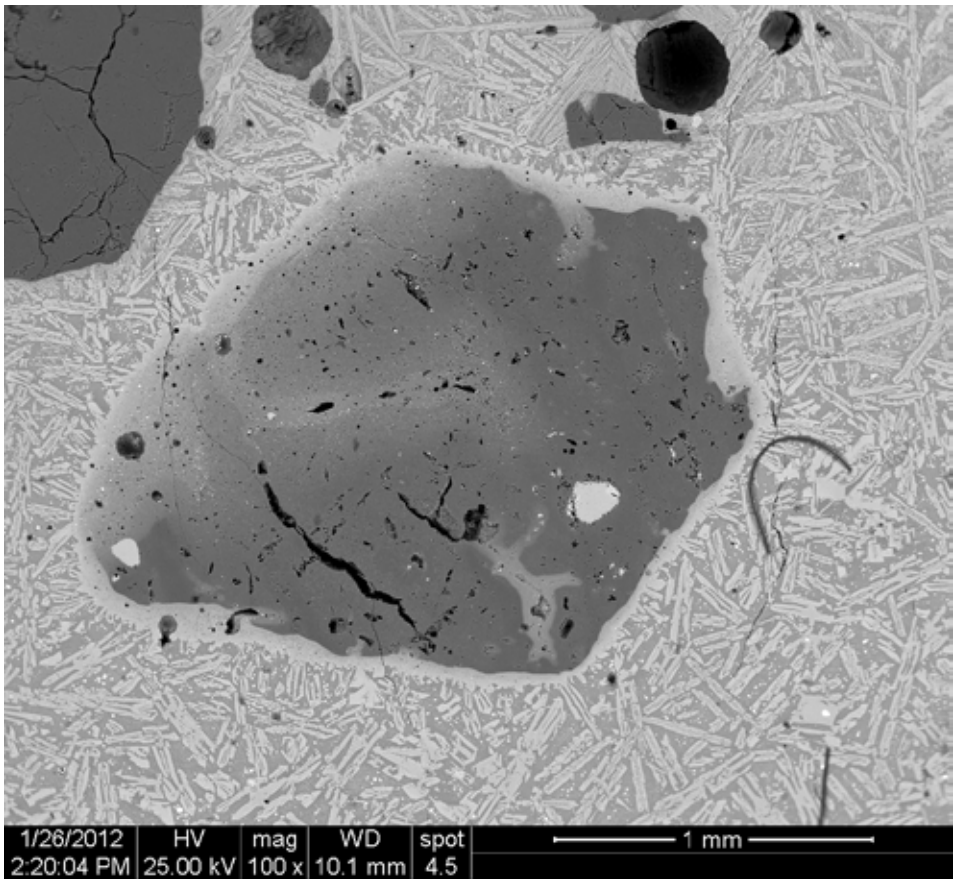


Figure 6.17 Chromite inclusions embedded in a talc inclusion in Ust'ye slag (light grey in main inclusion) in UST11 69 spectra 2

in Figure 6.12 and, in some cases, showing copper sulphide as a halo around a copper prill (Figure 6.13).

At Ust'ye copper sulphides were not identified. Iron was present in all of the samples ranging from trace amounts to, in one instance, 23%; however the average was less than 4%. There were three main types of prill; pure copper (with some iron), arsenical copper and tin bronze. By far the most common type was arsenical copper which was found in 21 analyses from 6 samples. Three samples (5 analysis) contained pure copper with only one sample containing tin (5 analyses) (Figure 6.14).

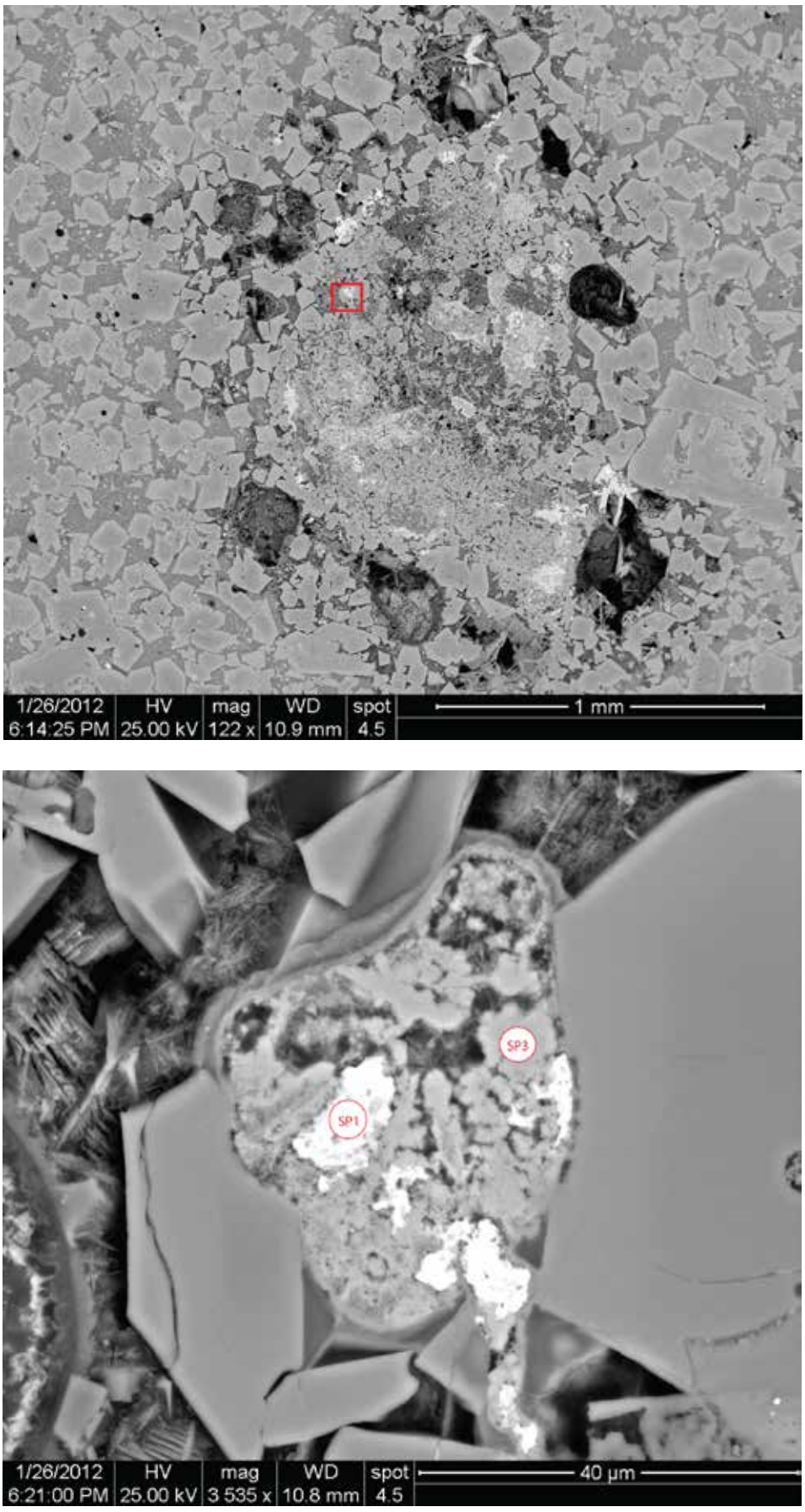


Figure 6.18 Micrograph showing the mineral inclusion in sample STEP09-105.2 (top) and he highlighted area (bottom which shows the locations of spot analysis.

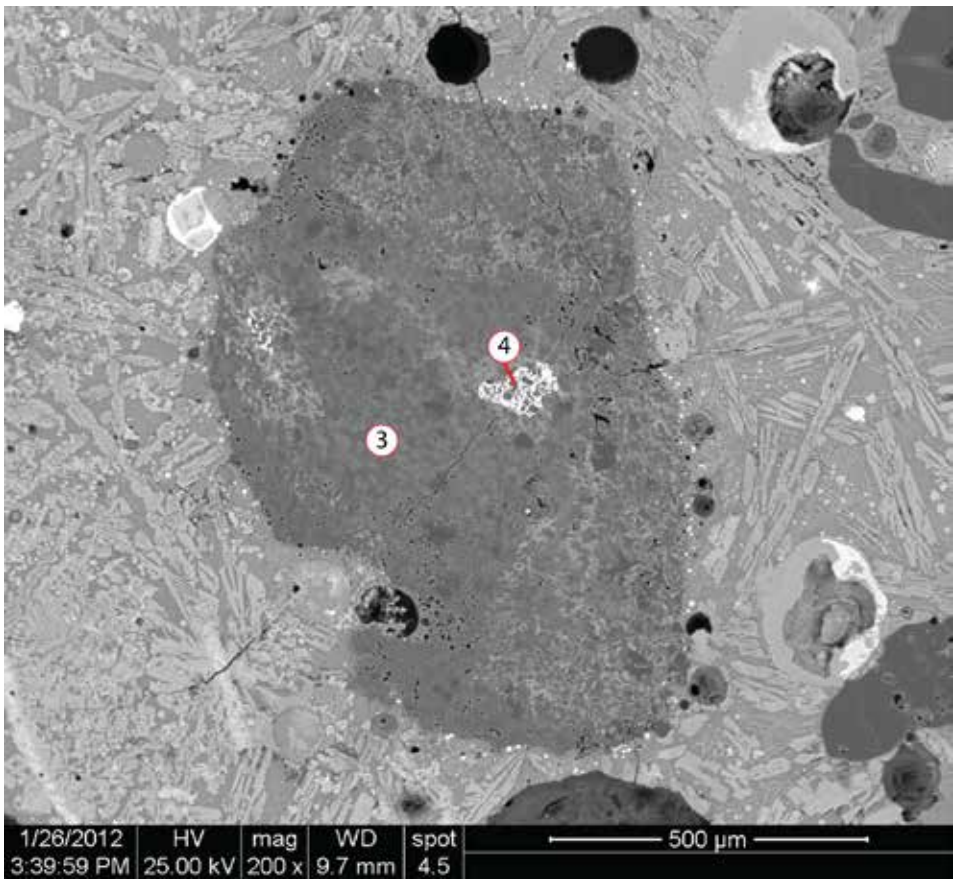


Figure 6.19 Showing a copper mineral inclusion in sample UST11-77 and the locations of spot analyses.

Chromites

The average composition of the chromites in the Stepnoye slag was 50% Cr_2O_3, 28% FeO, 12% Al_2O_3 and 7% MgO (Figure 6.15 and Table 6.5) which was broadly similar to the Ust'ye chromites (49% Cr_2O_3, 26% FeO, 15% Al_2O_3 and 9% MgO). Indeed the range of results was broadly similar between the two sites (Figure 6.15). While many of the chromites were discrete inclusions a number were found in association with other phases; three of the chromites analysed in STEP09-117 (Spectrum 1-3, Table 6.5) were found in, or in close association with a ceramic inclusion (Figure 6.16) and one of the inclusions in the Ust'ye slag was embedded within a talc inclusion (Figure 6.17).

Copper mineral inclusions

The analysis of the mineral inclusions in the Stepnoye slag confirmed the presence of copper sulphides (Figure 6.18). The composition of the sulphide phases was broadly consistent with the sulphide mineral bornite, however it is possible that the mineral had begun to be enriched in copper by the volatilisation/decomposition of some sulphur and iron being fluxed to the slag, as seen in the formation of iron silicates (Table 6.6).

Only one sample containing copper mineral inclusions was analysed form Ust'ye (UST11-77). Two of the inclusions were analysed in different spots (Figure 6.19). The most white, spectrum 4, contained almost pure cuprite, with only a small amount of silica (Table 6.5). The rest of the inclusion however consisted of a mixed copper silicate. It is likely, based on the reflected light microscopy, that this contained intergrowths of malachite (see above).

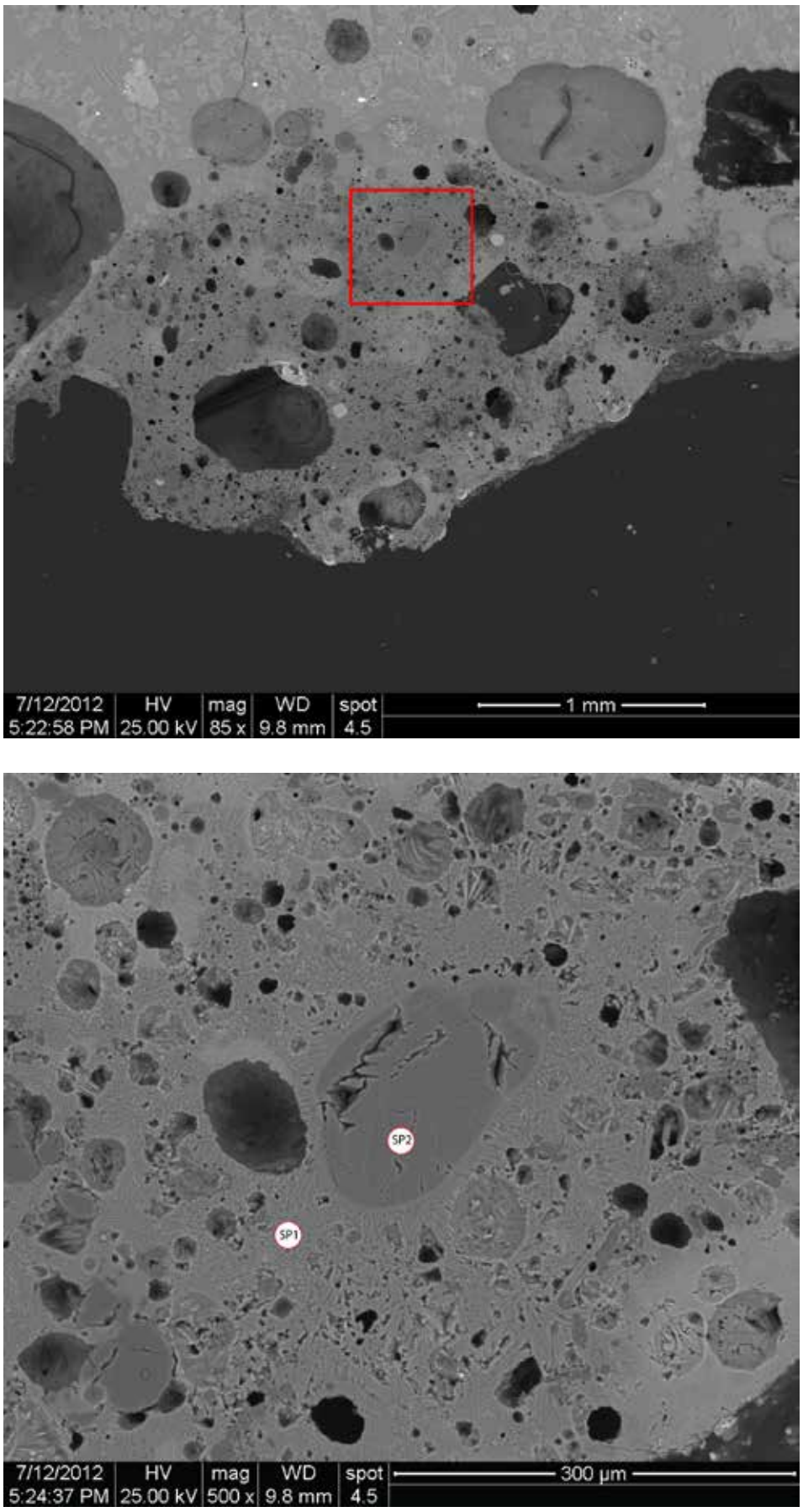


Figure 6.20 Showing an area of ceramic adhered to slag in samples STEP09-64 (top) and the highlighted area (bottom) is showing the ceramic microstructure and talc inclusions and the locations of spot analyses.

Table 6.7 Selected SEM-EDS analysis of some of the non slag incisions.

Site	Sample	Area	Spect.	MgO	Al_2O_3	SiO_2	K_2O	CaO	FeO	NiO	CuO
Stepnoye	64	Ceramic	1	4.9	5.8	54.8	2.7	11.5	18.7	n.d	n.d
Stepnoye	64	Talc	2	31.9	0.1	65	0.1	n.d	2.8	n.d	n.d
Stepnoye	1	Talc	1	31.8	n.d	64.9	0.1	0.1	3.1	n.d	0.1
Stepnoye	1	Talc	2	29.4	n.d	62.7	0.2	0.1	7.1	n.d	0.3
Stepnoye	117	Talc	5	39.2	0.5	49.7	n.d	0.3	8.3	0.7	1.1
Stepnoye	117	Talc	6	38.4	1.0	51.1	n.d	0.3	7.4	0.9	0.6
Ust'ye	69	Talc	2	45.3	n.d.	49.4	n.d.	n.d.	3.3	0.4	1.7
Ust'ye	77	Free silica	1	n.d.	n.d.	98.8	n.d.	n.d.	1.2	n.d.	n.d.
Ust'ye	77	Ceramic	1	n.d.	14.6	70.4	7.7	n.d.	7.3	n.d.	n.d.
Ust'ye	83	Talc	1	31.1	0.2	64.9	0.1	n.d.	3.8	n.d.	n.d.
Ust'ye	10007	Talc	1	42.5	0.6	45.9	n.d.	0.17	9.2	0.3	1.3
Ust'ye	10007	Talc	3	39.2	0.4	48	n.d.	0.23	5.8	0.4	6

Other inclusions

A selection of the other inclusions, which included ceramic, talc and free silica, were also analysed.

The ceramic inclusions appeared as glassy areas under reflected light, barely recognisable from the surrounding slag structure, but they were clearly identifiable with SEM. One sample containing ceramic was analysed from each site (Figure 6.20). Ceramic inclusions were identified both embedded into the slag matrix and on the edge of the samples. The SEM-EDS analysis of the individual phases of STEP09-64 can be seen in Table 6.7. The inclusions analysed within the ceramic were typical of a talc temper and the analysis of the body suggested a silica rich, calcareous clay mixture which is often found in metallurgical ceramics (Hein et al. 2007).

Talc inclusions were analysed in detail from three of the Stepnoye samples (STEP09 1, 64 and 117) and three Ust'ye samples. Analysis of the free silica inclusions during the programme of SEM revealed little beyond silica and iron, therefore only one detailed spectra was recorded (Table 6.7)

Matrix

The average composition of the slag matrix in the Stepnoye slag was 40% SiO_2, 30% FeO, 13% Al_2O_3 and 10% CaO. However, the CaO content varied significantly by sample from only 3% up to 15%. This was similar to the Ust'ye slag which had a typical composition of; 42% SiO_2, 31% FeO, 14% Al_2O_3 and 5% CaO (Appendix C). It is notable that while the Stepnoye slags had an absence of MgO in the matrix it was present in the Ust'ye slag up to 1.7%.

Micro x-ray fluorescence

Analysis by μXRF was undertaken to better understand the composition and distribution of inclusions, especially chromite, through the use of high resolution elemental mapping. One sample from each site was analysis using μ-XRF. The Stepnoye sample STEP09-131 was selected as it contained a cross section of all of the major slag attributes; an ingot impression, overspill, upper and lower surfaces and a small area that came into contact

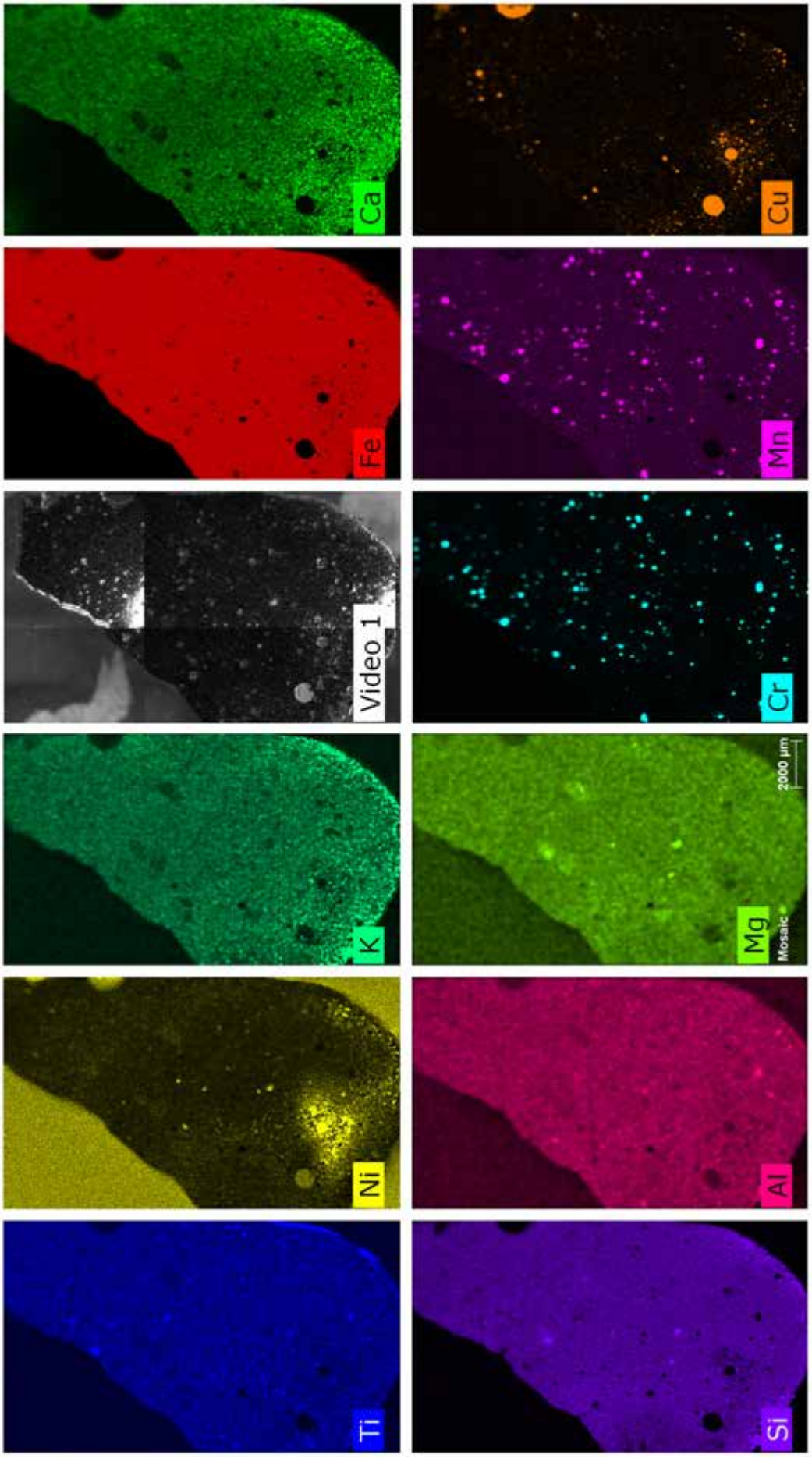


Figure 6.21 µ-XRF elemental maps of sample STEP09-131

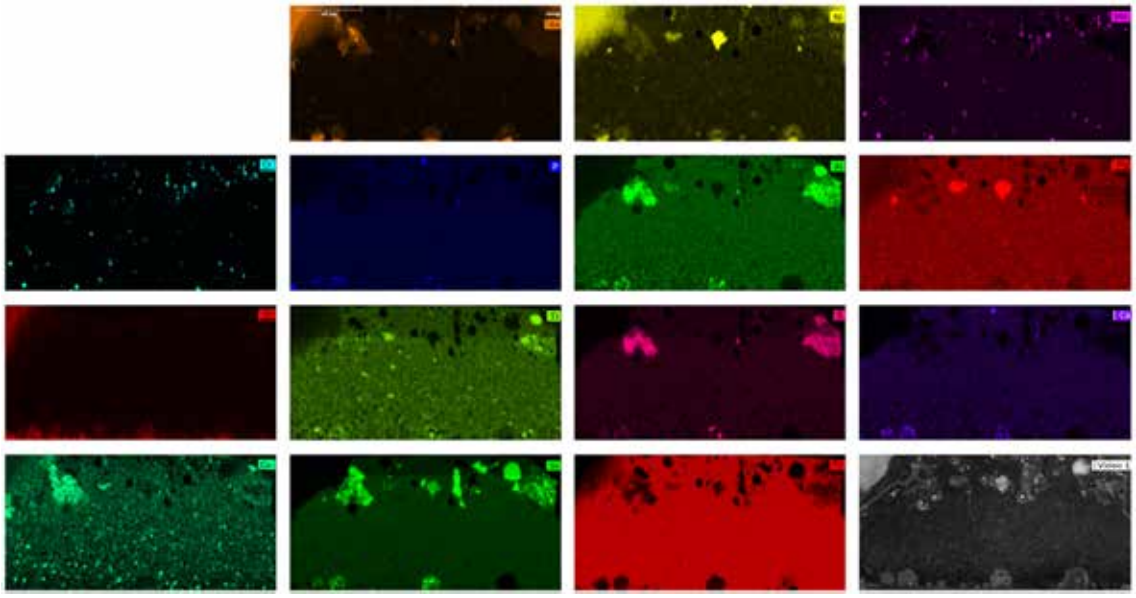


Figure 6.22 Individual elemental maps of sample 161y-3290 (the top of the sample is to the left).

with the ingot (Figure 6.21). Conversely, the sample from Ust'ye (161y-3290) was selected as it has likely formed over the centre of the ingot, rather than near the edge. Therefore it featured only the upper and lower surface of the slag (Figure 6.22)

The results from Stepnoye show heterogeneity within the sample with some elements, i.e. potassium, copper, calcium and nickel, concentrated towards the edge of the sample. This suggests that conditions across the slag were, as might be expected, non-uniform with the edge likely to be cooler and hence more viscous preventing the easy separation of copper from slag. Chromite distribution was also non-uniform with discrete clusters noted in regions of the sample with some suggestion that concentrations of high chromite were devoid of copper prills. The results from Ust'ye showed some heterogeneity with chromium concentrating near to the upper surface of the sample, and copper concentrating near to the lower surface. The other elements however concentrated within mineral inclusions, the main slag areas were fairly homogenous at this scale. The zoning of the copper is most likely caused as the liquid copper fell through the liquid slag to form the ingot.

6.1.3 Mineralogical analysis

Mineralogical characterisation was carried out using X-ray diffraction (XRD) in a total seven samples from Stepnoye and five from Ust'ye. All of the samples analysed were dominated by phases of the olivine group, most of which were fayalite, only two samples showed evidence for magnesium rich olivines (forsterite), however, the spectra for fayalite with low levels of magnesium replacement are very similar to those of pure fayalite (Table 6.8).

The samples from Stepnoye were much higher in iron oxides, in the form of magnetite and wüstite, than the Ust'ye slag where they were present in only one sample. Only one sample from Stepnoye contained free silica whereas it was present in all of the Ust'ye samples in the form of quartz, crystoballite and stishovite. The presence of such high concentrations

Table 6.8 Semi-quantitative results of XRD analysis of slag form Stepnoye and Ust'ye.

Site	Sample	Fayalite	Quartz	Cristoballite	stishovite	Magnetite	Wüstite	Iron Aluminium Oxide	Magnesium Iron Oxide	Magnesium Aluminium Oxide
Stepnoye	STEP09 23	●●●●						●	●	
Stepnoye	STEP09 57	●●●●				●				●
Stepnoye	STEP09 64	●●●●				●	●			
Stepnoye	STEP09 104	●●●●				●				
Stepnoye	STEP09 105	●●●	●●							
Stepnoye	STEP09 117	●●●●				●				
Stepnoye	STEP2 220	●●●●						●		
Ust'ye	UST11 8	●●●	●●		●					
Ust'ye	UST11 62	●●●	●●			●				
Ust'ye	UST11 64	●●	●●●	●						
Ust'ye	161y 10007	●●●	●●							
Ust'ye	161y 10379	●●	●●	●				●		

Table 6.9 The key advantages and disadvantages to the bulk analytical techniques employed.

Technique	Advantages	Disadvantages
pXRF	- Rapid analysis of a large sample	- no sodium
	- good for transition metals	- poor for light elements
	- good for trace elements	- can be impacted by surface topography
	- little or no sample prep	-analysis near surface only
SEM-EDS	- good check on XRF	- poor with minor and trace elements
	- can avoid unrepresentative areas of the samples	- small beam size
		- analysis near surface only
PGAA	- true bulk analysis of all of the sample	- poor with some elements (such as Pb)
	-good for rare earth elements	- not many facilities exist
	-good for selected light elements (such as boron)	- slow sample times

of quartz in slag is indicative of a mix that has an excess of silica, low firing temperatures or a mixture of both (Bachmann 1982).

6.1.4 Bulk chemical analysis

Bulk analyses were produced using three complimentary analytical techniques; the main programme was carried out using x-ray fluorescence (XRF), with a subsample subjected to prompt gamma activation analysis (PGAA) and SEM-EDS. The advantages and disadvantages of the techniques are outlined in Table 6.9.

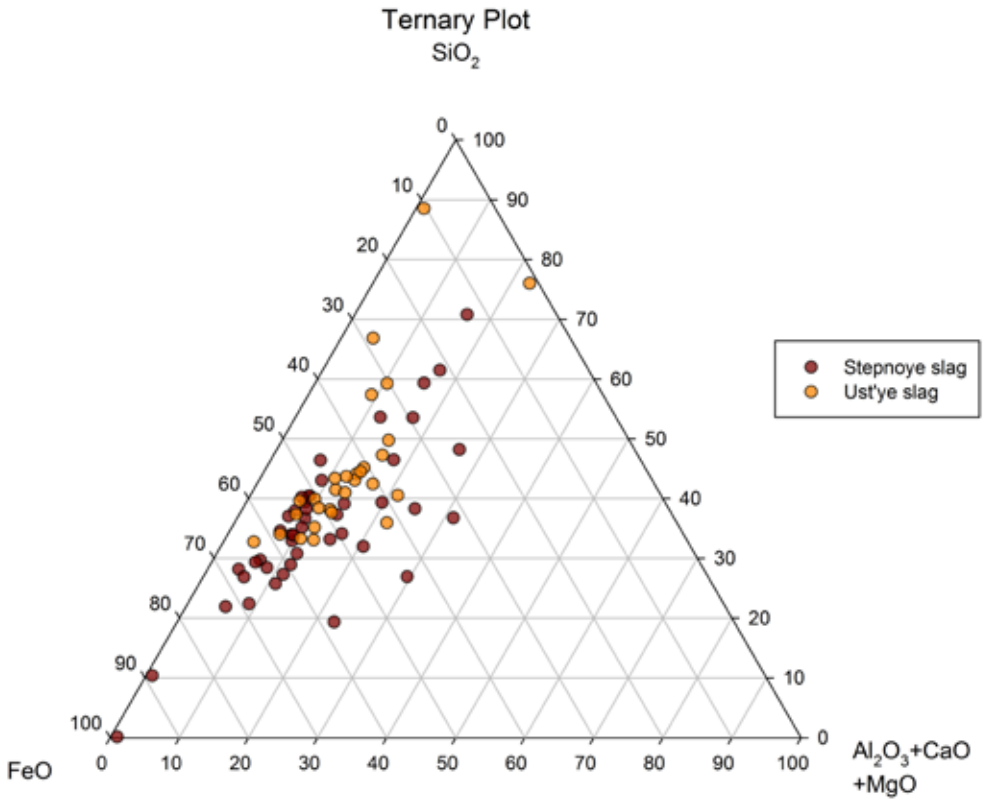


Figure 6.23 Ternary diagram showing the ratios of major elements in the Ust'ye and Stepnoye slag (pXRF)

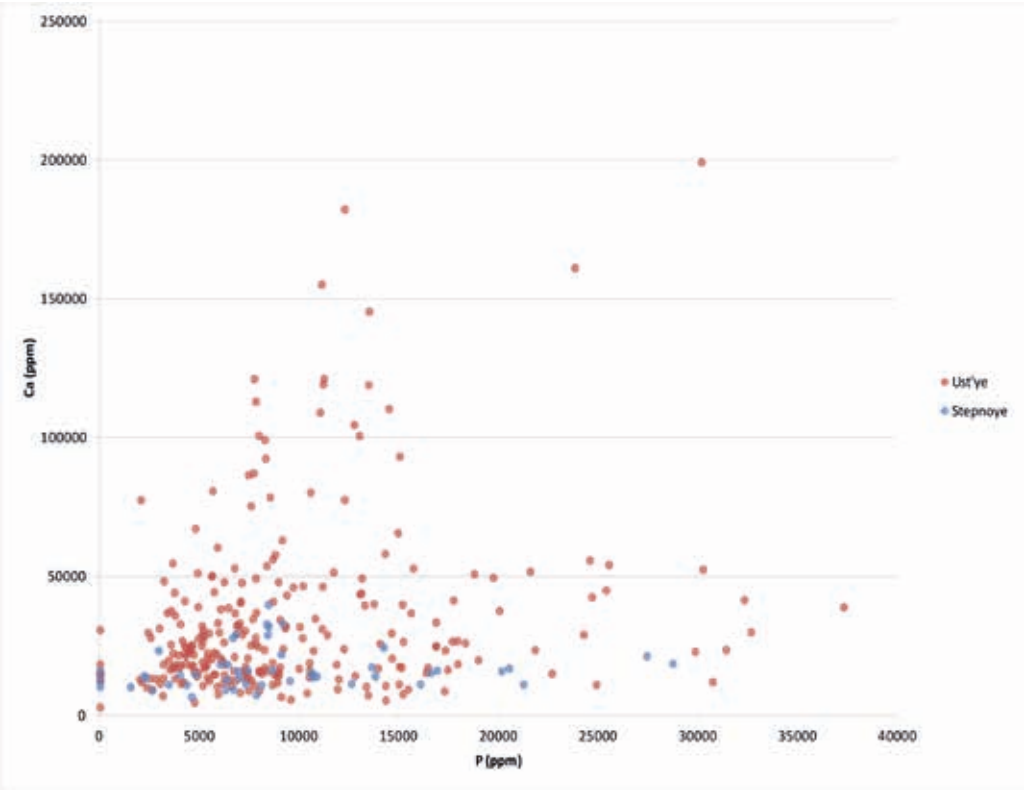


Figure 6.24 Shows the P:Ca ratios from selected data drawn from the Chelyabinsk series of analysis

pXRF

Analysis using portable x-ray fluorescence (pXRF) was carried out in two discrete programmes. The first programme, carried out in Chelyabinsk, analysed over 200 slag samples. The second programme, carried out in Sheffield, analysed all of the polished and prepared samples (47 from Stepnoye and 44 from Ust'ye) . The latter programme had the benefit of presenting a perfectly flat surface for analysis which increased the precision of the analysis but also allowed the x-ray beam to focus on the core of the samples, avoiding any potential problems due to corrosion or surface effects. The full analytical protocols can be seen in the methods outlined in appendix A. Initially the analysis form Stepnoye and Ust'ye were divided by excavation context to identify any discernible difference in slag between the different areas of recovery. It is apparent that through the compositions of the major elements, Fe, Al, Ca and Mg and Si, it is not possible to differentiate easily between Ust'ye and Stepnoye slags although it is apparent that Ust'ye slags are generally richer in Si. Figure 6.23 shows a comparison in major element ratios between the two sites. While the major elements were broadly comparable between the two sites, minor elements and traces do allow a higher degree of segregation. Perhaps the most significant difference overall is the higher occurrence of sulphur in the Stepnoye samples. This correlates with the heightened presence of copper sulphide phases noted microscopically. Nickel was also noted in more of the samples from Stepnoye than Ust'ye.

The similarities between the major composition, and correlation in some major and minor constituents was noted in the Chelyabinsk series of data. The variation was most notable in the concentration of calcium and phosphorus (Figure 6.24). The correlation between the two elements in the Ust'ye data forms two groups, one with a steep correlation and one

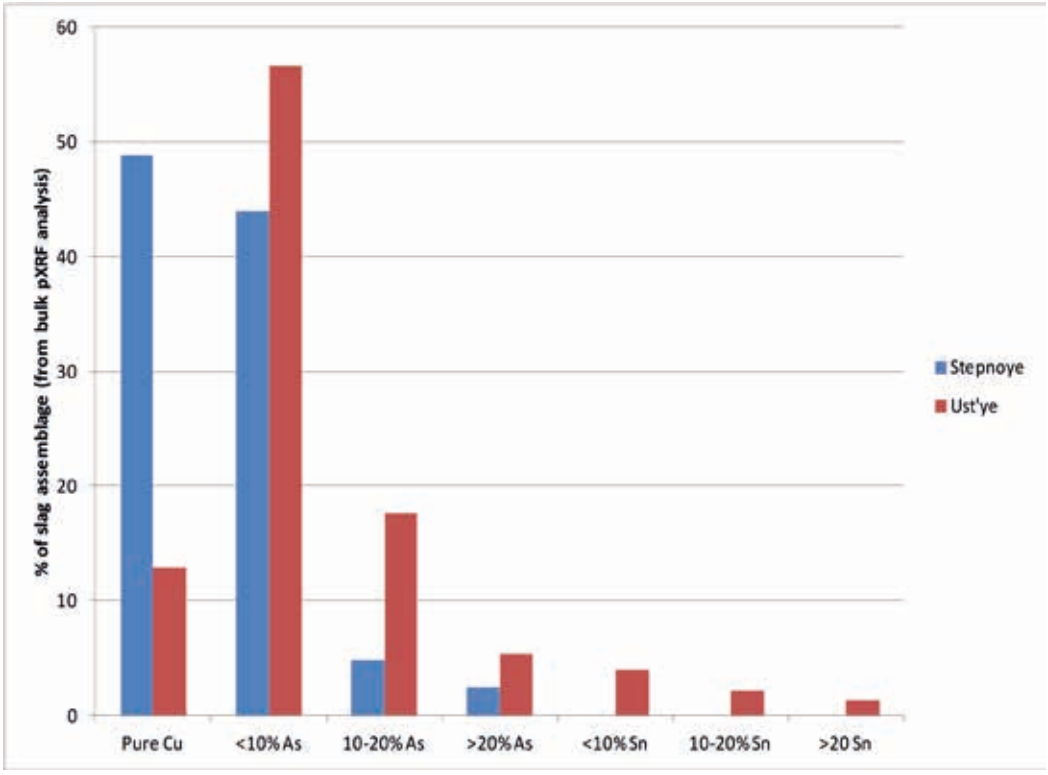


Figure 6.25 Inferred alloy types extrapolated from normalised copper/arsenic ratios in Stepnoye and Ust'ye slag (Normalised to percentages to account for the difference in sample count)

lower whereas the Stepnoye data only forms a lower correlation. The range of calcium in the Ust'ye slag was much greater than at Stepnoye with the majority of the Stepnoye slag containing less than 2% Ca whereas half of the Ust'ye slags were over, with many between 5 and 10%. While the difference is not enormous it does suggest that the charge used at Ust'ye may have been richer in calcium. The fact that the higher calcium correlates with a rise in phosphorus may suggest that it was derived from the addition of bone (Hauptmann 2007), however no bone was identified in the slag microscopically to this is only one possibility. If bone was used it is significant, as Karageorghis and Kassianidou (1999) note that bone ash could be used as a deoxidising agent.

A specific question regarding metal production is whether alloying took place during primary production or at a later stage. Therefore the presence of the typical Bronze Age alloying elements, particularly arsenic and tin, is an important consideration. The analysis of the slag from Stepnoye did not identify any tin, yet over half of the material analysed contained traces of arsenic from 70ppm to 1% in the bulk slag. In contrast some of the Ust'ye samples did contain tin, but by far the majority of the samples contained arsenic. During the Chelyabinsk series of analysis tin was noted in over 8% of the Ust'ye assemblage.

The relative quantities of copper and arsenic in the slag were extracted and normalised to produce hypothetical alloy types, these were broken up into broad categories of pure copper (where As and Sn were not detected), <10% As, 10- 20% As, >10% As, <10% Sn, 10-20% Sn and <20% Sn. The results of which have been plotted in Figure 6.25.

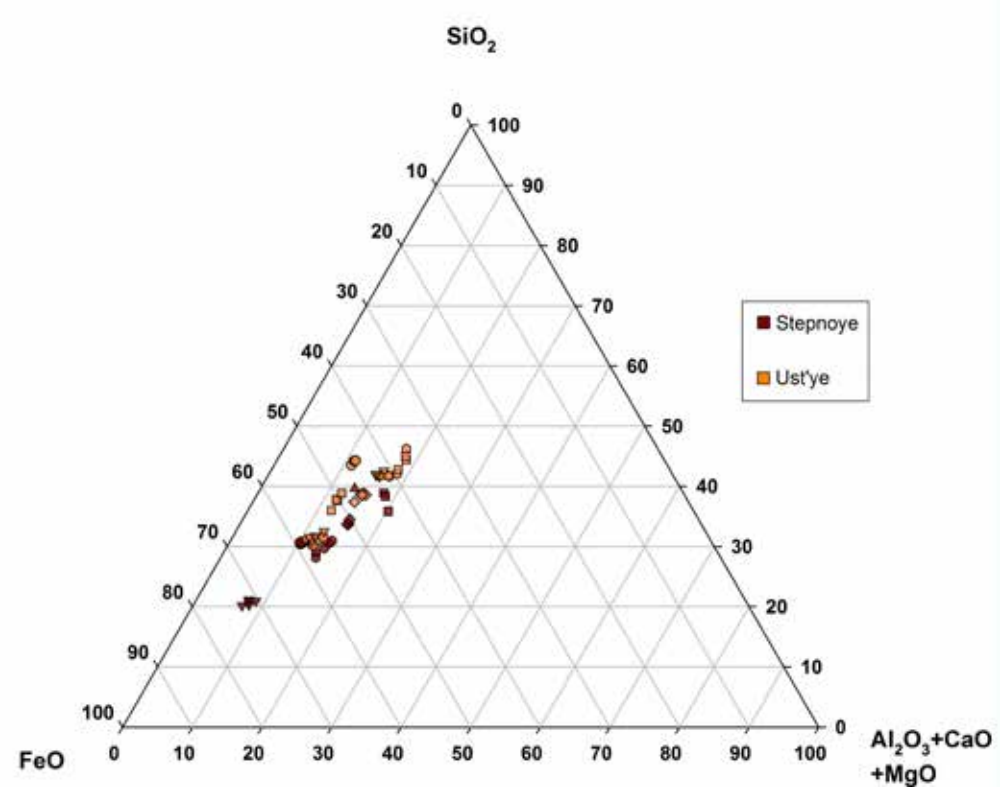


Figure 6.26 Ternary diagram showing the internal variation of bulk analysis of the slag form Stepnoye and Ust'ye (individual samples in different shapes).

The ratios suggest that the slag from Stepnoye was derived from the production of either pure copper or arsenical copper while arsenical copper is the dominant alloy type at Ust'ye. Although drawn from a larger dataset, these hypothetical alloy ratios correspond well with the analysis of metal prills using SEM-EDS.

SEM-EDS

Bulk analysis using SEM-EDS was undertaken at a uniform magnification with the beam height adjusted to scan a wide area of ~600µm. SEM-EDS was primarily used to corroborate the other bulk analyses and importantly could be used to ascertain bulk composition of slags in areas that did not include unrepresentative inclusions such as ceramic, ore or rock fragments. Multiple bulk analysis were taken at various places throughout the samples in order to asses internal variation and to compare the overall composition with the other bulk analytical techniques (see appendix C for micrographs of the areas analysed).

The results from Stepnoye and Ust'ye were largely congruent with the other bulk analysis. Like the other analyses there is significant range within the assemblage with the Ust'ye slag being slightly more silica rich that the Stepnoye slag. The overall high silica content is noteworthy as free silica incisions were avoided where possible. This is consistent with the overall higher occurrence of silica noted in the other programmes of analysis outlined in later sections and supports the likelihood of a silica heavy flux/gangue. The range noted between the samples however, was not reflected within them which, overall, show a broad homogeneity (Figure 6.26). This suggests that there was little bulk variability throughout the samples.

PGAA

Prompt gamma activation analysis (PGAA) was applied to a selection of slags form Stepnoye and Ust'ye because its sensitively to boron is far greater than pXRF. This is of considerable value in the context of the Southern Urals due to the presence of regionalised tourmaline geology which is rich in Boron (Brown et al. 2006). Importantly boron was noted in significant quantities in slag analysed form Arkaim (Zaykov et al. 1999) which, in turn, necessitates the need to establish the presence absence in the assemblage studied here. A total of 12 samples from each site were analysed using PGAA. In terms of bulk chemistry the results are broadly comparable with the pXRF data (see correlation in Appendix A). Overall however, boron was low in the samples from both sites; typically less than 35ppm. Such minor traces are indicative of a non-tourmaline source for ore minerals.

In addition to boron, is interesting to note that the analysis identified gold in nearly all of the samples at around 60ppm[1]. This is significant as much of the region was exploited for precious metals in historic and early modern periods. It is likely that, if ancient miners were exploiting ores rich in precious metals comparatively near to the surface, those same deposits would have drawn the attention of more modern miners which would make identifying ancient copper mining problematic. The presence of gold in the Ust'ye slag is also significant as it was also identified in analysis of minerals form the nearest copper deposit (see mineral section later in the chapter).

1 - with a maximum concentration of 198ppm, if found in a mineral, would be economically viable in modern terms.

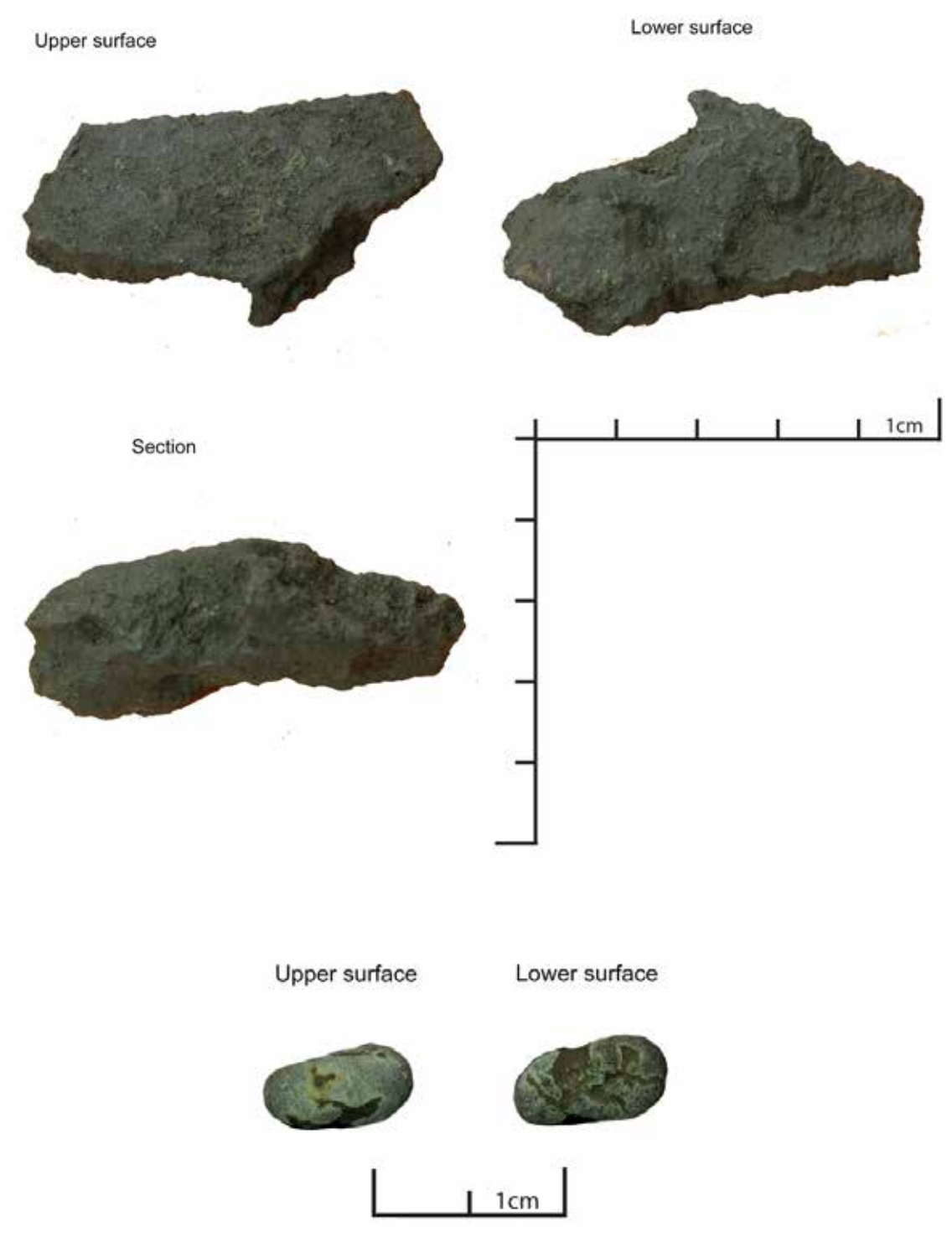


Figure 6.27 The copper ingot form Stepnoye (top) and the prill/droplet (bottom) in hand specimen.

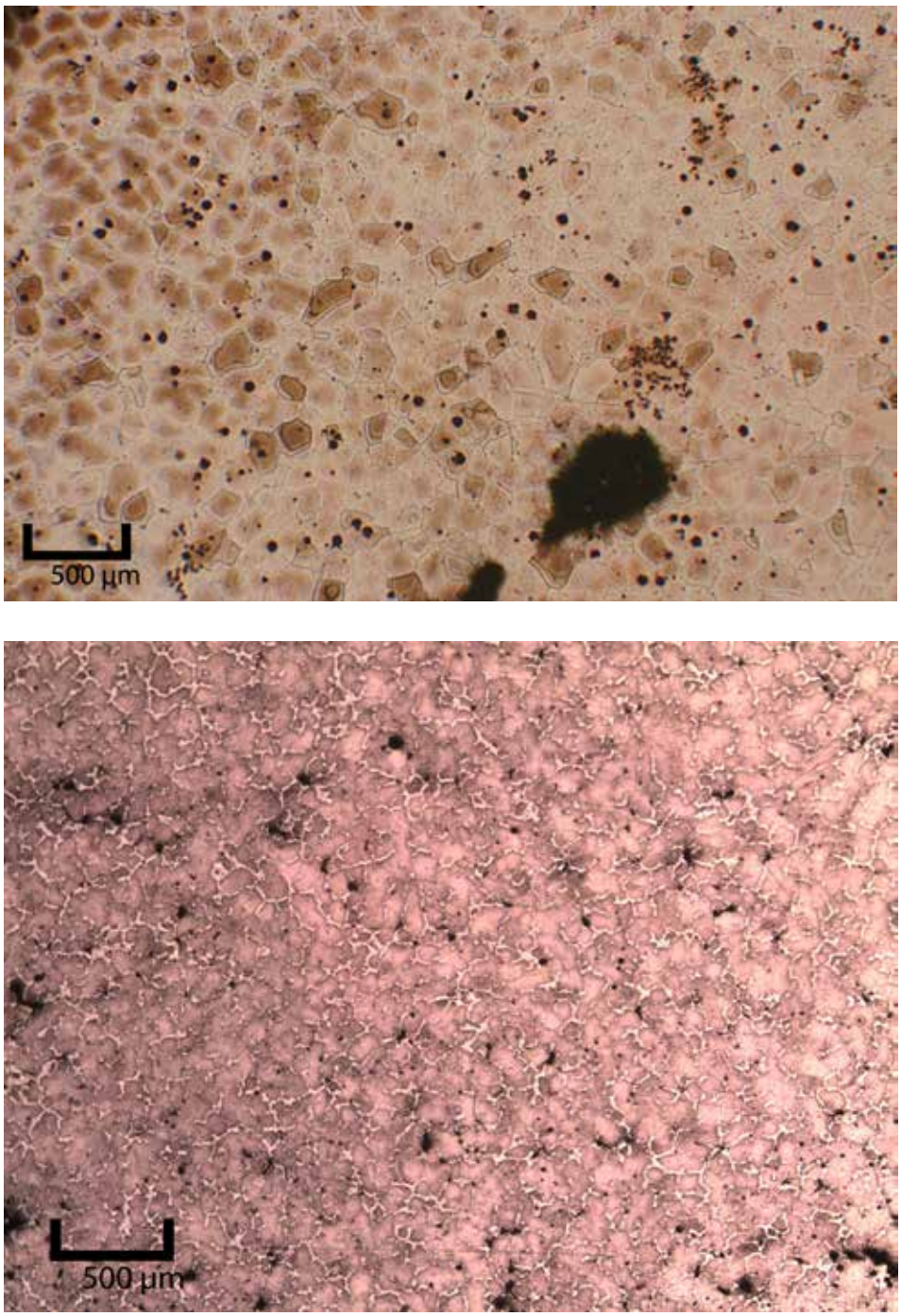


Figure 6.28 Etched reflected light micrograph of the ingot (top) showing the equi-axed grain structure and the prill (bottom) showing the slightly smaller grain size.

Table 6.10 SEM analysis of STEP09 89

Site	Sample	Spec.	S	Fe	Cu
Stepnoye	89	1	n.d.	3.2	96.8
Stepnoye	89	2	23.1	8	68.9
Stepnoye	89	3	33.3	8.7	57.9

6.2 Metallic copper

The excavations at Stepnoye recovered two pieces of primary metallic copper; an ingot weighing 53g, and a large c.2cm copper droplet both recovered from the main excavation trench.

6.2.1 Visual characterisation

The ingot, shown in Figure 6.27 retained fracture surfaces and was identified as a fragment of a larger piece. The upper surface was smooth while the lower was irregular. Based on the size of the fragment it was likely drawn from an ingot of around 4-500g. The shallow curvature of the underside suggests it was formed on a shallow, curving surface, similar to the plate identified at Ust'ye (see later). The droplet/prill was rounded with no angular features. It is likely that it ether formed within a slag, which was subsequently broke to remove it, or was spilled form a crucible or during a cast (Figure 6.27).

Table 6.11 XRF analysis of metallic copper samples

Site	Sample	Fe	Ca	Cu	As	Cl	Ni	Ag
Stepnoye	89	2.1	0.8	97.1	n.d.	n.d.	n.d.	n.d.
Stepnoye	216	n.d.	0.9	97.9	0.9	0.2	0.1	0.1

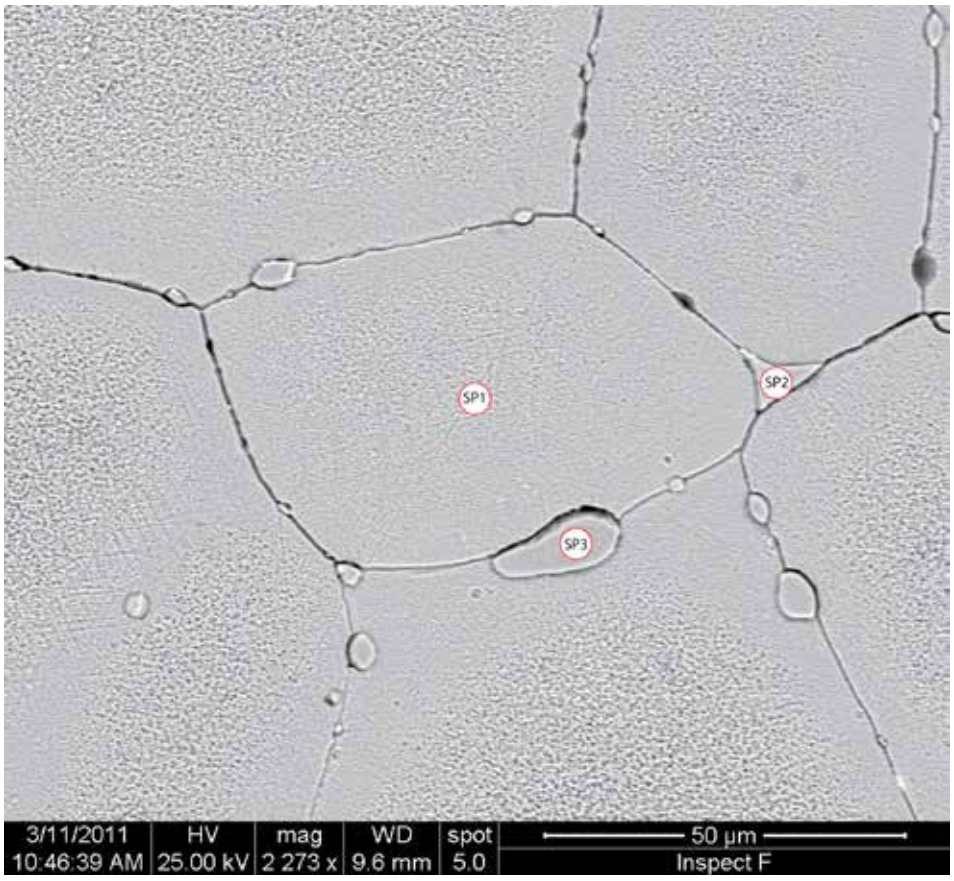


Figure 6.29 High magnification electron micrograph showing the grain boundaries in samples STEP09-89

6.2.2 Microstructural analysis

Microstructural analysis of the polished section of the ingot revealed a large equi-axed grain structure along with copper sulphide inclusions at the grain boundaries. The grains ranged in size form 75-120 μm. No dendritic structure was visible (Figure 6.28, Ottaway and Wang 2004). The prill was similar in micrustructure with had a broadly equi-axed structure (Figure 6.28). The grains were slightly smaller, between 50 and 60 μm. There was no evidence of worked structures in either the ingot or the prill.

6.2.3 Compositional Analysis

Chemical analysis of the ingot using SEM-EDS showed that it consisted of two phases, iron rich copper and copper iron sulphides (Figure 6.29 and Table 6.10). The analysis of the copper phase did not contain any arsenic, which is consistent with the pXRF analysis of the ingot. Chemical analysis of the droplet using pXRF showed that it was an arsenical copper alloy with no detectable iron. This would also suggest that it was derived from a later stage of smelting or secondary production due to the lack of iron content when compared to the ingot (Table 6.11). The presence of arsenic is also interesting as it was absent in the ingot while being present in much of the slag.



Figure 6.30 Copper minerals recovered from the Stepnoye excavations



Figure 6.31 Examples of Ust'ye copper mineral samples and their XRF numbers

6.3 Minerals

Mineral fragments were found at both sites, however significantly more were recovered during the Ust'ye excavations. Following an appraisal of the Stepnoye assemblage only six fragments of suspected ore were identified, two from the copper anomaly trench and four from the main excavation. In contrast over 250 fragments of ore mineral were identified during the original programme of excavation, with nearly 200 of these found in a single deposit; pit 17 in structure 10 (Figure 5.35).

6.3.1 Visual characterisation

All of the fragments from Stepnoye were small, c.2cm, but they were visually distinct from slag in that they had a more powdery appearance. The fragments appeared to have been heat altered (Figure 6.30). Two of the sampled pieces had a powdery blue/green appearance while the third (STEP09-83) had a deep red appearance, particularly on fresh breaks.

The majority of the ore fragments from Ust'ye were green in colour, with a smaller number of pale grey and deep red fragments. The fragments ranged in size from <5mm to over 50mm; although it is notable that the majority of the fragments are of a similar size, around 1-2cm. Figure 6.31 shows a typical range of fragments. The majority of the fragments are also homogenous, with little sign of gangue minerals or attached host rock which suggesting they were beneficiated.

6.3.2 Microstructural analysis

Three fragments from Stepnoye and four from Ust'ye were sampled and returned to Sheffield for detailed microstructural analysis. Samples were analysed both optically and using SEM-EDS.

Optical microscopy

In the analysis of copper ores, particularly secondary oxide and carbonate ores, optical microscopy is especially useful in differentiating between mineral types. This is because the spot and bulk analytical techniques applied during this project cannot quantitatively differentiate between oxides and carbonate ores. Therefore the mineral types were primarily characterised according to the optical properties set out by Ixer (2003) and Pracejus (2008).

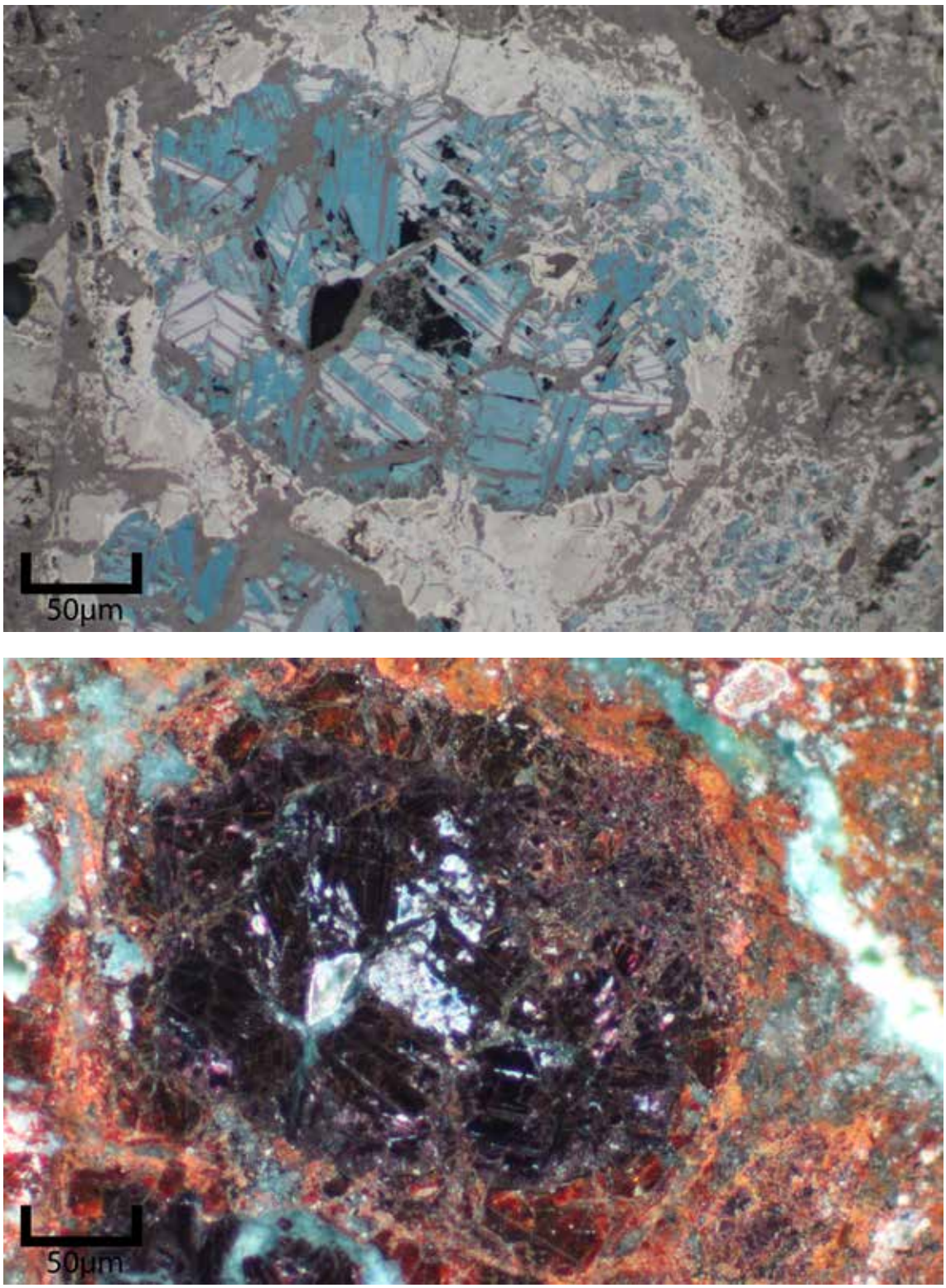


Figure 6.32 Optical micrograph showing the mixed sulphide (grey-blue, top) and oxide (red, bottom) microstructure of STEP09-180.

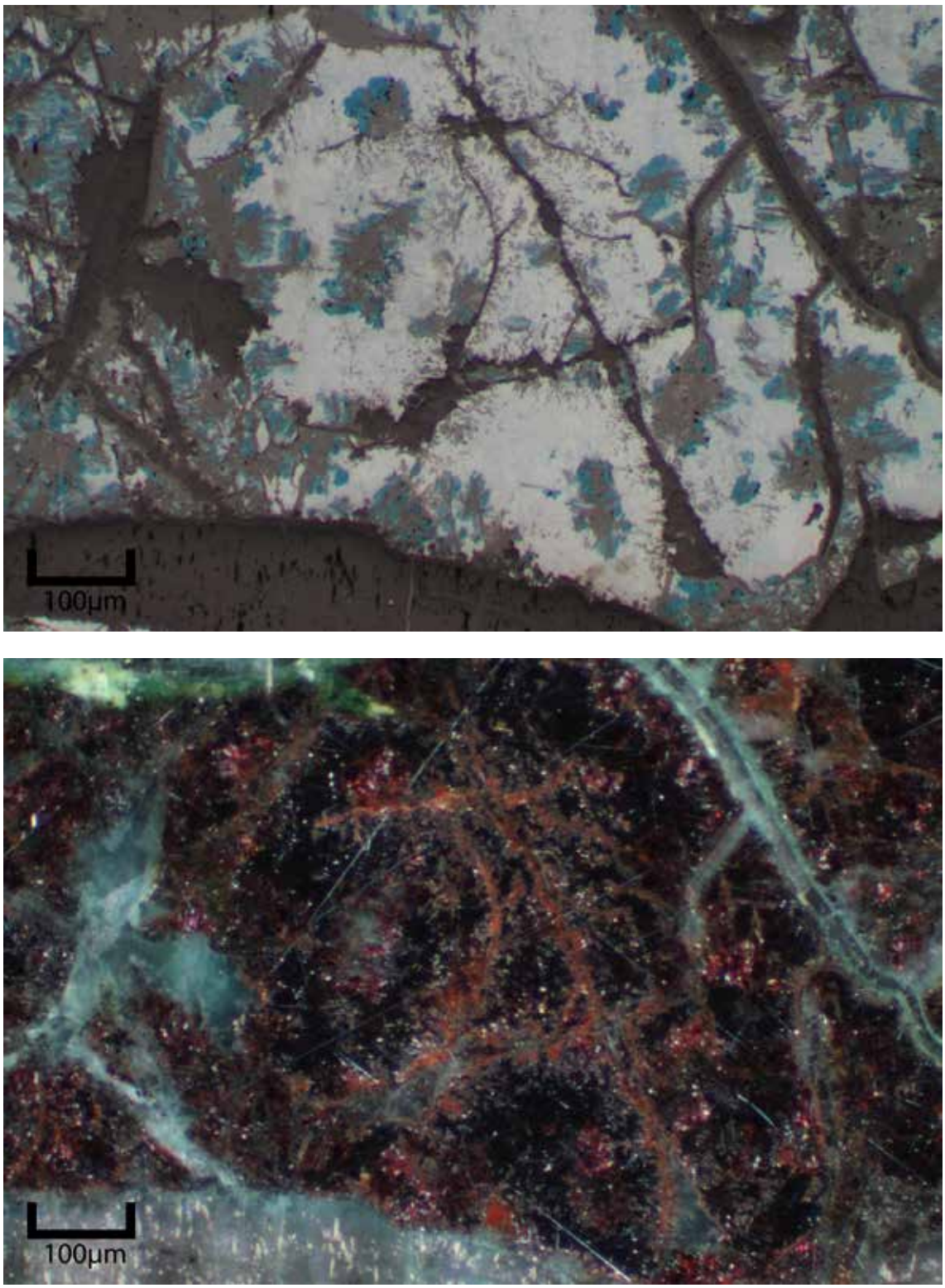


Figure 6.33 Optical micrograph of an Ust'ye mineral fragment showing the dominance of cuprite (grey top, and dark red, bottom)

The samples from Stepnoye (STEP09-128 and 180) were analysed using reflected light which showed clear copper sulphide inclusions that appeared a deep blue under bright field and had a strong reflectance under dark field (Figure 6.32). There were also inclusions which had strong red internal reflections. These characteristics are indicative of a mixed ore of cuprite and chalcocite or a semi-roasted sulphide ore.

The mineral fragments from Ust'ye contained a complex structure of intergrown copper oxides, carbonates and occasional sulphides. Figure 6.33 shows a typical example which features cuprite (blue top, deep red bottom), tenorite (light grey top, deep brown bottom) and malachite (dark grey top and rich green bottom).

Table 6.12 SEM-EDS analysis of ore minerals found (%wt normalised)

Site	Sample	Spec.	MgO	Al_2O_3	SiO_2	FeO	CuO	FeS	CuS
Stepnoye	128	3	n.d	n.d	n.d	n.d	n.d	0.7	99.3
Stepnoye	128	4	10.0	41.5	34.4	12.5	1.5	n.d	n.d
Ust'ye	pit2012	1	n.d	n.d	0.3	0.1	n.d	n.d.	97.4
Ust'ye	pit2012	2	n.d	n.d	1.5	2.5	94.6	n.d.	n.d.
Ust'ye	pit2012	3	n.d	n.d	0.4	0.6	97.3	n.d.	n.d.
Ust'ye	pit2012	4	n.d	n.d	0.3	1.1	97.1	n.d.	n.d.
Ust'ye	pit2012	5	n.d	n.d	11.1	3.1	21.2	n.d.	n.d.
Ust'ye	pit2012	6	n.d	n.d	97.9	0.1	1.1	n.d.	n.d.
Ust'ye	pit2012	7	n.d	n.d	9.2	2.5	28.5	n.d.	n.d.

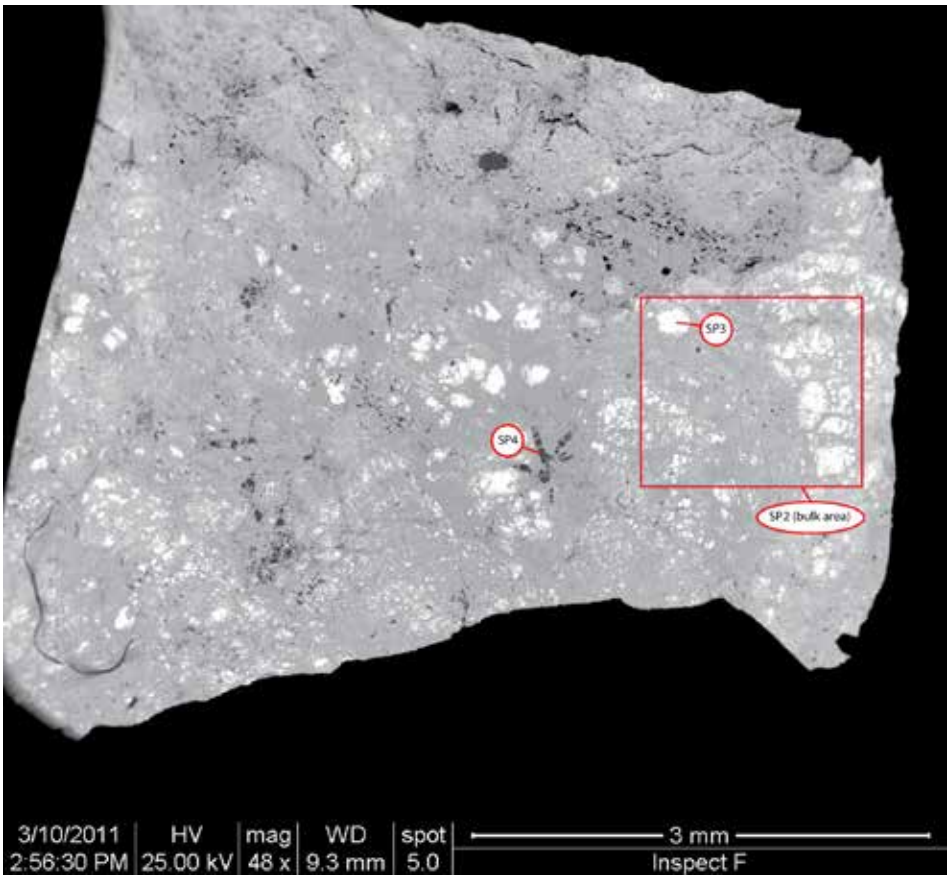


Figure 6.34 Electron micrograph ofSTEP-09 128 showing the location of spot analysis and the elemental map (figure 8.42).

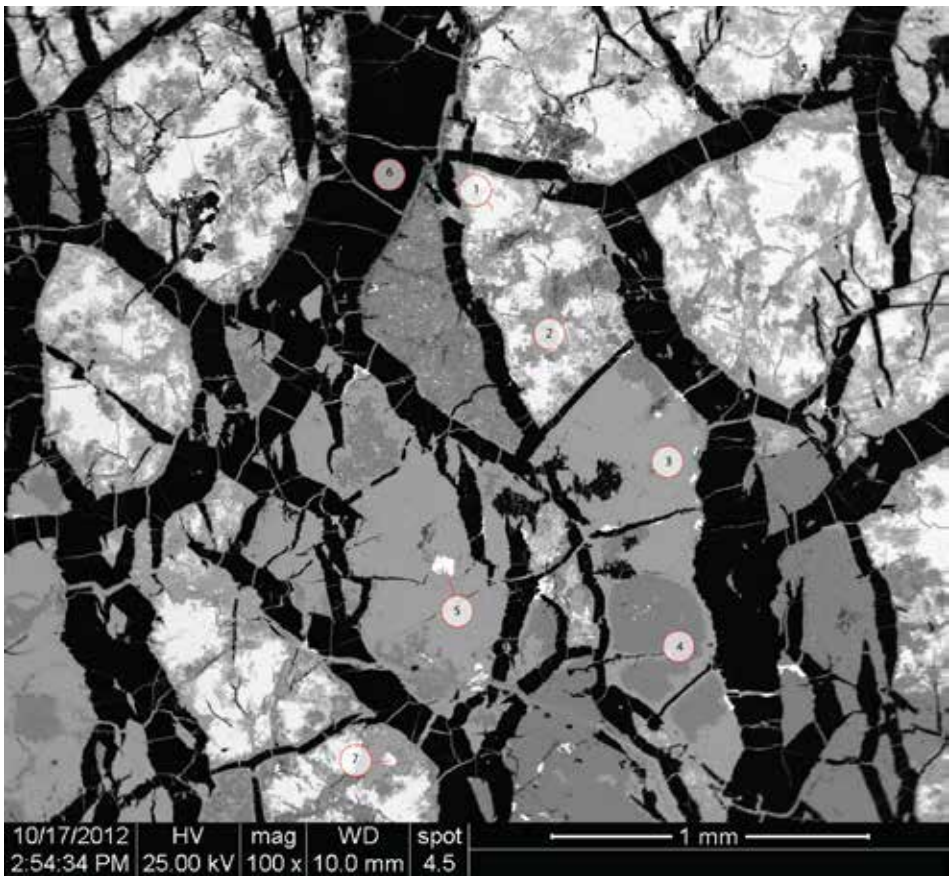


Figure 6.35 Electron micrograph from 161y-pit 2012 showing the locations of the spot analyses.

SEM-EDS

The presence of chalcocite and copper oxide minerals in the Stepnoye samples was confirmed using SEM-EDS (Table 6.11 and Figure 6.34).

Analysis of fragments form Ust'ye, such as the micrograph shown in Figure 6.35 confirmed the presence of high grade copper oxides and occasional copper sulphides (Table 6.12). The SEM also showed phases of pure silica within the sample. It is important to note that no chromite inclusions were identified in any of the sections. Indeed, beyond the various copper phases and free silica there were very few impurities

6.3.3 Bulk chemical analysis

Three samples from Stepnoye and 23 from Ust'ye were analysed using pXRF. The results from Stepnoye showed two different mineral types. Sample 83 contained only 2% copper and no sulphur, (Table 6.13). The other two minerals were high in copper with smaller amounts of iron and sulphur, as was suggested during the microscopy and phase analysis. It is notable that all of the samples contained trace amounts of arsenic, which could, at least in part, account for its presence in the slag and metalwork. However, the Cu:As ratio is relatively low in the main copper bearing samples.

The analysis of copper minerals from Ust'ye, shown in Table 6.12. These have very high concentrations of copper up to 72% CuO, along with varying amounts of silica, iron oxide and alumina. Unlike Stepnoye no arsenic was detected in any of the Ust'ye minerals.

Table 6.13 Selected pXRF analyses of ore fragments form Stepnoye and Ust'ye.

Site	SAMPLE	CuO	SiO_2	Al_2O_3	CaO	FeO	MnO	As_2O_3	FeS	CuS
Stepnoye	128	n.d.	0.4	n.d.	0.6	n.d.	n.d.	0.1	20.9	78.0
Stepnoye	180	n.d.	n.d.	n.d.	0.6	n.d.	n.d.	0.1	19.5	79.9
Ust'ye	Cu ore (pit)	59.8	24.2	n.d.	4.8	4.0	0.1	0.0	2.0	n.d.
Ust'ye	Cu ore (pit)	59.6	30.4	5.8	2.5	1.1	n.d.	0.0	n.d.	n.d.
Ust'ye	Cu ore (pit)	62.8	19.4	13.4	2.9	0.7	0.2	n.d.	n.d.	n.d.
Ust'ye	Cu ore (pit)	72.6	15.3	9.2	1.6	0.7	0.2	0.0	n.d.	n.d.
Ust'ye	Cu ore (pit)	40.7	14.3	6.0	3.0	34.6	0.1	0.0	0.5	n.d.
Ust'ye	Cu ore (other)	69.1	19.3	8.2	1.0	1.4	0.3	n.d.	n.d.	n.d.
Ust'ye	Cu ore (other)	49.0	29.7	11.8	2.4	4.6	1.0	n.d.	n.d.	n.d.
Ust'ye	Cu ore (other)	0.1	50.9	11.9	3.4	26.5	0.1	n.d.	5.0	n.d.
Ust'ye	Cu ore (other)	46.3	28.7	11.1	2.3	2.3	3.0	n.d.	2.2	n.d.
Ust'ye	Cu ore (other)	22.1	67.1	6.3	1.4	1.9	0.1	n.d.	n.d.	n.d.

Table 6.14 XRF analysis of selected ore samples from the Stepnoye surveys (selected elements).

SAMPLE	CuO	FeO	SiO_2	SO_3	CaO	MgO	ZnO	As_2O_3	MnO
sda4-1	51.3	0.1	47.8	0.1	n.d	n.d	0.6	n.d	0.1
sda4-1	41.3	0.4	56.4	n.d	0.1	n.d	0.6	n.d	0.1
sda 4-2	0.1	10.9	26.5	4.9	39.4	8.9	0.1	0.1	1.4
K-Lenin 2	33.9	11.9	0.3	51.8	0.1	n.d	0.2	0.2	n.d

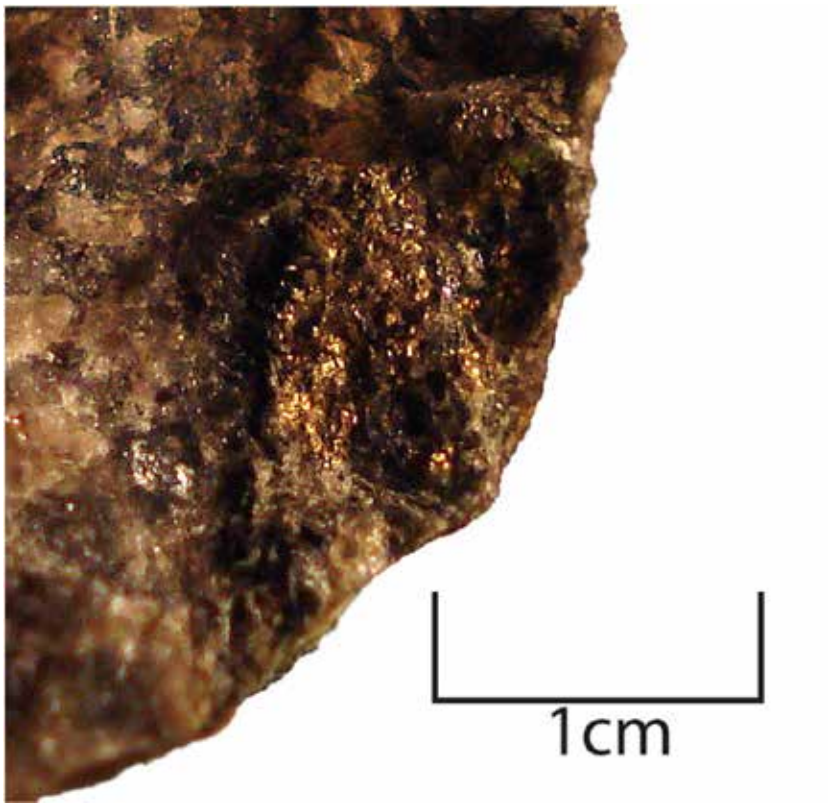


Figure 6.36 Macroscopic photograph of sulphide minerals on the surface of a sample from SDA.

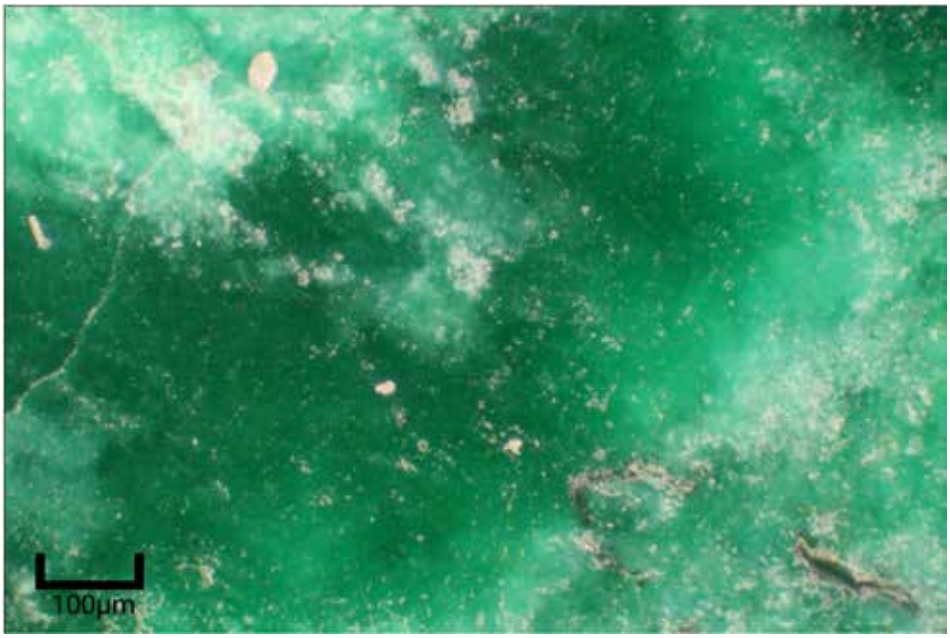


Figure 6.37 Optical micrograph of the ore sample from SDA (SDA4-1).

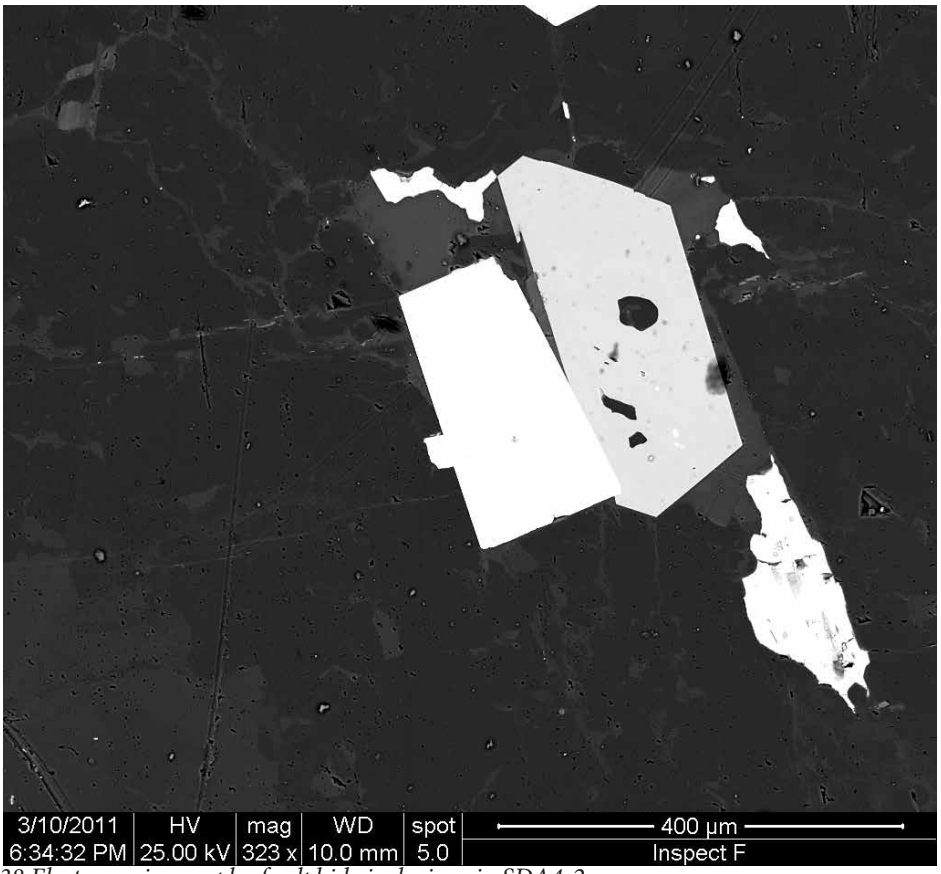


Figure 6.38 Electron micrograph of sulphide inclusions in SDA4-2

3.3.4 Minerals form the Stepnoye and Ust'ye mining surveys

During the programme of material characterisation, mineral from the four mining sites explored during the two SCARP surveys were analysed. Samples were selected through rapid, in-situ analysis in the field using HHpXRF.

Sanarka Dacha A (SDA)

Macroscopically both carbonate and sulphide minerals were present at SDA. Mineral samples were found both on the eroded track-way and during the excavation of SDA3. One

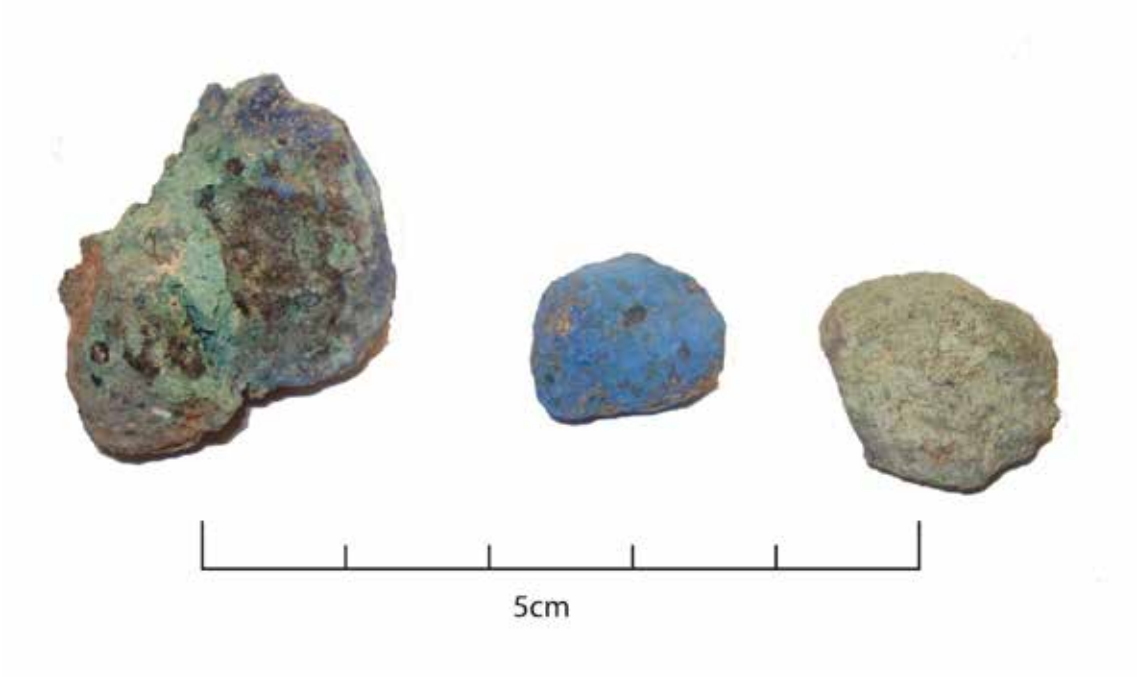


Figure 6.39 Malachite and azurite from Kordon-Lenin.

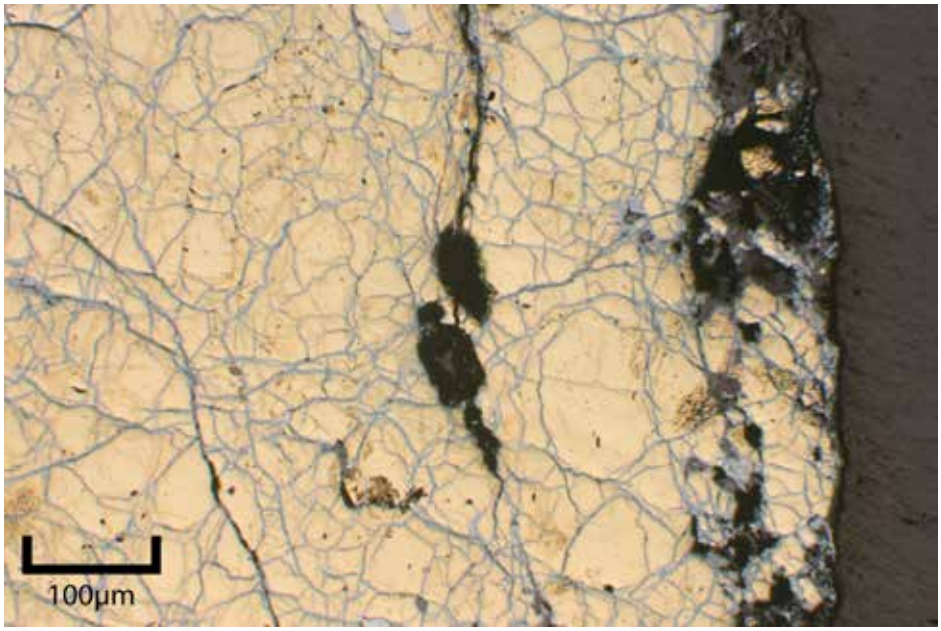


Figure 6.40 Optical micrograph of the chalcopyrite sample form Kordon Lenin showing the dominant chalcopyrite structure with a chalcocite intergrowth

of the mineral fragments found in SDA3 was analysed in the field and found to contain ~30% copper. Two samples were subjected to further analysis, a fragment of possible malachite and a sulphide mineral (Figure 6.36). Reflected light microscopy confirmed that the former sample (SDA4-1) was malachite (Figure 6.37, Pracejus 2008).

Analysis of the surface of the sulphide mineral (SDA4-2) revealed 2000ppm copper which hinted at the possibility of copper sulphide mineralisation. However, SEM-EDS analysis, shown in Figure 6.38, only identified inclusions of iron pyrite and arsenical pyrite. Bulk chemical analysis of the minerals from SDA however, confirmed the presence of both pure copper carbonate ores and sulphides (Table 6.14).

Kordon Lenin

The ore samples from Kordon Lenin contained both carbonate and sulphide ores, with carboante more abundant. Macroscopically the carbonate ores were distinct and consisted of very finely disseminated malachite and azurite (Figure 6.39). The sulphide ore was much more difficult to characterize in hand specimen, indeed it was only positively identified upon sectioning (Figure 6.40). SEM analysis of this sample showed chalcopyrite grains intergrown with chalcocite. The sample was a particularly high grade ore which was confirmed by the XRF analysis (Table 6.13).

Gorny-Toguzak

Macroscopically the ore from Gorny-Toguzak consisted of three main types; malachite, azurite and a tenorite which was in association with both. All of the fragments were found in association with quartz. Figure 6.41 shows a quartz boulder containing ore inclusions; both the green malachite and the grey tenorite.

Microscopic analysis of the ore samples showed that they contained a mixture of carbonate, oxide and sulphide minerals; with oxide and carbonate minerals most prevalent (Figure 6.42). Spot analysis using SEM-EDS revealed a mixture of high grade ore with very few

Table 6.15 SEM-EDS spot analyses form the Ust'ye mining surveys.

Site	Sample	Spec.	SiO_2	Cl	Ca	Cr_2O_3	FeO	CuO	Ag	Au	FeS	CuS
Gorny	1	Spot 1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.1	99.9
Gorny	1	Spot 2	n.d.	n.d.	n.d.	n.d.	0.1	98.7	n.d.	n.d.	n.d.	n.d.
Gorny	1	Spot 3	n.d.	n.d.	n.d.	n.d.	0.1	99.1	n.d.	n.d.	n.d.	n.d.
Gorny	1	Bulk 1	n.d.	n.d.	n.d.	n.d.	n.d.	90.6	n.d.	n.d.	n.d.	n.d.
Gorny	1	Bulk 2	n.d.	n.d.	n.d.	n.d.	0.3	91.7	n.d.	n.d.	n.d.	n.d.
Ust'ye North	1	Spot 1	0.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	48.1	51.6
Ust'ye North	1	Spot 2	9.2	0.1	0.9	n.d.	69.8	18.8	n.d.	n.d.	n.d.	n.d.
Ust'ye North	1	Spot 3	n.d.	20.1	n.d.	n.d.	n.d.	79.8	0.1	n.d.	n.d.	n.d.
Ust'ye North	1	Spot 4	n.d.	0.3	n.d.	n.d.	n.d.	0.2	10.9	88.6	n.d.	n.d.
Ust'ye North	1	Bulk 1	5.3	2.6	0.4	n.d.	40.0	48.3	n.d.	n.d.	n.d.	n.d.
Ust'ye North	1	Bulk 2	3.1	2.6	0.2	n.d.	28.1	64.2	n.d.	n.d.	n.d.	n.d.
Ust'ye North	1	Bulk 3	5.7	4.2	0.3	n.d.	40.5	48.4	n.d.	n.d.	n.d.	n.d.
Ust'ye North	1	Bulk 4	n.d.	19.9	n.d.	n.d.	n.d.	80.1	n.d.	n.d.	n.d.	n.d.
Ust'ye North	2	Bulk 1	4.4	n.d.	n.d.	0.2	94.5	n.d.	n.d.	n.d.	n.d.	n.d.
Ust'ye North	2	Bulk 2	4.6	n.d.	n.d.	0.3	93.9	n.d.	n.d.	n.d.	n.d.	n.d.
Ust'ye North	2	Bulk 3	4.3	n.d.	n.d.	0.2	94.3	n.d.	n.d.	n.d.	n.d.	n.d.



Figure 6.41 Large quartzite boulder from Gorny containing a rich vein of tenorite and malachite (grey and green respectively).

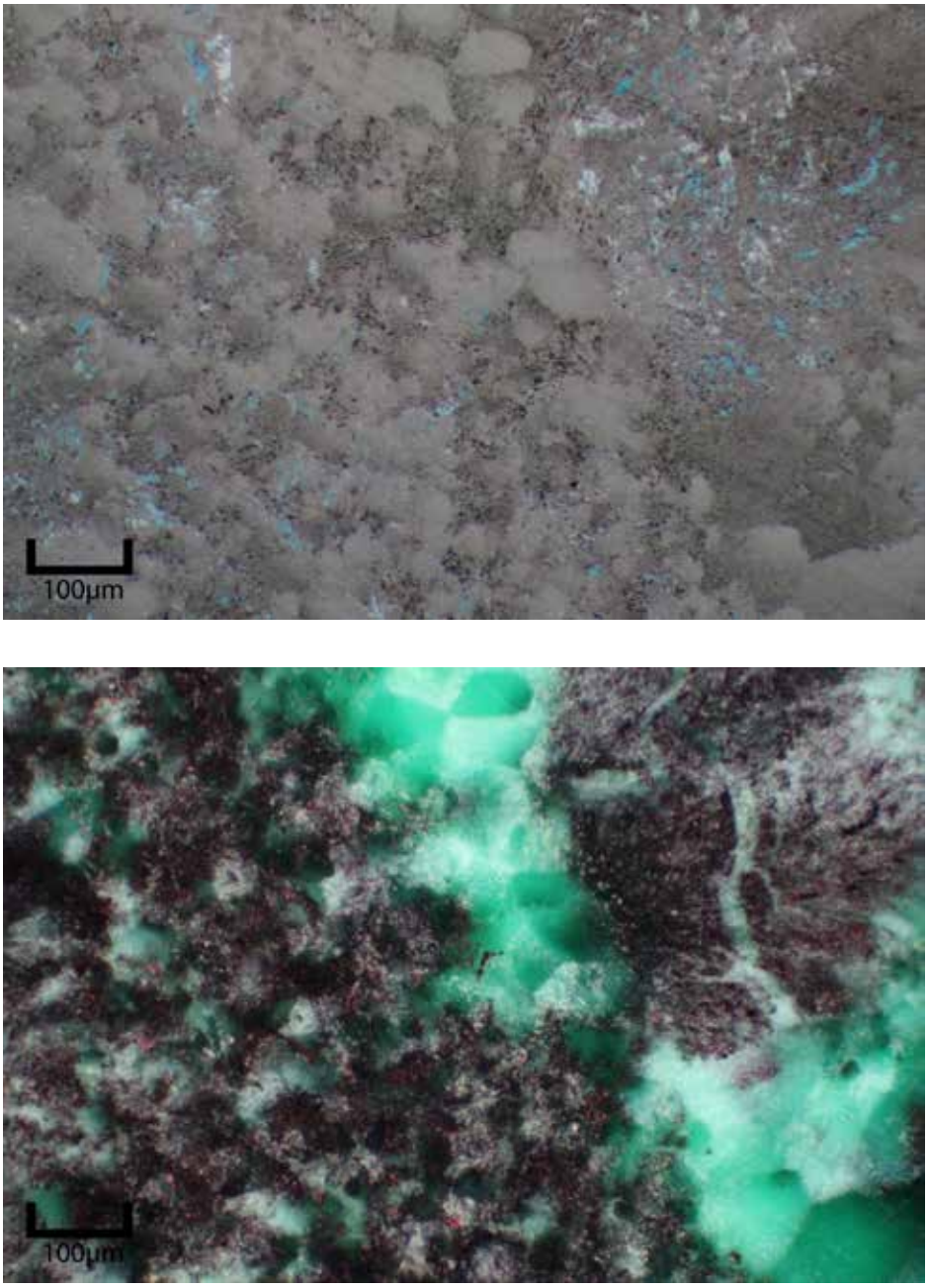


Figure 6.42 Malachite with inter-grown copper (2) oxide (cuprite and tenortite) and occasional copper sulphide.

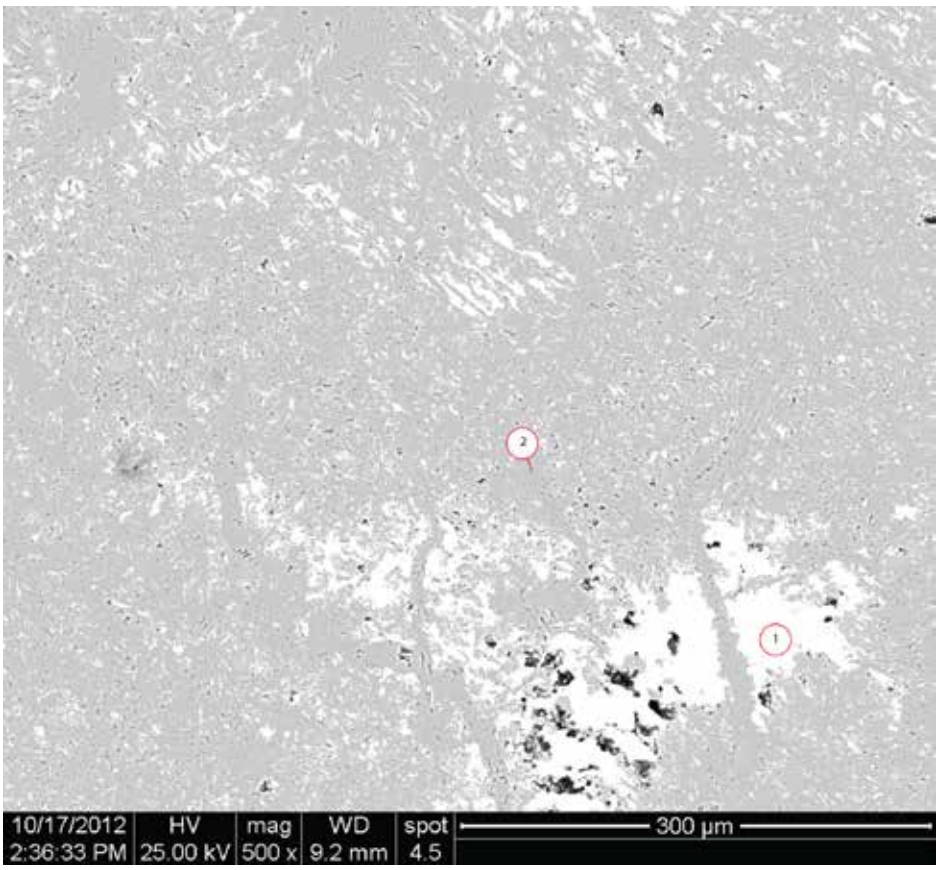


Figure 6.43 electron micrograph showing sample Gorny-1 and the locations of spot analyses.



Figure 6.44 A sample of copper mineral from the Ust'ye North mine showing malachite embedded in quartz.

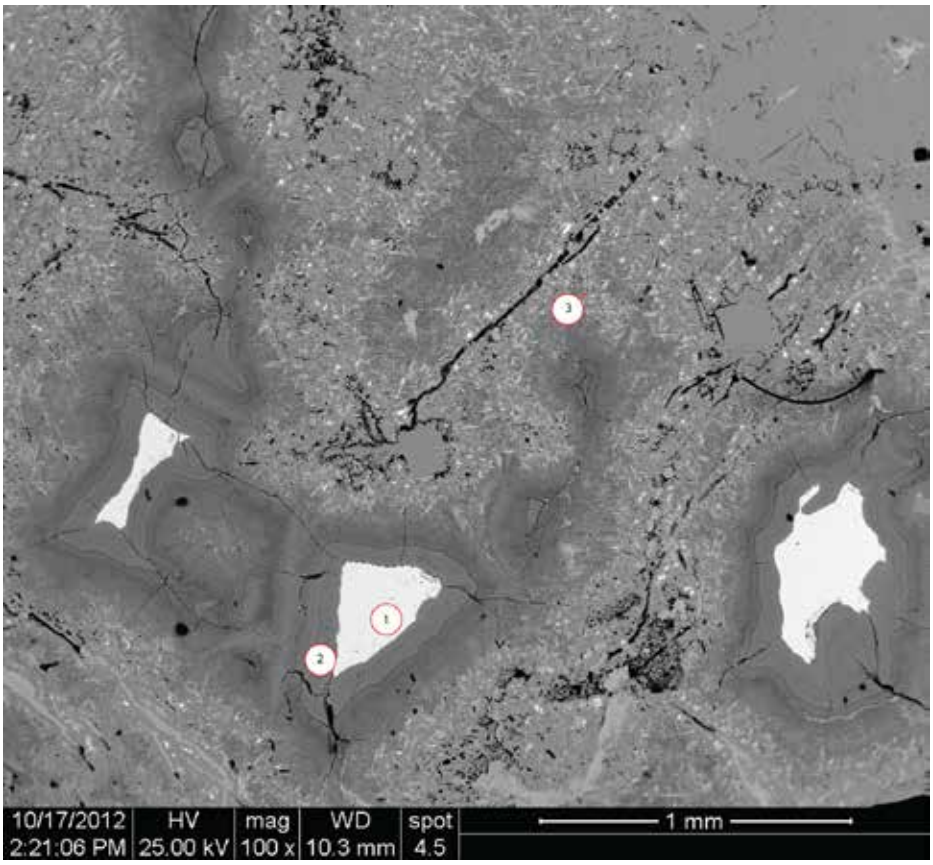


Figure 6.45 electron micrograph of 161y-9148 showing the locations of spot analysis

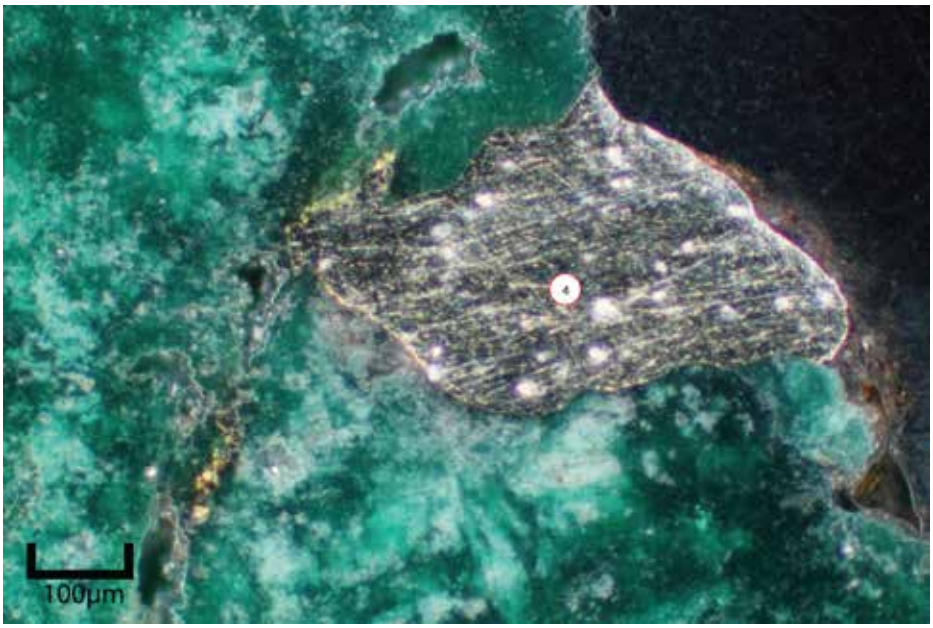


Figure 6.46 Optical micrograph of the gold inclusion in sample Ust'ye North embedded in a malachite matrix.

impurities (Figure 6.43 and Table 6.15). Although the spot analyses could not quantitatively differentiate between carbonate and oxide minerals, the un-normalised values suggested that both types were present (see appendix C).

Ust'ye North

Overall the mineral at Ust'ye North was broadly similar to Gorny-Toguzak with a mixture of different secondary carbonates, oxides and sulphides with the former most prevalent (Figure 6.44). The minerals were all associated with quartz (Figure 6.45).

Analysis of two of the samples revealed both high grade copper ore and gold inclusions (Figure 6.46 and Table 6.15). Although the gold inclusions were rare they were present in economically significant values, which is consistent with the modern history of the mine.

In addition to the copper mineral a fragment of iron oxide was also analysed from Ust'ye North (2), the analysis showed that it contained up to 0.3% Cr_2O_3. So while all of the ore from the site and the mining survey contained no chromite, there were minerals in the area that did.

6.4 Metallurgical ceramic

Only three fragments of metallurgical ceramic were identified at Stepnoye, two of which were returned to Sheffield for detailed analysis. Both of these fragments were recovered from the copper anomaly test pit. In contrast 98 fragments of ceramic and ceramic artefacts had been identified in the Ust'ye assemblage that may have been used in a metallurgical context.

6.4.1 Visual characterisation

Visually the ceramics all were of similar composition with clear talc and silica inclusions. The ceramics were also relatively thin walled with most around 10-15mm in thickness.

Macroscopically, the sherds from Stepnoye had no features which would suggest that they were used in a metallurgical context other than a small amount of light, localised vitrification (Figure 6.47). However, because they were excavated in the copper anomaly



Figure 6.47 Fragment of metallurgical ceramic from Stepnoye.

test pit they were analysed due to the contextual association with archaeological slag, had they been identified in the main excavation it is unlikely that they would have been identified as metallurgical in function.

The range of possible metallurgical ceramics at Ust'ye was far more extensive than that of Stepnoye. Therefore the assemblage was split in to three broad categories before further sampling and analysis; vitrified fragments of decorated pottery, vitrified and amorphous fragments of pottery and vessels with low verification. In addition to this there were two exceptional pieces; a plate shaped artefact and a possible tuyére.



Figure 6.48 Decorated metallurgical ceramic (161y-9148).



Figure 6.49 Cross section of sample 10272 showing the embedded copper prill (left) and heavily vitrified ceramic fragment 9529 (right).

Vitrified fragments of decorated pottery

These sherds bore a strong formal resemblance to what could be considered typical Middle Bronze Age ceramic in the Southern Urals in that they were part of large, beaker like vessels with linear incised and stamped decoration with a slightly defined shoulder and rim (Koryakova and Epimakov 2007).

These fragments showed evidence of localized vitrification which in some cases was especially extreme (Figure 6.48). Vitrification in many of the fragments was not limited to the surface but continued into the body of the sherd, There was evidence that suggested the ceramic had been heated after it had broken with vitrification on the edge and, in one instance, with a metallic copper prill embedded in the break of the ceramic (Figure 6.49). It is possible that these were initially complete vessels which were used beyond their point of failure, however, the abundance of vitrified edges may suggest that the fragments were heated intensively after the original vessel had already broken; possibly acting as some sort of ad-hoc furnace cowling (See discussion).

Vitrified and amorphous fragments

These were, in the most part, vitrified on every surface leaving few distinguishing characteristics (Figure 6.49). With so little surface remaining un-vitrified it is almost certain that these sherds were introduced to high temperatures in an already broken state. Their glassy exteriors suggest exposure to significantly high temperatures, probably in excess of 1150°C (Hein et al. 2007).

The tuyére

The tuyére had an internal diameter of 2 cm and a length of 6 cm (Figure 6.50). Unfortunately the tuyére had lost both its tip and much of its shaft therefore it impossible to suggest a total length. The tuyére did contain an embellished ridge which featured finger impression decoration around what is possibly the tip end.



Figure 6.50 Tuyére fragment from Ust'ye.

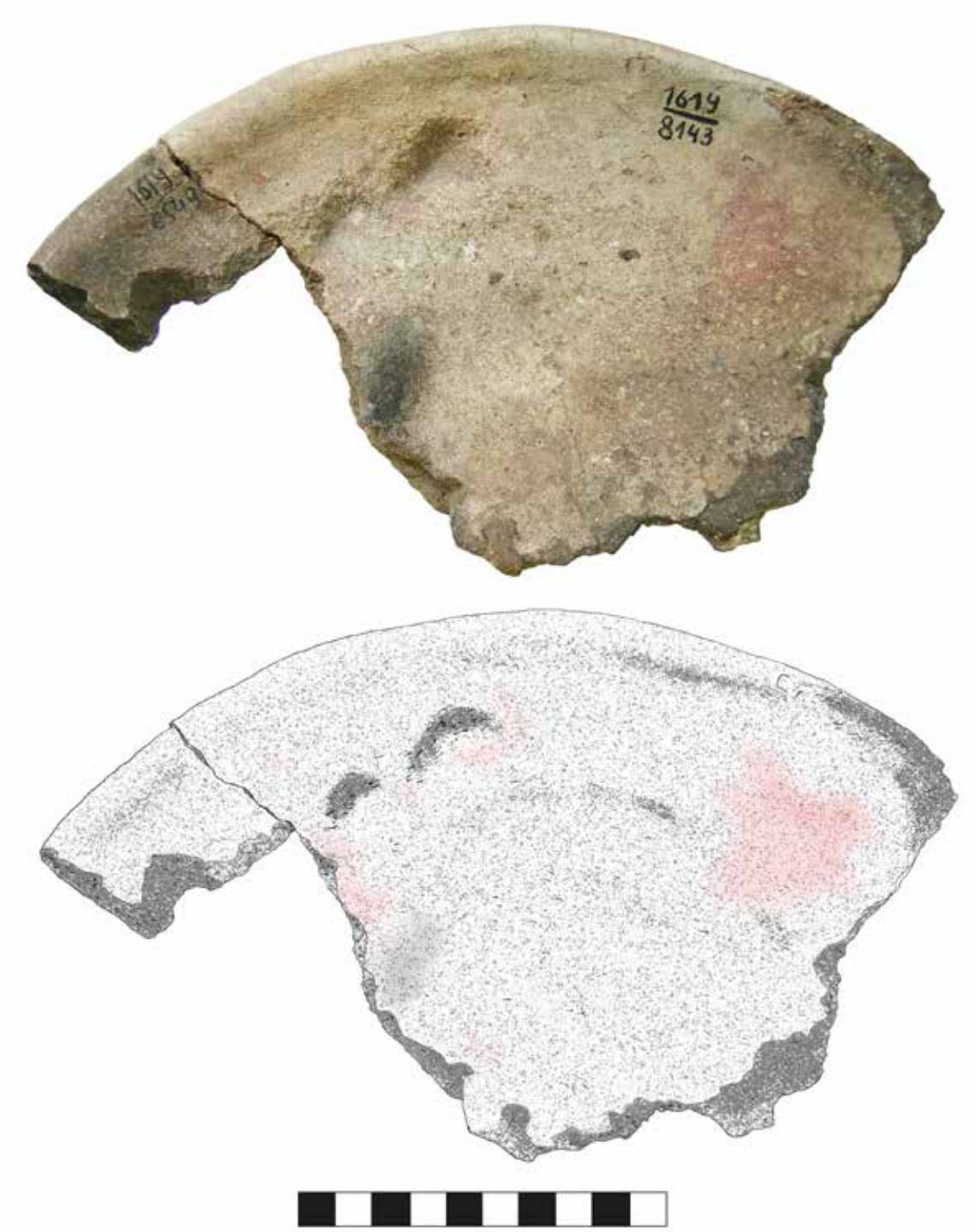


Figure 6.51 Photograph of the upper surface of 161y-6549/8143 showing and a line drawing highlighting the area of surface scarring, charring and copper staining.

Ceramic plate 161y-6549/8143

A unique example was ceramic 161y-6549/8143 which came from Vinogradov's excavations in the 1980s. Described by the excavators as a 'plate crucible', it appeared odd with little evidence of vitrification. The plate had an approximate diameter of 25-30cm and was ~15mm in thickness. Unlike some of the decorated fragments the plate showed no excessive vitrification. However, the upper surface did have a significant amount of surface scarring in the middle of the plate and on the edge of which were two groves (Figure 6.51). The upper surface also had limited areas of reddening, which may have been caused by exposure to copper in a reducing environment.

Table 6.16 Qualitative pXRF analysis of the surface of suspected metallurgical ceramics (n.d.=not detected, tr < 500ppm, + 500-1000ppm, ++ 1000-10,000ppm, +++ >10,000ppm).

Group	SAMPLE	Description	Location of analysis	Cu	Sn	As
Stepnoye	(TP2)	sherd	Inside	++	n.d.	n.d.
			Outside	+	n.d.	n.d.
	(TP3)	slightly vitrified sherd	Inside	++	n.d.	tr
			Outside	+	n.d.	n.d.
Ust'ye 1	161y-9208	Heavily vitrified sherd	Inside	++	n.d.	n.d.
			Outside	tr	n.d.	n.d.
	161y-3616	Heavily vitrified sherd	Surface	+++	+	n.d.
	161y-6455	Heavily vitrified sherd	Side 1	+++	n.d.	n.d.
			Side 2	+++	n.d.	n.d.
	161y-8185	Heavily vitrified sherd	Surface	++	n.d.	tr
	161y-29(0)0	Vessel fragment	Surface	++	n.d.	tr
	161y-9529	Vessel fragment	Surface	+	n.d.	tr
Ust'ye 2	161y-9085	Vessel fragment	Surface	++	n.d.	n.d.
	161y-9148	Decorated rim with vitrified interior	Outside	tr	n.d.	n.d.
			Inside	+	n.d.	tr
	161y-6549/8143	Flat plate with reddened surface	Interior (surface)	++	n.d.	n.d.
			exterior (surface)	tr	n.d.	n.d.
	161y-131	Small vessel fragment	Surface	++	n.d.	n.d.
	161y-10272	Decorated rim with a vitrified interior and an embedded copper prill	Side 1	++	n.d.	n.d.
			Side 2	++	n.d.	n.d.
	161y-3866	Reddened shoulder fragment	Surface	+	n.d.	n.d.
Ust'ye 3	161y-7386	Vessel fragment	Surface	tr	n.d.	n.d.
	161y-5984	Heavily vitrified sherd	Surface	tr	n.d.	tr
	161y-1455	Vessel fragment	Surface	tr	n.d.	n.d.
	161y-9638	Vessel fragment	Surface	tr	n.d.	tr
	161y-5252	Vessel fragment	Surface	tr	n.d.	n.d.
	161y 10422	Vessel fragment	Surface	tr	n.d.	n.d.
	161y7430	Vessel fragment	Surface	tr	n.d.	n.d.
	161y7142	Vessel fragment	Surface	tr	n.d.	n.d.
Ust'ye N/A	161y 10668	Tuyère	Body	tr	n.d.	n.d.
			Ridge	tr	n.d.	n.d.
			Tip	tr	n.d.	n.d.

6.4.2 Residual metals analysis

With the exception of one sample (161y-10272) which contained a metallic copper prill, and the slight reddening of some fragments, it was impossible to say with certainty that the high levels of vitrification noted were the result of copper metallurgy (Figure 6.51). Therefore a subsample of fragments and vessels were subjected to surface analysis to explore the presence of any residual metals.

The possible metallurgical ceramics from Stepnoye and a sub-sample of the suspected metallurgical ceramics were analysed multiple times with analyses performed on both the inner and outer surfaces where possible. Semi- quantitative analyses were used to confirm the functionality of the ceramics through the identification of copper concentrations on the ceramic surface. It was assumed that elevated copper concentrations (>1000ppm) on the internal surface of the ceramic indicated the use of the ceramic in metallurgical processes (Bayley 1989; Kearns et al. 2010). In total, 2 sherds were analysed from Stepnoye and 21 from Ust'ye with samples from each macroscopic group (including discrete artefact types).

The results of the residual metals analysis of the Stepnoye ceramic can be seen in Table 6.16. This clearly shows that both copper and zinc were significantly enhanced on the inner surface of the samples, with copper increasing by over a magnitude. The second sherd also has an enrichment of arsenic from below detection limits to over 100ppm. This enrichment is indicative of a ceramic which had been exposed to copper alloy at high temperature.

From Ust'ye, the heavily vitrified sherds contained the highest concentration of copper on their surface, particularly 161y-6455 which was a magnitude higher than any of the other samples. However, even the decorated fragments contained significant amounts of copper on their surfaces. The plate also had elevated levels of copper on its upper surface. The tuyére however only had trace levels of copper, this is not surprising though as the tip, which would have been nearest to the reaction zone was missing.

The analysed fragments were split into the following groups based on their physical characteristics and residue analysis, and the full results can be seen in Table 6.16.

Group one: Heavily vitrified sherds that retain very few morphological features but containing significantly high levels of copper on all of the surfaces analysed.

Group two: Decorated and near complete vessels with relatively clean surfaces, with little or no adhered slag but some reddening and increased copper levels on the interior surface.

Group three: Fragments that are either heavily vitrified or low fired with very low levels of copper on analysed surfaces.

It is clear that Group one was used in a metallurgical context and possibly consists of fragments of crucibles or improvised furnace cladding. Group two also represents ceramics used in a metallurgical context; however these fragments are more difficult to interpret without further analysis. The high levels of copper on the interior surface can only have been caused by contact with a copper bearing charge when under great temperatures; however the relatively low levels of vitrification would seem to contradict this. It may be

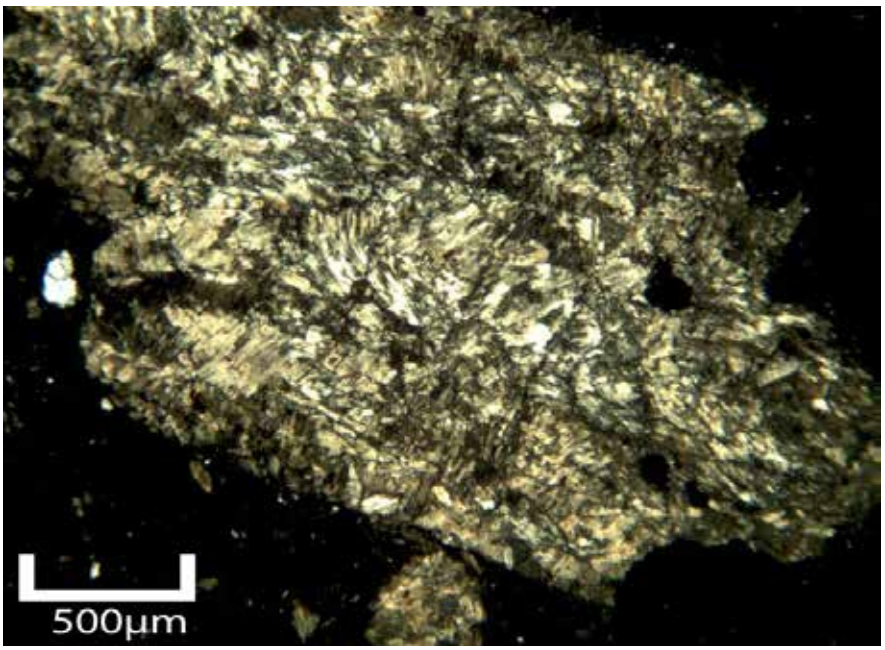


Figure 6.52 Thin section of a small fragment of metallurgical ceramic found at Stepnoye showing heat altered talc inclusions.

possible that the comparatively clean surface may be the result of a specific fabric type formulated for metallurgical use—a technical ceramic. It is much less likely that group three was used in a metallurgical context, especially with the reaction zone of a furnace, however due to the trace amounts of copper on all of the sherds it cannot be ruled out. It is more likely that they were used in a secondary process.

The plate was subjected to more detailed reside analysis with the upper surface analysed to explore any spatial patterning in the copper concentrations. This showed that the copper was slightly more enriched towards the centre of the plate. The high copper concentrations correlated well with the area of surface scarring. It seems likely that this was a result of the plate being used to contain a copper charge, perhaps even used as an open smelting crucible. This would correspond with the underside of the slag which typically shows evidence of having formed on a plate lie surface.

6.4.3 Microstuructural analysis

Selected ceramic samples were subjected to optical microscopy, in the form of thin section petrography, and SEM-EDS.

Thin section petrography

Thin section petrography is a relatively quick and economical means through which to gain insight in to important mineral suites present in ceramics. Thin section analysis of the metallurgical ceramics fragments from Stepnoye showed that the main inclusions were talc with some silica. It is possible that these inclusions occur naturally in the clay. However, analysis of a local clay deposit indicated no talc was present; thus, it is possible that this inclusion was an intentional additive. In modern metallurgy, the thermodynamic properties of talc are well known. Talc has both a low coefficient of thermal expansion and, when heated to above 900°C (in the presence of silica or silicates) becomes altered

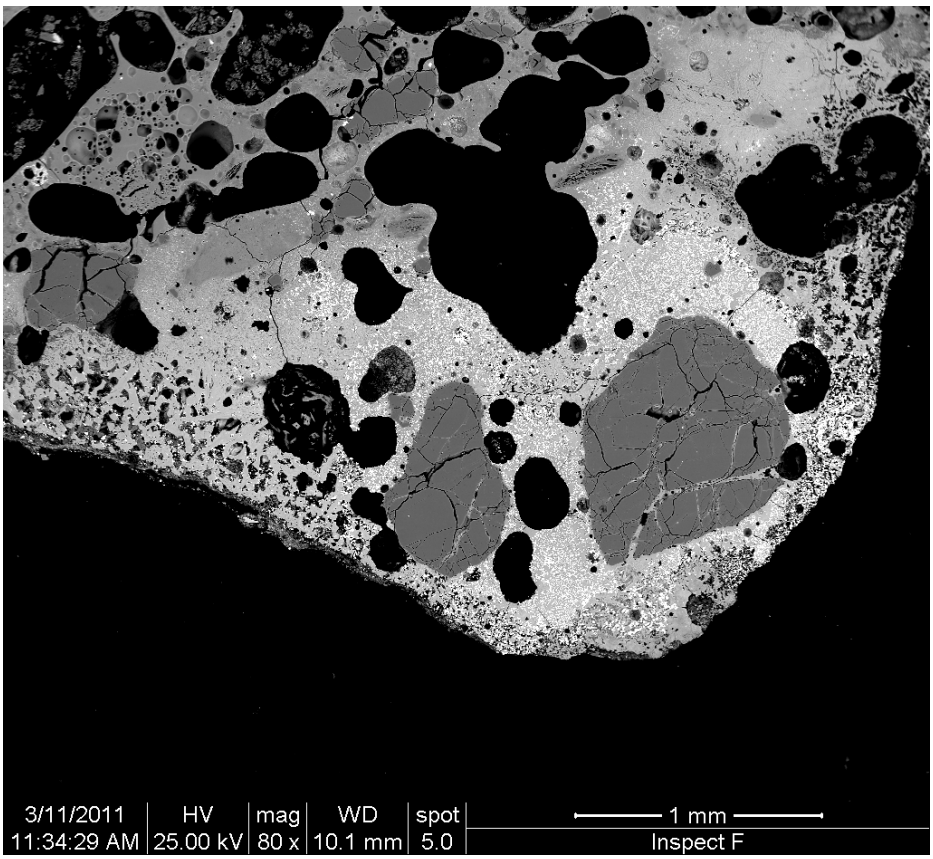


Figure 6.53 SEM micrograph showing slag adhered to the surface of the fragment of metallurgical ceramic from Stepnoye.

to enstatite, which causes it to increase in hardness while also being a good refractory. It is these properties that may make talc an ideal temper in metallurgical ceramics (Rice 1986 105; Rapp 2009, 125). Under crossed polarised light, this alteration removes the mineral's bright pleochroism that produces a dull yellow colour, as is evident in Figure 6.52 (cf. Yardley et al. 1990).

SEM-EDS

Analysis of one of the fragments from Stepnoye identified a thin layer of magnetite-rich slag adhering to the outer surface of one of the ceramic fragments (Figure 6.53). This, coupled with the inorganic residue analysis and the altered talc inclusions, confirms that the sherds were used in a metallurgical context.

In total three samples from Ust'ye were selected for SEM; 6549/8143, 9208 and 9148. The samples were selected from the two groups which were most likely associated with metallurgy (1 and 2). The ultimate aim of the SEM programme was to broadly characterize the ceramic type, identify any evidence of copper metallurgy and to identify the presence/absence and composition of chromite spinels. The programme of analysis generated both electron micrographs and individual spot analysis of inclusions. The full analytical results can be seen in Appendix C.

Fabric type

Although not a full petrographic study, it is possible based on the analysis of inclusions to broadly characterize the ceramic type. Like much of the non-metallurgical ceramic in the region the dominant inclusions seem to be talc and silica. Indeed, once initially identified talc

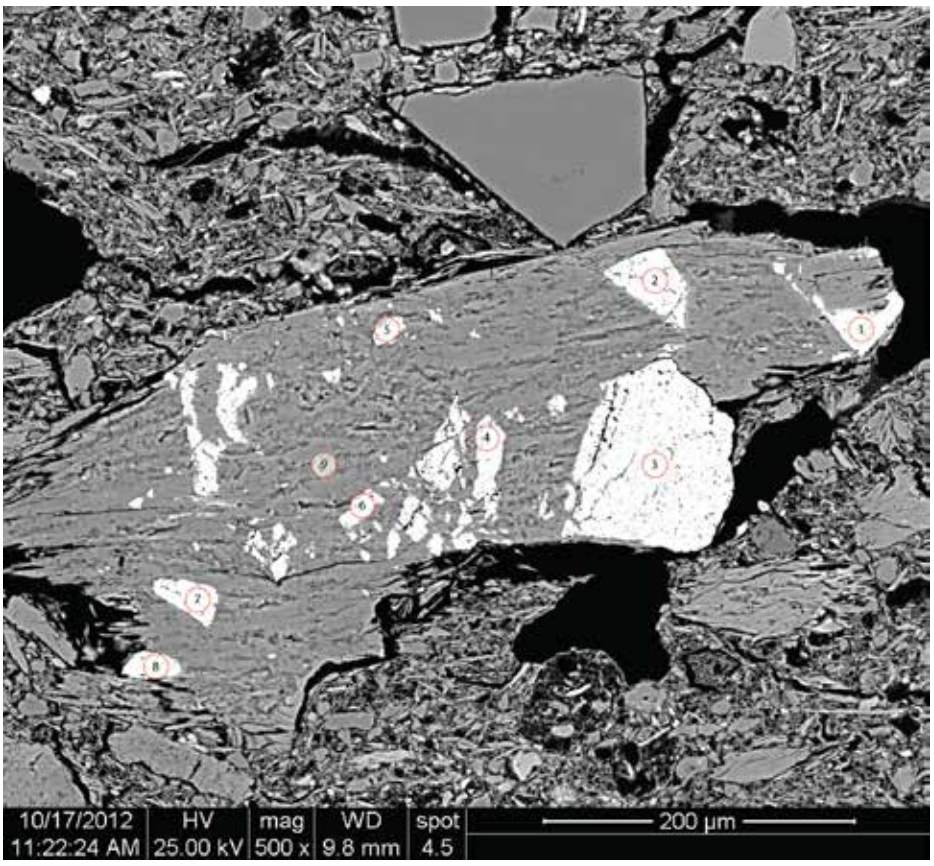


Figure 6.54 Electron micrograph of samples 161y9148 sowing an inclusion of talc within the ceramic matrix and the location of the spot analysis in Table 6.16. The image features numerous chromite inclusions (1-8) within a talc inclusion (9).

Table 6.17 SEM-EDS spot analysis of inclusions in ceramic sample 161y9148.

Site	Sample	Spec.	MgO	Al_2O_3	SiO_2	CaO	TiO2	V2O5	Cr3O3	MnO	FeO	ZnO
161y	9148	1	4.8	0.6	7.4	0.3	1.2	0.5	46.1	0.6	37.4	1.1
161y	9148	2	9.0	n.d.	15.0	0.1	0.8	0.4	40.4	0.5	32.9	0.9
161y	9148	3	6.0	n.d.	11.4	0.1	0.8	0.5	44.0	0.4	35.9	0.9
161y	9148	4	5.5	0.6	10.7	0.1	0.8	0.5	45.1	0.6	35.0	1.0
161y	9148	5	7.6	0.2	13.2	0.3	0.8	0.4	42.9	0.6	33.1	1.0
161y	9148	6	5.2	0.4	8.5	0.1	0.7	0.5	47.2	0.6	35.4	1.4
161y	9148	7	4.6	n.d.	9.6	0.1	1.0	0.5	47.4	0.8	34.7	1.2
161y	9148	8	5.6	n,d,	9.4	0.1	1.0	0.5	45.0	0.5	36.8	1.1
161y	9148	9	31.1	n.d.	65.2	0.1	n.d.	n.d.	0.1	n.d.	3.4	n.d.

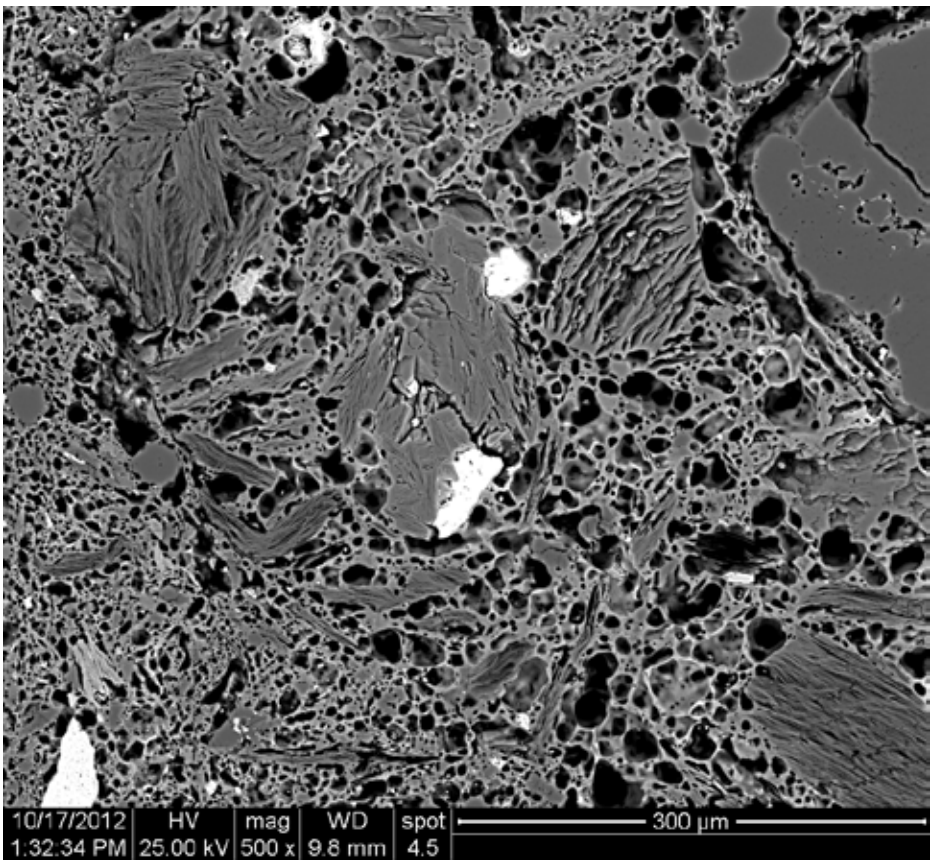


Figure 6.55 Electron micrograph showing the vitrified and glassy texture near the surface of sample 161y 9208.

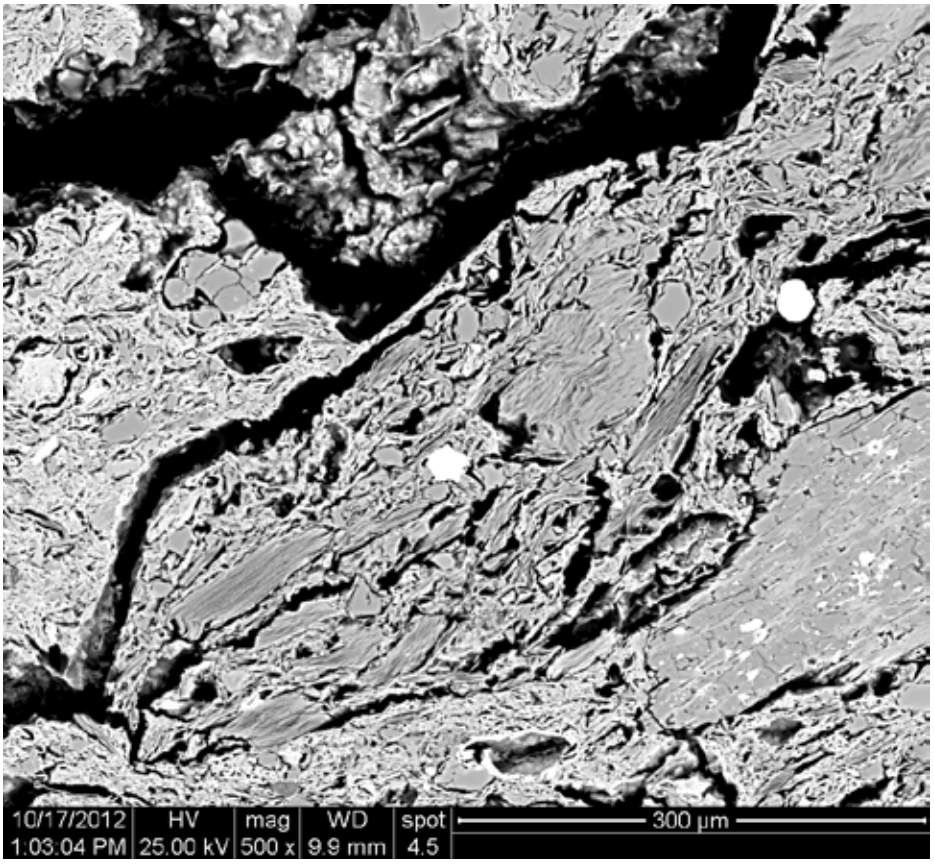


Figure 6.56 Electron micrograph showing copper prills in ceramic sample 161y-9208 (white).

has a characteristic laminated appearance under election microscopy which makes it easy to identify rapidly. Both talc and silica were present in all of the samples analysed. What was interesting about many of the talc fragments was that they contained chromite inclusions (Figure 6.54, Table 6.17). Given the significance placed on the presence of chromite spinels in slags this is especially important. There were also fairly common inclusions of calcium aluminium silicate minerals which. Analysis of these inclusions indicated a composition of $CaAlSi_2O_6$ (MacKenzie and Adams 1997; Yardley et al. 1990).

Evidence of copper metallurgy

Given the high copper reading on the surface of the ceramics it was anticipated that thin layers of slag may be present on the surface of the fragments. This was only visible on the example form Stepnoye. The only evidence for excessive temperature microstructurally in the Ust'ye ceramics was found in the form of a section of ceramic which had vitrified to form porous, glassy texture (Figure 6.55). In addition, sample 161y 9208 showed compelling evidence for their metallurgical application in the form of two copper prills embedded into the ceramic matrix (Figure 6.56).

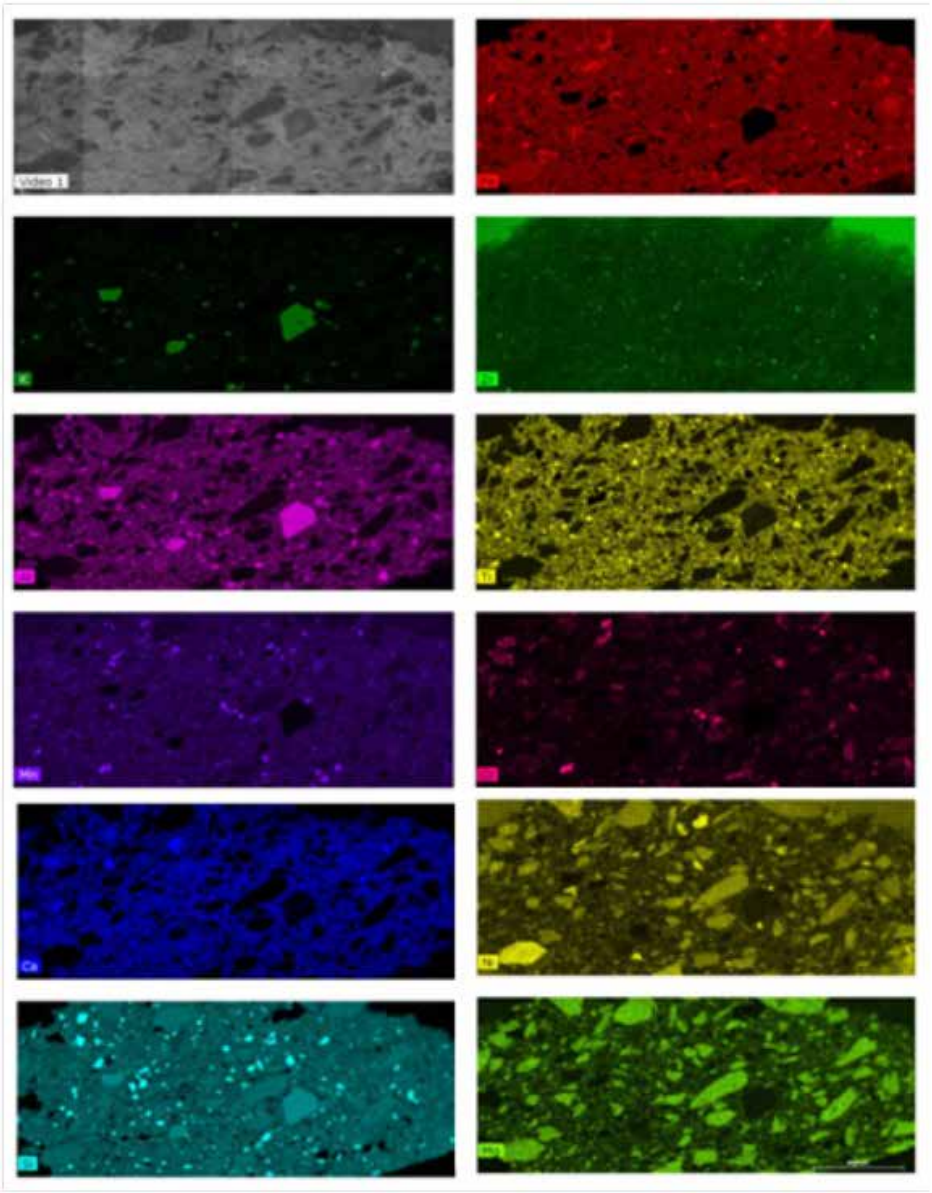


Figure 6.57 Individual elemental maps of sample 161y-9148.

Chromite inclusions

The surface analysis of some of the suspected metallurgical ceramics showed the presence of chrome it was hypothesized that this was due to the presence of chromite spinels. A brief appraisal of the samples using optical microscopy supported this hypothesis, showing some highly reflected inclusions in all of the samples. The composition of these inclusions was confirmed during the SEM programme. The majority of these inclusions contained high levels of chrome, iron and aluminium, confirming that they do belong to the chrome spinel group.

Micro X-ray Fluorescence

One fragment of metallurgical ceramic was analyzed using μ-XRF; 161y-9148 (Figure 6.57). This was aimed at exploring the distribution and density of chromite spinels in the ceramic. The distribution shows a significant quantity of small and large chromium based inclusions in the ceramic both in association with talc inclusions and within the fabric itself. This is significant as it suggests that both the base clay fabric and the temper/inclusions could be the source of chromites in the slag. Indeed with no chromite spinels identified in any of the copper mineral fragments found at Ust'ye these ceramics are the most likely source of the chromite spinels in the slag.

6.5 Processing tools

In addition to the analysis of metallurgical debris and ceramics the lithic assemblage from the Ust'ye settlement was also appraised. Those which, based on their visual characteristics, could have been used in a metallurgical context were selected for surface analysis.

The artefacts selected consisted largely of polished slabs, whetstones and hammer stones. While the presence of enriched copper on the working surface of an object strongly suggests that it was used in a metallurgical context it important to acknowledge that surface analysis cannot concussively rule out that an object was used in metallurgy.



Figure 6.58 Small hammerstone identified in the Ust'ye lithic assemblage



Figure 6.59 The large mallet like hammerstone identified in the Ust'ye lithic assemblage

Only two objects contained significantly more copper on the working surface than elsewhere on the artefact; a small spherical hammer stone (Figure 6.58) and a mallet like hammer stone (Figure 6.59) which had originally been interpreted by the excavators as a rams head (Vinogradov 2013).

Both of these stone artefacts showed signs of working on one of the surfaces. The small hammerstone had both small and large chips on one of the faces while the large mallet had a slightly smoothed handle and a chipped working face. It seems likely that both of these tools were used for hammering (albeit at very different scales), rather than grinding or as abrasives. The mass and ergonomics of the larger hammer stone would have make it ideal for breaking large ore fragments or fragmenting host rock and the smaller stone would have been useful in the delicate removal of gangue minerals from ore fragments.

6.6 Summary

This chapter has outlined the key results from an extensive programme of analysis, the full results and methods can be found in the Appendix. What is clear from these results is that the metallurgical debris from Stepnoye and Ust'ye shared a number of traits yet differed in others. Ores were notably different yet slag morphology was remarkably similar. Together this suggests a common approach to metallurgy yet a willingness to adapt the common approaches to local resources.

Slag was the most abundant metallurgical material from both sites. While morphologically similar, key differences were noted in chemistry and microstructre. The formal characteristics of the slag from both sites suggest that they were formed under the same conditions; within a furnace, atop a liquid ingot. Microstruturally, the slag contained a similar range of minerals although they were present in different ratios and forms. The most visible difference between the two datasets was in the type of fayalite present and the quantity of iron oxides. At Stepnoye the slag was dominated by euhedral falyalite structures which were likely formed due to a slower rate of cooling coupled with longer dwell times, while also having significant enough quantities of magnesia to suggest higher formation temperatures while at Ust'ye the assemblage was dominated by the faster forming lath-like structures but had incorporated less magnesia. It is possible that the hotter, longer smelts at Stepnoye were necessary to win copper from a mineral that included significant quantities of sulphide.

The near ubiquitous present of iron oxides (and other substituted metal oxides) at Stepnoye strongly suggests a process which contained both an abundance of iron minerals and an oxidizing/mildly oxidizing atmosphere. This can be seen in contrast to the material from Ust'ye, which low in such oxides, was likely formed in a more reducing environment.

Beyond the common slag phases there was cases of significant variation among the more infrequent phases present. Most notably in the presence of copper sulphide inclusions in the Stepnoye slag and the frequent presence of free silica in the Ust'ye slag. Noted both microscopically and in the XRD analysis, the consistent prescience of free silica in the Ust'ye slags as opposed to the near total absence in the Stepnoye material coupled with the opposite for copper sulphides suggests a significant difference in mineral choices and/or

flux type. The presence of free silica in the Ust'ye slag is significant as it would suggest the use of high silica minerals found locally. Also of significance is the possibility that sulphide ore was central to the smelting process at Stepnoye as this would result in the need for a completely different approach to smelting regimes.

The variation noted microscopically was also evident in the bulk analysis. While there is some overlap between the results there is a clear trend in which the Ust'ye slags were more silica rich than the Stepnoye slags, which were richer in Fayalite. This variability was visible in both programmes of analysis but is particularly clear in the SEM results. This is most likely due to the tighter grouping of analytical data as SEM allowed inclusions to be avoided in the analysis. This suggests that while the free silica has some bearing on the overall silica content, there was still a higher representation of silica in the overall slag matrix.

It was also evident that the metal types being produced at each site were not the same. The spot analysis of copper prills and the bulk analysis of slag showed the presence of both arsenic and tin, with the latter exclusively found at Ust'ye. What is interesting is that there were also cases, more abundant at Stepnoye, where pure copper was identified.

The analytical results presented here are important for the characterisation of the materials relating to metallurgical production. However, on their own they explain little about the specific of the process, i.e. how slag forms and the viability of different furnace structures. The following chapter discusses experimental approaches and aims to develop practical encounters with similar material and conditions with the intention of using this to aid a more complete interpretation of the material.

Chapter 7

Experimental Programme

As indicated from the varied material evidence and proposed models for Sintashta metallurgy, the process of smelting is complex, and challenging to reconstruct. Within archaeometallurgy, experimental reconstruction has become a widely accepted method for testing proposed models and exploring the behaviour of pyrotechnical structures and materials (Merkel 2013) alongside the kinds of techniques and practices that they facilitate (Doonan 2013). In this chapter the results of a series of experimental studies are reported that were undertaken to elucidate a number of aspects of the metallurgical evidence recovered from Stepnoye and Ust'ye and to clarify a number of claims found in the published literature (Grigoryev 2013). In addition, the experiments aimed to explore specific issues arising from the earlier phases of the project, especially the analytical studies of material and inferred processes.

The series of experiments range from those carried out under tightly controlled laboratory conditions to those which adopted 'field' approaches which reconstructed processes at full scale. The experiments focused on establishing the following issues;

- The effects of ore beneficiation on furnace charge
- The behavior of ceramics in metallurgical processes
- The functionality of Sintashta tuyéres with both bellows
- The ability of selected hearths identified at Sintashta and Arkaim to produce adequate smelting conditions
- The formation of slag and related materials in a Sintashta type reconstruction

A summary of the experiments presented here, including their aims and methods can be seen in Table 7.1.

Table 7.1 A summary of the experiments presented din this chapter.

Phase	Aims	Methods
Phase 1: Mineral beneficiation	To explore the effects that different beneficiation practice and direction can have on the resultant furnace charge.	Copper minerals were beneficiated by different participants given different processes to follow with the results analysed chemically to asses levels of enrichment/change.
Phase 2: Behaviour of refractory ceramics	Understand the role of Sintashta ceramic fabrics in the metallurgical process. Specifically; the effects of talc temper on the function of the ceramics.	Different ceramic recipes were tested in the laboratory and field by charging crucibles with sulphide ore and slag and assessing the levels of interaction between the charge and ceramic body.
Phase 3: Airflow	To understand the effectiveness of different configurations of bellows in producing a fusion zone capable of producing Sintashta type slag.	Programs bellows experiments that measured the extent of fusion zones and temperatures achieved.
Phase 4: Furnace architecture/slag morphology	To explore the ability of different of metallurgical structures in producing an atmosphere and fusion zone suitable to produce small slag plates..	Different furnace structures were constructed from unlined pits to more elaborate superstructures with temperatures recorded and then tested with a simulated charge.
Phase 5: Charge type	to enact the different smelting pathways suggested for both oxide and sulphide ore and to explore the resultant slag types.	A series of five smelts in small heart structures using different respites featuring both types of ore following various processes.

7.1 Mineral beneficiation

As mentioned earlier, ore beneficiation, the enrichment of metal bearing minerals by non-pyrotechnical means, is an often overlooked aspect of metallurgy yet it is perhaps the most effective means of enriching a primary mineral. There is significant archaeological evidence suggesting that ore beneficiation was routinely carried out in prehistory with crushing stones, mortars and tailings found on a number of ancient metallurgical sites around the world (Doonan 1996; Ottaway 2001; Yener and Vandiver 1993).

At Stepnoye and Ust'ye the presence of a beneficiation stage was suggested by the regular size of ore fragments at both sites, the homogeneity of the ore, particularly at Ust'ye, and the number of tools that may have been used in ore preparation. These experiments were undertaken to explore the effects that differing direction, mineral type, and beneficiation practice can have on furnace charge.

7.1.1 Methods

Two different types of sulphide ore were used in these experiments, one from Rio Tinto in Spain and a sample from an unknown mine from a mineral supplier. Each mineral had a different concentration and suite of gangue minerals. A sample of each ore type was crushed, homogenised and analysed using pXRF before the start of the experiment. This allowed subsequent comparison of the gangue to ore ratio for different beneficiation strategies.

All of the ore was crushed to produce fragment sizes of less that 1cm. Following the initial crushing different instructions were given to individual participants (students) to hand pick the ore. The students had all been studying an archaeomaterials masters course and were, to varying degrees aware of how to identify copper ore. Table 7.2 shows the instructions given.

7.1.2 Results

Analysis of ore samples from each group following their selection confirmed that there was some enrichment of Cu, Fe and S caused by hand selection in the groups asked to pick ore *from* gangue and those told to only separate the 'yellow' ore (M3 and XY), (see Figure 7.1). Overall, enrichment was low. The levels of enrichment varied across the different students. Only two students conducted both washed and unwashed experiments with ore 1 (PD and JB). One of the students failed to enrich the ore to gangue ratio when the ore was unwashed, but did succeed in identifying higher grade fragments following the washing while the other manage to enrich the unwashed ore but failed to enrich the washed ore.

There was also a slight difference between the two types of post-washing methods. The three students who were told to only pick the ' yellow' samples (XY) seemed to perform better than those who were simply told to separate the ore from the gangue (M3). However, this also seems dependant on the individual participant.

Experiments with ore 2 were all carried out by the same pair of students, it is therefore possible to better note the variations between the methods. In addition to this the ore had nearly double the overall copper content of ore 1. All three methods and instruction

Table 7.2 The instructions given to students during the beneficiation experiments.

Mode	Instructions given to the student
M2	crush and then sort by hand, pick the ***gangue*** from the ore
M3	crush the samples, wash and then sort, pick the ***gangue*** from the ore.
M4	wash and hand sort, pick the ***ore*** from the gangue.
XY	following washing and crushing pick the yellow lustrous fragments.

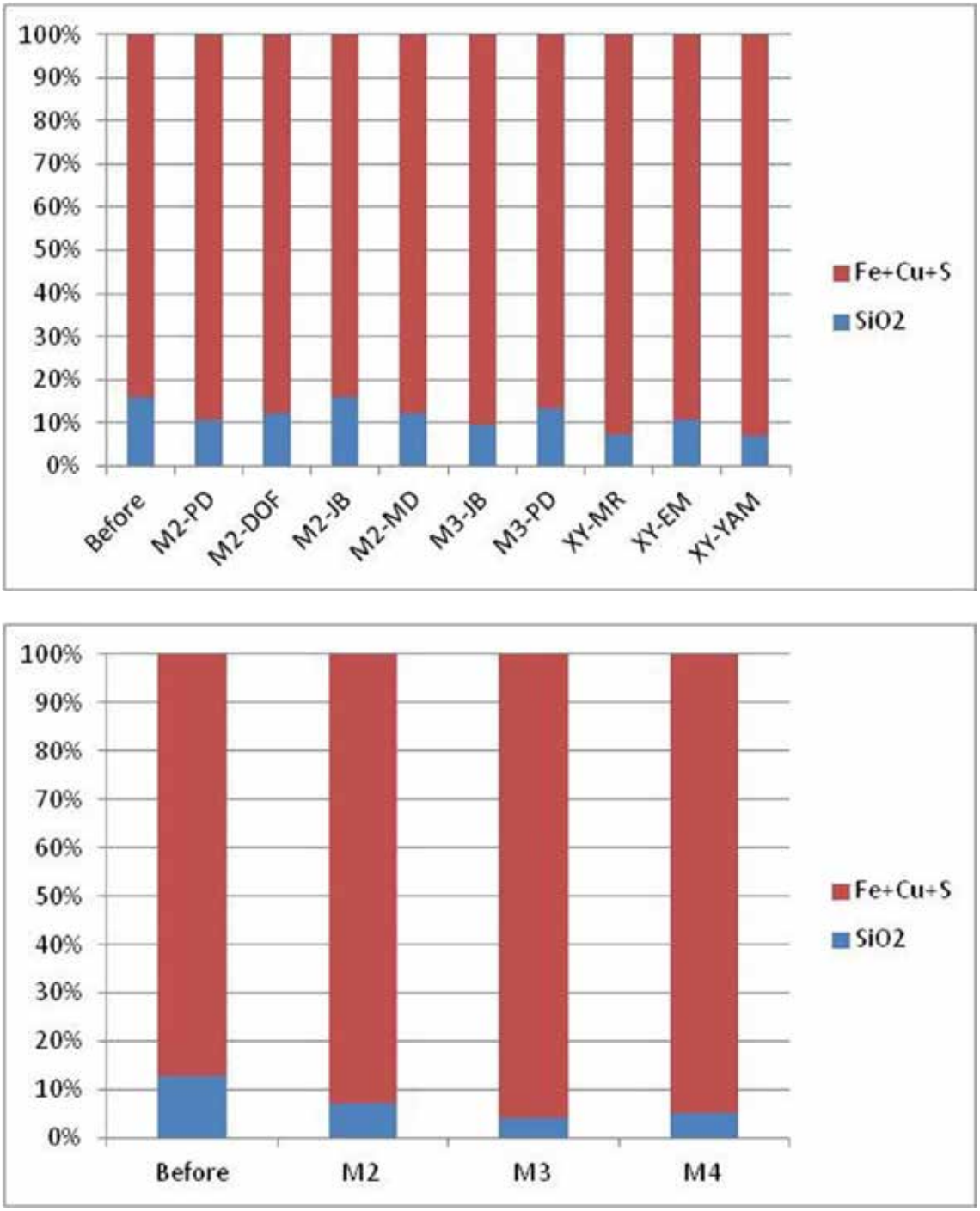


Figure 7.1 Ratio of ore minerals to gangue in the ore 1 experiment (top) and the ore 2 experiments (bottom).

sets resulted in an enrichment of the ore. The most enrichment occurred during M3 where samples were washed and the students were instructed to remove the gangue.

7.1.3 Conclusions

Overall these experiments show that both experience, and how the task is conceptualised can have a bearing on outcome of the beneficiation process. Throughout the experiment the students who were fully engaged with the process beyond simply following instructions, produced better results. In the cases where like for like methods were used the more enthusiastic students were more selective and produced a more enriched charge. This is also true for the levels of innovation noted during the day. While none of the students were especially skilled in beneficiation those who made an effort to understand the overall process, by the end, learned quicker and produced stronger results. Therefore, while beneficiation is a skilled task, it is one which can be learnt quite quickly. It relies more on visual acuity than physical prowess and skill. It is also noteworthy that washing had a measurable effect on success, with some of the most successful experiments resulting from washed samples. The proximity of Sintashta settlements to water may be significant in this context.

7.2 THE BEHAVIOUR OF REFRACTORY CERAMICS

Ceramic behaviour was explored both in the laboratory and through full-scale field reconstructions. The infrequent presence of heavily vitrified ceramics in the material examined is unusual as such 'technical' ceramics (Martinon-Torres and Rehren 2014) are a normal component of archaeometallurgical assemblages. It has already been noted that lightly vitrified and heat scorched ceramics are noted from Ust'ye and these were associated with elevated copper concentrations supporting their role in the metallurgical process. Typically, ancient metallurgical ceramics were coarse and highly tempered with organics (Hauptmann 2007; Thornton and Rehren 2009) exemplified by the mining district of Faynan, Jordan. However, the material attributed to metallurgy at Ust'ye and Stepnoye was fairy fine and was largely indistinguishable in fabric from non-metallurgical ceramics. So, despite the analysis presenting compelling evidence that the ceramics were indeed used in a metallurgical context it posed significant questions regarding how they could have possibly survived the process. To better understand the role of ceramics a series of experiments were undertaken that were targeted at understanding the mechanics of ceramic/slag/charge interaction (Table 7.3).

7.2.1 Methods

In the first phase of experiments, carried out in a set of ceramic crucibles which were constructed and fired in a high temperature furnace, were conducted with two types of charge, A, crushed archaeological slag and, B, a copper matte (an intermediate product in the smelting of sulphide minerals).

In both sets of experiments small briquette crucibles were fashioned with a standard sized (c.1.5cm) depression in the top. The depressions were filled with 0.5g of charge before being placed in an Lenton electric furnace at 1200°C. As the furnace was highly oxidizing each briquette was covered in a piece of charcoal to prevent loss of charge (particularly in

the case of the matte). Following the firings the briquettes were sectioned and prepared for reflected light microscopy (see appendix A for methods).

The field programme consisted of five smelts carried out in a relatively simple clay bowl furnace (Figure 7.2). The charge was the same for each smelt; consisting of beneficiated chalcopyrite, which had been crushed to <1cm fragments, and pure silica. In total 100g of chalcopyrite was mixed with 20g of silica. The charge was placed in the plate crucible and placed in the furnace prior to the addition of fuel (Figure 7.2).

Each smelt was run for approximately 30 minutes with a total of 740g of charcoal added throughout. The airflow was supplied by a single fixed tuyére producing approximately 200 litres of air per minute. The location of the tuyére was based on the in-situ tuyére excavated at Arkaim. The crucible was then removed and left to cool.

7.2.2 Results

The results of this phase of experiments have been divided between the laboratory and field experiments.

Laboratory

The range of results from the slag tests can be seen in Figure 7.3 and the range of results from the matte laboratory tests can be seen in Figure 7.4 with a summary of the results can be seen in Table 7.4. It is clear that the different tempers have a significant effect on the relationship between ceramic and charge.

Both series of experiments produced broadly similar results with talc and sand tempered crucibles retaining the interacting with the charge much less than the organic tempers. While the slag and ceramic reacted in most cases to form an 'interaction layer' the matte charge tended to 'search'. Searching is where the liquid matte penetrates into the body of the ceramic fluxing with the finer fractions. The full results showed that while an increase in talc and sand produced a higher resistance to the ***searching*** characteristics of the matte, often limiting penetration less than 1mm, higher quantities of organic temper typically accelerated the ***searching***, in some cases running deep into the body of the crucible.

Field

A summary of the overall results can be seen in Table 7.5 and selected cross sections of crucibles are shown in Figure 7.5. Overall the interactions between ceramic and charge mirrored the results of the laboratory tests. Indeed the more successful retention of matte, coupled with the least interaction between ceramic and slag were the crucibles which contained either talc, or both talc and sand. It is important to note, that although the interaction zone between ceramic and slag was low it remained difficult to remove the slag from the crucible without severely damaging the surface.

7.2.3 Refractory ceramics: conclusions

The laboratory experiments show that, under relatively controlled conditions, the type of temper used can have significant affects on the level of interaction between ceramic and slag and the level of matte searching. The presence of talc seemed to have a significant



Figure 7.2 The plate crucible loaded with ore and placed into the experimental furnace (Top, photo A Forshaw) and the furnace brought up to temperature by the electric forced draft (Bottom, right).

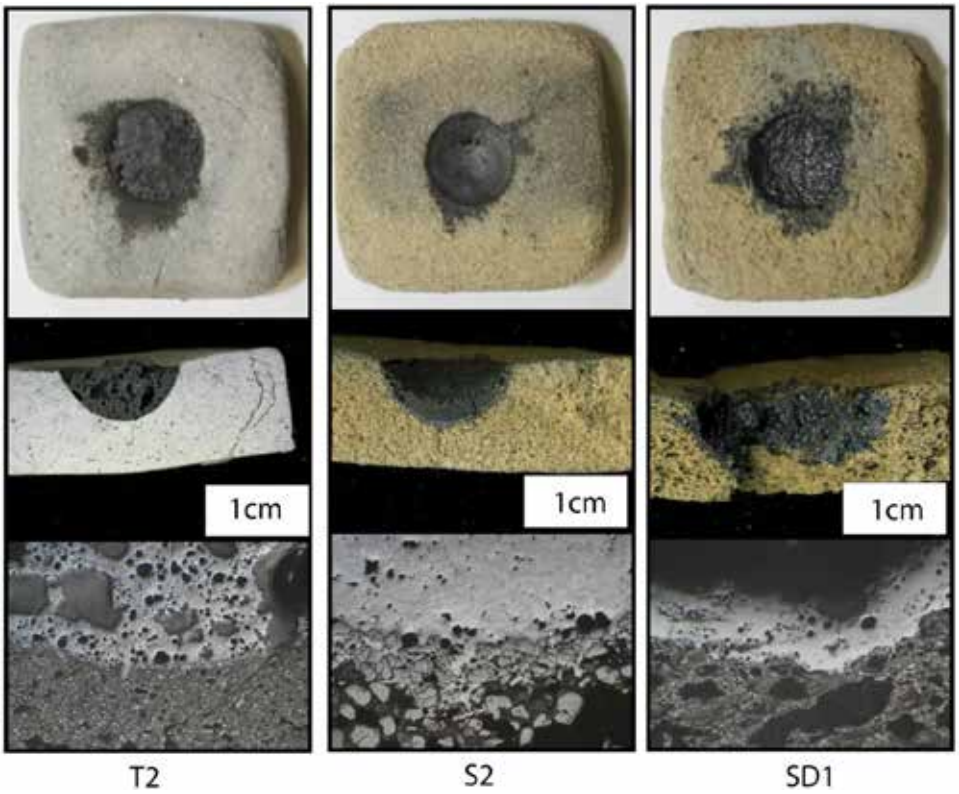


Figure 7.3 a selection of the crucible experiments showing the interaction zones between the crushed archaeological slag and the talc tempered ceramic (T2), the sand based fabric (S2) and the sawdust tempered ceramic.

Table 7.4 Summary of the results of the ceramic interaction experiments.

Dominant Temper	Slag interaction zone	Matte retention
Sand	2mm	Good, no 'searching'
Talc	<0.5mm	Good, no 'searching'
Organic (sawdust, manure etc.)	10mm	Poor, extensive searching

Table 7.3 Summary of the refractory ceramic experiments carried out.

Program	Experiment	Aim	Methods
Refractory Ceramics	Laboratory A	explore the levels of interaction between slag and a ceramic using a variety of tempers in a controlled	Briquette-crucibles tempered with sand, talc, sawdust and charcoal charged with crushed archaeological slag and heated to 1200oC in an electric furnace
	Laboratory B	explore the levels of interaction between matte and a ceramic using a variety of tempers in a controlled	Briquette-crucibles tempered with sand, talc, sawdust and charcoal charged with crushed archaeological slag and heated to 1200oC in an electric furnace
	Field	test the effects of different tempers on the ability of a crucible to maintain a sulphide rich charge in a charcoal fuel furnace	Plate crucibles tempered with sand, talc, sawdust and charcoal charged with sulphide or and smelted using charcoal with air supplied by an electric fan

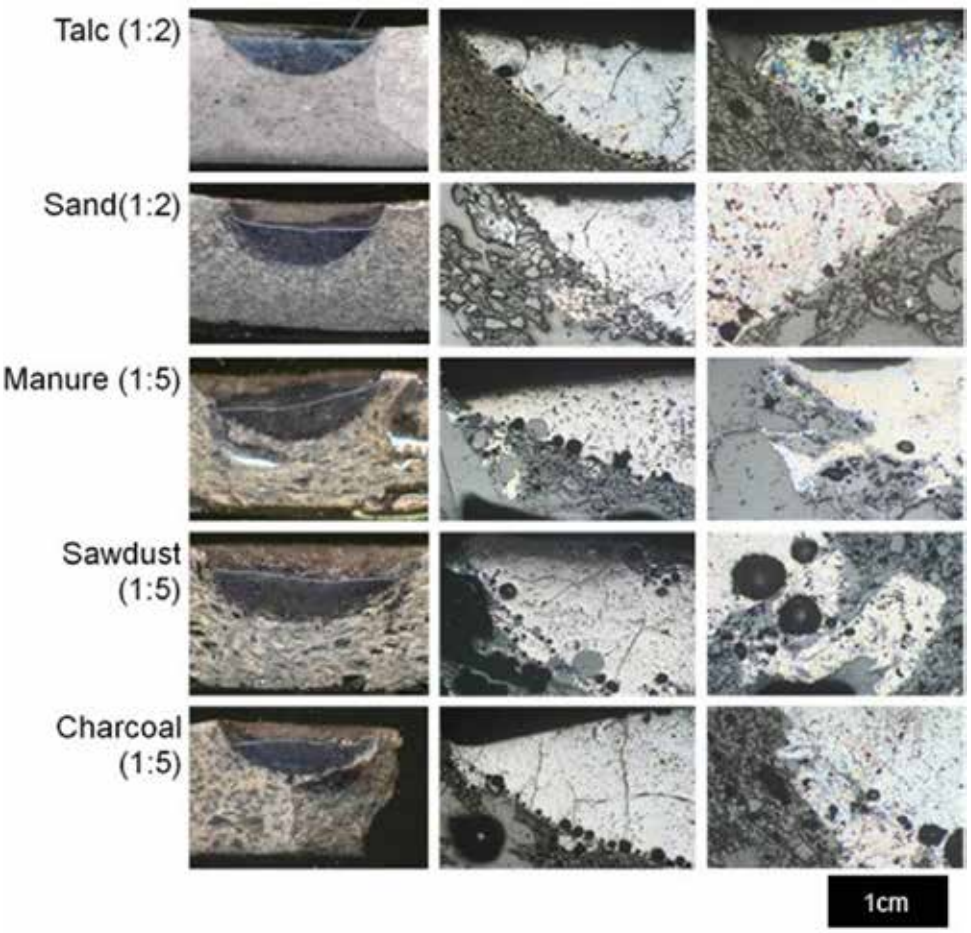


Figure 7.4 A selection of the crucible experiments showing the interaction zones between the matte and the talc tempered ceramic (top), the sand tempered fabric the sawdust tempered ceramic and the charcoal tempered fabric.

Table 7.5 Observations of the ceramic/charge interaction (adapted from Forshaw 2011)

No.	Ceramic	observations	Charge adhesion
1	Talc	Very little interaction between charge and crucible with some searching in fissures.	Very strong, difficult to separate the charge from the body.
2	Sand	Very little interaction between the matte and crucible but some interaction between the slag and ceramic.	Very strong, difficult to separate the charge from the body.
3	Charcoal	Some clear searching and distortion of the surface of the crucible with a clear interaction layer between ceramic and slag.	Very strong, difficult to separate the charge from the body.
4	Talc and charcoal	Considerable searching on a fissure at one side of the crucible in the area which seemed to have been hottest with smaller searching areas in other parts.	Very strong, difficult to separate the charge from the body.
5	Talc and sand	Full retention of the charge with very little interaction between matte and ceramic but a defined interaction layer where the slag was in contact with the ceramic surface.	Very strong, difficult to separate the charge from the body.

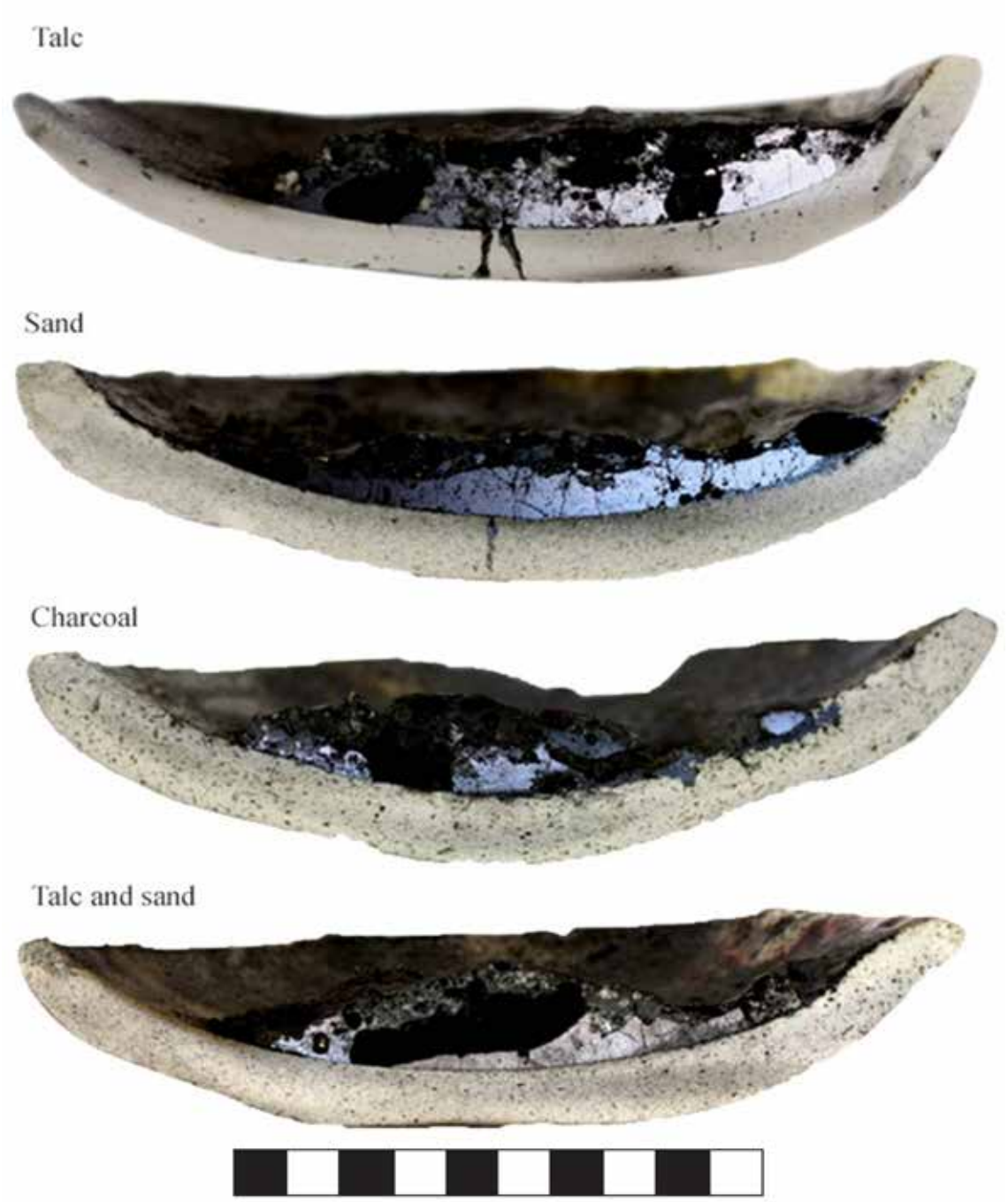


Figure 7.5 The reaction between the charge and crucibles during the field firings.

effect on the behaviour of these crucibles and it is likely that talc temper was a significant feature of Sintashta ceramics.

These experiments have shown the importance of understanding ceramic slag interaction. The results present the possibility that the ceramics highly tempered with talc found in the Southern Urals were excellent refractory ceramics, however, they still cannot account for the relatively clean surface of the metallurgical ceramics and the well- formed lower surfaces of the slag. It is likely that talc tempered clay deposits were either sought deliberately of a temper was added to local clays. The recipes used in these experiments, which are as close an approximation of Sintashta ceramics as possible, were used throughout the rest of the experimental programme.

7.3 The use of air in the smelting process

The manner in which air is introduced in to a pyrotechnical system affects more than temperature and furnace environment , it also affects how introduced materials, including ceramic crucibles are affected by heat (see section above). The airflow rate and manner in which it was introduced into the furnace were themes continually explored during this programme but were addressed explicitly during this phase of experiments. To date, two types of tuyére have been identified in the Southern Urals, narrow internal diameter (<5mm) and wider internal diameter (~20mm) with both examples found at Ust'ye. It is possible that the former were associated with blowpipes while the latter were associated with bellows. However, the narrower examples have not been directly associated with metallurgy. Therefore only bellows are explored here. It has also been suggested that bellows were used to supplement the natural draft in the elaborate well-tunnel furnaces, and that wood may have been used as a fuel (Grigor'yev and Rusanov 1995), therefore it is important to understand the size of fusion zone produced by Sintashta type tuyères. The aim of this program was to understand the effect of different bellow configuration on both wood and charcoal and to explore the structure of the high temperature 'fusion zone' created.

The experiments were carried out in three identical bowl heaths with various tuyére configurations (Figure 7.6). The aim was to identify the extent of the 'fusion-zone' created by each tuyére, when used in isolations and in parallel with others, as well as the effect that fuel type has on the size and structure of the hot zone.

7.3.1 Methods

These experiments were each run over a period of an hour with a 20 minute preheat before each firing. Temperature recordings were taken after bellowing commenced and continued to be recorded until the temperature became stable. During the main phase of the firing, when two sets of bellows were present, the bellows were pumped simultaneously at an average rate of 50 strokes per minute. The same rate was used for the single bellows. Following the main firing different bellowing procedures, specifically alternate bellowing, were attempted and ad-hoc temperature reading were taken in order to assess the differences. However, the main methods were as follows;

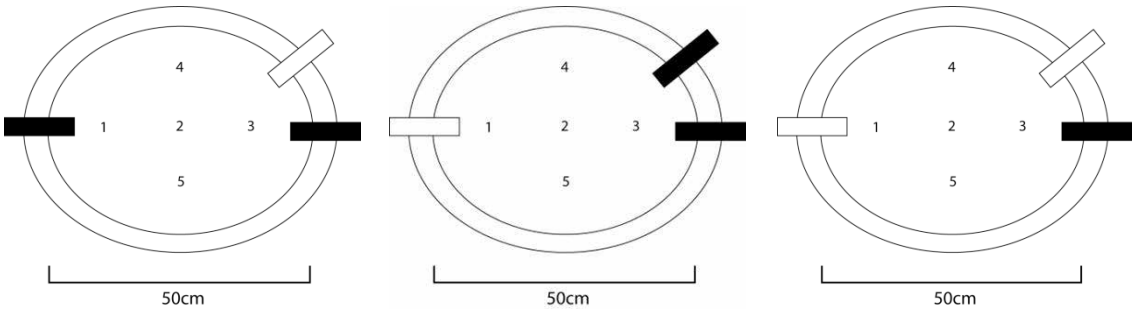


Figure 7.6 Schematic plan of the furnace used during the airflow experiments showing the location of thermocouples (1-5) and the tuyére configurations (black rectangles).

- Simple bag bellows were used with a maximum capacity of 10 litres which, at the average bellow rate gives a maximum theoretical airflow of 500 litres per minute/ bellow.

- Temperatures were recorded every 5 minutes at the locations labeled 1-5 in Figure 7.6.

- All of the temperatures were recorded using transition junction, high temperature thermocouples.

- They were placed in the furnace at the time of recording to prevent the tip from becoming over heated due to their maximum operating temperature of 1300°C.

- Following the experiments the results were integrated to produce isothermal models of each experimental set up.

Through modelling isotherms it was possible capture a snapshot of furnace performance and the distribution of heat.

7.3.2 Results

A summary of experiments are shown in Table 7.6, with isothermal contours given in Figure 7.7 and 7.8 for each experimental trial. In both the wood and charcoal firings the hottest recorded temperature occurred using a single tuyére. This was surprising and suggests that the use of more tuyéres and bellows had the effect of cooling the charge (Merkel 1982). It was soon established that it resulted in an overall drop in temperature.

7.3.4 Airflow: Conclusions

The presence of a defined fusion zone, something that has been observed experimentally elsewhere (Juleff 1997), is something that was clearly noted throughout these experiments. The dynamics and structure of the fusion zone(s) seemed to be dependent on multiple factors. When using wood as a fuel the heat was not as high as with charcoal, but the position and structure of the fusion zone seemed fairly consistent. It was only when the single bellows were used that the fusion zone moved to the right of the furnace and

became more compact. Whereas with charcoal the hot zone was consistently around 25cm in diameter and was typically near to the tuyére. The only exception was in the second charcoal firing (firing 6) where the combined force of the two bellows seems to have forced the fusion zone to the centre of the furnace. The cause of this difference is possibly due to the structure of wood versus charcoal; while the charcoal was typically of a standard size and shape the wood was more irregular. It is likely that the size and shape of the charcoal both prevents the blast from penetrating beyond a certain point and acts as a temporary superstructure, keeping the hot zone confined. The structure of the hot zones in clearly visible in Figures 7.7 and 7.7.

Air draught has a significant impact on the development of fusion zones within the furnace. Experiments with bellows showed the fusion zone generated by each tuyére was maintained when two, parallel tuyéres were used. When two opposing tuyéres were employed, two discrete fusion zones were formed and left a slightly cooler area in the middle, despite the relatively small furnace size. Therefore the most effective configurations were two parallel tuyéres or even a single tuyére. Indeed the latter could be considered the most efficient given that two tuyéres gave only a small expansion of the fusion zone for double the effort. This has significant implications regarding the organisation of metallurgical practice. It would be possible for only one person to conduct a smelt and produce the types of slag identified at Stepnoye and Ust'ye.

7.4 Furnace Architecture and slag morphology

This programme of smelts consisted of two phases of firings using a variety of furnace structures and bellow positions which were based on the results from the previous experimental campaign. The aim of this campaign was to explore the possibility that small and ephemeral furnaces could be used to produce the characteristic plate like slag.

The morphology of the slag plates from both Stepnoye and Ust'ye suggested that they could have been produced in a relatively small furnace, perhaps no bigger than 25cm in diameter. This is in stark contrast to the well-tunnel-furnace configuration detailed in Chapter 4. In addition to the evidence from the slag plates numerous smaller hearth structures were noted at Sintashta and Arkaim which seem far less complex than the well-tunnel-furnace. Indeed, one example at Arkaim strongly resembles a simple bowl furnace with a single, in-situ, tuyére. Some of the hearth structures at Sintashta and Arkaim were 0.4–0.5m in diameter and housed considerable evidence for burning with some containing slag and some of the features had one or two impressions where bellows might have been placed

Table 7.6 Summary of the airflow experiments.

Fuel	Tuyères	Max temp (T°C).	Min temp (T°C).	Average temp (T°C).	Differential at the hottest moment (T°C)	Standard dev. of hottest area thought firing (T°C)
Wood	Two, opposite	1100	570	832	450	57.4
Wood	Two, parallel*	1095	560	808	535	90.7
Wood	One*	1131	498	810	503	57.2
Charcoal	Two, opposite	1118	399	862	398	87.4
Charcoal	Two, parallel*	1250	540	879	570	86.6
Charcoal	One*	1300	422	754	878	90.8

**shown on the right hand side in all illustrations and graphs*

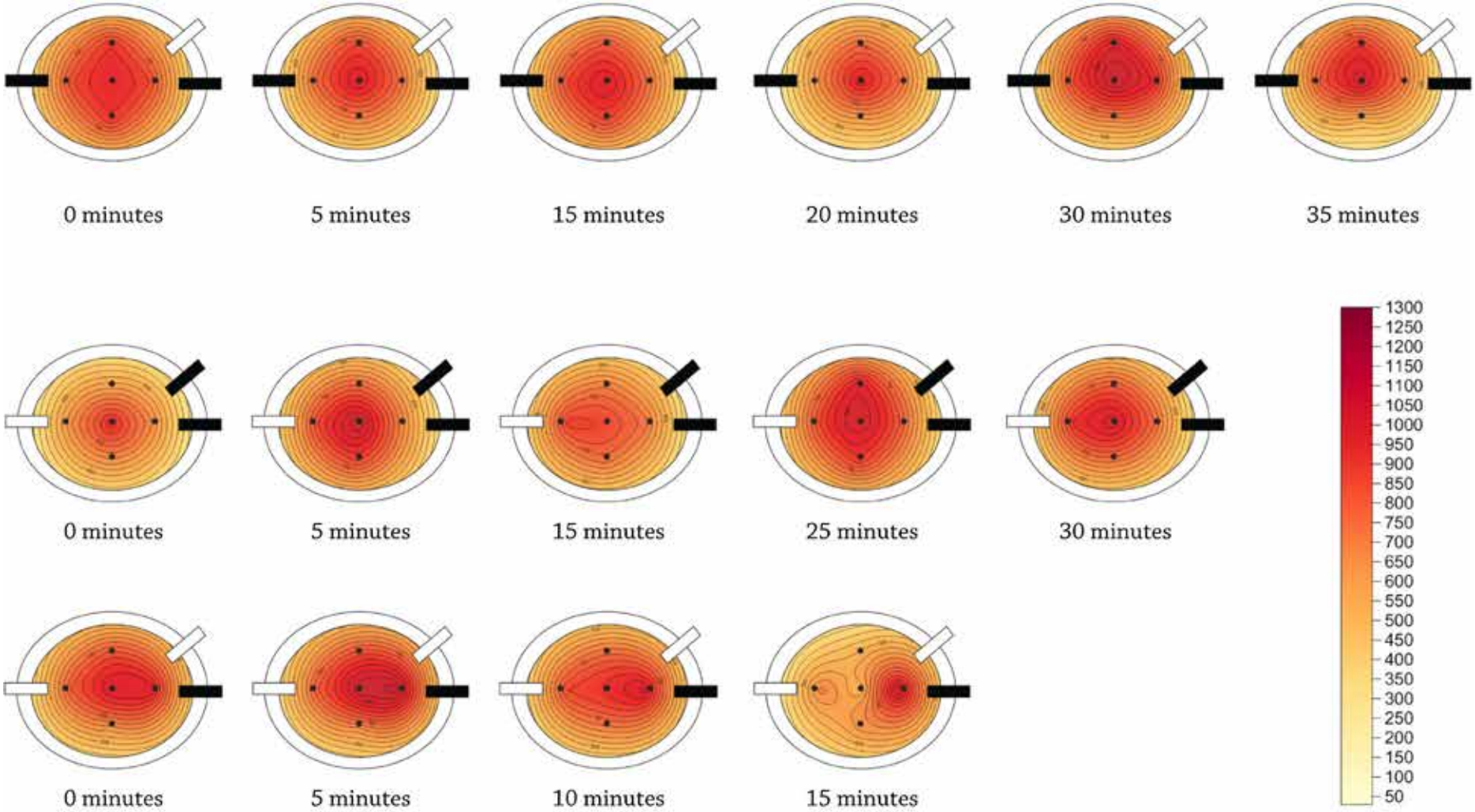


Figure 7.7 Furnace plan with horizontal heat profile using wood fuel (black rectangle =tuyère in use, black dot=thermocouple location)

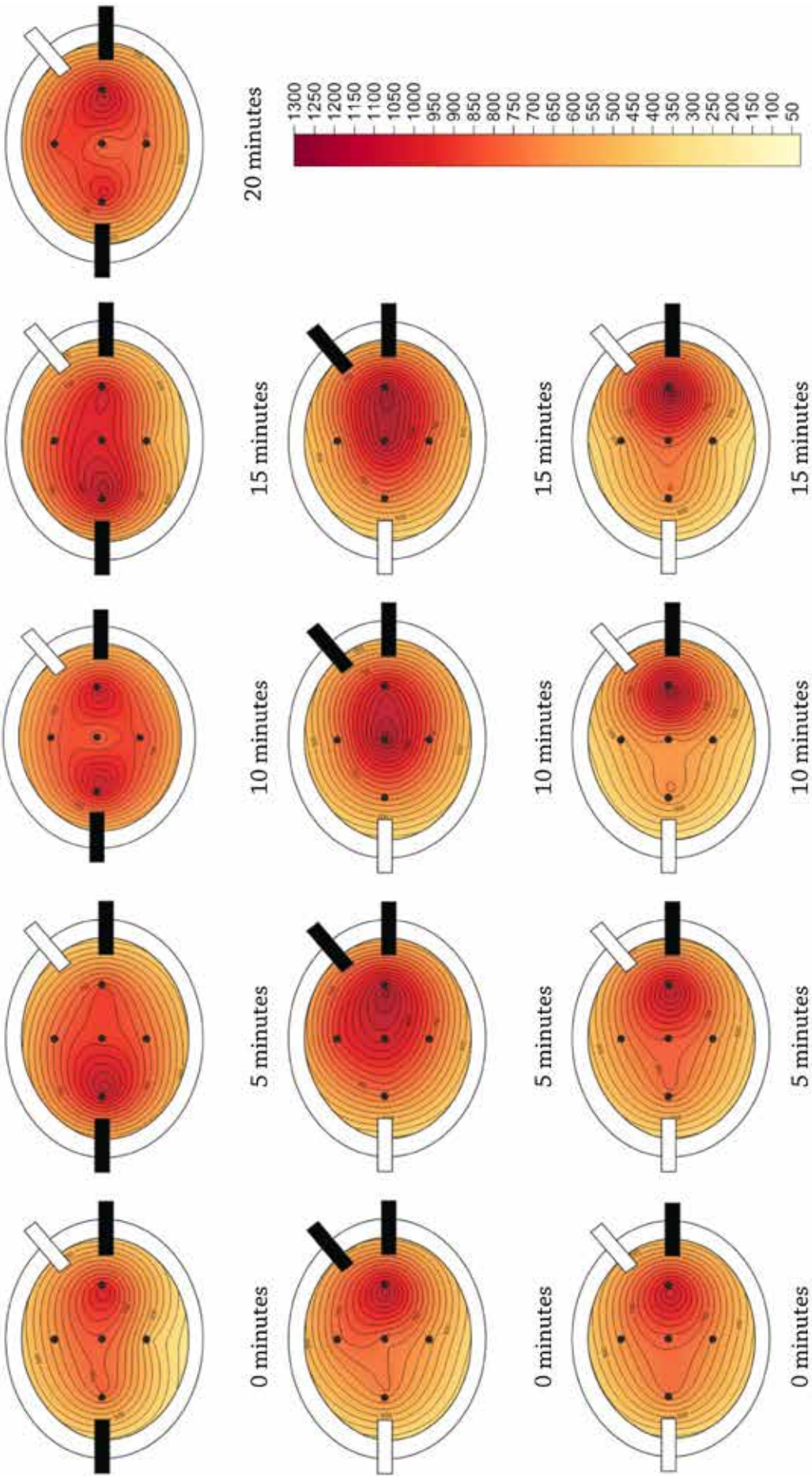


Figure 7.8 Furnace plan with horizontal heat profile using charcoal fuel (black rectangle = tuyère in use, black dot=thermocouple location).

Table 7.7 The main aims of the furnace architecture phase.

Experiment	Aim
Furnace design	Exploring the ability of a bowl hearth to reach smelting temperatures with and without different configurations of superstructure.
Slag Morphology	To produce a Sintashta type slag plates and ingots from a simulated charge of copper shot and crushed slag.



Figure 7.9 The furnace used during experimental smelt F2.

Table 7.8 Description of the furnaces used and the main results of the furnace structure experiments.

Phase	Experiment	Furnace	Tuyère configuration	Maximum sustainable temperature
Furnace structure	1	Open, clay lined pit c. 30cm in diameter	Single tuyère	900°C
	2	Clay lined pit with raised rim and an aperture of 25cm	Single tuyère	1000°C
	3	Clay lined pit with a dome shaped superstructure with an aperture of 15cm	Single tuyère	1250°C
	4	Clay lined pit with a dome shaped superstructure with an aperture of 15cm	Two, opposite tuyères	1250°C
Slag Morphology	1	Clay lined pit with a dome shaped superstructure with an aperture of 15cm	Two, opposite tuyères	N.A.

(Gening et al 1992). The fill of the hearths suggested that some form of superstructure may have been employed, possibly dome shaped (Genning et al 1992; Grigor'yev 2000). The aim of these two sets of experiments can be seen in Table 7.7.

7.4.1 Phase 1: furnace structure

These experiments attempted to reproduce adequate and consistent smelting temperatures using open bowl and covered hearths with different types of lining. The type of bellows used in all of the experiments were simple bag bellows with an internal capacity of approximately 10 litres, the bellowing rate was noted at 40 strokes per minute, which would have produced an airflow, under optimum conditions of up to 400l/m though a 2cm tuyére. The clay linings and superstructures were made from ball clay tempered with sand and straw. Each hearth structure was made on the day of the firing and dried out during the preheat phase. All of the experiments used a mix of oak/ beech charcoal and lasted up to an hour with fuel being added when the charcoal began to burn down. A summary of the methods and results can be seen in Table 7.8.

The first firing produced recorded temperatures of only 900°C and while it is possible that higher temperatures were reached in localised areas it was difficult to maintain high temperatures.

The second firing managed to reach higher temperatures, but the fusion zone was extremely localised and struggled to reach and maintain 1000°C. The third experiment easily attained the maximum temperature observable by the thermocouple of 1250°C. However, it required a significant physical effort to maintain this temperature for an extended duration. The final smelt of phase 1, which consisted of two opposing tuyéres with the same superstructure as the third (Figure 7.9), successfully reached the same high temperature and was maintained with ease for a prolonged period of time with comparatively little effort.

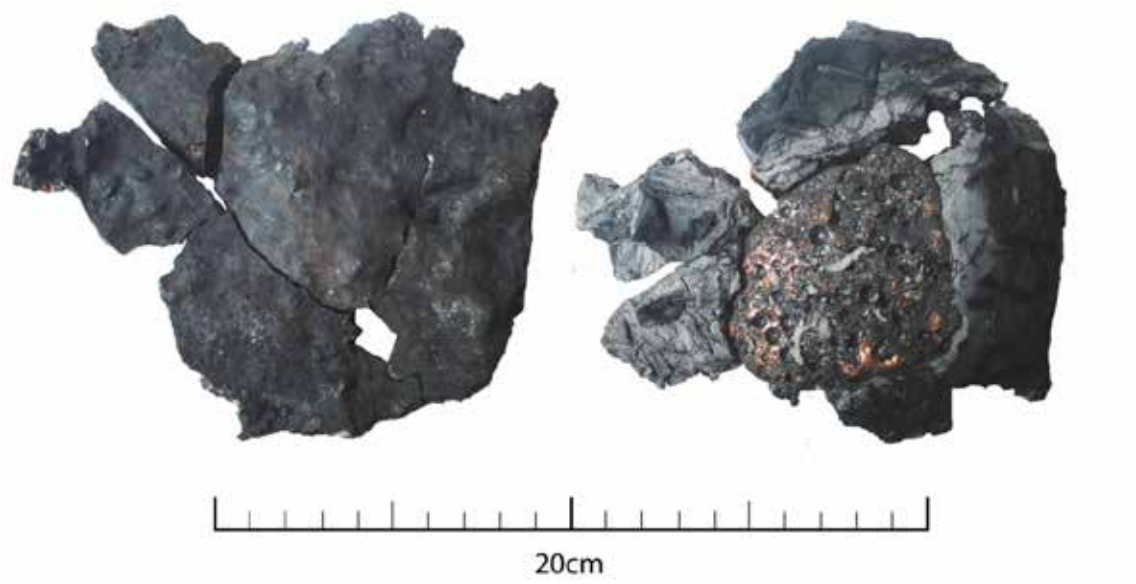


Figure 7.10 The product of experiment smelt F2 showing the morphology the slag and the coalesced copper ingot

7.4.1 Phase 2: Slag morphology

This phase consisted of only one experiment using a simulated charge of crushed slag and copper shot. The crushed slag was produced during earlier matte conversion experiments at the University of Sheffield. The simulated charge was made from 0.3kg of slag and 0.2kg of copper shot that was mixed into five smaller batches of 0.1kg. No crucibles were used in this experiment; however, the furnace base was made from the same ball clay, sand and straw mixture as in the previous experiments.

The experiment ran for two hours and the charcoal was allowed to burn down to about half of the internal cavity before being refuelled. Bellowing was kept as close to 40 strokes per minute as possible, which would produce a hypothetical maximum of 400 litres per minute. Realistically, due to inefficiency and variation in pumping action, the bellows probably produced closer to c. 150-200 litres per minute as shown by John Merkel in his early experiments (1982). The furnace was preheated for 30 minutes before the first batch was added. Batches were added approximately every 6 minutes between each refuelling. When all of the charge had been inserted, the furnace was given a final amount of fuel and then left to burn down over a period of 15 minutes. After which, the furnace was then allowed to cool for 30 minutes before being extinguished with water and the charge was then removed for examination.

The slag and ingot formed in this experiment bore a strong formal resemblance to the archaeological slag from Stepnoye. Some of the key traits, such as the underside impression and undulating upper surface, were present (Figure 7.10). Interestingly, when the charge was removed from the furnace it was evident that it has fused substantially to the furnace lining. This caused the slag to form without a defined lower surface and edge, which is one of the key morphological differences with the archaeological slag. While the archaeological slag typically has beaded edges, the experimental slag had completely fused with the ceramic lining suggesting either an incorrect composition or environment. An interesting observation drawn from this experiment was that the quenching had caused the slag to fracture into fragments similar in size to the archaeological examples. In addition,

if the experimental slag had not been fused to the furnace lining, it would have been very easy to remove the copper ingot.

7.4.3 Conclusions

These experiments show that it is possible to create and sustain an environment that can produce Sintashta type slag in a simple furnace. Building on the results of the airflow phase it is possible to suggest that simple furnaces can also be considered candidates for Sintashta metallurgy and certainly more so than the complex multi-chambered superstructures suggested by Grigoryev (2000) and would most likely require far fewer people to maintain a smelt. The use of smaller, less elaborate furnaces could significantly change the overall view of the so-called 'domestic units' in Middle Bronze Age settlements. The furnaces used in these experiments left an ephemeral footprint that bears more of a resemblance to the shallow scoops noted at Sintashta sites rather than the large burnt pits that are often interpreted as furnaces (Gening *et al* 1992).

7.5 Charge type

The aim of these experiments was to explore the outcomes of the different smelting pathways noted in chapter 3; direct reduction, roasting and reduction and co-smelting. The specific themes explored during this programme can be seen in Table 7.9. The aim of the second and third smelts was to conduct a direct reduction smelt using malachite as the charge. It was initially intended to be a single smelt but unfortunately the bellows failed during the initial firing and the charge was re-used for a second smelt.

7.5.1 Methods

These experiments were carried out following to the methods shown in Table 7.10. Three different furnaces were used in the experiments;

Furnace 1 consisted of an unlined pit with a 50cm in diameter cut 25cm into the ground (Figure 7.11). The pit was cut into compact sand, similar to the upper layers of steppe soil.

Furnace 2, shown in Figure 7.12, featured a 50cm clay lined pit (~4cm thick) with a raised superstructure and a 20cm aperture with two tuyére holes on opposing sided of the furnace that could be blocked when necessary.

Furnace 3, shown in Figure 7.13 consisted of a 30cm diameter clay lined pit with a 30cm aperture. The location of the tuyére and the floor plan of the furnace was aimed to best replicate the example excavated at Arkaim which contained an in-situ tuyère (Grigor'yev 2000).

In all of the experiments, fuel was added in 300-400g batches as required. Before each smelt the furnace was preheated, the fuel/embers was removed and the charged crucible placed in the base of the furnace. The burning fuel was then re-added and the furnace was brought back up to temperature. At the end of each smelt any remaining embers were scraped back before the crucible was removed and quenched slightly with water before being left to cool.

Table 7.9 The main aims of the charge type phase of experiments

Experiment	Aim
4.1	To explore the outcome of smelting a relatively pure carbonate ore in a simple pit hearth without lining or superstructure
4.2	To explore the outcomes of a direct reduction smelt in a more elaborate, clay lined bowl hearth using a carbonate ore and iron/silica flux
4.3	To explore the outcome of smelting the semi-fused product of a failed reduction smelt.
4.4	To explore the outcome of a co-smelt using a mixture of sulphide and oxide ore and a small bowl hearth
4.5	To explore the outcome of a partial roast followed by co-smelt/matte conversion in a small bowl hearth

Table 7.10 Summary of the experimental methods carried out during the charge type phase.

Experiment	Charge	Furnace structure/ Airflow	Pathway	Duration	Fuel use
4.1	100g of crushed malachite (c.20% Cu)	Furnace 1, single tuyére, bag bellows	Direct reduction	40 mins	1.5kg
4.2	200g of crushed malachite and 50g of crushed ironstone.	Furnace 2, single tuyére, bag bellows	Direct reduction	20 mins	1kg
4.3	Unaltered product of 4.2.	Furnace 2, single tuyére, electric pump (~200l/m)	Reduction (following partial reduction)	30 mins	2kg
4.4	175g crushed malachite, 100g of chalcopyrite and 100g of silica.	Furnace 3, single tuyére, bag bellows	Co-smelt	60 mins	2kg
4.5	200g, of crushed and roasted chalcopyrite and 100g of silica.	Furnace 3, single tuyére, bag bellows	Partial roast-- reduction	40 mins	1.5kg

The resultant slag and copper/matte was analysed using optical microscopy according to the methods outlined in Appendix A.

7.5.2 Results

Smelt 4.1

Smelt 4.1 produced a combination of semi-fused slag, copper prills and a significant amount of slightly roasted ore. The alteration structure of the charge in plan suggested that the heat had been focused on only one part of the crucible (Figure 7.14). Upon quenching it became clear that only a small amount of ore had reached temperatures that were high enough to smelt copper, a small number of copper prills had formed which ranged from sub-millimetre to four millimetres in diameter; therefore the hot zone must have been at least partially reducing.

Reflected microscopy of the slag showed that it was predominantly glassy with only some areas containing any crystalline phases which, when present, were lath like in structure. There were numerous small copper prills throughout the slag (Figure 7.15). Bulk chemical



Figure 7.11 The unlined pit acting as an impromptu bowl hearth during smelt 4.1



Figure 7.12 Furnace 2 in its single tuyére configuration.



Figure 7.13 The single tuyére and the furnace used during smelt 4.5 and 4.6.

analysis of the slag confirmed that it was highly siliceous and had absorbed a considerable amount of copper. It is likely that there was insufficient iron in the charge to form an optimum fayalitic slag, which also explains the high frequency of copper prills. An iron oxide flux would have significantly improved this smelt, and the resultant slag would have likely better resembled those from Ust'ye.

Smelt 4.2

Smelt 4.2 produced, 10g of well formed copper, which was surprising; given the small time the charge was exposed to temperature. Optical microscopy of the slag that had formed showed that it consisted of a glassy matrix with frequent delafosite, wüstite and skeletal magnetite with occasional metallic copper and free silica inclusions (Figure 7.16). This suggests that, for the time the smelt was at temperature, it was producing mildly oxidising conditions.

Smelt 4.3

Drung this smelt the charge had clearly reached higher temperatures than in the previous smelt as the crucible itself had become heavily vitrified and the tuyére tip has melted. The crucible was broken to reveal a mixture of slag, large copper prills and a small ingot. In total around 20g of copper was produced. Analysis of the slag showed that it was dominated by a glassy matrix with frequent copper prills (Figure 7.17). There were also numerous free silica inclusions, interestingly there were very few clear falayite phases, which suggests that there was still not enough iron in the flux to produce an optimum slag. Indeed the bulk analysis of the slag confirmed that it was high in silica. The formation of copper and the total absence of iron oxide would suggest that the furnace was sufficiently reducing. However, the ratio of silica/iron oxide in the charge was still less than ideal.

Smelt 4.4

When this crucible was removed from the furnace it was clear the it had fractured and



Figure 7.14 The semi fused product of smelt 4.1

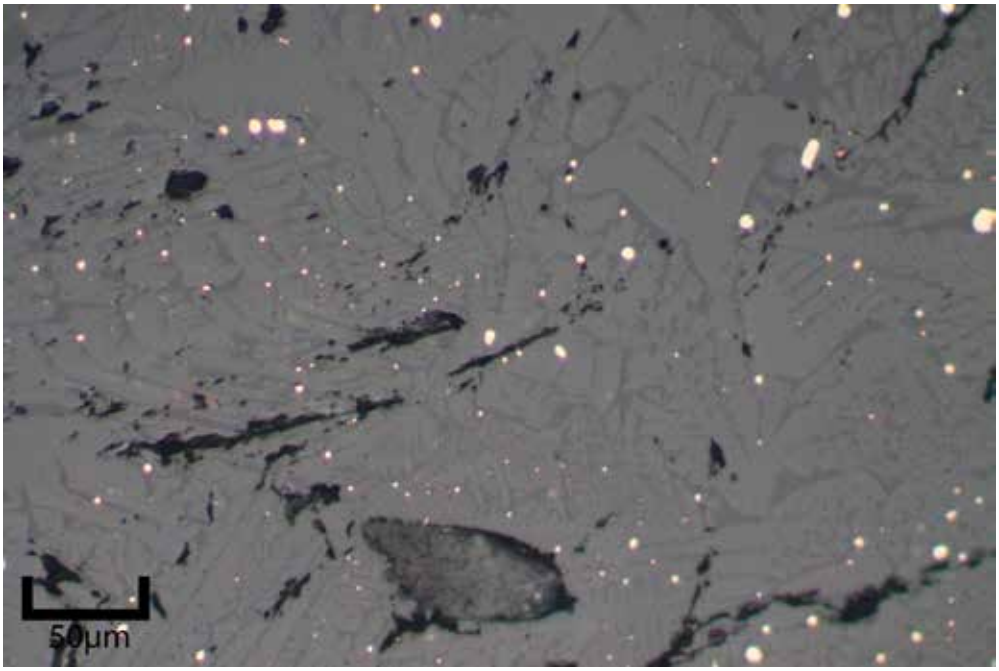


Figure 7.15 Photomicrograph of a section of slag form smelt 4.1 showing faint lath like phase formation and numerous copper prills.

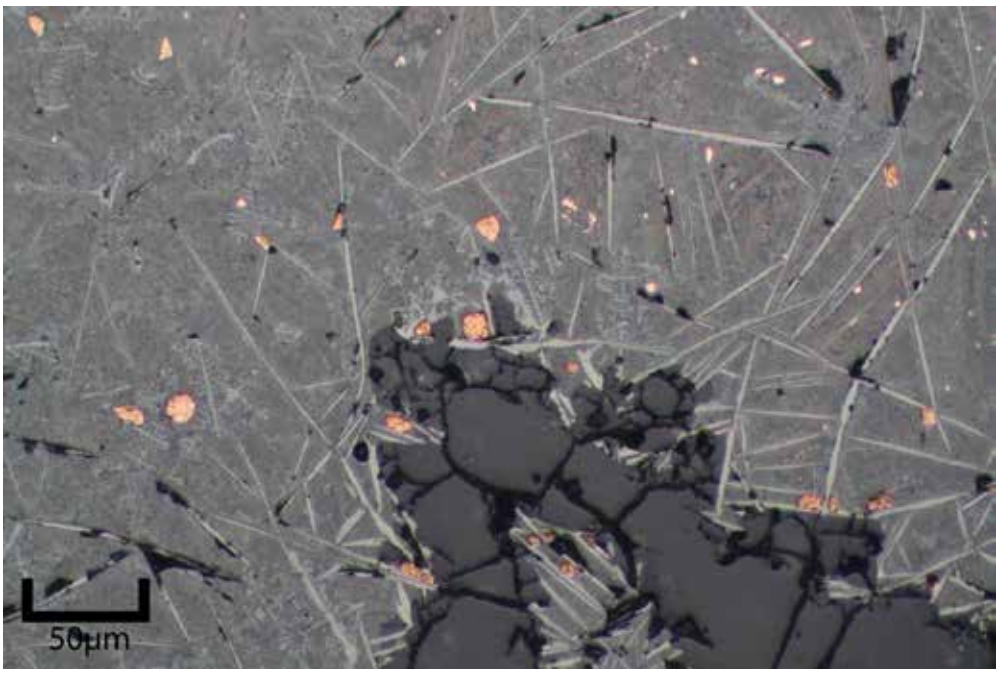


Figure 7.16 Granular free silica, copper prills, small, dendiritic wüstite and needle like delafosite in the slag produced during the first firing (4.2).

lost some of the charge. However, the majority remained in the part of the crucible near to the tuyére (Figure 7.18). The overall appearance of the upper surface of the slag bore a strong resemblance to the examples from both Stepnoye and Ust'ye. Indeed even the edges had begun to 'bead up' in places. The slag plate was then sectioned, however it immediately fractured into a numerous pieces revealing three 'ingots' which were dark grey and had a metallic lustre. One of the ingots had clear metallic copper inclusions.

Optical microscopy of the slag revealed a microstructure which so closely resembled Stepnoye slag it would be indistinguishable alongside the archaeological assemblage (Figure 7.19). It had a euhedral/lath like fayalite structure in a glassy matrix with common iron oxides in both dendritic and isometric form (wüstite and magnetite). There were also numerous copper prills, many of which had copper sulphide halos. It had initially been hypothesized that this phase configuration was indicative of a mildly oxidising matte conversion smelt (see chapter 4). Chemical analysis of the slag confirmed that it was similar in composition to the Stepnoye slag.

Analysis of the ingot revealed that is was dominated by a pale blue phase, which was likely chalcocite- (Cu_2S) which surrounded numerous copper prills (Figure 7.20). The rich copper sulphide composition of the ingot was confirmed using pXRF. It is likely that this experiment produced a copper rich matte. If the blue mineral is pure chalcocite then the following equation bet account for the reaction;

$$\mathbf{4CuO_2 + 5CuFeS + SiO_2 \rightarrow 4Cu_2S + Cu + Fe_2SiO_4 + Fe_3O_4 + SO_2}$$

It is likely that upon formation the matte became surrounded by slag, which prevented any oxygen from removing the excess sulphur, effectively choking the smelt. However if the ingot were placed in an oxidising atmosphere it would likely lose much of the sulphur producing a relatively pure metallic copper. It may also suggest that the process was only partially complete.

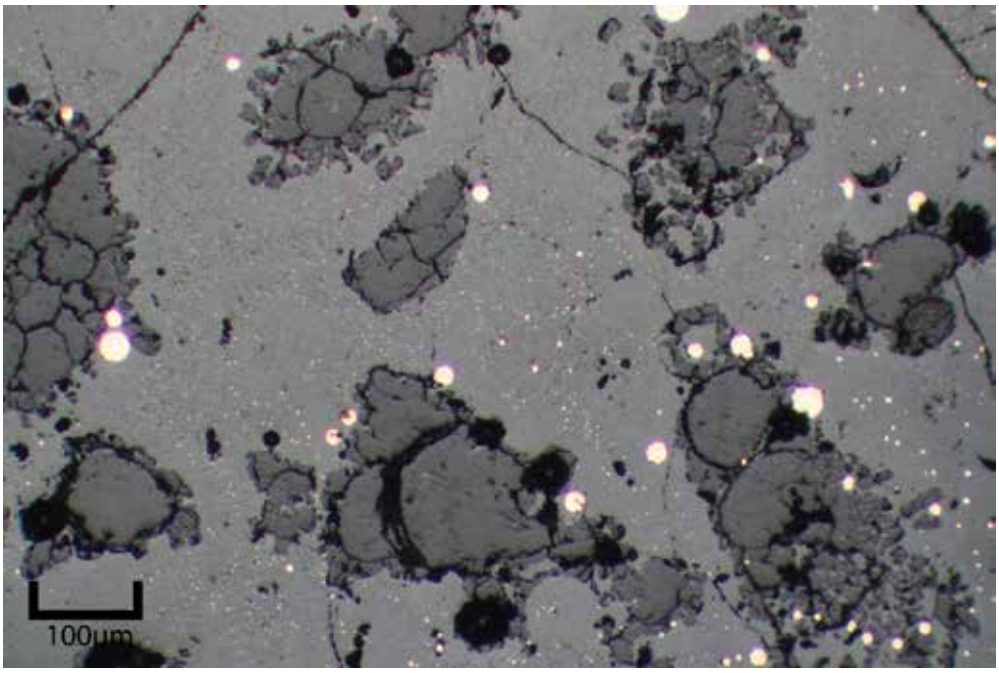


Figure 7.17 The more glassy product of smelt 4.3, showing none of the microstructure of 4.2 with the exception of the granular free silica.



Figure 7.18 The localised slag formation produced during experiment 4.5.

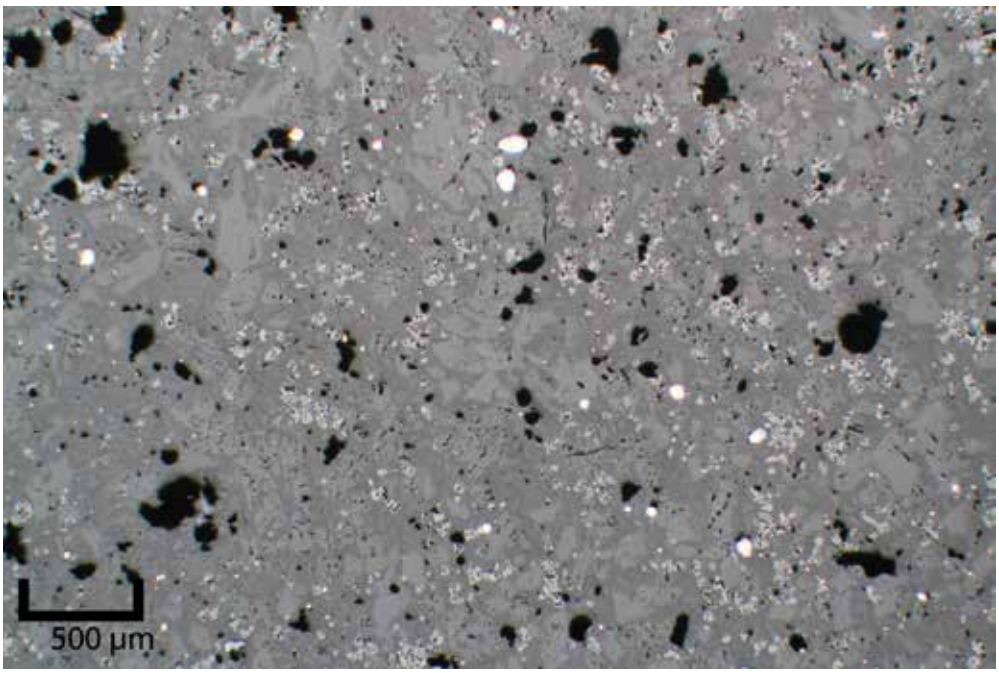


Figure 7.19 The slag produced during the co-smelt showing tabular silicates, magnetite spines, sulphide inclusions and copper prills in a glassy matrix.

Smelt 4.5

Following this smelt the appearance of the charge bore a strong resemblance to the previous smelt (Figure 7.21). Indeed upon sectioning the slag fractured into numerous small fragments, revealing numerous ingots which were dark with a metallic lustre.

Optical microscopy revealed the fragments were a mixture of unaltered chalcopyrite, enriched chalcocite/bornite and metallic copper (Figure 7.22). The metallic copper was formed along the chalcocite/bornite grain boundaries. It is possible that the copper was derived from areas of copper oxide which were produced during the roasting phase, with the sulphur lost from some of the chalcopyrite acting as a reducing agent.

Analysis of the slag (Figure 7.23) showed that it was overall fairly glassy, with some localised fayalite, wüstite and copper sulphide inclusions. However the overall lack of fayalite formation is consistent with the high iron content in the ingot.

7.5.3 Conclusions

This final phase of experiments provided significant insight into different aspects of the copper smelting process. The first smelt (4.1) confirmed the possibility that a relatively pure copper ore could be reduced with the most ephemeral of structures. Had this been embellished slightly, perhaps with an ad-hoc arrangement of ceramic sherds like those found at Ust'ye, more copper and a well formed slag would likely have been produced. The significant difference noted in the products of the second and third smelts confirms the effectiveness of a slightly more established furnace. Even in the limited time of smelt 4.2 a small of amount of slag and copper was produced with even better results in the third experiment. However, the slag was not comparable to the archaeological material and it was clear that the charge was too rich in silica. More iron oxide may have produced a more successful result.

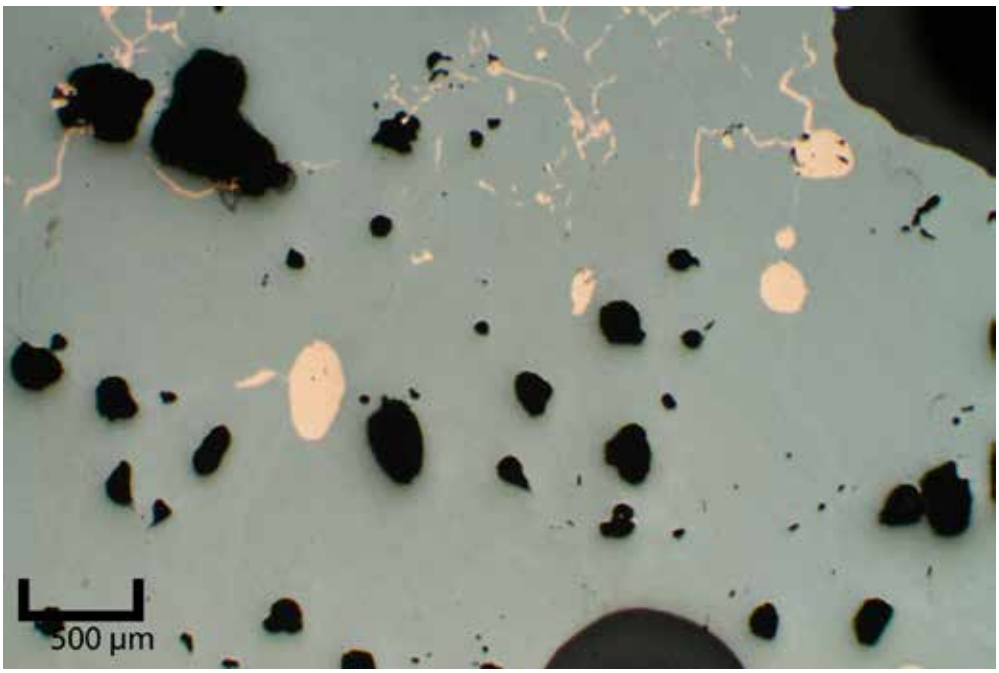


Figure 7.20 Photomicrograph showing the matte ingot produced during smelt 4.6 showing the metallic copper inclusions and the blue copper sulphide.



Figure 7.21 The product of smelt 4.6 showing the well formed slag.

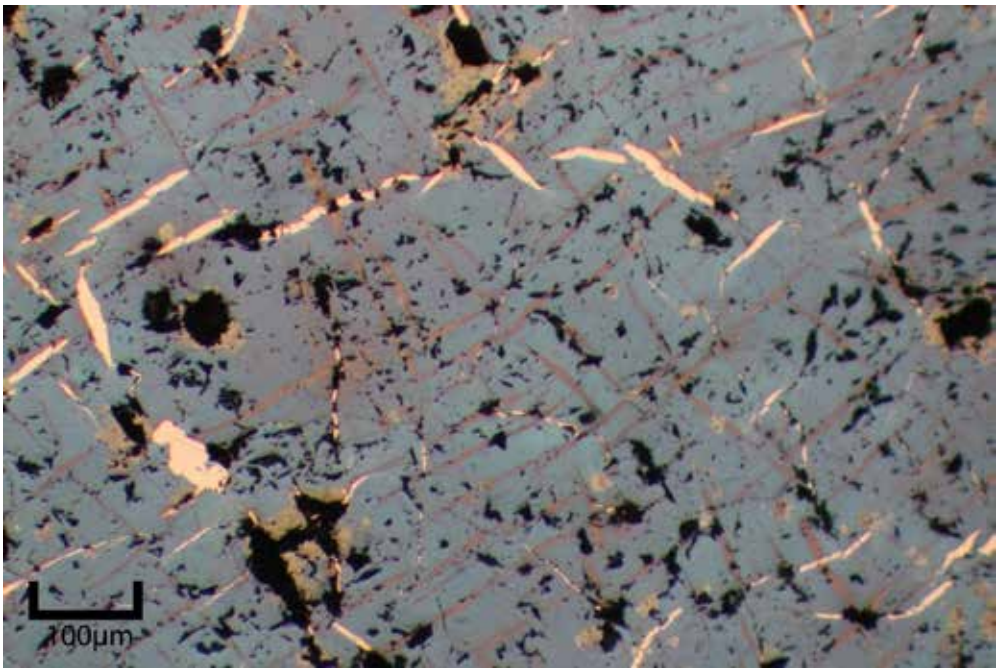


Figure 7.22 The charge formed during experiment 4.6 showing the metallic copper forming on the grain boundaries of the ore.

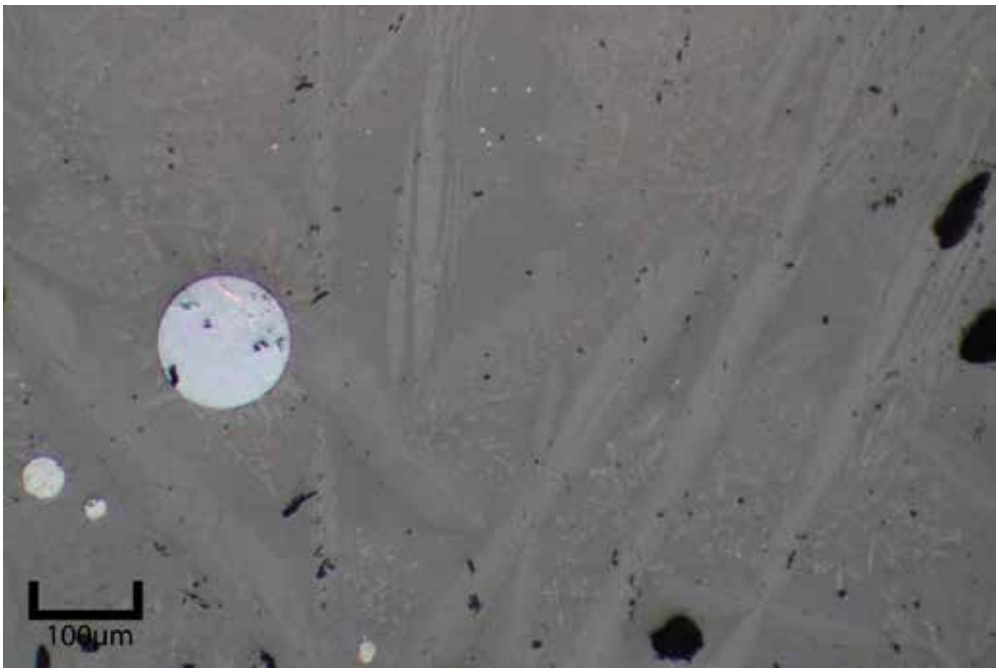


Figure 7.23 The slag formed during 4.6 showing the early formation of lath like silicates and a large copper sulphide prill.

The fourth smelt, which followed the co-smelt pathway was the first to produce a slag which resembled the archaeological material in form and composition. While still not fully formed in the characteristic plate-like appearance some attributes were present. Particularly striking was the microstructural resemblance to Stepnoye slag. While this does not prove that co-smelting was practiced at Stepnoye it does at least present the possibility.

The final experiment also produced a slag with some of the formal characteristics of the archaeological materials. However it was clear that the process was less than complete. It suggests that the roasting phase was not completely effective and may explain the presence of residual sulphides in the archaeological slags

7.6 Summary

The experimental campaign has covered themes from beneficiation through to smelting practice. Many of the problems investigated here were drawn directly from the SCARP fieldwork programme and questions that arose through the programme of analysis presented in the previous chapter.

The beneficiation experiments showed that the practice of crushing, sorting and washing an ore can have significant implications regarding its composition and would in turn effect smelting choices. A surprising variance in ability was noted among participants suggesting an otherwise menial task required a degree of skill.

Airflow is an intangible aspect of the metallurgical process yet a critical one. It is only represented archaeologically in the form of tuyères and evidence of elevated temperatures. With both narrow gauge and larger tuyères found at Sintashta sites it is possible that both blowpipes and bellows were used however, it is not clear whether they would be used in different aspects of production, or in parallel. It is clear though, that even the larger tuyères could only produce a maxim fusion zone of ~25cm. This has significant implications regarding how smelts were organised and the number of people that were directly involved in the smelts.

In the context of the Southern Urals the experiments which centred on the use of metallurgical ceramics and the observations drawn from the programme are significant. The experiments confirmed that different tempers cause the ceramic to act in vastly different ways when exposed to smelting conditions. This is particularity true in the case of talc which dramatically alters the eventual appearance of metallurgical ceramics. While none of the experiments successfully produced a slag and ceramic that were easily separated the benefits of talc were clearly noted. It seems that, while talc pottery is common in the period, it is very appropriate for metallurgy. There are however, still issues to resolve. Notably the origin of the impressions on the lower surface of the slag and just how the slag and ceramic interacted.

The unique characteristics of Sintashta slag would necessitate a highly controlled fusion zone, airflow and furnace architecture, and the small, ephemeral furnaces used here, in combination with focused airflow seem to be the most straightforward way to produce this. In fact, it would seem doubtful that such conditions would be possible in a large furnace like

the well tunnel features that have been suggested. It seems unlikely that the induction of air produced by a heat differential with a well could have produced such a defined fusion zone.

All of the smelts carried out here were fairly small scale, in that they used comparatively small amounts of charcoal. The durations of the smelts were also comparatively short, with the majority running less than an hour. This is important because, as shown by the final experiments, the slag was already well formed in this time. This would presumably separate the ingot/charge form the furnace atmosphere, preventing any further reaction until the slag was removed. Therefore it seems likely that, even with larger charges, the duration of the smelts would unlikely be significantly longer which would have positive implications where fuel was scarce. The small scale of the smelts would also necessitate a different use of space to that hypothesised with the well-tunnel features.

Furnace lining is not readily found on Sintashta sites and is absent from the assemblages at Stepnoye and Ust'ye. It was notable that all of the experiments where a superstructure was used, at least some of the furnace lining became vitrified. This is significant as smelting, even at a low frequency, would likely produce significantly more vitrified furnace lining than is found. In some of the experiments presented here, and the many that failed during various pilot phases the most the slag produced was more amorphous than the typical slag found on Sintashta sites. Indeed, poorly formed slag is largely absent from the archaeological record. If these products are taken of an indication of innovation/experimentation, then it is reasonable to suggest that the practice at these sites was well established.

There are some key conclusions that can be drawn from this experimental programme that have specific implications regarding metallurgical in the Southern Urals. These are;

- The type of ceramic fabric that dominated the archaeological record is particularly suitable for metallurgy. It has good refractory propertied that were likely caused by the combination of talc and silica tempers. This is significant as it may suggest that specialised technical ceramics were not produced, instead metallurgists used what was already readily available.

- Only small and ephemeral furnaces were required to produce metallurgical debris found in the Southern Urals. Moreover smaller structures seem a much more likely candidates for smelting furnaces than much of what is discussed in the literature (Girgor'yev 2003).

- The most efficient bellow configuration to produce the defined fusion zone necessary to generate small slag plates is through the use of a single set of bellows. This means that groups as small as two people, or even could smelt copper. This has significant implications regarding the organisation of production.

- This programme smelted the types of ore found at Stepnoye and Ust'ye and showed that copper carbonate ores could be smelted with relative ease in informal structures (even an unlined pit) and that both a combination of sulphide and carbonate minerals, and a roasted sulphide could be smelted to produce slag similar to that identified at Stepnoye.

These points will be expanded in the next chapter where the results of this programme will

be discussed in more detail in the wider context of this thesis along with the results of the previous chapter.

Chapter 8

Discussion

The study of Sintashta metallurgy provides critical data for evaluating existing models of the Southern Ural Bronze Age cultural synthesis. In turn, models accounting for the Middle Bronze Age development in the Southern Urals have played a central role in studies which have aimed at understanding, defining, and characterising a wider Bronze Age World System (Kohl 1996). The importance, then, of Sintashta metallurgy is defined by both local and global archaeological traditions; we may also include its relevance to the body of knowledge generated under the banner of archaeometallurgy. The Middle Bronze Age groups of the Southern Urals have been seen as a "*new step*" in the wider development of the Eurasian steppe through the formation of what Zdanovich and Zdanovich (2002: 253) call "proto-state structures". The 'proto-state' is thought of as being a hierarchical society and is seen as indicative of warrior elites/aristocracies which, from fortified settlements, control a wider region (Anthony 2007: 371; Kristiansen and Larsson 2005: 174). Central to these arguments has been the role of Sintashta settlements as dedicated production and distribution centres under central coordination, mediating the control and distribution of resources over a wide region (Kristiansen and Larsson 2005: 175).

Primary copper production has been given a significant role in these discussions, acting as both a driving force to the development of these communities and the stimulus for long distance, intense interactions (Kuzmina 2008 Anthony 2007; Hanks 2010a; Frachetti 2012). Despite this prominence it remains poorly characterised in terms of resource perception and choice, archaeological evidence, organisation and specific practice. The characterisation of metallurgical practice and its organisation should be absolutely central to any discussion which relies on the Sintashta culture to support wider syntheses. This chapter will discuss these issues in the light of the data presented here and will address the key problems individually, before presenting a new proposal for copper production in the Southern Urals during the Middle Bronze Age.

8.1 Deconstructing the 'Sintashta Metallurgical Process'

The Sintashta cultural development has been seen as a centrally coordinated political entity geared towards the production and distribution of significant copper resources (Anthony 2007; Zdanovich and Zdanovich 2002). The coordination of copper metallurgy is thought to have been extensive, incorporating all communities and all members of a community, with the assumption that copper production was routinely practiced by entire communities (Grigor'yev 2003; Koryakova and Epimakhov 2007). Such arguments have looked to alleged evidence for the abundance of copper metallurgy at Sintashta settlements; the assumed prevalence of copper metallurgical debris in 'household' units, coupled with the idea that copper minerals were centrally sourced and distributed amongst communities so as to guarantee production at a significant scale (Anthony 2007; Grigor'yev 2002: 127; Zaykov et al. 2005). Understood in such terms it is apparent that metallurgy among Sintashta communities has been conceptualised as a single tradition using common resources and techniques, and being organised in a similar manner.

8.1.1 Centrally procured minerals

It was outlined in Chapter 4 that the nature of ore procurement strategies has figured strongly in the wider interpretations regarding the complexity and cooperation of MBA communities (Hanks and Doonan 2009; Zaykov et al. 2012). As illustrated earlier there is no compelling evidence for a shared resource base, indeed the bulk of the evidence seems to suggest the opposite; that resources were procured within local catchment zones, with little or no direct coordination between settlements. However, there is specific material evidence that has drawn scholars to these conclusions.

The presence of chromites in slags

The aspect of material analysis which has typically been used to suggest that a single ore source was shared throughout many of the communities has been the presence of chromite spinels in the analyses of archaeological slags (Grigor'yev 2013; Zaykov et al. 2005, 2012). The three main principles of this method, outlined by Grigor'yev, were:

> 1. In contrast to late Bronze Age metallurgy, Sintashta metallurgy was based on the melting of ultramafic ores; ore and slag almost always contain inclusions of Cr-spinels, which are characteristic of this group of fields.
>
> 2. Chromite spinels are highly refractory and their chemical composition is not changed during melting ore; they hardly interact with other components of the melt, as shown by studies of many Sintashta slags. This is different from all the other components, and of the chemical composition of the ore and slag in general.
>
> 3. Within one field the chromite composition was quite homogenous and could be considered as an important diagnostic feature. (Grigor'yev 2007, translated by the Author).

These principles assert a simple relationship between the components of an ore body and the product of a smelt (Figure 8.1). Tempting though such reductionist models may be, copper production needs to be conceptualised as something more than a geochemical transformation of mineral to metal. To employ simple geochemical pathways as models for metallurgical practice is to remove human agency from any analysis and subsequent archaeological narrative. Metallurgy then, as human practice, draws on numerous choices, including techniques, raw materials, an understanding of space and memory as well as knowledge of practice.

While it is true that the refractory nature of chromite spinels means they were unlikely to have been altered during a smelt, their presence in archaeological ores (meaning ore found on production sites) is not well established. Where they have been identified at Middle Bronze Age sites it has typically been within slag, whereas in ore they have only been found at a restricted number of mines (notably at Voroskaya Yama, Grigor'yev 2007). No ore fragment analysed from Stepnoye or Ust'ye contained a single chromite spinel. At Ust'ye the ore samples were notable for being free of inclusions apart from quartz. On this basis, the inclusion of chromites in the Ust'ye and Stepnoye slags needs to be accounted for in some other way.

The analysis of the material from Ust'ye and Stepnoye presented two possible hypotheses for the inclusion of the chromite spinels; either the chromite spinels were being added to the smelt along with a flux, or the chromite spinels were being incorporated into the smelt through the thermal decomposition of metallurgical ceramics. Given the rarity of chromite spinels in the minerals analysed at both sites and the limited direct evidence for the addition of flux minerals the first hypothesis is difficult to support.

Analysis of the metallurgical ceramics on both sites confirmed that they were heavily talc tempered (like the majority of non-metallurgical ceramics). Talc, like chromite spinels, forms during the metamorphosis of serpentinite and ultra-basic geologies (Posukhova et al. 2013). The metallurgical ceramics identified at Ust'ye contain both talc inclusions and chromite spinels. On this basis alone it is possible to suggest that the spinels in the slag were derived from the metallurgical ceramic facilitated by vilification of the ceramic and subsequent fusion with the slag during the smelt. Evidence for this pathway also comes from the analyses of slag, wherein inclusions of ceramic, talc, and chromite were all found in association with each other (see chapter 6, Figure 6.17 and 6.20). In one case the chromite spinels were embedded in a larger inclusion of talc; directly confirming the common origin of talc inclusions and chromites (Figure 6.17). It seems highly likely that the chromite inclusions found in the slag at Stepnoye and Ust'ye were resultant from the decision to employ a talc rich ceramic, rather than being a by-product of a specific ore choice. Therefore the chromite's journey was a complex one (Figures 8.1 and 8.2), and a result of the specific technological choices relating to paraphernalia and geology beyond the ore source.

To date, the presence of chromites in metallurgical ceramics has not been considered. Further the dismissal of local mineral deposits as viable Bronze Age sources of copper mineral is based on the inference of chromites in slag, indicating a serpentinite source; the outcome of metallurgy being conceptualised as a simplistic geochemical process concerning only ore and slag. The identification of viable non-serpentinite surface outcrops in the vicinity of both the examined sites, strongly coupled with the identification of chromites in

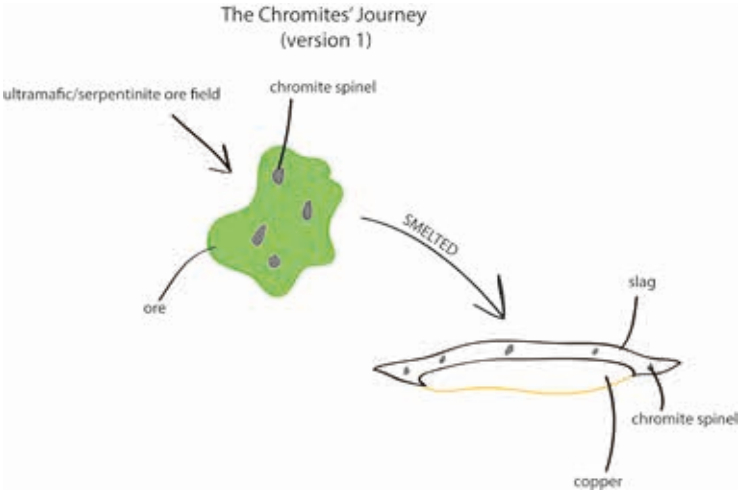


Figure 8.1 The chromites' journey version 1, in which the chromite present in the ore are simply accumulate in the slag

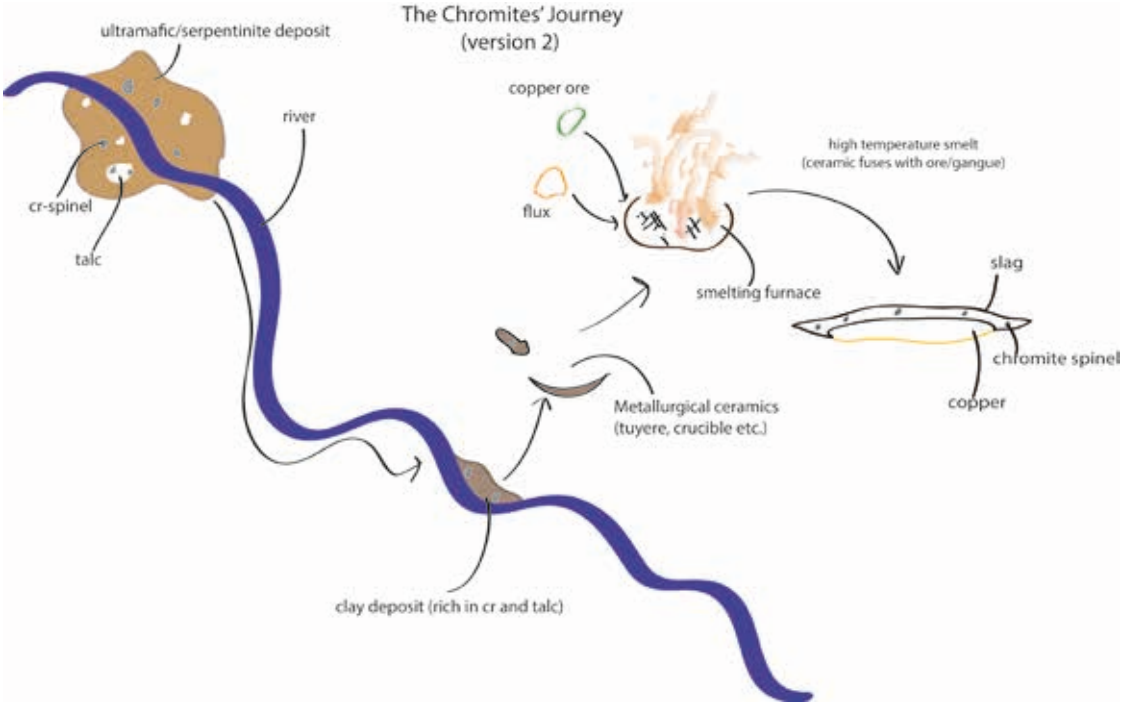


Figure 8.2 The chromites' journey 2, in which the chromite is eroded from its original host rock and transported along a river system

metallurgical ceramics, is compelling evidence against the centralised procurement model proposed in previous studies by Zaykov and colleagues (2005).

8.1.2 The organization of mineral procurement: a decentralized model

It was clear from the earliest analysis of copper smelting slag at Stepnoye that the choice of ore employed at the site did not conform to the prevailing model for production in the region. The preliminary analysis of material carried out by Hanks and Doonan (2009) identified numerous sulphide inclusions in the slag, which hinted at the use of a sulphide ore; something not noted in other, existing studies. It was this early work that stimulated the initial phase of the SCARP resource procurement survey outlined in this thesis.

The surveys at Stepnoye identified numerous copper deposits with strong evidence indicating their prehistoric exploitation. What seems clear is that the geology in the region surrounding Stepnoye is diverse, with both oxide and sulphide ores available at near surface deposits in a variety of geological zones. Both Zmiye Yama and Sarnaka Dacha A (SDA) showed evidence of prehistoric presence, with a Kurgan cemetery near to Zmeye Yama and Bronze Age ceramic identified at SDA. Both sites had mining morphologies consistent with ancient exploitation.

The morphology of the earliest exploited veins, the 'picked' surface and the Bronze Age ceramic all suggest that SDA was exploited in antiquity. The morphology of Zmiye Yama was no less compelling, as there were features suggestive of trench mines with minerals appearing at the surface. Its location in the vicinity of Bronze Age kurgans suggests that the area was clearly within the catchment of Bronze Age communities, and while it is not possible to assign an exact date to the kurgan cemetery, it is noted throughout the region that such funerary sites were repeatedly visited and developed throughout the Bronze Age (Koryakova and Epimakhov 2007). If we conclude that both sites were known and available to the metal producers at Stepnoye, it suggests that the location of the mineral source was considerably more local than suggested by existing studies. In addition to the morphology and availability there are strong parallels between the types of mineral identified at SDA and Stepnoye. The presence of heat-altered sulphide ore at Stepnoye supports the suggestion by Hanks and Doonan (2009) that sulphide ore was being exploited at the site and offers convincing links to the local mineralogy.

The initial analysis of the slag from Ust'ye suggested that, unlike that of Stepnoye, an oxide/carbonate ore had been used. Indeed the extensive ore assemblage at Ust'ye was dominated by malachite, azurite, and tenorite, all of which seemed to be in association with quartz. As mentioned previously, there was no evidence that the ore was imported from a serpentinite-type source, even though Ust'ye was comparatively nearer to the main serpentinite ore zones than Stepnoye (although still being over 100km away).

The resource survey carried out in the vicinity of Ust'ye proved particularly successful, not only did it identify a potential site only 900m from the site, but each mineral-rich deposit surveyed showed a similar mineral suite as those minerals found at the settlement site. The abundance of ore in the area of the site meant that it would have been particularly surprising if it had been overlooked. While the transformative nature of metallurgy means it is notoriously difficult to conclusively link an ore to a slag through chemical means, the analytical results strongly suggest that the type of ore found at the mines just to the north of Ust'ye, and their associated gangue, would, with only the addition of an iron rich flux, have produced the slag found on site. This is especially convincing if, as mentioned previously, the chromite spinels were drawn from the metallurgical ceramics. The use of ore from the local vicinity, particularly from Gorny-Toguzak and Ust'ye North, was also supported by the presence of gold in all of the slag analysed by PGAA. Which in some cases was up to modern economically viable concentrations. While gold was not frequently detectable in the ore itself it was visible, microscopically (and confirmed by spot analysis), in one of the geological samples.

What is clear from both surveys is that local ores were similar to fragments found at the settlement sites and were consistent with slag chemistry; it would be difficult to suggest



Figure 8.3 The scarred landscape of Kargaly showing some of the many mining shafts (left) and one of the excavated shafts (right, Evgenni Cernykh).

that the resources were not exploited. This supports a model where minerals were procured locally. There is no need, or evidence, for the long distant importation of ore from a central resource. Instead there is now evidence that copper minerals were procured locally within the immediate environment of settlement sites. All mineral were noted outcropping at the surface, and while there is a variety of evidence to support prehistoric exploitation it is worth highlighting that this is not large-scale or intensive. Even the evidence at Voroskaya Yama, which itself is not coherently dated to the Sintashta period, suggests that exploitation was not at a significant scale, and certainly not comparable to that noted in later periods at sites like Kargarly (Chernykh 2002) see figure 8.3.

In summary then the evidence for Sintashta mining at Stepnoye and Ust'ye points to local, near surface mineral deposits, being exploited, though not on a substantial scale, and certainly considerably less so than in the Later Bronze Age at other sites such as Kargaly. This is supported by the analysis of copper ore that found significant similarity in samples between the archaeological sites and their associated deposits. It would suggest that local procurement was undertaken episodically. There is no reason to suppose that this was undertaken by any group other than those engaged in the smelting of the same minerals.

8.1.3 Furnace Architecture: Fanning the flames of complexity?

Arguments regarding the scale and prevalence of copper production at Sintashta sites centre on the presence of numerous, complex, metallurgical furnaces at Sintashta period sites. Published plans of Arkaim and Sintashta show furnaces in every structure (Grigor'yev 2003). The basis for this interpretation is unclear (see Grigor'yev 2013); these could easily be considered as domestic hearth features as there is no specific reference is made to any diagnostic furnace feature, i.e. slagging or vitrification, which would indicate their use in

high temperature metallurgy (Grigor'yev 2003). They are noted as burnt, with the presence of fired clay, with occasional finds of slag nearby (Grigor'yev 2013: 102). Grigory'yev concedes on this basis that the furnaces may have been multifunction, serving both domestic and industrial needs yet an 'industrial' use is not supported by the evidence. The presence of vittrification associated with metallurgical furnaces is well attested (Craddock 1995; Tylecote 1987).

At Arkaim twenty-two hearth structures were identified and were interpreted as metallurgical furnaces, albeit these being multifunction (Grigor'yev and Rusanov 1995; Grigor'yev 2013). They were typically large, with an internal diameter of 0.7-1m. Only one, smaller feature had direct evidence for metallurgy, in the form of an in-situ tuyére (Grigor'yev 2003, 2013). As noted in Chapter 4, some pit features at Sintashta did contain slag, but there was no mention of any furnace lining or associated debris (Gening et al. 1992). There is a clear lack of evidence for any of these supposed furnace/hearth features actually being used for metallurgy. This is a conclusion that Rusanov, who initially reconstructed Sintashta furnaces experimentally with Grigoryev, has recently posited, suggesting that only features with direct evidence of metallurgy should be considered furnaces (Rusanov 2011). He argues that such features would likely be smaller, since the larger hearth features are unlikely to be capable of attaining the temperatures necessary for copper metallurgy.

The well-tunnel features, typical of the furnaces described by Grigory'ev, were never fully investigated experimentally by Grigoryev and Rusanov (1995), which is surprising given the central role afforded to the tunnel and well in inducing a forced draught into the structures (Figure 8.4). Recently Comeau (2012) has investigated these structures extensively from an experimental perspective and found that attaining high temperatures was a challenge, and that the tunnel and well arrangement seemed to provide little assistance in inducing air to the hearth. Given the ambiguity of archaeological features attributed to metallurgical practice, the approach adopted in this study focused more on establishing what would be required to produce Sintashta-type slag.

Based on the formal investigations of the slag it seems unlikely, even unnecessary, for a furnace to be as large and complex as those suggested (Grigory'ev 2002). Rather, the small slag plates, indicative of a rather low yield per smelt (~400g), would suggest a much smaller furnace architecture. If the central hearth features were used in a metallurgical context it seems more likely that only a portion of the area was used for smelting, perhaps enclosed by a more ad-hoc superstructure. To use a furnace of one metre in diameter to consistently produce well-formed slag plates of less than 25cm not only seems excessive, but improbable. To maintain the temperature and atmosphere in such a large space would require significantly high airflows of considerable pressure, which were simply not attainable under prehistoric conditions. Merkel has clearly demonstrated that air blasts are difficult to induce at distances greater than 20cm (1983). It would be a significant challenge to raise the temperature of such a structure, and we should not forget that such structures would be the largest furnace diameters of any pyrotechnical structure reported in the entire Bronze Age world (Tylecote 1987; Hauptman 2007; Merkel 1982; Doonan 1999; Weeks 2003).

If these hearths were successfully heated to smelting temperatures then it would be inevitable that a range of secondary debris, in the form of vitrified furnace lining and other

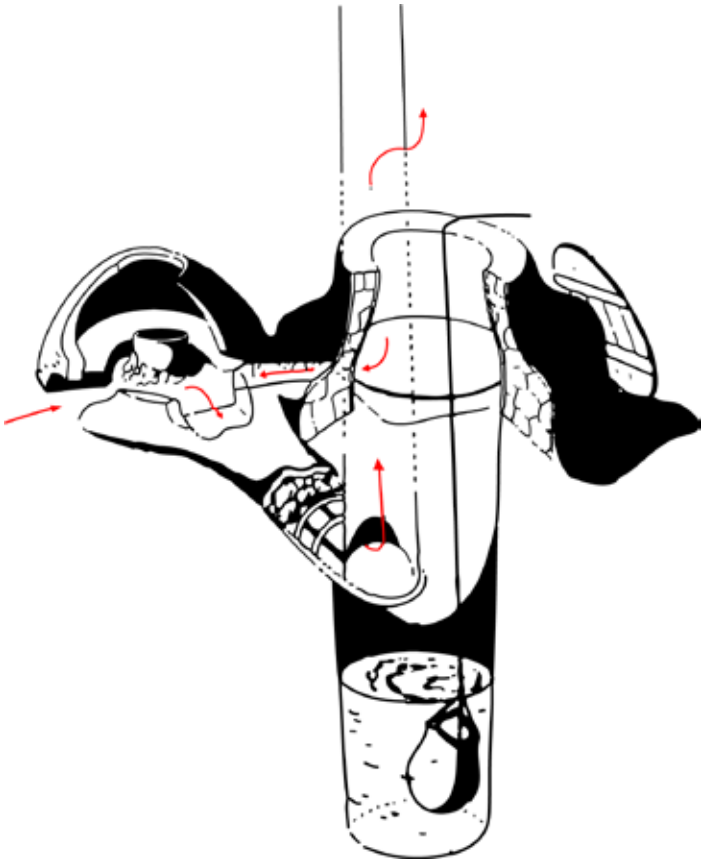


Figure 8.4 A schematic of Grigor'yev's furnace structure.

slag types, would be produced. The absence of such evidence points to a misidentification of these structures and suggests that there is another class of feature, likely smaller and more ephemeral, which was associated with copper metallurgy. The questioning of the evidence of 'household hearth as furnace' simultaneously invites the questioning of the prevalence and scale of Sintashta copper production.

This has consequences regarding the number of people involved in smelting activity. It was shown in the previous chapter that producing and maintaining conditions suitable for the production of such low yield smelts could be done with only one or two people. Indeed, a larger group would find it difficult to operate in the small area around the furnace. In summary then it seems that the features normally identified as Sintashta copper smelting furnaces are unlikely to have been used for copper production. There is no evidence to suggest that they were. It is likely that smaller features were used, such as those highlighted above at Arkaim and Sintashta (Grigor'yev 2003; Gening et al. 1992). The small features suggested here as furnaces were likely to have been operated by a few individuals; experimental reconstruction suggests that as few as two and possibility even one person would have been sufficient to make such features function as an effective copper smelting furnace.

8.1.4 The prevalence of copper production among Sintashta communities

The idea of entire communities engaged in copper production activities has made the Southern Urals central to many studies which have sought to establish a Bronze Age world system with wide-ranging connections maintained by complex social institutions. (Kristiansen and Larsson 2005; Kuzmina 2008; Zhang 2009; Kohl 2007). Although such perspectives have been largely developed in light of Wallenstein's world systems theory (Kohl 1996) and among some archaeologists keen to connect disparate regions of Eurasia (Kristiansen 2011), they are keenly adopted by Russian scholars, perhaps because of the central role thus afforded to the region which can then be included in wider global narratives.

The other important aspect of the dominant model is the idea of the distributed labour model (Shnirelman 1998, 1999). Support for the distributed labour model relies heavily on the argument that furnaces were located in every house. As highlighted in the previous section this claim is dubious and not supported by the archaeological evidence. There are specific strands of evidence, visible aspects of an intensive chaîne opératoire, that might be expected if the distributed labour model was correct.

First, the geochemical site signature would likely be very different to that outlined above (see Chapter 5). Rather than one or two major Cu anomalies, one might expect small anomalies in each household, or at least a number of anomalies distributed across the site. Recent excavations, including those by the SCARP project, have noted only small quantities of slag spread throughout the settlements (Doonan et al. In press; Koryakova et al. 2011; Vinogradov 2013). If Sintashta settlements housed dedicated metalworking communities then much more significant deposits of slag might be expected. The quantity of slag recovered from these sites is low, especially in comparison to other sites across the Eurasian landmass (Craddock 1995). The prevalence of metallurgical practice across Sintashta sites cannot therefore be supported, and in turn the proposition that these sites were established to support specialised metallurgical communities should be questioned (Kristiansen and Larsson 2005; Kuzmina 2008; Zhang 2009; Kohl 2007).

The inception of the Sintashta settlement pattern is exceptional (Zdanovich 2002); it appears that the constellation of highly organised, if not planned, settlements emerged in the Middle Bronze Age with scant, if any, evidence of a developmental phase (Zdanovich and Batanina 2007). The commonly accepted narrative for settlement development considers a shift from nomadic pastoralism towards settled communities. While climate change, specifically a period with little rainfall, has been held responsible for groups congregating/settling around natural springs (Anthony 2009) it is the preoccupation with copper metallurgy which is seen to sustain settlement and habitation in these areas. The re-evaluation of the prevalence and scale (see below) of metallurgy suggests that current studies over-estimate the extent of production. The issue which therefore needs to be addressed is that, if the motivation for settlement was not the extensive exploitation of local or central copper deposits, then how might the sudden appearance of Sintashta settlements begin to be explained?

Table 8.1 Estimated annual copper output based on an average sized settlement featuring 40 house structures (kg)

	Copper production figures (kg)			
proportion of site involved in smelting	1 smelt/yr	1 smelt/week	1 smelt/day	3 smelts/day
1 structure	<1	21	146	438
10% of structures	2	83	584	1,752
50% of structures	8	416	2,920	8,760
100% of structures	16	832	5,840	17,520

8.1.5 The scale and intensity of production

It is suggested that copper was exported from the Southern Urals in significant quantities. For instance Anthony has argued that a single shipment may have been up to 20 tonnes (Anthony 2007: 391). Yet, as has been discussed already, some of the foundations of this argument are untenable. It is unlikely that large furnaces were located in every house and doubtful that they relied on centrally sourced minerals to facilitate the continuous production of copper. It is clear that if Anthony's figure was a regular occurrence, not only would smelting need to be frequent and widespread among communities, it would also produce significant debris. Table 8.1 shows estimations of what evidence would be expected for different scales of production. While these figures may be somewhat hyperbolic, when put into context with the extent of the Stepnoye and Ust'ye assemblages, these figures are significant and suggest that production at Stepnoye and Ust'ye would fall extremely short of Anthony's volume.

At Stepnoye the total slag excavated to date (2.6kg) would account for only seven average sized smelts producing no more than 3kg of copper. The extrapolated geochemical data suggests that no more than 10,000kg of slag is likely to be present at Stepnoye, which over a 150 year period would account around for 60-100 individual smelts a year. The experiments presented here suggest that each smelt could be completed in less than two hours with the involvement of very few people. Therefore a single household smelting 4-8 times a day over a two week period, or one or two times a week over the year could account for such levels of production. The material excavated from Ust'ye to date (8.5kg) accounts for 26 smelts producing less than 10kg of copper. Preliminary predictions at Ust'ye based on the geochemical survey produced a total of 13,000kg of slag. However when the longer period of occupation is taken into account the eventual number of smelts annually is similar to that at Stepnoye (Doonan et al. In Press).

Therefore, when combined with the results of the SCARP project, the analytical and experimental data presented here culminates with the conclusion that metallurgy was far from a regular practice on Sintashta sites. Indeed the quantities of slag excavated and the type of production practiced suggests that metal was primarily produced to fill rather insignificant local demands (Doonan et al. Forthcoming). There is little evidence at either Stepnoye or Ust'ye for smelting on a scale which would allow the Country of Towns to provide the "*bottomless markets*" of Central Asia with the quantities of copper which have been suggested (Anthony 2007: 391). When drawn together, the evidence for primary

metallurgical production at Stepnoye and Ust'ye suggests a production strategy adapted to local conditions in terms of both resource procurement and consumption of final products (c.f. Grigor'yev 2013).

8.1.6 Primary metallurgical production at Stepnoye and Ust'ye

The last sections have highlighted the ways in which the production process does not conform to the prevailing models. In this section looks in more detail at the characterisation of specific elements of the archaeological evidence and the technical choices they reveal. This allows their implications to the wider chaîne opératoire and taskscape of Sintashta metallurgy to be better understood, allowing particular attention to be paid to a comparative analysis of the two sites studied.

Ore pre-treatment

Identifying direct evidence for ore processing at Stepnoye and Ust'ye, in the form of processing areas or toolkits, is problematic, as many of the artefacts involved in the process can have multiple functions, and ore tailings were unlikely to be noted in publications. While hammerstones have been identified, some with possible copper residue, the presence of pestles and mortars alone does not confirm the presence of onsite ore processing. However, it is clear from the surveys of the mineralised zones that some form of processing would have been necessary both to prepare the ore for a smelt and to fully beneficiate the ore. Indeed, the limited assemblage of ore from Stepnoye and the more extensive material from Ust'ye showed good evidence of preparation; specifically low levels of host rock and a reduction in size to ~1cm3. This suggests that some form of beneficiation must have taken place. Therefore it is important to consider the location, extent, and type of ore processing and preparation.

While no gangue minerals have been identified at Stepnoye, recent excavations at Ust'ye recovered, with other metallurgical debris, numerous heat-altered quartzite nodules in a midden context. This suggests, along with the presence of hammerstones, that ore processing took place in the context of the settlement site, rather than at the mine. However, without a sustained and large scale program of investigation, the extent of modern mining at nearly all of the mineral sources investigated would make it near impossible to identify any primary processing near the mines themselves.

Ceramic choice

It was shown earlier that the unique characteristics of the ceramics used in the metallurgical process at both Stepnoye and Ust'ye had implications regarding the identification of ore source. The talc temper has specific benefits regarding metallurgical practice. Talc as a dominant temper, has been shown here and elsewhere (Thornton and Rehren 2009) to have unique pyrotechnical qualities; specifically its low thermal expansion, its resistance to slagging, and its forming at high temperature of enstatite, a hard, heat resistant mineral. This means that any ceramic which contains enough talc would likely have good refractory properties. While talc has been shown to assist in the smelting process, experimental reconstruction has failed to mimic the archaeological evidence precisely. Experimental trials showed that slag ceramic interaction was still a problem, therefore there remains a question as to how the ceramics behaved in the manner observed archaeologically.

The grass-like impressions on the underside of slag plates could present something of a clue, suggesting that an organic material was used to line the crucible before use. Although not tested here, such experiments were carried out by Rusanov, who argues that a wreath of coiled grass may have produced such impressions; unfortunately, the results were inconclusive (Rusanov pers comm).

Significantly, metallurgical ceramics seem broadly similar in composition to the majority of other ceramics used during the Middle Bronze Age. It is important, therefore, to ask whether the inclusion of talc into metallurgical ceramics was a deliberate technological choice, an accidental by-product of an established ceramic tradition, or even a combination of both. Either way, the materiality of the ceramics employed would have facilitated their effective use in a metallurgical context. Based on examination of metallurgical ceramics at Ust'ye it is difficult to suggest that metallurgy provided the impetus for a specialised assemblage of metallurgically-related ceramic. The open-plate crucibles may well be a specialised form, yet the composition and recipe seem usual and are directly comparable to domestic ceramic. It is suggested then that no significant innovation in ceramic practice occurred as a result of metallurgical practice.

Metallurgical architecture

Metallurgical architecture is another aspect of primary metallurgy which is dependent on a good understanding of refractory ceramics. However, no such material has been identified in the Southern Urals. This chapter has already discussed the problems with the complex well-tunnel features that have been suggested. The experiments here have shown that only a small fusion-zone would be necessary to produce small slag plates, and it has been



Figure 8.5 A reconstruction of a smelt employing only a single set of bellows with an improvised furnace utilising broken pot sherds.

shown here and elsewhere that it becomes difficult to maintain a focused atmosphere in larger structures (Comeau 2012; Juleff 1997). The gauge of the tuyéres is also such that, experimentally, they could only produce small hot-zones.

The evidence presented here, and the insight drawn from the experimental programme suggests, that only small and ephemeral furnace structures were used. There are possible candidates at both Sintashta and Arkaim for such features. One of the features was noted in Chapter 4 at Sintashta, which is referred to in the publication as a "*wall furnace*" (House 13, Gening et al 1992: 72), and the example with a tuyére at Arkaim conforms to the dimensions expected. However, extensive evidence for a superstructure is not reported in either case. It was mentioned earlier that small and ephemeral structures were likely used, and it is possible that these were embellished with ad-hoc arrangements of broken ceramic sherds (Figure 8.5). This would account for the vitrified, decorated sherds which showed evidence of adhering metal, as discussed in Chapter 6.

Primary smelting practices

Slag morphology reveals significant details about many aspects of the smelting process. It is not unusual for significant proportions of a slag assemblage to be non-diagnostic (Bachmann 1982). While subsequent chemical analysis may well indicate a number of process parameters, non-diagnostic forms are, as the name suggests, of low interpretive value. There are, of course, a number of slag forms such as tap slag, furnace conglomerates and hearth bottoms, which are easily identified. Conventionally, the identification of such forms is seen to indicate specific processes, for instance the tapping of slag from a furnace or the smithing of iron, though rarely are such slag morphologies interpreted in terms of the spatial or temporal aspects of the process. It was discussed earlier how the plate form with the ingot impression allows us to make accurate estimates of charge volume and mass. The shape also indicates that the slags were formed in relatively small features which would perhaps support the skilled practice of no more than two persons. In addition to the insight regarding how space might be used around a furnace it is also possible to comment, relatively precisely, about the temporality of a smelt. The slag dimensions and weight suggest that the process was a batch process; reasonable estimations supported by experimental observations would suggest a single smelt would last no longer than a couple of hours, suggesting that several smelts were possible within a single day. This stands in stark contrast to some prehistoric evidence (Rothernberg 1991), where copper smelting practices may have relied on using a furnace for several days on end. The temporality of practice therefore tells us something about the rhythms of copper production, and point strongly to a practice which was congruent with the routines of daily life, rather than a practice which was the focus for a group for an extended period which sat outside of routines of daily practice.

Drawing together several strands of evidence, we can begin to gain a detailed insight in to likely Sintashta practice. The curved lower surface of the slag suggests that it was formed on a plate-like surface, and some fragments even show evidence of having formed over an edge, suggesting they cooled on top of a plate-like vessel (Figure 8.6). It is likely that plates, like the one found at Ust'ye, were commonplace, acting like removable furnace bases that were consumed and destroyed during the production process. Open, plate-like crucibles are also found at sites to the west of the Urals, being attributed to the Abashevo type sites (Koryakova and Epimakhov 2007: 34). The overall absence of metallurgical ceramics



Figure 8.6 A 3d reconstruction of the slag-ingot-plate arrange evident at Stepnoye and Ust'ye (R. Potter).

in the Southern Urals, when compared to the (relative) abundance of slag, needs to be acknowledged. It is possible that they were crushed and used as a flux in subsequent smelts. Indeed this practice been argued by Rusanov, who suggests that crushed ceramic was a central component in the smelting recipe and would also account for the presence of chromite spinels (Rusanov 2011).

At Stepnoye the analysis of the slag strongly suggests a sulphidic ore source. Hanks and Doonan (2009) have proposed that, due to the use of a sulphide ore, Stepnoye metallurgists enacted a multi-steppe matte conversion process. However, following the analysis of a wider sample here, it seems more likely that sulphide ore was co-smelted or dead-roasted prior to being smelted. This has implications regarding the organisation of the smelts, but may still have required extra production steps. Both co-smelting and partial-roast smelts allow the charge to facilitate co-reduction (see Karageorghis and Kassianidou 1999; Rostoker et al. 1989). This would mean that the smelt would require less fuel and not require such stringent control of a reducing atmosphere. In contrast, the ore used at Ust'ye would have required a different type of smelting. The presence of carbonate ore and high-grade tenorite would necessitate a direct reduction smelt. While this is seemingly more straightforward in terms of chemistry than that which has been noted at Stepnoye, it would have required the creation and maintenance of a reducing atmosphere. This is typically achieved through the use of a confined superstructure; however, the lack of vitrified hearth lining, and the unique ceramics at Ust'ye, suggest a different solution.

In addition to copper minerals it is clear from the analysis that the charge was fluxed. The high-silica ore at Ust'ye would have needed the addition of iron oxide in order to form the composition of slag found. Conversely the high iron content of the copper minerals at Stepnoye would have called for the addition of a silica flux. However, it is clear from the analysis of slag at both sites that, in addition to the relatively clean ore, alloying agents were intentionally added at the smelting stage to produce alloys.

The incorporation of high-arsenic, and later tin minerals, at the smelting stage is most apparent in the Ust'ye assemblage, where copper minerals were not sufficiently high enough in these elements to account for the concentration of them in either the slag/prills or the finished products. It is notable that at Stepnoye, where more pure copper was identified in the slag, that the addition of arsenic was not uniform. This suggests that the decision to produce pure copper and an arsenical copper/bronze was an intentional technological choice.

8.1.7 The Sintashta metallurgical tradition

Many studies have discussed evidence for Sintashta metallurgy in terms of it being a coherent tradition or practice, yet such studies have not scrutinised the actual evidence for practice. In numerous instances discussions of metallurgical evidence from Sintahsta-type sites are dominated by language such as "*Sintashta slag is..*" or, "*Sintashta metallurgists would typically...*" (Grigor'yev 2013). The use of such language betrays a deeper conceptual framework which assumes a homogeneous practice across the whole region that, in turn, defines research agendas and, to some extent, outcomes.

One of the initial objectives of this programme of work was to explore variation both among and within Sintashta type sites. The study has shown that while there are common elements, i.e. slag morphology, this apparent similarity is not mirrored in the considerable compositional variation of slags, ores and processes. When the archaeometallurgical data is translated into practice terms -- the result of skilled, perception-response interactions -- it suggests that there was clearly a shared repertoire among those engaged in metallurgy at Sintashta-type sites. For instance it is apparent that the techniques associated with slag formation were shared, which by inference extends also the furnace structures. However, strategies of resource procurement, i.e. exploitation of oxide or sulphide deposits and other aspects of the process, seemed to have varied considerably.

The most tangible shared aspect of the metallurgical evidence from across Sintashta sites is the form of the slag. It is this similarity which forms the basis of the assumption that a single shared tradition existed. Metric analysis of slag at both Stepnoye and Ust'ye showed remarkable similarities in the characteristics of the slag plates. This is something that is mirrored at other sites (Grigor'yev 2013). It suggests that the size of furnace and smelting technique and temporality were remarkably similar for each smelt and at each site. The fragmentary nature of the slag fragments suggests that they were broken up to remove the ingot in a similar manner.

The similarities in craft practice at the two sites could all be considered to be commonalities in technique in that they are habits of practice and traditions of know-how, rather than selective choices relating to resources. Conversely, the differences in practice at the sites were primarily drawn from varying use of resources. As seen earlier, each site followed its own unique procurement strategy situated in the immediate hinterland of the sites. This had necessary implications regarding the act of winning copper from the ore. In addition, the differences would have necessitated either a different understanding of the materiality of the resources or a wide understanding of a range of resources. Therefore those who made metal at each site practiced a recognisably common approach, yet were able to adapt to local resources and environments.

While it could be argued that there were aspects of a shared tradition at the two sites, the variation in resource use is significant. The implications of a group of communities adapting a common tradition to suit the local environment are very different to a unified group of sites adhering to an inflexible tradition enforced through the use of a shared centrally administered mineral source (i.e. Voraskaya Yama). The latter would suggest a coordinated relationship among the sites, whereas the former would suggest a shared and mutual development of the metallurgical tradition as it develops in connected but nonetheless independent centres.

It is apparent that when new evidence is considered alongside a critical evaluation of existing models it is difficult to sustain existing models of how Sintashta metallurgy was organised, and in turn many of the ideas relating to the character of wider Sintashta society. In light of this the evidence discussed here necessitates a significant re-evaluation of our ideas of Sintashta metallurgy, and indeed wider Sintashta social organisation.

8.2 Sintashta Metallurgies—A New Proposal

The previous section has shown, in challenging some of the key assumptions which underpin our understanding of Bronze Age metallurgy in the Southern Urals, the benefits of a detailed and integrative programme of archaeometallurgical characterisation. This section builds on this re-evaluation to explore how aspects of primary metallurgical practice at Stepnoye and Ust'ye can be understood in the wider context of community organisation, before then considering the wider implications for the Eurasian prehistory. It is of course important, at this stage, to acknowledge that the focus of this thesis has been on only two sites, and that the extent to which they are representative of all Sintashta types is unclear. In fact, what this discussion has shown so far is that significant heterogeneity exists in the region. However, the aim of this discussion is not to make general statements which can be uncritically applied to the region as a whole, but to explore both the variation and trends at the two sites and to open up the debate as to the implications for the wider Southern Ural narrative.

Evidence supporting local procurement strategies for minerals has a significant impact on our understanding of how communities were organised (Knapp 2002). Further it has direct implications for understanding to what extent political power was exercised centrally, if at all, over Sintashta type settlements (Zaykov et al 2005; Zdanovich and Zdanovich 2002). In drawing on local resources from the local environment the communities at Stepnoye and Ust'ye seem to have acted autonomously from any central authority mediating the supply of ore. However, even between the two sites, the organisation of ore procurement was different. The supply of ore at Stepnoye seems to have been more diverse, with both sulphide and oxide ores exploited from sites which were an appreciable distance from a settlement (20km), whereas the core supply at Ust'ye seems to have been fairly consistent and in close proximity to the settlement. The close proximity of ores and the higher production figures for Ust'ye suggest that metallurgy was more routinely practiced by the inhabitants of Ust'ye than Stepnoye. Notably, despite Chernorech'ye being equidistant with Stepnoye to the Sanarka deposits, there is, based on field walking, geophysics and geochemistry, no evidence of metallurgical practice (Doonan et al forthcoming).

We should, then, expect to see a range of strategies concerning the commitment of different communities to metallurgical practice, raising the important question as to what different conditions at different Sintashta sites informed the various strategies.

The proximity of settlements to mining sites, albeit variable, allows for associated mining features to be insubstantial and hence ephemeral. For instance, significant mineral deposits are a less than a 10 minute walk from the Ust'ye settlement, whereas mineral deposits are several hours from Stepnoye. A intensively exploited mine would suggest specialised

mining groups, whereas exploiting nearby resources on a small scale draws more parallels with casual gathering practices. The causal gathering of surface deposits seems to be more in keeping with the kind of commitment to metallurgy one might expect with a mobile or semi-mobile lifestyle. This is not to suggest that Sintashta communities were not settled, but rather that the commitment to metallurgy was not one of intensive year round exploitation. Rather the impression is very much of a metallurgical tradition which was episodic, possibly seasonal, but a strategy nonetheless which was not committed to the out and out exploitation of proximal deposits. This of course needs to be explained.

Metals are often cast as the stimulus to intensive production, exchange and competition between groups (i.e Renfrew 1972), yet this does not seem to be the case for Sintashta communities. The issue remains, how then can we explain what appears to be less than a full commitment to metallurgical production? As the steppe environment is often considered to be a challenging environment with restricted resources, this is a significant task. In many ways, the environmental conditions might be expected to foster a dependency on exploitable resources, whatever they may be; in a similar fashion to how Shennan has argued for Bronze Age copper miners in the Alps, or the palm oil producers of the Cameroon grassfields (1999). Shennan highlighted how communities inhabiting liminal environments that struggle to support a mixed economy can become increasingly specialised by virtue of a developing dependency on a single kind of production. It is in this way that he explains the significant investment in manpower and energy in the exploitation of central European copper deposits at sites like Mitterberg. It is apparent that the communities of the Southern Urals did not follow such a trajectory, and it is in understanding alternative strategies that we might reveal the conditions under which Sintashta communities maintained what is in many ways a strangely underwhelming relationship with metallurgical production.

8.2.1 The temporality of production

The very different temporalities of mineral procurement highlighted above for Ust'ye and Stepnoye invites a critical analysis of the various relations which develop around ore procurement and exchange. There is a verticality to the organisation of labour in copper production which is rarely considered in archaeometallurgical studies. Mining in hard rock environments is a task which necessitates group effort (Herbert 2002). The moving of large rocks, the movement of people and materials, both vertically and horizontally, requires cooperative effort. In an ethnographic context, due to both labour and safety concerns, mining is typically understood as a group activity (Barrientos-Delgado et al 2011). Even when small groups of two or three people mine relatively soft tills it is usual to work in close proximity to other groups across a landscape (Hammel et al 2000); collaboration can be relied upon when needed, i.e. in times of danger or when there is a need to move significant quantities of material or equipment.

Unlike mining, which is an undoubtedly a group activity, albeit one that might be organised according to various strategies (Knapp 2002), metallurgy, and specifically, copper smelting, can be undertaken by very small groups or even individuals. This establishes an interesting social dynamic between those who mine and those who smelt; if it is the same group then this dynamic is realised more in terms of the time spent in each activity. Whereas while a large group would likely cooperate to extract a considerable volume of ore, a single smith could quite easily manage a smelting operation. Put another way, a day smelting by a single smith

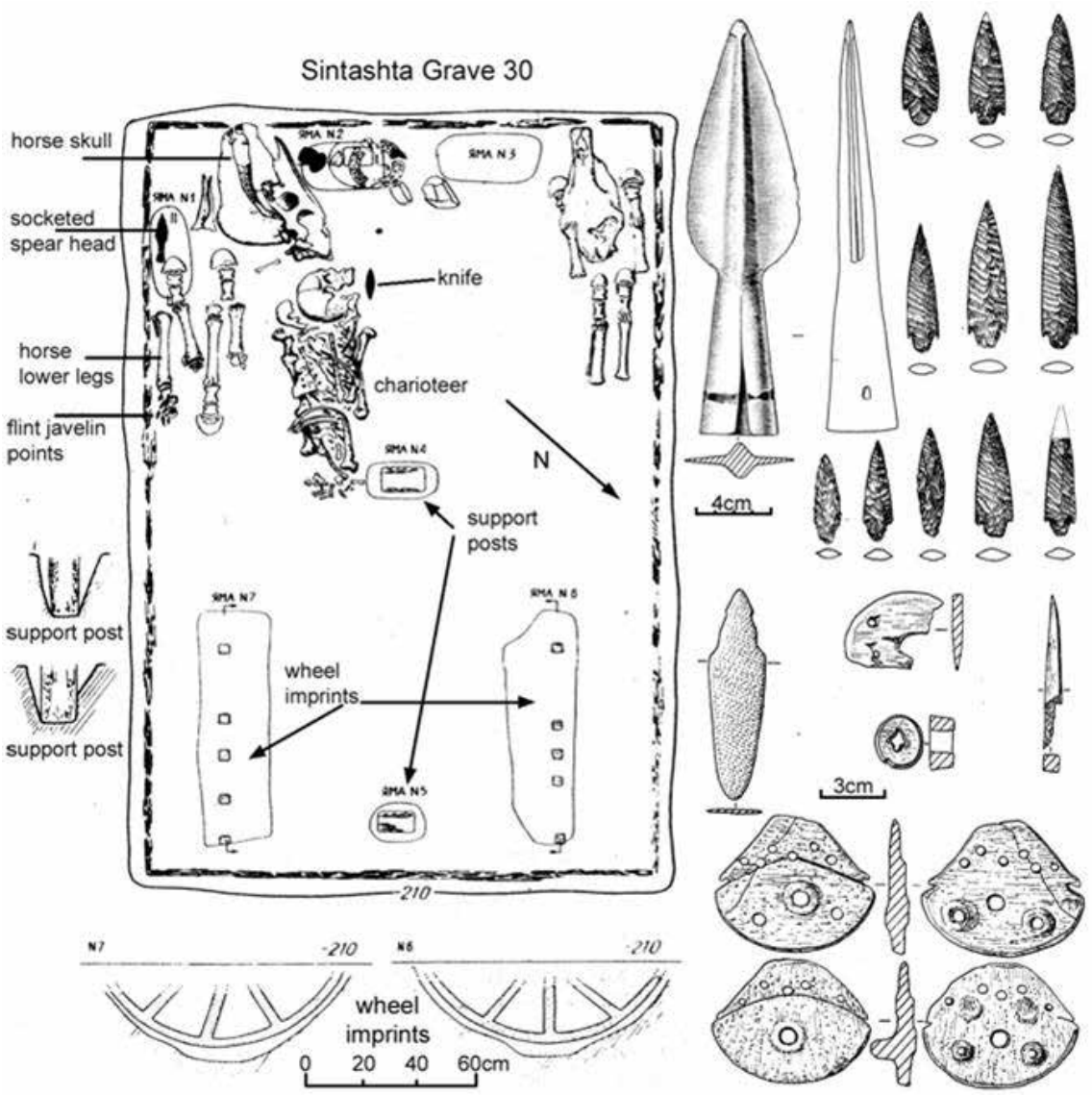


Figure 8.7 Plan of an excavated grave pit at Sintashta showing a an abundant suite of funerary goods.

could consume a whole group's ore output from a day of mining. This vertical relationship can manifest itself between people in terms of who smelts and who mines, or it can manifest itself temporally in terms of how long small groups or individuals spend mining and smelting.

It seems likely, based on the current evidence that, like smelting, ore processing was carried out at the settlement sites. It is perhaps logical, with both of the settlements located near to water bodies, to suggest that there was an advantage to beneficiating the ore at the sites, and there is strong evidence to suggest that smelting was enacted in specific areas. However, the SCARP fieldwork identified likely midden deposits which contained metallurgical debris mixed with other refuse, ceramics, bone etc., and should be considered multipurpose. With no dedicated metallurgical refuse areas, such as slag heaps, it seems likely that metallurgy took place alongside other activities. The mixed refuse also attests to the episodic nature of production; continuous and intensive production would have produced dedicated refuse strategies (Hauptman 2007; Doonan 1999; Weeks 2003), whereas small-scale production waste could easily be discarded along with other household waste (Table 8.2).

This has parallels with ethnographic examples of production in pastoral and semi-mobile

economies where family units are central to the organisation of production (Khazanov 1976) and metalworkers are responsible for religious, spiritual and other aspects or ritual life (Herbert 1993: 12). In so far as only certain households were engaged in production, Sintashta communities indicate clear signs of specialism, yet no clear hierarchy. So it seems likely that those social fields that engaged in production would have needed to either maintain some level of subsistence strategy, or been allowed to exist outside of subsistence through furnishing other community needs. Both strategies would account for the episodic nature of production, but the close association between the volume of material produced and the consumption of metal in burial rituals could suggest that production was tied in a community to the rhythms of life and death (Doonan et al. 2015).

The proximity and visibility of neighbouring kurgan cemeteries suggests that the landscape of death bore heavily on the lives of Sintashta communities and the proximity of contexts of production, especially at Stepnoye, with funerary contexts of consumption, link death and metals by more than the simple internment of metal artefacts in the grave. Doonan et al. 2015, have shown how artefacts which were interred during funerary rituals had all led "*eventful lives*" as evidenced by usewear patterns. Almost all metal grave goods (and ceramics) show evidence of extensive use and repair. Death not only takes objects out of circulation, but also people with defined identities, and it is through death that new social roles are taken on by new community members. It seems likely that production was initiated as new members went through rites of passage, whatever they may have been, such as is seen among recent pastoralists in northern Kenya (Larick 1986, 1991). It seems then that Sintashta metallurgy was not a technology used for the production of funerary goods, yet the elaborate rites (Figure 8.7) associated with burial were, in part, responsible for taking metals out of circulation among the living. Recognising that the disposal of the dead was one practice which would have stimulated demand for metal production is not to suggest that metallurgy was wholly focused towards death, but rather it reminds us that death ties together cycles of consumption and production.

There is an often obscured symmetry of practice between metal mining and the disposal of the dead. Both involve the construction of deep negative features in the earth, with mining pits and burial pits both sharing techniques of construction. It is possible, then, that groups associated with the treatment of the dead and the production of metals shared divergent interests in how each was engaged in funerary rituals and associated practices.

8.2.2 The organisation of Sintashta communities

The typical model for the organisation of Sintashta communities proposed a complex hierarchy which featured proto-state structures dominated by warrior-based aristocracies (Anthony 2009; Kristiansen and Larsson 2005). Within such hierarchies, warrior figures play a central role in the mediation of power, and in turn may be 'tenured ' by the a chief and associated kin to maintain power over the wider region (Treherne 1995). As such craft producers and the wider agrarian/pastoral communities would be subsumed under more dominant classes who would maintain power through ritual institutions, or even the threat of violence (Kristiansen 1999). Such complex institutions are seen as necessary when constructing and maintaining an intense production strategy situated within large scale, long distance exchange networks (Gilman et al. 1981). It is argued here, however, that production was enacted on a much smaller scale, predominantly serving the needs

of the communities themselves, and was carried out only sparingly, mediated by other aspects of life such as death (Doonan et al. 2015). It is important therefore, in the light of such arguments, to address the issue of how these communities were organised.

Hierarchies, such as those proposed for the region, are largely based on European models (see Kristiansen 1999). However, there are considerable differences between how groups subsist in Bronze Age Europe and the Southern Urals. For example, the wider agrarian community in an archetypal European chiefdom are typically seen as sedentary, with crop-based agriculture playing a central role in subsistence; but much of the evidence in the Southern Urals suggests a strong pastoral element to subsistence. A community whose wealth is manifest in livestock maintains a very different relationship with the wider landscape than one which is based on sowing grain (Shennan 2011). Control over resources and space would be vastly different when aspects of the community are relatively mobile and inhabit wide areas of the landscape. Such groups are much more likely to form horizontal control structures centred on contesting groups, where different aspects of the group sustain each other in a more mutually beneficial, perhaps more egalitarian, system. In order to understand how craft practice manifests in such egalitarian organisations it is important to explore the role metallurgists within such a community. Were they subservient to a dominant class, part of a social system that structured itself on laterally informed taboos, or even engaged in mutually sustaining relationships?

In death those burials that are seen as craft practitioners, albeit in a simple association, were given equal esteem with other aspects of the community. In cases where such burials have been identified in association with other groups, such as 'ritual specialists' and charioteers, the relationship is not always uniform (Epimakhov 1996; Gening et al. 1992; Kaliyeva and Logvin 2009; Vinogradov 2003). At both Sintashta and Krivoe Ozero the 'metal producer' graves seem to be given unique significance and are in association with what have been seen as ritual individuals. There is also a direct spatial relationship between metallurgists and charioteers at Krivoye Ozero, where the metallurgist/ritual kurgan was located next to a chariot kurgan, disarticulated from the rest of the necropolis (Vinogradov 2003), while at Solntse the two classes feature in the same kurgans (Epimakhov 2009). There is no evidence in the burial record that those who produced metal were in any way subjugated by those who consumed it, in fact it seems that they were given equal (Krivoye Ozero, Solnste), or greater, status (Sintashta). It is possible that, where in some examples copper producers negotiated an economic value for their product though exchange (Shennan 1998), perhaps metallurgists at Stepnoye and Ust'ye negotiated social value through the production and control of metal, either in isolation, or mediated by other 'ritual' aspects of social life. Thus there was never an abundance of metal goods.

Simply put, with copper ores so abundant in the region, and a clear ability to smelt metal, a system governed by strong hierarchical control would accumulate significantly more (metal) wealth than is evident. The absence of evidence for unbridled material accumulation, the means to wealth, points to a set of social institutions which served to moderate the interests of specific groups, i.e. metallurgists, most likely through taboos, restricted access to labour and skills, resources and/or a mediation of the status which is anointed through the ownership of metal goods (Doonan et al 2015). Therefore it seems likely that, rather than a rigidly hierarchical structure, Sintashta society developed institutions that served to actively mediate and enforce egalitarian values.

Table 8.2 Key modes of metallurgical production and associated characteristics.

	Household/casual	Community mediated/ contested	Specialised/ dedicated	Industrial
Mining practice	Casual, akin to gathering, informal	Small scale, seasonal, localised	Mining camps/ subsurface investment, centralised control	Mining camps/ subsurface investment, centralised control, significant infrastructure, ventilation hoists etc.
Metallurgical architecture	Small temporary	Small, ephemeral	Permanent	Factories
Metallurgical ceramics	Opportunistic/non-specialist	Opportunistic/ non-specialist	Specialist forms and fabrics	Specialist forms and fabrics
Refuse strategy	Sparse and difficult to identify	Mixed with domestic	Slag heaps	Slag dumps
People involved in smelting	Individuals/small groups	Specialist aspects of the community	Specialist groups	Individuals under social contract
Production steps	Single step-direct	Direct/ segmented	Multistep	Complex multistage processes
Temporality	Episodic	Seasonal	Continuous	Full time
Settlement	Temporary camps/ ephemeral	Organised/ritual structures	Nucleated/unequal/ palaces	Towns/cities
Extent/ specialisation	Non-specialist/ communal	Simi specialist	Full time specialist	Full time specialist
Exchange/ reuse	Curation and reuse	Local exchange, mediated possession/ consumption	Wealth accumulation/ long distance, established	Large scale
Community organisation	Kin based	Mutual consent/ negotiation/ permission	Hierarchical structures/dispersed specialised	Commercial
Types of community	Mobile/pastoralist/ Hunter-gatherer	Structured, discrete institutional structures, sedentary aspects,	Sedentary, agricultural, agrarian,	States, nations
Scale	Small scale, when needed	Small to medium scale, when permitted	Large scale	Large scale

When we consider the attention given to understanding the Sintashta phenomenon as the development of a proto-state, this is a significant realisation. States and non-state societies both have specific sets of social relations and institutions, yet the state is often seen as an inevitable development of the non-state societies. Discussions of complexity have dominated Sintashta and wider Bronze Age studies and the emergence of complexity held as a significant point in societal development (Koryakova 1996). When the role of metallurgy is explored among Sintastha communities it is apparent that we come to a very different understanding of social development. More egalitarian polities are often seen as lacking critical institutions which facilitate the development of state-like relations (Service 1971); craft production and particularly metallurgy (Chapman 2003) have long been held as central concerns.

The contribution then of a model which sees metallurgical production tied to cycles of life and death demonstrates how craft production is constrained by groups respecting and enforcing taboos, most likely through the treatment of the dead (Doonan et al 2015). This is perhaps better understood as a tension or contest between specific groups and institutions which serves to actively enforce a more egalitarian society. From this perspective, Sintashta communities are not seen as important for being proto-states, that is, acting as way markers in a narrative concerning state development and social complexity, but rather as examples of societies where the sum of conditions is such so as to actively enforce egalitarian values. This offers an alternative to typical tautological analyses of state development. Instead we can begin to understand how particular social strategies enforce sets of relations through mediating the interests of specific groups (Table 8.2). The moderation of metal production through the enforcing of taboos associated with death may serve, in part, to limit the abilities of other groups to enhance their interests through increased production. This opens a much more interesting discourse wherein we can begin to think about state-like organisation as arising more through the failure of social institutions which mediate competing groups than developing as the result of a coherent society reaching threshold conditions in terms of economy, settlement, religion, and social organisation.

In Chapter 4 we saw that there is an assumption that the Sintashta metallurgy, in terms of scale and practice, is often seen as an intermediate step in an intensification from Early Bronze Age to Late Bronze Age. This perspective derives from an approach which assumes a progressive force driving societal development and looks to archaeological evidence to support this assumption. Beginning with critical evaluation of evidence, seeking to establish modes of production based on observed characteristics, provides an opportunity to write a very different history of Sintashta communities. We can begin to abandon assumed developmental schemes and the desire to flag stages in that sequence and instead engage with an analysis of social institutions and conditions which given rise to different kinds of practice.

As mentioned at the beginning of this chapter, metallurgy is too often seen as being synonymous with complexity. Complexity is rarely adequately defined, but is often seen to be held close to proto-state or state development (Earle 1997). What is clearly apparent is that metallurgy, as a practice, can manifest itself in multiple ways, and it is clearly time that this was acknowledged more widely by archaeologists. Table 8.2 presents a scheme showing how different modes of metallurgical practice might manifest themselves, and how metallurgical groups may relate to other social fields. It is not comprehensive and there

are likely more modes of production than the four highlighted. It is certainly not intended as a generalising scheme, but when considered alongside specific aspects of archaeological evidence some of the main characteristics noted archaeologically can act as an important guide. It is important to note that they are neither threshold conditions (any particular case may fall between or across particular stages) nor should not be seen as mutually exclusive, rather, they should be seen as a framework through which to understand how different kinds of production might manifest archaeologically among different communities.

It is suggested here that Sintashta metal production was organised through collective agreement among social groups, groups which were not necessarily competitive but were engaged in contesting outcomes with one another. Social mediation in this manner again turns us towards a set of lifeways which might be thought of as being more typical of mobile or semi-mobile communities (Ingold 2000: 40). Nomadic communities act collectively in their mobility. They hold among themselves a shared sense of directionality and temporality which is reinforced frequently, perhaps even step by step, and certainly in ways that established communities who exist within the gravitational pull of a settlement do not.

The directionality and temporality of mobile groups could be drawn from their shared experience of the seasonal dichotomy which formed through the annual migrations of populations (Mauss 1906). As Marcel Mauss observed, it is through these movements that seasonally mobile groups maintained their social, moral, legal and spiritual modes, which he argued were inseparably connected to their temporal and spatial context (Mauss 1979: 27; Stucknberger 2006). Therefore the shared localities form the basis of social organisation and its physical manifestations, such as the location of Kurgan creameries near good winter grazing, could suggest that funerary rituals were tied to the annual movement cycle; a pattern which continued even as Sintashta groups became more spatially static. Perhaps it was a worsening of conditions that led to the desire for a more intense collective occupation of these sites.

This is not to say that these choices were dictated by their environment, but were driven by a social cohesion that maintained a clear sense of purpose regarding both the relationship to the environment and livestock (Dwyer and Istomin 2008; Dyson-Hudson and Dyson-Hudson 1980). Nomadic lifestyles require a sense of readiness to hand of shelter and, in the absence of significant storage, strict organisation in the securing of foodstuffs (Ingold 2000). Simultaneously highly ordered yet with a tendency towards expediency, the strategies of nomadic communities stand in clear contrast to those communities which draw upon a settlement to buffer their daily actions.

Seen from this perspective, aspects of Sintashta settlements, specifically the highly structured architecture and the tight adherence to specific environmental conditions e.g. geological contact zones, water courses and cultural resources, e.g. cemeteries, can be understood as settled nomadic communities. The social institutions which once mediated strategies of mobility now turned towards settlement organisation and the exploitation of the immediate environment. It is, then, in the Middle Bronze Age that we start to see what a settled nomadic community looks like and how long-established social institutions endure in very different environmental and cultural conditions.

8.2.3 Readdressing Sintashta settlement interpretations

The focus of this chapter has been primarily on the role metallurgy has played in the interpretation of Sintashta archaeology. The implications of such allow a reassessment of some of the wider interpretations which have been drawn for the Sintashta development and its role in Eurasian synthesis.

The striking settlement form, and the nucleation of, Sintashta-type settlement in the Southern Urals. Explanations for both have tended to focus on a collective response to stress in the form of either an increased period of tension or a competition for resources (Kuzmina 2000 and Anthony 2009). However, both explanations assert a level of hierarchy in order to account for the nucleation of settlement and the architectural consistency. However, with the possible absence of such hierarchy it is important to account for this evidence.

It is argued here that the character of production practice displays elements of a nomadic heritage and that the mode of production is locally orientated. This is seemingly at odds with the settlement evidence, particularly the planned organisation of the sites themselves. Typically it is argued that the earliest settlement forms are circular (Zdanovich and Batanina 2007) with recent evidence suggesting that they were expanded through numerous extensions (Merrony et al. 2009). While the layout in its earliest form is seen to suggest an element of pre-planning and is often cited as evidence of highly organised communities, it is possible that this too reflects a nomadic character of the original builders. It has been strongly argued elsewhere (Rapoport 1994: 488; Ingold 2000: 181) that in constructing camp sites mobile groups plan their layout cognitively long before their eventual material expression, and that mobility leaves no room for trial and error (Holl 2009). The ability of these groups to follow a mental blueprint is what allows them to relocate whenever necessary. Therefore the planning of Sintashta settlement enclosures could be an extension of a pre-existing, ephemeral template given archaeological longevity by more permanent, static construction methods.

The lack of any differential architectural styles may also support the argument expressed here for a more hierarchical social organisation. While it is clear that the tasks enacted within each structure are not uniform across the site, there is no clear stratification in structure, size or location. Even the most compelling evidence for social differentiation, which comes in the form of burials, seems more related to variation in social field than any form of hierarchical control. Close relationship between social fields, although not necessarily fixed, does suggest an element of multitasking expressed in diverse practices; perhaps enacted seasonally. This is evident in ethnographic studies of pastoral communities where practices beyond subsistence are just one facet of multifaceted groups/individuals (Herbert 1993: 12). So in the case of some Sintashta communities metallurgists could act as both producers and ritual specialists, or in others, they may have been associated/marshalled by bellicose social fields. In turn, those characterised as warriors may also be responsible for managing and moving herds of livestock; the central reservoir of wealth in pastoral economies (Fratkin et. al 1994).

All of this has an impact on how Sintashta communities could be defined, and it is important to reassess the use of the use of the terms ‘proto-urban’ and ‘proto-state’. The terms are used frequently in discussion of the nature of Sintashta settlement (Koryakova

1996; Zdanovich and Zdanovich 2002) and yet are rarely defined. Hanks and Linduff (2007) suggest that this is born out of a desire to find a model that "*fits*", rather than they necessarily being the best descriptors, arguing that a lack of visible hierarchy undermines use of the terms. Even by definition the prefix 'proto' hints at a state of becoming and, in the context of communities which could never be considered fully urban in terms of their cultural, economic and political organisation, is inappropriate. The same could be argued for the term 'proto-state', the discussion here strongly suggesting a lack of state-like cohesion or overriding infrastructure amongst Sintashta groups; if anything they could be described as extra-mobile or extra-nomadic, in that they maintained much of their mobile character while becoming more sedentary in the landscape.

Recasting the Sintashta metallurgical tradition and our understanding of social organisation has significant repercussions for wider Eurasian syntheses, specifically in terms of pan regional interaction (Anthony 2009; Frachetti 2012; Kohl 2007). Occupying the narrow tract of grass steppe between the rolling hills of the Urals to the north and the arid deserts of modern day Kazakhstan to the south places the so-called Country of Towns in a significant geographic location in terms of east-west movement. Given the importance of the region for the development of chariotry and horsemanship and the supposed importance of these in long distant elite relations (Anthony 2009; Frachetti 2012; Kristiansen and Larsson 2005) it is clear that challenging the means of metal production also challenges the basis of these wider continental syntheses.

The focus of current scholarship towards establishing such parameters as an index of complexity is not only misleading but actually resists the intriguing challenges of working with this material. While the work presented here can be used as a counter to such arguments, the real question that should be addressed relates not so much to tracking social complexity (cf. Koryakova 1996), but at understanding how the social institutions that converged on practices such as metal production were woven in to the wider fabric of social life in and beyond individual communities.

Moving beyond the Southern Urals it is now difficult to use the Sintashta phenomenon in support of wide ranging metallurgical production and exchange networks (cf. Anthony 2009). There is no evidence at Stepnoye and Ust'ye for the kind or reciprocity which would be indicative of such a model. Indeed there is little to suggest that metal was produced for any more than local needs. Models such as Michael Frachetti's, which sees Sintashta communities from the western steppes to China as key agents in the spread of bronze technology by virtue of their 'dealing' in elite packages of metals, horses and chariots (Frachetti 2012) seem particularly vulnerable. The place of Sintashta communities in grand, continental syntheses, in the guise of either complex proto-states (Zdanovich and Zdanovich 2002), metallurgical hubs (Anthony 2009) or influential warrior aristocracies (Kristiansen and Larsson 2005) seems wholly unsubstantiated. Drawing such large scale narratives can serve to obscure the local and regional mechanisms through which groups engage and change over time. In acknowledging the potential for diversity in production practice it becomes possible to understand the Southern Urals not as a component in an expansive Eurasian system, but as a region which played host to diverse and dynamic communities that participated in varied and widespread social phenomena. The task is not to document and describe these widespread phenomena, but more to unpick the strategies through which participation was maintained (Hanks and Doonan 2009).

Chapter 9

Conclusions and Future work

This thesis set out to characterise metallurgical production debris found on sites dating to the Middle Bronze Age in the Southern Urals and to evaluate existing models for copper production. The campaign of work has demonstrated that the scale and organisation of Sintashta metallurgical production has been significantly misrepresented in the published literature (Grigor'yev 2013) which has, in turn, stimulated wide-scale narratives of exchange and complexity which centre on Sinstashta communities as being 'proto-state' formations. The evidence presented here has not only questioned existing understandings, but also attempted to explain how such understandings have come about. It has been shown that much of the evidence for primary metallurgical production indicates significantly smaller-scale production centred on a range of local practices and traditions. The following sections gather together many of the issues discussed in the last chapter in order to develop a series of specific conclusions and suggestions for further work.

9.1 Conclusions

It has been clearly demonstrated that copper production was not widely practised at these sites. Nor was it practiced intensively. The slag morphology, found at the majority of the excavated sites, supports the view that copper was smelted by a small group or number of individuals, and it is likely that these individuals or groups constructed, at least in part, their identity through this practice. Copper metallurgy is a transformative craft and carries within it an element of drama and risk. It involves the performance of a process which seeks closure in the production of copper. The skilled performance of smelting alone does not guarantee the production of copper; the process is also contingent on raw materials and the satisfactory behaviour of ceramics and fuel. Luck plays a part.

Metallurgy then, is a skilled practice and one that relies on the marshalling of numerous elements, all at the limits of their physical properties. Ceramics are used as containing solids yet, as the vitrified remains suggest, as they fuse in to a molten mass, they are moments from catastrophic failure. The rate of airflow is such that it is a struggle to attain the necessary temperatures and further, to assure these are directed to the relevant part of the furnace. With so many variables teetering on 'failure' it is unsurprising that metallurgy is so often understood as having been associated with taboo and ritual (Dobres 2000, Bradley 1990). Whether any such aspects attended Sintashta-type practices it is impossible to say,



Figure 9.1 Characteristic Sintashta vessel featuring a copper alloy pot clasp.

yet it is certain that Sintashta metal workers would have developed their own strategies for negotiating the risks associated with a process which was central to their identity.

This thesis has already highlighted the number of burials that contain metallurgical paraphernalia, which includes decorated crucibles, ore charges, animal bone and charcoal. There too seems a statistically significant incidence of peculiar or distinct individuals associated with metallurgy, such the elderly, large jawed man of Krivoe Ozero, and the lonely internment at Sintashta accompanied only by de-fleshed skulls. Together we start to see metallurgy not as a collective practice to which a whole community was oriented, but rather a restricted practice undertaken by a few individuals, and who used these practices to themselves construct a unique identity. This, to some extent, was likely as much social as it was biological, as in some cases it seems that those buried with metallurgical remains exhibited signs of poisoning symptomatic of metallurgical practice.

Restricted though it may have been, Sintashta metallurgy was clearly not a specialised practice in terms of the materials employed. The absence of dedicated technical ceramics and elaborated furnace structures points to a process undertaken in a somewhat ad-hoc

manner which made use of materials ready to hand. It is difficult, at present, to draw any conclusions regarding the relationship between potters and metallurgists, and we should not assume that they were separate groups.

The presence of copper alloy staples to hold ceramics together has been noted in several instances (Figure 9.1). Many of these are noted as repairs to vessels that had failed in service, yet a number have also been identified which show the use of staples to repair firing defects. This is interesting on two counts. Firstly in confirms very much the observation made earlier (Doonan et al 2015) that Sintashta material culture was commonly repaired and reused, but it also hints at a relative scheme of value between metals and ceramics. The number of metal staples used in some ceramic vessels seems to surprisingly high; up to 14 in one instance. This quantity of copper alloy was considerable and could be compared to an amount useful for making a small Sintashta-type knife which were so often held in esteem as high status objects (Figure 9.2).

This is not to argue for the relative availability of copper and ceramic -- as this thesis has already argued, copper sources were readily available in the vicinity of settlements -- more it is to highlight the fact that ceramic vessels themselves should not be over-looked. The use of copper alloy in the early production stages of ceramic vessels may indicate that



Figure 9.2 Collection of metal artefacts highlighting their range of sizes

there was considerable overlap between the two crafts. The further evidence of repair and curation points strongly to a community which valued objects in a way that meant that it was meaningful for them to be used, repaired and reused. The significance of this is intriguing especially when considered against an environmental background where clay and metal deposits were hardly in short supply. It is too early to develop a comprehensive discussion of this matter, but it has already been suggested that the production of metal might have been controlled by taboos associated with cycles of death. It also seems that ceramic vessels were kept in circulation significantly longer than by other contemporary cultures. This may indicate very specific conservative attitudes towards things, and in turn production, that are incongruent with models of production and resource exploitation that are so often geared towards maximising resource control and productivity. It is certainly premature but nonetheless tempting to consider the Sintashta attitude to things as being informed by a value system that would have been recognisable to nomadic pastoralist communities where production operates under strict controls and conditions (Dwyer and Istomin 2008).

If it is anything the Sintashta metallurgical process is a one which produces flat plate slags that solidify on top of a copper ingot. The ability for it to be adapted to local conditions is an interesting aspect of the metallurgical tradition and quite unlike many documented elsewhere in the Bronze Age world. To be able to accommodate a range of furnace atmospheres and to utilise very different ore types is unique among documented traditions. It is clear that the spread of this tradition was not the result of a single origin process being taken-up in a linear fashion by other communities. Rather, it points very much to the co-development of an existing technology in several places simultaneously. This is an important realisation as it suggests that any tradition that Sintashta metallurgy builds upon was adaptable to a range of environments.

Yamnaya metallurgy has been documented in some detail (Chernykh 1992), yet its evidence is almost solely from grave contexts in the form of finished artefacts. To date we know nothing of Yamnaya production processes. Nonetheless it is intriguing to consider that Yamnaya metal goods are the product of a mobile community; something that until relatively recently was an anathema to the assumed stadial progression of society (Childe 1944, Plucienniek 2005). This is relevant to our emerging understanding of Sintashta society. If the metallurgical tradition of pre-Sintashta communities was one which relied on exploiting diverse and varied mineral deposits across a wide-ranging catchment such as a mobile-pastoral community might encounter then we can begin to appreciate a defining characteristic of Sintashta metallurgy. The ability to accommodate diverse minerals may not have been the result of adaptable and innovative Sintashta metallurgists themselves, but rather the consequence of a long-practiced tradition which had evolved over time to accommodate the varied resources encountered by a mobile community.

The uniformity of plate slags at the sites examined here, published sites and sites that have been glimpsed in museum archives is remarkable. It is clear that a tradition of metallurgy centred on plate slags was established well before communities became tied to a defined settlement and catchment. There is no evidence of a developmental stage or a trial and error process. The conservative nature of Sintashta metallurgy is further supported with the arrival of tin-bronze, when innovation in tin is identified among plate slags which are morphologically identical to early copper and copper-arsenic plate slags.

It was argued in the previous chapter and above that taboos and cycles of death mediated copper production, and that this mediation was played out by particular groups through existing social institutions. Metallurgists, or perhaps it might be better expressed as those who worked metals, would have formed important members of these contesting groups, and while they played a role in death they, and metals necessarily played an important role in life.

There is clear evidence in the material record for metal associated with other activities including: fishing, hunting, gathering (in the form of sickles), woodworking, and textile production. Although these activities have been discussed to some extent in the literature (Koryakova 1998; Kupriyanova 2008) they have always been seen as secondary to metallurgy. While the term 'metallurgical community' is inappropriate when discussing Sintashta sites, it is certain that Sintashta communities were metal-using. The identity of those who produced metals was negotiated though supplying the wider community with tools for everyday tasks, not just in furnishing bellicose individuals with weapons, but carpenters with chisels, farmers/gatherers with sickles, and textile workers with awls. In marshalling the supply of these tools metallurgists may have held a central role in the maintaining the range of activities through which the community reproduced itself.

Considered overall we begin to see those who produced metal goods as holding significant roles in the community. Is it though, possible to comment as to who controlled metallurgy during the Middle Bronze Age? Earlier the idea of mutually consenting groups was introduced to explain how metallurgical production was limited through appealing to taboos and restrictions likely associated with death. This proposal replaces a model with consenting specialised communities seeking to maximise copper production for "*bottomless*" markets to the south (Anthony 2007) with one where various fields moderate one another through a myriad of social negotiations. The result is that no single group gains an advantage and the highly ordered, apparently stable communities so typical of Sintashta sites endure.

Institutionalising restrictive controls on production strategies, rather than permitting specific groups to maximise their own interests through production, suggests that local strategies were likely developed at each site which reflected their unique political, social and environmental conditions. The more distant mineral deposits to Stepnoye would have been accessed under different conditions to those more proximal at Ust'ye. Likewise, it could be argued from the burial record that at Ust'ye metallurgy was tied to bellicose individuals, while at Chernorech'ye it was related to ritual/religions specialists, and that at Sintashta metallurgists may have maintained their position in isolation.

Earlier, attention was drawn to the presence of metallurgy among Yamnaya mobile communities. Without significant settlements or extensive exploitation, metallurgy remains difficult to locate in a distributed taskscape. The focus here on Sintashta metallurgy is very much in response to the attention it has received by other scholars (Anthony 2009; Kohl 2007; Koryakova and Epimakhov 2007) as it is used to support a development of states (Zdanovich and Zdanovich 2002). However, while the Sintashta cultural phenomenon is often highlighted as part of the state-building process, few scholars turn to examine where Sintashta communities have gone by the Late Bronze Age. Rather than seeing them develop into fully fledged state structures we see something very different. The highly structured settlements which characterise the MBA are abandoned, though not totally; we do not see a simple and

complete reversion to mobile pastoralism. Instead we see a loosening of settlement structure (Koryakova and Epimakhov 2007). By the Petrovka and Alakul phases we see a distributed settlement pattern across the landscape of smaller irregular hamlets and agglomerations of house platforms. Whatever maintained the highly ordered and structured settlements of the Sintashta communities has gone, and instead we see settled communities dispersed in a loose, less organised structure. Interestingly though, especially in terms of metallurgy, we start to see some significant developments. Chernykh has excavated extensively at Kargaly and noted the impressive scale of production. The last chapter raised the important point that this scale of production was likely the result of the social institutions that moderated production breaking down and allowing groups to pursue production for their own gain; the tightly controlled settlement structures collapse in tandem with this intensification of production, suggesting that rather than seeing this cultural development as the emergence of 'state', what we are actually witnessing is the fragmenting of social institutions and the unleashing of productive power among specific groups.

To conclude, the study of production and resource procurement in the Southern Urals, when viewed as a fully social phenomenon (Pfafenberger 1992), can provide extensive insight in to the way in which communities were formed and maintained through the ongoing negotiation of social relationships; not just between individuals and groups but among things, people and environment. To date, much of the way metallurgy has been dealt with in the region is unsatisfactory. It seems that the presence of metal is always simply equated with complex political control. It is rarely considered either in its wider social context, or as a set of situated practices, rather it is conceived as a generic practice indicative of a threshold condition useful for characterising social development. Of course, metallurgy can be a means to wealth and status, but there extends a myriad of conditions under which it can be practiced and its analysis should not be restricted to such terms. In adopting a more local scale integrative approach this thesis has shown that significant insight can be gained through a programme of research which focuses on local scale activities and practices. It has attempted, not to identify signifiers of complexity, but to present an explanatory narrative that highlights detailed evidence.

9.2 Future Work

Although the work undertaken here, and the wider SCARP project, is a significant contribution to the study of the Bronze Age of the Southern Urals there remain many questions partly or wholly unanswered. The aim of this thesis was to provide a critical engagement with the dominant models and to highlight the effectiveness of an approach which re-examined their central assumptions at multiple scales. Thus the focus was narrowed to two sites on which metallurgy was practiced. In choosing to focus on just two main sites it was possible to fully explore these questions through the analysis of material remains while still evaluating long held assumptions on intra-regional practices. The logical route to build on this work is to maintain such a focus, but to expand the geographical and temporal scope of the study. Therefore the following questions are of paramount importance and could be answered though an exploration of craft practice.

How were communities organised at the other sites in the Country of Towns? Can any sub-regional traditions be identified?

The work here investigated only two sites and yet the insight gained was significant in terms of how the two communities were organised. Applying this method to a wider sample of sites would greatly enhance our ability to characterise the social dynamics and community organisation within the Country of Towns. This is particularly important in areas where sites are located close together, as it is possible that these sites formed micro-regional groups/traditions and as such understanding their relationships is of particular importance.

How were Petrovka and Alakul communities similar to/different from Sintashta communities?

While it is important to gain a wider understanding of Sintashta community dynamics it is also necessary to place such dynamics into the wider historical narrative. The sudden appearance of planned settlements and a well-established metallurgical theme likely had origins in the early Bronze Age, yet how this manifests in metallurgical practice is poorly understood. However, it is unlikely that significant inroads can be made into understanding Yamnaya communities without substantial development of methods to identify Yamnaya practice archaeologically. Yamnaya sites remain archaeological scant especially in the region addressed here. More important is an understanding of the decline and dispersal of settlements coupled with selective specialisation and intensification of production. It is apparent that by the Middle Iron Age the region is largely supporting mobile pastoral communities, yet it is often assumed that this represents a rapid transition from Sintashta lifeways. The presence of an increasing number of Petrovka and Alakul settlements demands a similar analytical approach to that endorsed by this study. To investigate production practice, as has been done here, of later communities would offer significant insight not only for the exploration of the ideas proposed here for the collapse of Sintashta communities, but into the organisation and character of the later groups in their own right.

What was the relationship between Sintashta groups and neighbouring populations?

Due to the extent of the attention placed on Sintashta settlements, their contemporaneous groups, at least in western publications, tend to be seen as secondary and are rarely explored (Frachetti 2012; Anthony 2009). This has had the result of making the Sintashta settlements one of the most studied phenomena in the region, yet they stand out as an archaeological oasis in a desert of knowledge. Nonetheless, many still draw these studies into wide ranging narratives to connect dots on maps many thousands of kilometres apart. Evidence for metallurgy has been identified at both Abashevo and Petrovka sites, and yet it is either dismissed as a stage in Sintashta development (Anthony 2009), as being at a lower level of complexity, or as simply not useful in the common dialogues (Koryakova 1996). However, with Sintashta production much smaller in scale, and subject to complex power relations, it is vital to understand how production manifests in neighbouring groups. This is so as to better understand not just how it related to Sintashta populations, but to the nature of the local interaction networks that likely form the underlying mechanisms through which the trans-regional movement of material (such as Seima-Turbino metalwork) took place.

To what extent can migrations and/or internal development be significant in how communities produced metal?

Migration versus internal development is a prominent theme in Central Eurasian archaeology, though not addressed in this study. The openness of the terrain is seen to favour migrations/expansion/invasions (Koryakova and Epimakhov 2007), but much of the evidential basis for such discussions rest on changes in material culture and the movement/spread of different styles. In applying the methods of this thesis, namely the characterisation of production practice, to this question it is possible to better understand such changes. There may be evidence for vastly different modes of production, suggesting the arrival of new groups, or of continuity in practice, which would suggest that the populations remained the same, only incorporating new designs and materials. This would provide significant insight into a question that has long been associated with the region, and could form the basis of a practice-based narrative.

This thesis has shown that in exploring production as a fully social phenomenon questions regarding the organisation of communities can be explored in a way that can challenge existing models and draw significant conclusions regarding the organisation of ancient communities. In so doing, wider narratives and syntheses will have stronger foundations, and perhaps find it more challenging to employ such evidence, and the result should be a more nuanced understanding of the cultural groups which too often are seen to inhabit the Steppe as nothing more than chronological markers. If this thesis has achieved anything then it is hoped that is has provided some insight in to the lifeways of Sintashta communities.

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Appendix A

Analytical Methods and Protocol

A1- Recovery and identification

The first step of the characterisation process was to outline the extent of the assemblages and to provide broad identification of the material types present. This was done by the author in Chelyabinsk. The initial identification of the Stepnoye material took place in the field. In line with Russian archaeological guidelines for excavation the finds were sorted by type, e.g. ceramic, slag, metallurgical debris, bone etc. For the main excavation this was done primarily by students who had been briefed on the main characteristics of the key material types. The finds from the test pits were all appraised by the author. The excavations at Stepnoye are unique in the Southern Urals in that sieving was carried out as standard. This is important to acknowledge as this likely produced significantly more smaller fragments of metallurgical debris than was found during other, older excavations. Because the bulk of the material studied from Ust'ye was recovered during the excavations in the 1980s the material had already been pre sorted into categories. However the author was given full access to the other finds in order to establish if anything had been overlooked. Following the initial identification of material the finds were grouped according to broad typologies before being subjected to detailed metric analysis, preliminary bulk chemical characterisation and destructive sampling.

The slag was grouped into a broad typological framework based on the work Bachman (1982), which for copper slag consists of; plate slag, furnace conglomerate, tap slag, and fuel ash slag. This was done largely though the materials distinct formal characteristics which are indicative of its formation process (Bachman 1982). Minerals were broadly grouped by their main visual characteristic in hand specimen using reference material from 'The University of Sheffield Archaeometallurgical Reference Collection'. Metallurgical ceramics were initially identified by eye, taking into account form and levels of vitrification but due to the unique nature of ceramics the region a program of residual metals analysis.

A2- Metric analysis of slag

At Stepnoye all of the excavated material from the 2008 and 2010 seasons was recorded metrically. Due to the extent of the Ust'ye assemblage only a subsample of the main excavation slag was fully analysed, however all of the recently excavated material from 2011 was recorded.

In order to fully characterise the metric variance the following characteristics were measured using vernier callipers: the thickness of the plate within the area bounded by the meniscus impression, the thickness of the meniscus impression and the thickness of the outer edge area beyond the meniscus impression. The weight and major/minor axis were also recorded.

As well as these principle metric traits the following characteristics were also recorded; the presence/absence of an, edge, meniscus impression and organic impressions, the colour, level of porosity, surface corrosion. Where possible the diameter of the slag plate and ingot were also recorded. Unfortunately none of the fragments were complete enough to be able to directly measure these traits, therefore the diameters were typically inferred using a standard ceramic rim chart (when at least 7.5% of the curve was present).

A3- Initial bulk chemical Appraisal

The initial phase of analysis was carried out in Chelyabinsk and applied to considerably more material than it was possible to sample and export. Although this program was initially qualitative in nature it allowed the rapid appraisal of a large number of samples using portable x-ray fluoresce (pXRF). This ability to rapidly analyse large quantities of material in a relatively short timeframe proved most useful in identifying a representative sample and producing a wide range of chemical analysis of material which would not normally be available for such extensive analysis. This phase of analysis was split into two categories; bulk with light elements and without. The initial aim of the program was to conduct good quality, quantifiable, broad spectrum analysis. This was to be achieved by procuring a good supply of helium in Russia that could be used to purge the system and allow it to analyze elements as light as silicon. Ultimately though, the flow of helium was inconsistent which resulted in light elements not consistently being identified. Fortunately standards were analyzed every five readings which allowed the unquantifiable analyses to be separated from those which were.

Despite the problems encountered during the analysis, the quantity of samples analysed means that both datasets were useful in characterizing the assemblage and all of the data was scrutinised before any destructive sampling was carried out. Samples were analysed in mining mode using main (20 seconds), low (10 seconds), high (10 seconds) and light (65 seconds when helium was available) filters.

Residual metal analysis

Residual metal analysis using pXRF was undertaken primarily to establish the presence of copper enrichment that was not discernible by eye. It focused predominantly on ceramic but was also used in more limited studies of lithic tools. Numerous analyses were carried out on each sample including interior and exterior surfaces, working faces and unworked areas. Comparison of a number of analyses on a single artefact were used to establish if a ceramic or lithic surface had been in contact with elevated levels of copper such as might be encountered in metallurgical production. The analytical times varied, and were qualitative in nature, but tended to focus on main mode elements and run for between 25 and 60 seconds.

Sampling strategy

Sampling for subsequent analysis was carried out following the initial bulk analysis and the metric analysis. Samples were taken which would represent variation within both the assemblage and context. Unfortunately the majority of the samples had to be small, typically less than 1cm, due to the export restrictions. However, some larger samples were taken in order to compare the variability within a single artefact.

A4 Microstructural analysis

The samples which were returned to the UK from the 2010 and 2011 seasons were all prepared for microstructural analysis in addition to a selection of samples from 2007 and 2008. A total of 62 were prepared. Samples of slag, ore and ceramic were all prepared for analysis. The majority of the samples were prepared for reflected light and scanning electron microscopy which required making polished sections. A small number of samples, particularly ceramics, were also prepared for thin section analysis.

The samples selected for reflected light and scanning electron microscopy were all mounted in resin within moulds (typically 25mm). If the sample was friable it was impregnated under a vacuum (Voort 1984: 85). When cured the samples were polished using a combination of grit and diamond paste to a grade of 1um. If selected for SEM the samples were carbon coated.

The thin section samples were heat impregnated and mounted on glass slides which, when cured, were cut and polished using carbon powder before being masked with a cover slip.

Optical microscopy

The first phase of analysis was conducted using a Nikon Optiphoto-2 reflected light microscope. This allowed a rapid phase characterisation of all of the samples before more detailed analysis using scanning electron microscopy. This initial characterisation was essential as it was not possible to study the total assemblage under SEM.

Initial characterization and grouping

Slag samples

The samples were initially grouped microstructurally by silicate content and iron oxide content. Unlike ceramic petrography there is no widely accepted structure for the recording and description of archaeological slag (cf. Middleton and Freestone 1991). Most visual analysis of slag samples still follow the pioneering guidelines outlined by Bachman (1982) and, for mineralogical inclusions, Ixer (2003) and Pracejus (2008). However, this allows only broad characterization of the phases present. In order to better structure the characterization of slag for this project a custom database was constructed using Filmmaker. The database contained both micrographs, keyword descriptors and free text boxes. Figure A.1 shows a screen shot of the database in analytical mode. The common copper slag phases were all structured using drop-down boxes and keywords in order to describe their frequency which ranged from; absent, rare, occasional, common, frequent, dominant. Figure A.2 shows the visual guides which were used to assign percentage ranges

to these qualitative categories. In addition a dropdown box was created to identify the matrix type, either glassy or micro-phase, and percentage present. There was also a free text box for any additional phases and a description box. This system was used through the microscopy phase of analysis to build a full optical micro-analytical database for the assemblage. The database was supplemented by integrating both SEM analysis and bulk chemical analysis.

Following the initial phase characterization the samples were grouped according to their silicate type and by the presence, quantity and type of iron oxide. The groups were structured to incorporate both Ust'ye and Stepnoye slag. Table A.1 outlines the characteristic of the main groups and subgroups.

Ore and mineral samples

The ore and mineral samples, like the slag samples, were all impregnated, mounted and polished. The ore minerals were identified using Ixer (2003) and Pracejus (2008). Initially the ore samples were grouped as either sulphide ore, or oxide ore (including carbonates) before being fully characterised based on their optical properties.

A5- Mineralogical and phase analysis

The initial stage of mineralogical and phase analysis was carried out using optical microscopy. The results of the methods outlined above were calibrated by analysis of individual phases in selected samples using Scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS). This created an optical reference collection which was specific to the slag from

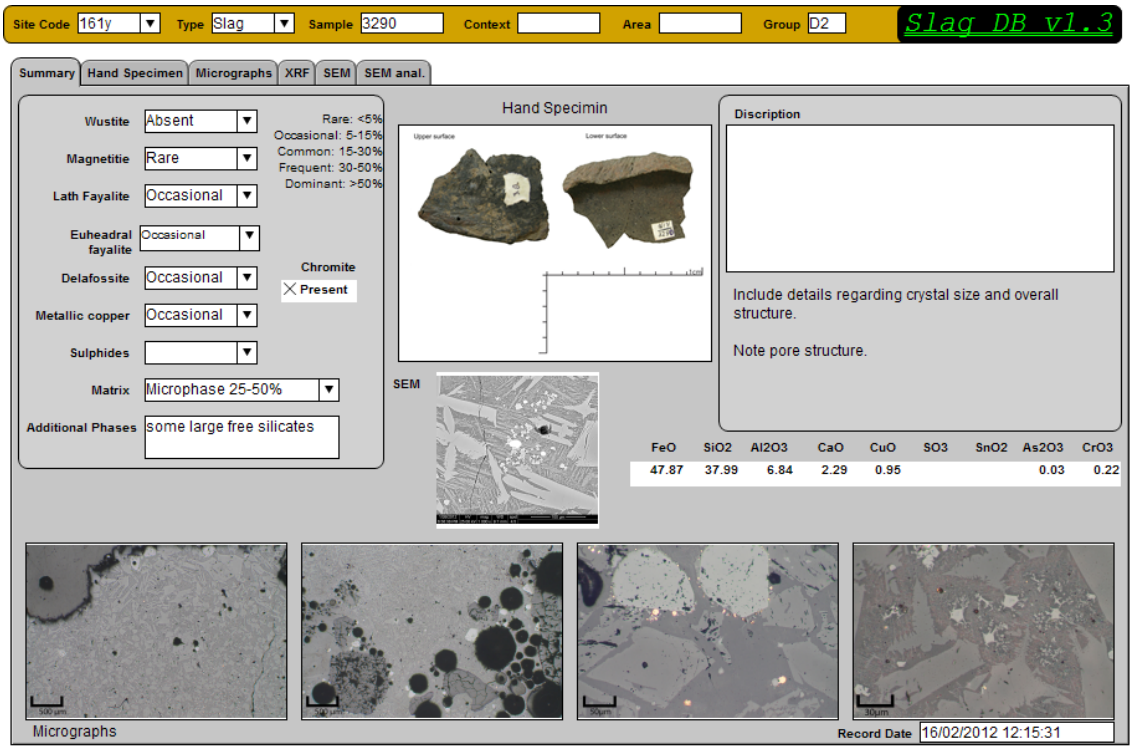


Figure A.1 Screen capture of the analytical database showing the integration of images, photo micrographs, electron micrographs, chemical analyses and descriptions.

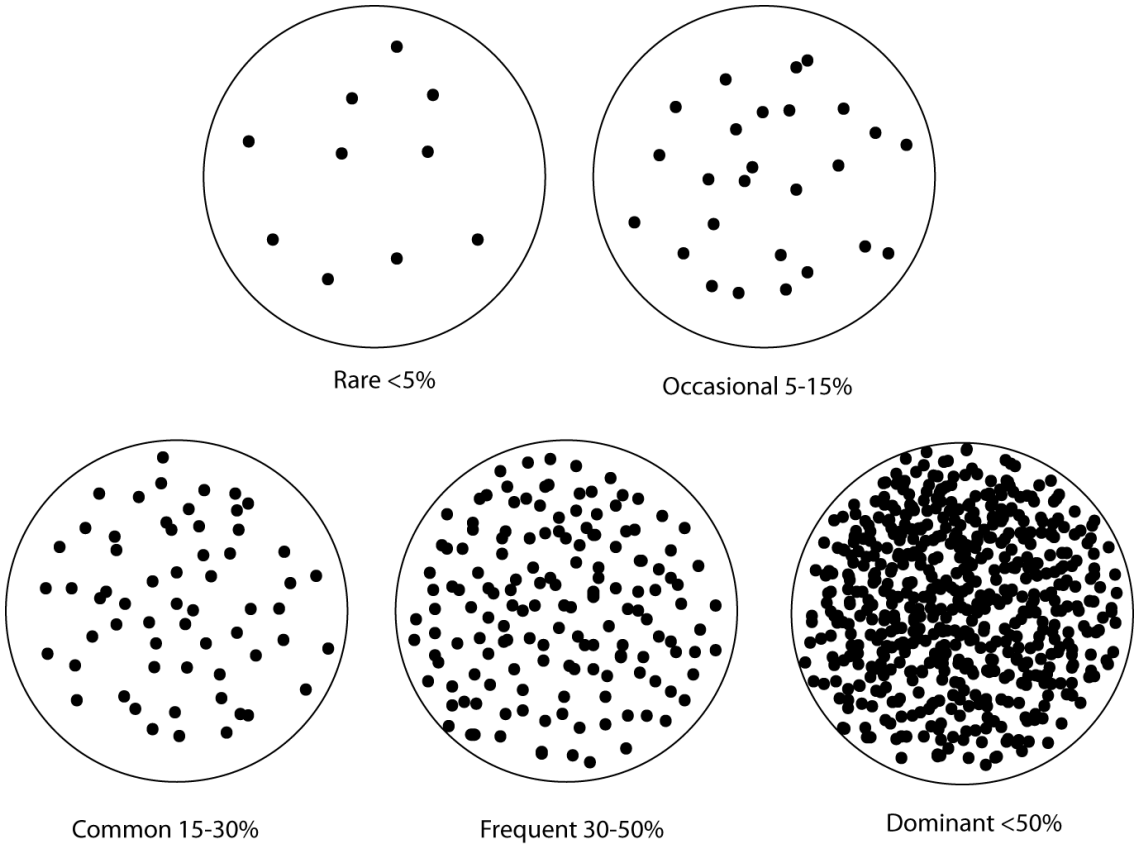


Figure A.2 Reference of phase distributions used in the microscopic analysis

Table A.1 The microscopic slag groups

Group/Sub-group	Name	Description
A	Lath group	This group predominantly contains crystalline silicate in the form of fayalitic laths with little or no tabular silicates
B	Tabular group	This group predominantly contains tabular crystalline silicate with little or no lath-like fayalite
C	Glassy group	The group contains little or no crystalline silicates
D	Lath/tabular group	This group contains both fayalitic laths and more tabular silicates.
1	FeO absent	This groups contains no iron oxides in any form
2	Some FeO	This group contains some iron oxides (either magnetite or wüstite) but no more than common.
3	High FeO	This group contain frequent iron oxide phases.

the Southern Urals and allowed phases confirmed using SEM-EDS to be identified over a wide collection of samples.

Scanning electron microscopy with energy dispersive spectroscopy

A representative sample of slag, ore and ceramics was analysed using SEM-EDS. The instrument used for the analysis was an FEI Inspect F SEM which was run at 25kv and used a beam current of around 12.nA. The spectra generated were detected by an Oxford instruments X-act SDD detector. They were optimised by calibrating with a cobalt standard. This produced a series of electron micrographs at a range of scales as well as individual analysis of slag/mineralogical phases.

Analysis of slag phases followed a set work flow for each sample in order to produce comparable results. Where possible a minimum of three analysis of each phase type were recorded for each sample. These were grouped by phase type based on the common visual characteristics. Therefore oxides were analysed as one group as were, silicates, metallic phases, and spinels. Individual analyses were also recorded for the glassy matrix and unknown phases. In addition to individual phase analysis, a minimum of four bulk analysis were taken for each ample at a set magnification of 500x. Spectra were gathered for a minimum of 60 seconds for each. Electron micrographs for each area of analysis were recorded. Both spot analysis and small number of elemental maps were produced to explore phase separation and areas of ambiguity.

For non-slag samples individual phases were analysed on an ad-hoc basis depending on what was present. Where possible, multiple areas were analysed for each sample. Analysis of ceramic samples followed a similar methodology; however special attention was paid to any spinel inclusions present with multiple inclusions analysed.

Micro X-ray fluorescence

In addition to the program of phase analysis using SEM-EDS a program of micro x-ray fluorescence (μ-XRF) was carried on a small number carefully selected samples. The benefit of μ-XRF is that it can produce two dimensional elemental cross sections of samples with a resolution as high as 25 μm using an automated $x\ y$ stage. This is particularly useful on certain samples, because where SEM can produce maps at a higher resolution; μ-XRF can produce maps of the whole polished surface of the sample on an automated cycle. This can highlight phase variability over the whole sample with relative ease. In the case of the slag and ceramic samples analysed here the scale of analysis fell between that of macroscopic and microscopic, giving an excellent understanding of how certain phases were distributed (Flude et al. 2011). High spatial resolution μ-XRF analysis has, until very recently been limited to very expensive synchrotron facilities, however recently several bench top instruments have been produced (Flude et al. 2011). This means that its routine application in archaeology has be fairly new with its only published applications limited to exceptional cases (Rabin and Hahn 2013). The instrumentation used for these analyses was a Bruker M4 Tornado with a voltage of 50kV. The pixel sizes raged form 10-20 μm and analysis times were between 60 and 130 minutes producing up to 800,000 pixels.

X-ray diffraction

Xray diffraction (XRD) was carried out in order to fully characterise the mineralogical compounds present within the slag. Unlike many of the other analytical techniques employed, which identify atomic structure, XRD directly identifies compounds through the way in which their crystallographic structure diffracts x-rays. These crystalline structures are determined using x-rays of known wavelengths which are fired at the sample at a range of angles (Pollard and Heron 2008). The basic terms; when an x-ray beam enters a sample at an angle it is 'reflected' back at a detector though the crystal lattice of the sample. As the x-ray penetrates the atomic structure of the sample it releases multiple diffraction patterns (Figure A.3). These patterns are characteristic of the minerals present. It is important to note that XRD does not identify glassy phases due to their lack of an internal crystal structure. As slags often contain a glassy matrix it is important to bear this in mind when interpreting the results.

A total of 12 representative samples of slag were subjected to XRD. XRD analysis was carried out using a Phillips PW1830 powder diffractometer which was selected as it was ideal for small sample size and producing phase analysis of vitreous materials. The x-ray tube operated at 40kv and 30mA. A secondary beam monochromator was used to reduce fluorescence and background noise.

Analytical procedure and mineralogical determination

The samples were crushed using an agate pestle and mortar until powdered. The powdered samples were then placed in a small metal tray and smoothed to an even flat surface suing a glass slide which was then placed in the diffraction chamber. Readings were recorded every 0.5 degrees from 15 to 60 degrees.

The spectra produced were processed using Sieve+ software which automatically identified the main peaks; with smaller peaks were identified by eye. The peak configurations were

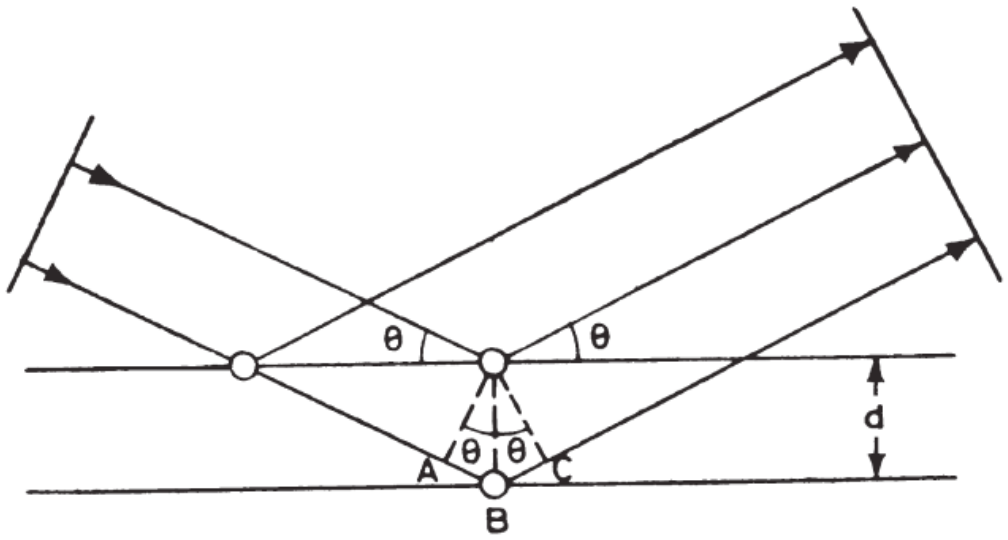


Figure A.3 Illustration showing the effect of Bragg's law of X-ray diffraction which shows parallel x-rays reflected of successive crystal planes (after Pollard and Heron 2008)

then compared to a selection of digital powder diffraction files (PDF). The PDFs were selected based on the range of element identified using other analytical techniques (c.2500 minerals). The peak configurations were matched using a combination of visually similarity, the software's 'Goodness of Match' score and by what would typically be expected for a metallurgical slag. This is important to note because the technique does not simply analyse the sample and produce an accurate identification, it is necessary to understand the nature of the sample and the limitations of the technique. The spectra were processed repeatedly in order to produce the best possible matches.

A6 Bulk Chemical analysis

Bulk analyses were produced using three complimentary analytical techniques; the main program was carried out using x-ray fluorescence (XRF), with a subsample subjected to prompt gamma activation analysis (PGAA) and low magnification SEM-EDS.

X-ray fluorescence

Recent developments in pXRF technology have seen the instruments gain significant portability in addition to heightened accuracy and precision all while producing much shorter analysis times (Frahm and Doonan 2013). However, an increased availability and usability of analytical equipment carries with it both potential rewards and risks to those studying ancient metallurgy. The ease at which the most recent instrumentation produces 'results' means that compositional data can be produced rapidly and on an extensive scale even in relatively unskilled hands. But this leaves the employment of pXRF open to extreme criticism by the traditional analytical community, some justified and yet more hyperbolic. While chapter 6 showed that pXRF can be used in novel ways in the field it has been shown that pXRF can go beyond the application of traditional, lab based techniques, by making the most of the portability and versatile nature of the instruments, However, there are also benefits to using in a more static, laboratory setting. In the context of this project its portability became invaluable in that it could be set up in laboratories in Russia and used to analyse far more material than could possibly have been exported. In laboratory mode the instrument, like any other XRF, can be calibrated to produce externally consistent results, and as long as traditional analytical are still followed, be very useful in the analysis of large assemblages.

Instrument setup

The instrument used was a Thermo-Niton XL3t, which was also used in the initial appraisal. The instrument was set to bench-top mode using a lead lined stand which allowed the instrument to be used safely for prolonged periods. The instrument was inverted giving a flat surface on which the polished sample was placed and was purged using a constant flow of helium which allowed the instrument to detect light elements (Mg to S). The instrument was equipped with four filters which vary the excitation energy in order to limit peak crossover and produce a better spectra (Table A.2).

Analytical procedure

Each sample was analysed for the same time period; a total of 155 seconds. This was split between the instrument's four filters with 45 seconds on main, 20 seconds on low, 20

seconds on high and 60 seconds on light. Selected standards were run every five samples (West Runton slag and Si std) in order to confirm the consistency of the helium purge and the overall precision of the results. Detailed analytical protocols and calibrations can be found in Appendix A.

Analytical principals

The underlying principal of XRF, both in the laboratory and field based instruments is that when an atom is exited by an external source (Such as x-rays, electrons or gamma rays) it emits characteristic secondary x-rays (Pollard and Heron 2008). This is because, when an atom is excited an inner shell electron jumps to the outer shell, as an electron falls to the inner shell to replace it an x-ray is released (Figure A.4). In a laboratory setting XRF records these emissions in two ways; through their wave lengths, called wavelength dispersive, and through their energies (WD), called energy dispersive (ED). The instrumentation used in this program, and to record the secondary emissions during the program of SEM, was energy dispersive spectroscopy (EDS). The basic principal of EDS is that as the electron falls to the inner shell it will release an x-ray at a known energy, these x-rays are then detected and the total number of each energy is noted; known as a point count. These points are then plotted to produce a spectra and their relative intensities are used to generate an elemental composition (Pollard and Heron 2008). However, it is not always so straightforward, as electrons within the atom do not always fall from the same shell, in some cases an excited atom will release numerous emissions, as shown in Figure A.4. These emissions are named after the shell to which they fall and from where they have fallen (a letter for the destination shell and a Greek notation of the shell they have fallen from, see Figure A.4). It is important to be aware of this as there is no differentiation between the alpha and beta peaks in the spectra and there may be some crossover between elements. However, this problem can be overcome using appropriate instrument setup, calibration and analytical procedures.

Calibration procedure

The data were recorded using stock calibrations but selected elements were post calibrated using a combination of certified reference material, in-house standards and custom made standards. The broad accuracy of the data were also confirmed by cross checking the analysis with the other bulk techniques (see Figures A.5 to A.9 for the detailed calibration data). The post calibrated elements were; Al, Ca, Fe, Mn, P and Si.

Table A.2 Elements analysed using pXRF separated by filter.

Filter	Elements
Main	Mo, Zr, Sr, U, Rb, Th, Pb, Se, As, Hg, Zn, W, Cu, Ni, Co, Fe and Mn
Low	Cr, V, Ti, Sc, Ca, K and S
High	Ba, Cs, Te, Sb, Sn, Cd, Ag and Pd
Light	Al, P, Si, Ca, K, Cl, S and Mg

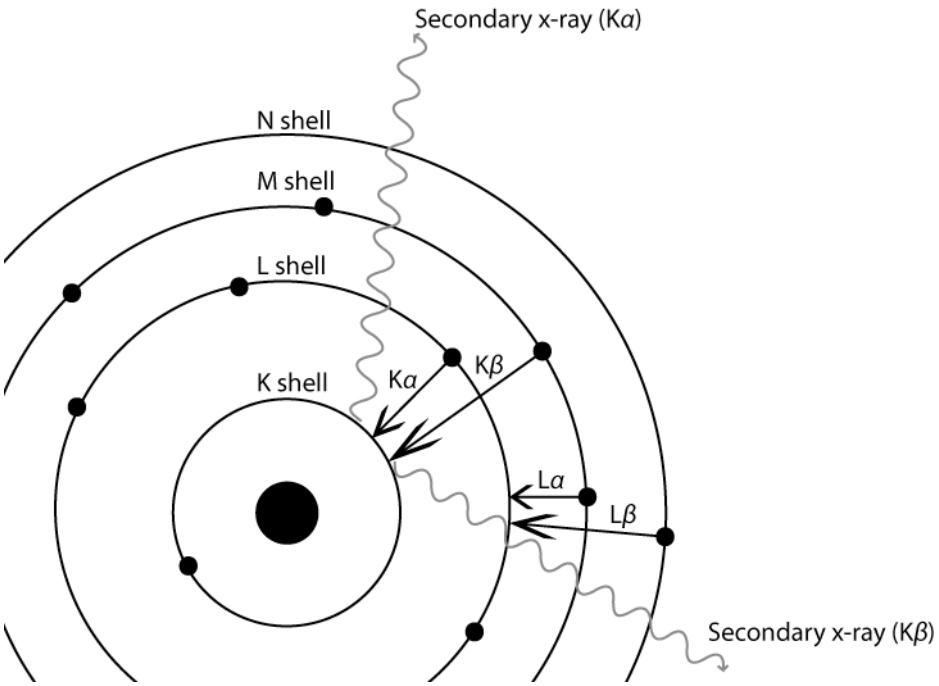


Figure A.4Schematic of the electron transition under XRF, redrawn from Shakely 2011

Data processing/compositional determination

The data from the laboratory analysis was all processed in the same way. Figure A.10 shows an overall workflow for the XRF analyses. In order to produce quantitative results the data output from the instrument was first scrutinised to confirm the validity of the peak identification. This was followed by the post calibration procedure outlined earlier. The equations produced by the calibration graphs were applied to the data in ppm format. The data were then converted to percent (*10000) before the major elements were converted to oxides using known conversion factors. The elements chosen for conversion were not always uniform, for example, in instances where known sulphides were present copper and sulphur were not always converted to oxide (see specific results for details). The data were then finally normalised to 100%.

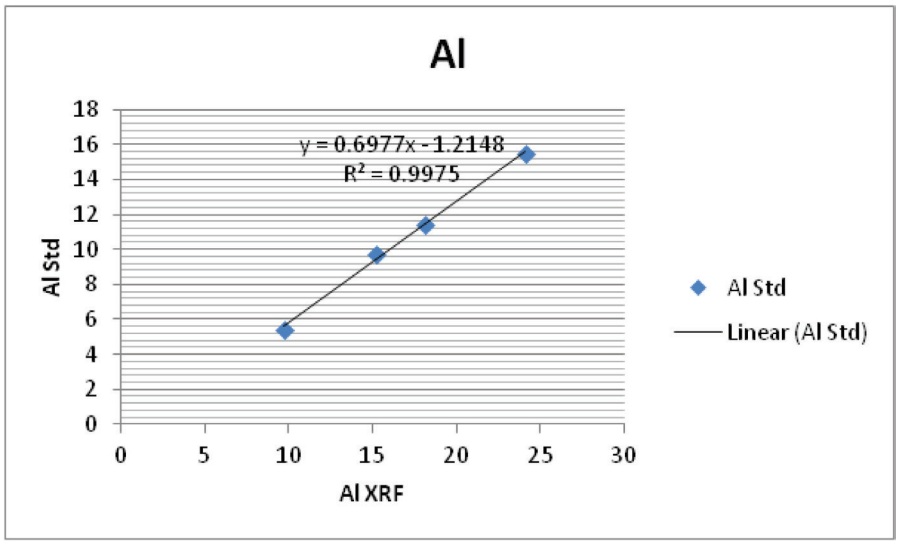


Figure A.5 Calibration data for Al.

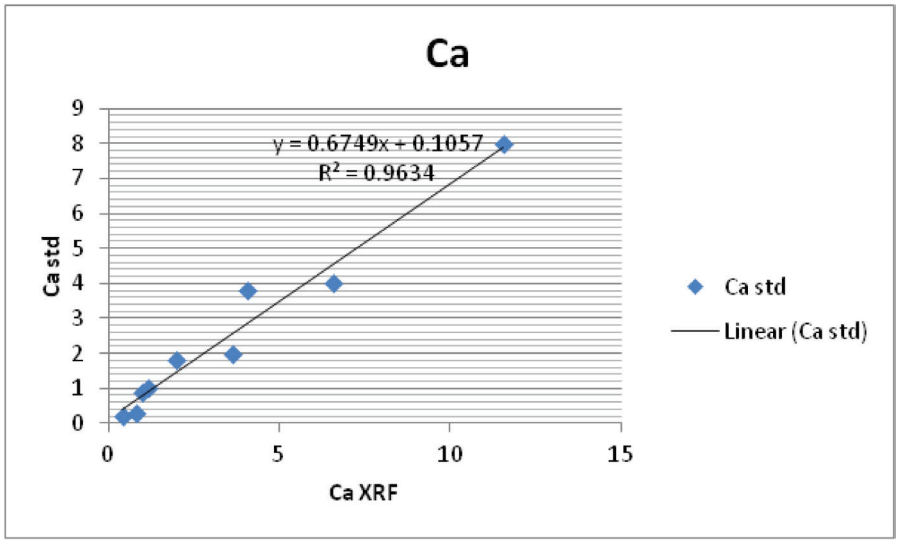


Figure A.6 Calibration data for Ca.

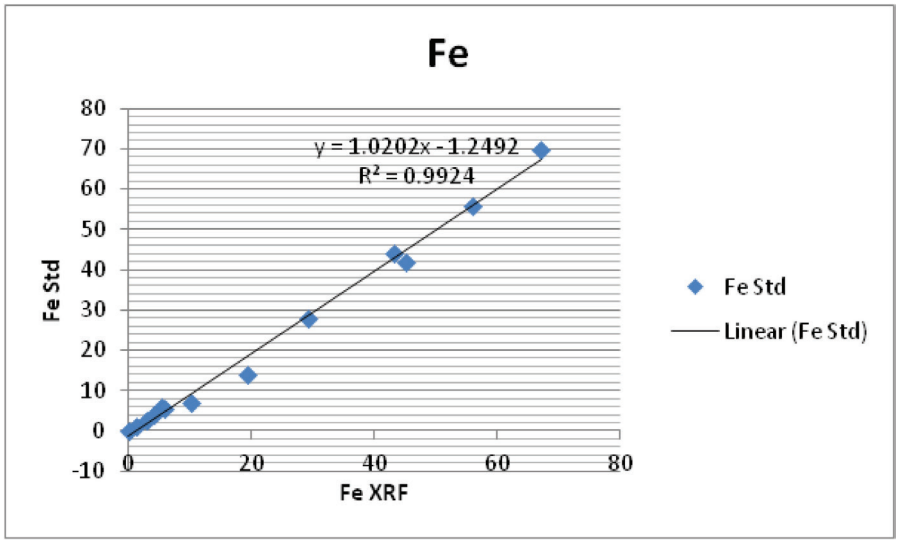


Figure A.7 Calibration data for Fe.

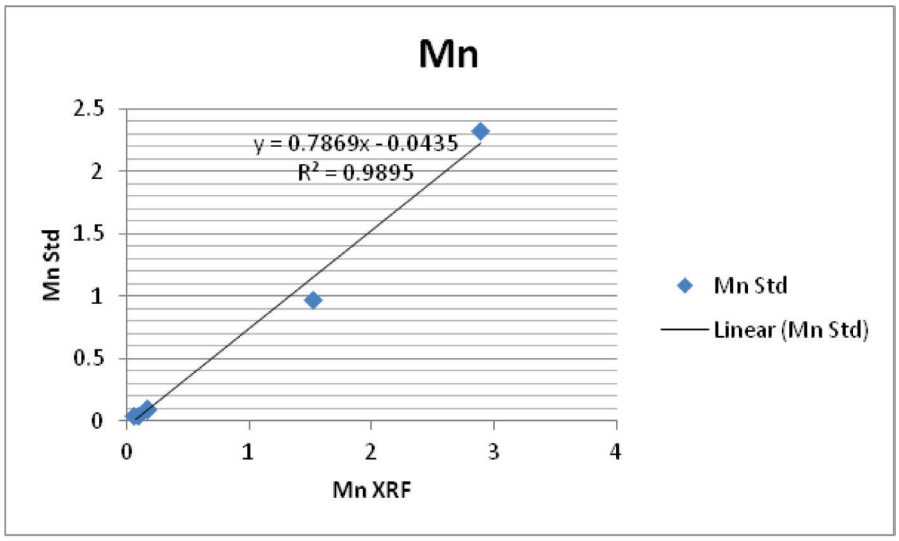


Figure A.8 Calibration data for Mn

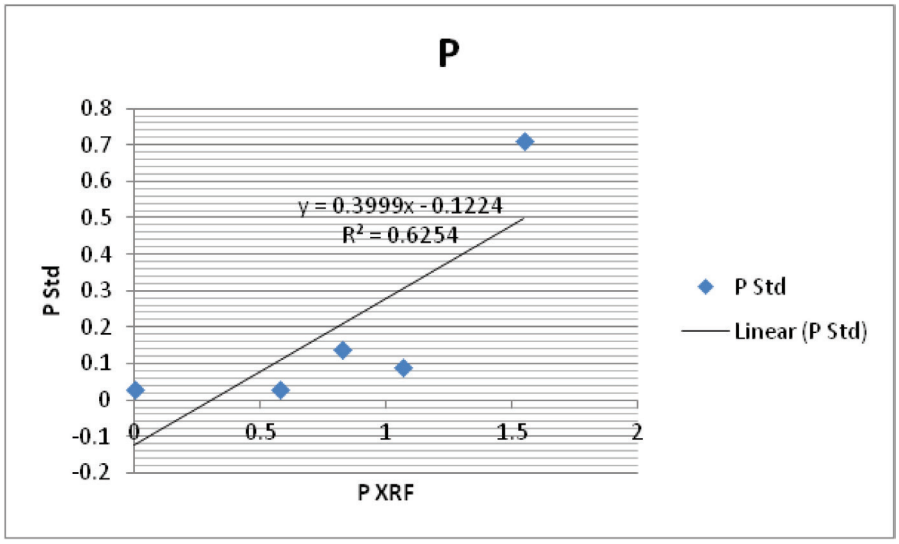


Figure A.9 Calibration data for P.

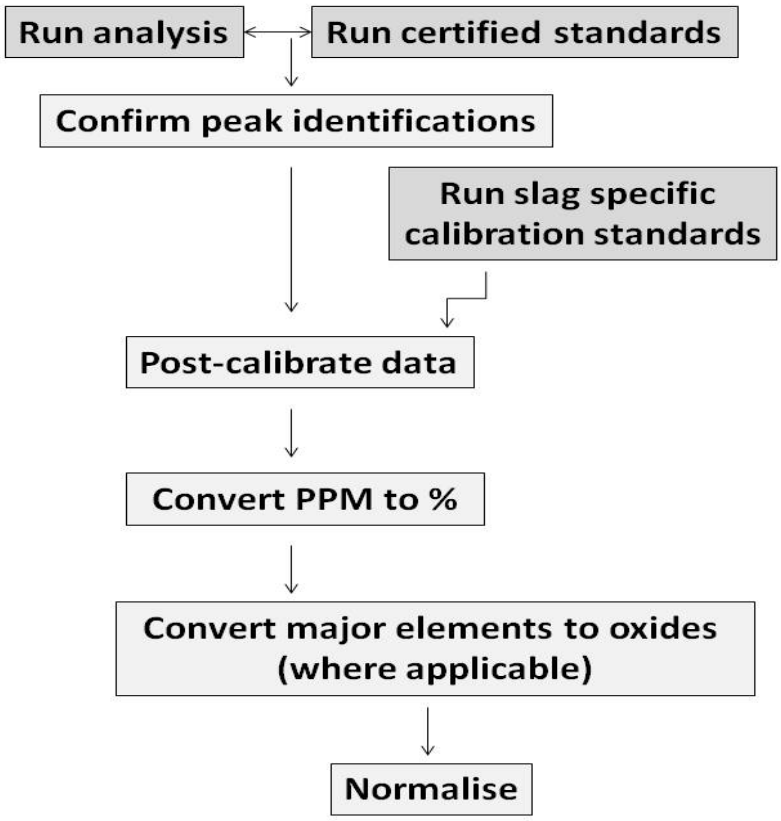


Figure A.10 Workflow diagram for XRF analysis.

Bulk SEM-EDS

In addition to the phase analysis the samples analyzed using SEM-EDS were also analyzed in bulk. This was achieved by analyzing five areas of the slag at low magnification and procuring both individual results and an average for each sample. The individual results allowed the variability within samples to be assessed while the average analysis provided a complimentary analysis for the other techniques. The magnification for each analysis was typically 500x, which produced an effective beam size of approximately 600μm. Micrographs were also taken for each point of analysis and can be found in appendix C.

Prompt Gamma Activation Analysis (PGAA)

In addition to the bulk analysis carried out using pXRF and SEM a short program of lab based PGAA was also employed to a sub-sample of slag, ore and mineralogical samples. Unlike other nuclear techniques such as Neutron Activation analysis (NAA), PGAA has only recently been adopted for archaeological material. PGAA has been used in the study of lithics but has yet to be routinely used to analyse archaeological slags (Szakmány and Kasztovszky 2004). This is potentially due its comparatively low sensitivity to certain elements common to ancient slag, especially aluminium, tin and lead. However, when used in parallel with other techniques the strengths of PGAA can be of great value to the study of metallurgical debris. Particularity the high sensitivity to Boron, an element commonly found in tourmaline mineralogy, and some rare earth elements (REE) make the technique particularly useful when exploring variations in technology and recourse procurement strategies.

A full description of the PGAA process can be found elsewhere (Gméling et al. 2005; Molnar 2004; Révay et al. 2004; Szakmány and Kasztovszky 2004) but the workflow and instrumentation can be seen in figures A.11 and A1.2. All of the analyses were carried out with the technical assistance of the physicists working at the institute of isotopes, Budapest.

In total 30 samples were analysed; 15 from the Ust'ye region and 15 from Stepnoye region. Table A.3 shows a breakdown of the samples. The samples were selected as they represented both the range of material present as well as the full range of internal chemical variation that was established using XRF.

Instrumentation

PGAA is classed as a multi-element, neutron based technique that relies on observing the prompt γ-radiation emitted whenever a nucleus captures a bombarding neutron (Molnar 2004). The facility in Budapest, used for these analyses, consists of three main parts; the cold neutron beam, the sample chamber and the detector. A schematic of these can be seen in Figure A.1. The neutron beam was generated by a 10mw research reactor that was split to a 30m neutron guide which fed the PGAA analyser. All of the analyses were recorded using the attached high-purity germanium, bismuth germanate (HPGe-BGO) γ-ray spectrometer (Molnar et al 1997). The γ-ray spectrometer was equipped with a Compton suppression shield which limited background noise produced by γ-ray Compton scattering thus producing more effective spectra.

Table A.3 Breakdown of PGAA samples analysed

Site	Type	Number of samples analysed
Stepnoye	Slag	12
	Mineral	3
Ust'ye	Slag	13
	Mineral	2

Analytical procedure

All of the samples analysed were solid, un-mounted and of similar size (c.1-2cm, 0.5-5g). The samples were placed in Teflon bags before being suspended in the sample chamber. Due to the differential compositions and densities of the samples the count rate varied considerably and was therefore controlled using collimating windows which ranged between 0.1 and 1.5cm^2 in size. These were selected following a test analysis of each sample. This prevented the sample from being over exposed, giving an ideal count rate for each sample of 500-1500cps, which allowed the boron concentration to be determined in less than two hours. The samples were simultaneously irradiated and analysed until a total of five million counts had been reached.

Elemental determination and data processing

Quantitative elemental analyses were determined using the intensity of γ -rays with were recorded in the spectra. As PGAA spectra are much more complex than traditional NAA spectra dedicated in house software was employed to quantify the elemental concentrations (Revay 2009). These were based on the institute of isotopes own spectroscopic database and data reduction algorithms. Following the determination of elements the major metallic elements were converted to their common oxide forms and normalised to 100 percent. A full workflow can be seen in Figure A.12.

A7- CROSS TECHNIQUE COMPARRISONS

Bulk chemical data derived from calibrated and processed SEM-EDS, XRF and PGAA analysis were compared to give a comparative accuracy for each technique. The following graphs show the correlations for the major slag constituents (SiO2, FeO and Al2O3).

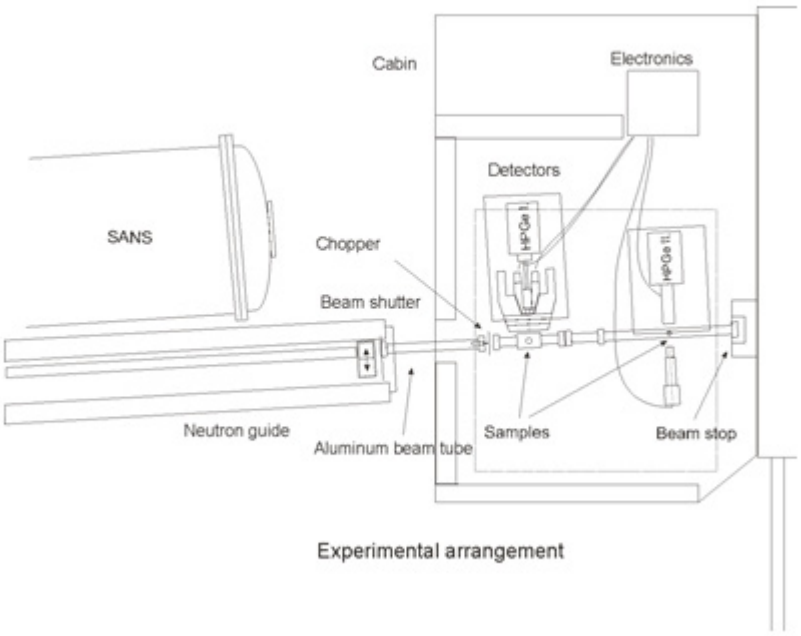


Figure A. 11 Schematic of the PGAA instrumentation (Molnar et al 1997).

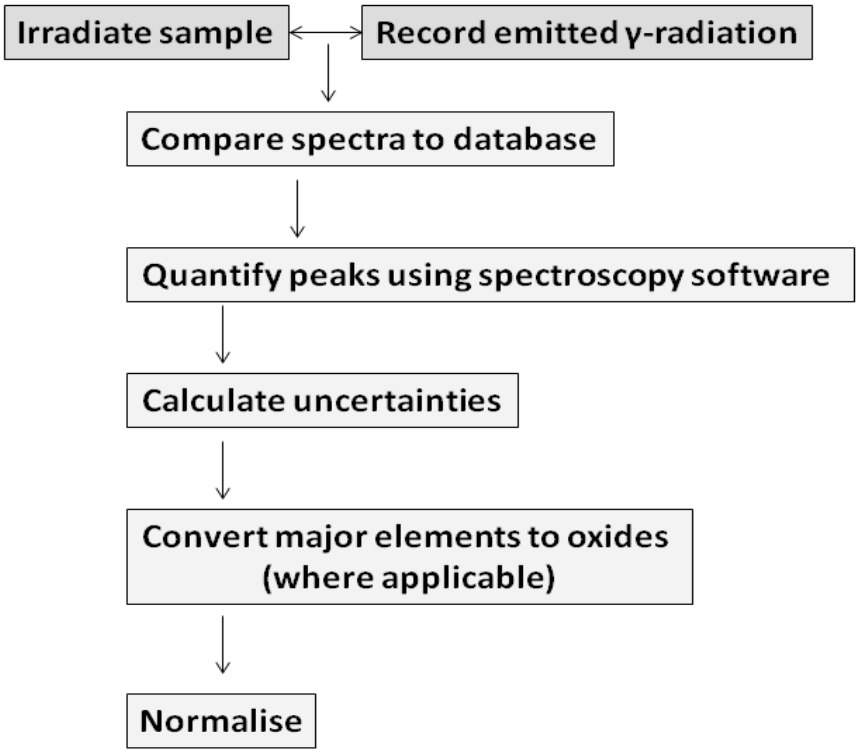
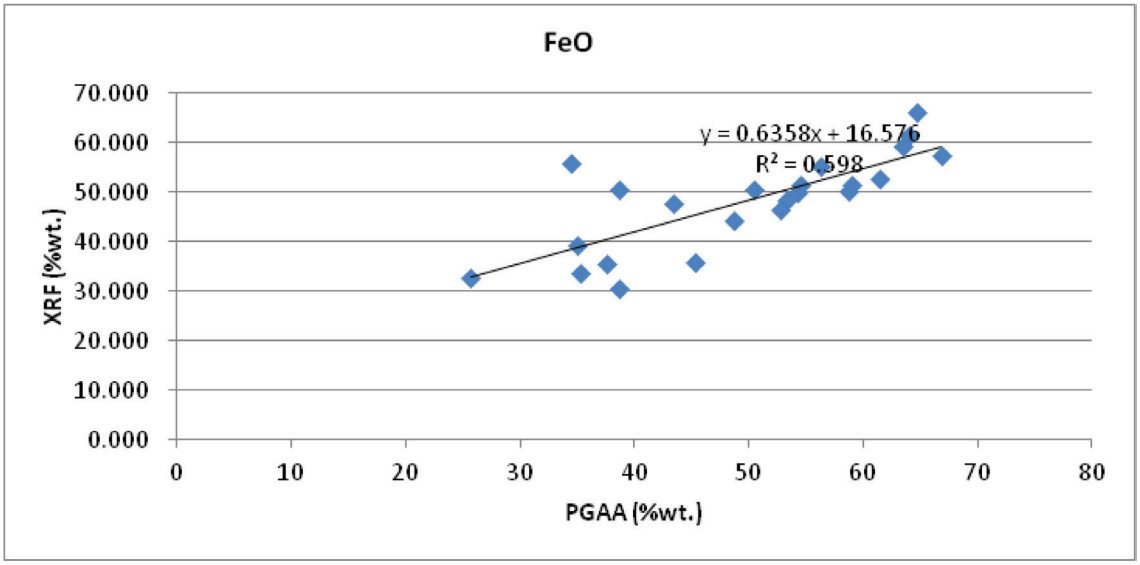
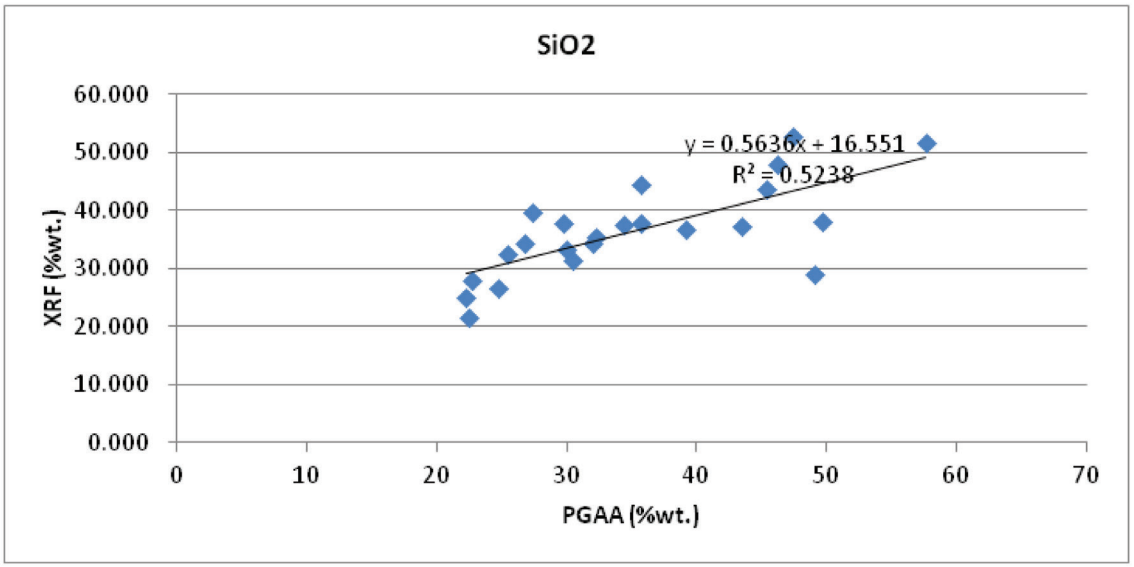


Figure A.12 Workflow diagram for PGAA analysis.





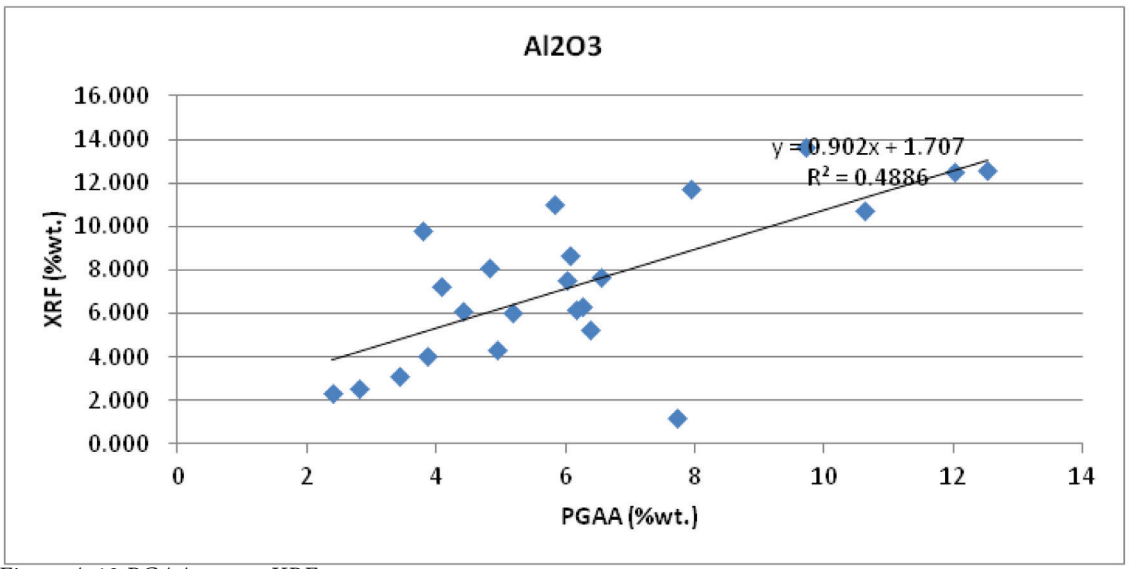
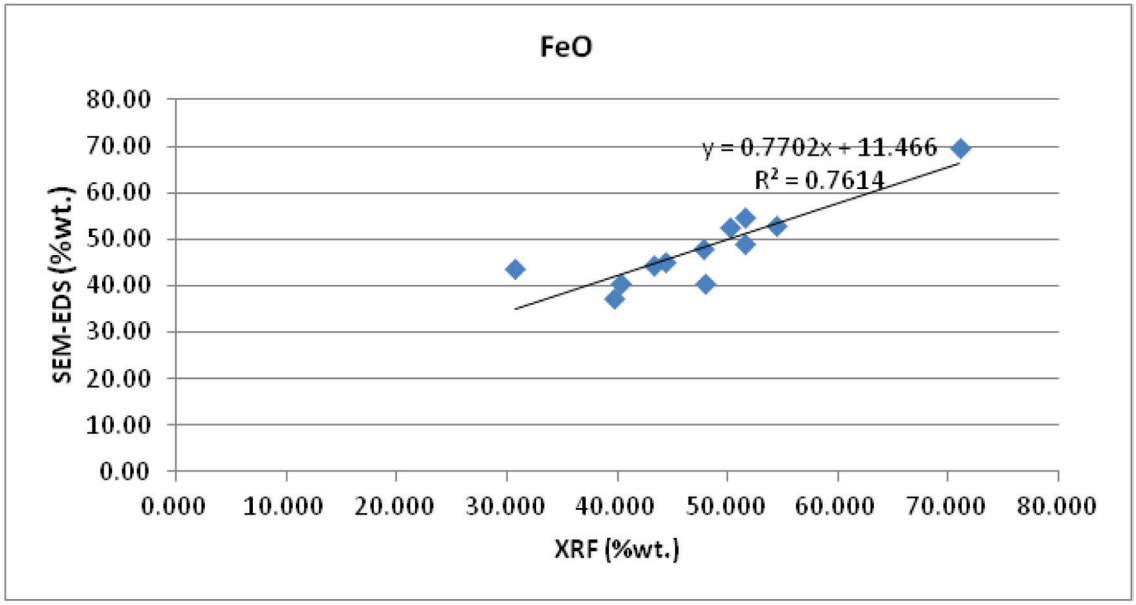
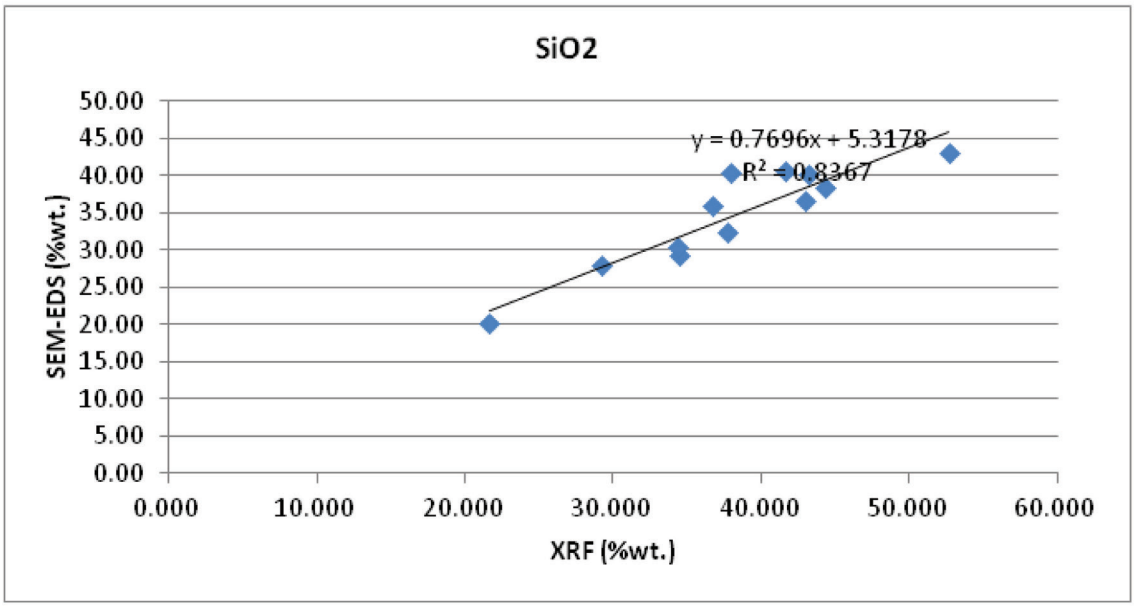


Figure A.13 PGAA versus XRF





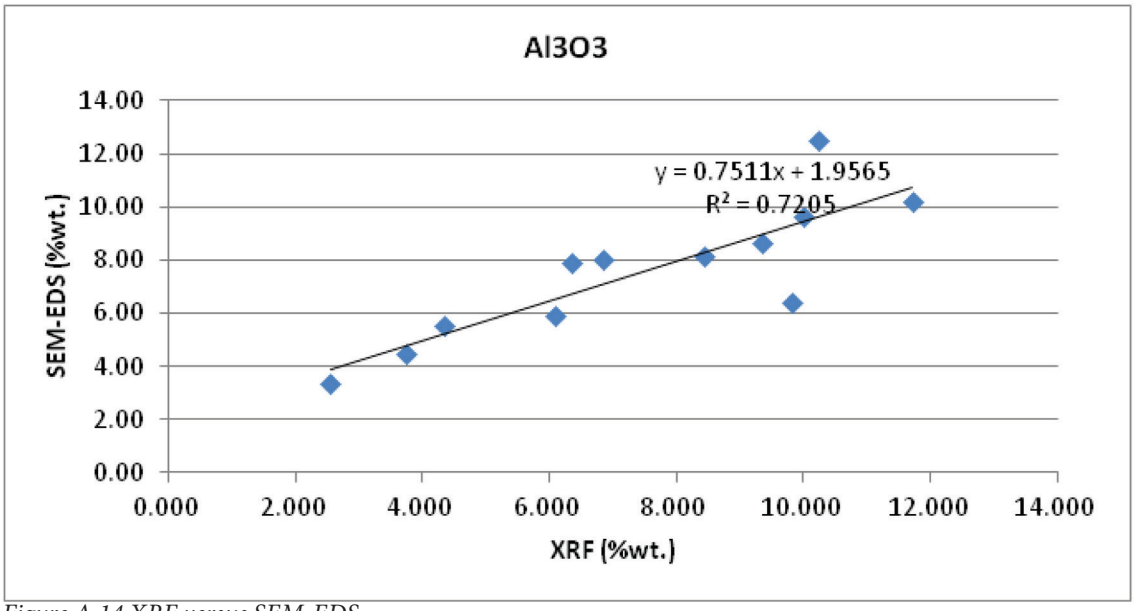


Figure A.14 XRF versus SEM-EDS

Appendix B

Microscopic Database

Site Code *161y* **Sample** *931* **Type** *Slag* **Area** *P-house*

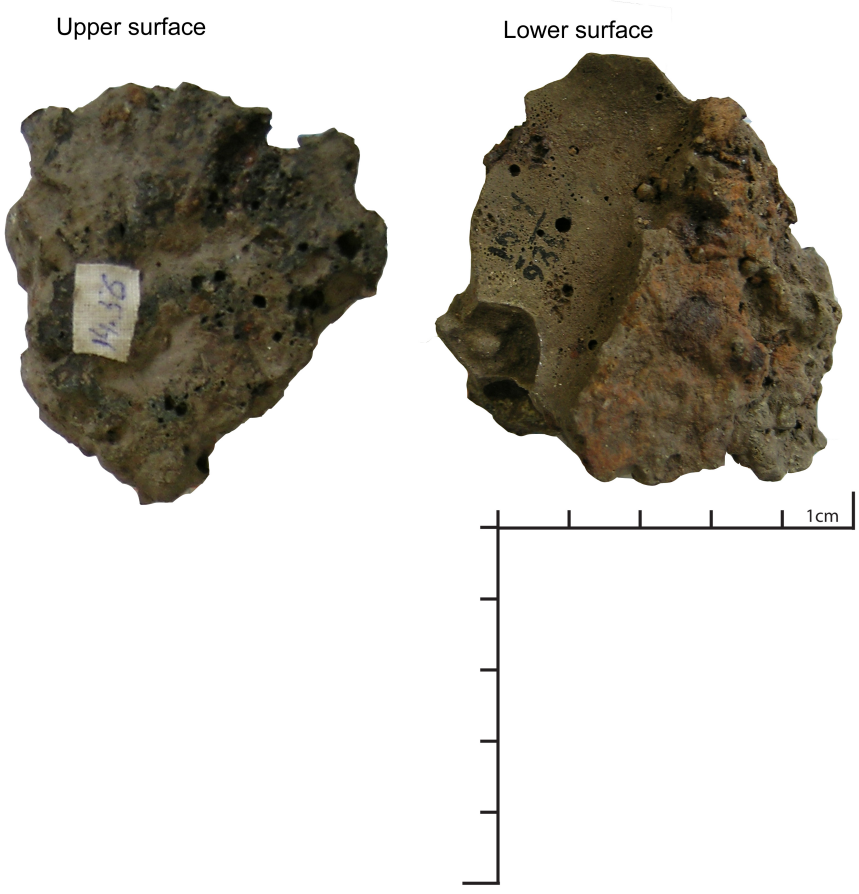
Wustite	*Rare*
Magnetitie	*Rare*
Lath Fayalite	*Frequent*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	*Very rare*
Euheadral fayalite	*Absent*
Matrix	*Glassy 10-25%*
Additional Phases	*rare copper oxide*

Additional notes

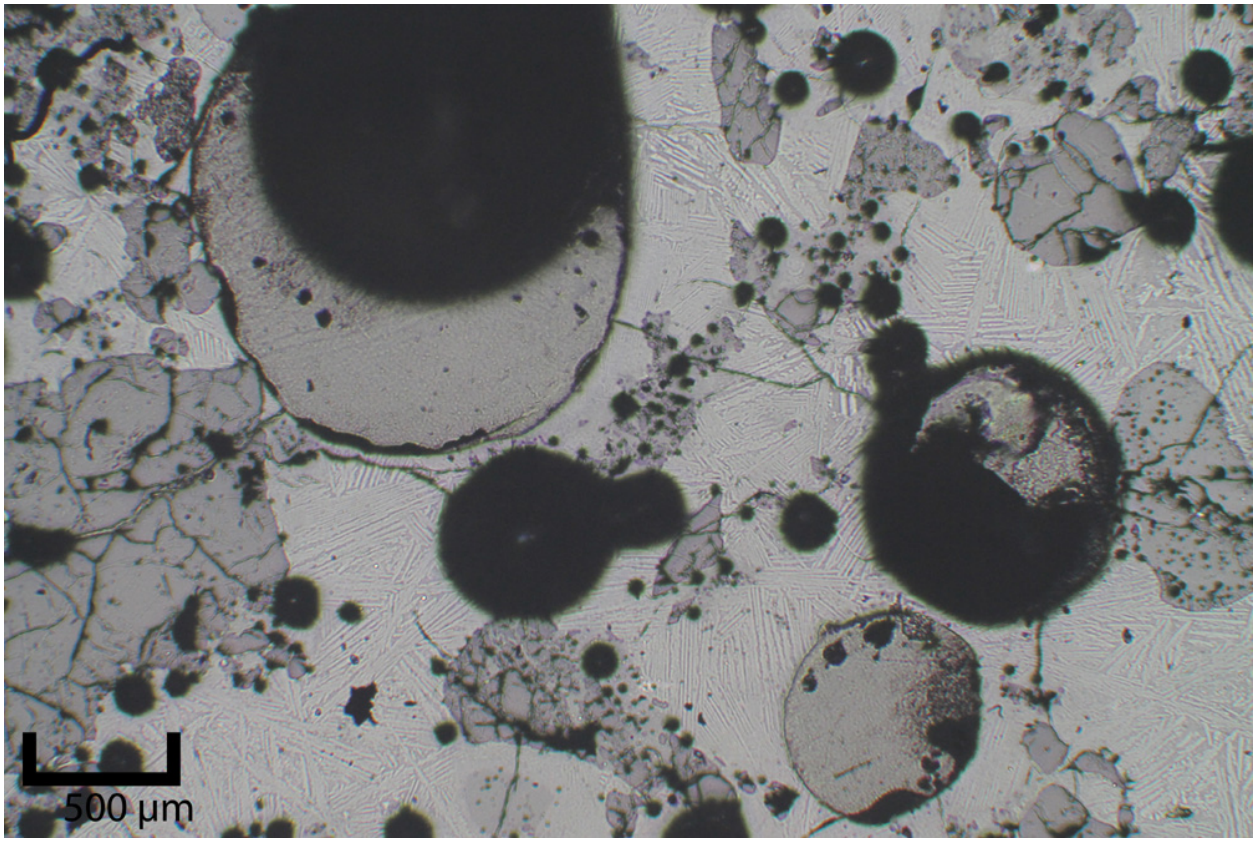
Chromite ***Present***

Group *A2*

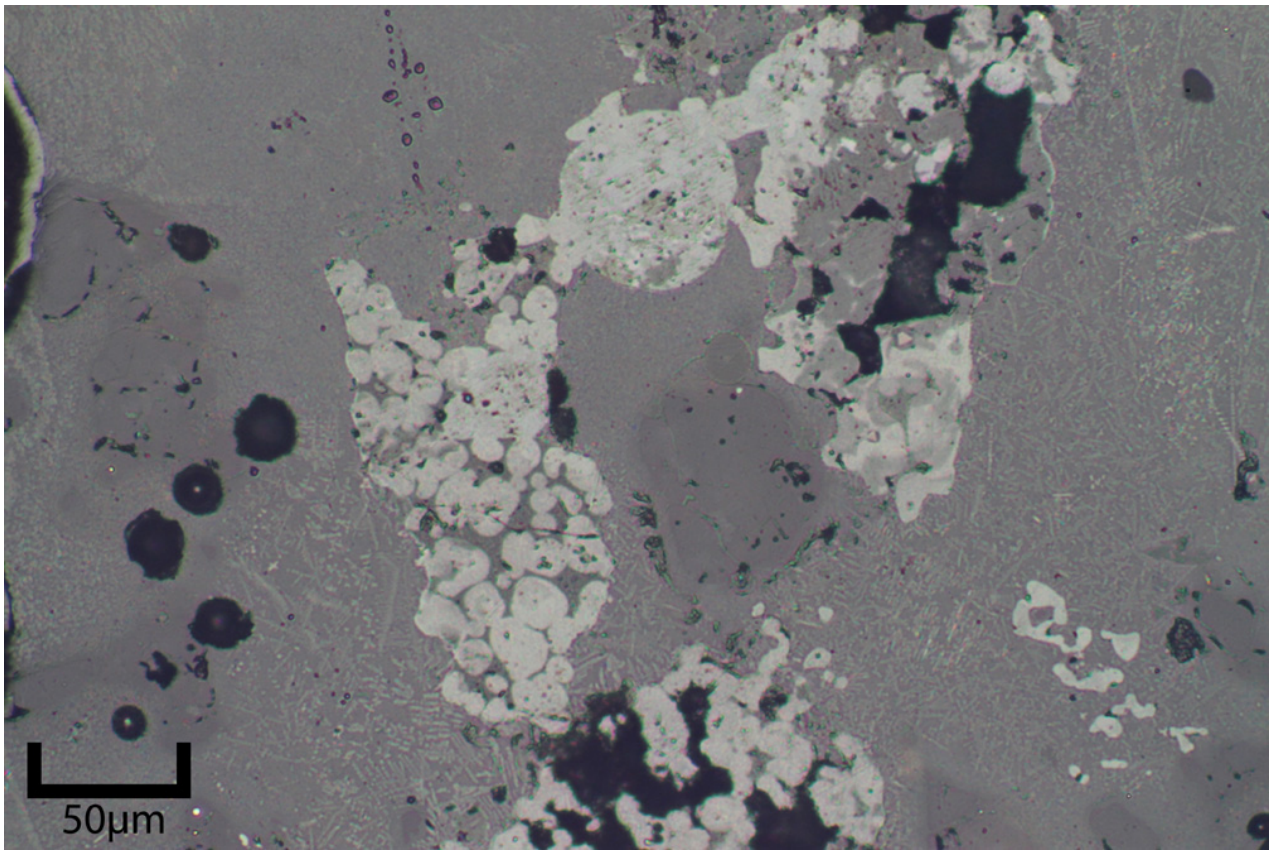
Hand Specimin



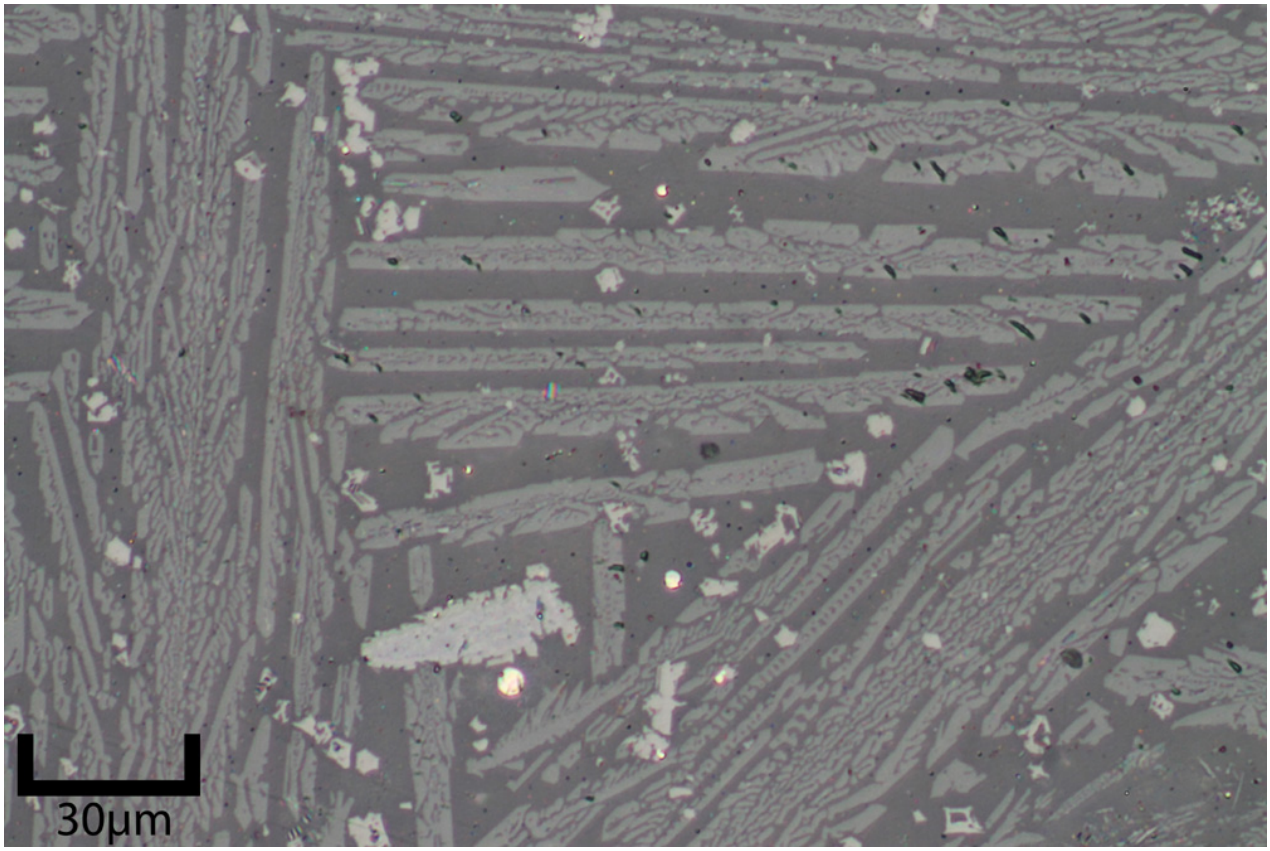
Micrograph 1



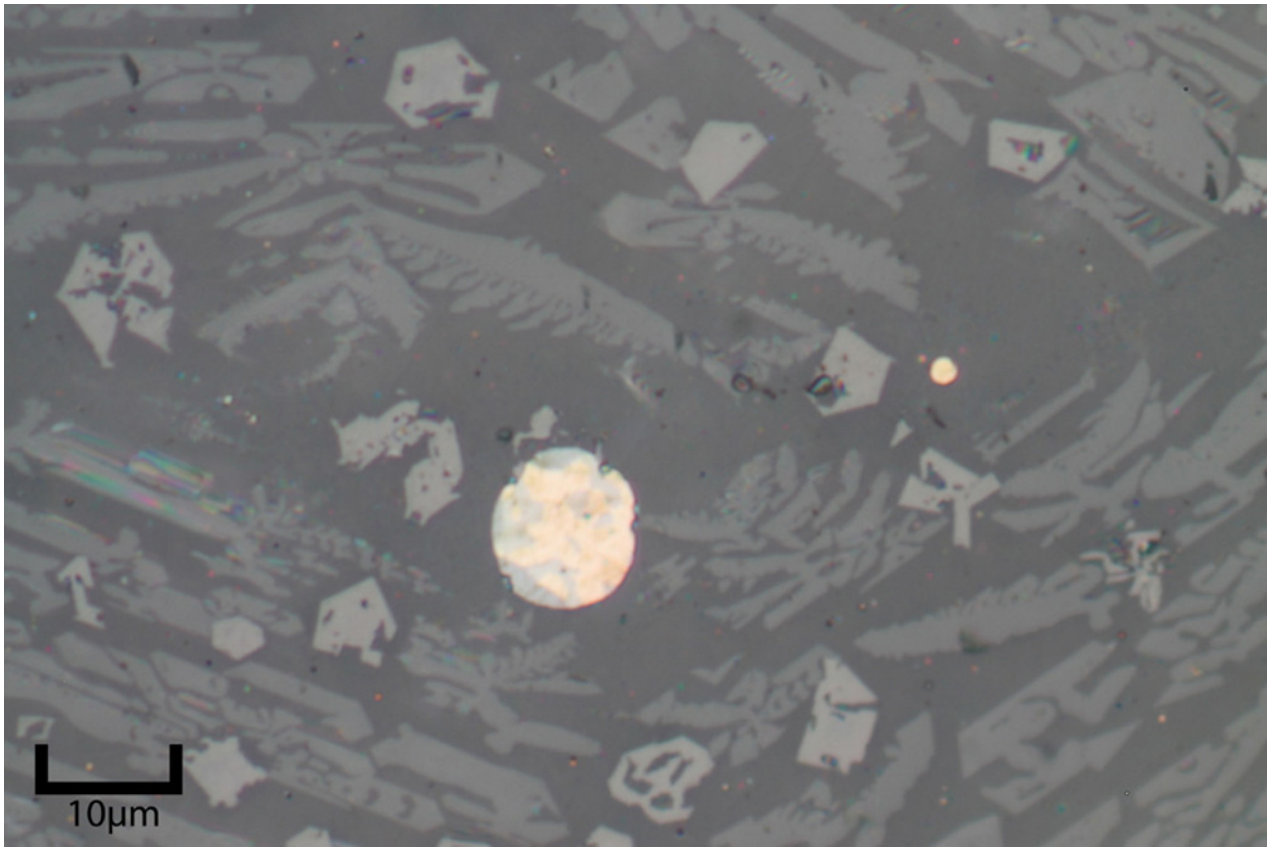
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *161y* **Sample** *1673* **Type** *Slag* **Area**

Wustite	*Very rare*
Magnetitie	*Very rare*
Lath Fayalite	*Frequent*
Delafossite	*Very rare*
Metallic copper	*Very rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	

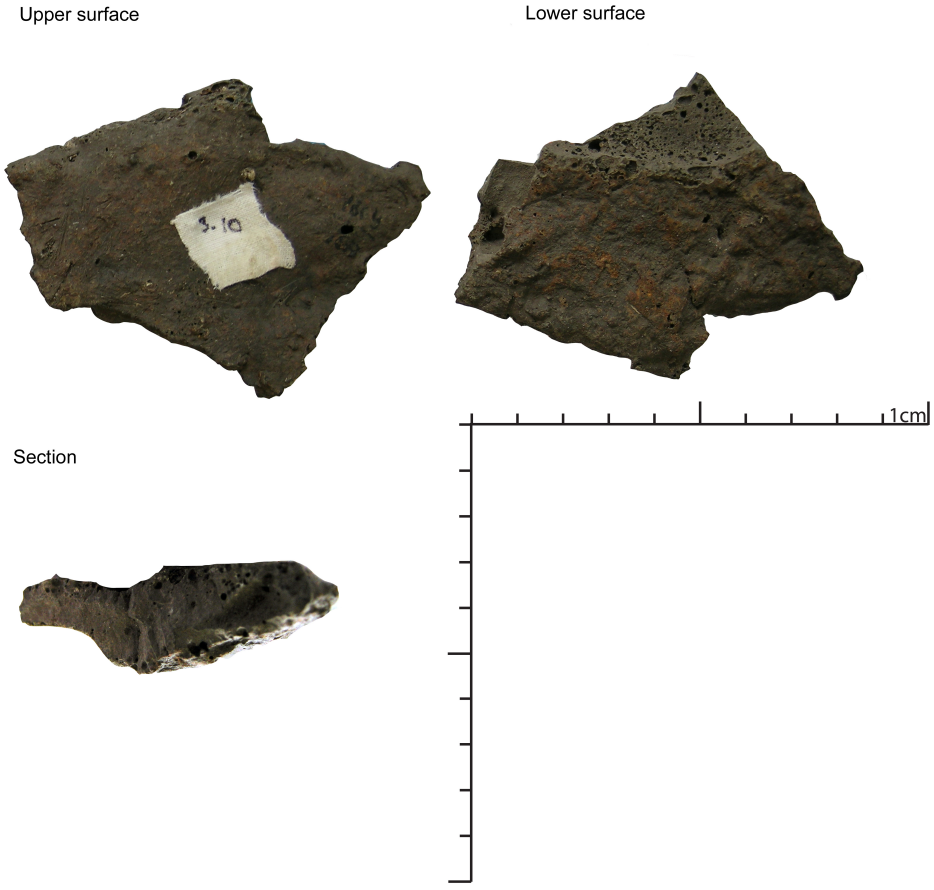
Additional notes

Possible ore inclusion (see micrograph 2)

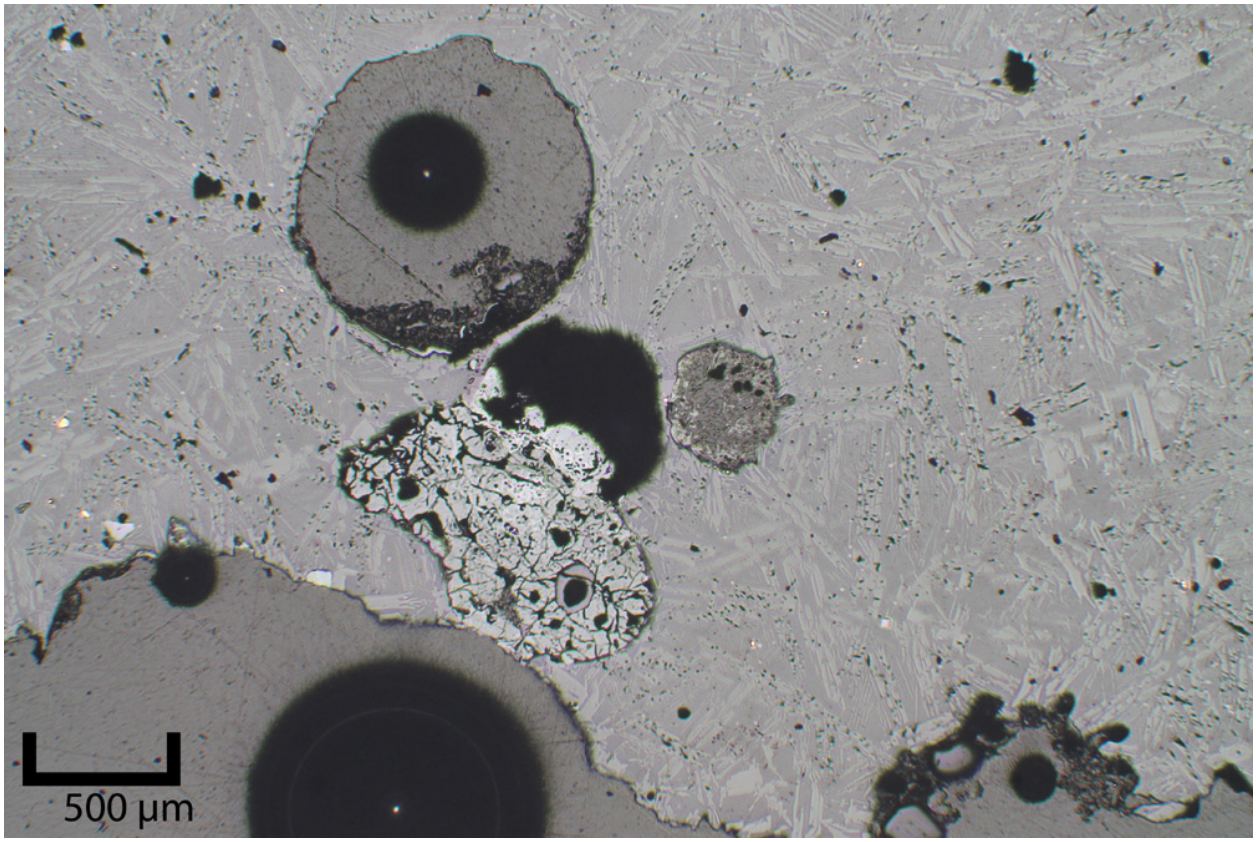
Chromite ***Present***

Group *A2*

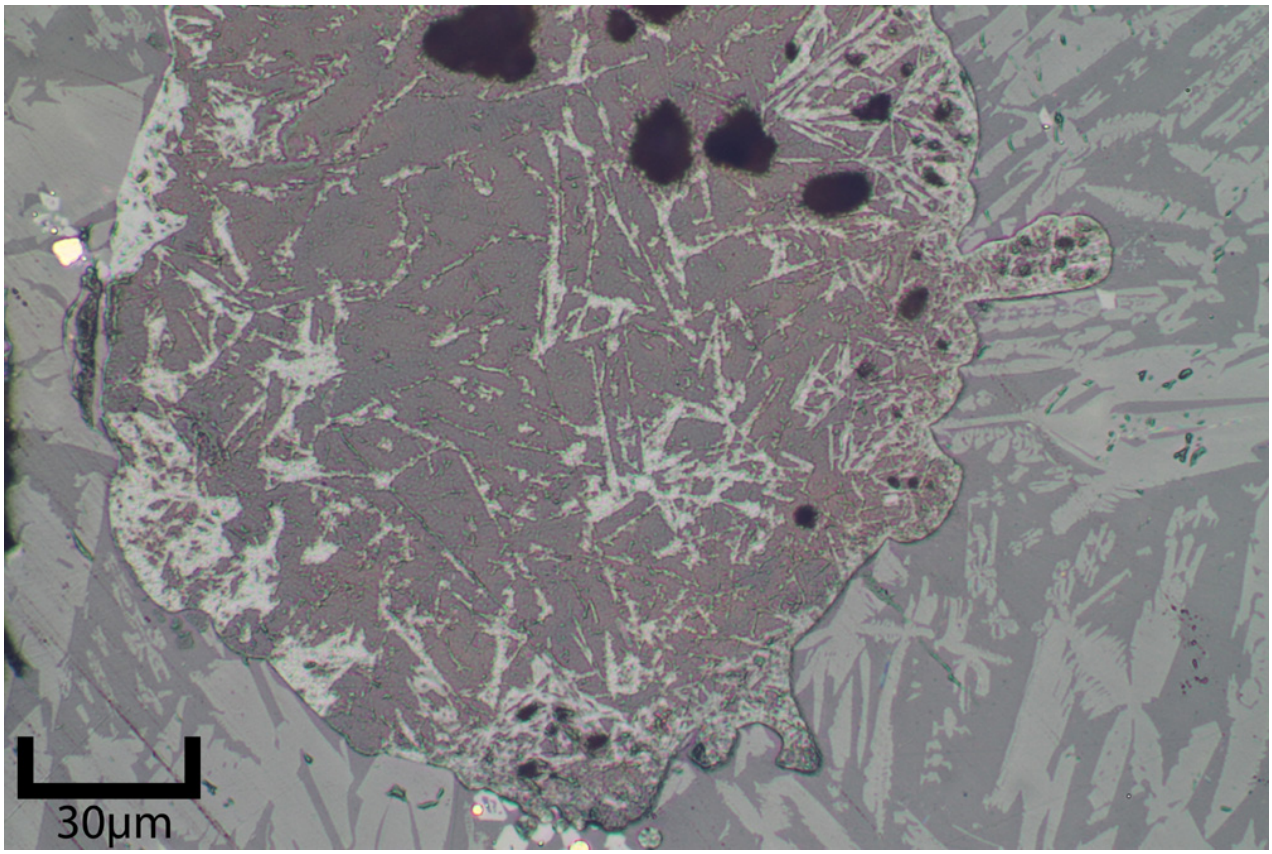
Hand Specimin



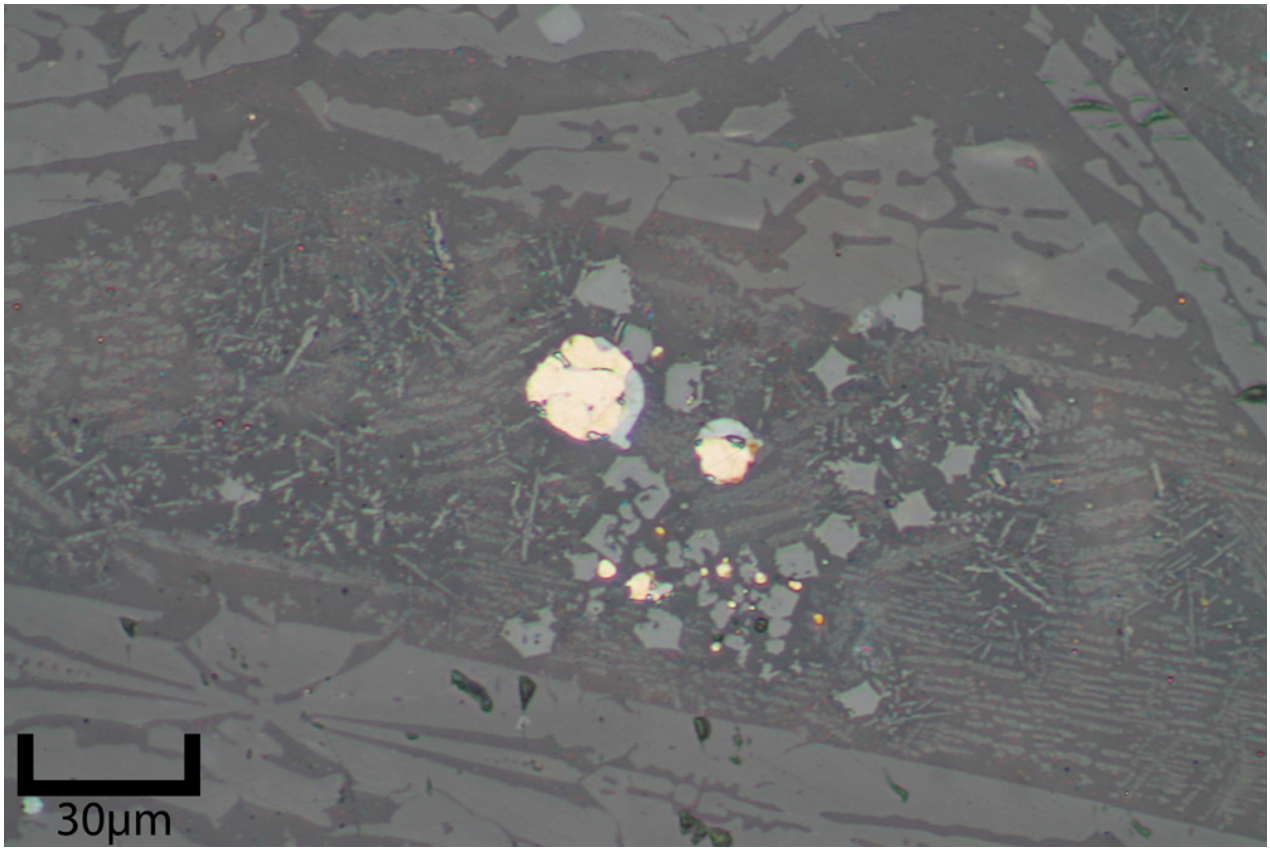
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

Site Code *161y* **Sample** *2043* **Type** *Slag* **Area**

Wustite	*Very rare*
Magnetitie	*Very rare*
Lath Fayalite	*Common*
Delafossite	*Rare*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Common*
Matrix	*Glassy 25-50%*
Additional Phases	*occasional chromites,*

Additional notes

Chromite × ***Present*** **Group** *D2*

Hand Specimin

Upper surface

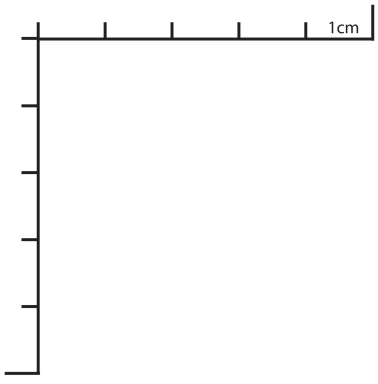


Lower surface

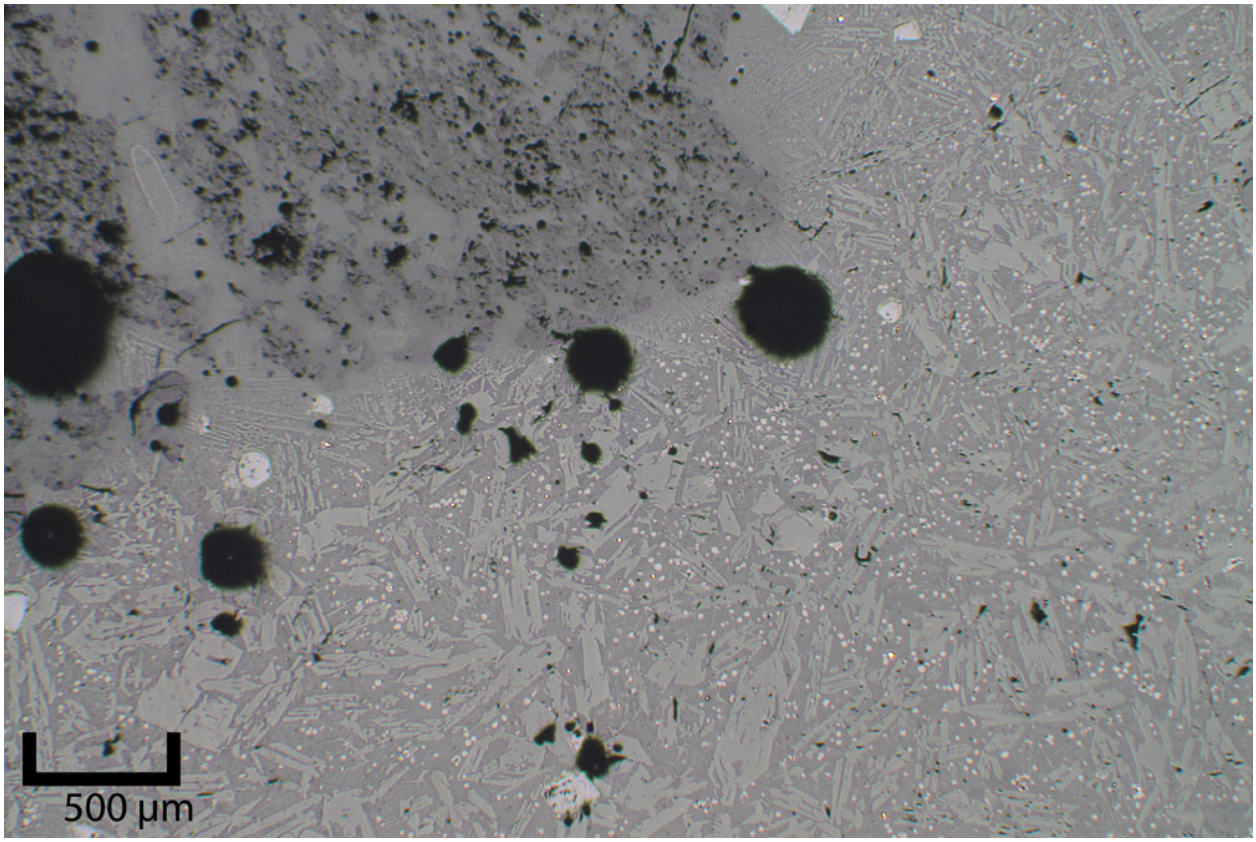


Section

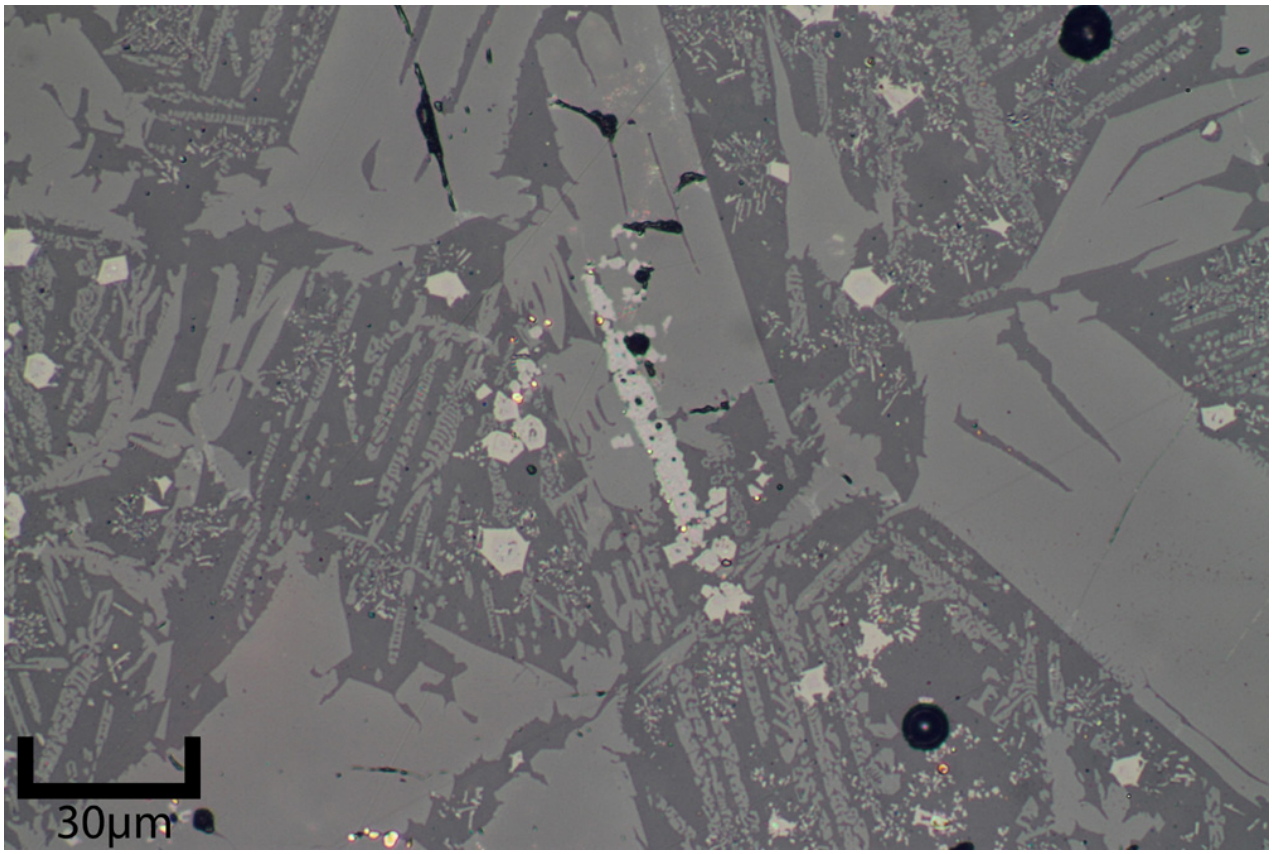




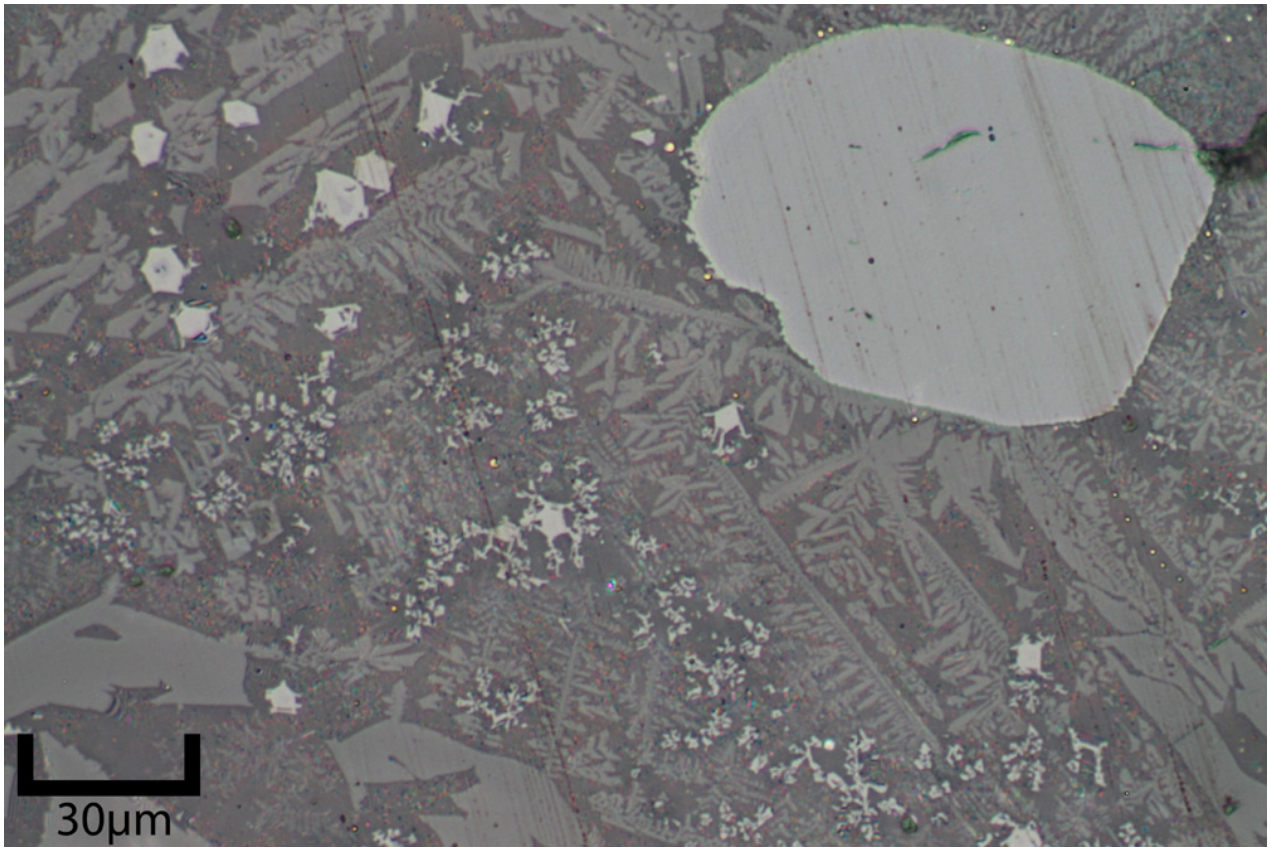
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

Site Code *161y* **Sample** *3250* **Type** *Slag* **Area**

Wustite	*Occasional*
Magnetitie	*Occasional*
Lath Fayalite	*Frequent*
Delafossite	*Rare*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 10-25%*
Additional Phases	*rare Chromites*

Additional notes

Chromite ✕ ***Present*** **Group** *A2*

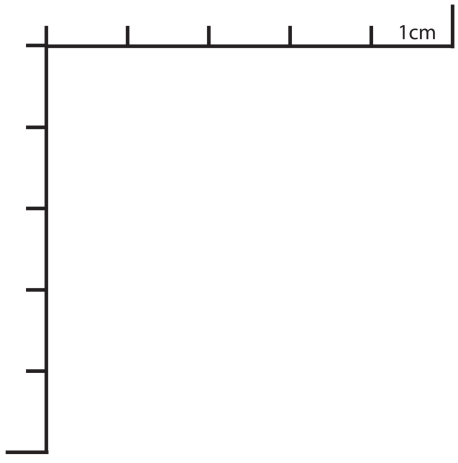
Hand Specimin

Upper surface

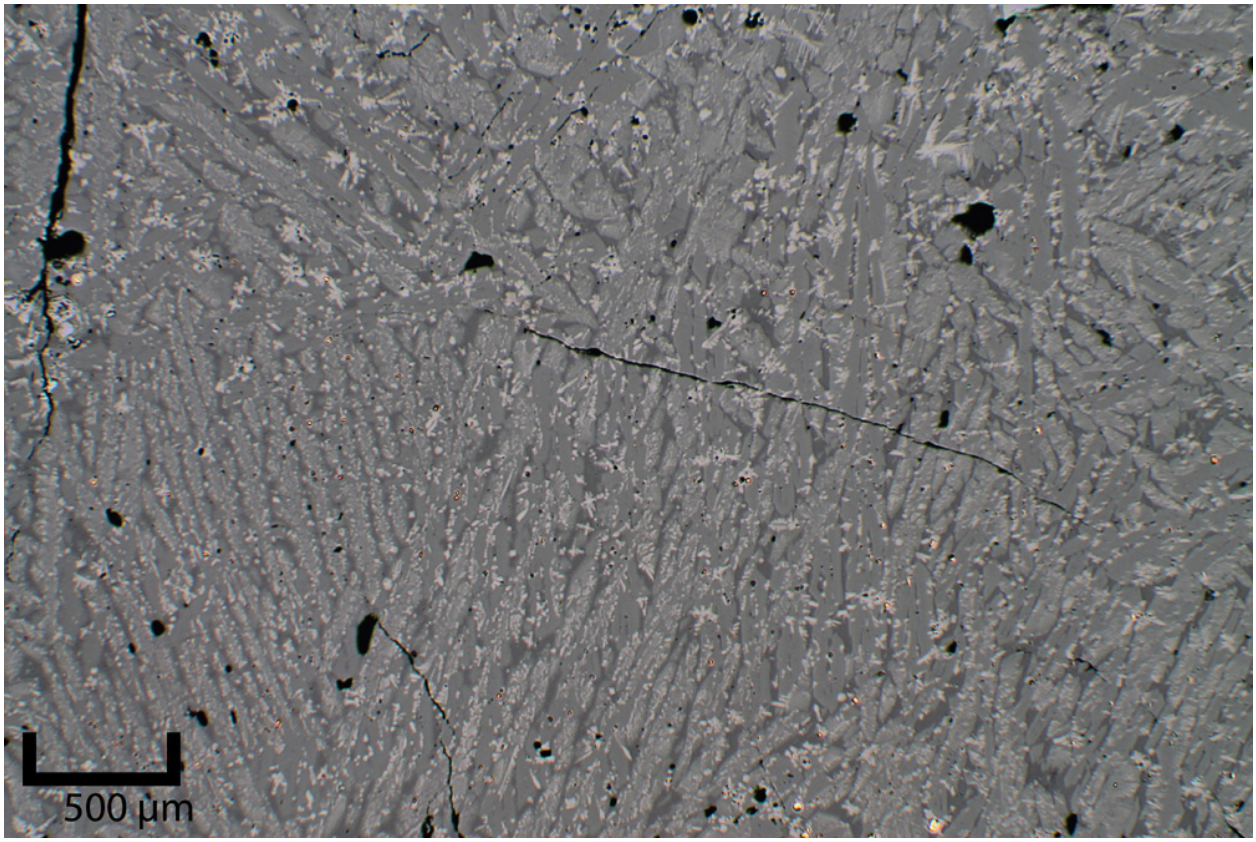


Lower surface

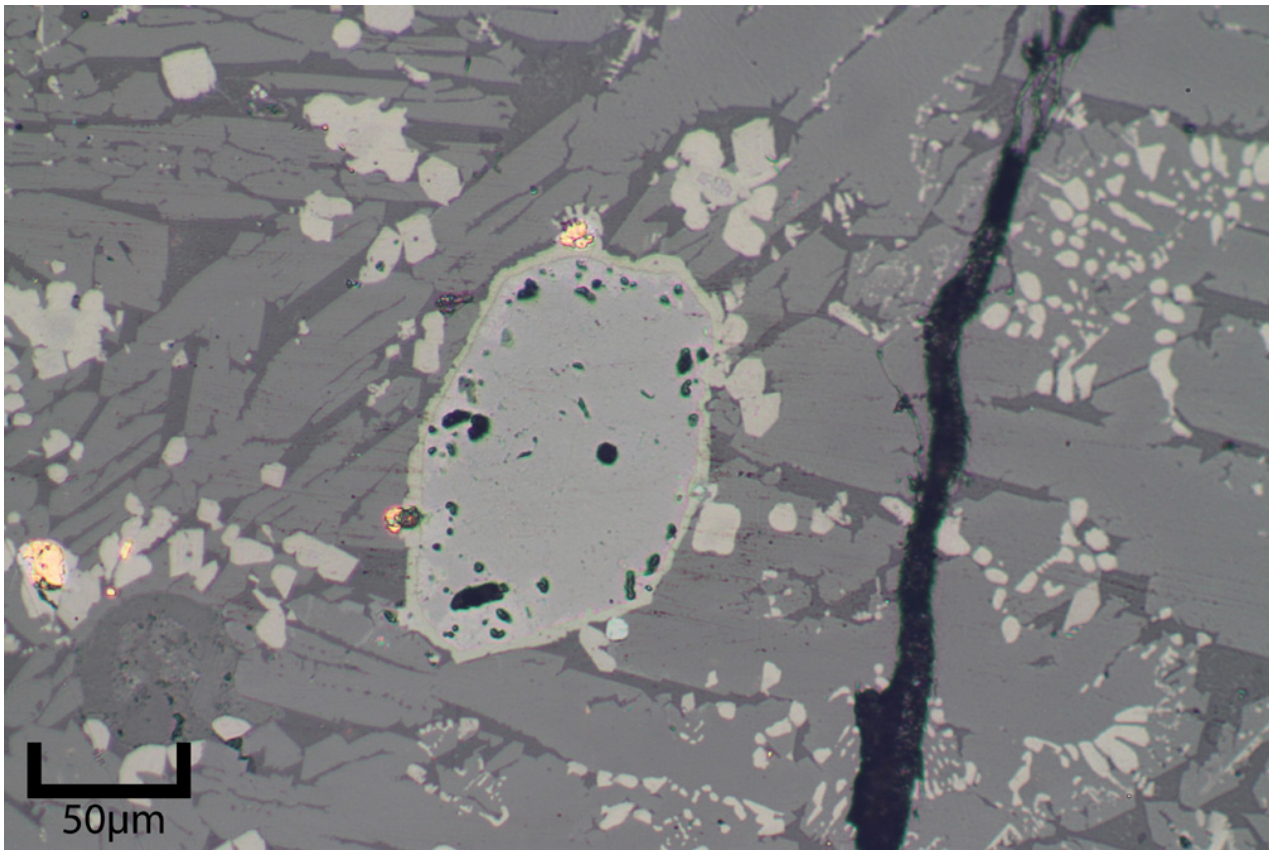




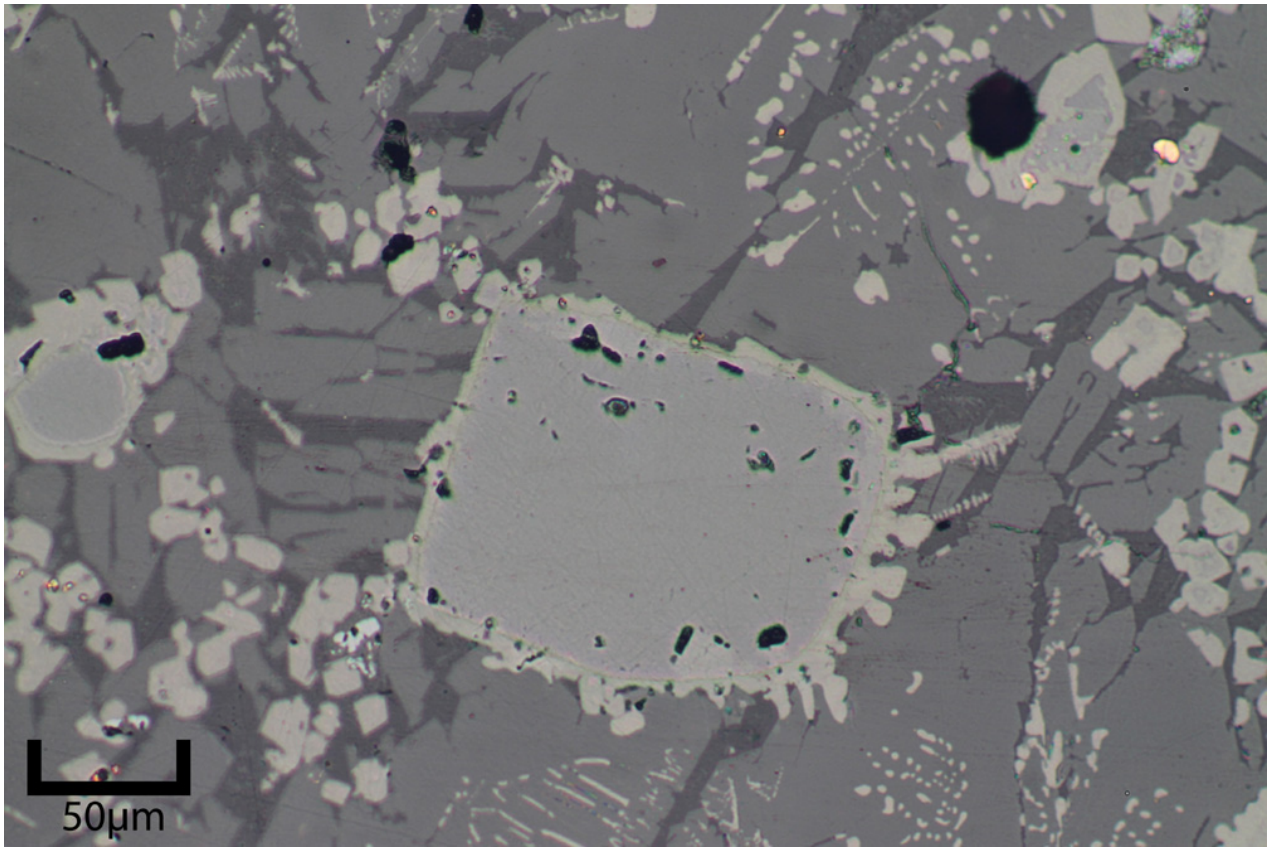
Micrograph 1



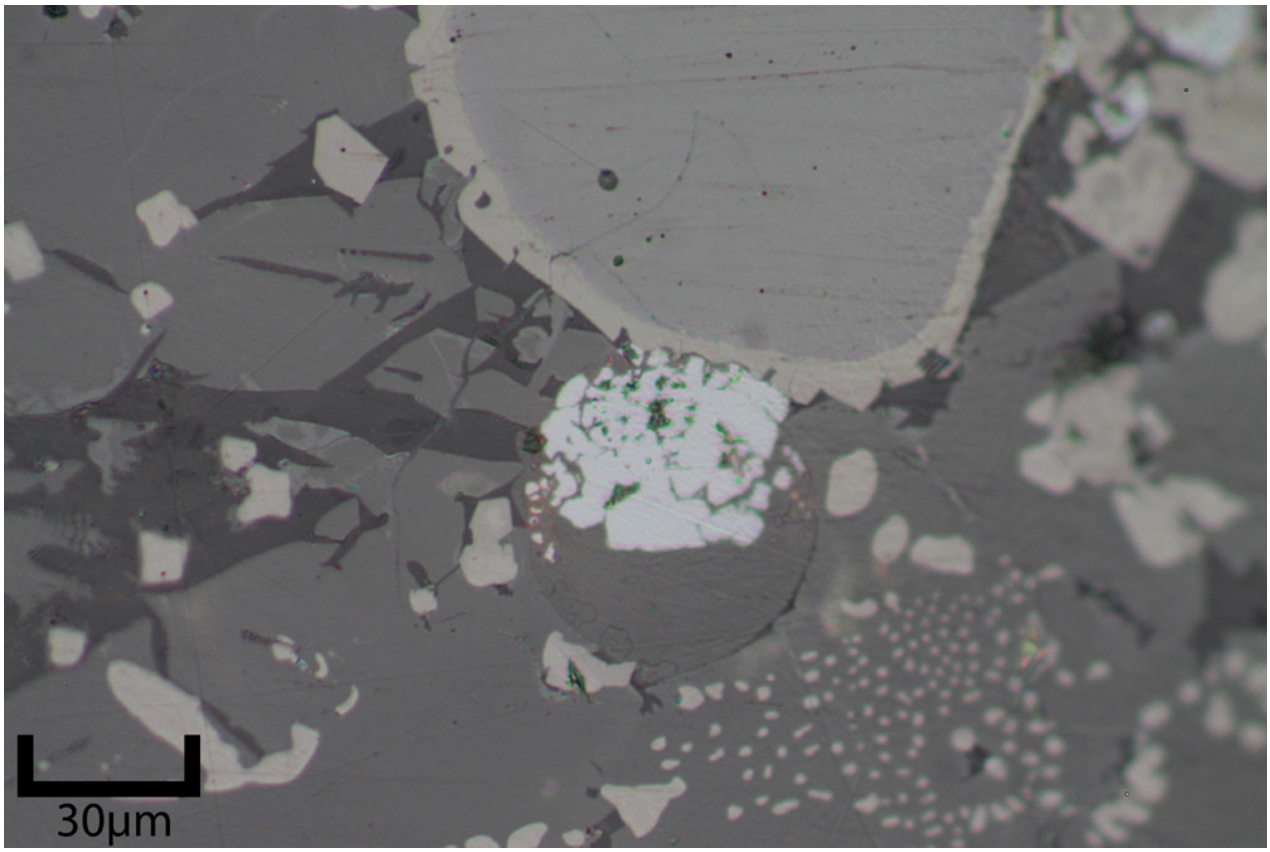
Micrograph 2



Micrograph 3



Micrograph 4

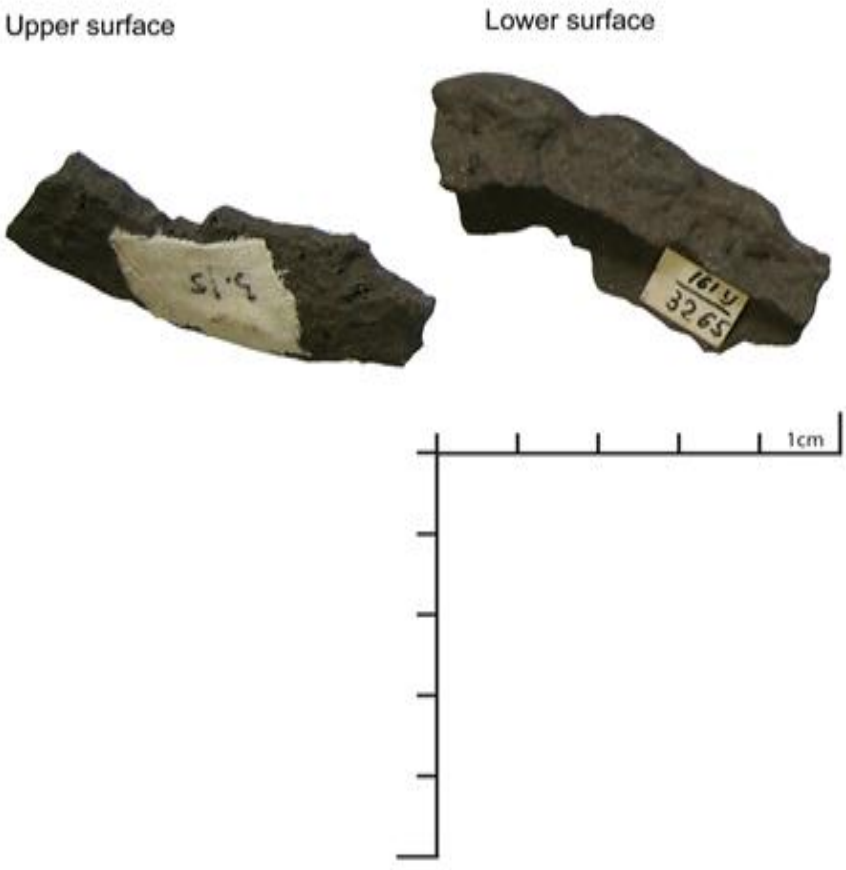


Site Code *161y* **Sample** *3265* **Type** *Slag* **Area**

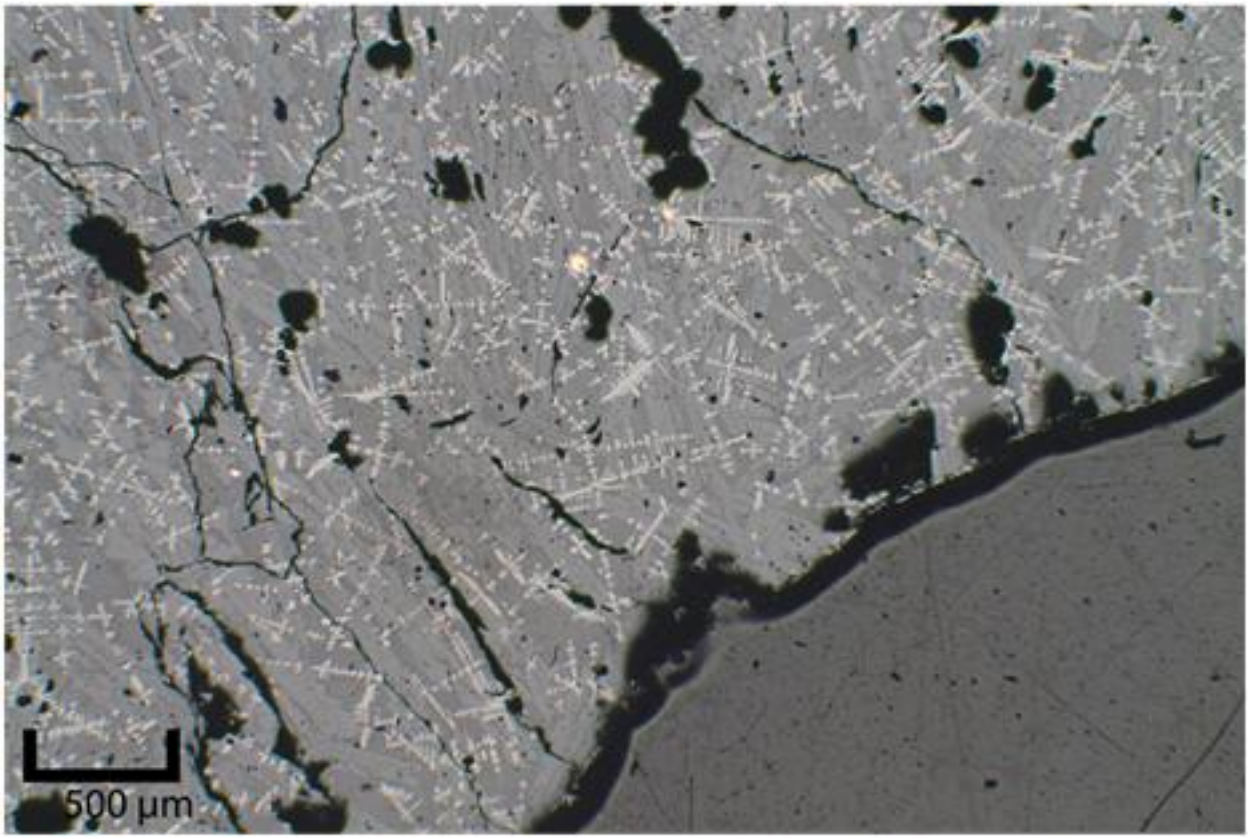
Wustite	*Common*	**Additional notes**
Magnetitie	*Absent*	
Lath Fayalite	*Dominant*	
Delafossite	*Absent*	
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 25-50%*	
Additional Phases		

Chromite ***Present*** **Group** *A2*

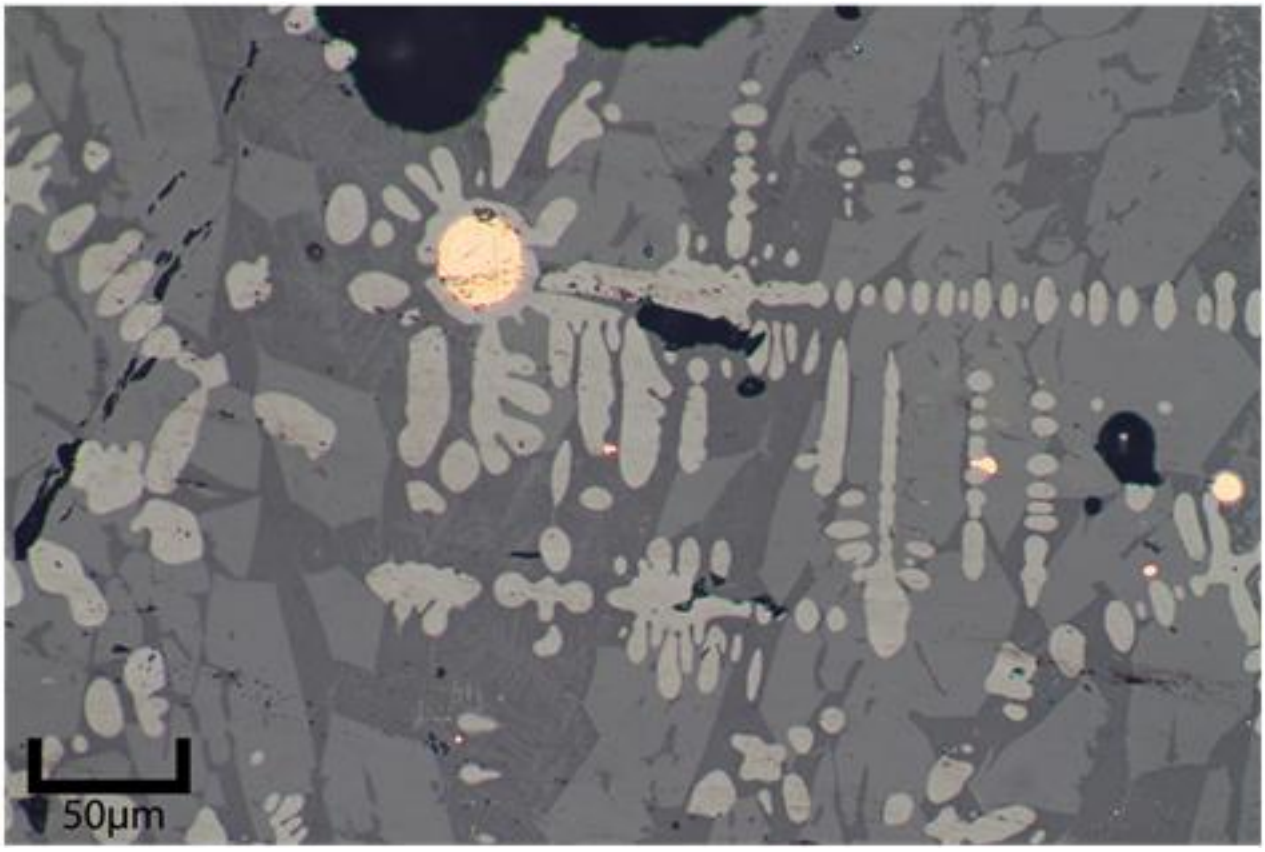
Hand Specimin



Micrograph 1



Micrograph 2



Site Code *161y* **Sample** *3290* **Type** *Slag* **Area**

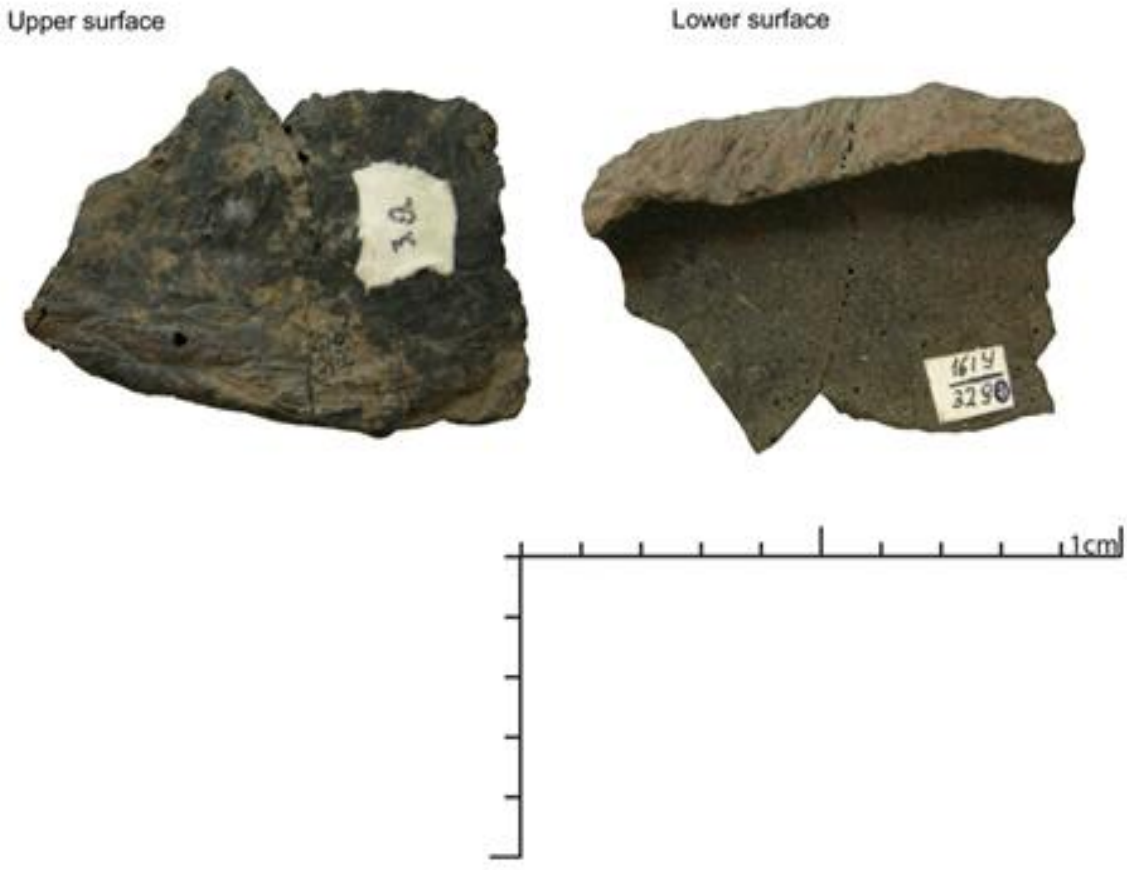
Wustite	*Absent*
Magnetitie	*Rare*
Lath Fayalite	*Occasional*
Delafossite	*Occasional*
Metallic copper	*Occasional*
Sulphides	
Euheadral fayalite	*Occasional*
Matrix	*Microphase 25-50%*
Additional Phases	*some large free silicates*

Additional notes

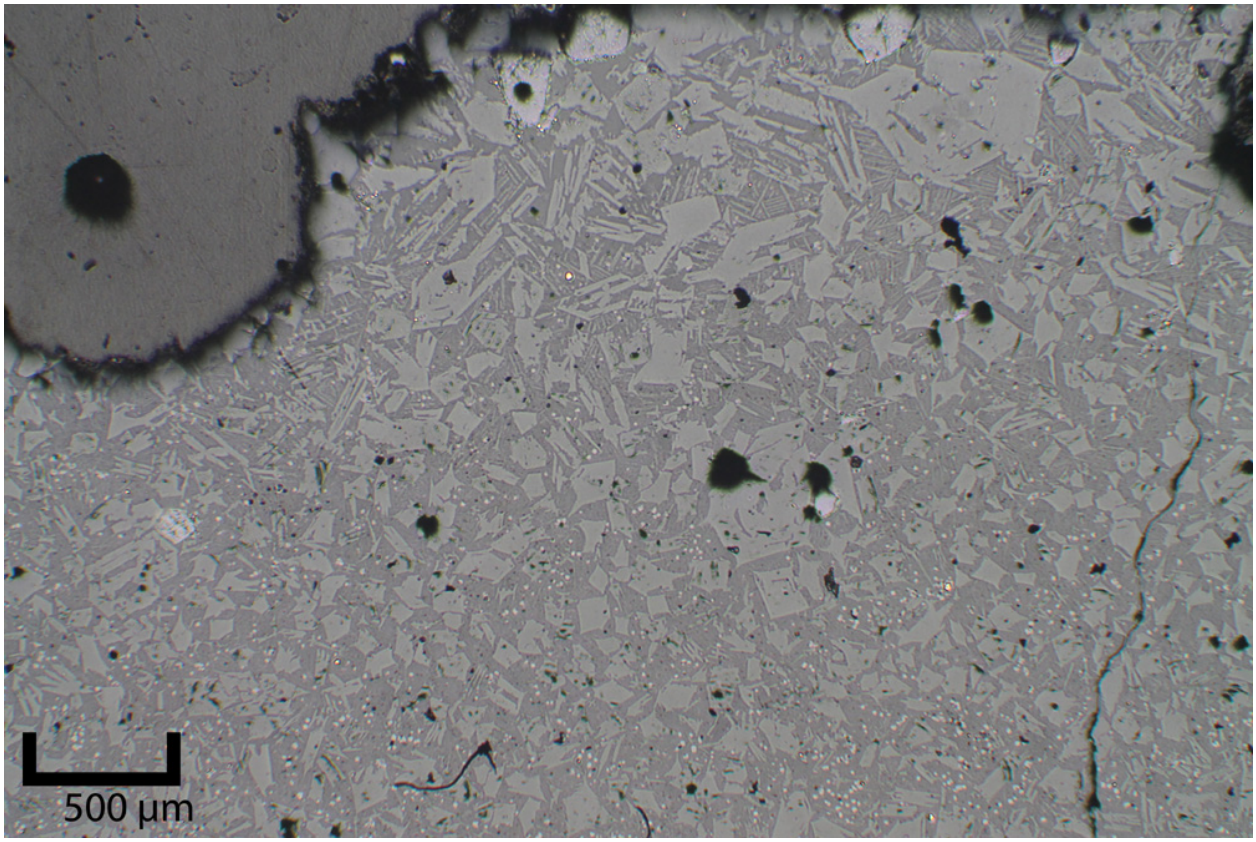
Chromite ✕ ***Present***

Group *D2*

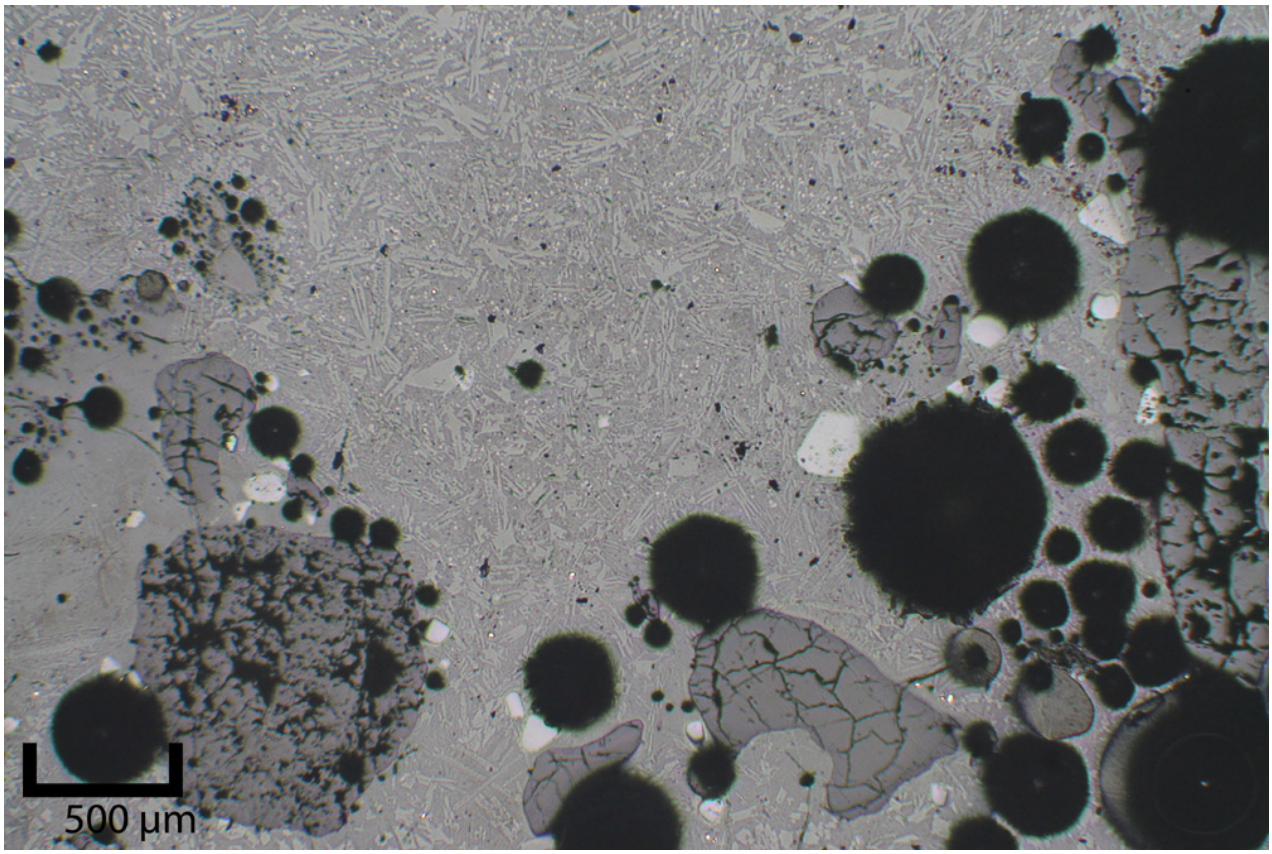
Hand Specimin



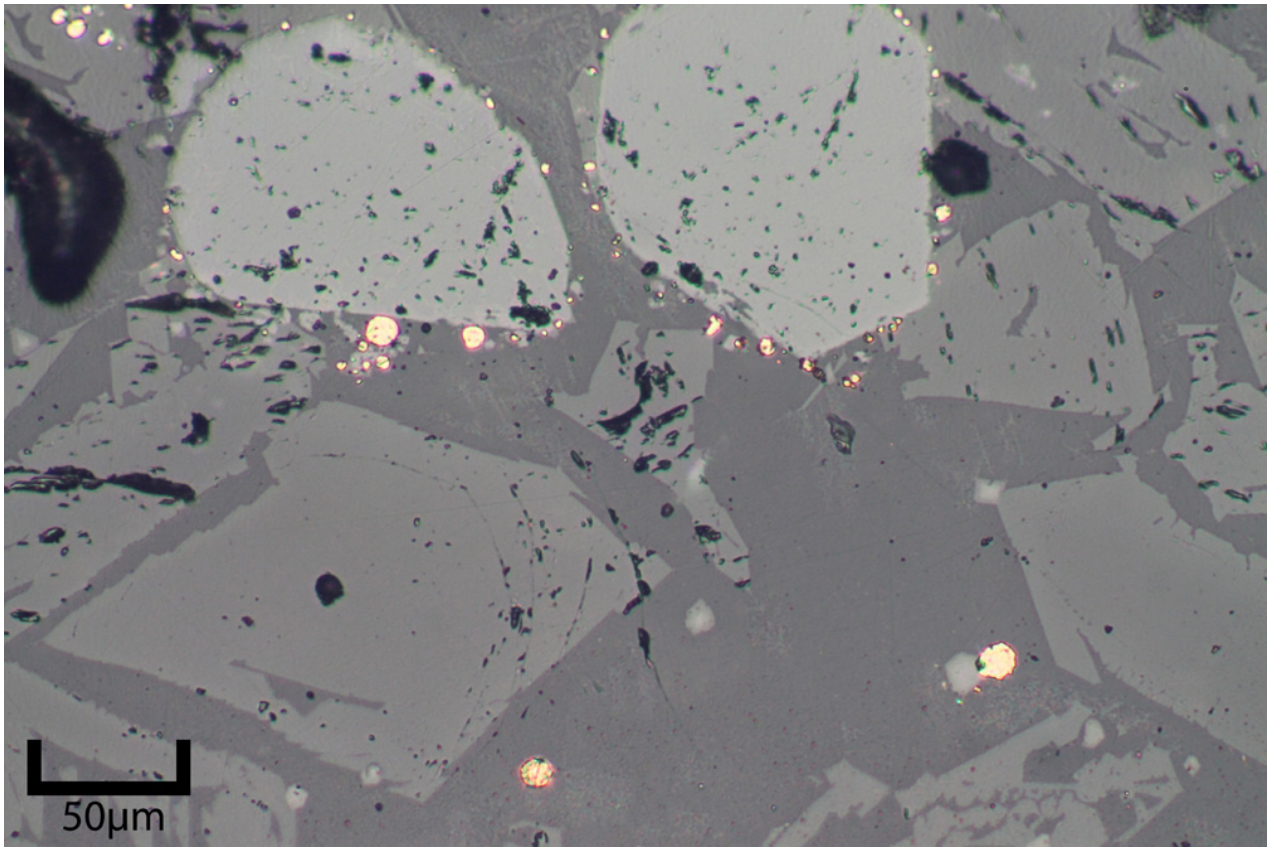
Micrograph 1



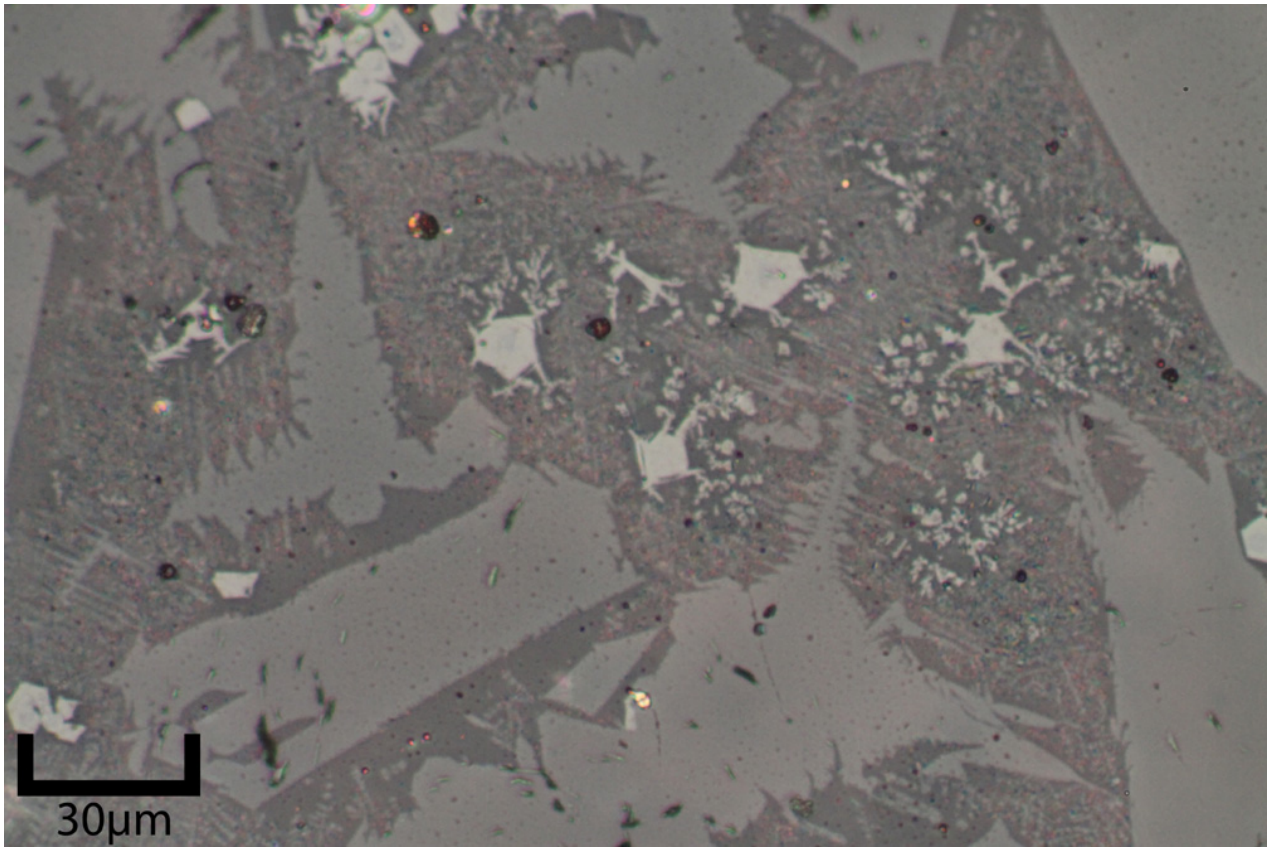
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *161y* **Sample** *5076* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Frequent*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	*chromites*

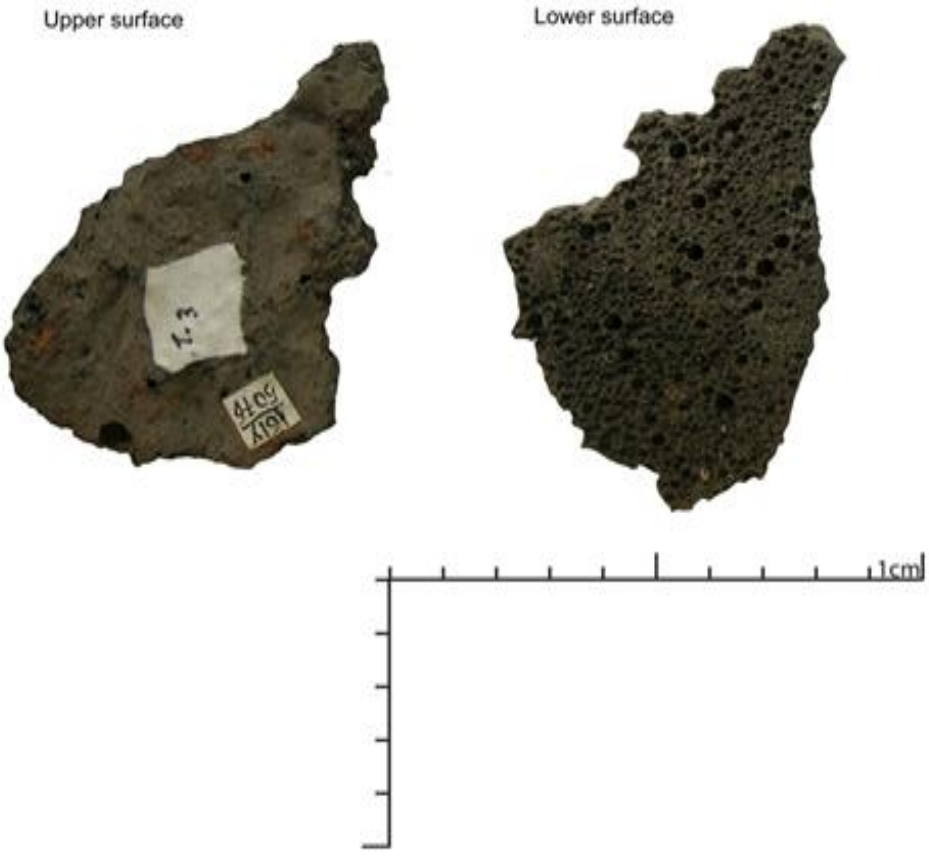
Additional notes

some large oxide ore inclusions and ceramic iclusions

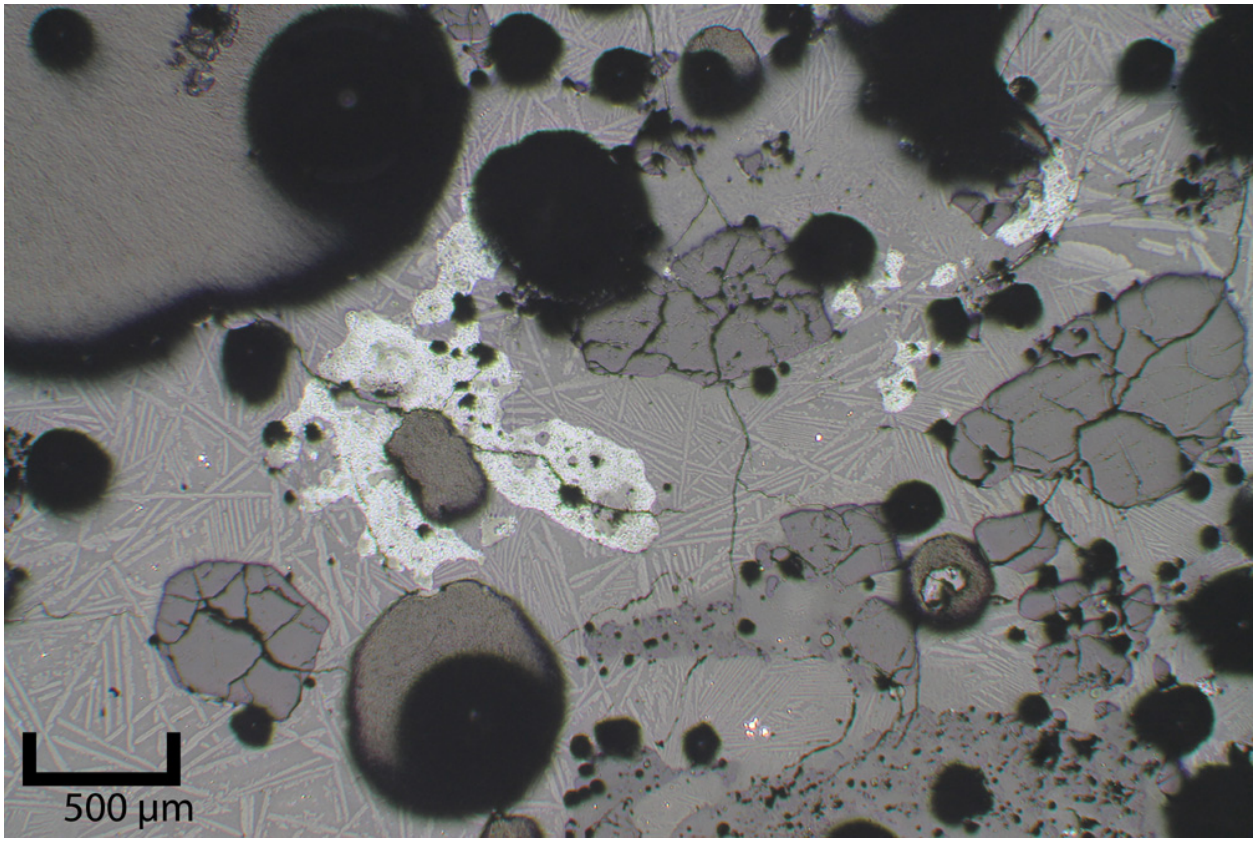
Chromite ✕ ***Present***

Group *A1*

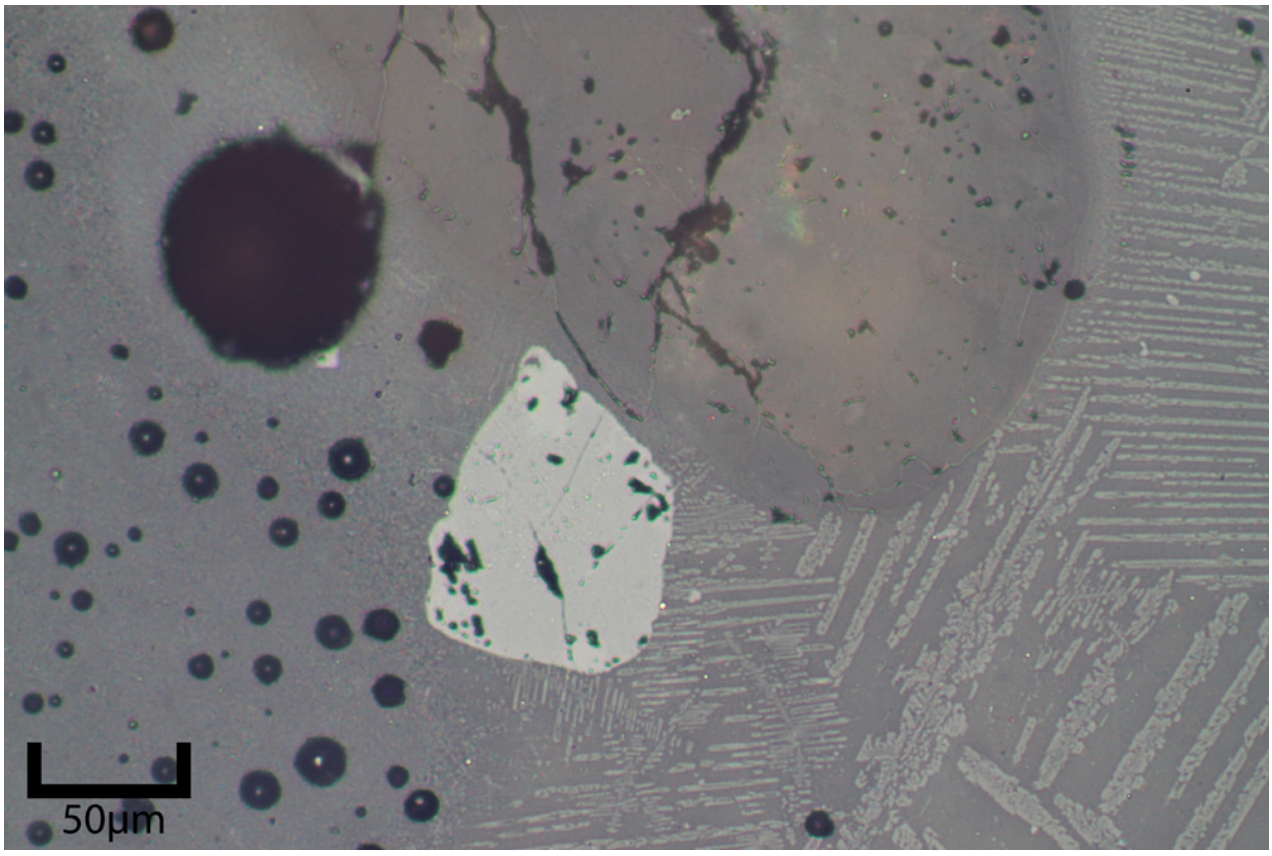
Hand Specimin



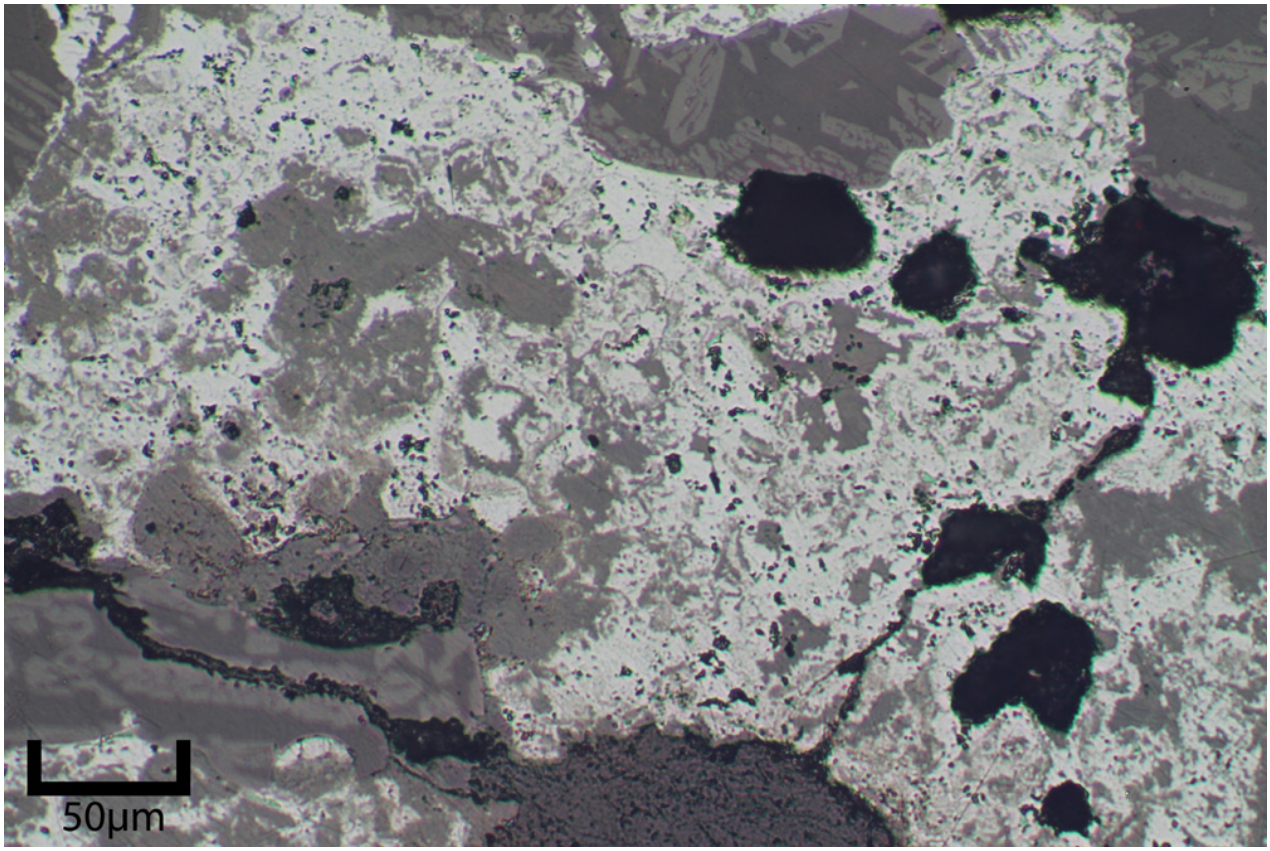
Micrograph 1



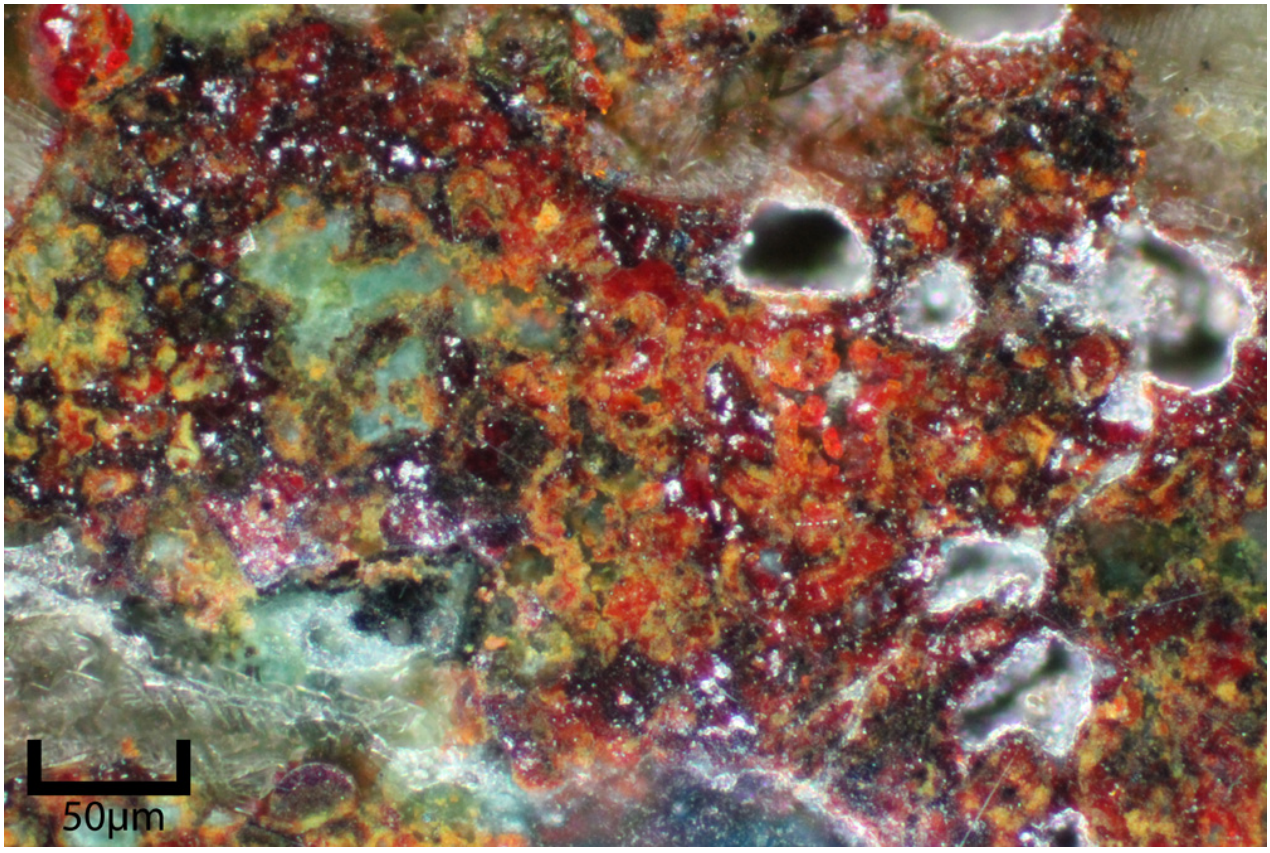
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *161y* **Sample** *5131* **Type** *Unknown* **Area**

Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Absent*
Delafossite	*Absent*
Metallic copper	*Occasional*
Sulphides	*Occasional*
Euheadral fayalite	*Absent*
Matrix	*Glassy 50-75%*
Additional Phases	*copper oxide*

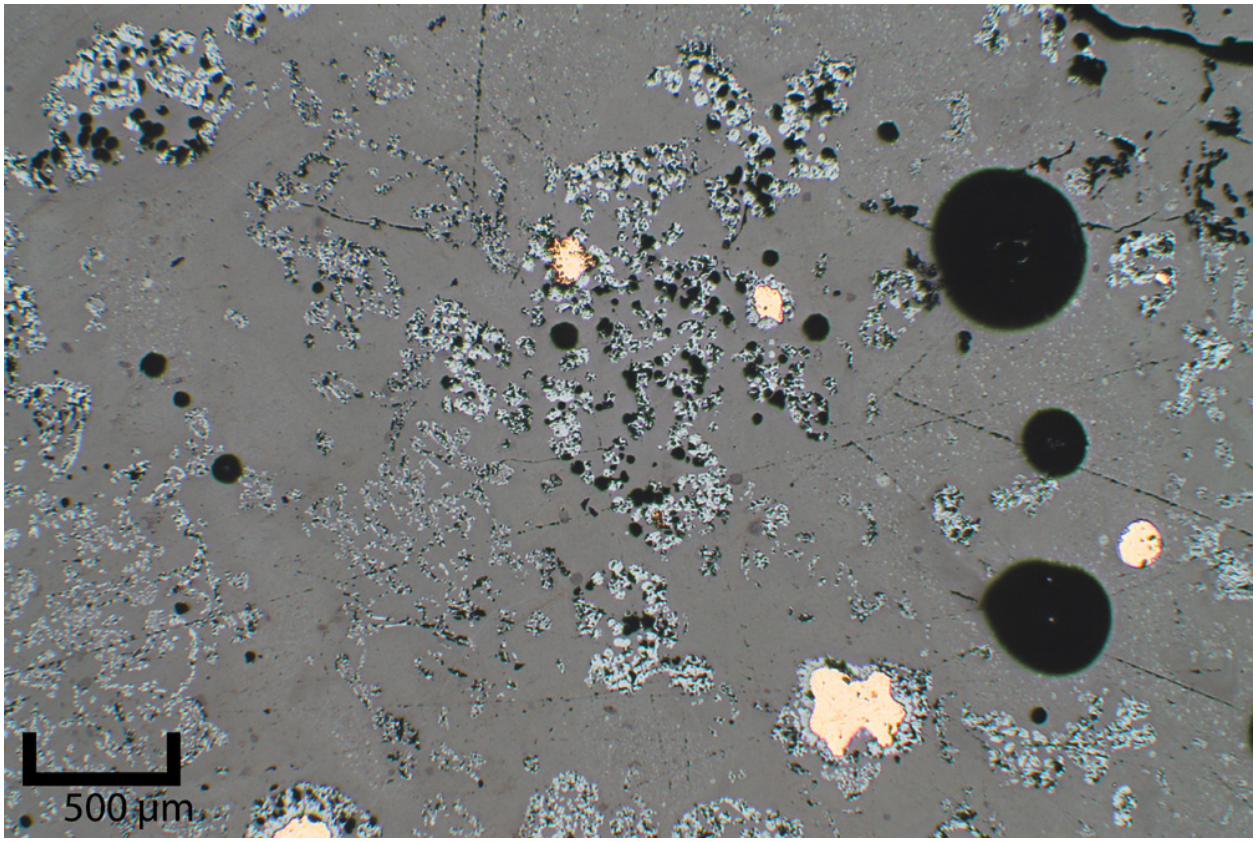
Additional notes
Very unusual sample

Chromite ***Present*** **Group** *na*

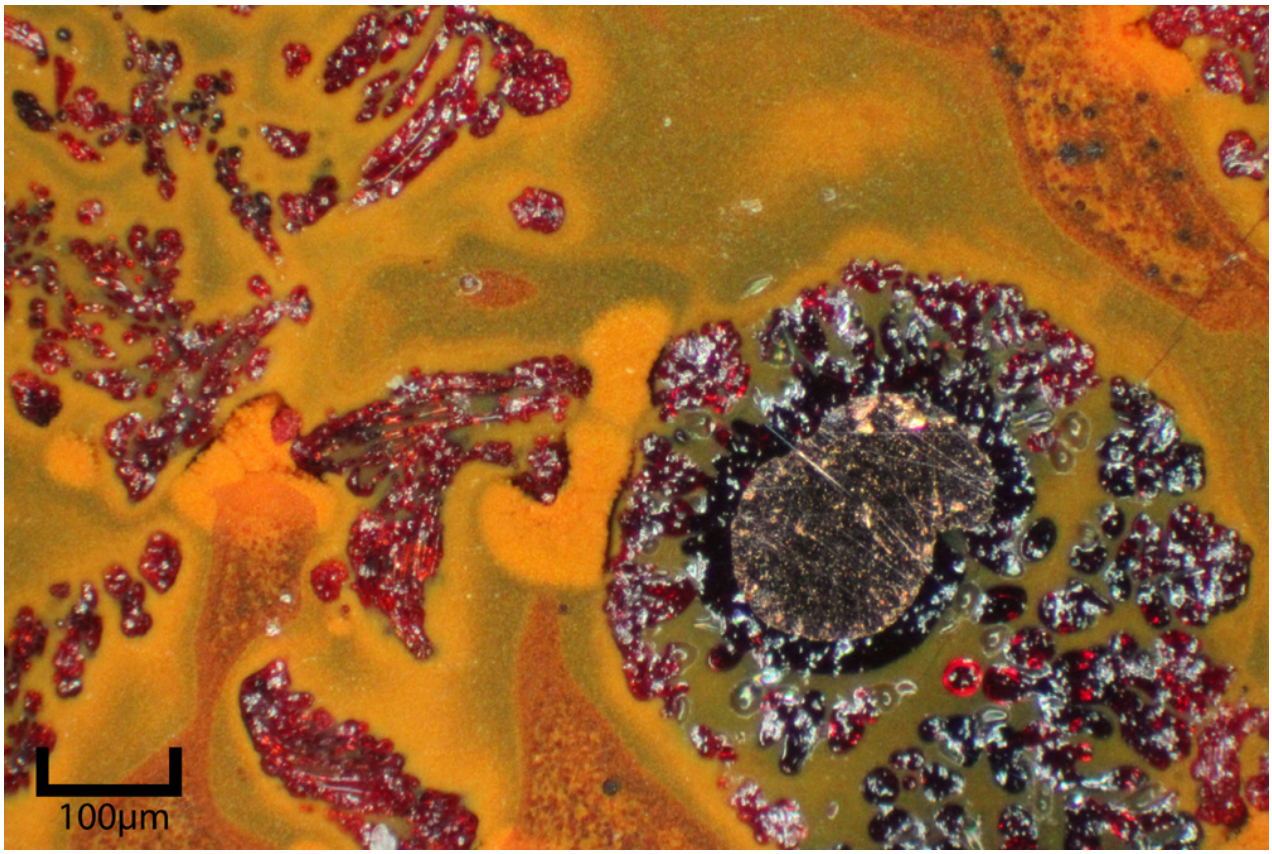
Hand Specimin



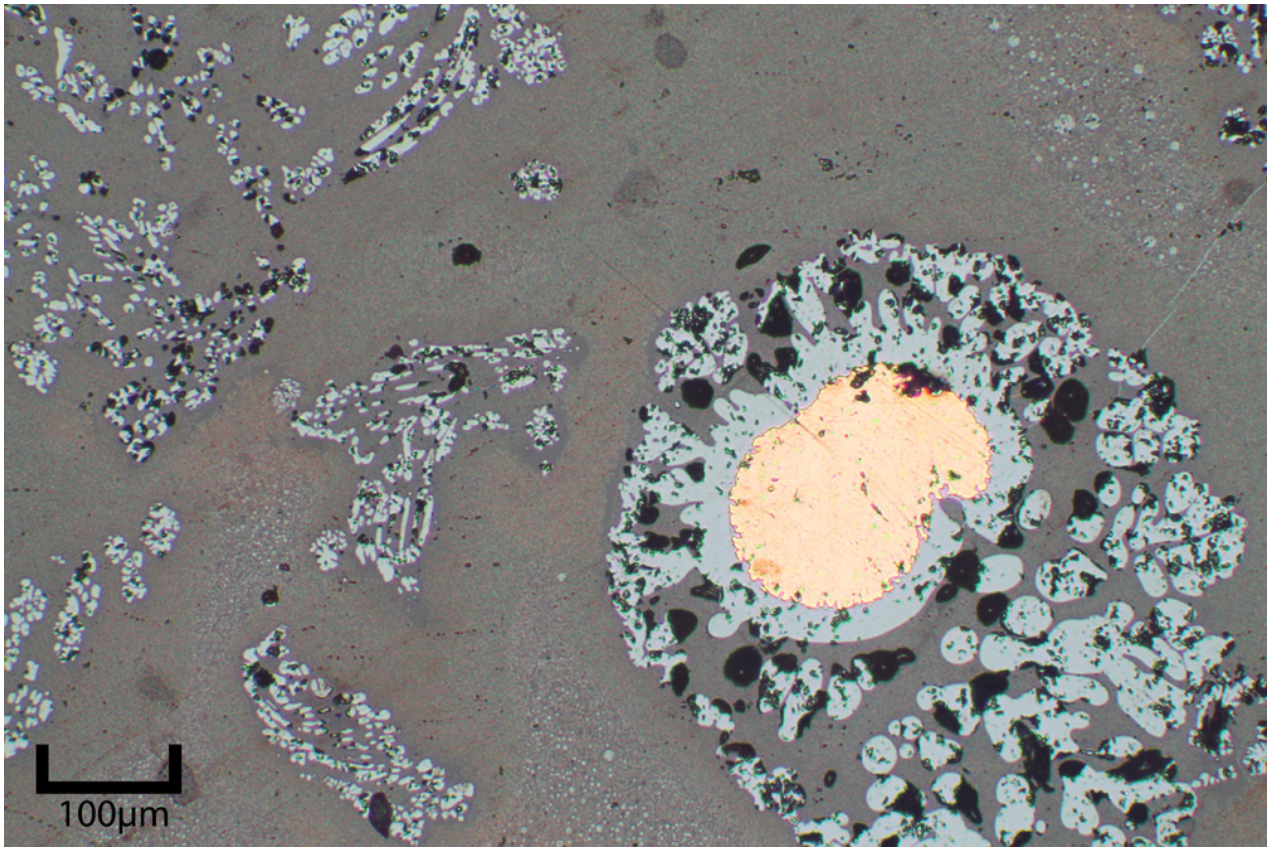
Micrograph 1



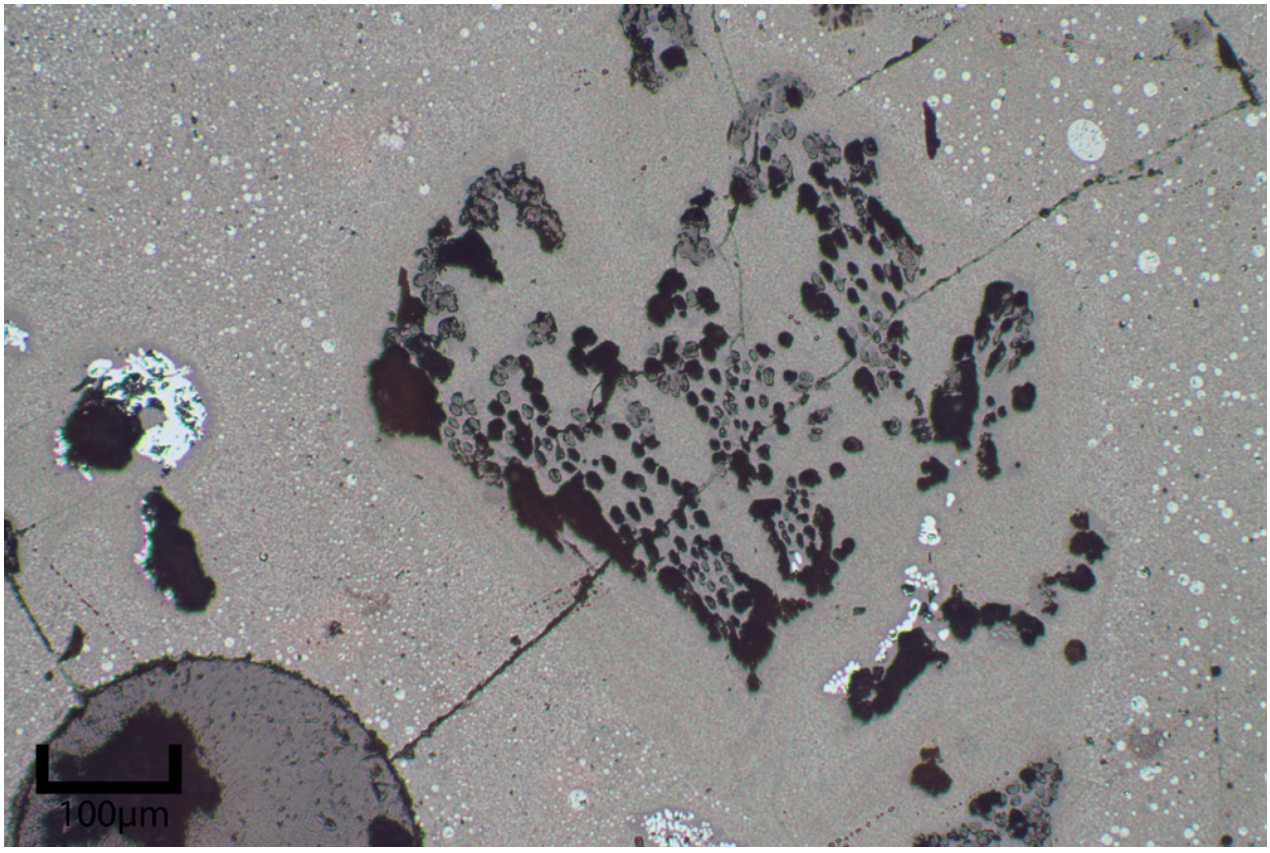
Micrograph 2



Micrograph 3



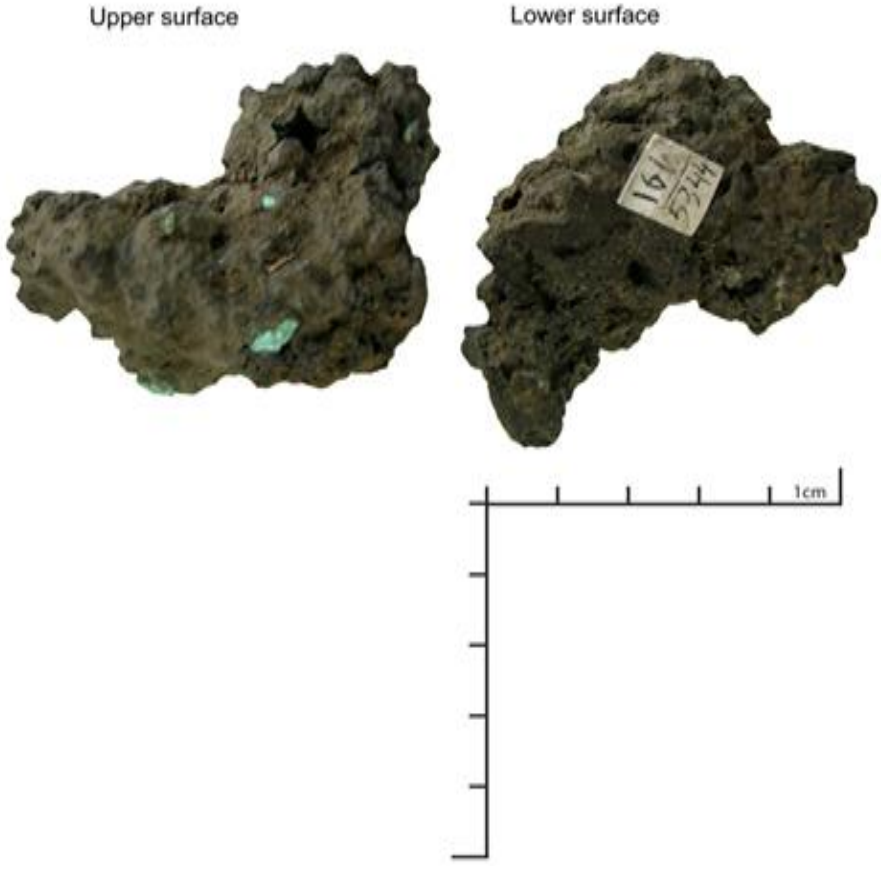
Micrograph 4



Site Code *161y* **Sample** *5344* **Type** *Slag* **Area**

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

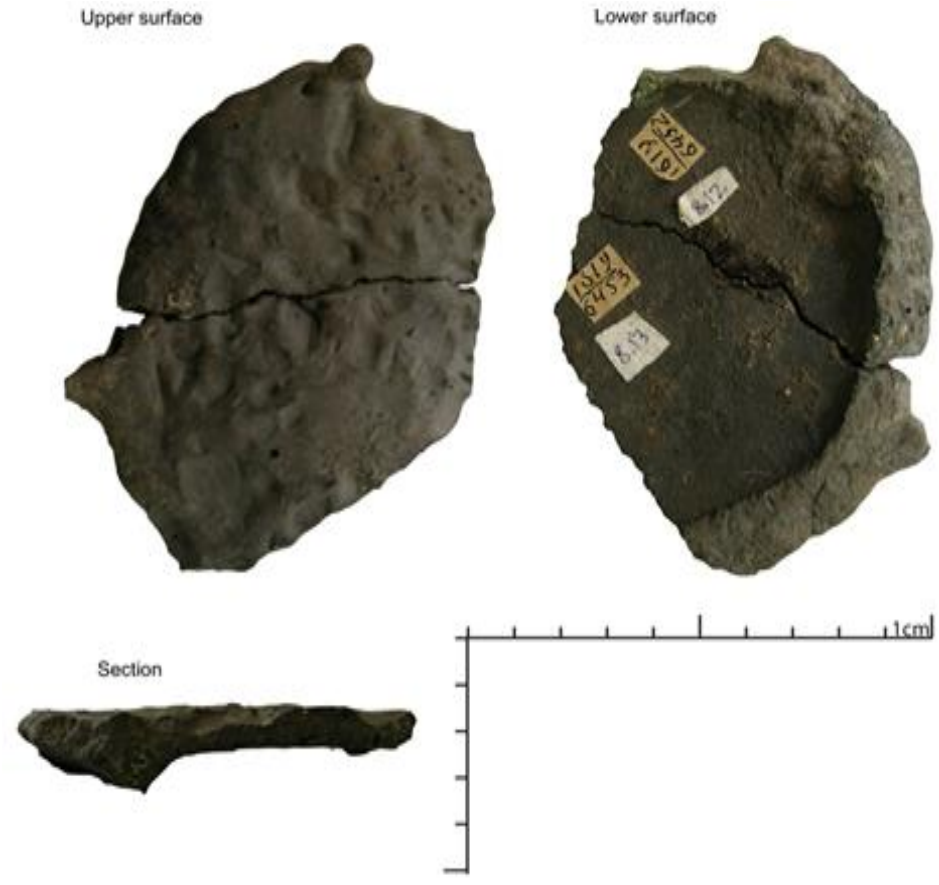
Hand Specimin



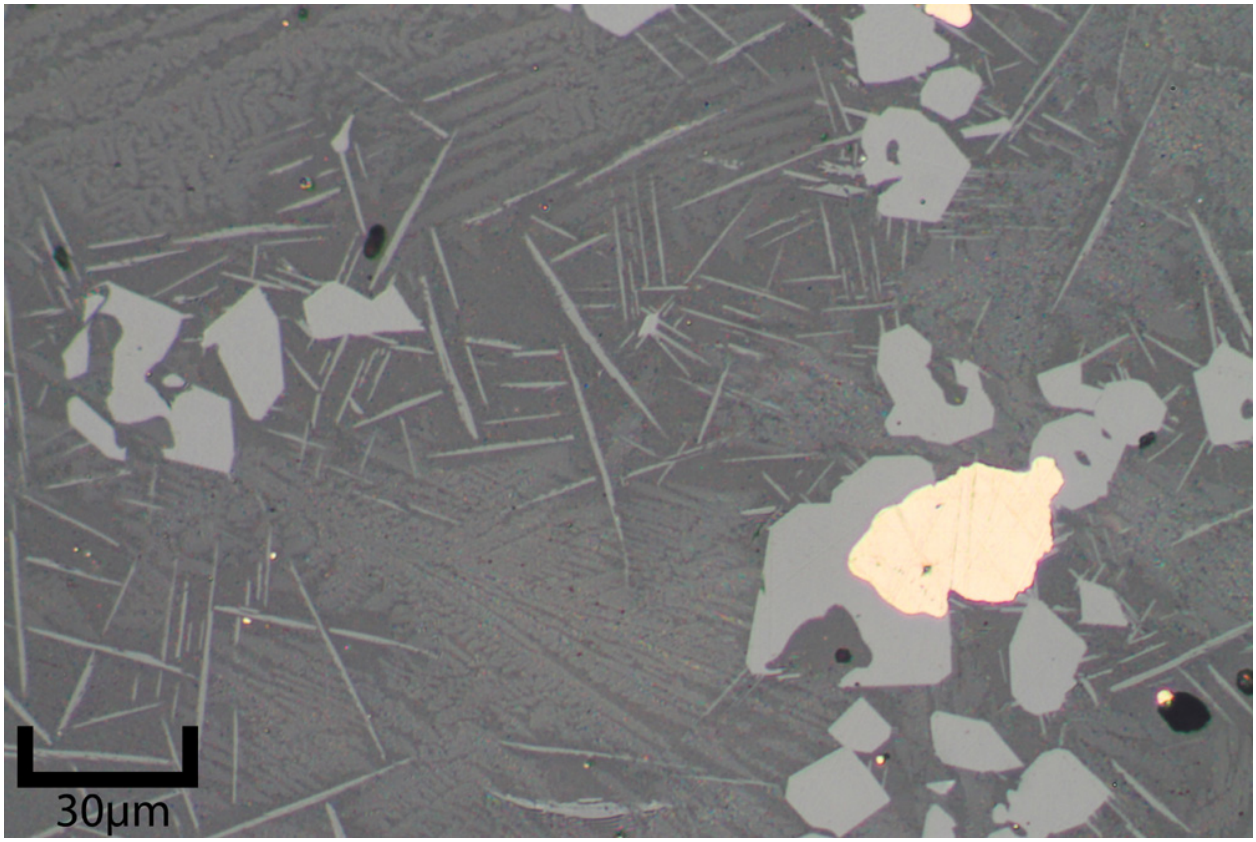
Site Code *161y* **Sample** *6452* **Type** *Slag* **Area**

Wustite	*Absent*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Occasional*	
Delafossite	*Occasional*	
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Occasional*	
Matrix	*Microphase 50-75%*	
Additional Phases		
Chromite	***Present***	**Group** *C2*

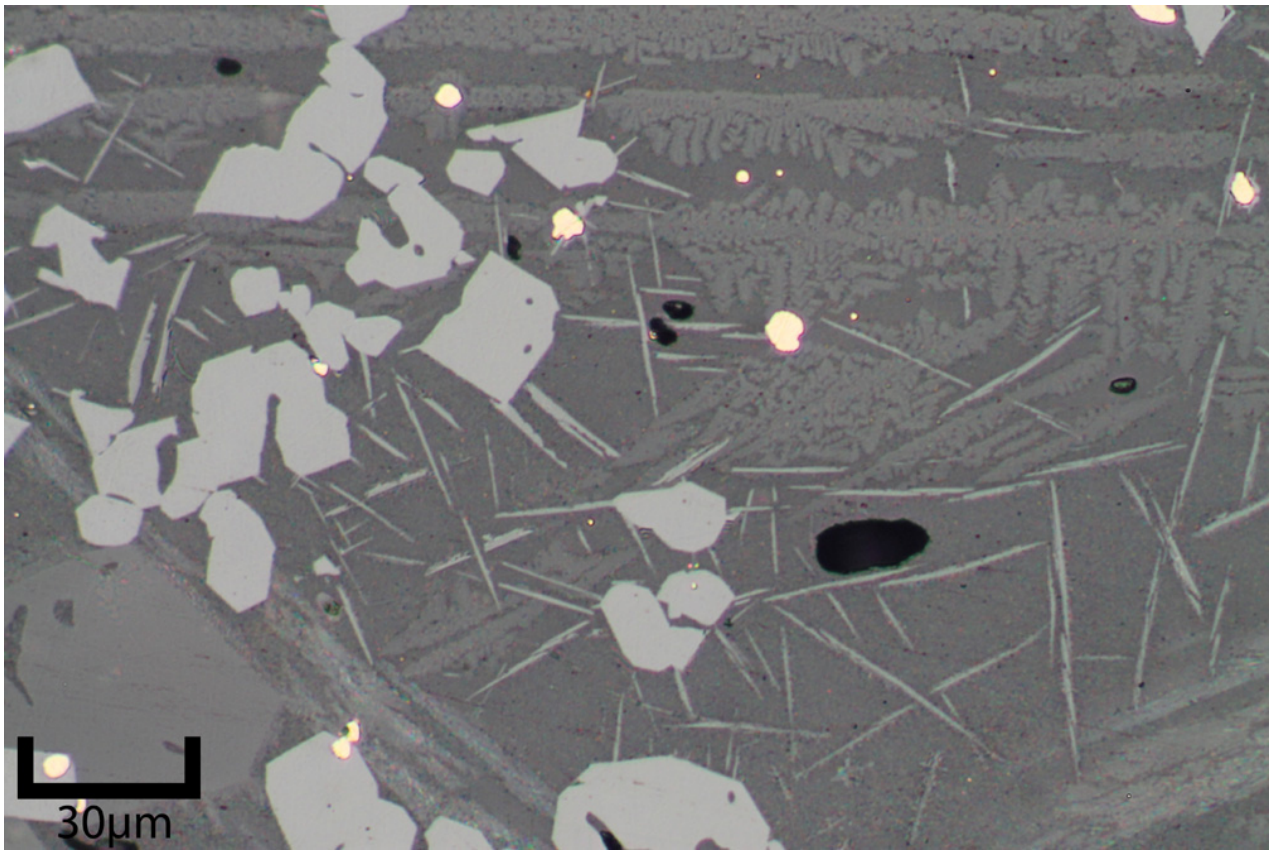
Hand Specimin



Micrograph 1



Micrograph 2



Site Code *161y* **Sample** *7235* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Dominant*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	

Additional notes

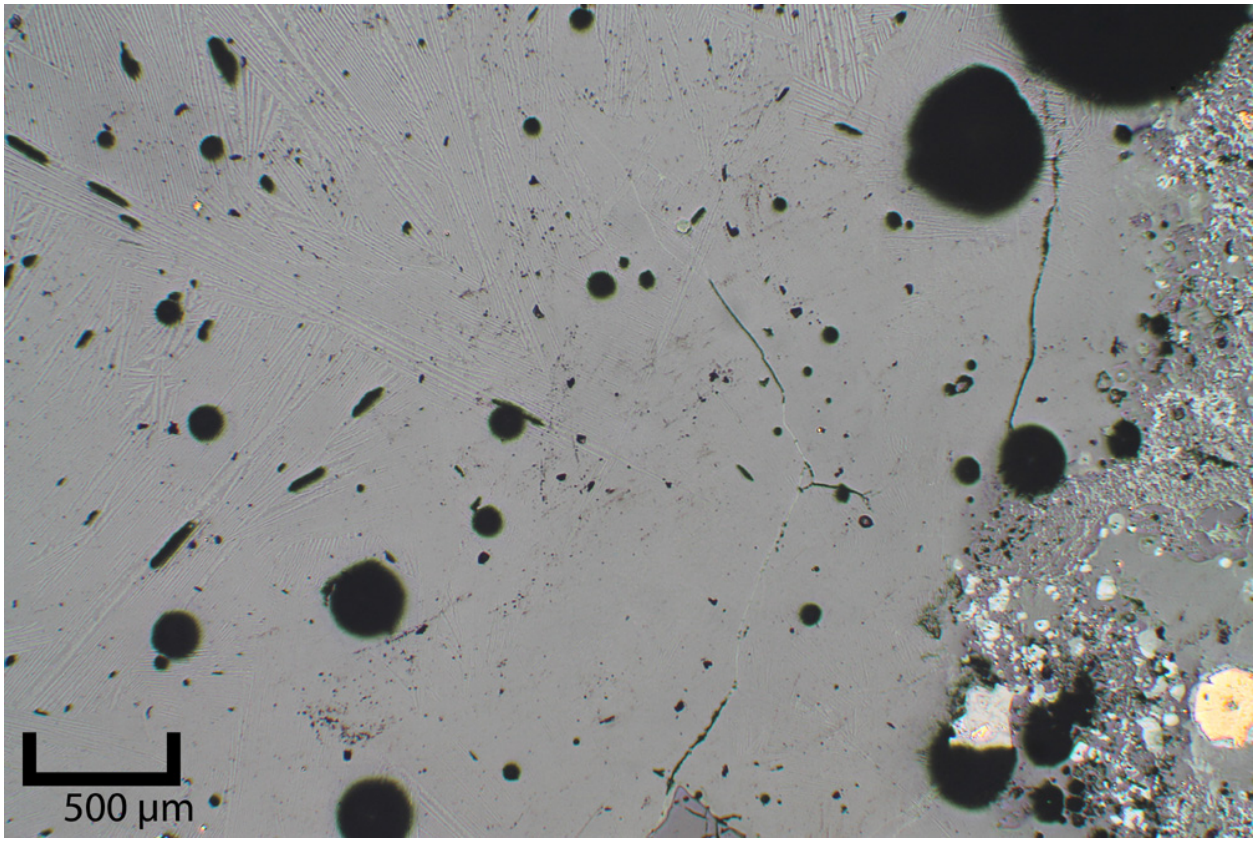
very fine, linear fayalitic microstructure. Some copper oxide/sulphide inclusions in association with metallic copper

Chromite ***Present***

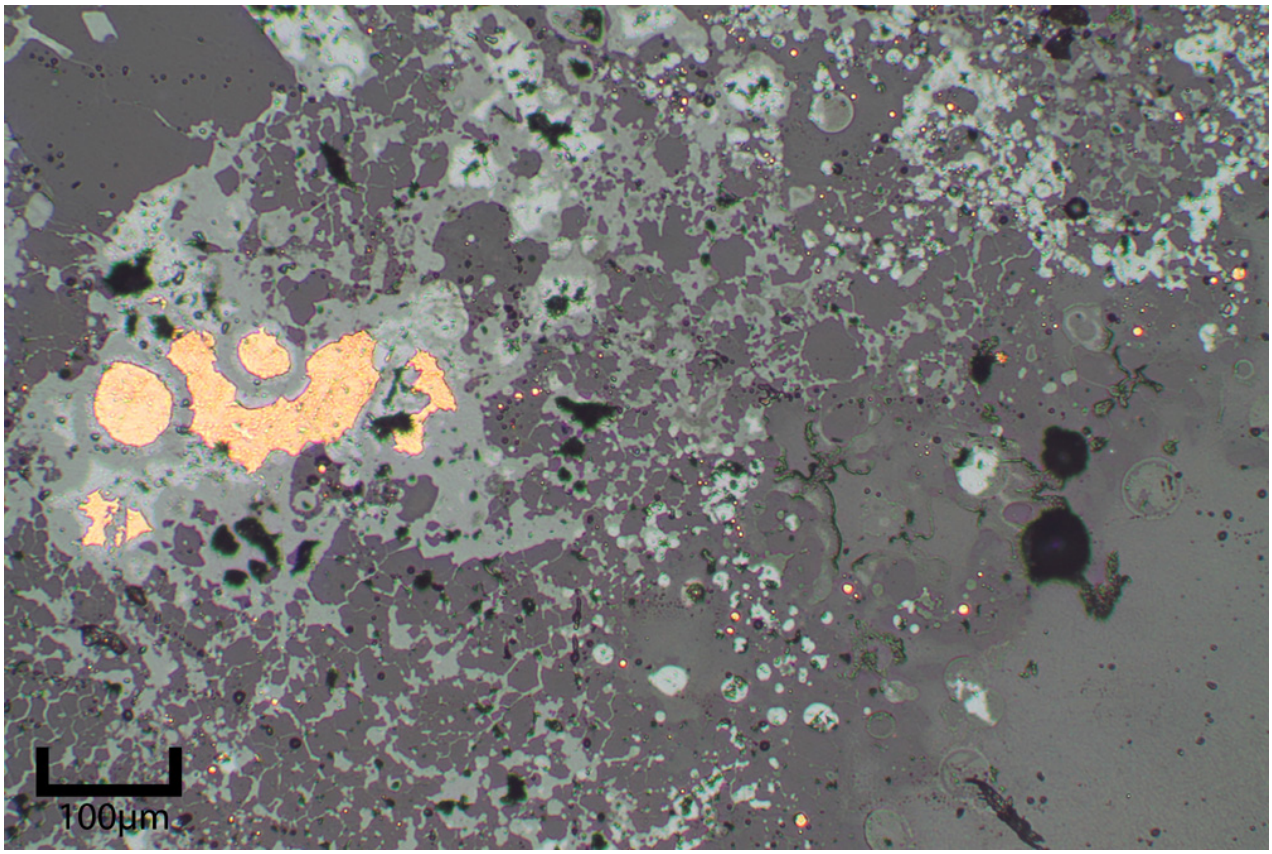
Group *A1*

Hand Specimin

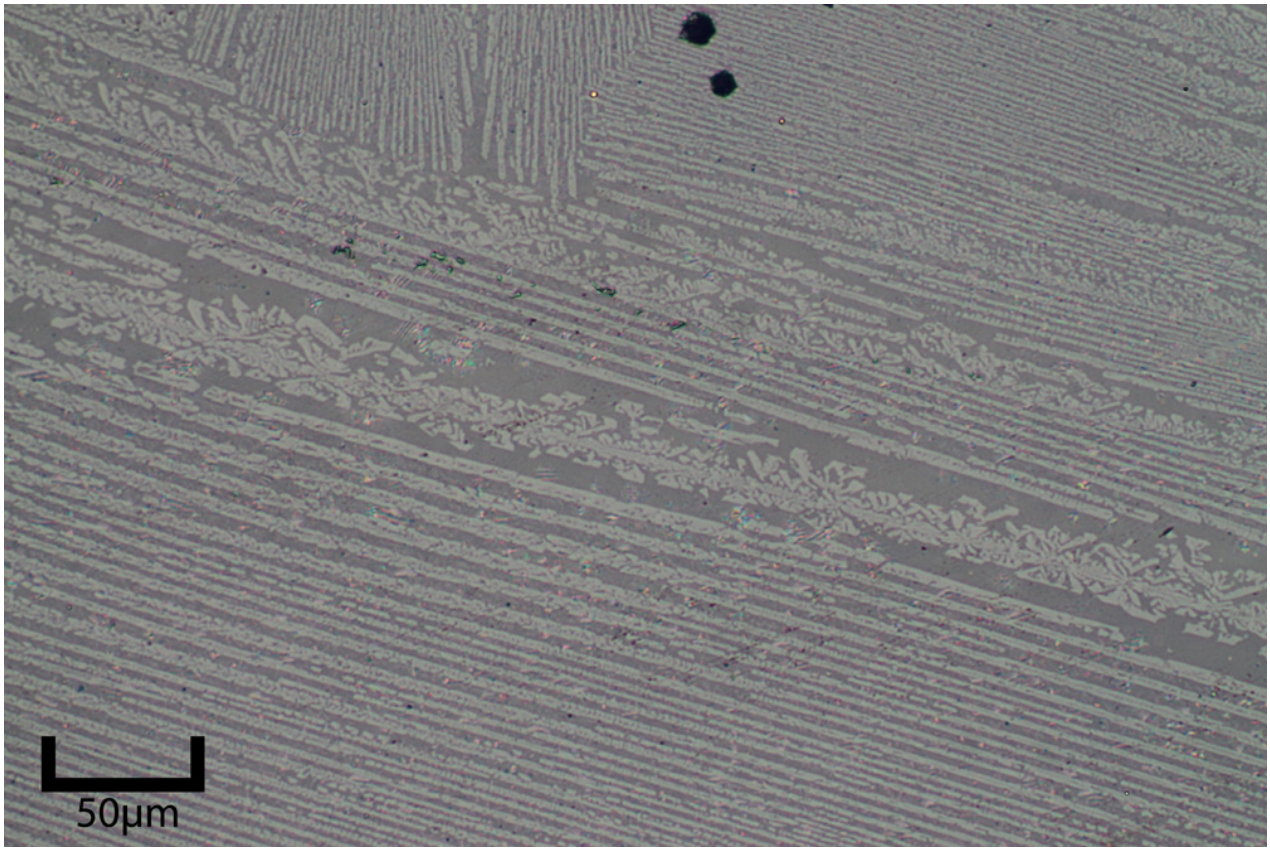
Micrograph 1



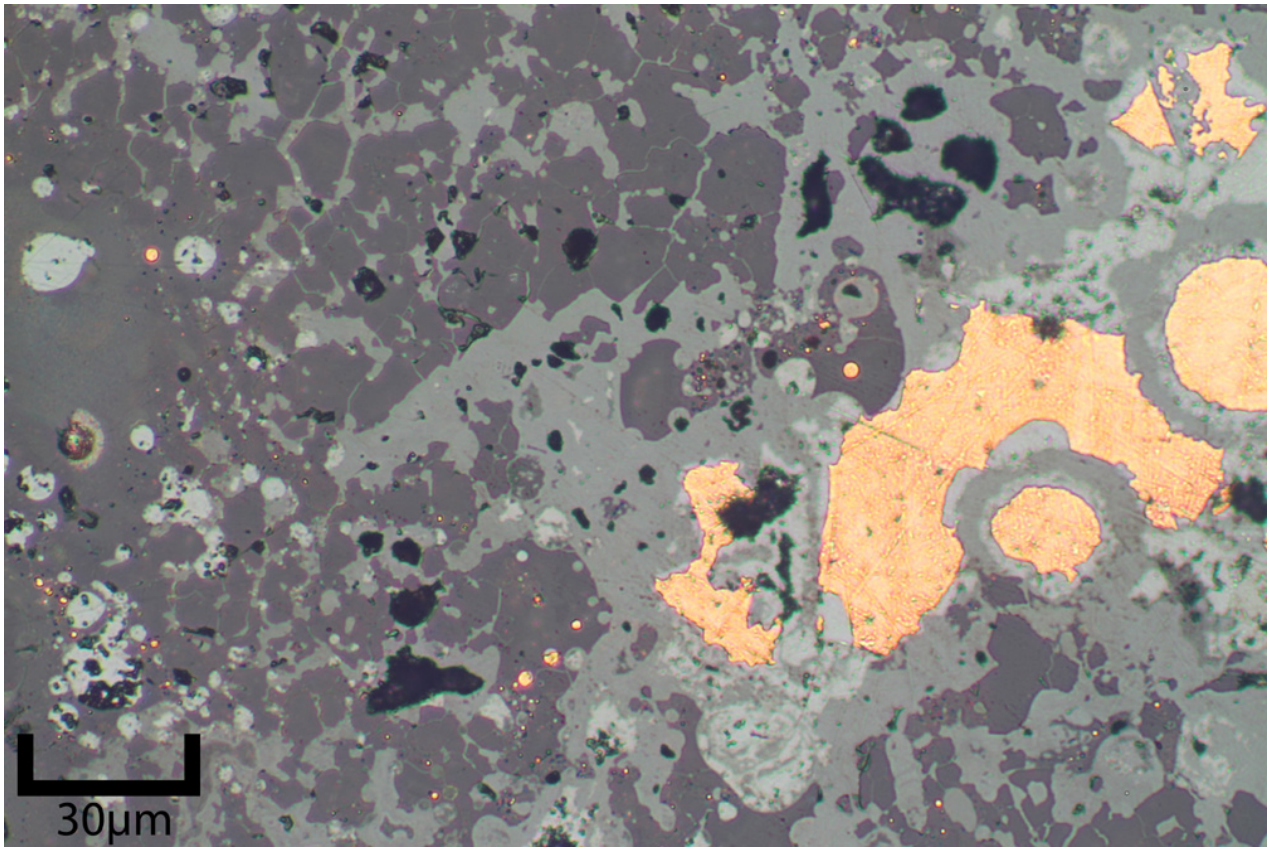
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *161y* **Sample** *10007* **Type** *Slag* **Area** *u'18*

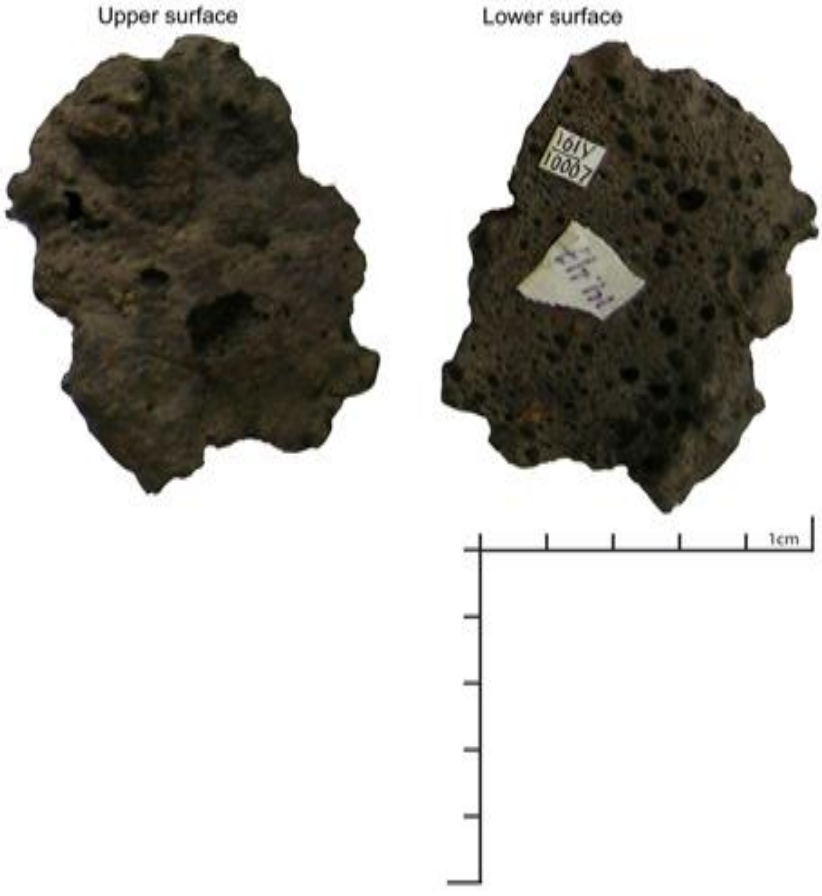
Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Absent*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Frequent*
Matrix	*Glassy 10-25%*
Additional Phases	*common chromites*

Additional notes

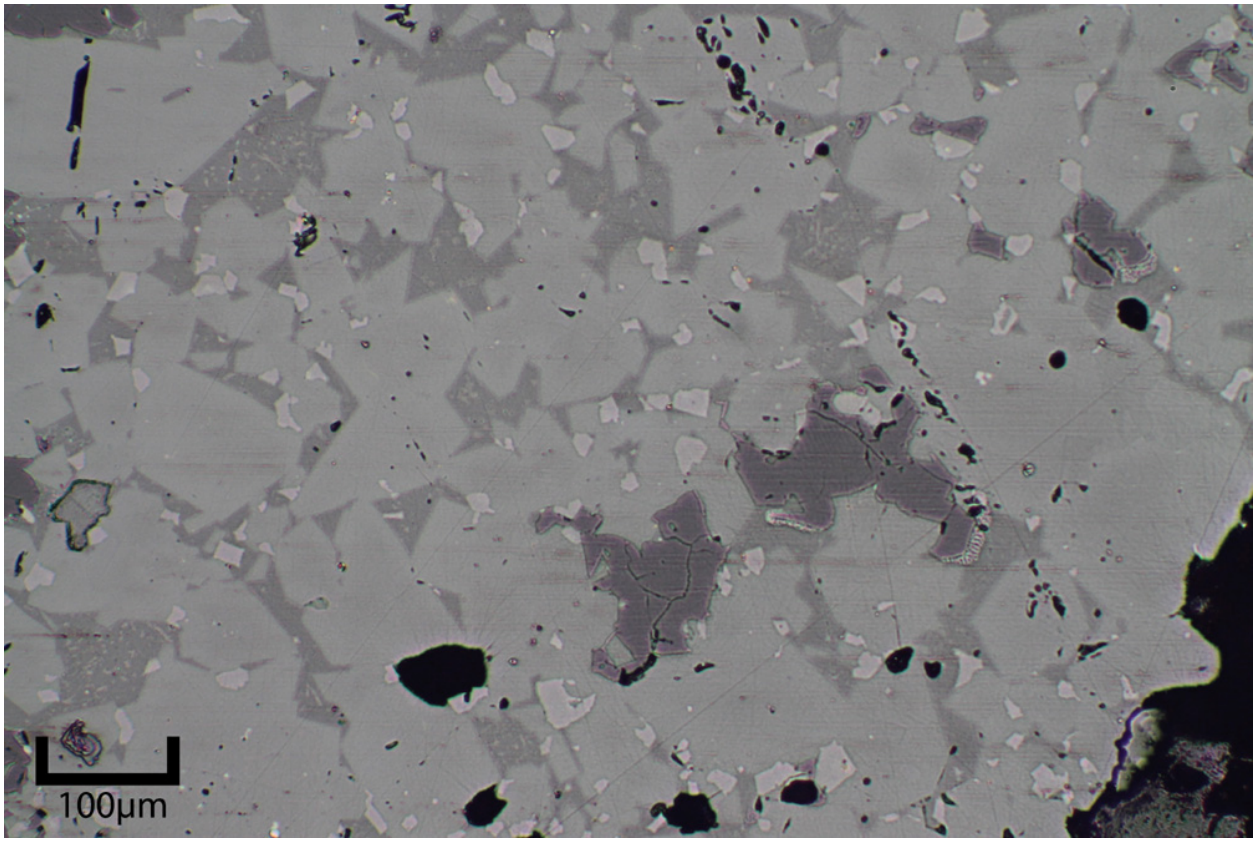
Chromite ✕ ***Present***

Group *B1*

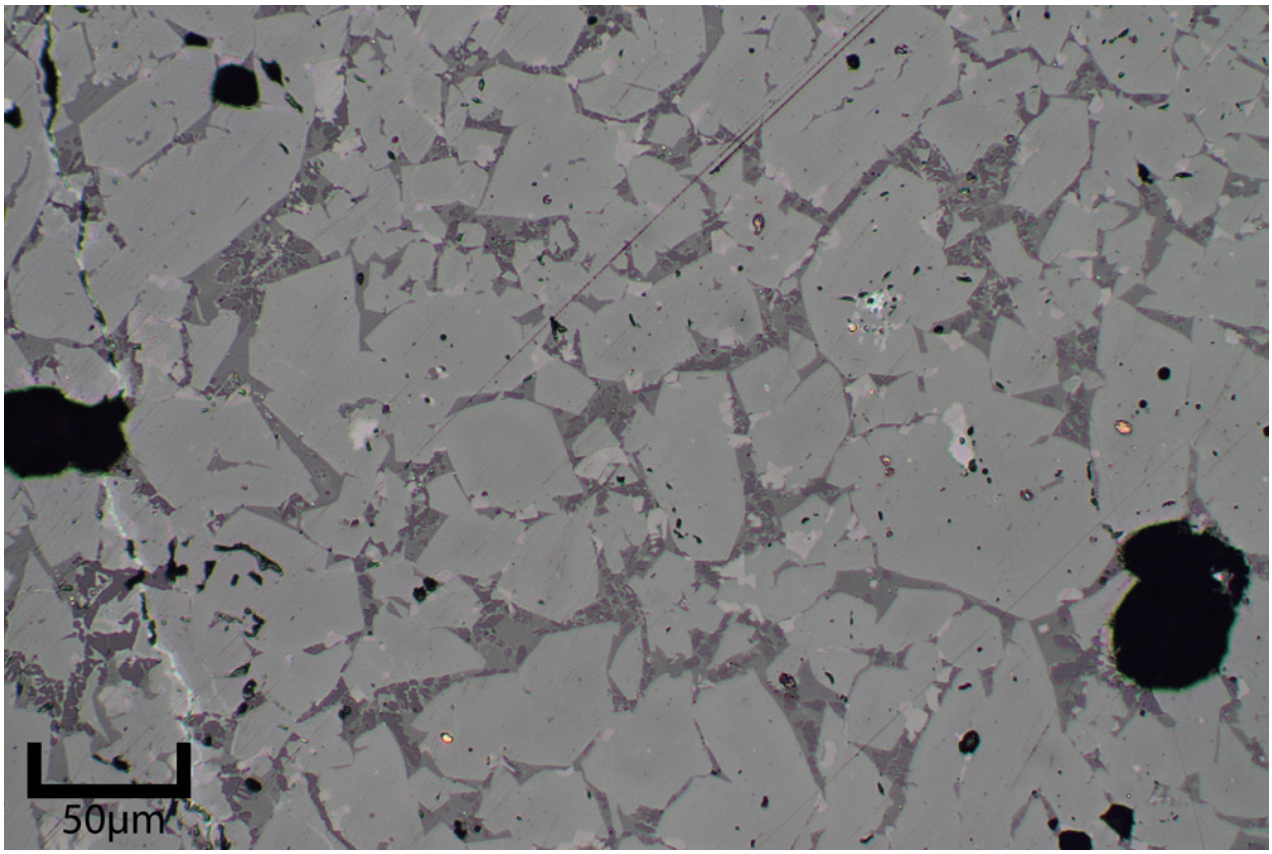
Hand Specimin



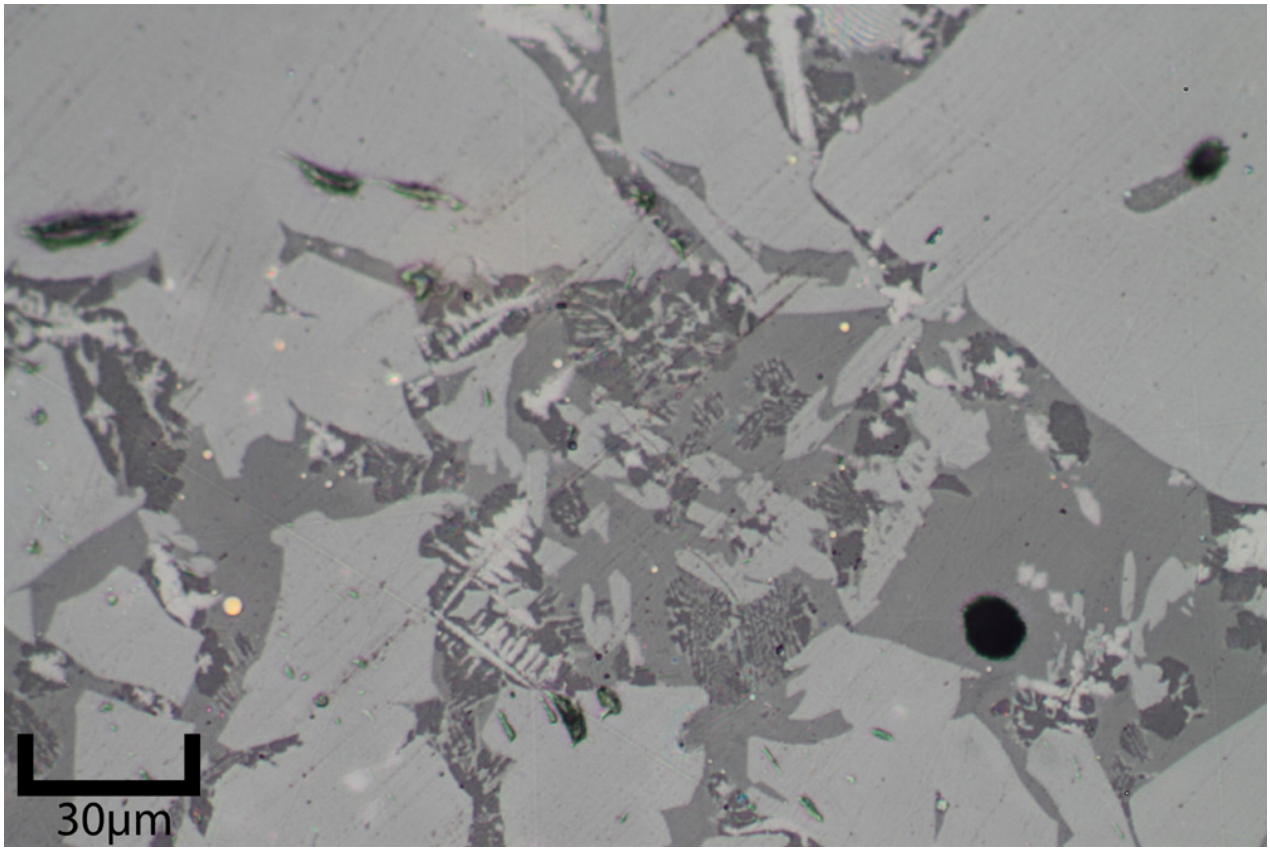
Micrograph 1



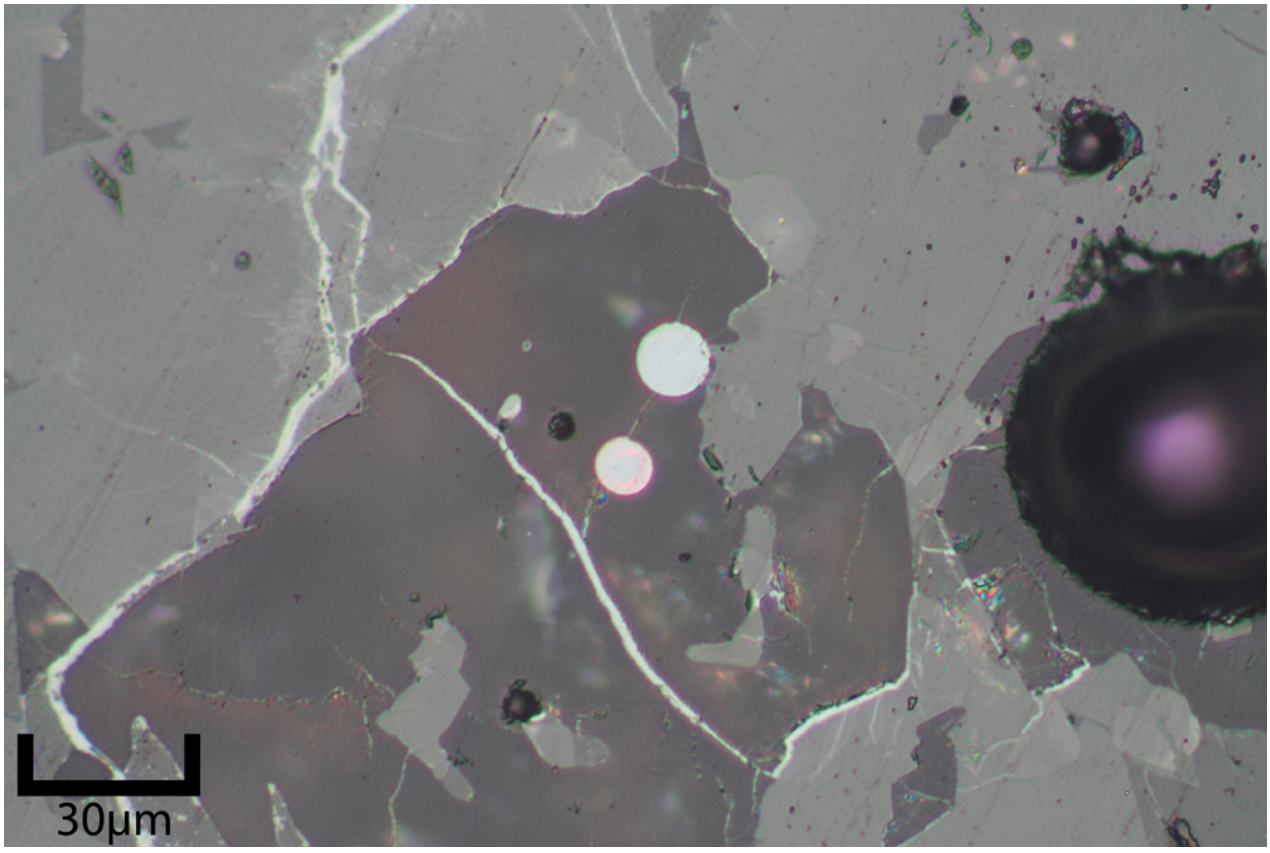
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *161y* **Sample** *10397* **Type** *Slag* **Area** *f'20*

Wustite	*Common*
Magnetitie	*Rare*
Lath Fayalite	*Dominant*
Delafossite	
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	*some possible sulphides*

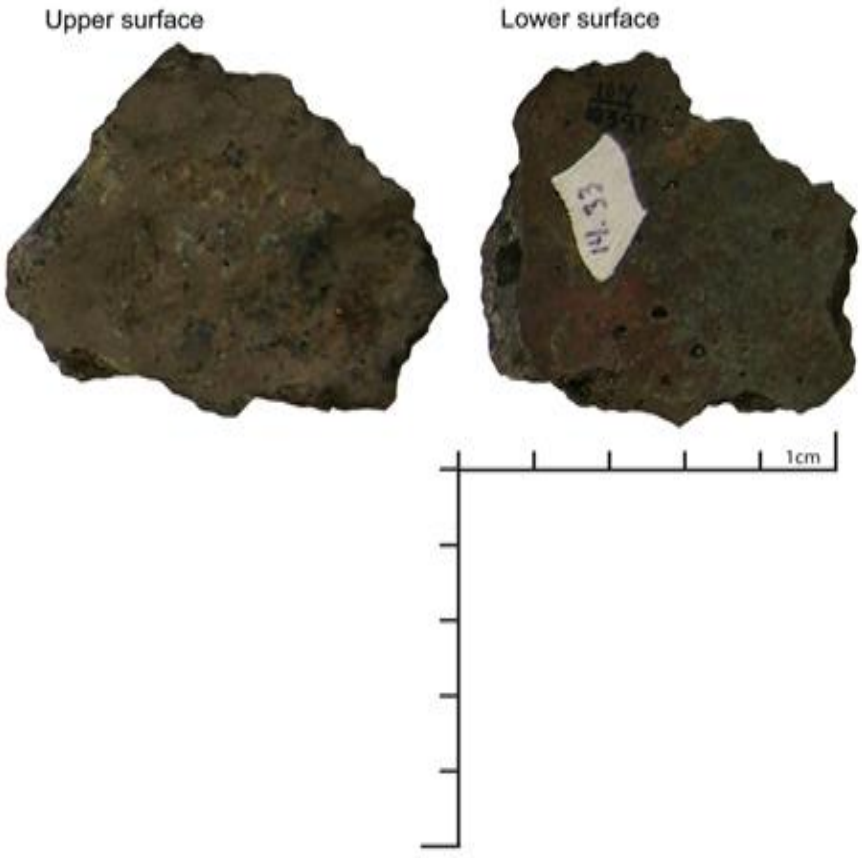
Additional notes

very lath like fayalite, whustite appears in cruciform skeletal structure; intermediate form

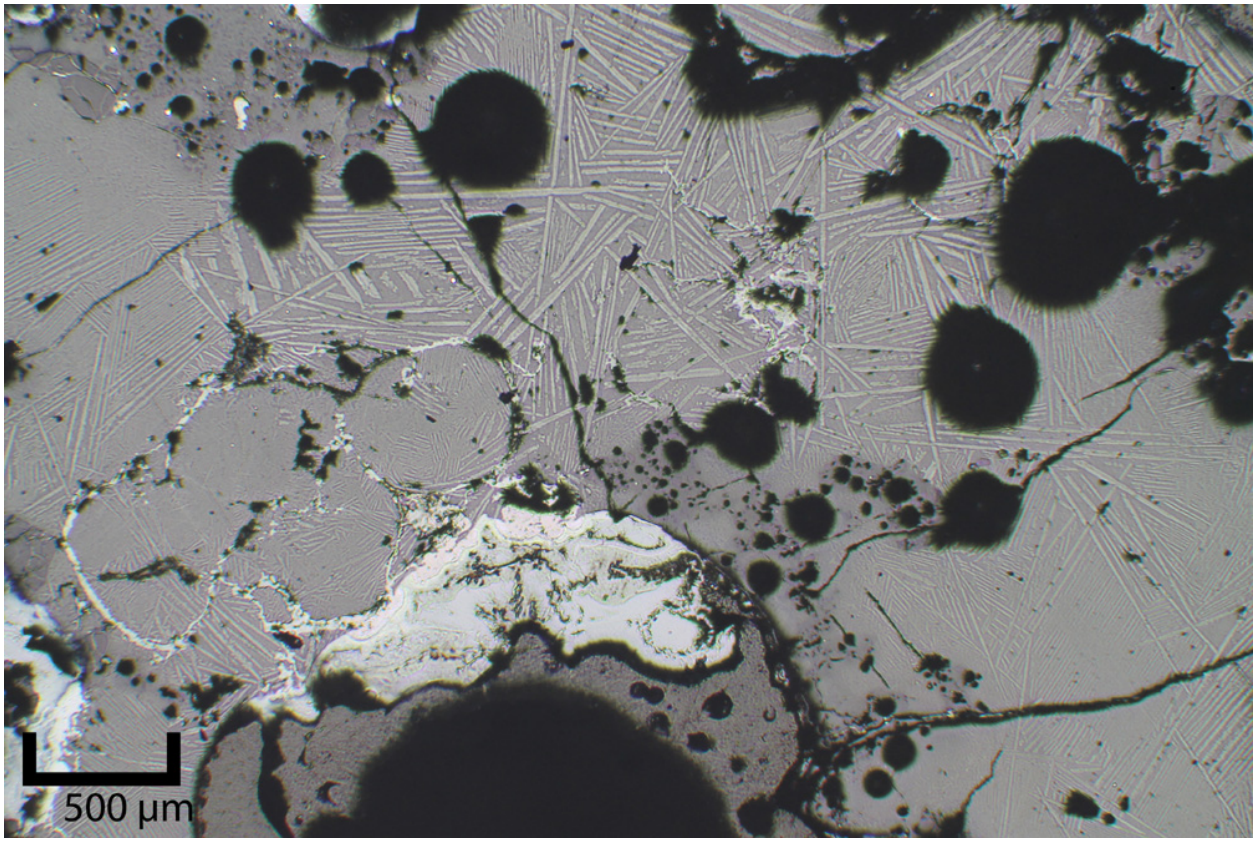
Chromite ***Present***

Group *A2*

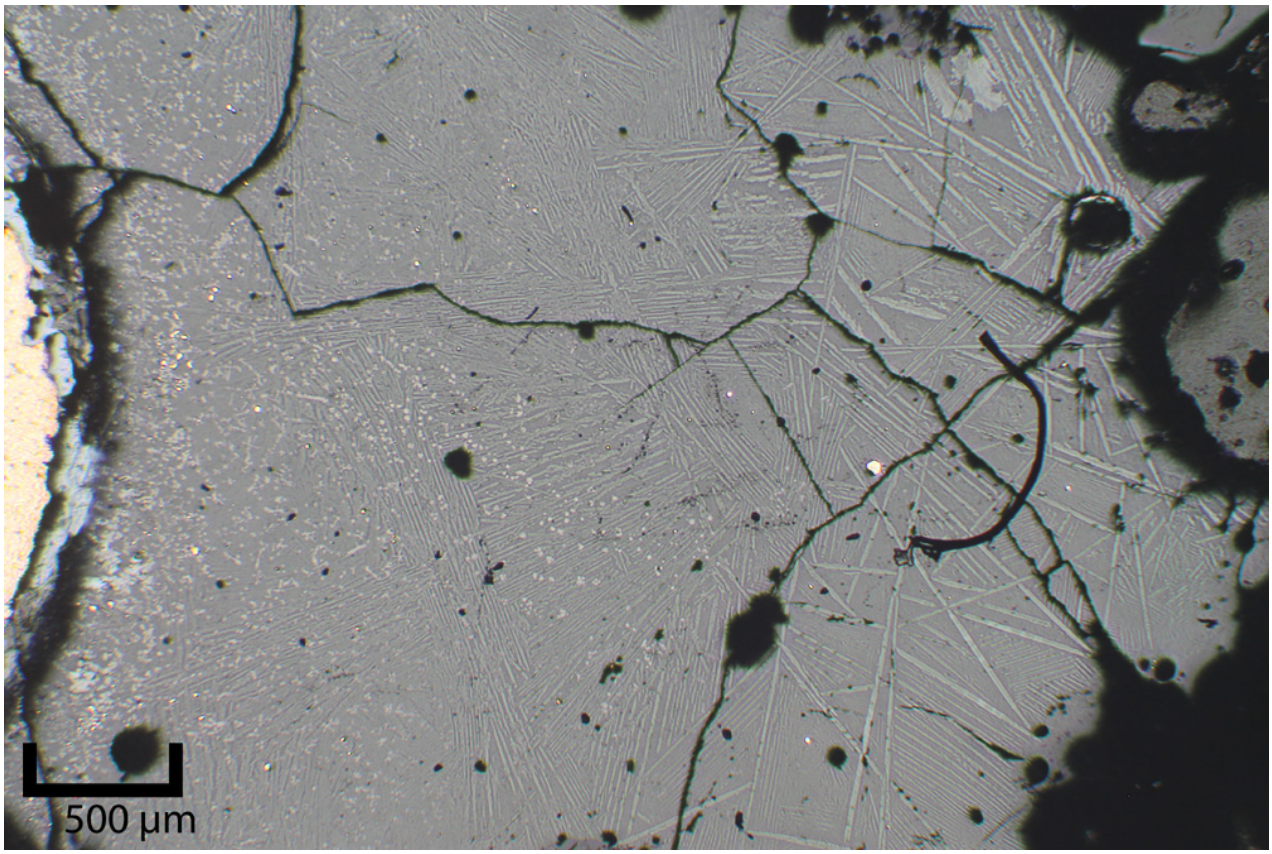
Hand Specimin



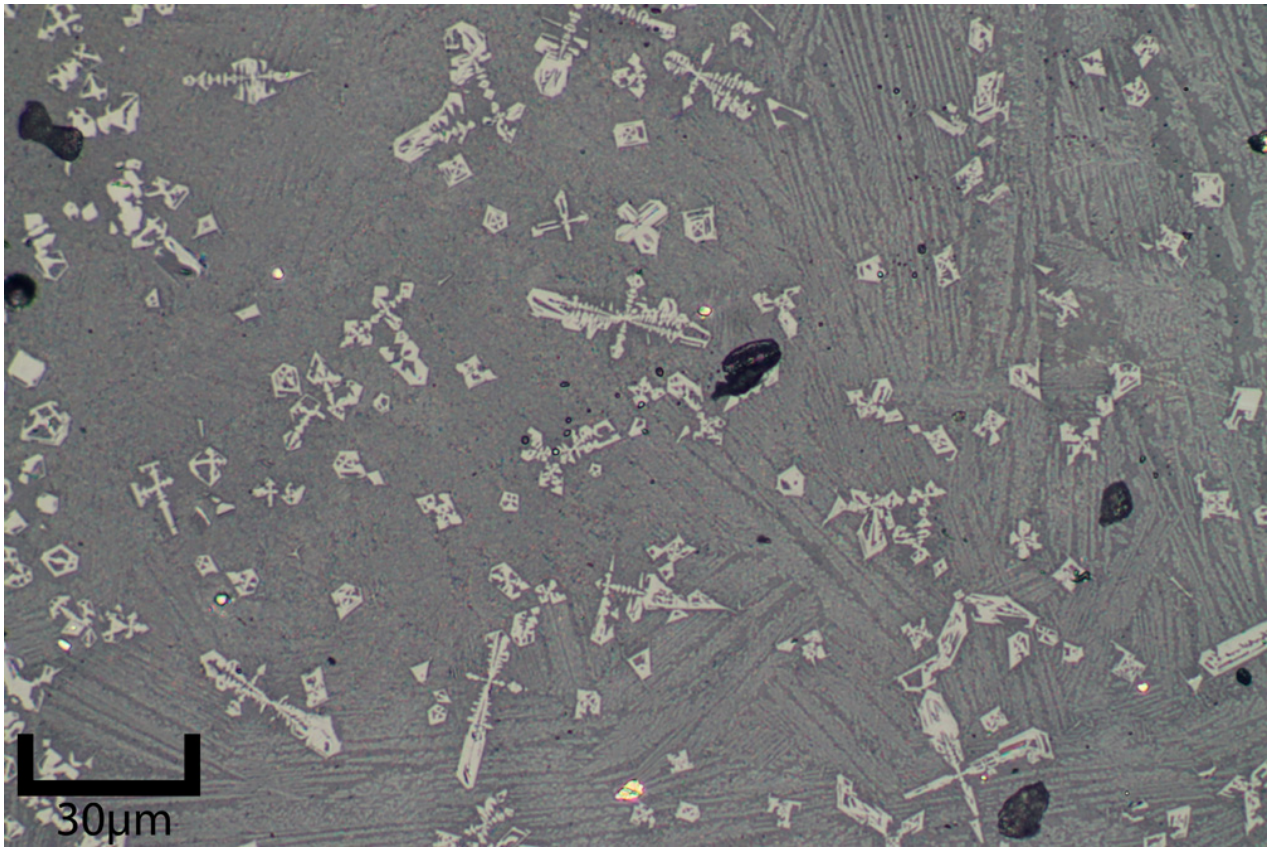
Micrograph 1



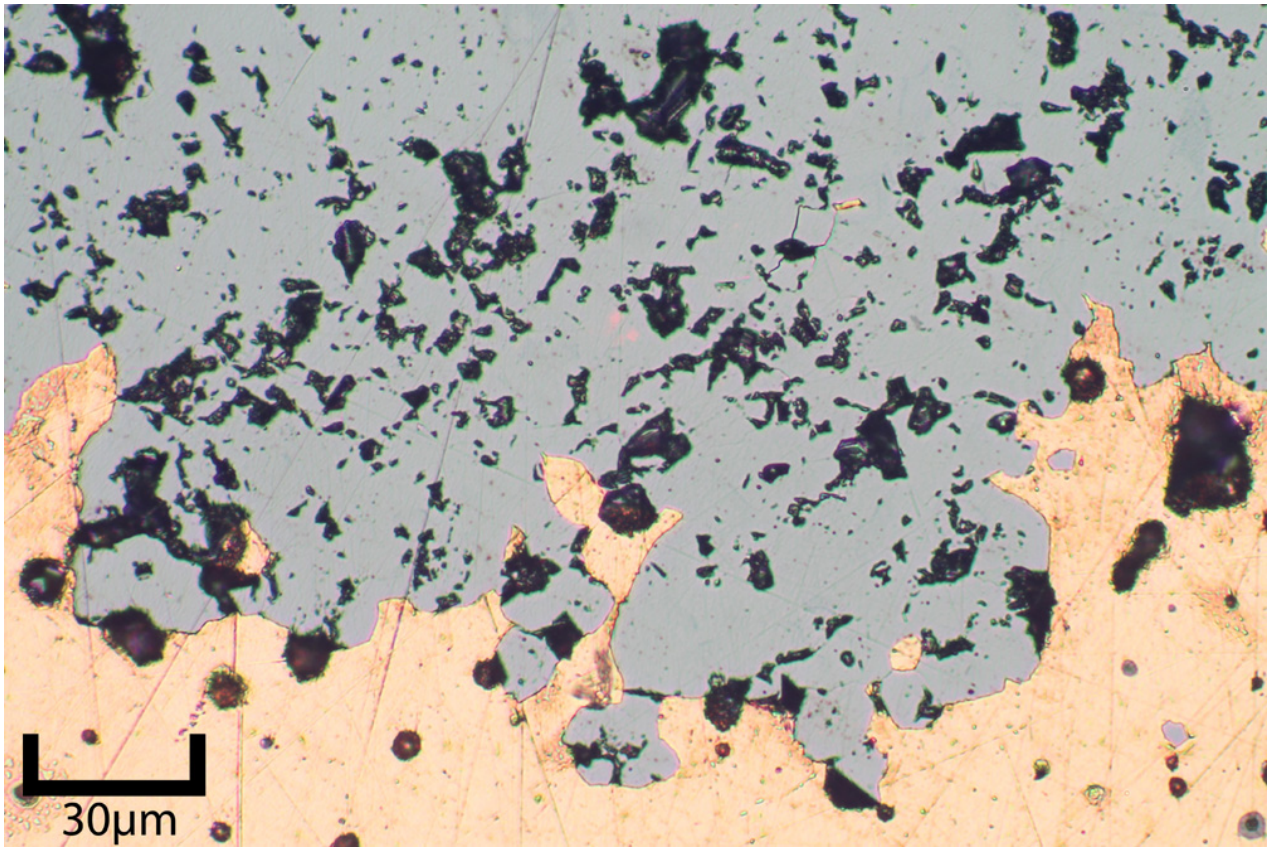
Micrograph 2



Micrograph 3



Micrograph 4

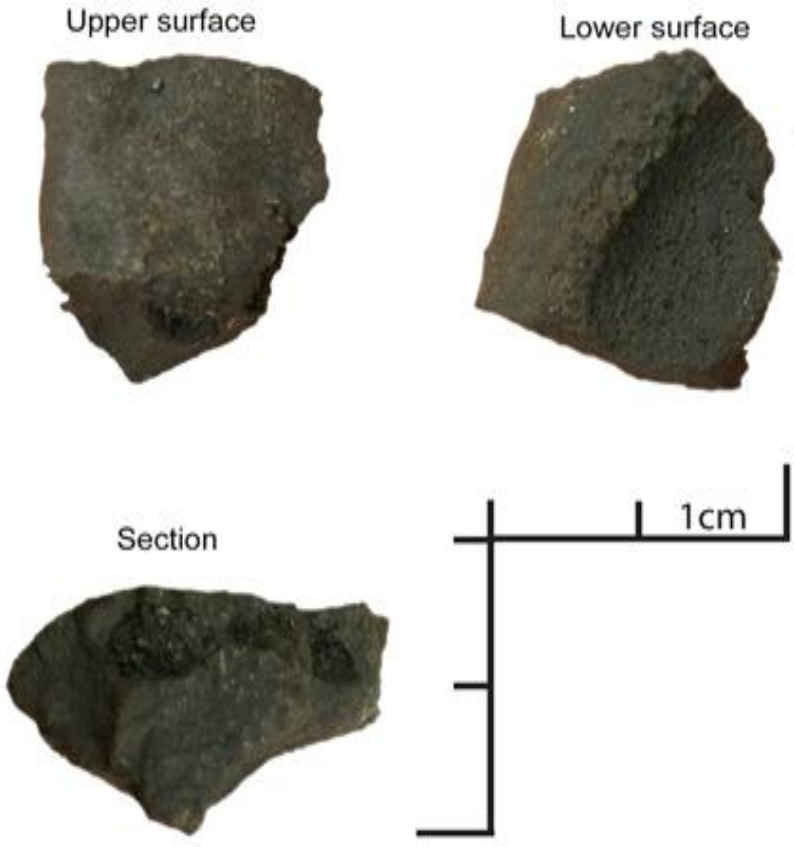


Site Code *STEP09* **Sample** *1* **Type** *Slag* **Area** *Cu TP2*

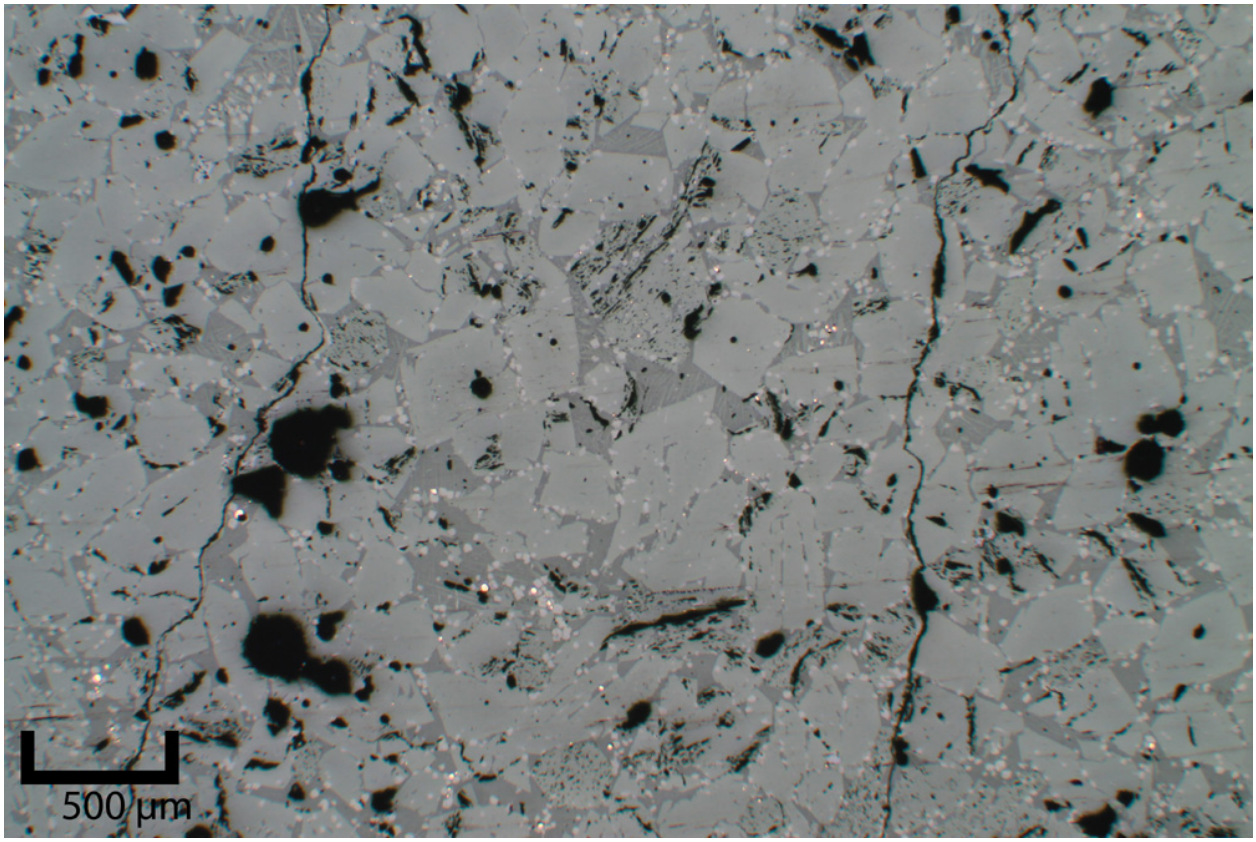
Wustite	*Rare*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Common*	
Delafossite	*Rare*	
Metallic copper	*Occasional*	
Sulphides		
Euheadral fayalite	*Common*	
Matrix	*Glassy 25-50%*	
Additional Phases		

Chromite ***Present*** **Group** *D2*

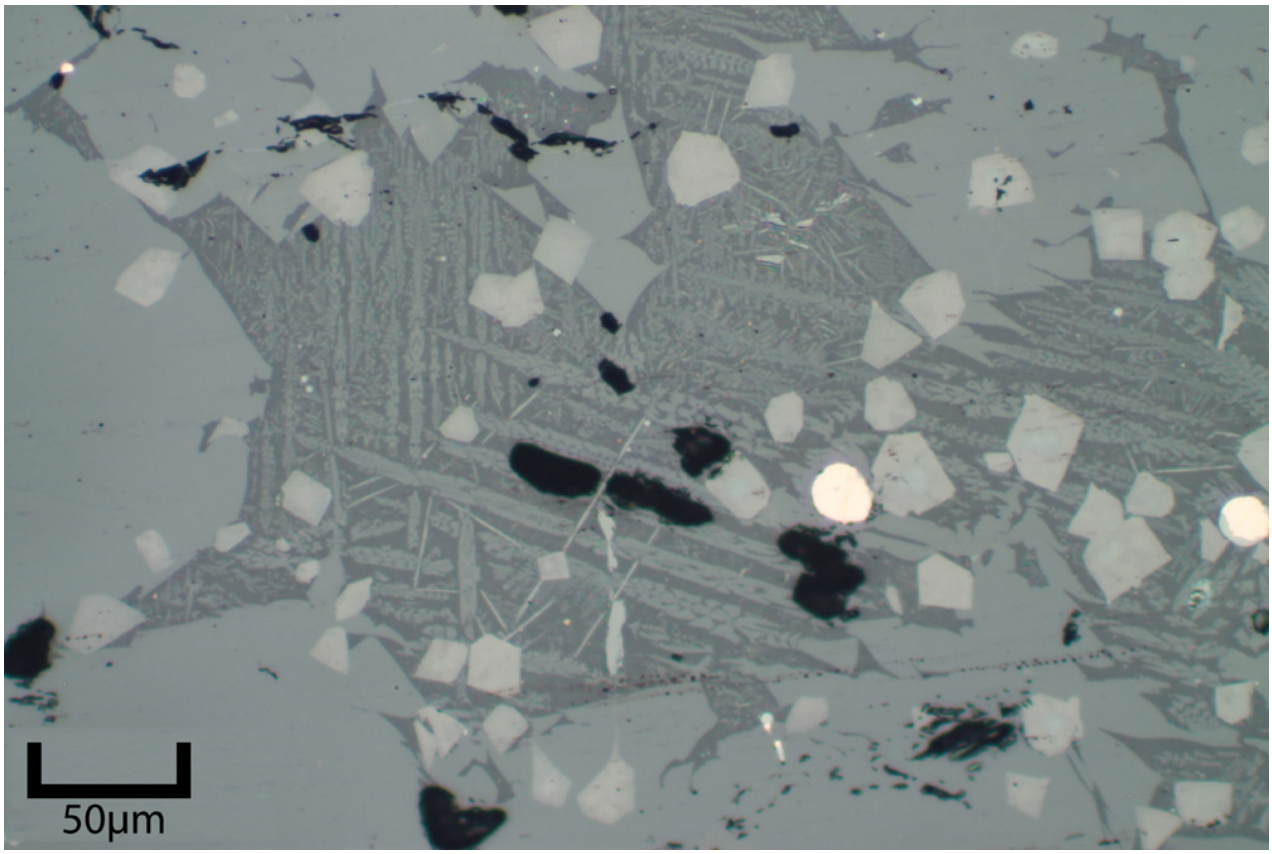
Hand Specimin



Micrograph 1



Micrograph 2

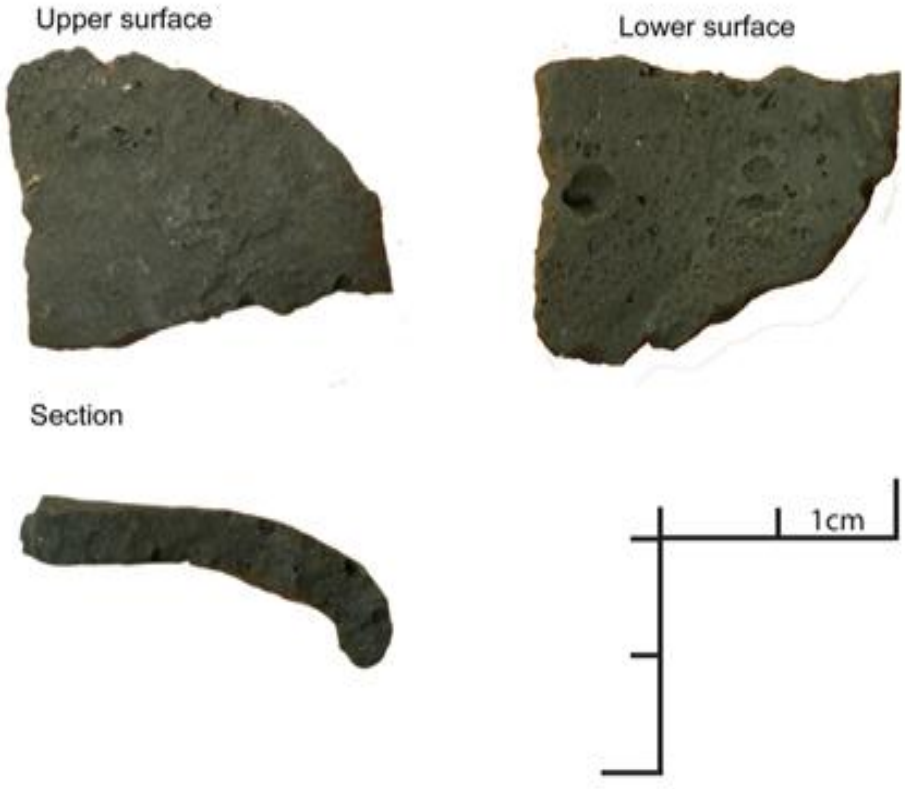


Site Code *STEP09* **Sample** *2* **Type** *Slag* **Area** *Cu TP2*

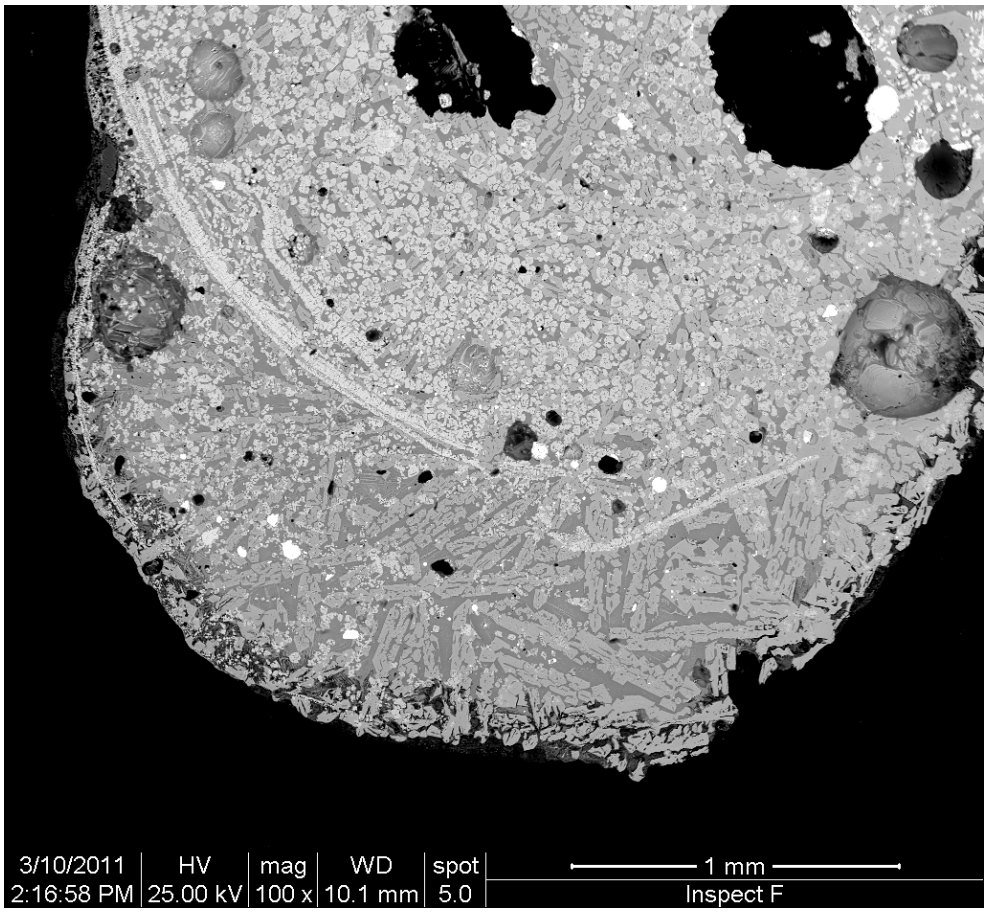
Wustite	*Common*	**Additional notes**
Magnetitie	*Occasional*	
Lath Fayalite	*Frequent*	
Delafossite		
Metallic copper	*Occasional*	
Sulphides	*Rare*	
Euheadral fayalite	*Common*	
Matrix	*Glassy 25-50%*	
Additional Phases		

Chromite ***Present*** **Group** *D3*

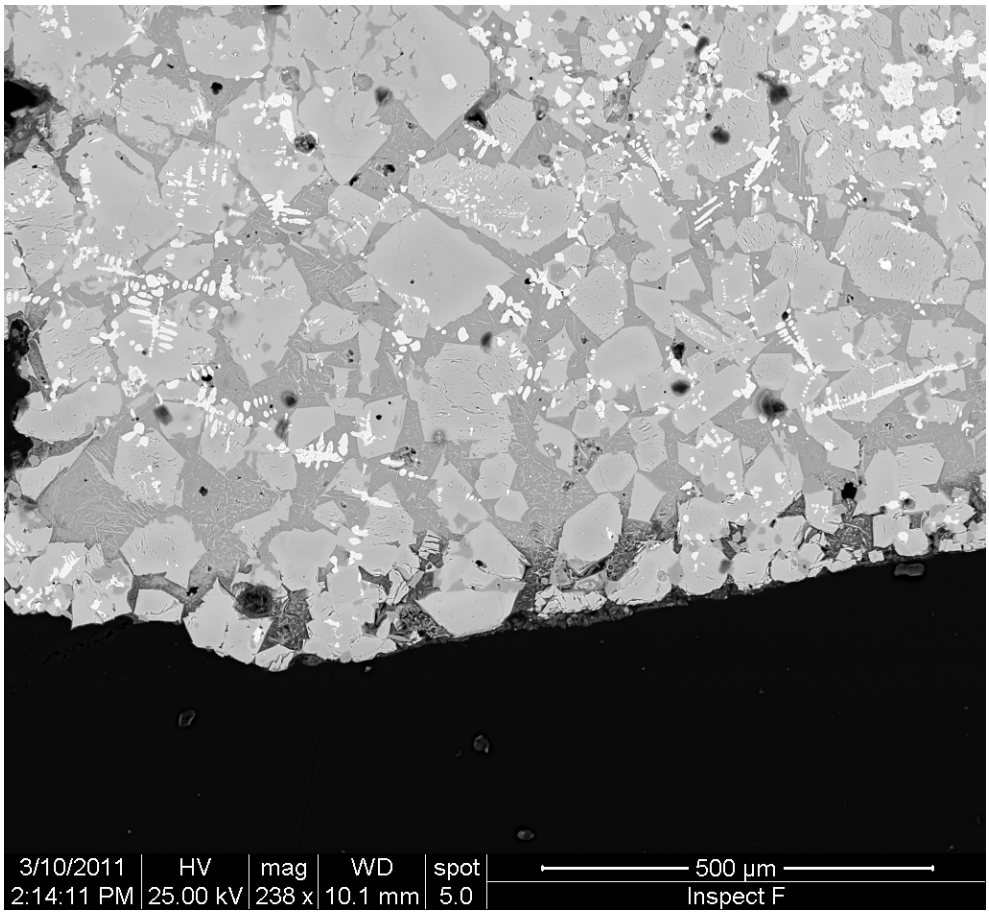
Hand Specimin



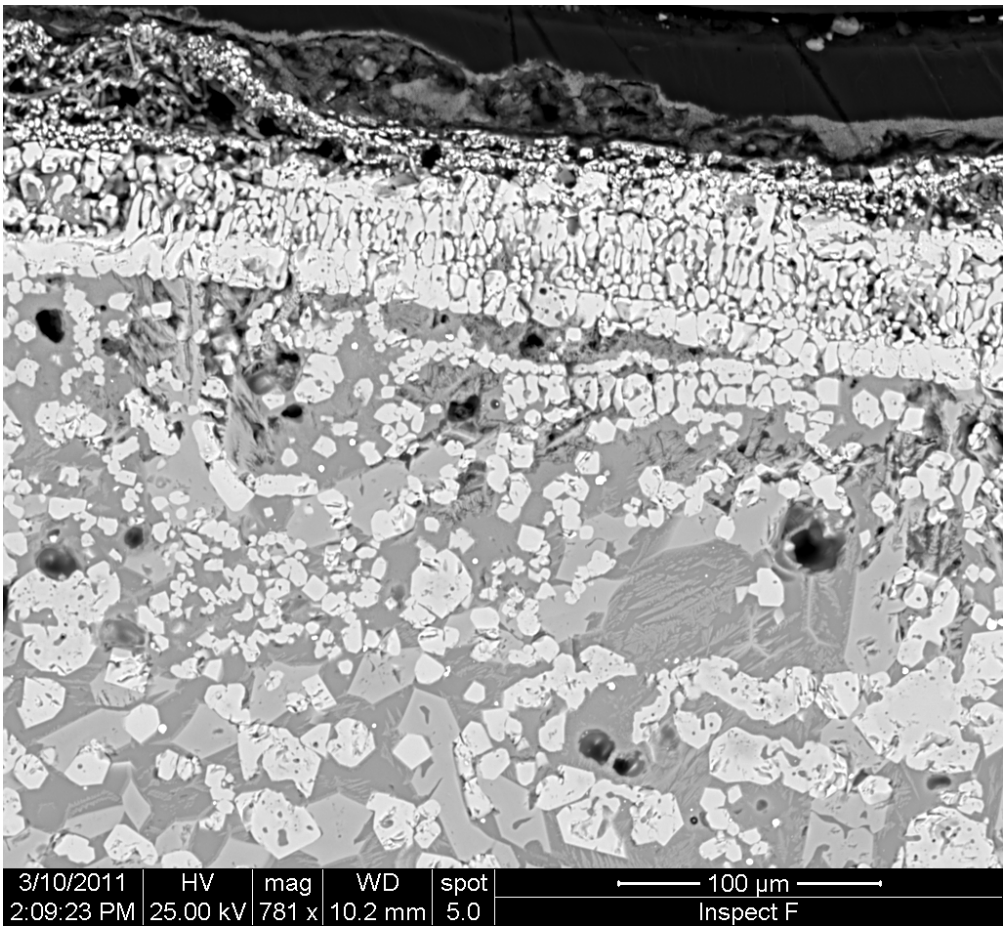
Micrograph 1



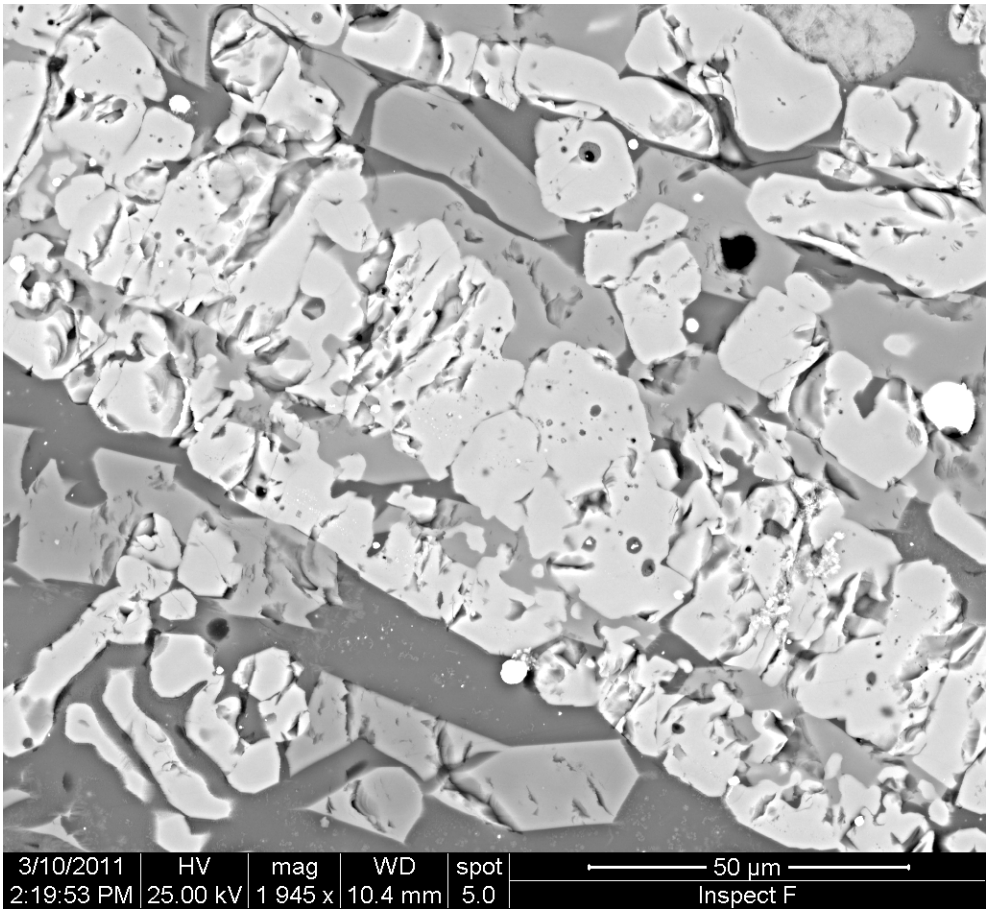
Micrograph 2



Micrograph 3



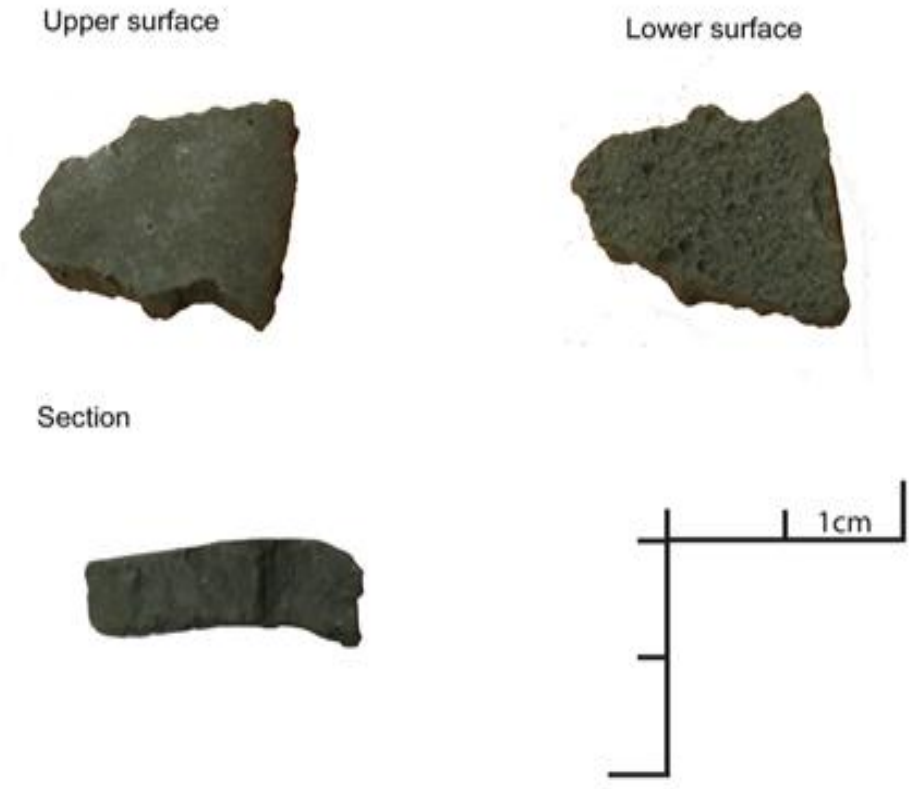
Micrograph 4



Site Code *STEP09* **Sample** *14* **Type** *Slag* **Area** *Cu TP2*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

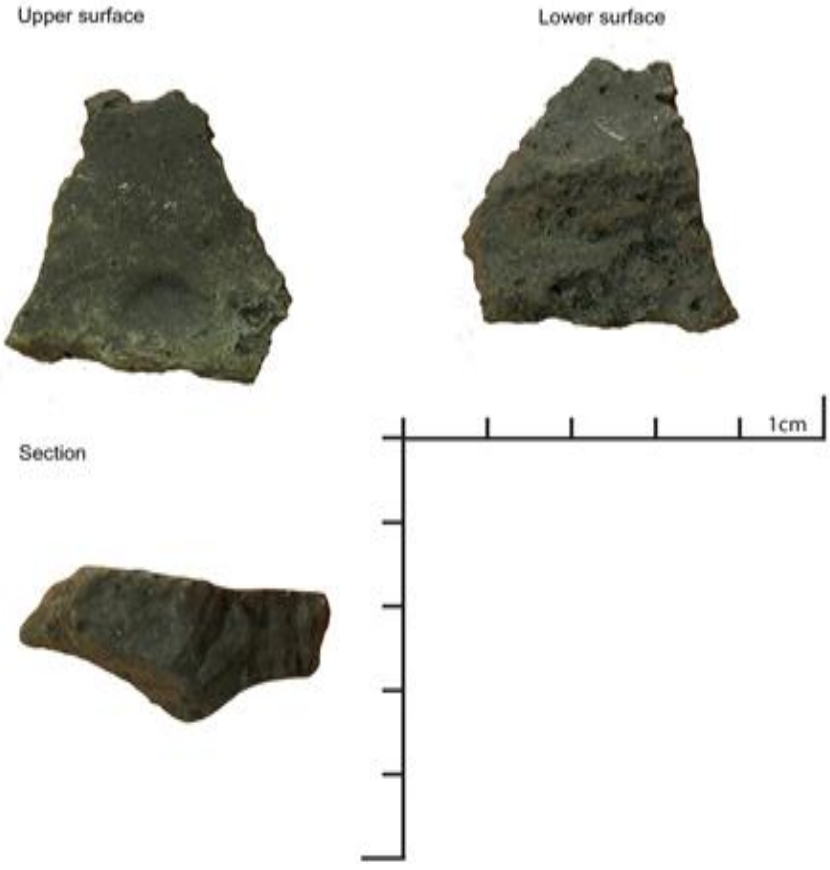


Site Code *STEP09* **Sample** *22* **Type** *Slag* **Area** *Cu TP2*

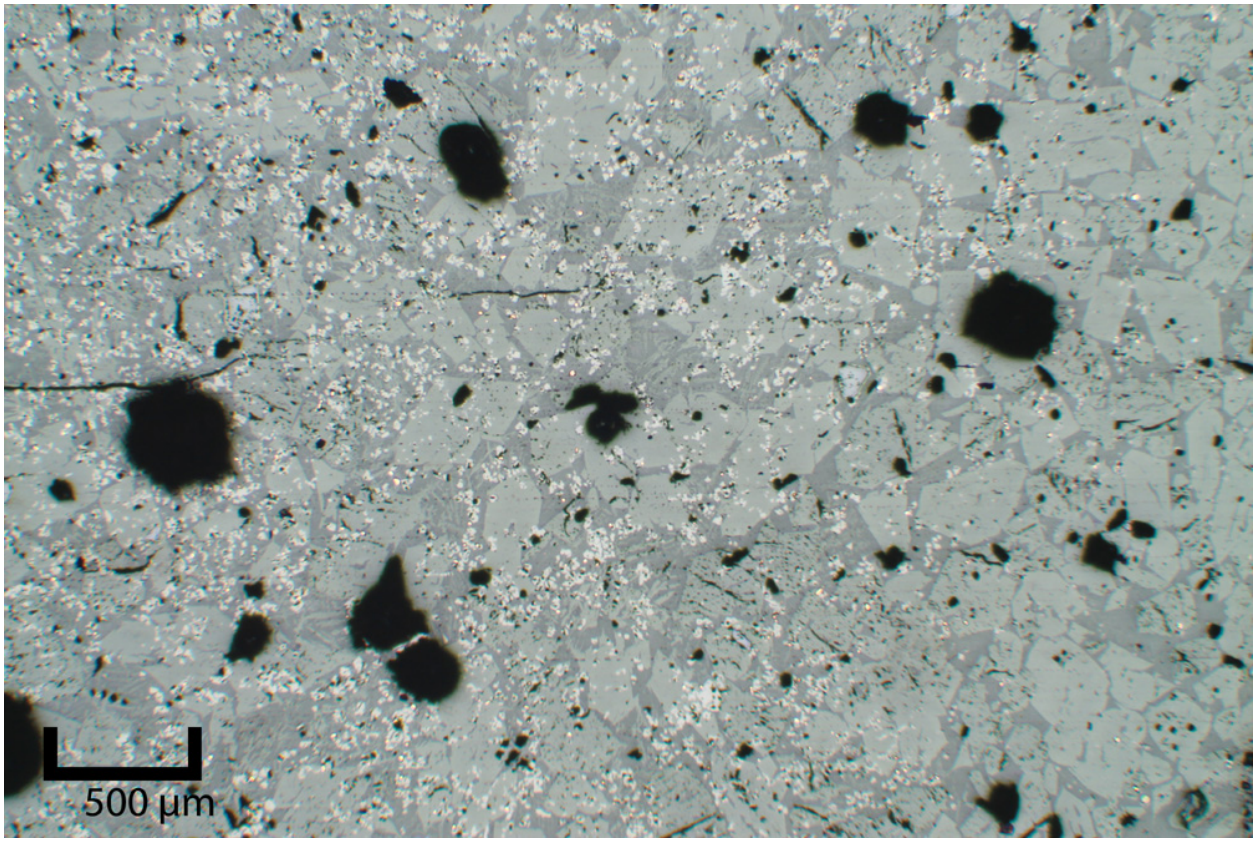
Wustite	*Rare*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Occasional*	
Delafossite		
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite		
Matrix	*Glassy 25-50%*	
Additional Phases	*rare chromites, frequent tabular silicate*	

Chromite ***Present*** **Group** *D3*

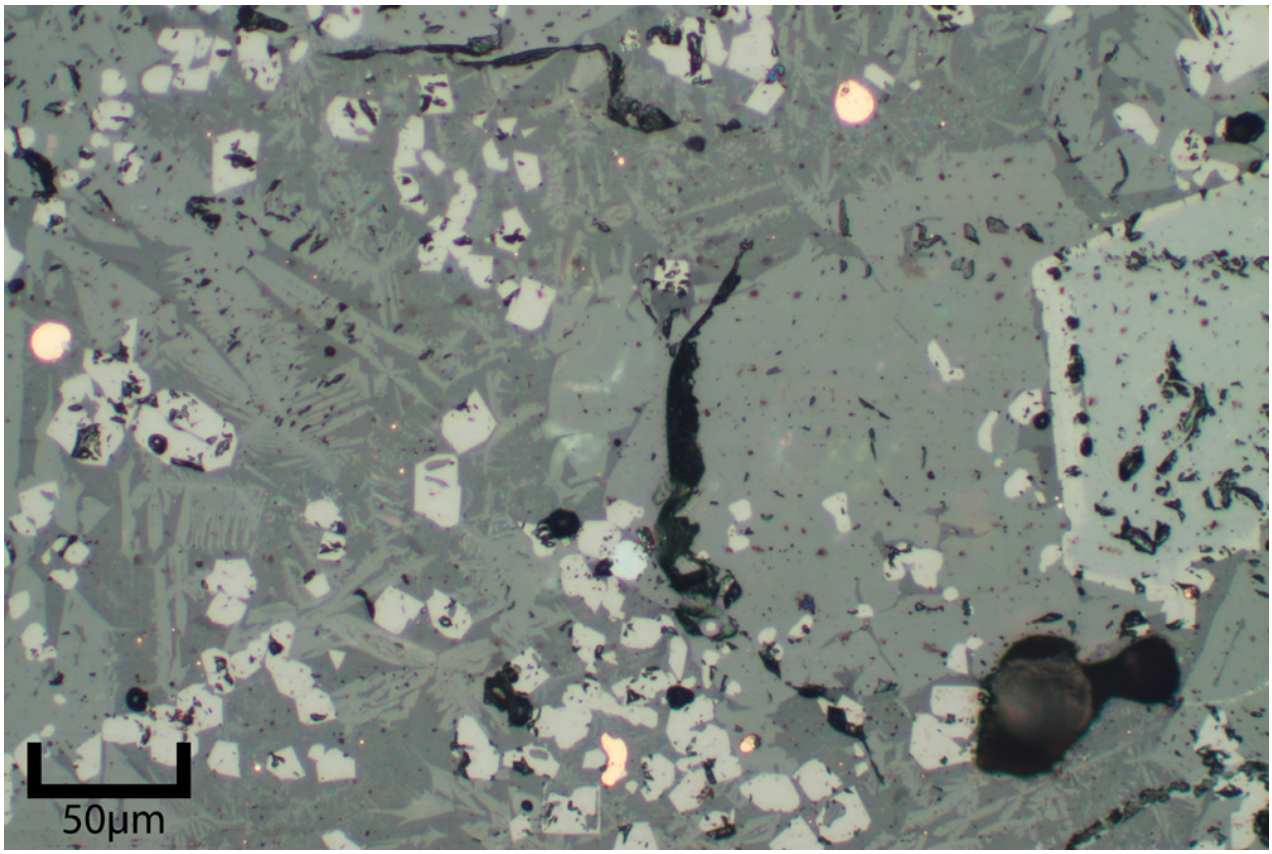
Hand Specimin



Micrograph 1



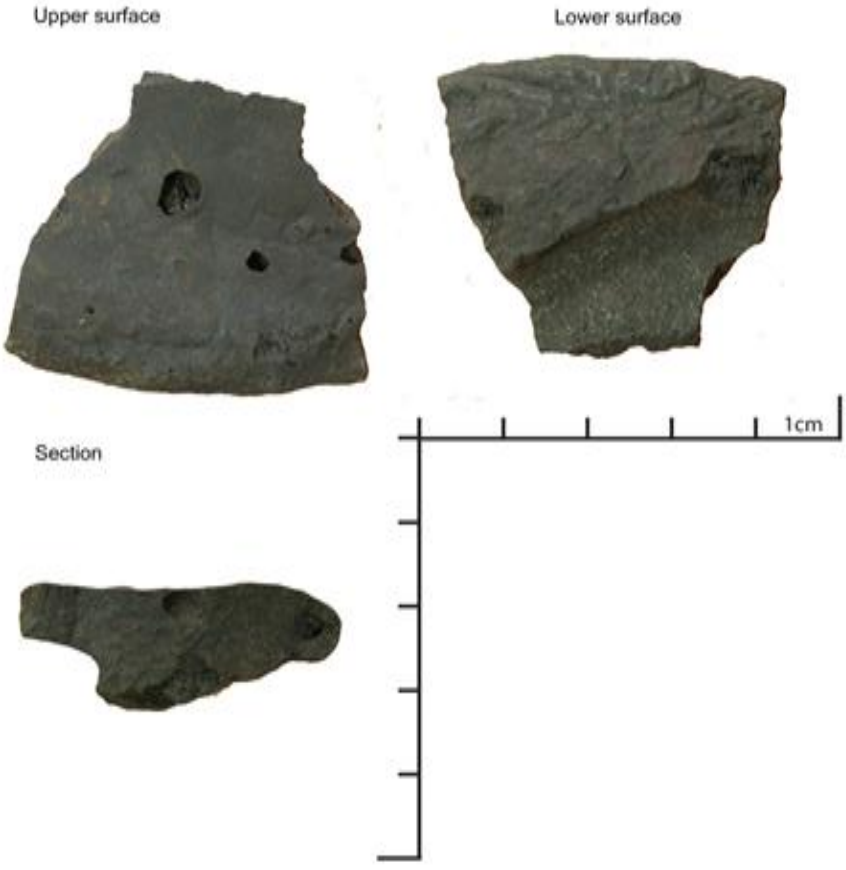
Micrograph 2



Site Code *STEP09* **Sample** *21* **Type** *Slag* **Area** *Cu TP2*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

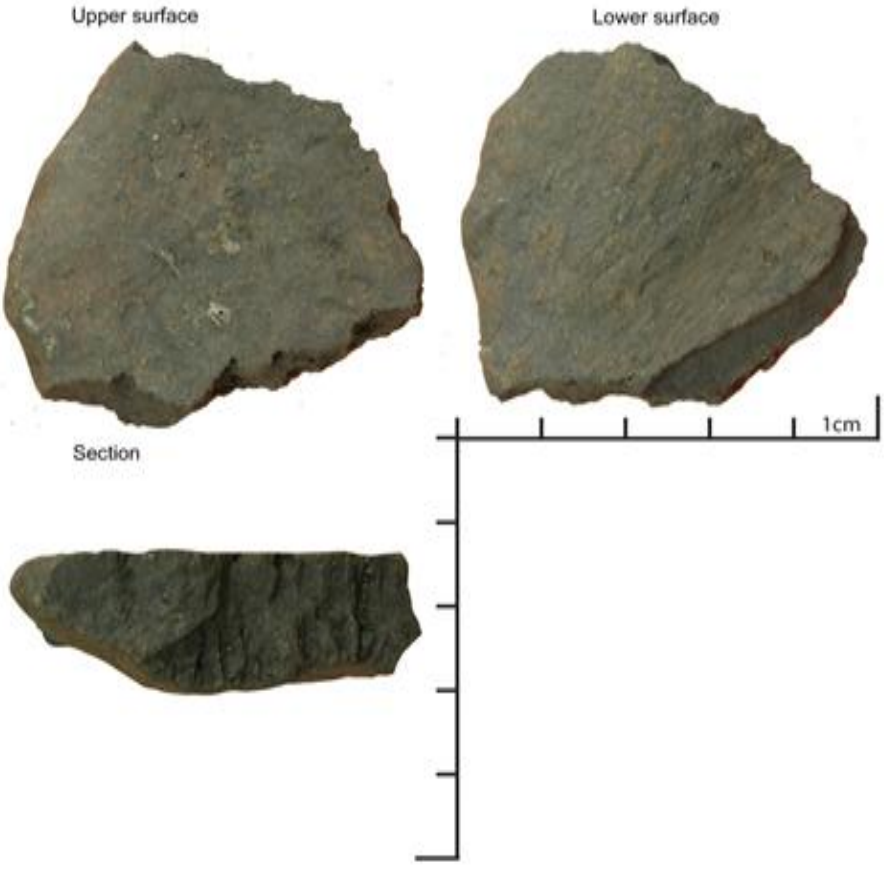


Site Code *STEP09* **Sample** *23* **Type** *Slag* **Area** *Cu TP2*

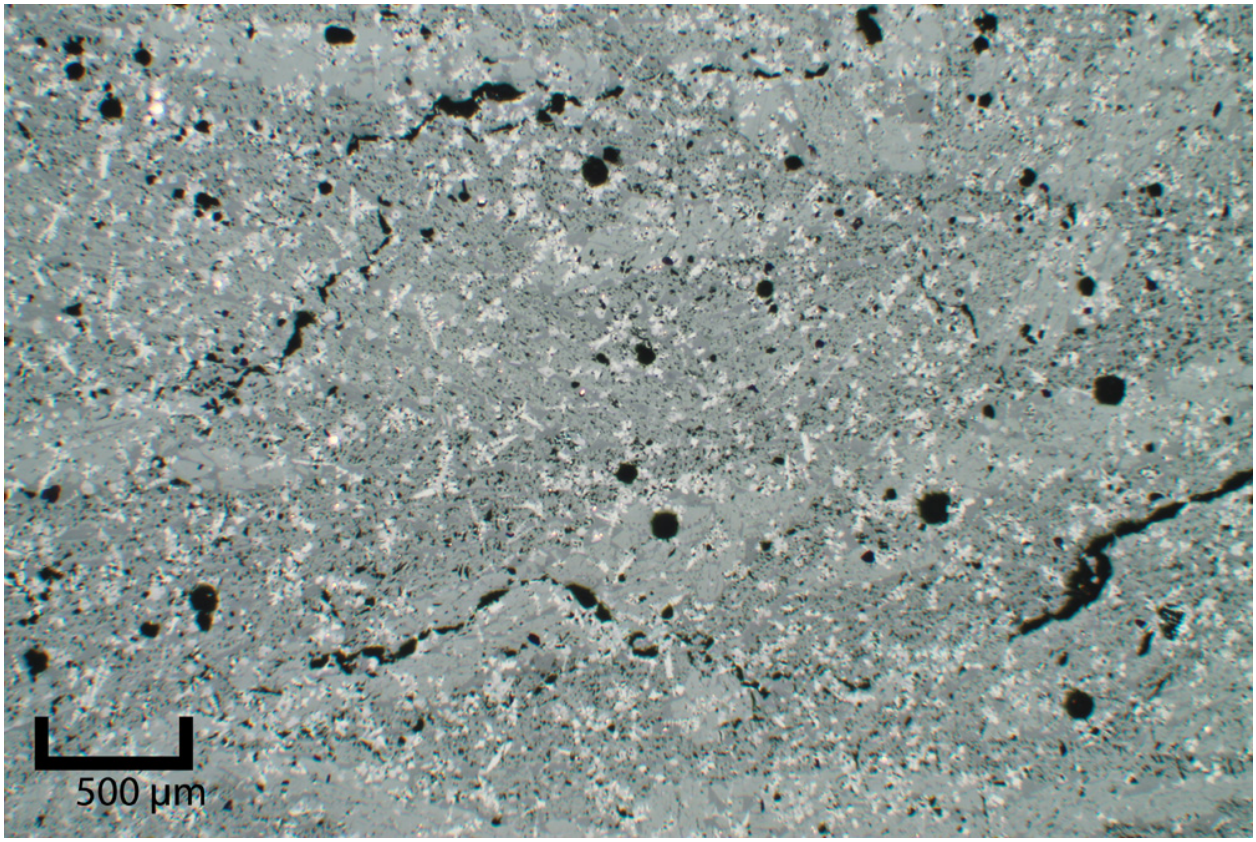
Wustite	*Common*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Frequent*	
Delafossite		
Metallic copper	*Rare*	
Sulphides	*Rare*	
Euheadral fayalite	*Common*	
Matrix	*Glassy 10-25%*	
Additional Phases		

Chromite ***Present*** **Group** *D3*

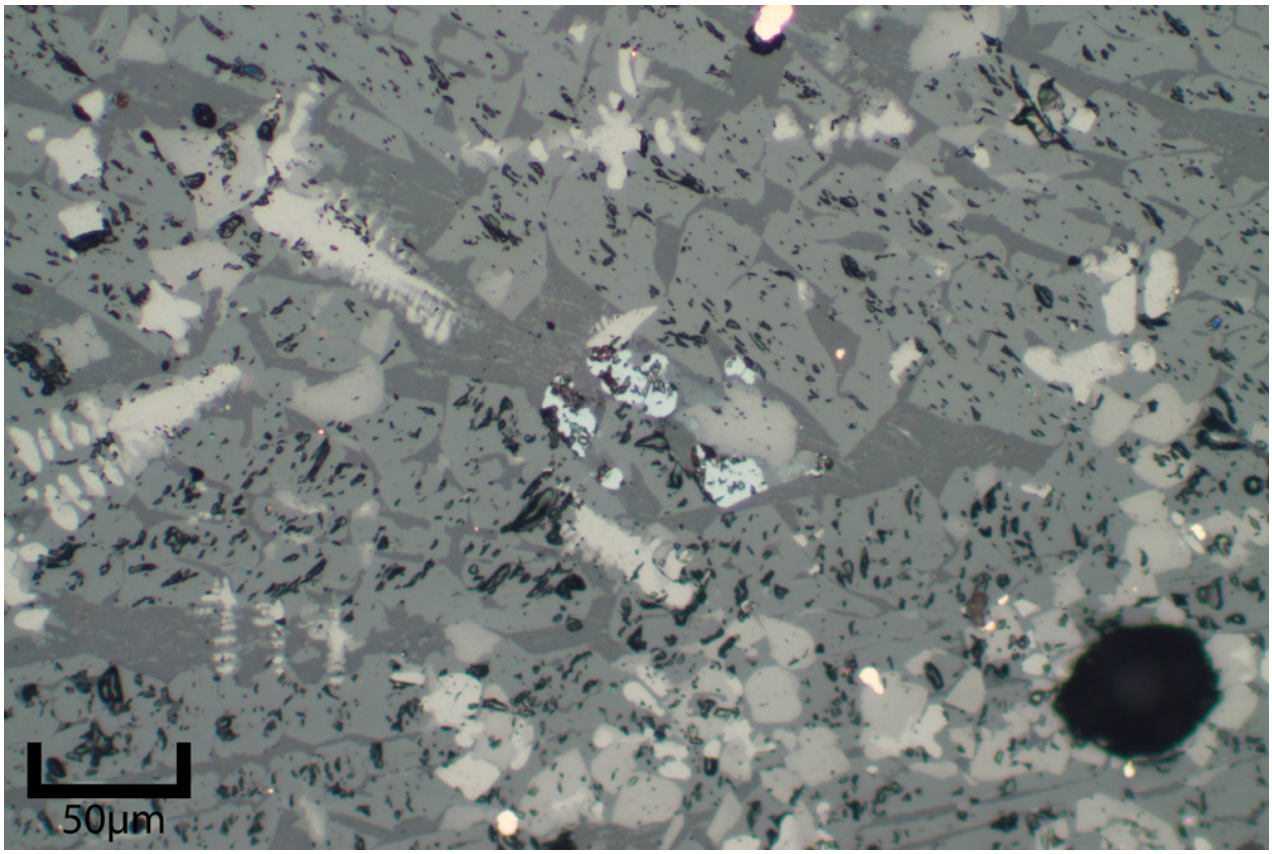
Hand Specimin



Micrograph 1



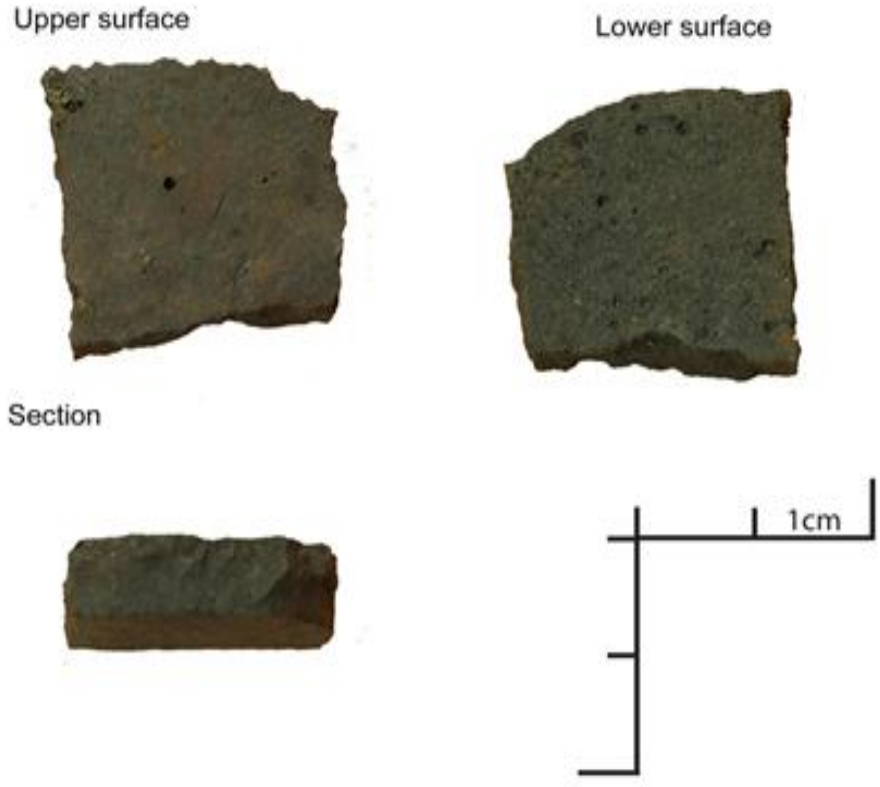
Micrograph 2



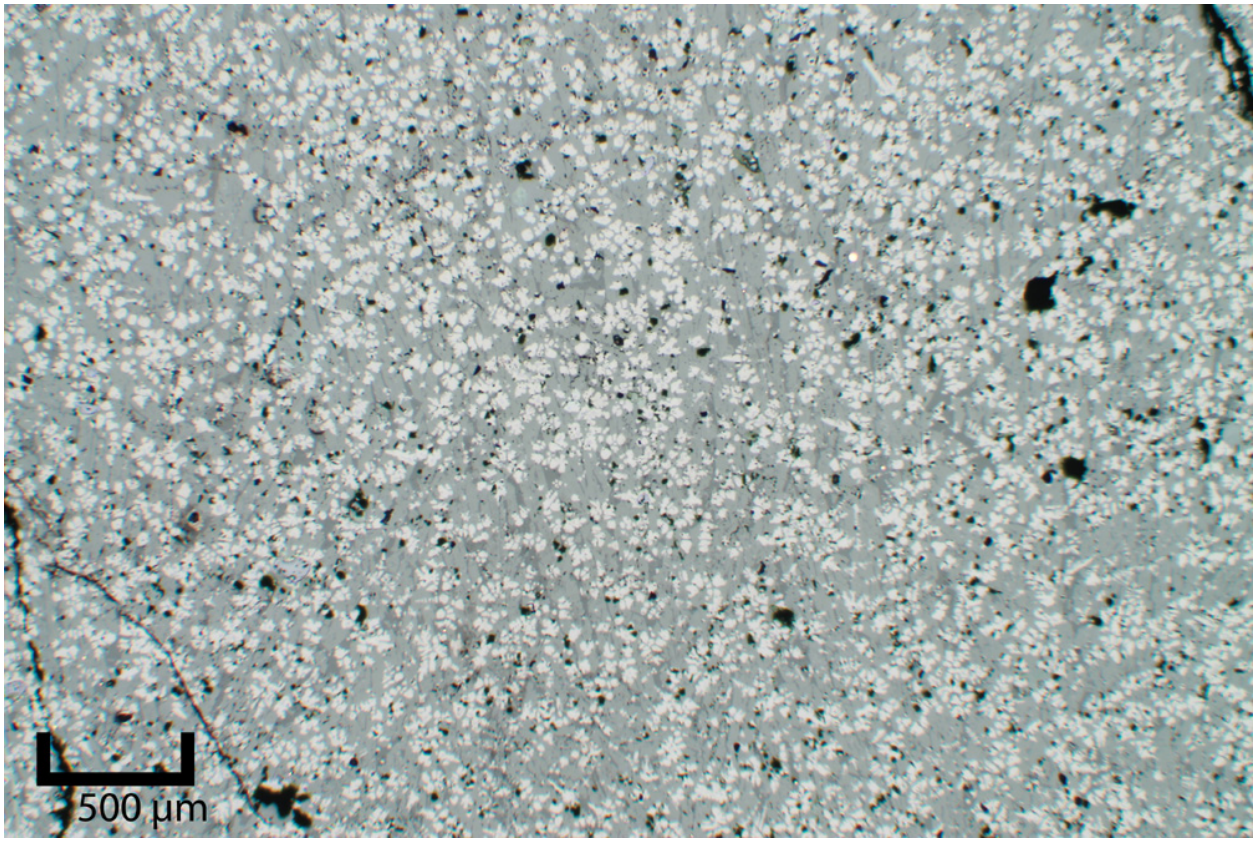
Site Code *STEP09* **Sample** *32* **Type** *Slag* **Area** *Cu TP2*

Wustite	*Frequent*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Common*	
Delafossite		
Metallic copper		
Sulphides	*Rare*	
Euheadral fayalite	*Absent*	
Matrix	*Glassy 10-25%*	
Additional Phases		
Chromite	***Present***	**Group** *A3*

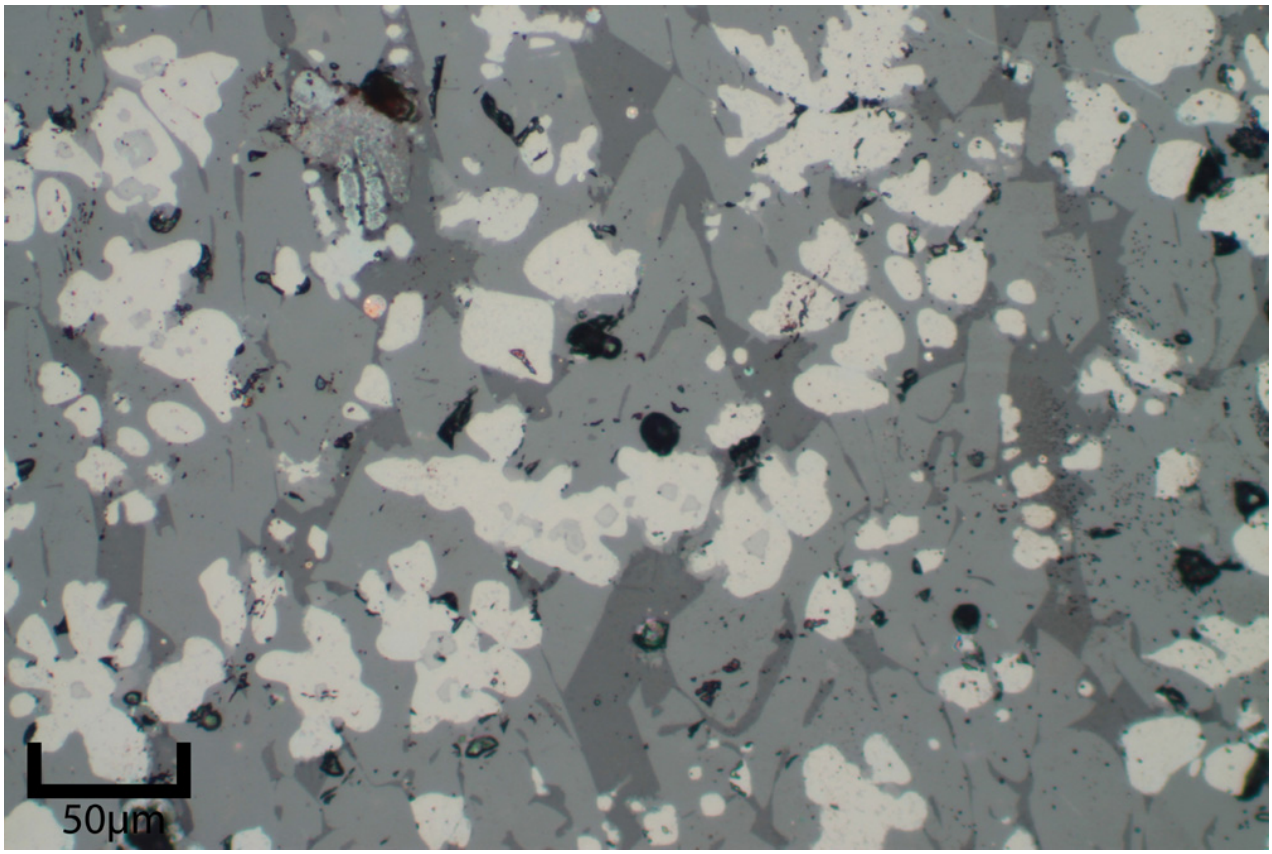
Hand Specimin



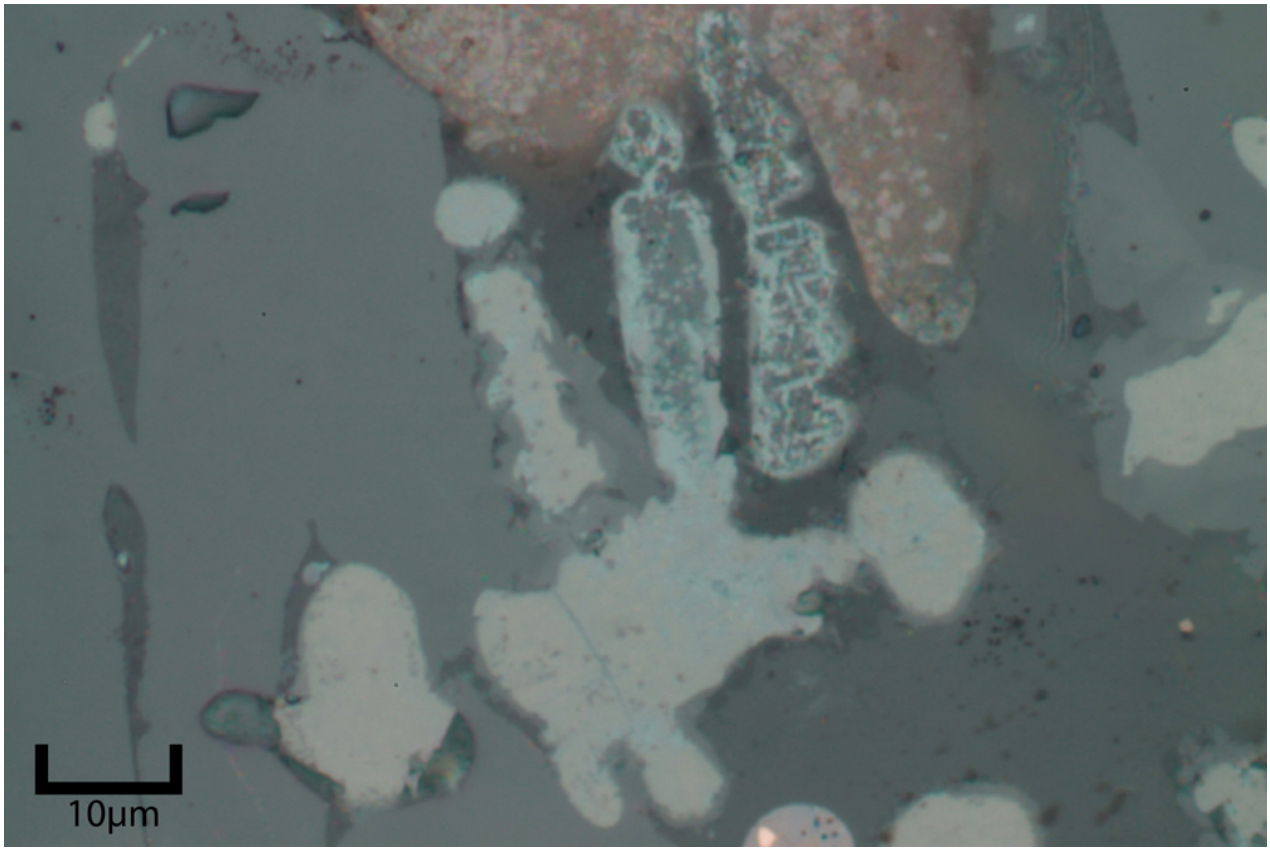
Micrograph 1



Micrograph 2



Micrograph 3



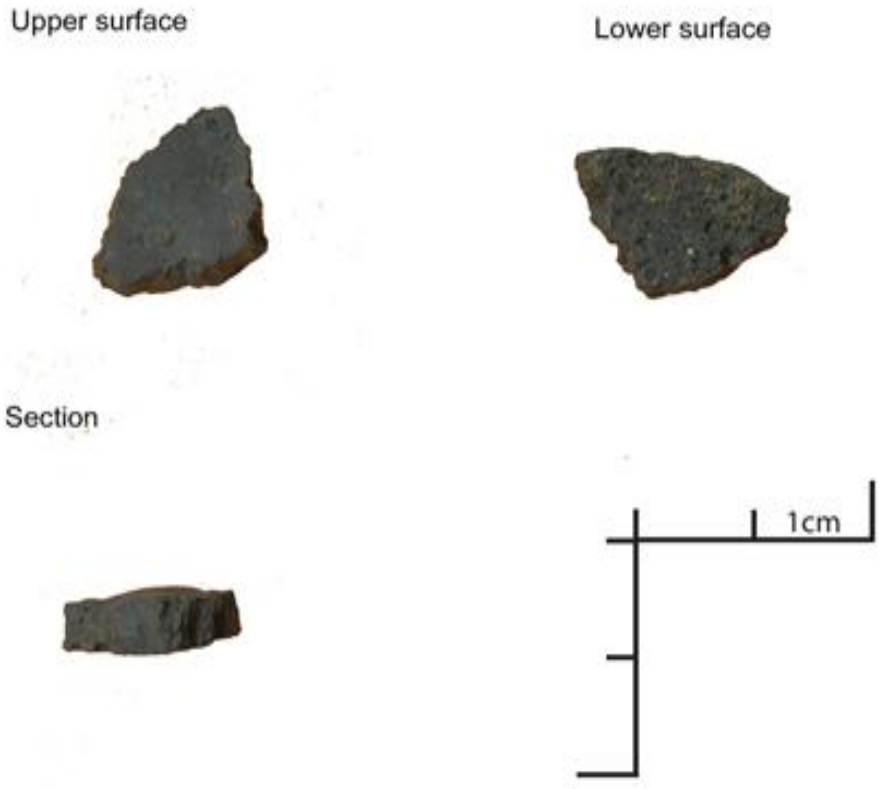
Micrograph 4

Site Code *STEP09* **Sample** *57* **Type** *Slag* **Area** *Cu TP2*

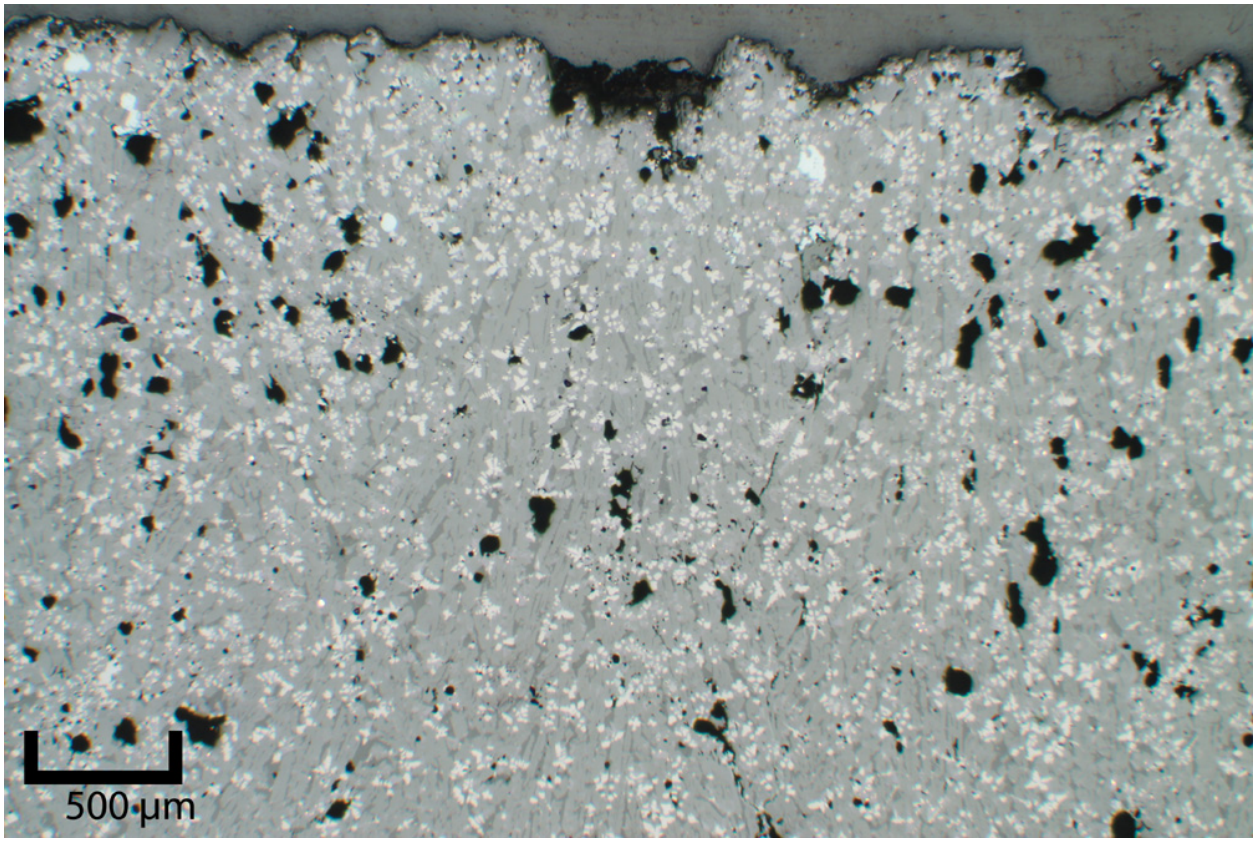
Wustite	*Common*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Dominant*	
Delafossite	*Absent*	
Metallic copper	*Absent*	
Sulphides	*Rare*	
Euheadral fayalite	*Absent*	
Matrix	*Glassy 0-10%*	
Additional Phases		

Chromite ***Present*** **Group** *A3*

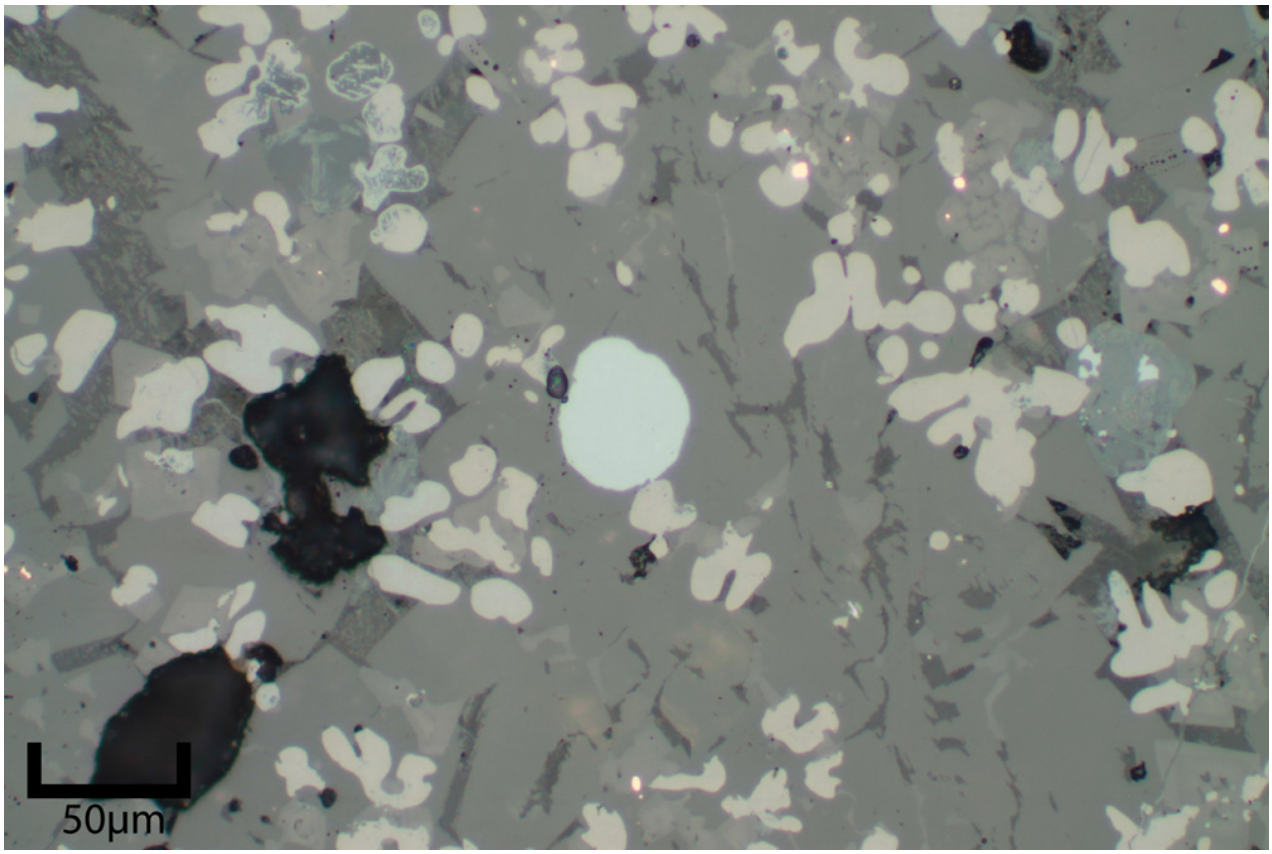
Hand Specimin



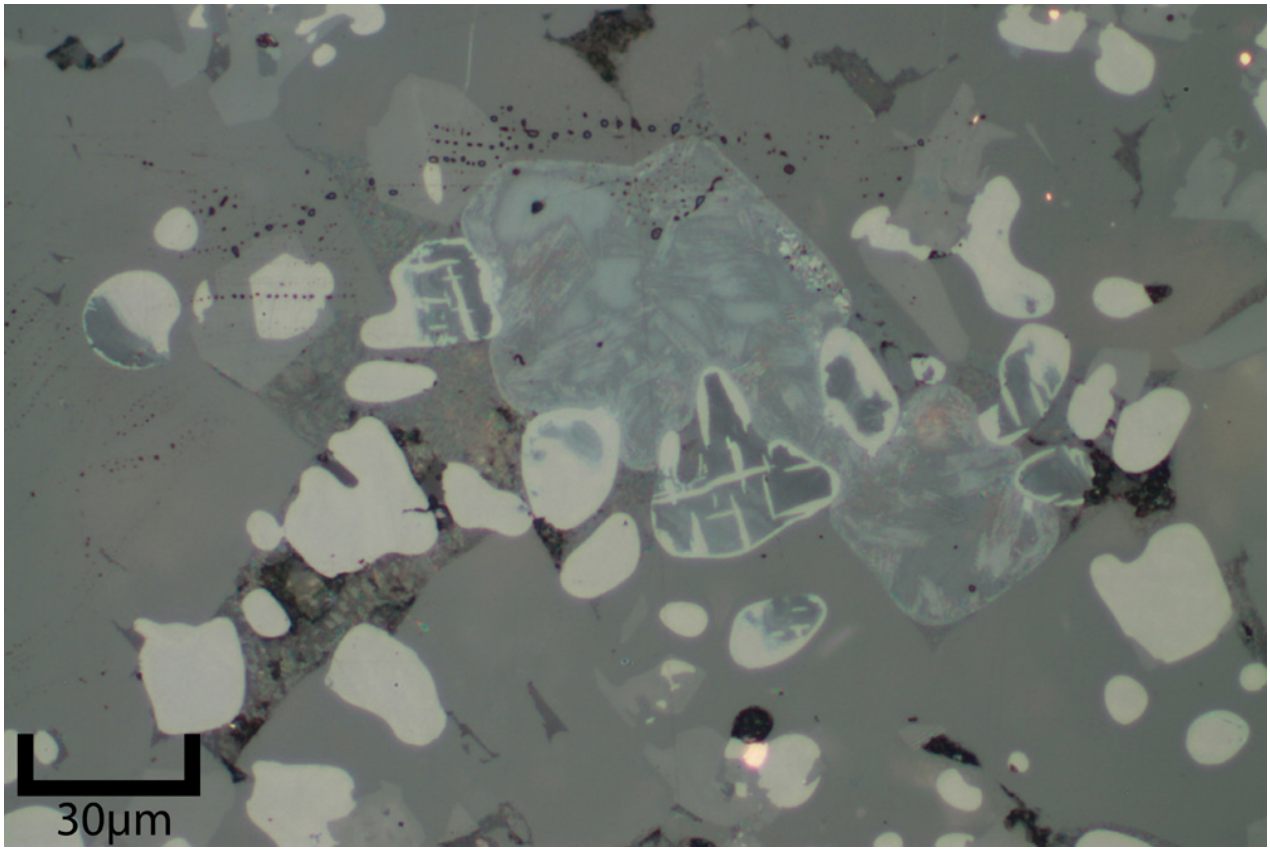
Micrograph 1



Micrograph 2



Micrograph 3

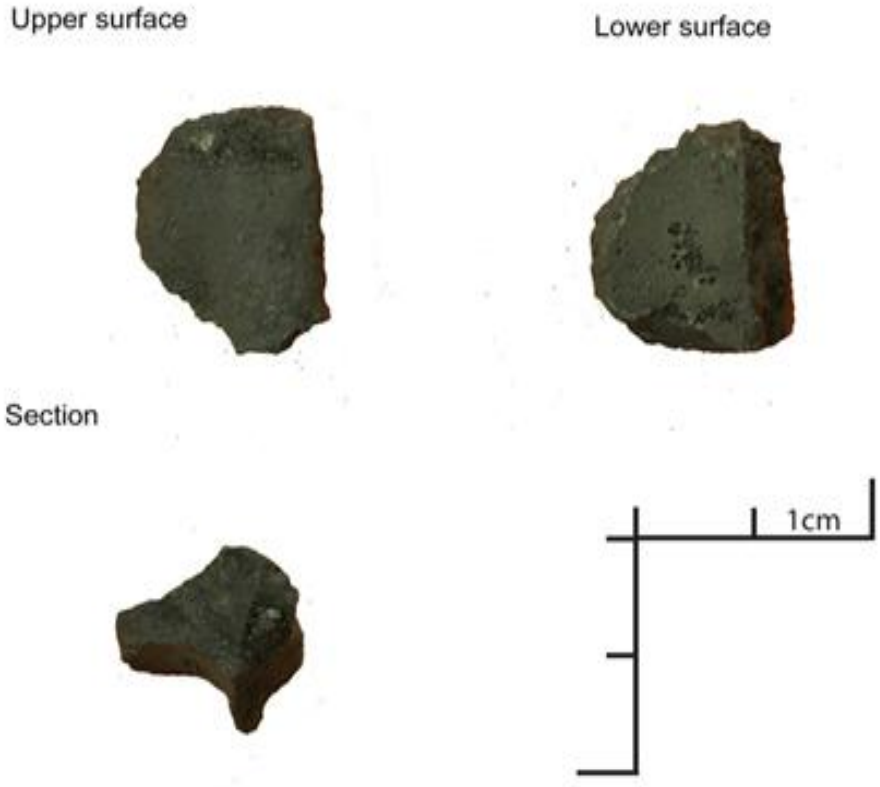


Micrograph 4

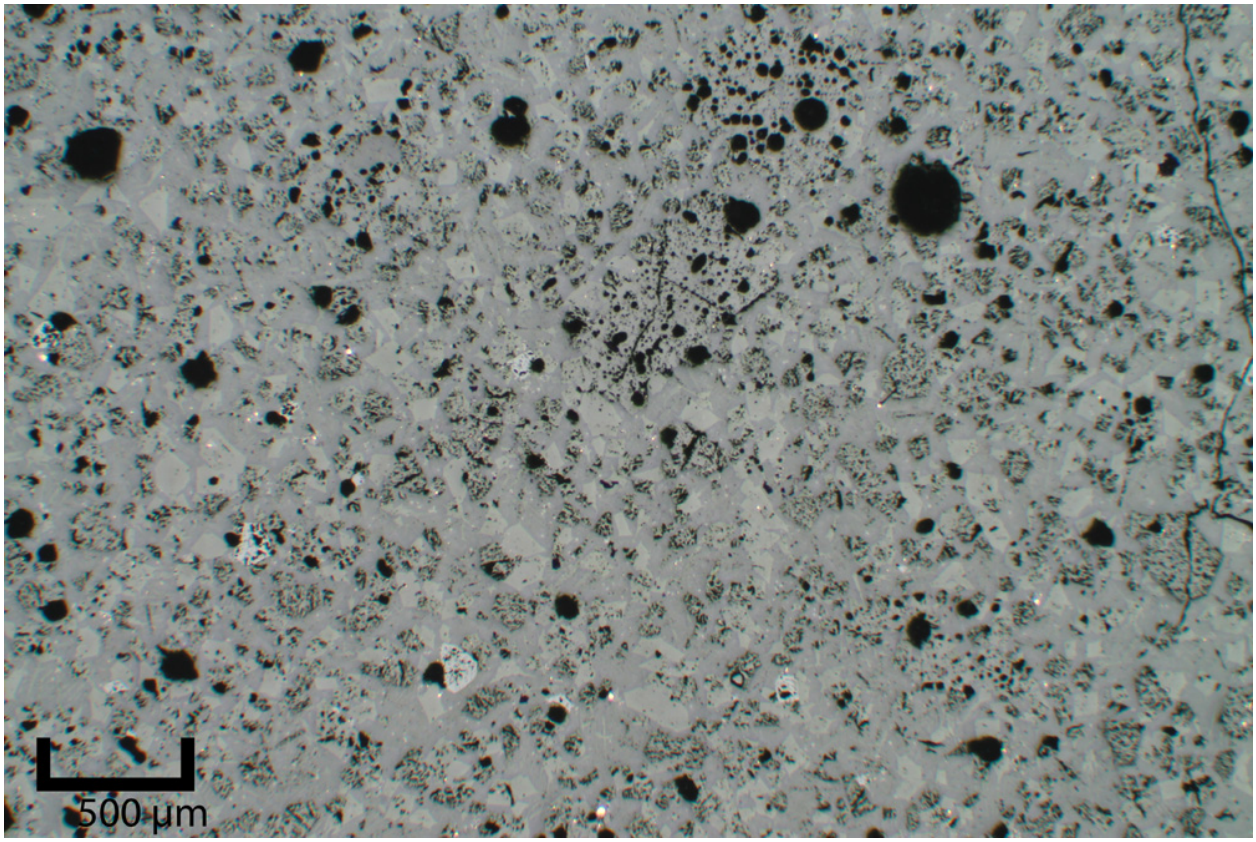
Site Code *STEP09* **Sample** *64* **Type** *Slag* **Area** *Cu TP2*

Wustite	*Absent*	**Additional notes**
Magnetitie	*Absent*	
Lath Fayalite	*Occasional*	
Delafossite		
Metallic copper	*Rare*	
Sulphides	*Rare*	
Euheadral fayalite	*Common*	
Matrix		
Additional Phases		
Chromite	***Present***	**Group** *D1*

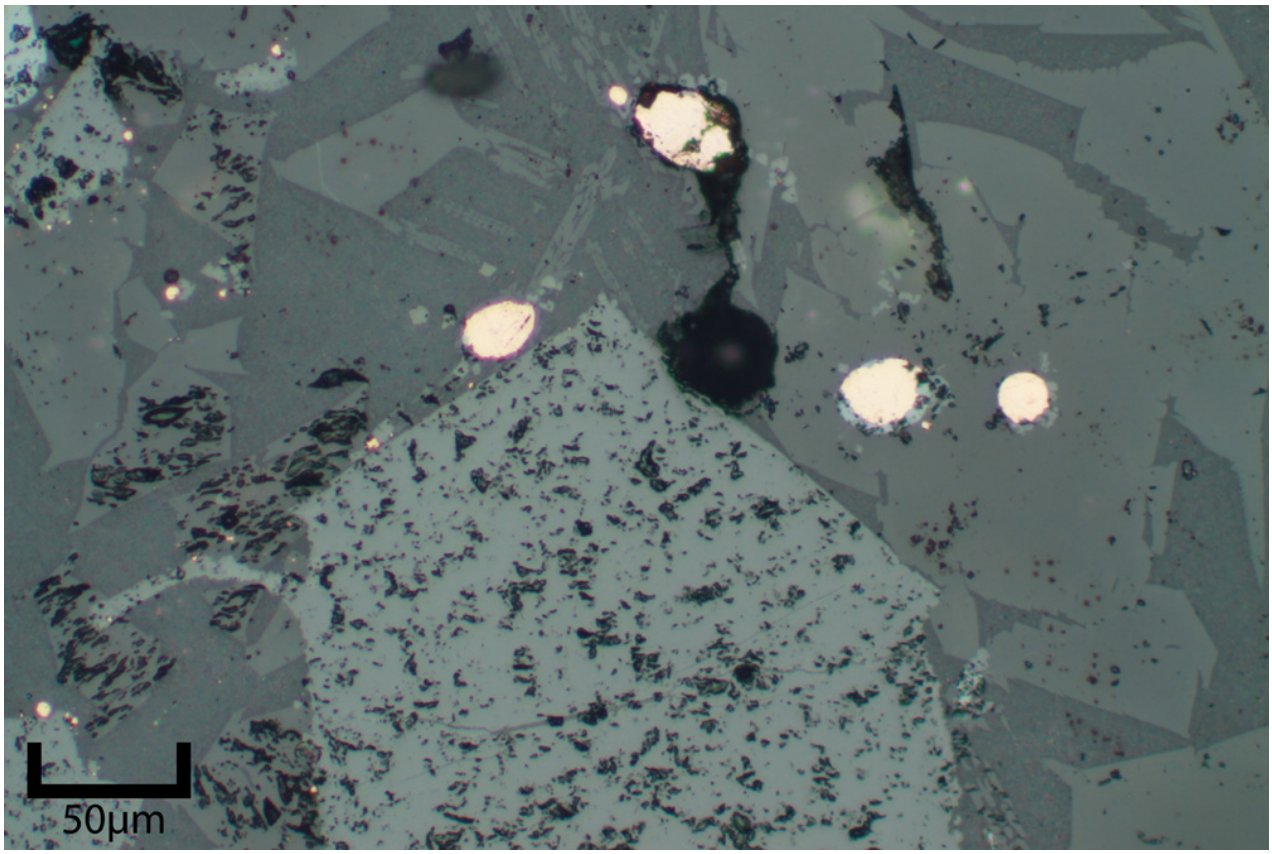
Hand Specimin



Micrograph 1



Micrograph 2

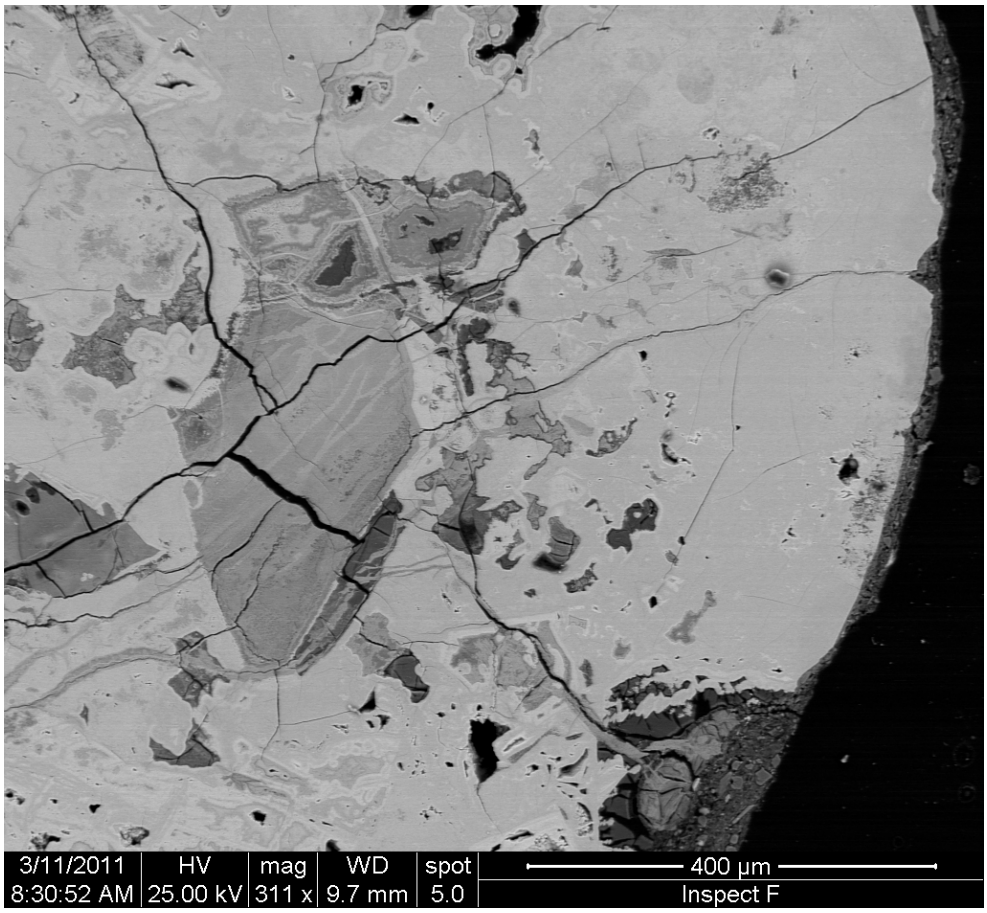


Site Code	*STEP09*	Sample	*83*	Type	*Ore*	Area	*Cu TP2*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

Micrograph 1

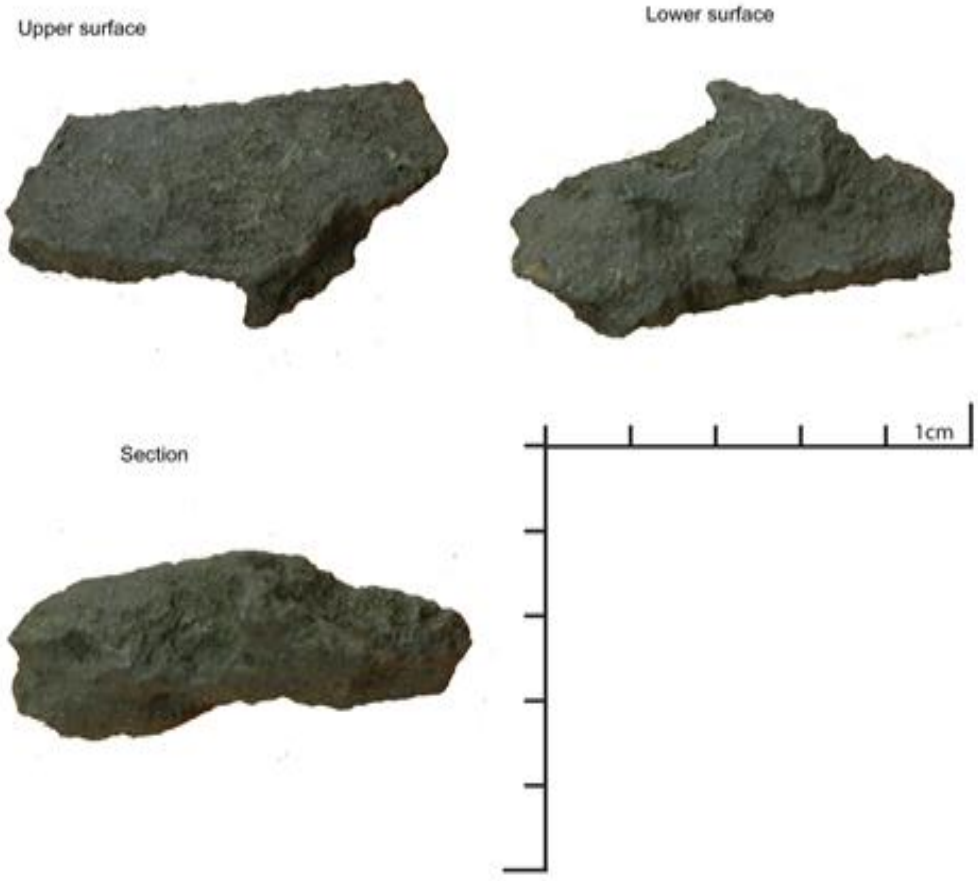


Micrograph 2

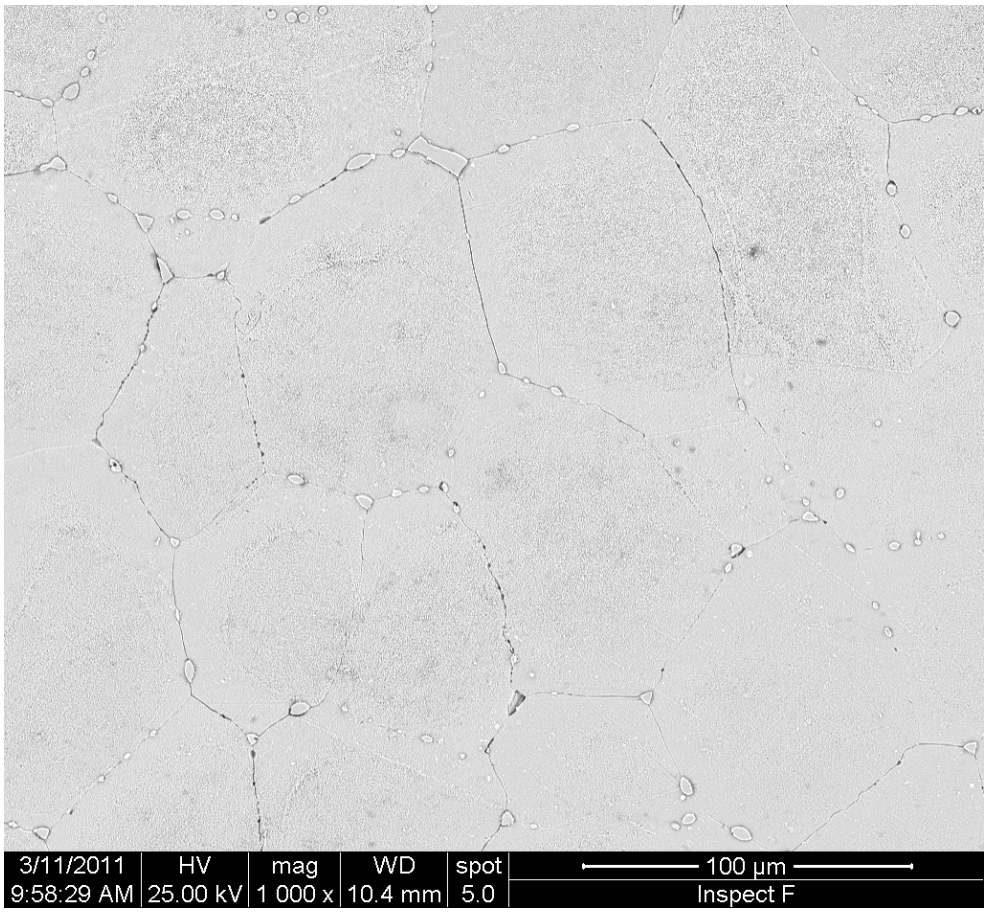
Site Code *STEP09* **Sample** *89* **Type** *Ingot* **Area** *Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

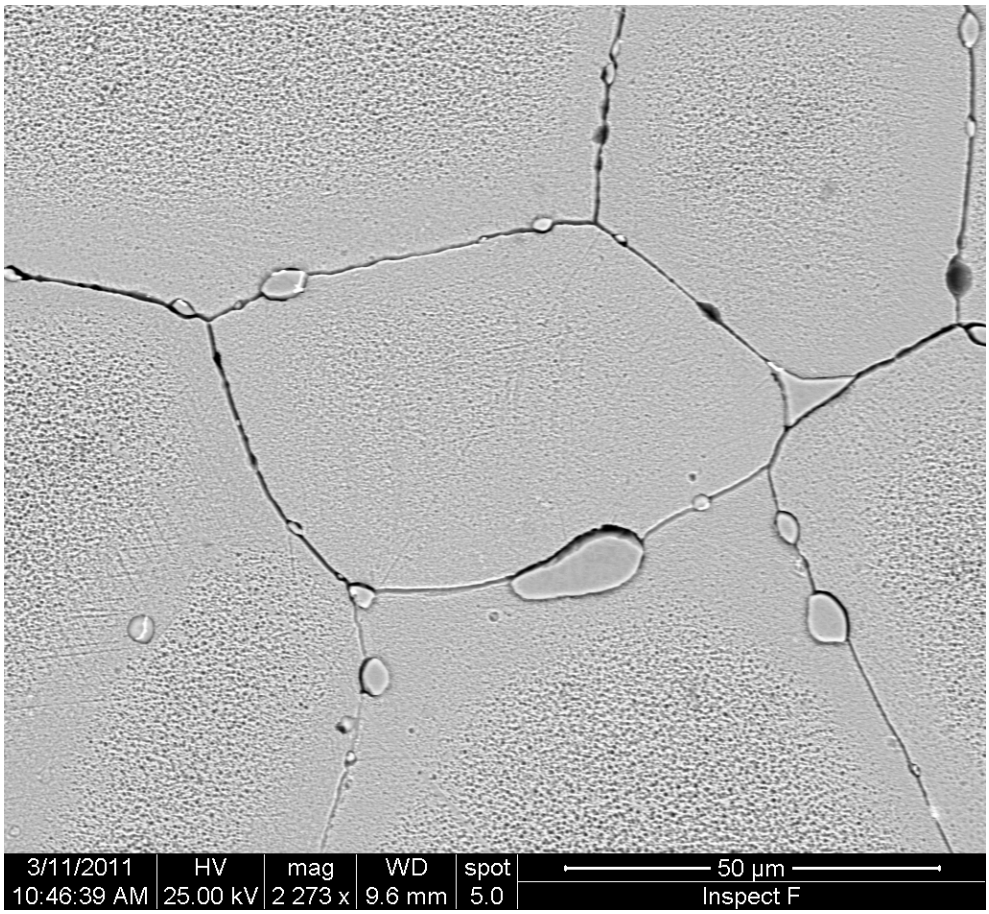
Hand Specimin



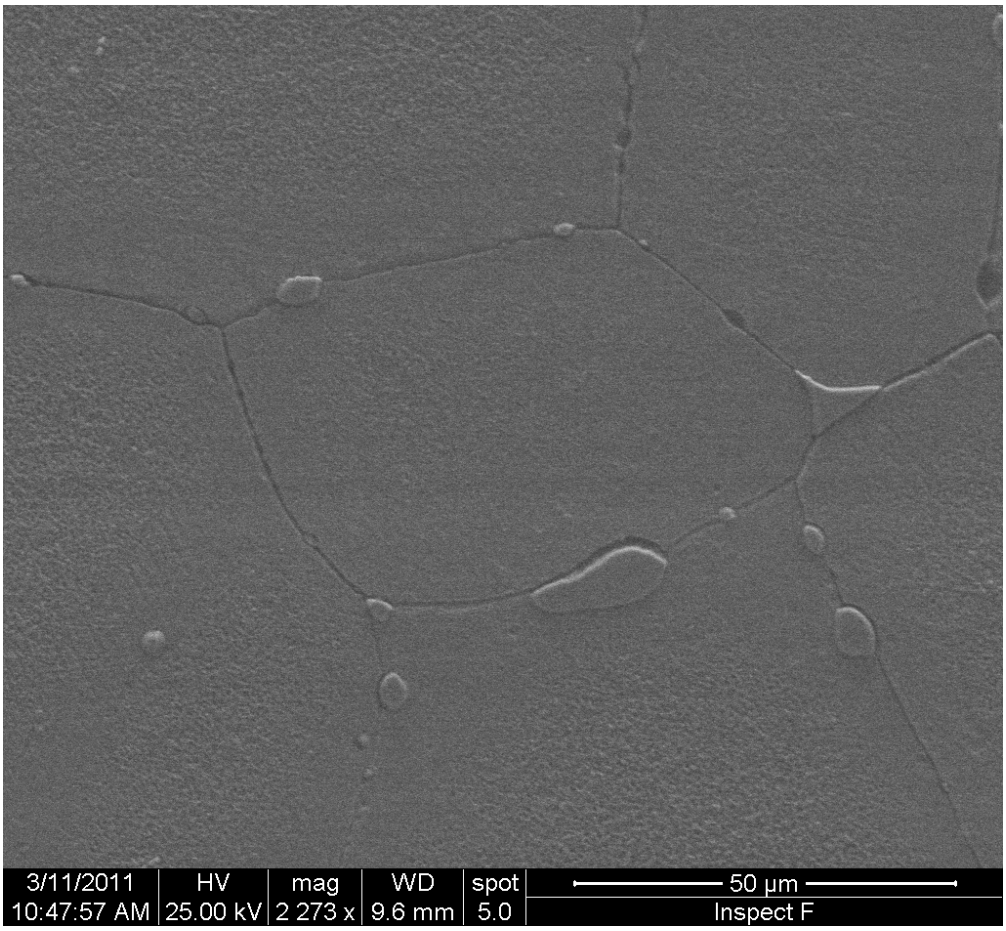
Micrograph 1



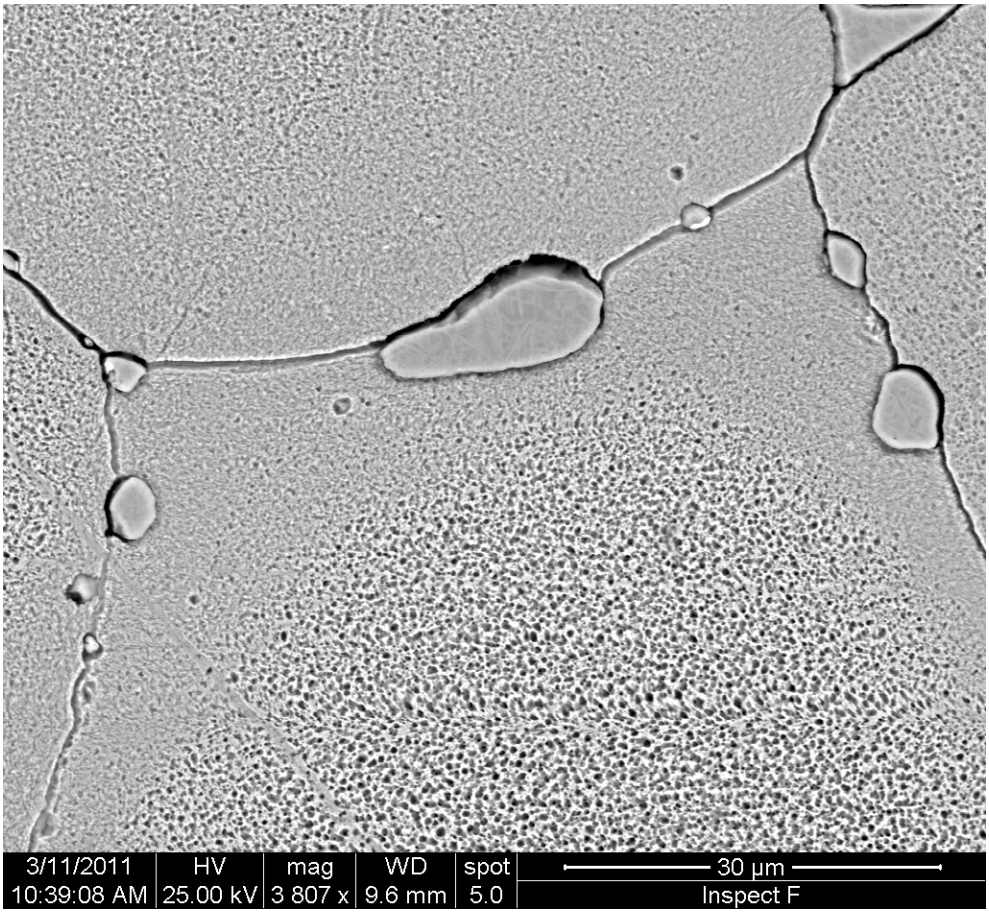
Micrograph 2



Micrograph 3



Micrograph 4

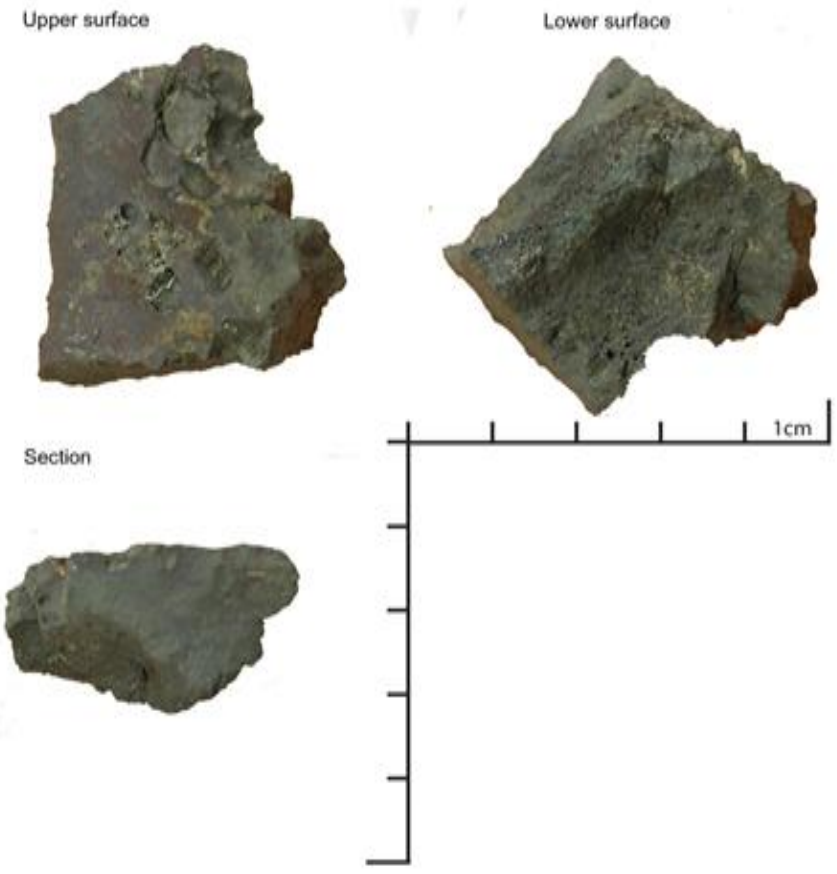


Site Code *STEP09* **Sample** *90* **Type** *Slag* **Area** *P Trench*

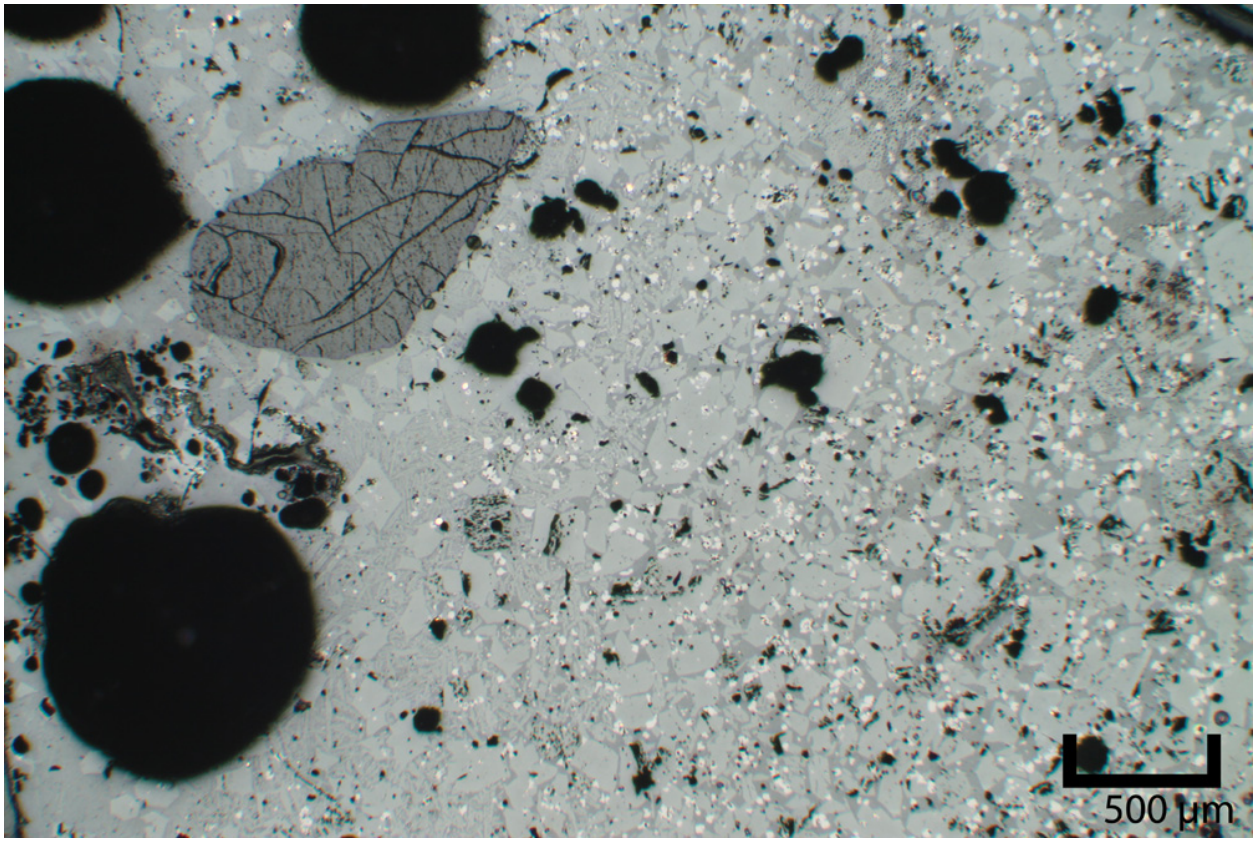
Wustite	*Occasional*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Frequent*	
Delafossite	*Frequent*	
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Frequent*	
Matrix	*Microphase 10-25%*	
Additional Phases	*occasional free silica*	

Chromite ***Present*** **Group** *D2*

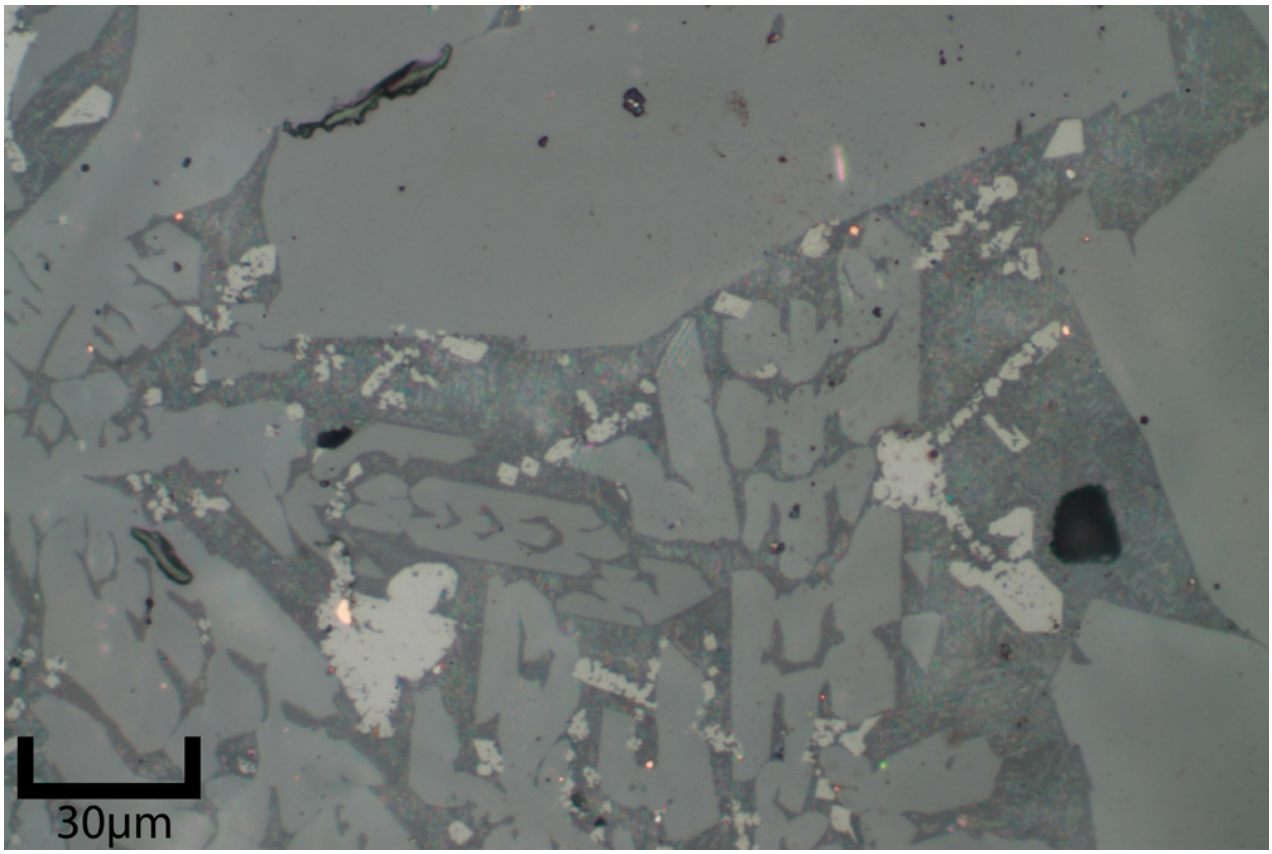
Hand Specimin



Micrograph 1



Micrograph 2



Site Code *STEP09* **Sample** *99* **Type** *Slag* **Area** *Trench*

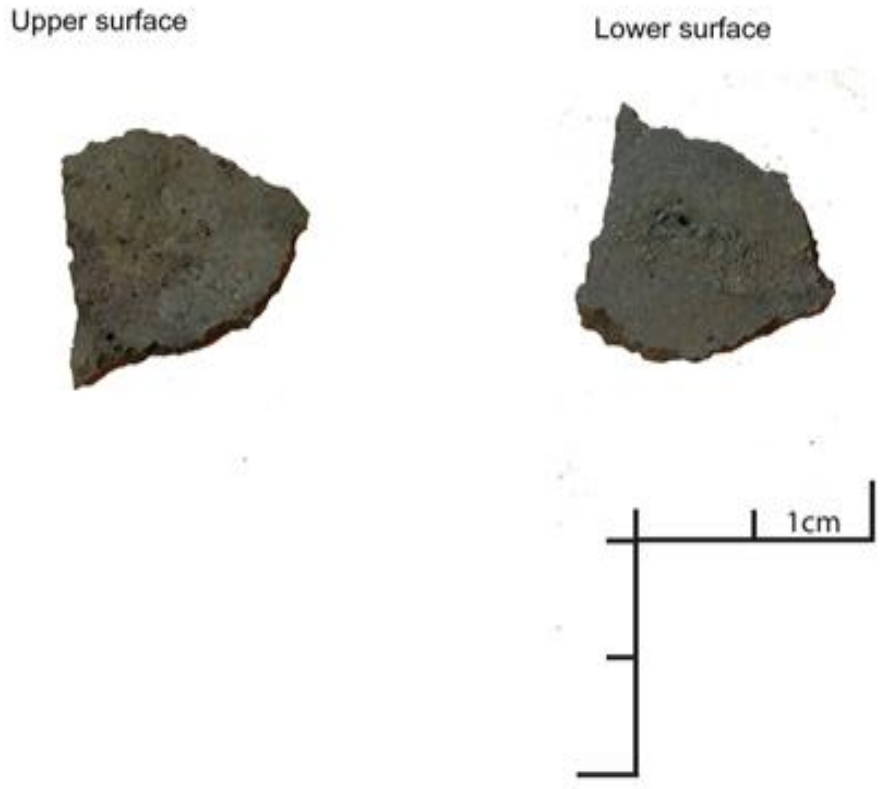
Wustite	*Common*
Magnetitie	*Absent*
Lath Fayalite	*Common*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	*Rare*
Euheadral fayalite	*Occasional*
Matrix	*Glassy 25-50%*
Additional Phases	*rare chromites,*

Additional notes
mineral inclusion, possible talc

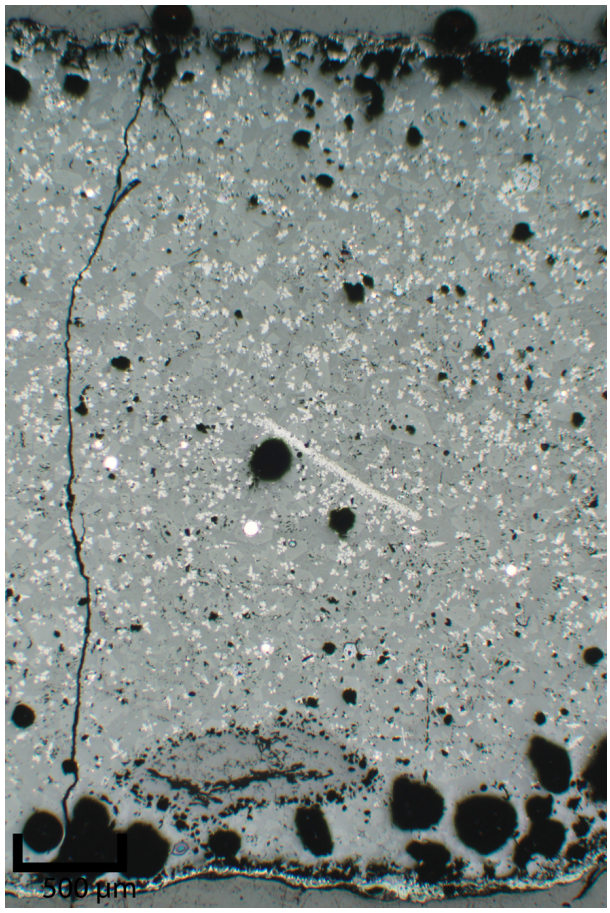
Chromite ✕ ***Present***

Group *D3*

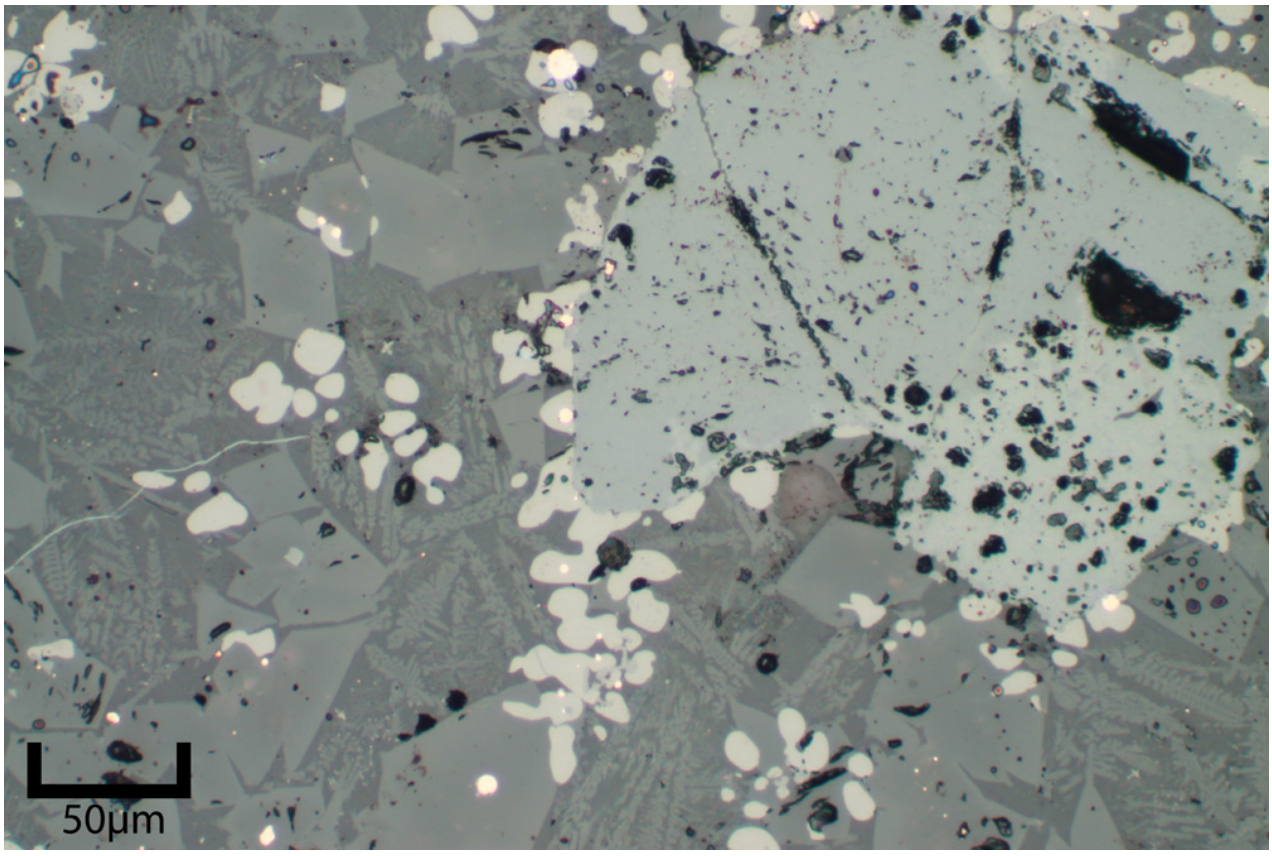
Hand Specimin



Micrograph 1



Micrograph 2

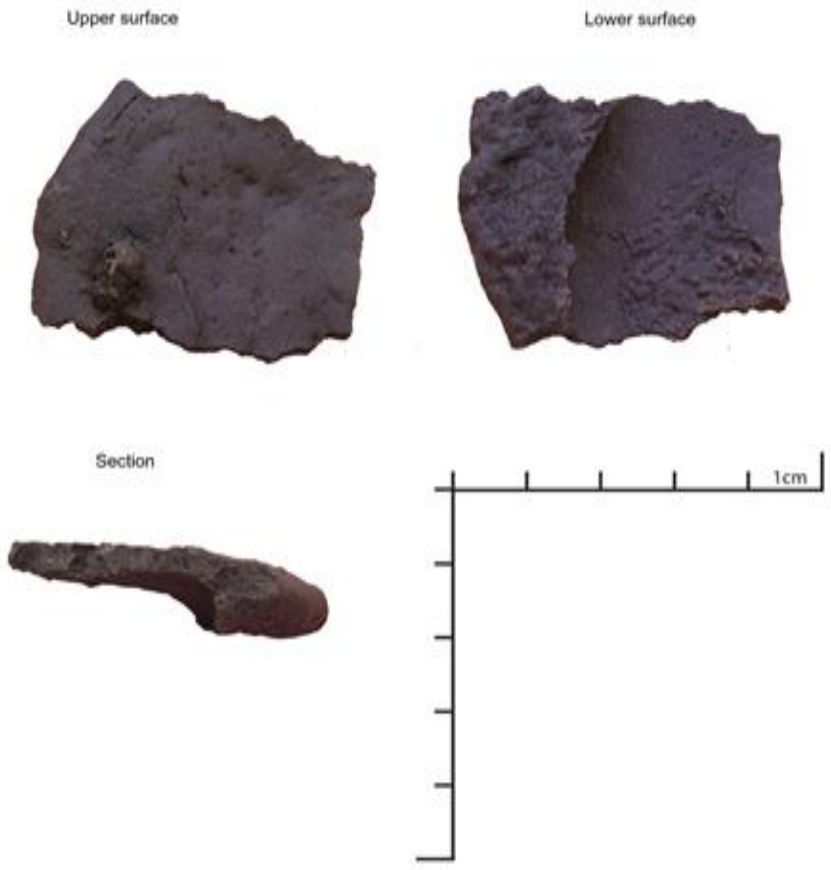


Site Code *STEP09* **Sample** *104.1* **Type** *Slag* **Area** *P Trench*

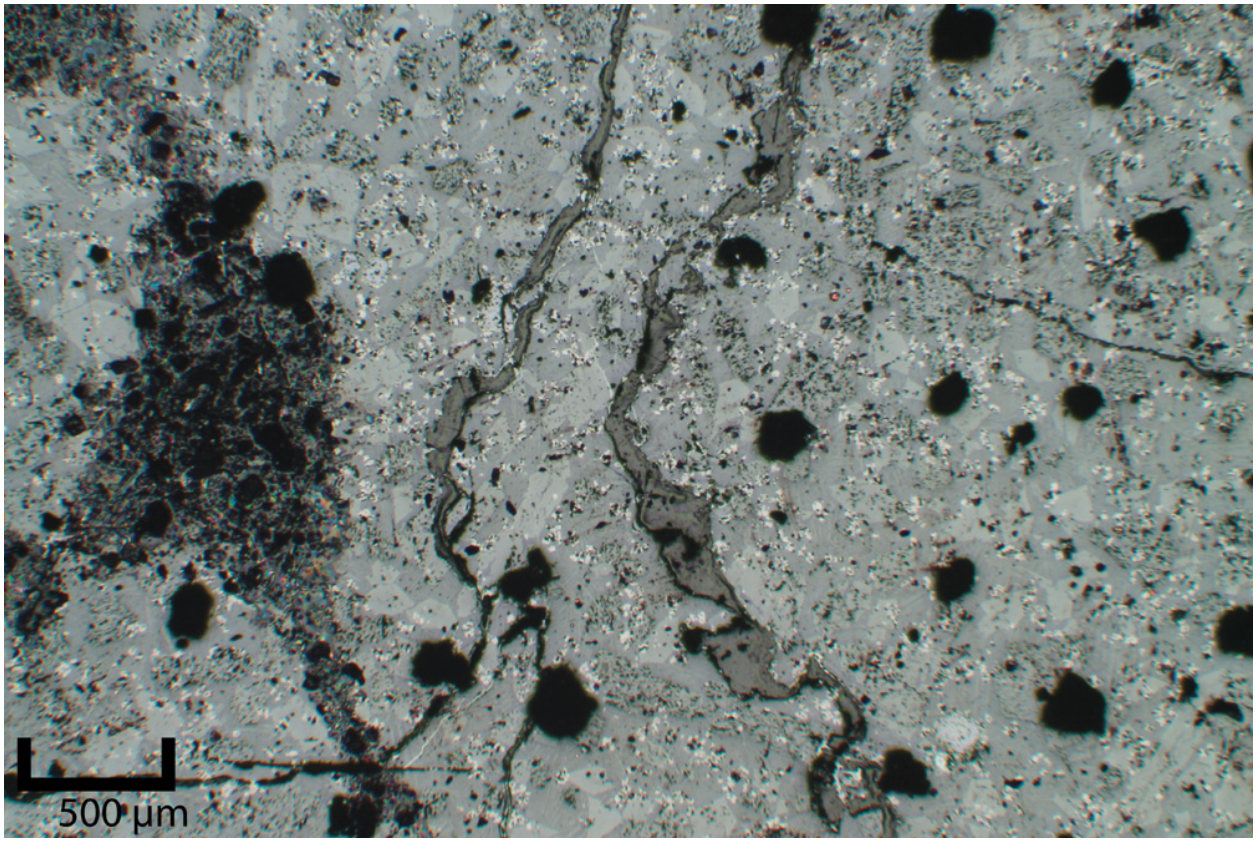
Wustite	*Rare*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Common*	
Delafossite		
Metallic copper		
Sulphides	*Rare*	
Euheadral fayalite	*Occasional*	
Matrix		
Additional Phases	*rare chromites*	

Chromite ☒ ***Present*** **Group** *D2*

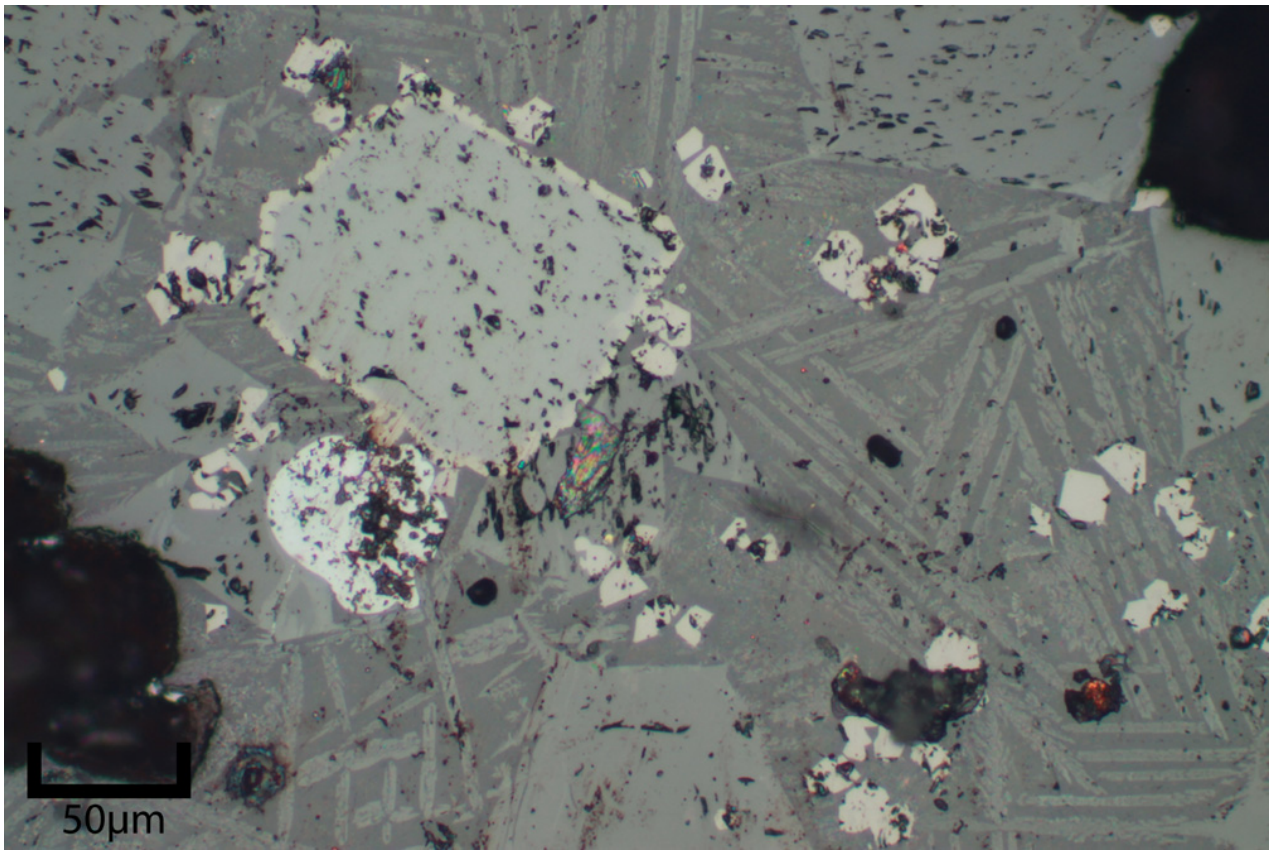
Hand Specimin



Micrograph 1



Micrograph 2

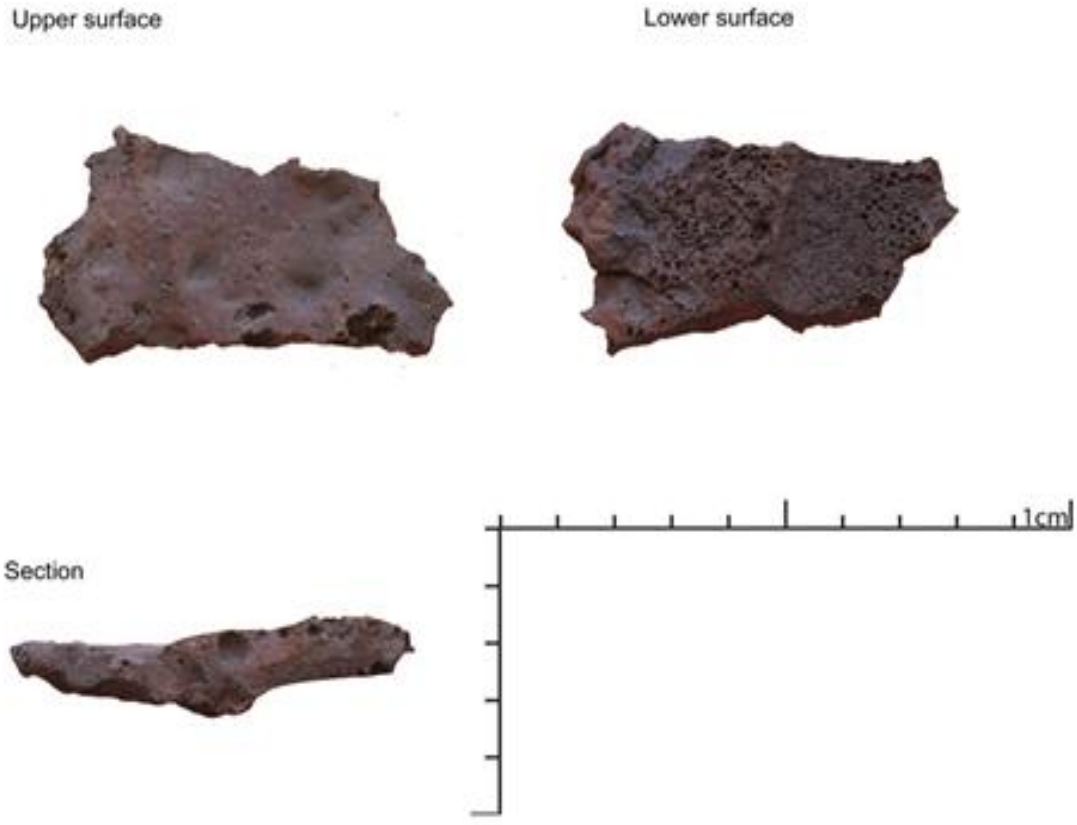


Site Code *STEP09* **Sample** *105.1* **Type** *Slag* **Area** *Trench*

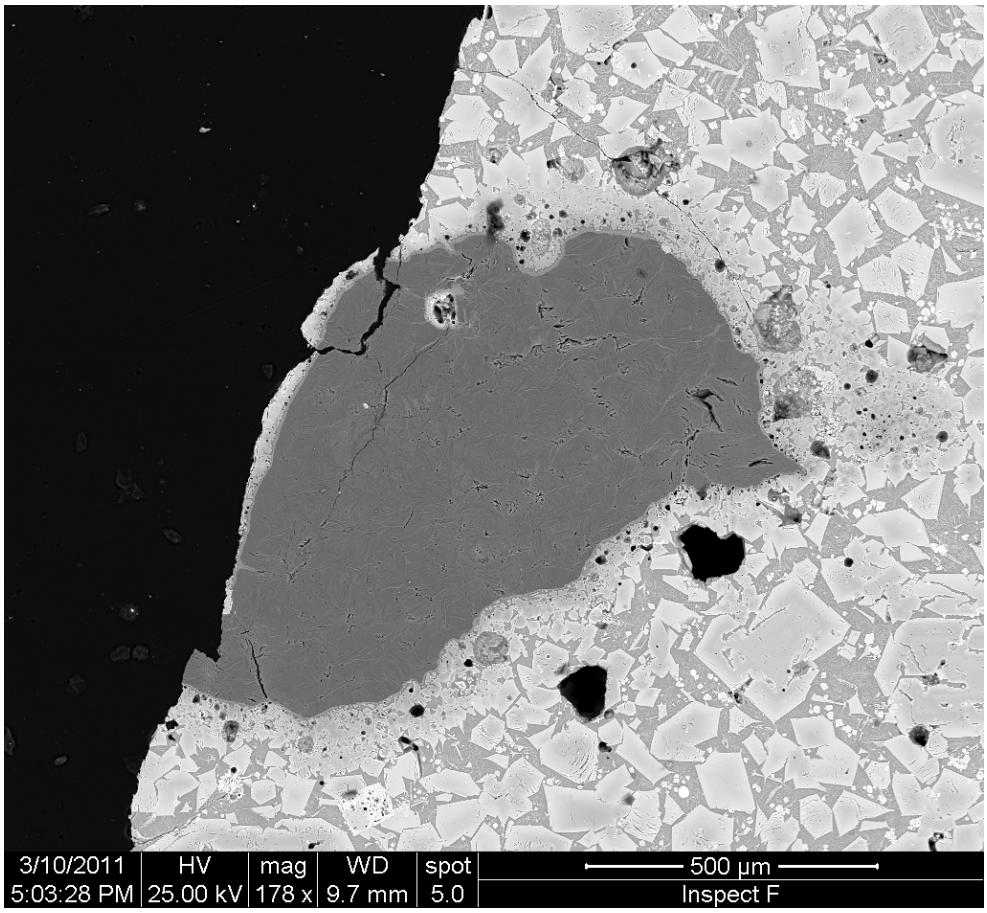
Wustite	*Rare*	**Additional notes**
Magnetitie	*Occasional*	
Lath Fayalite	*Rare*	
Delafossite		
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Frequent*	
Matrix	*Glassy 10-25%*	
Additional Phases		

Chromite ***Present*** **Group** *B2*

Hand Specimin



Micrograph 1



Micrograph 2

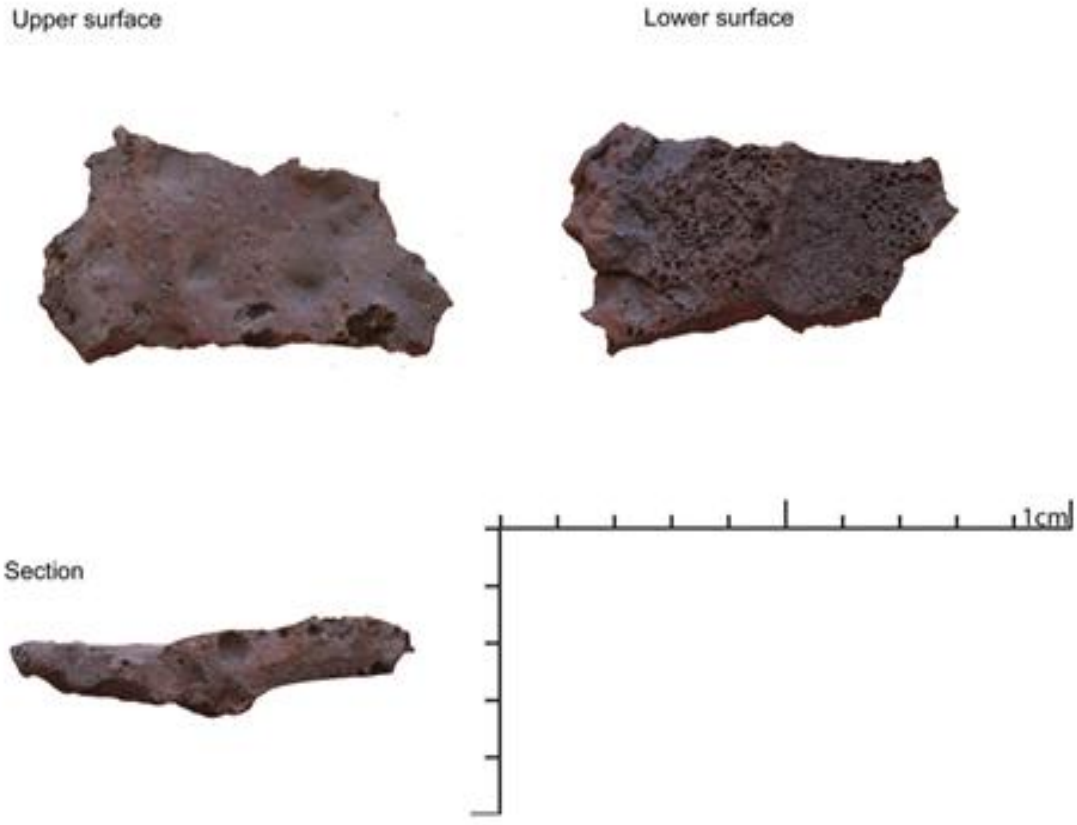
Site Code *STEP09* **Sample** *105.2* **Type** *Slag* **Area** *Trench*

Wustite	*Rare*
Magnetitie	*Absent*
Lath Fayalite	*Rare*
Delafossite	
Metallic copper	
Sulphides	*Rare*
Euheadral fayalite	*Common*
Matrix	*Glassy 10-25%*
Additional Phases	

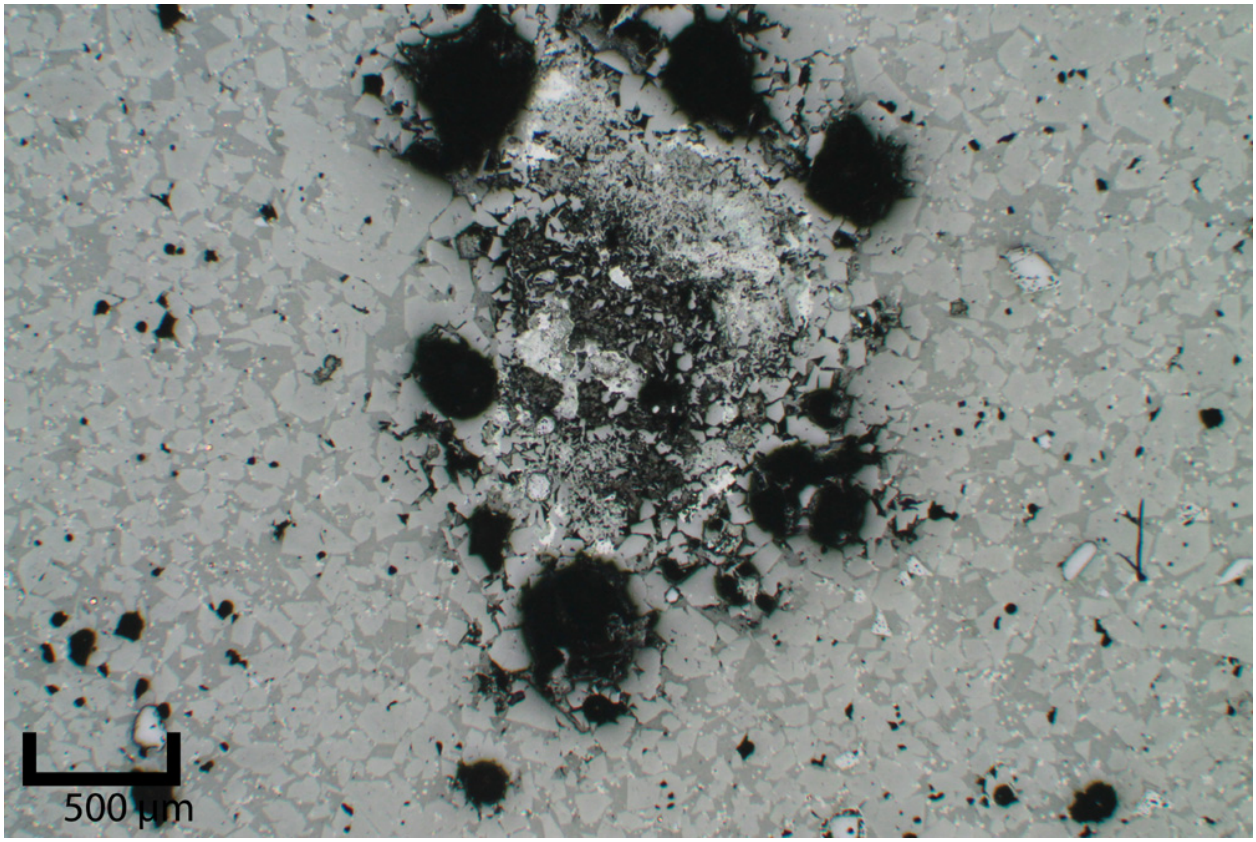
Additional notes
possible ore inclusion

Chromite ***Present*** **Group** *B2*

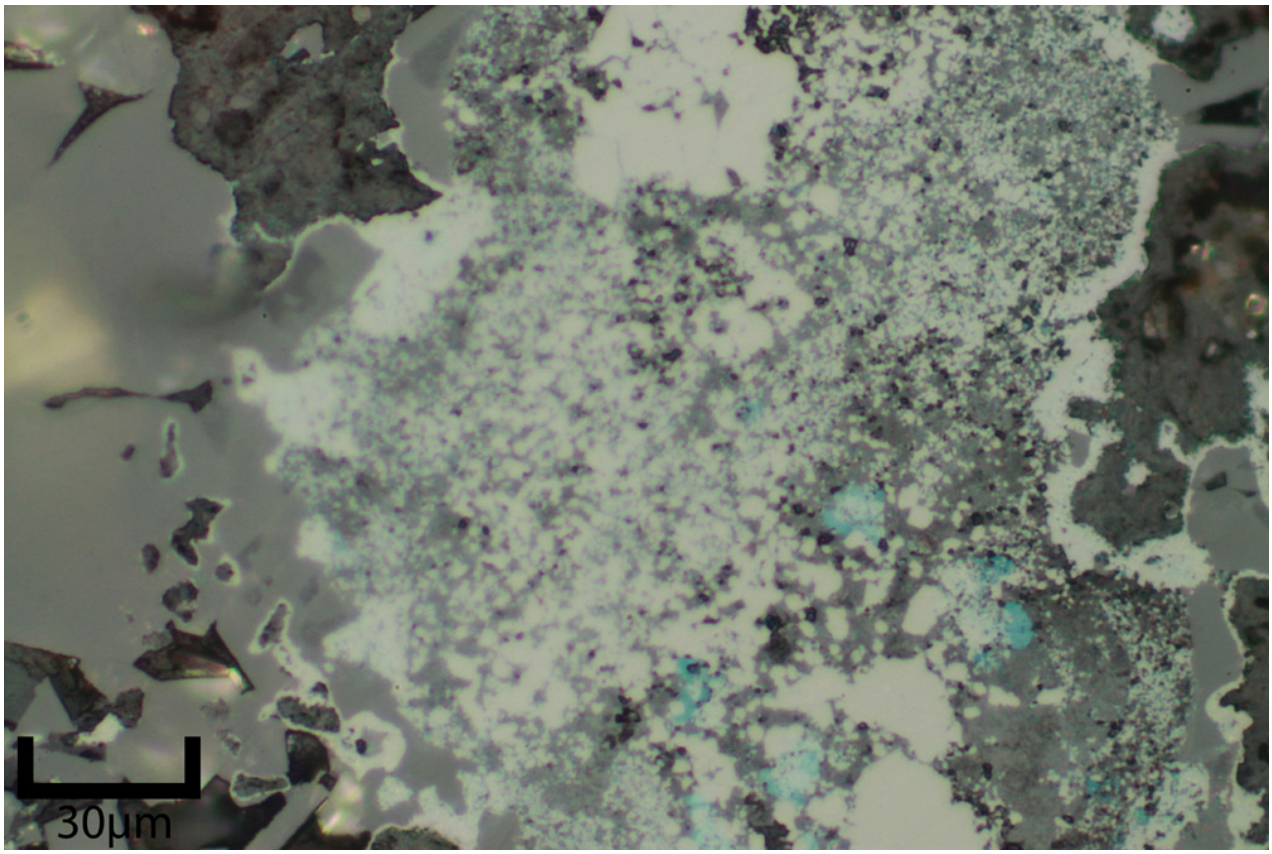
Hand Specimin



Micrograph 1



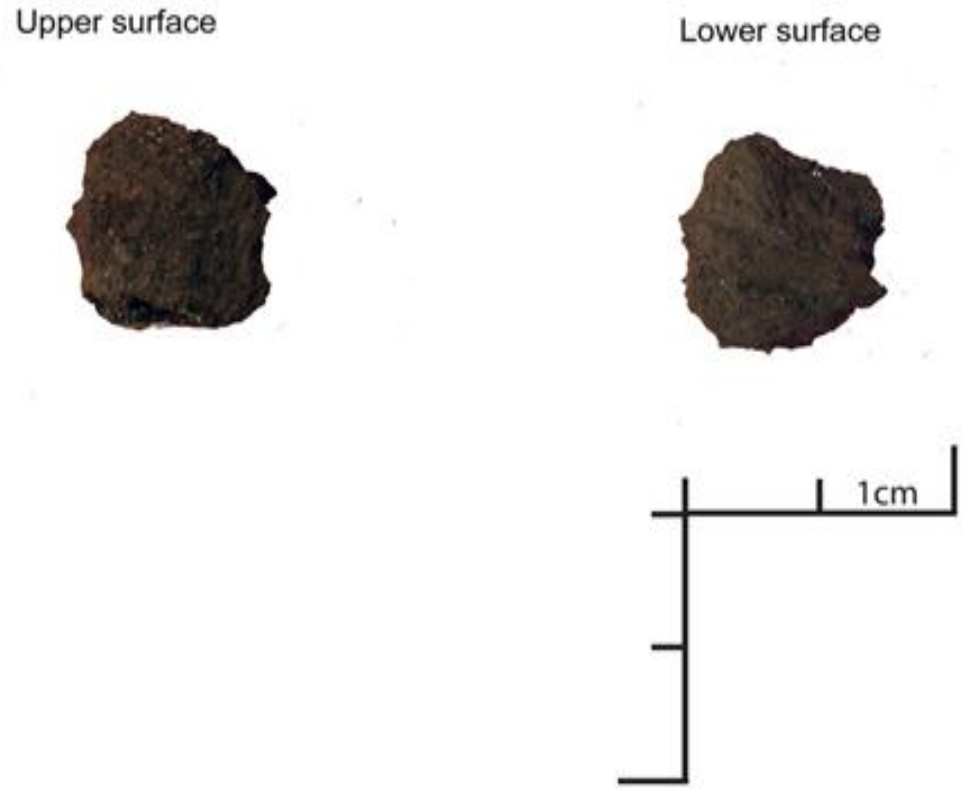
Micrograph 2



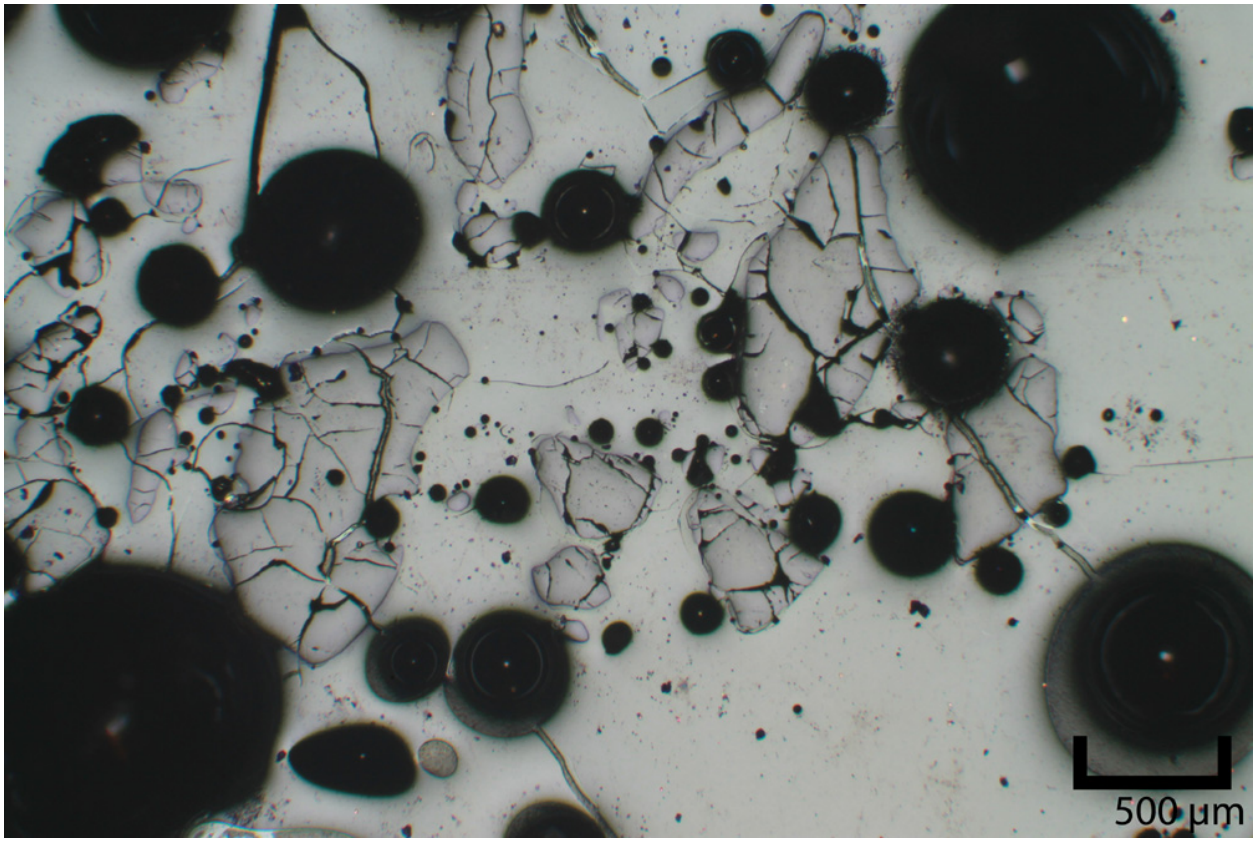
Site Code *STEP09* **Sample** *115* **Type** *Ore* **Area** *P Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

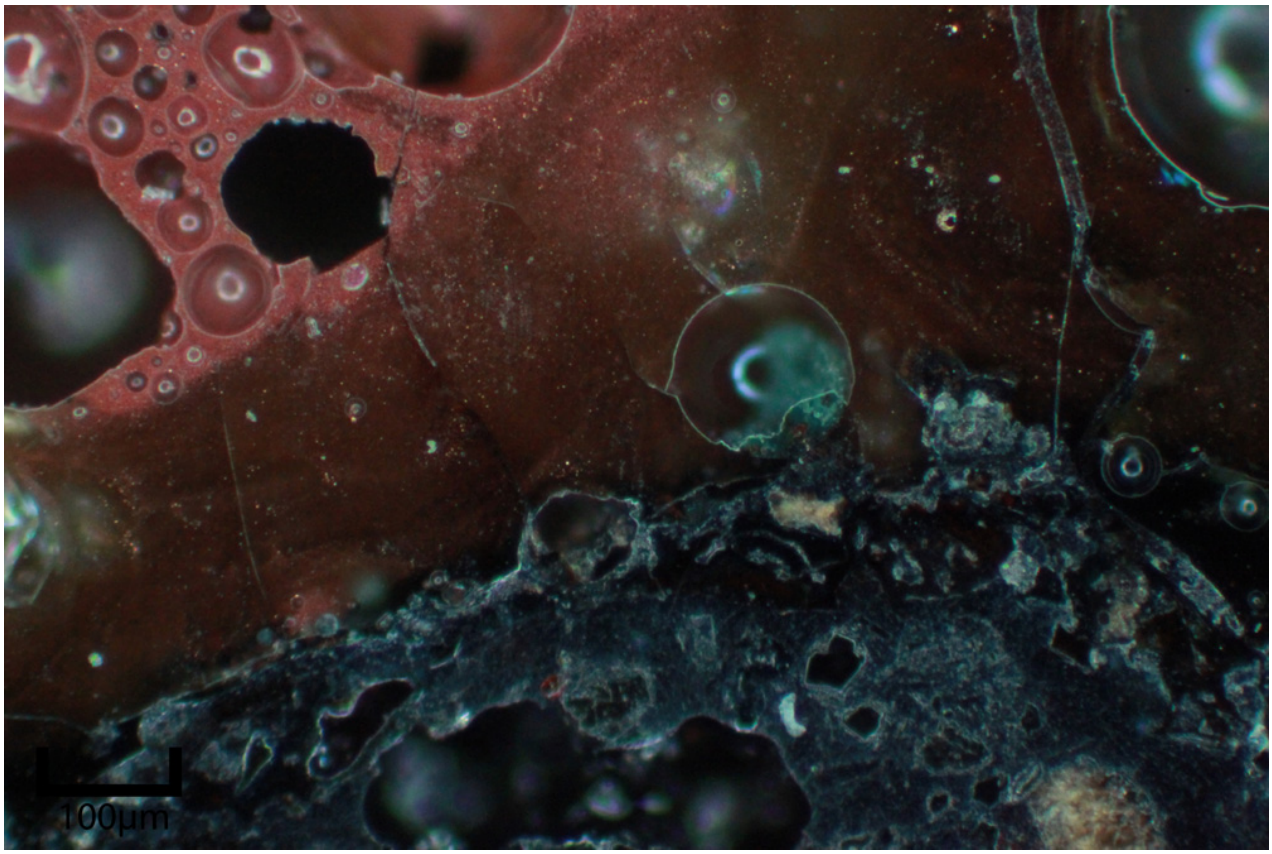
Hand Specimin



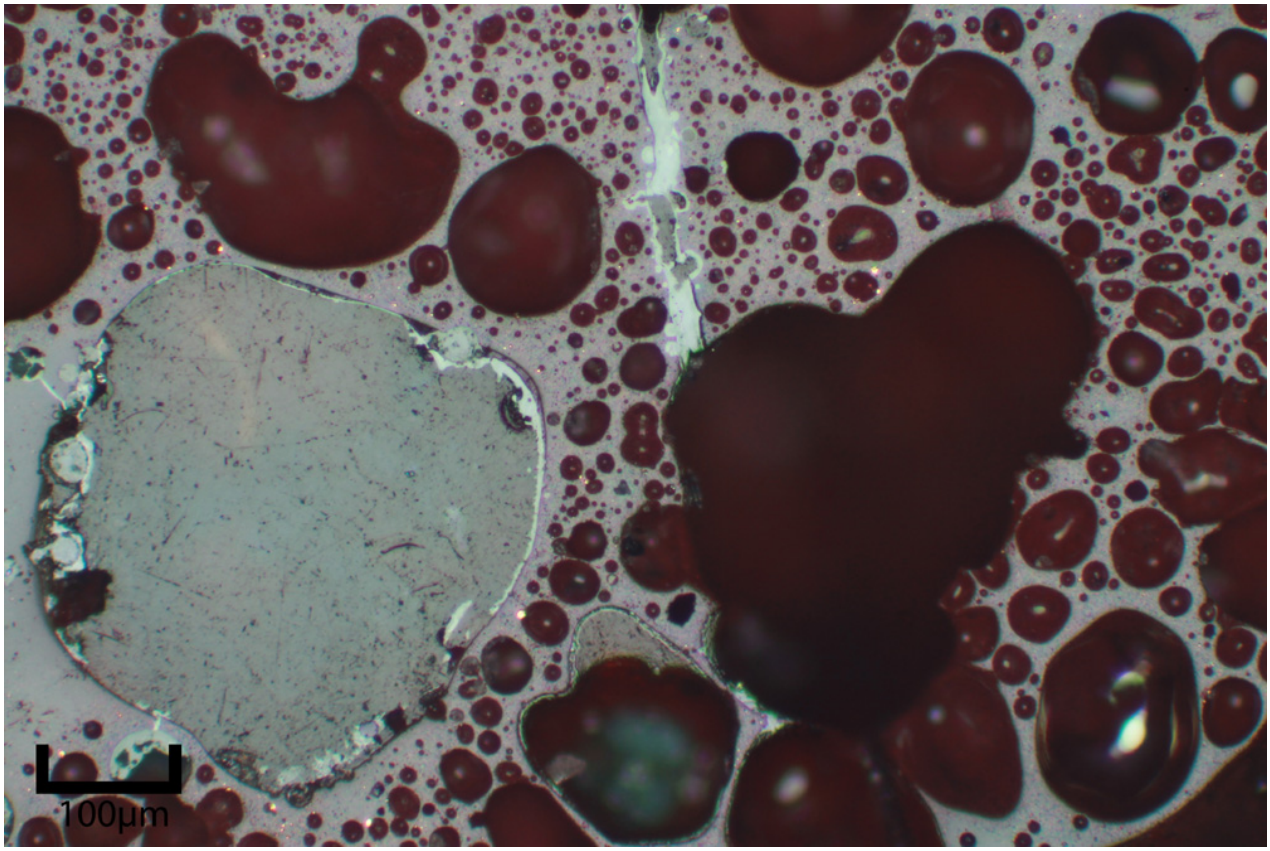
Micrograph 1



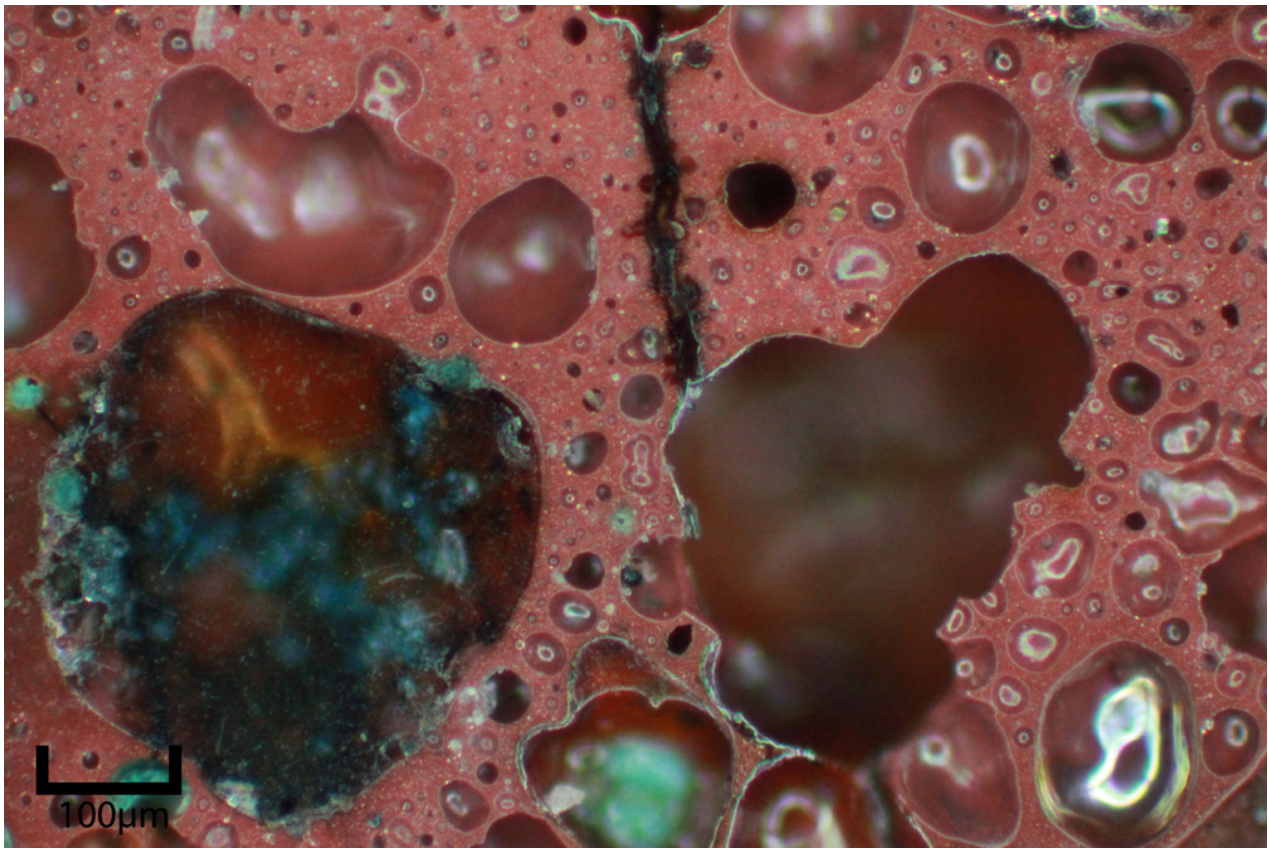
Micrograph 2



Micrograph 3



Micrograph 4

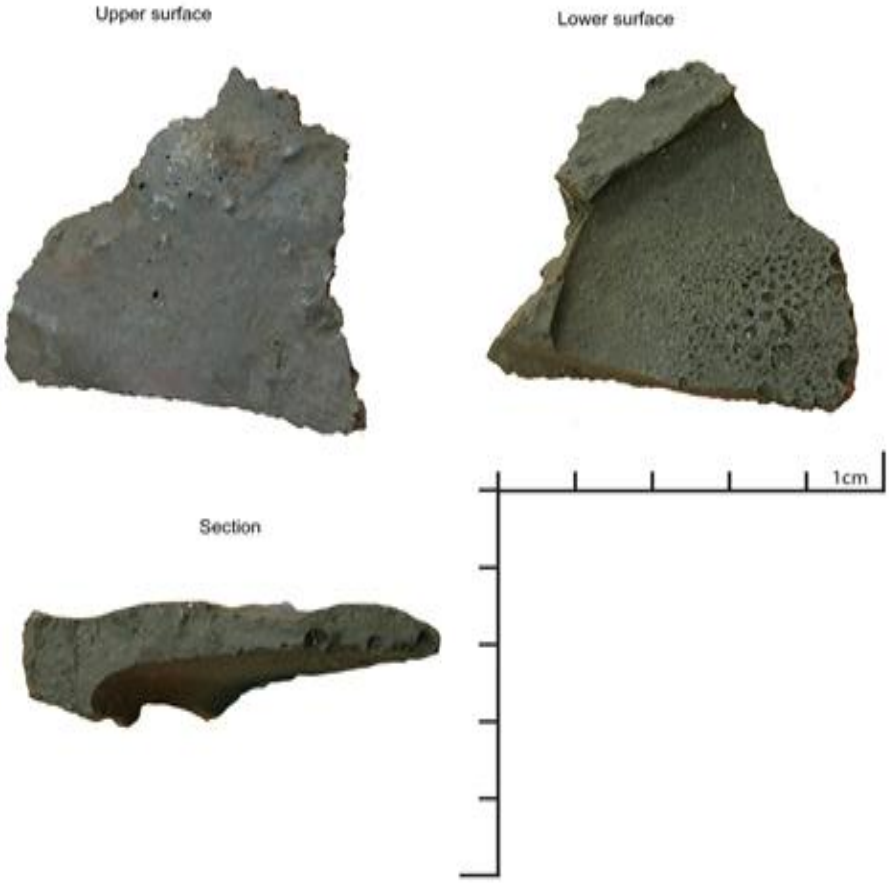


Site Code *STEP09* **Sample** *117* **Type** *Slag* **Area** *Trench*

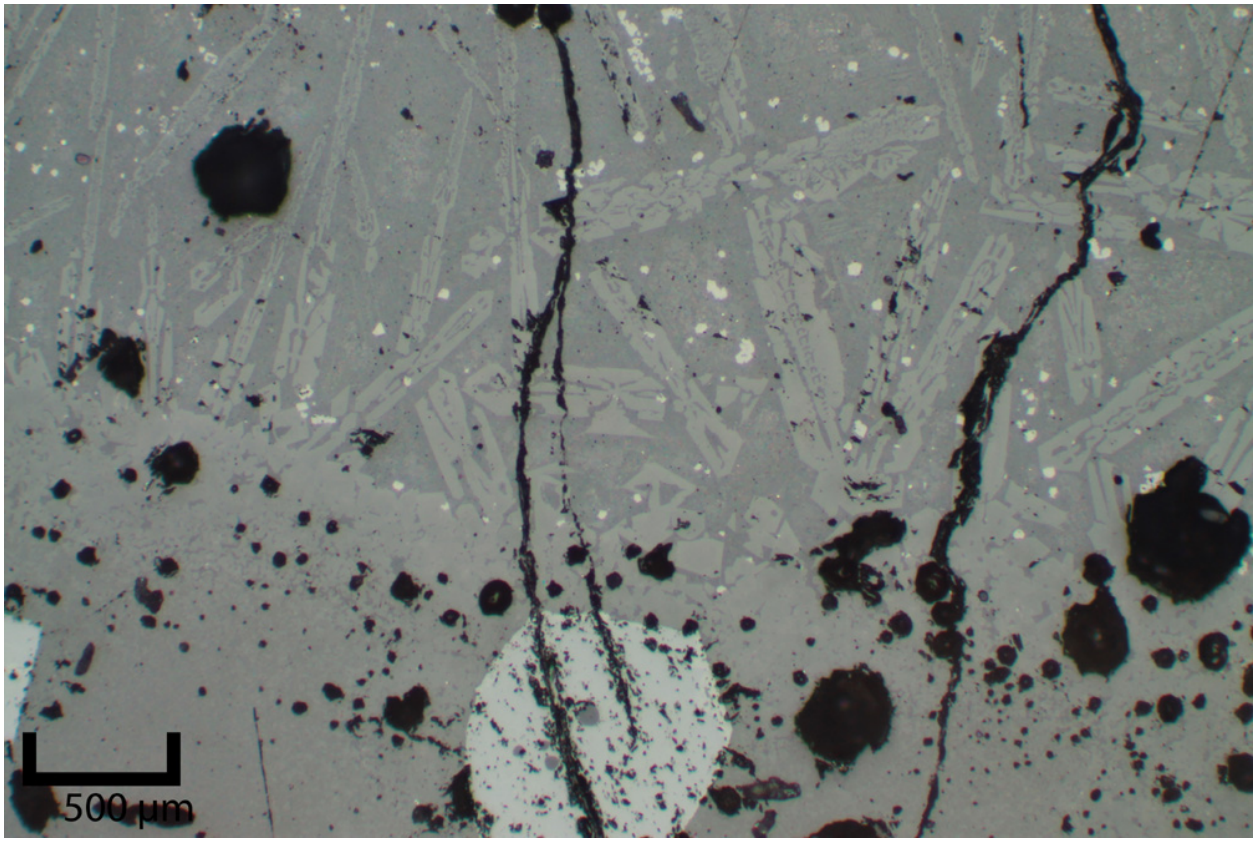
Wustite	*Rare*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Common*	
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 50-75%*	
Additional Phases	*rare chromite*	

Chromite ***Present*** **Group** *A2*

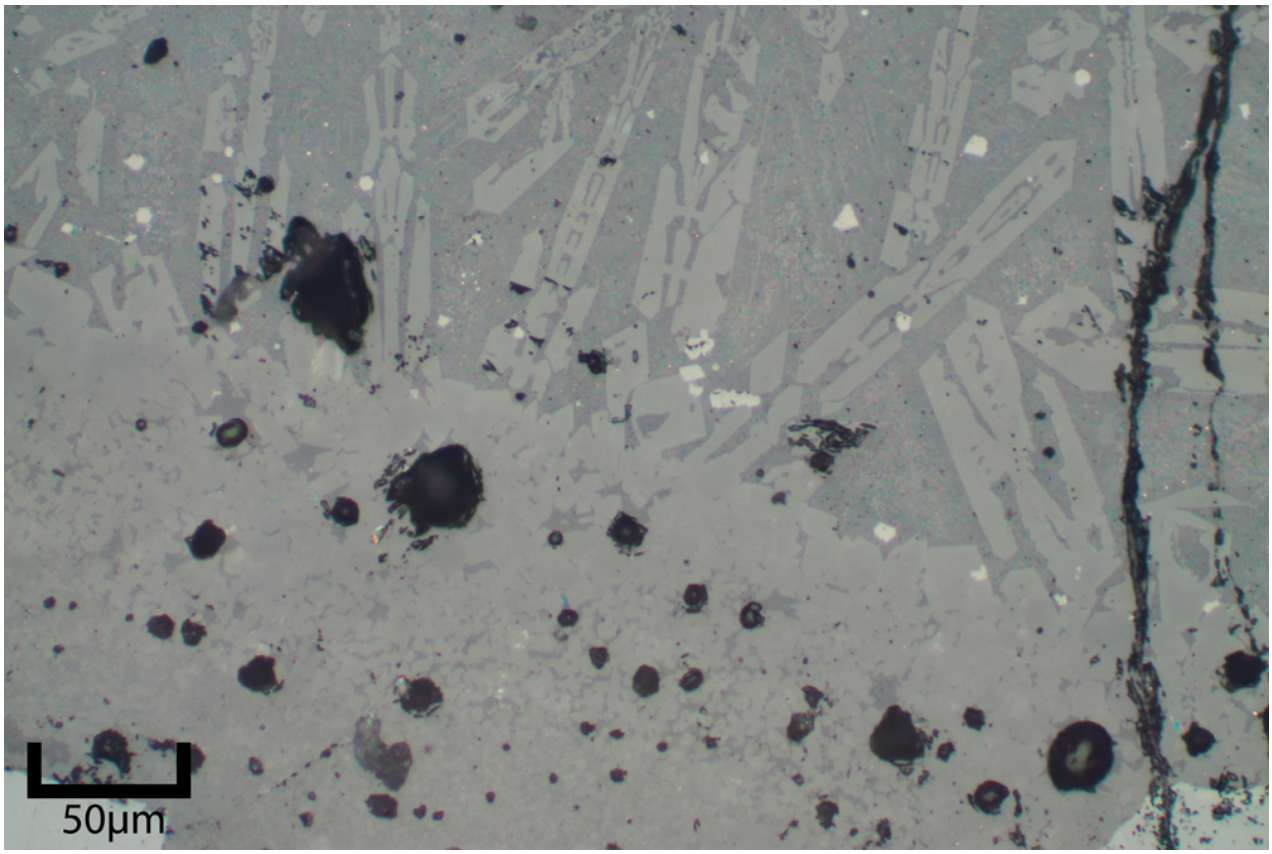
Hand Specimin



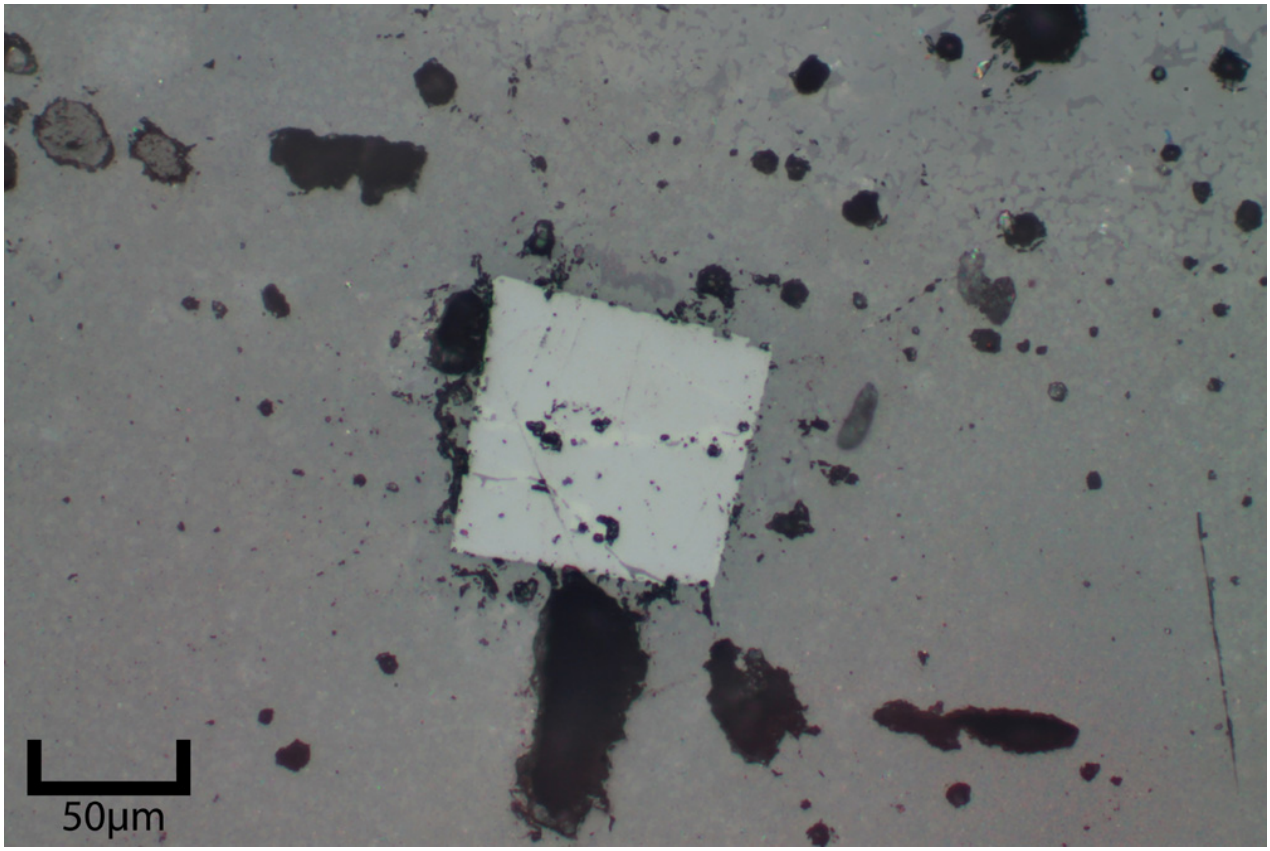
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

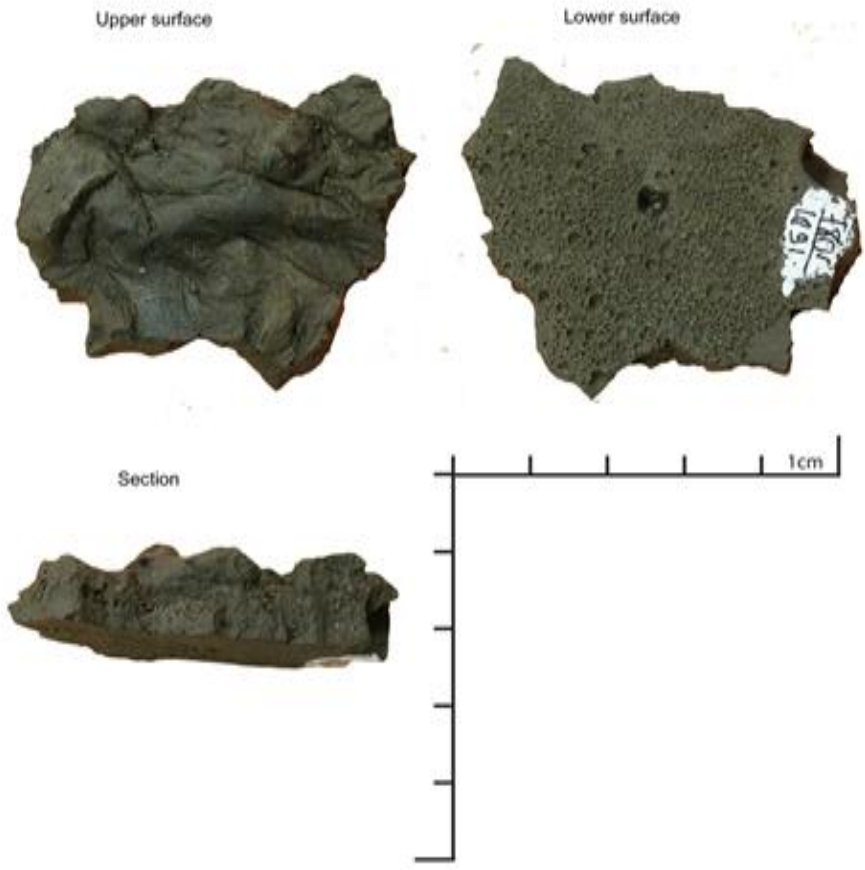
Site Code *STEP09* **Sample** *118* **Type** *Slag* **Area** *P Trench*

Wustite	*Rare*
Magnetitie	*Rare*
Lath Fayalite	*Absent*
Delafossite	
Metallic copper	*Rare*
Sulphides	*Rare*
Euheadral fayalite	*Absent*
Matrix	*Glassy 90-100%*
Additional Phases	*common free silica*

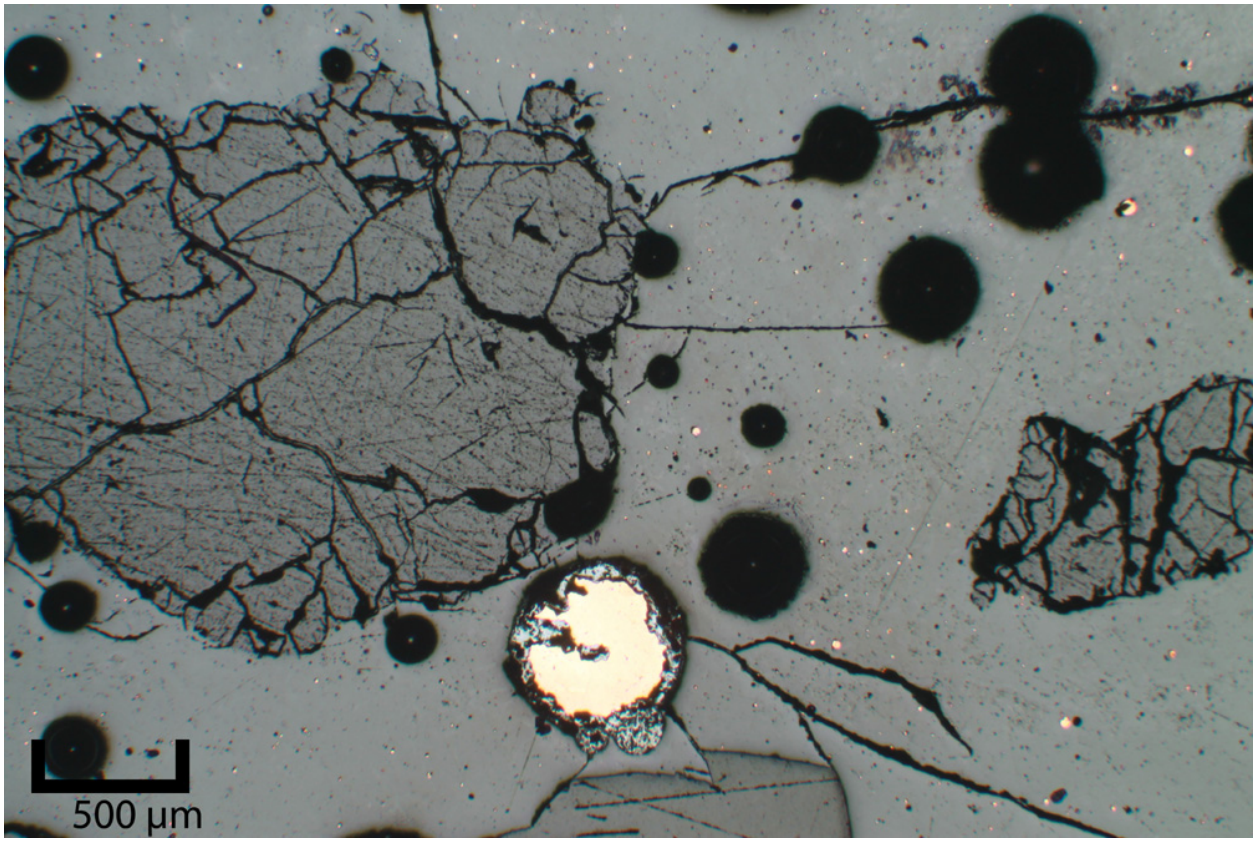
Additional notes

Chromite ***Present*** **Group** *C2*

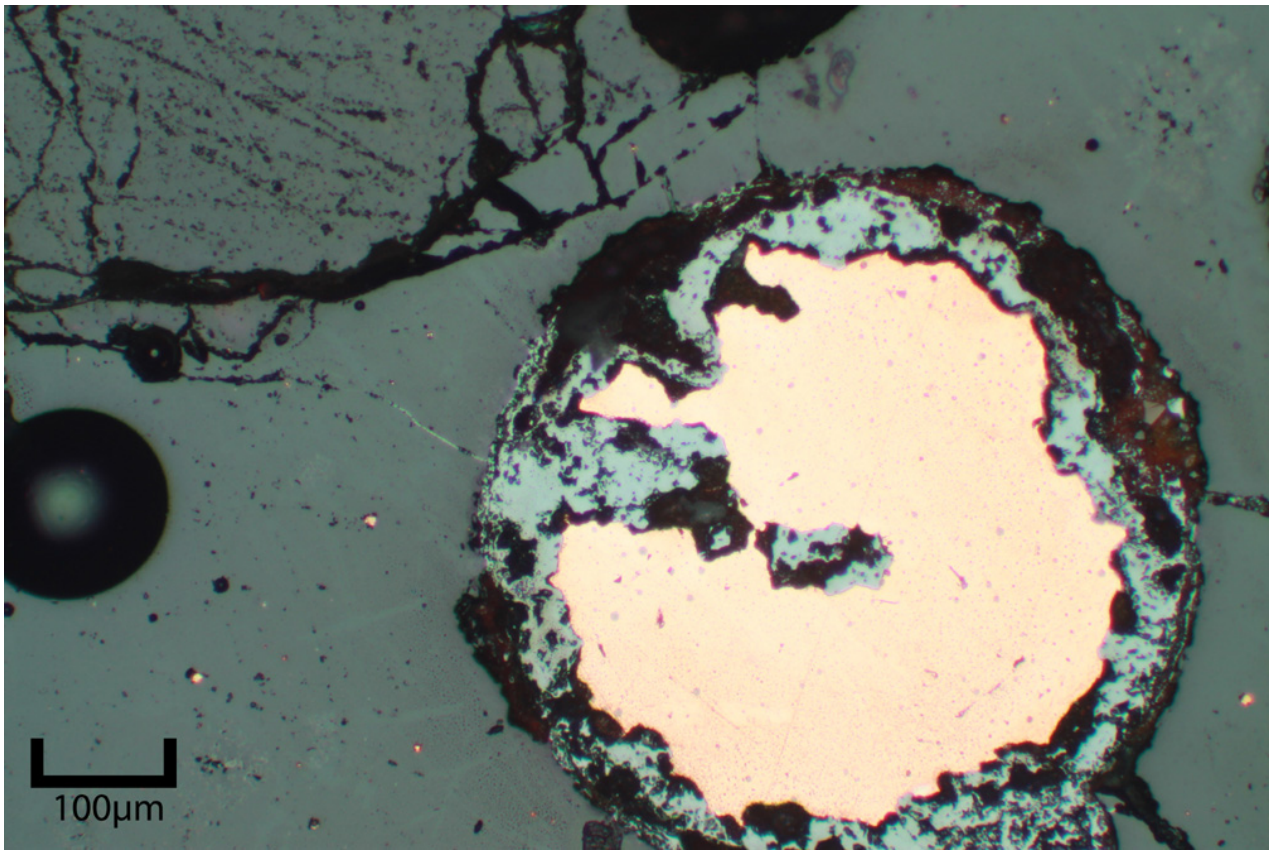
Hand Specimin



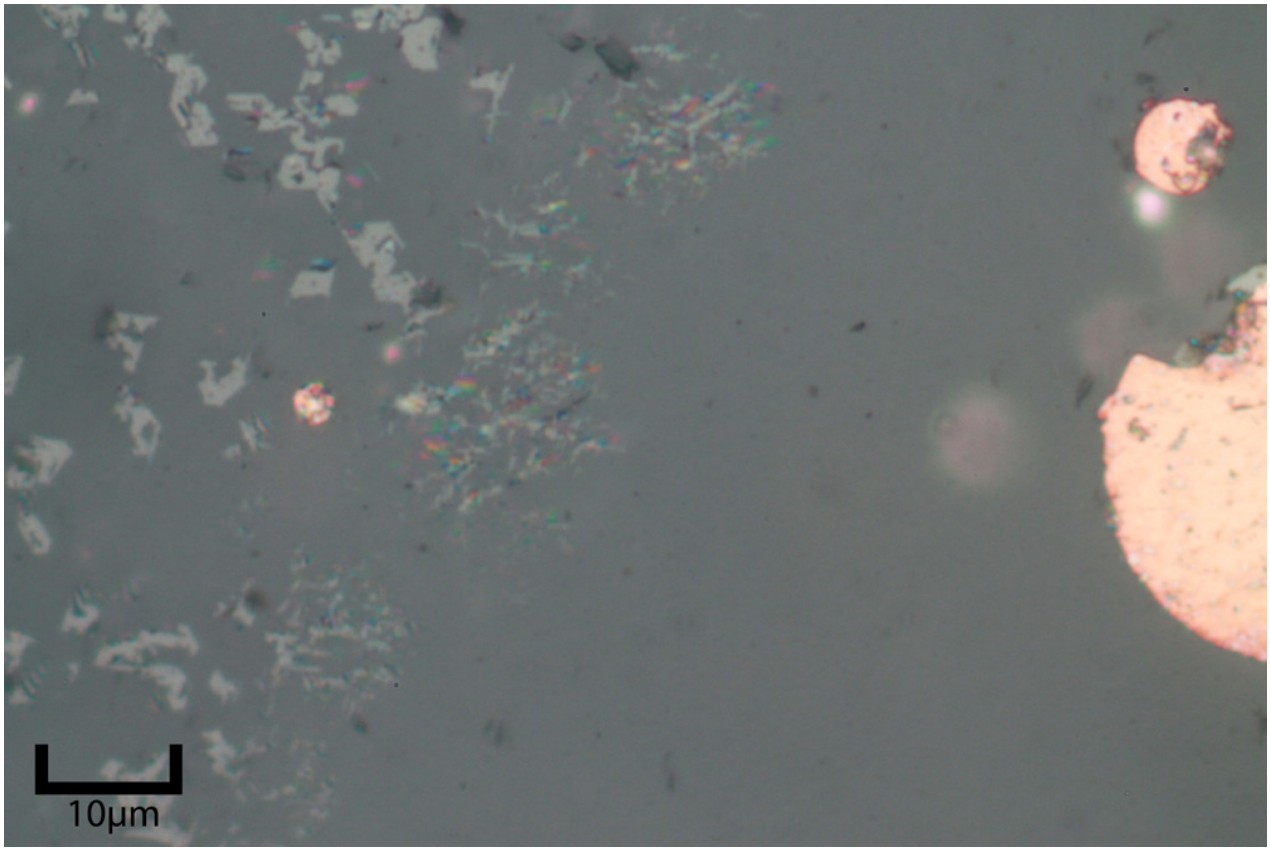
Micrograph 1



Micrograph 2



Micrograph 3



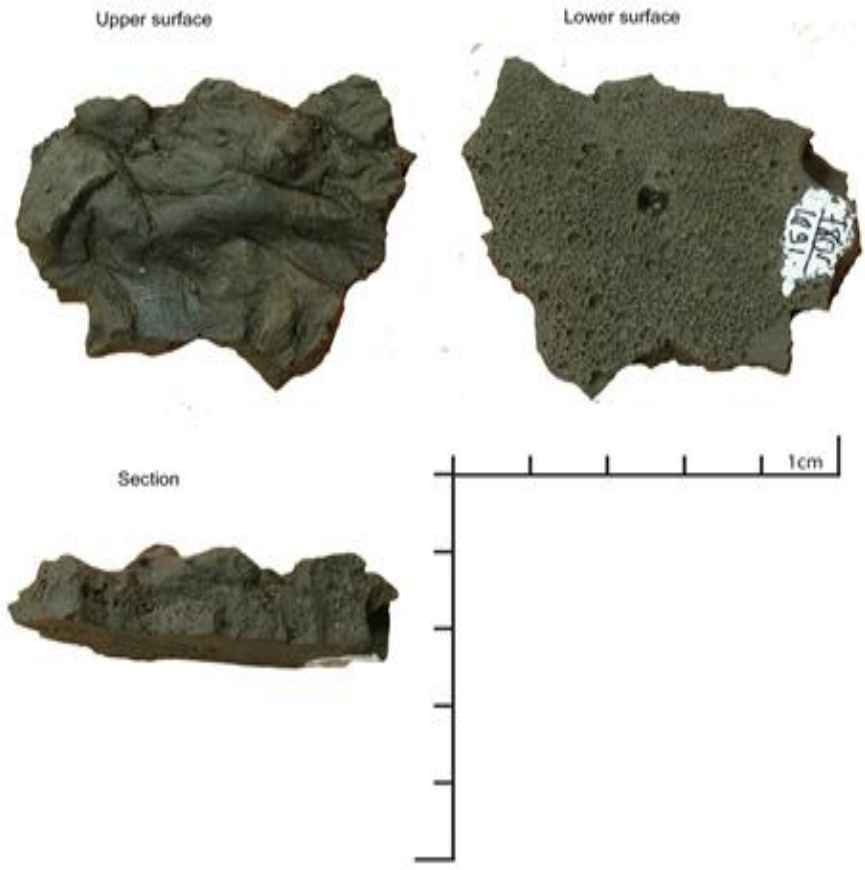
Micrograph 4

Site Code *STEP09* **Sample** *118.2* **Type** *Slag* **Area** *P Trench*

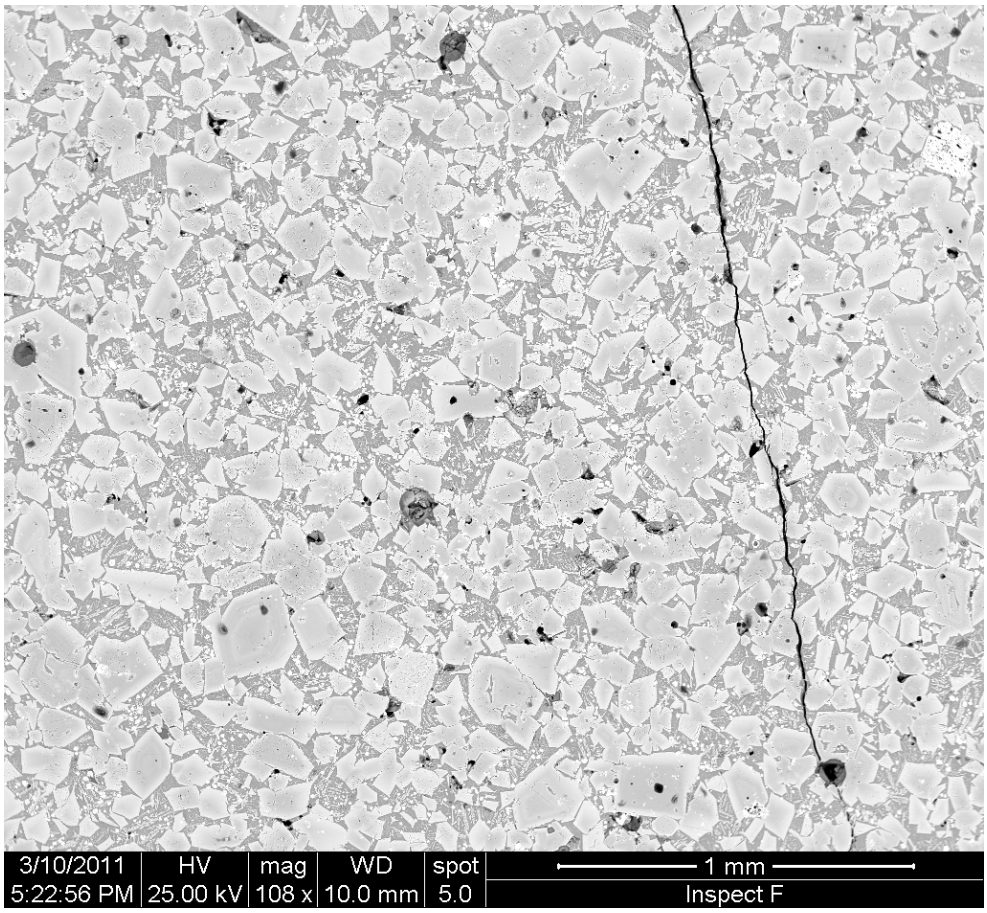
Wustite	*Occasional*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Occasional*	
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite	*Frequent*	
Matrix	*Glassy 10-25%*	
Additional Phases		

Chromite ***Present*** **Group** *B2*

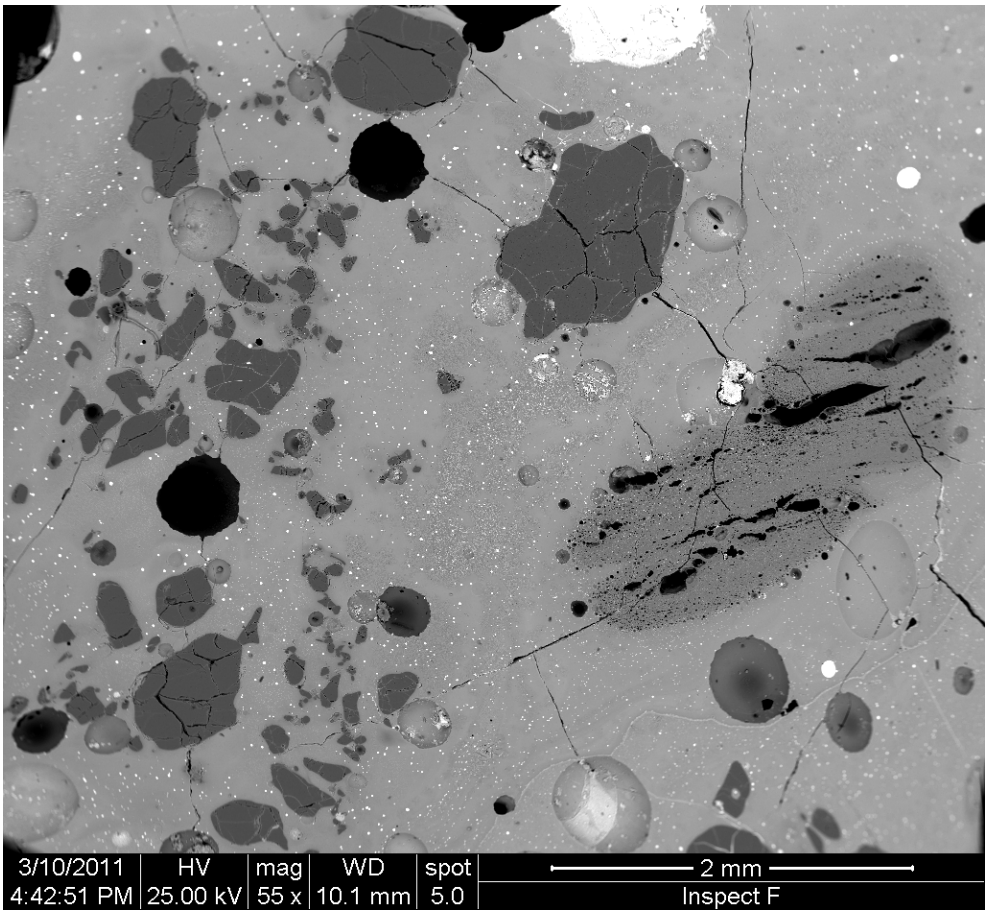
Hand Specimin



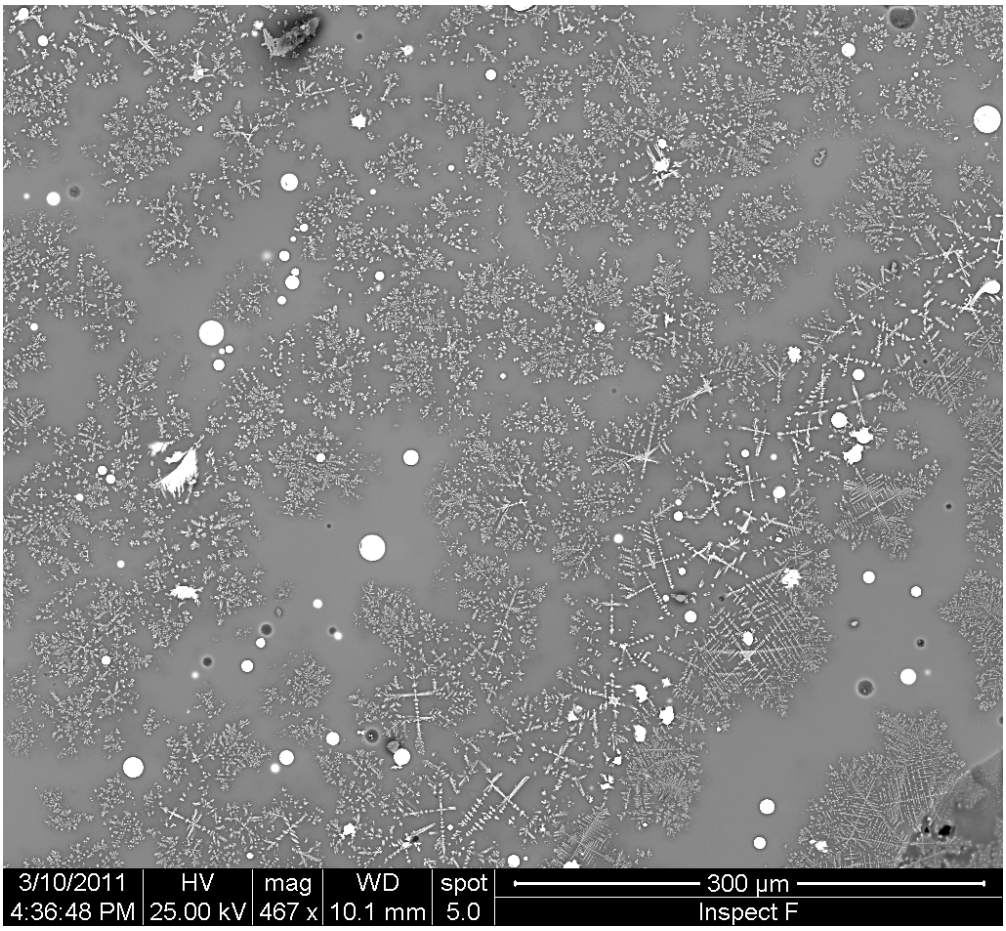
Micrograph 1



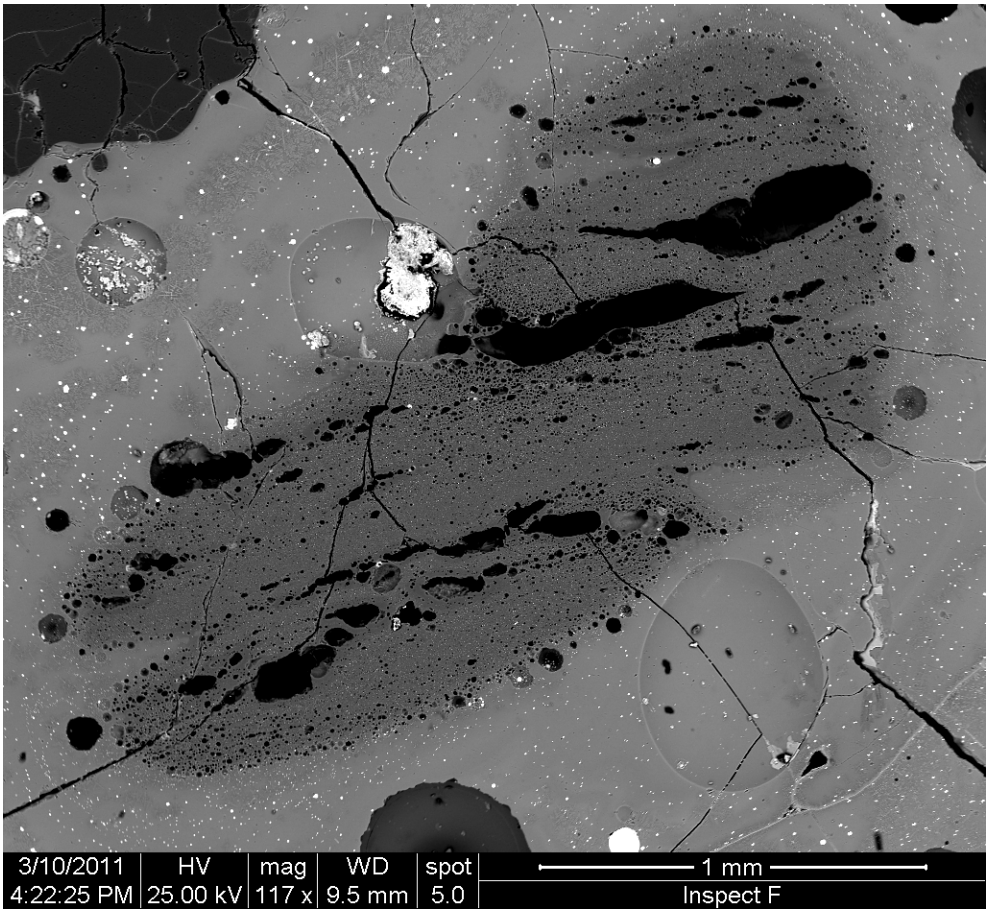
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *STEP09* **Sample** *119* **Type** *Slag* **Area** *P Trench*

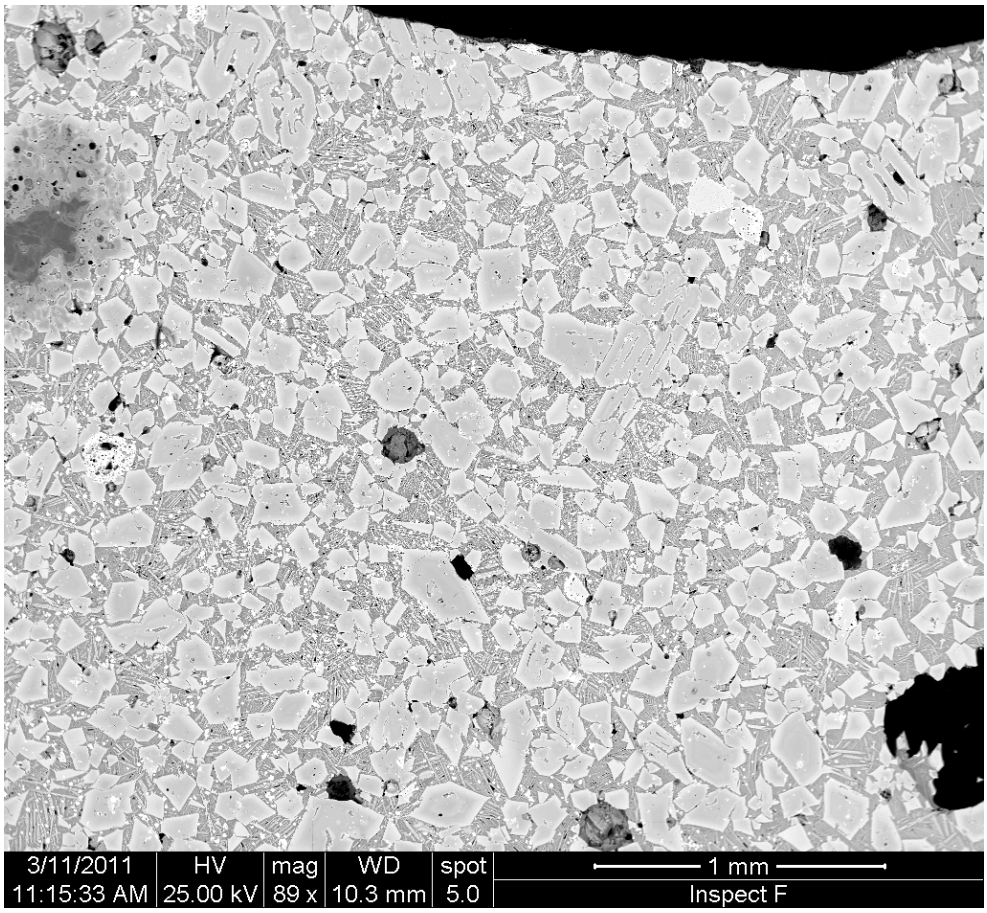
Wustite	*Rare*	**Additional notes**
Magnetitie	*Absent*	
Lath Fayalite	*Rare*	
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite	*Common*	
Matrix		
Additional Phases		

Chromite ***Present*** **Group** *B2*

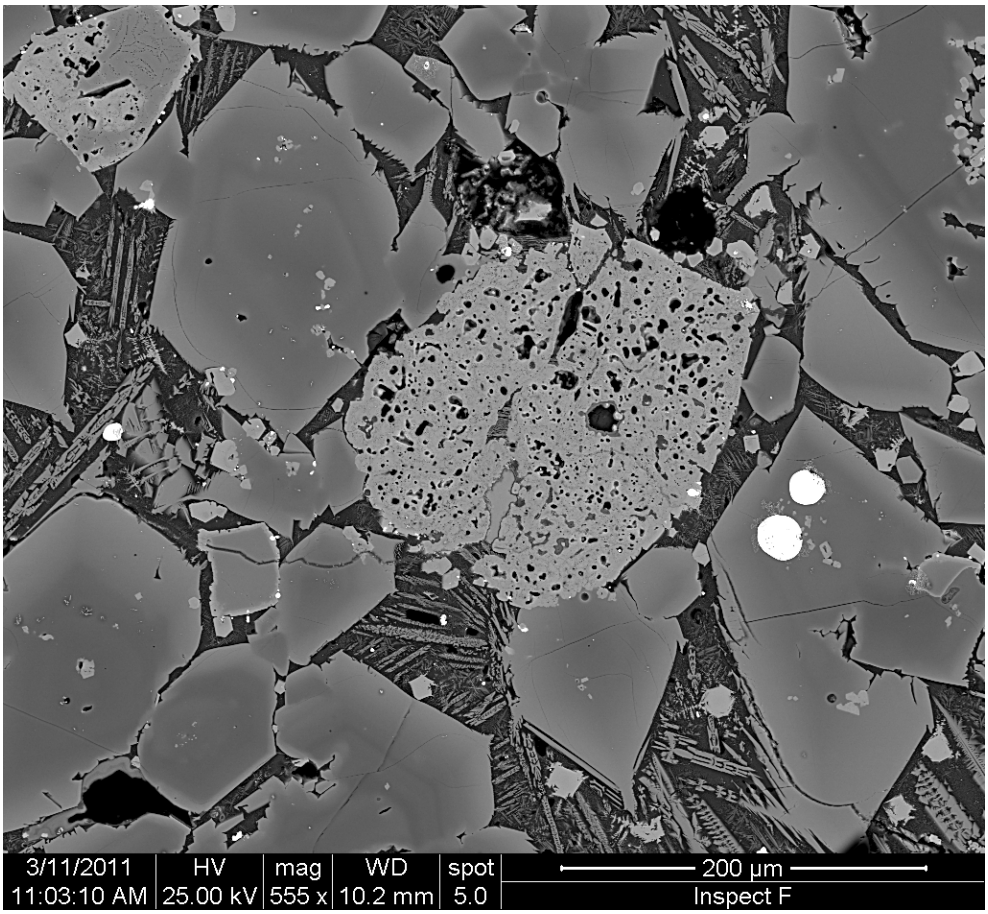
Hand Specimin



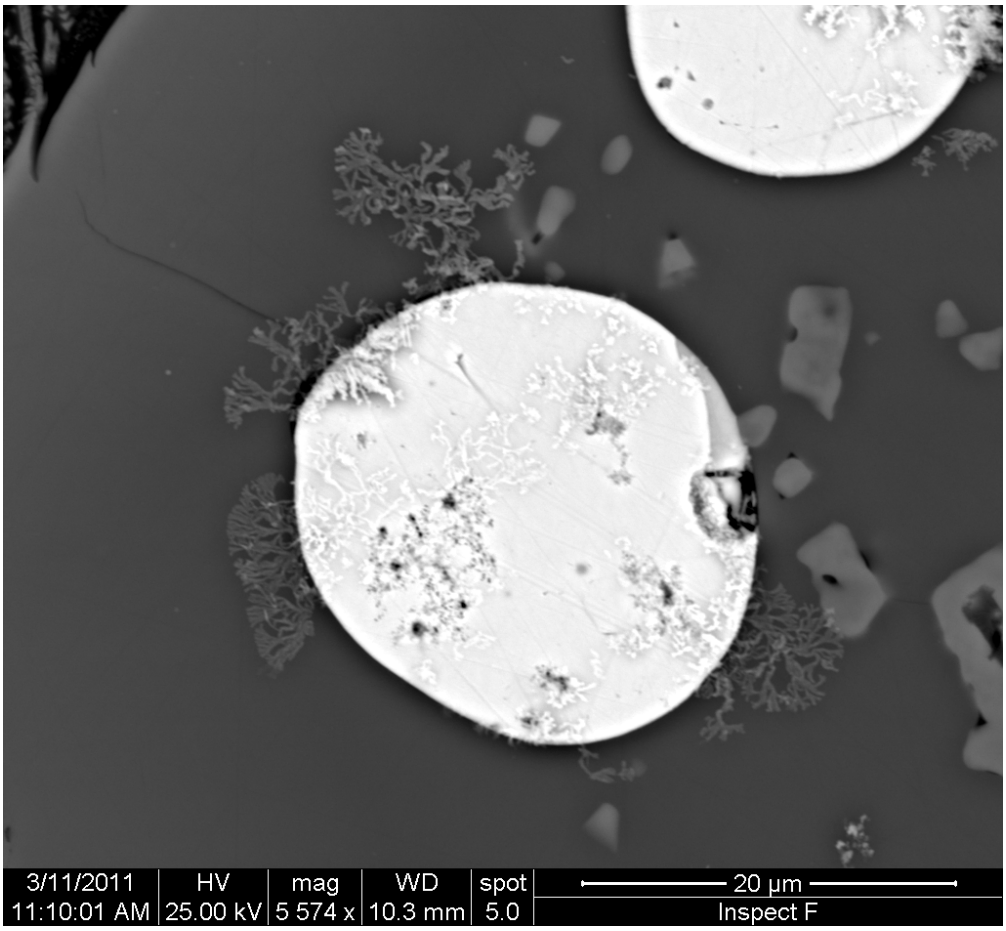
Micrograph 1



Micrograph 2



Micrograph 3

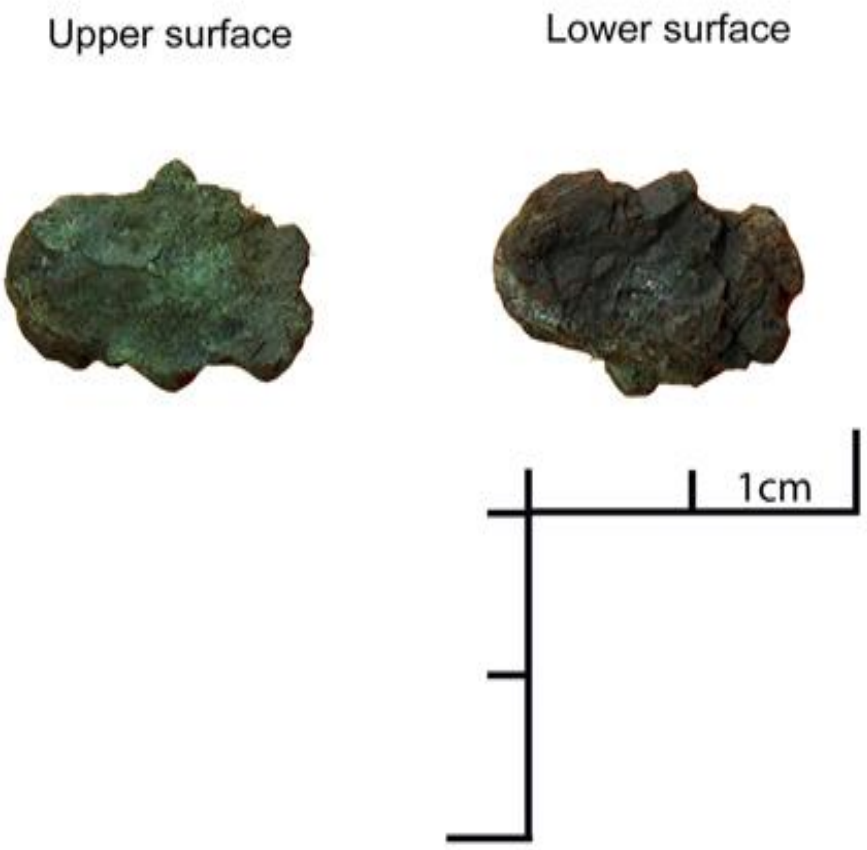


Micrograph 4

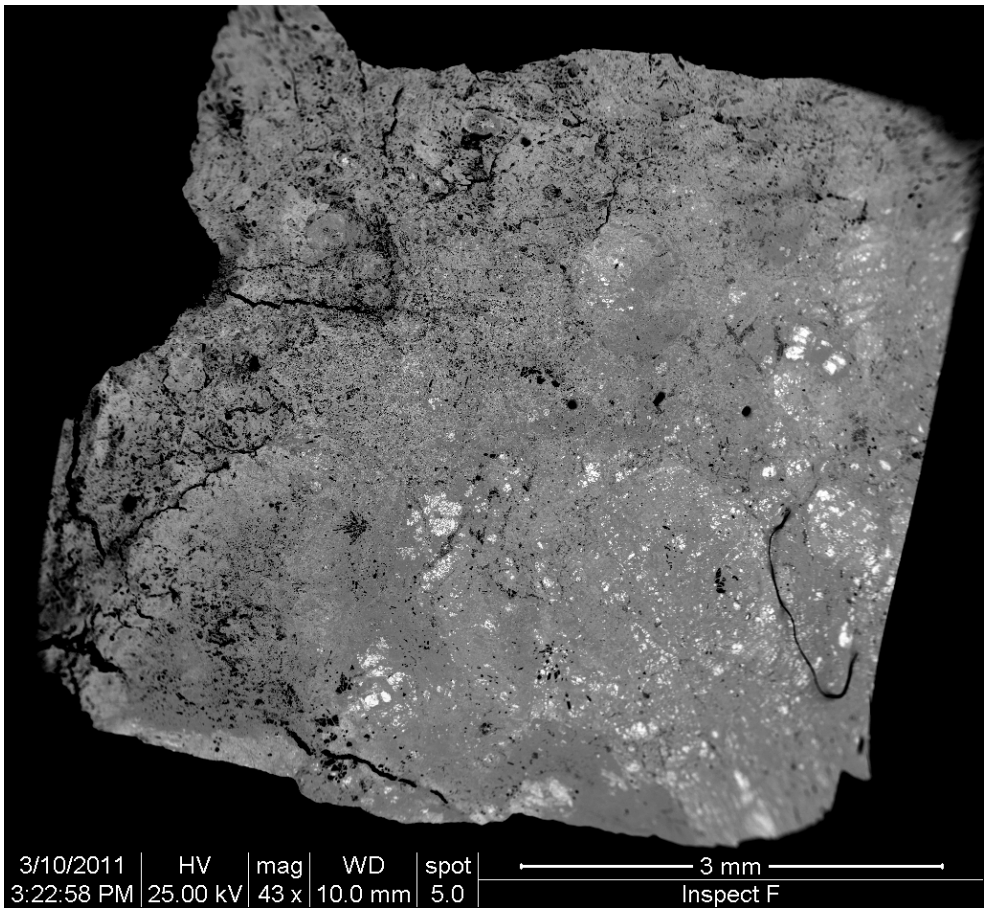
Site Code *STEP09* **Sample** *128* **Type** *Ore* **Area** *Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

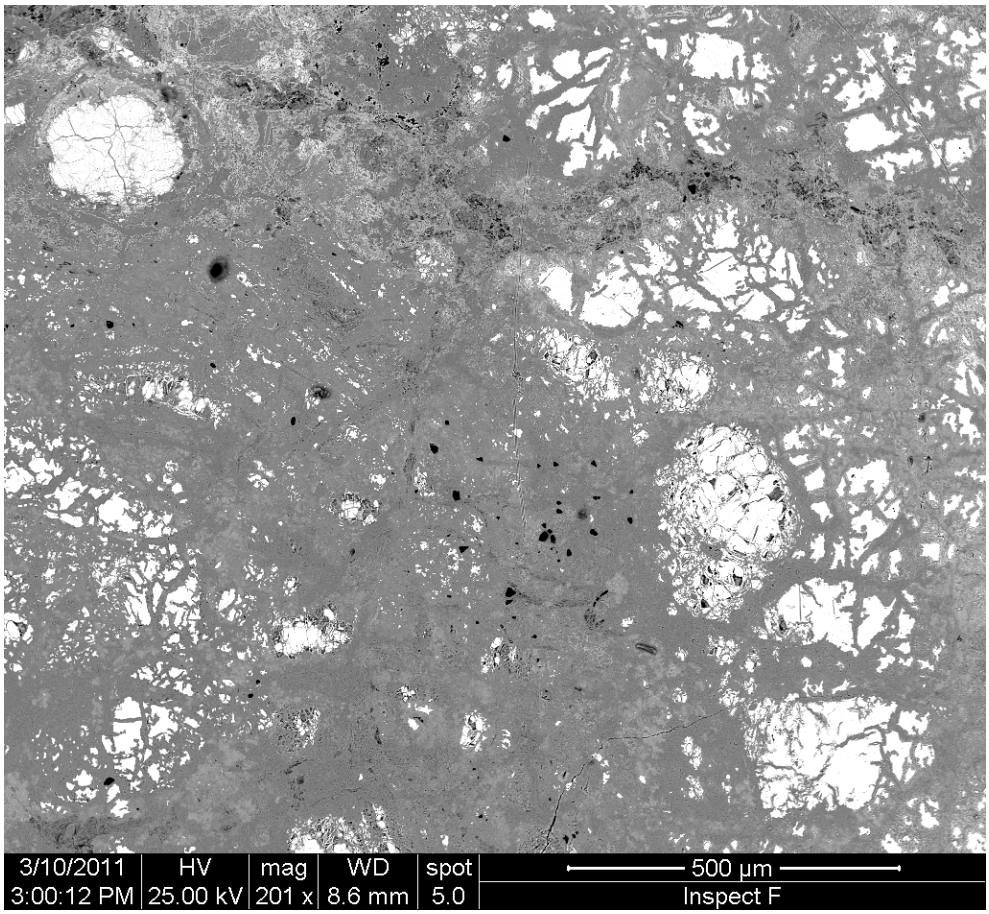
Hand Specimin



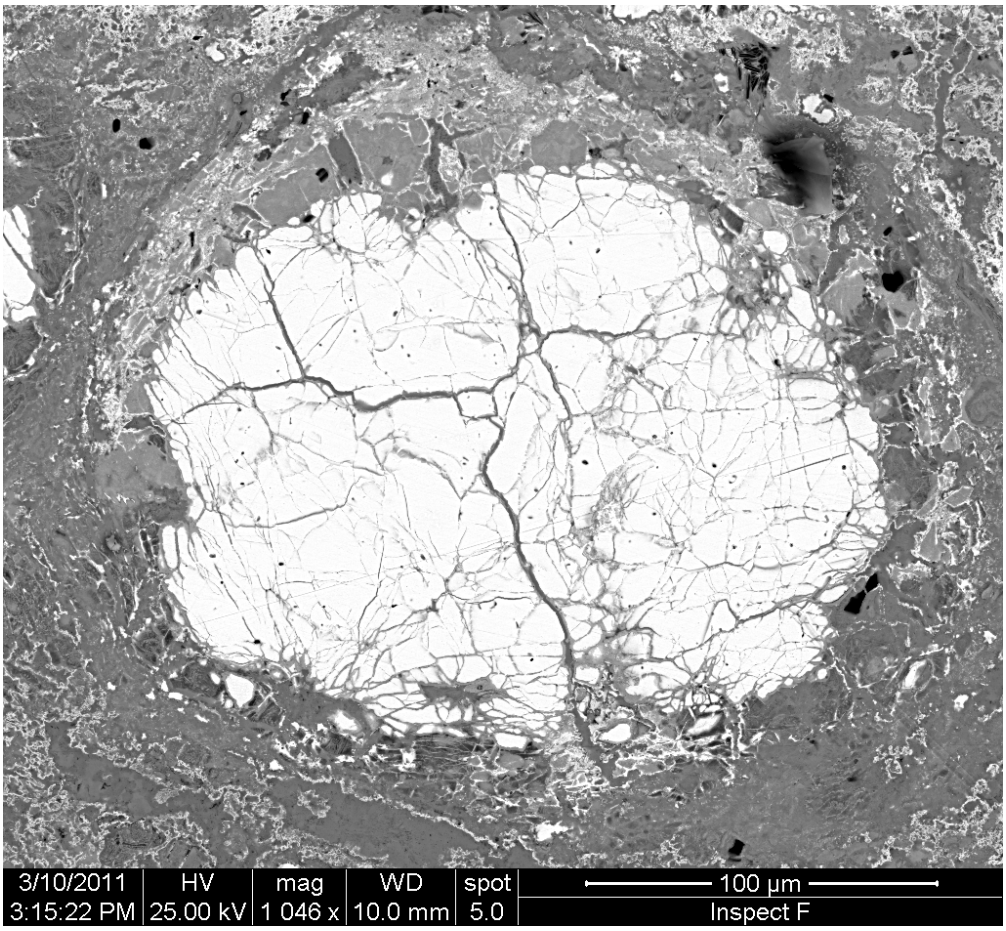
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

Site Code *STEP09* **Sample** *131* **Type** *Slag* **Area** *Trench*

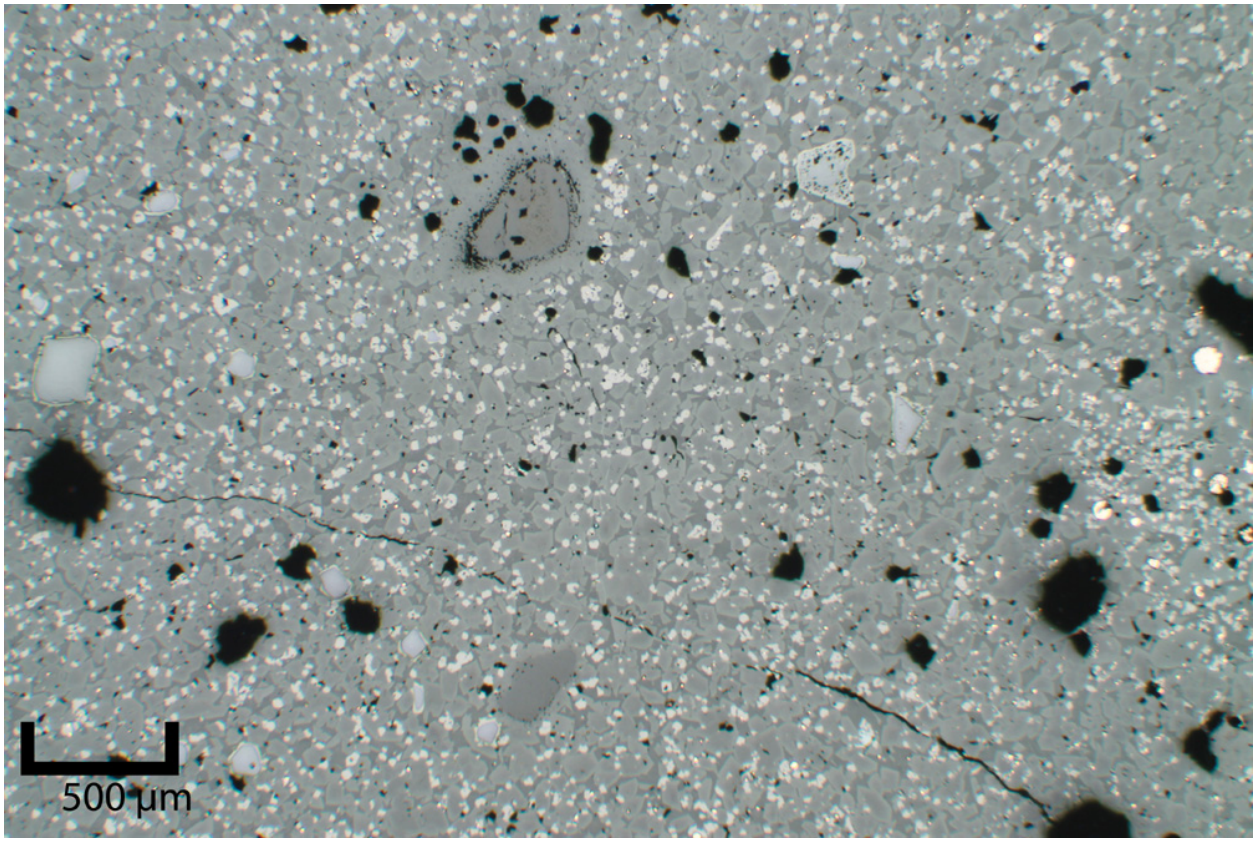
Wustite	*Rare*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Rare*	
Delafossite		
Metallic copper	*Rare*	
Sulphides	*Rare*	
Euheadral fayalite	*Dominant*	
Matrix		
Additional Phases	*, occasional chromites*	

Chromite ✕ ***Present*** **Group** *B3*

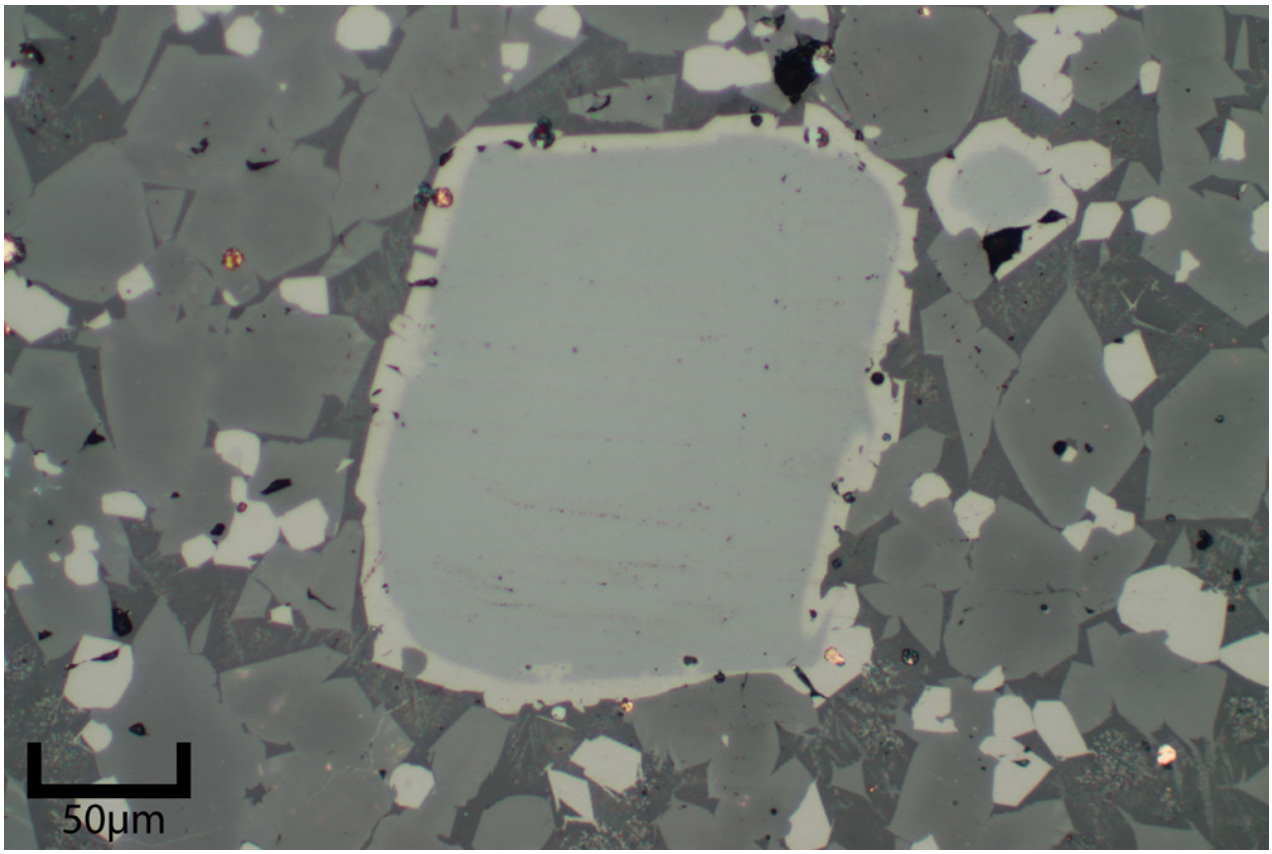
Hand Specimin



Micrograph 1



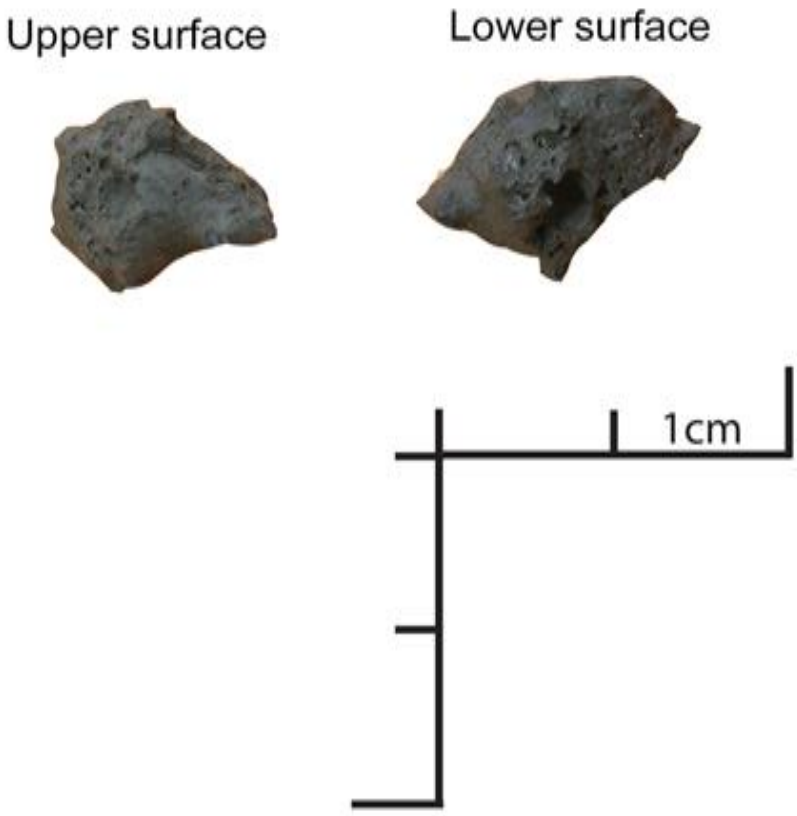
Micrograph 2



Site Code *STEP09* **Sample** *136* **Type** *Slag* **Area** *P Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

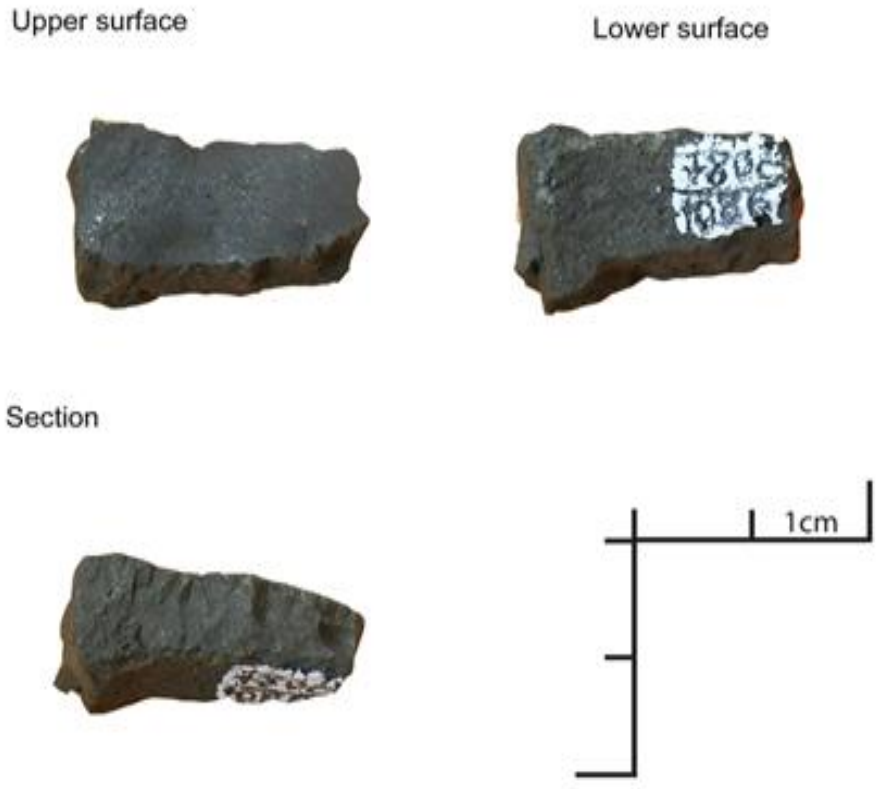


Site Code *STEP09* **Sample** *140.2* **Type** *Slag* **Area** *Trench*

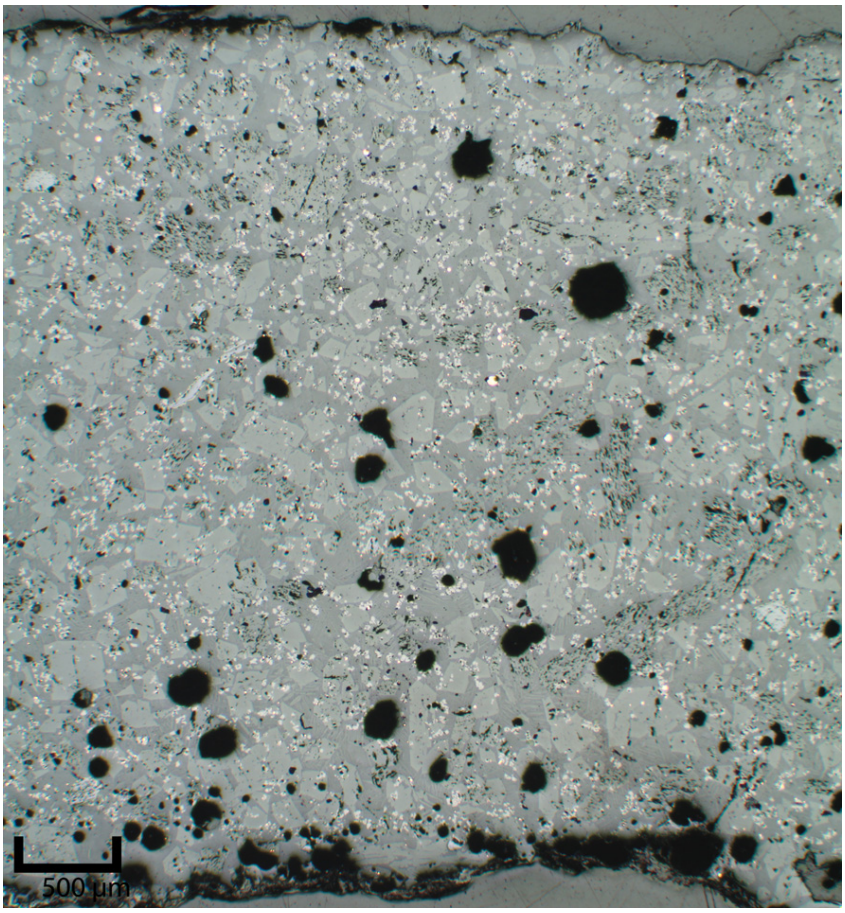
Wustite	*Rare*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Frequent*	
Delafossite		
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Common*	
Matrix	*Glassy 10-25%*	
Additional Phases	*occasional chromites,*	

Chromite ✕ ***Present*** **Group** *D3*

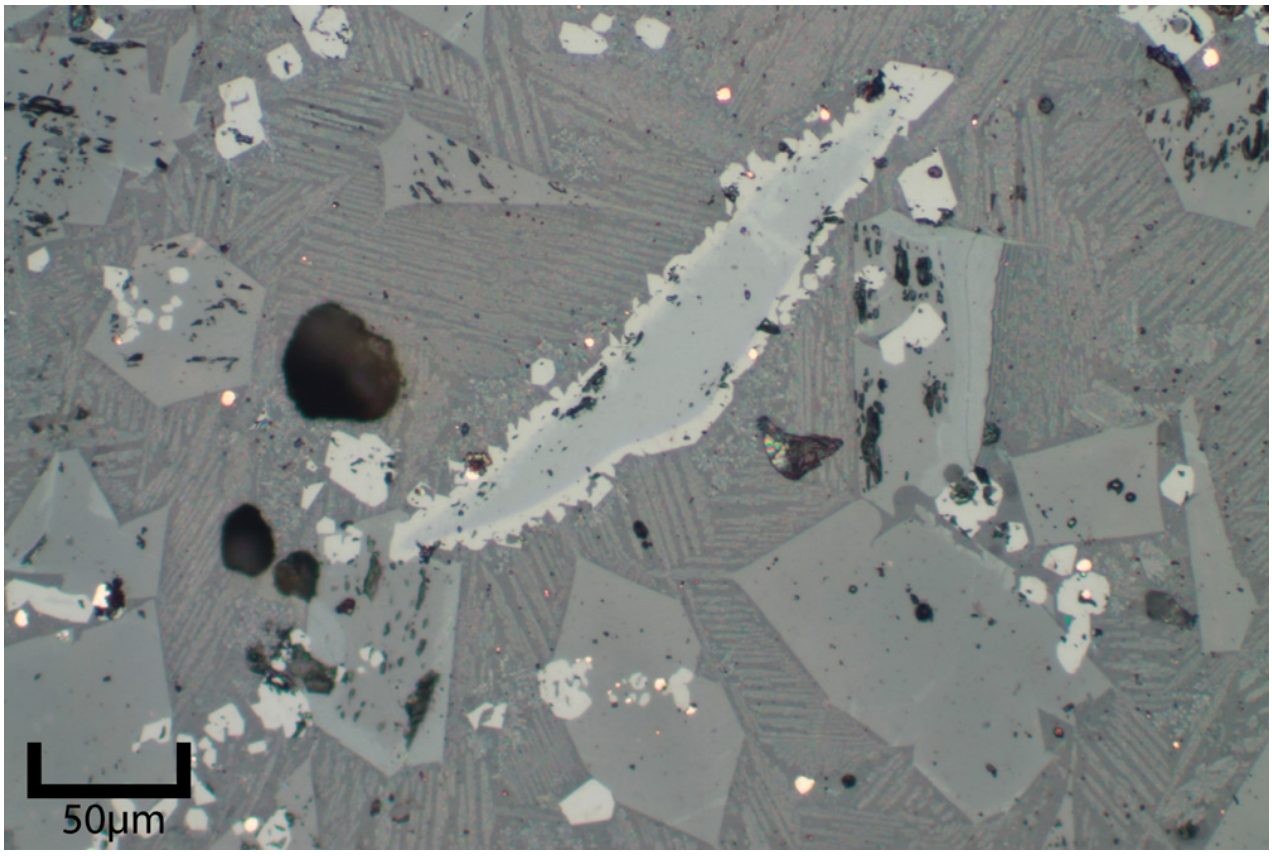
Hand Specimin



Micrograph 1



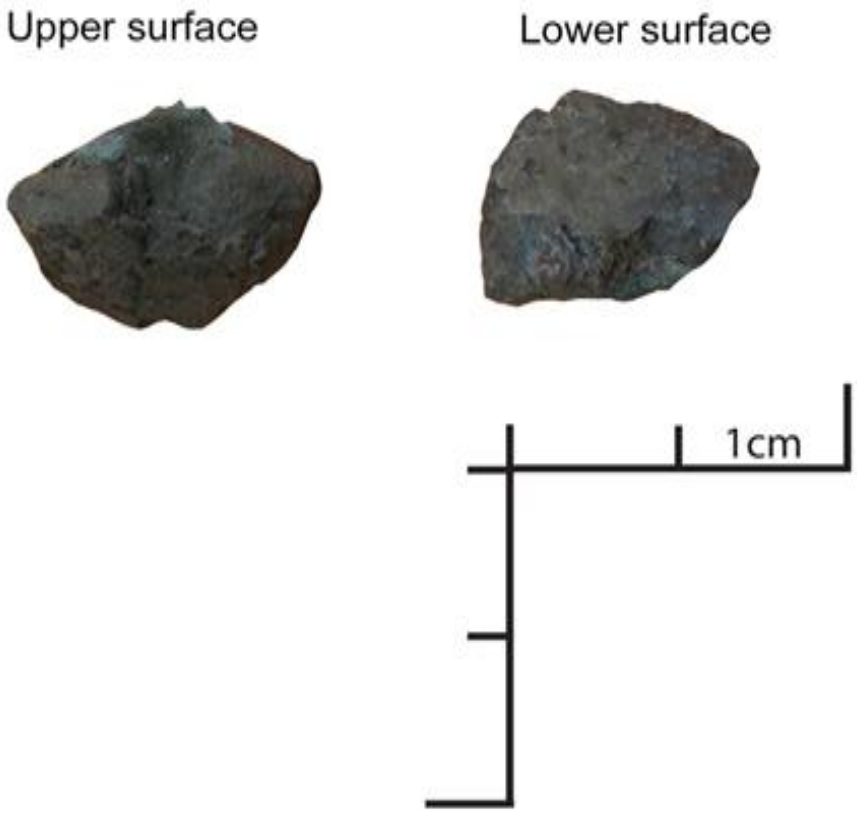
Micrograph 2



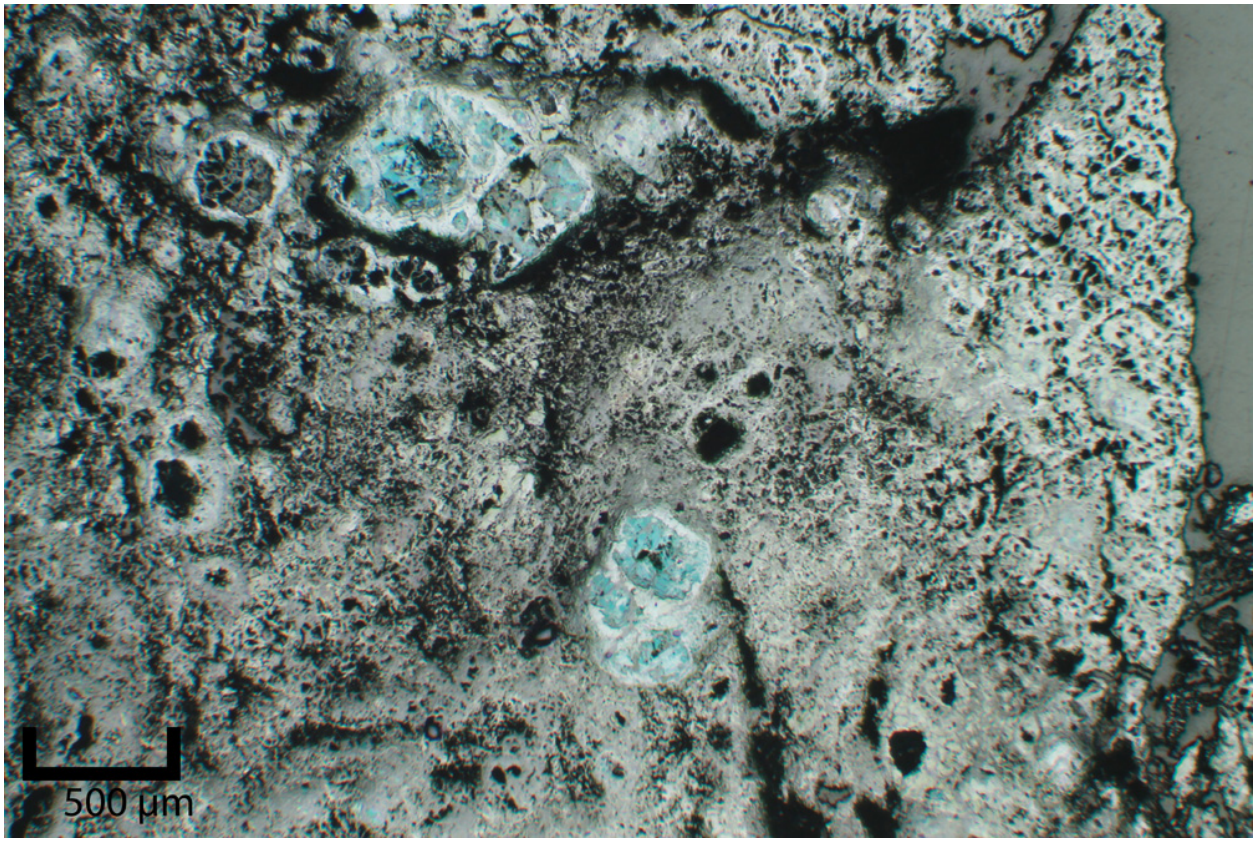
Site Code *STEP09* **Sample** *180* **Type** *Ore* **Area** *Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

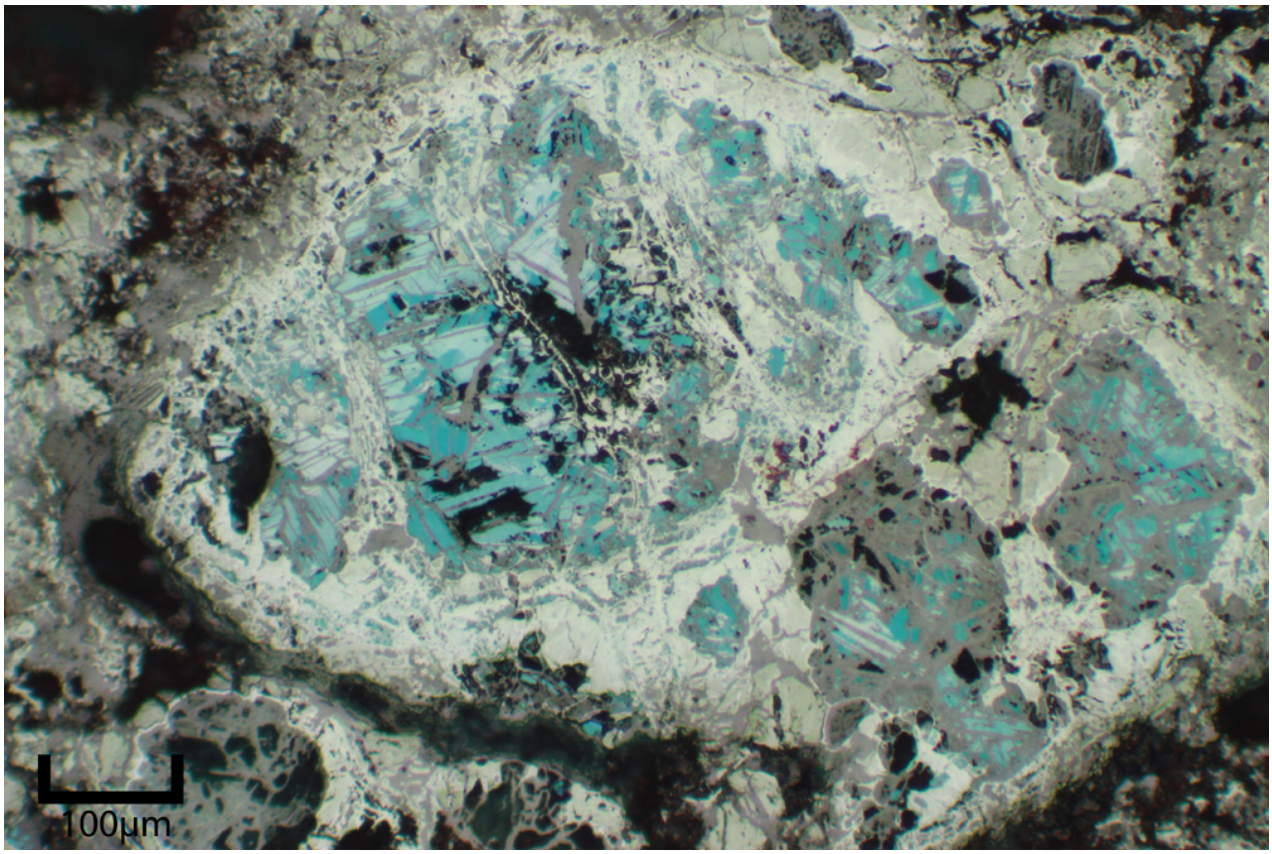
Hand Specimin



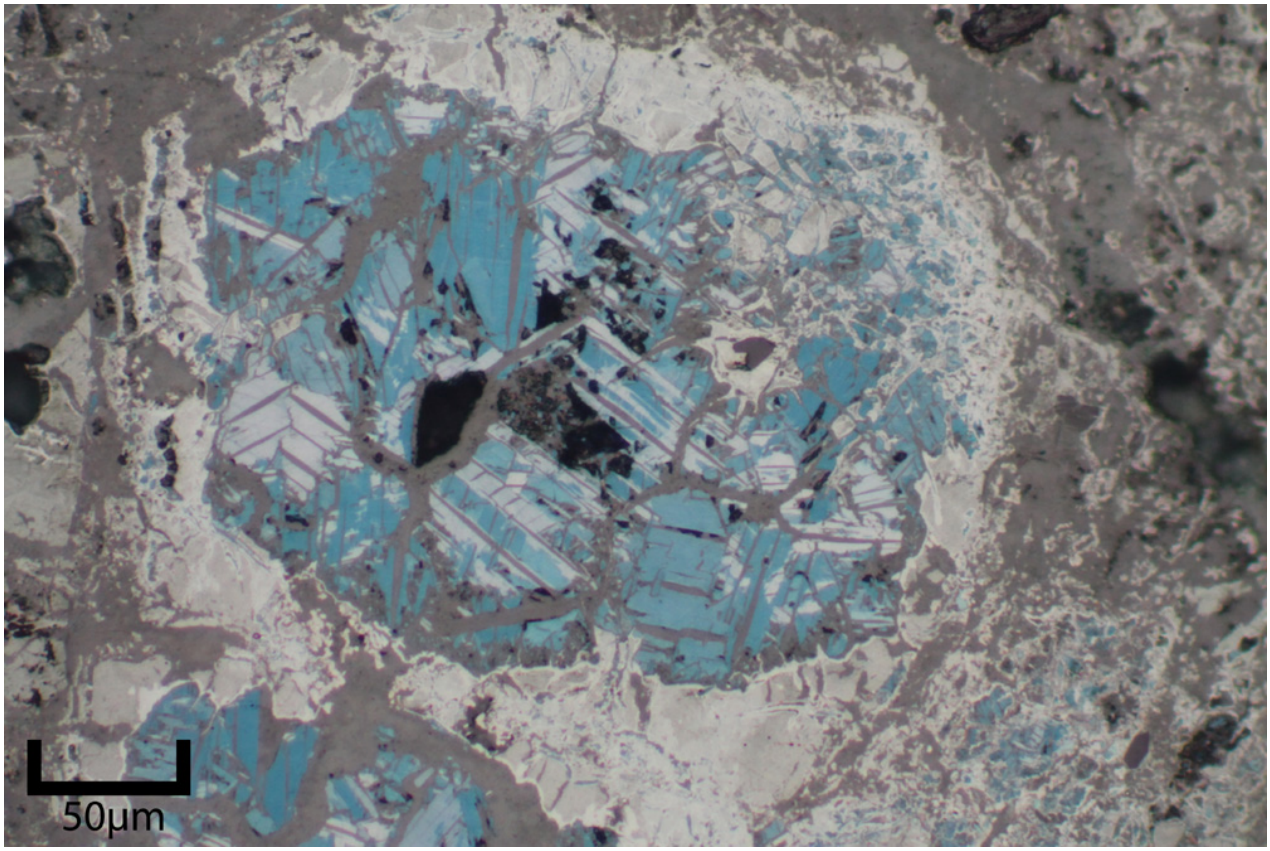
Micrograph 1



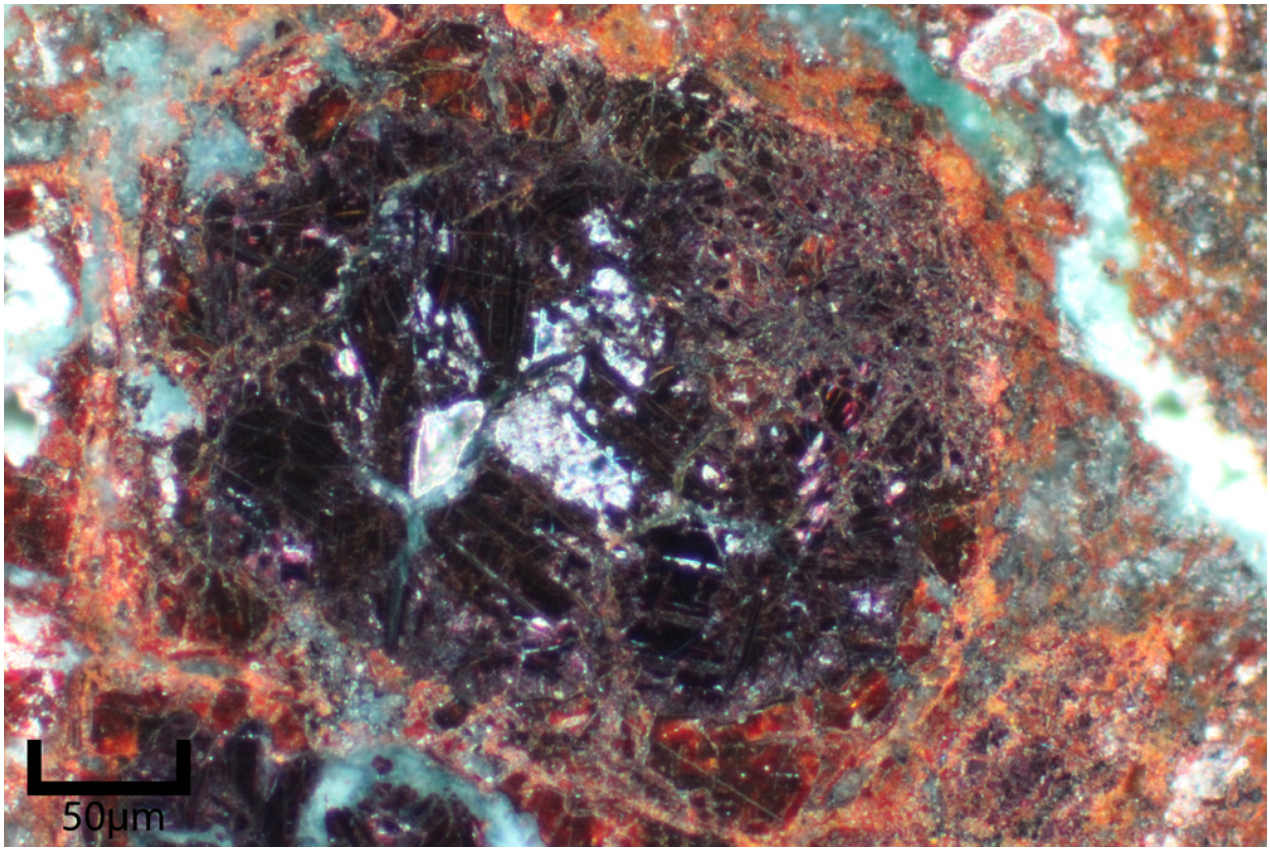
Micrograph 2



Micrograph 3



Micrograph 4

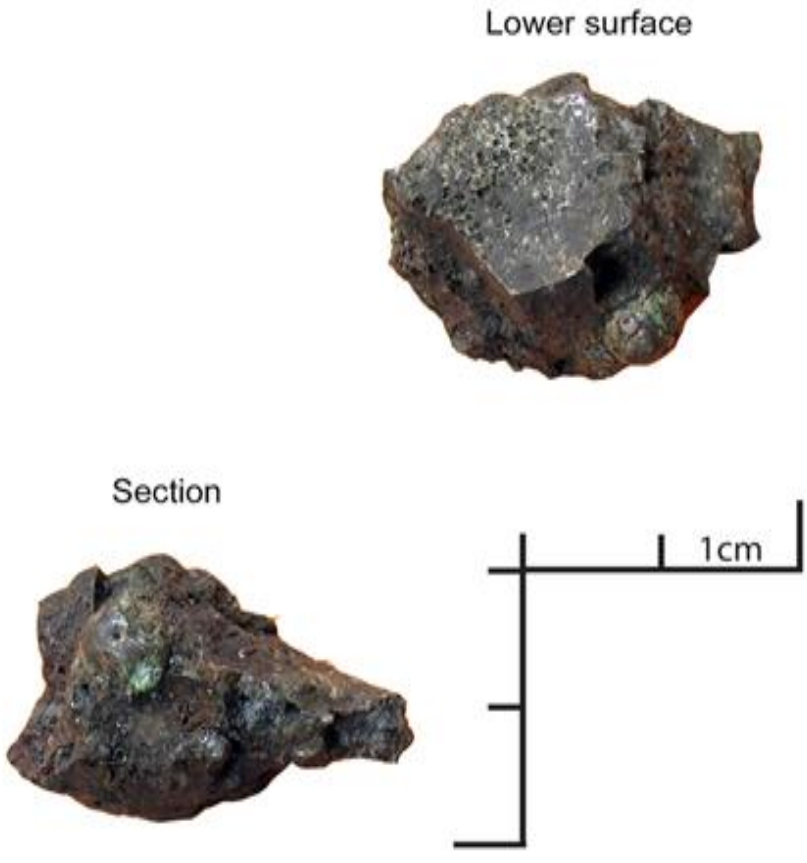


Site Code *STEP09* **Sample** *196* **Type** *Slag* **Area** *Cu TP1*

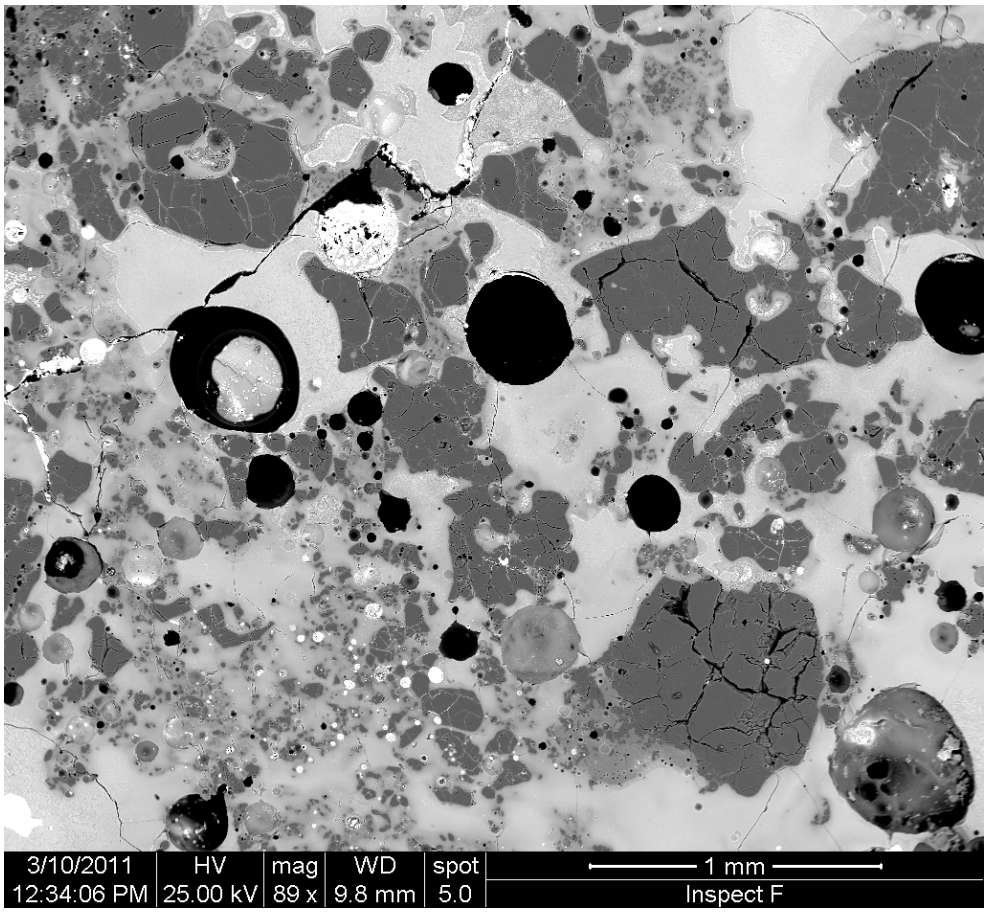
Wustite	*Absent*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Absent*	
Delafossite	*Absent*	
Metallic copper	*Common*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 90-100%*	
Additional Phases	*frequent free silica*	

Chromite ***Present*** **Group** *C1*

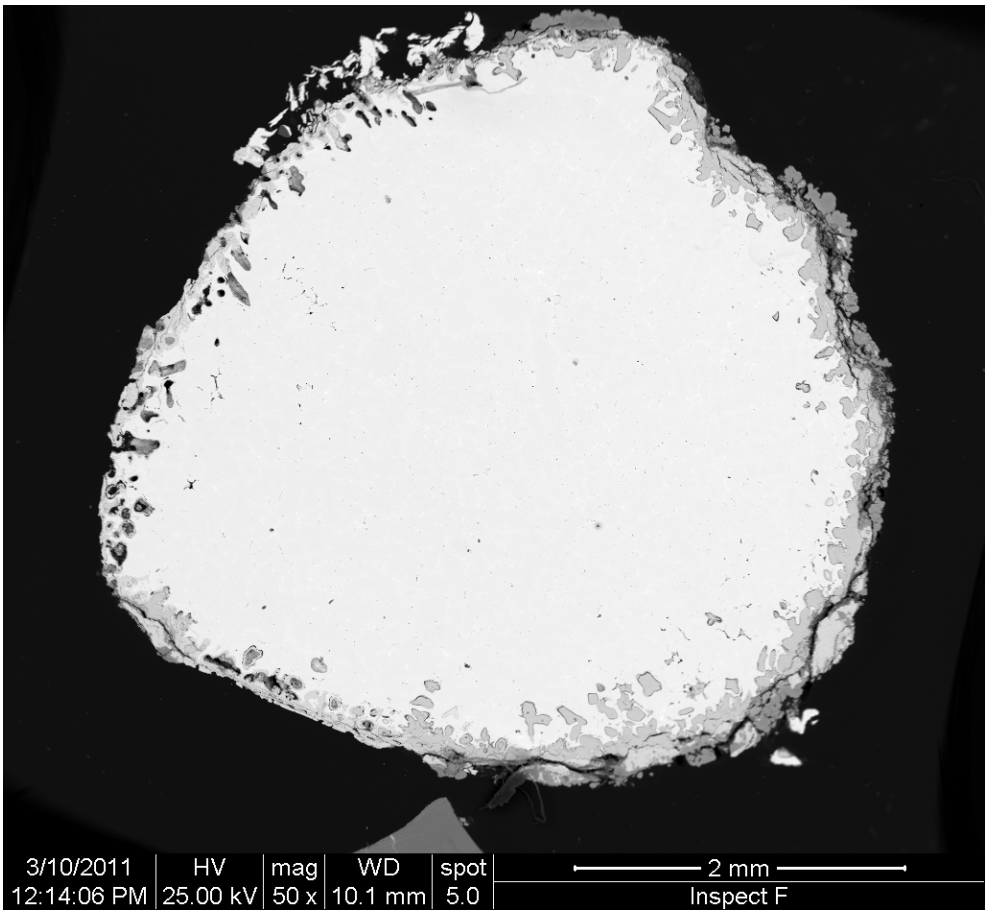
Hand Specimin



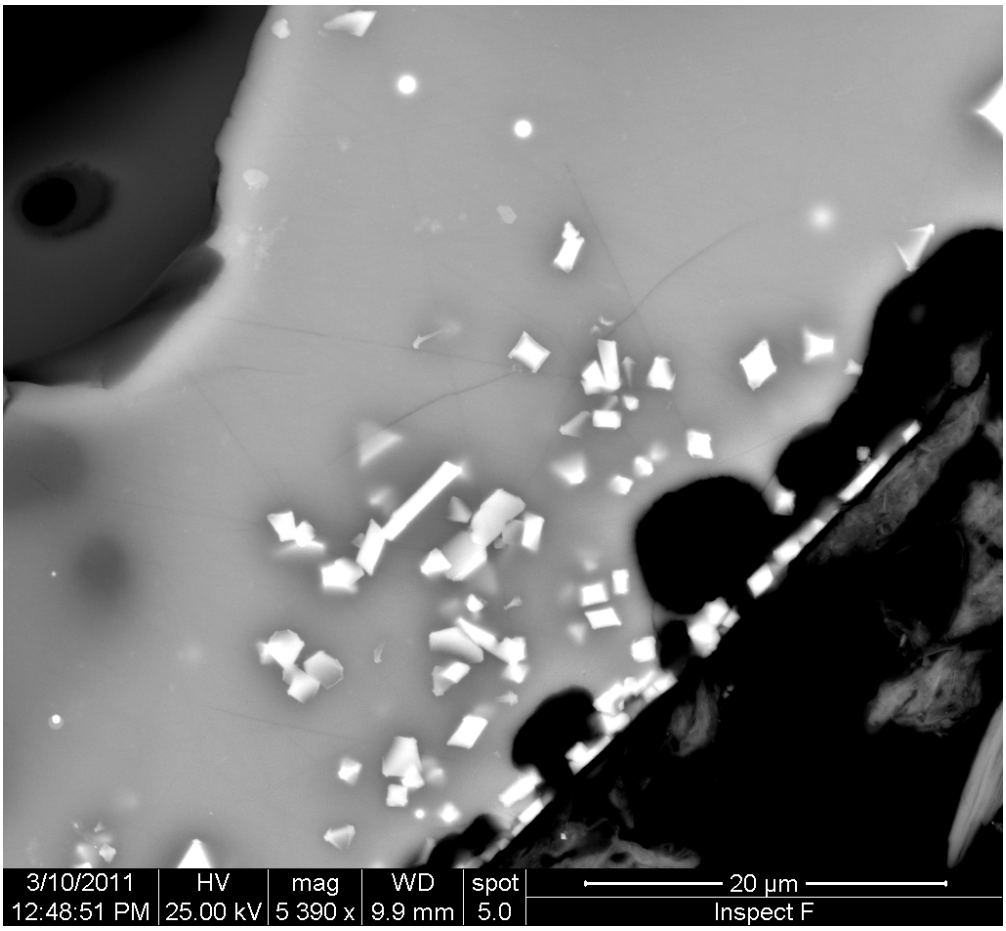
Micrograph 1



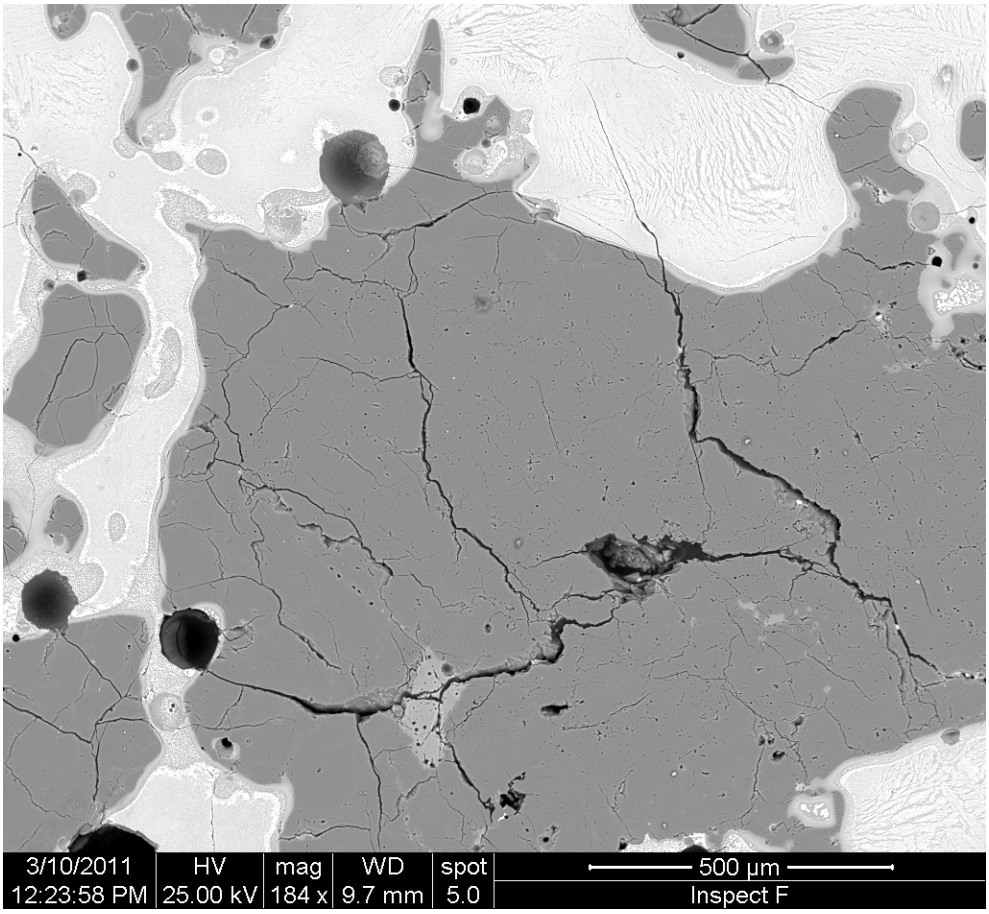
Micrograph 2



Micrograph 3



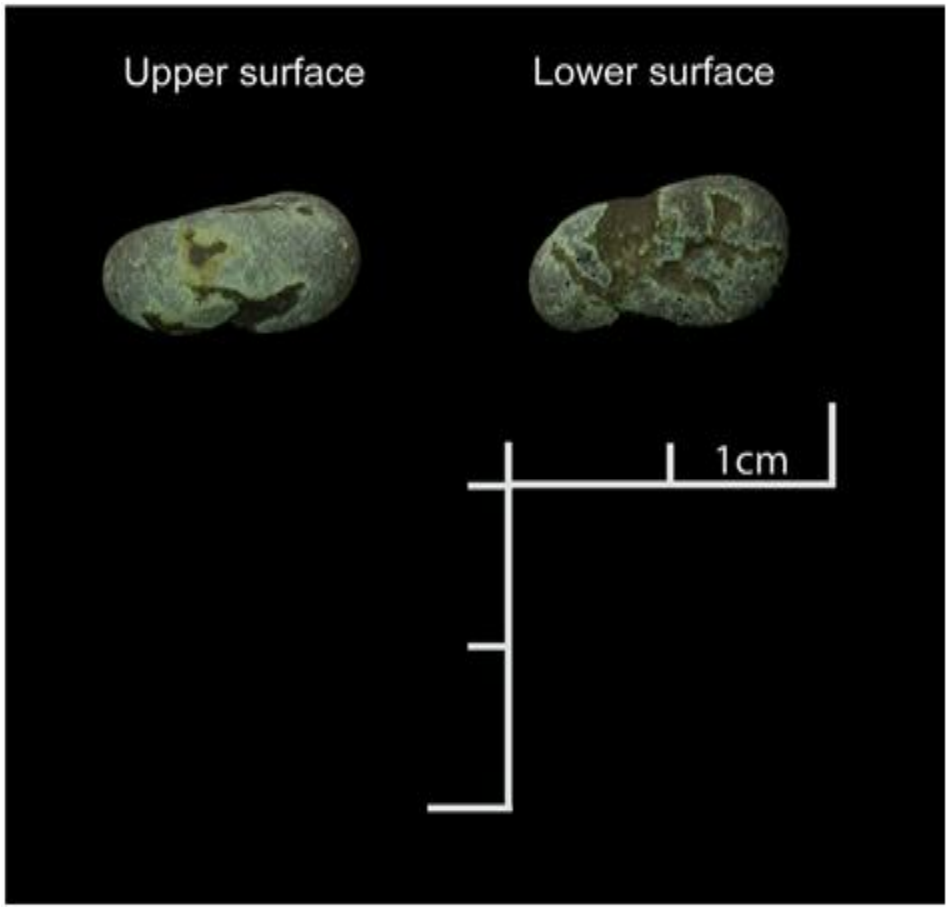
Micrograph 4



Site Code	*STEP09*	Sample	*216*	Type	*Cu Droplet*	Area	*Trench*

Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin



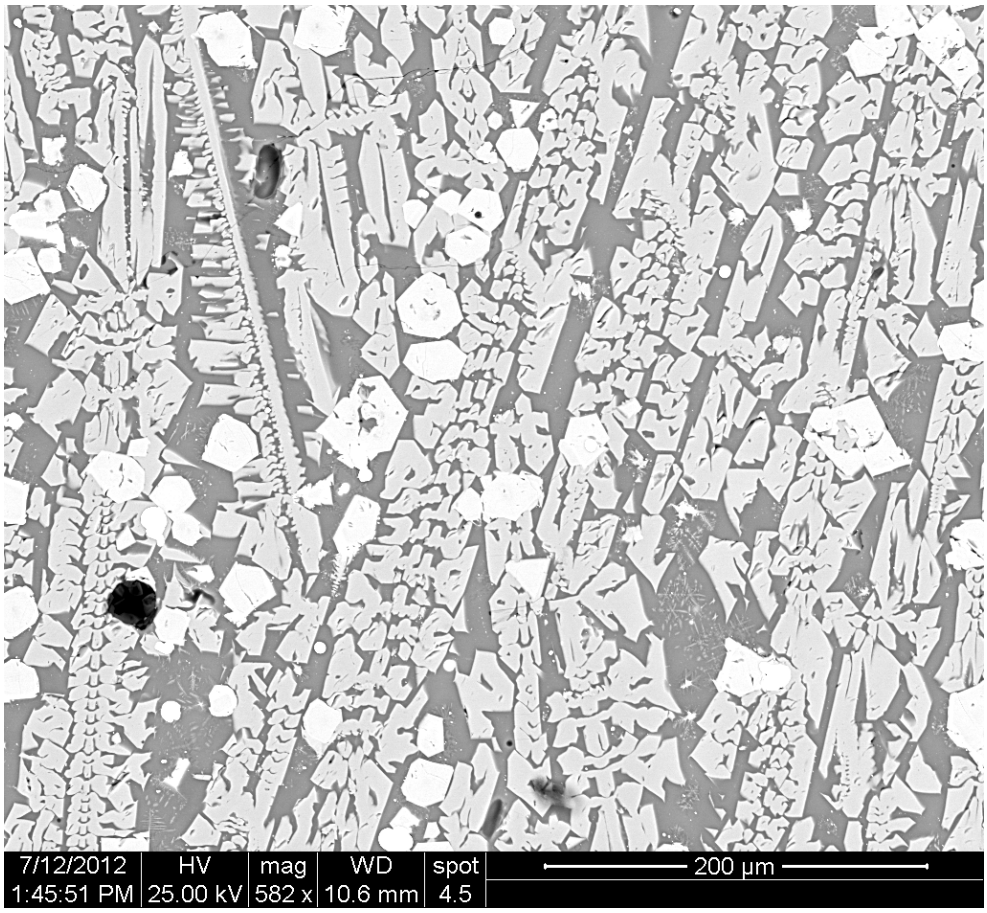
Site Code *STEP09* **Sample** *x1* **Type** *Slag* **Area** *2007TP*

Wustite	*Rare*	**Additional notes**
Magnetitie	*Common*	
Lath Fayalite	*Frequent*	
Delafossite		
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 25-50%*	
Additional Phases		

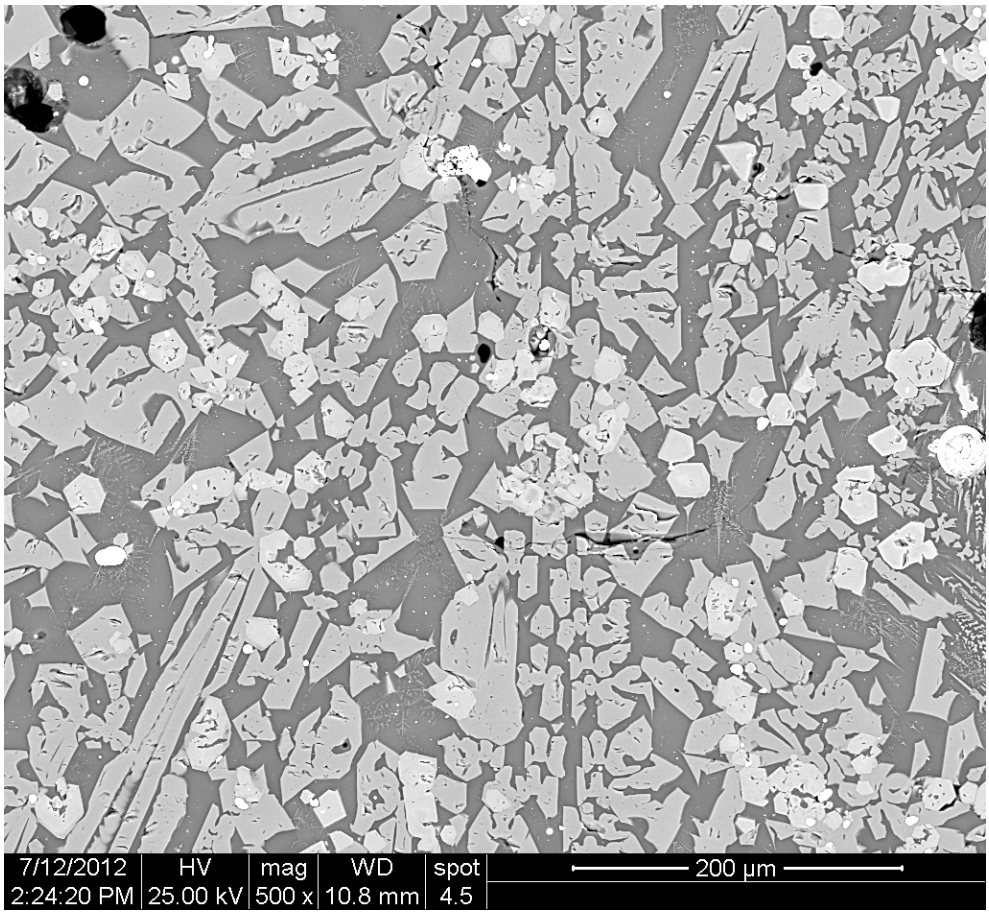
Chromite ***Present*** **Group** *A3*

Hand Specimin

Micrograph 1



Micrograph 2



Site Code *STEP2* **Sample** *220* **Type** *Slag* **Area** *Grave*

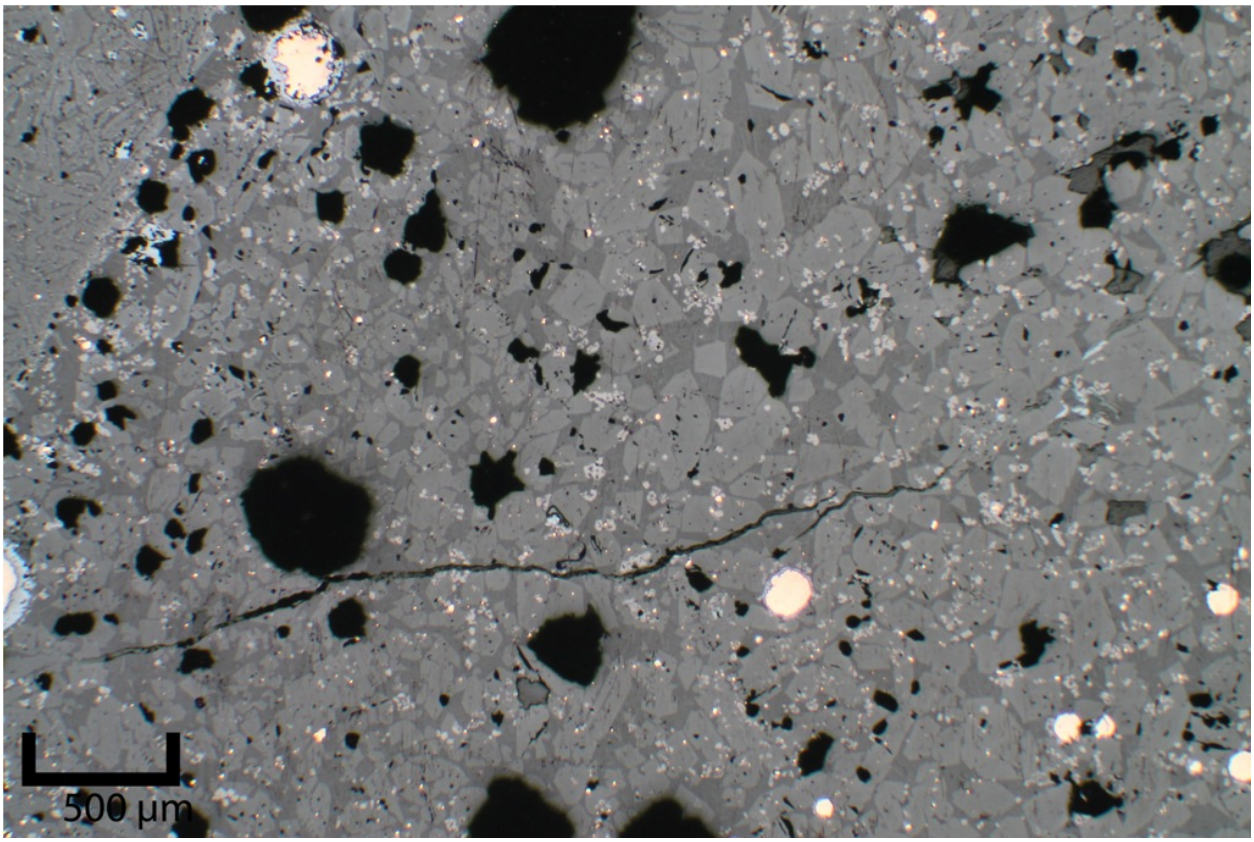
Wustite	*Rare*
Magnetitie	*Rare*
Lath Fayalite	*Rare*
Delafossite	
Metallic copper	*Occasional*
Sulphides	*Occasional*
Euheadral fayalite	*Frequent*
Matrix	*Glassy 25-50%*
Additional Phases	

Additional notes
probable ore inclusions

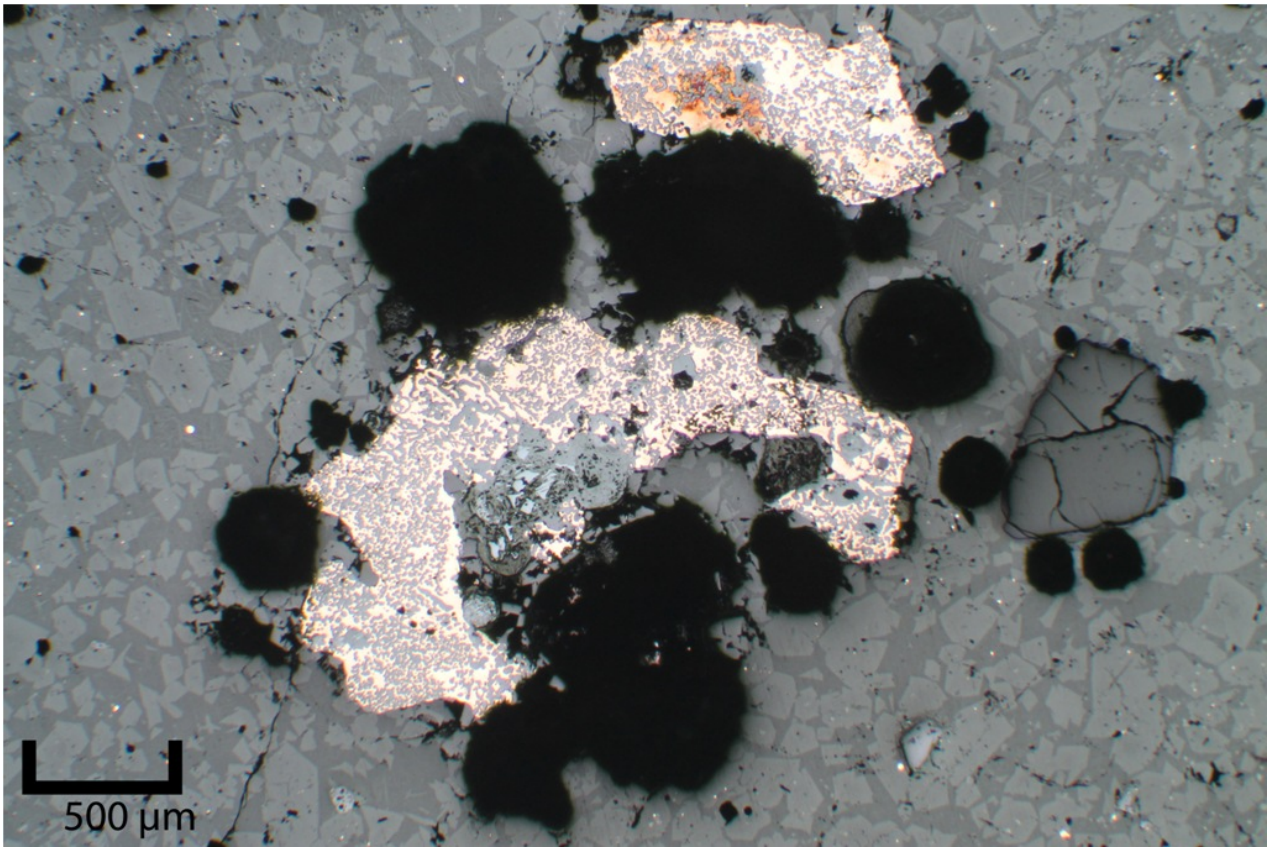
Chromite ***Present*** **Group** *B2*

Hand Specimin

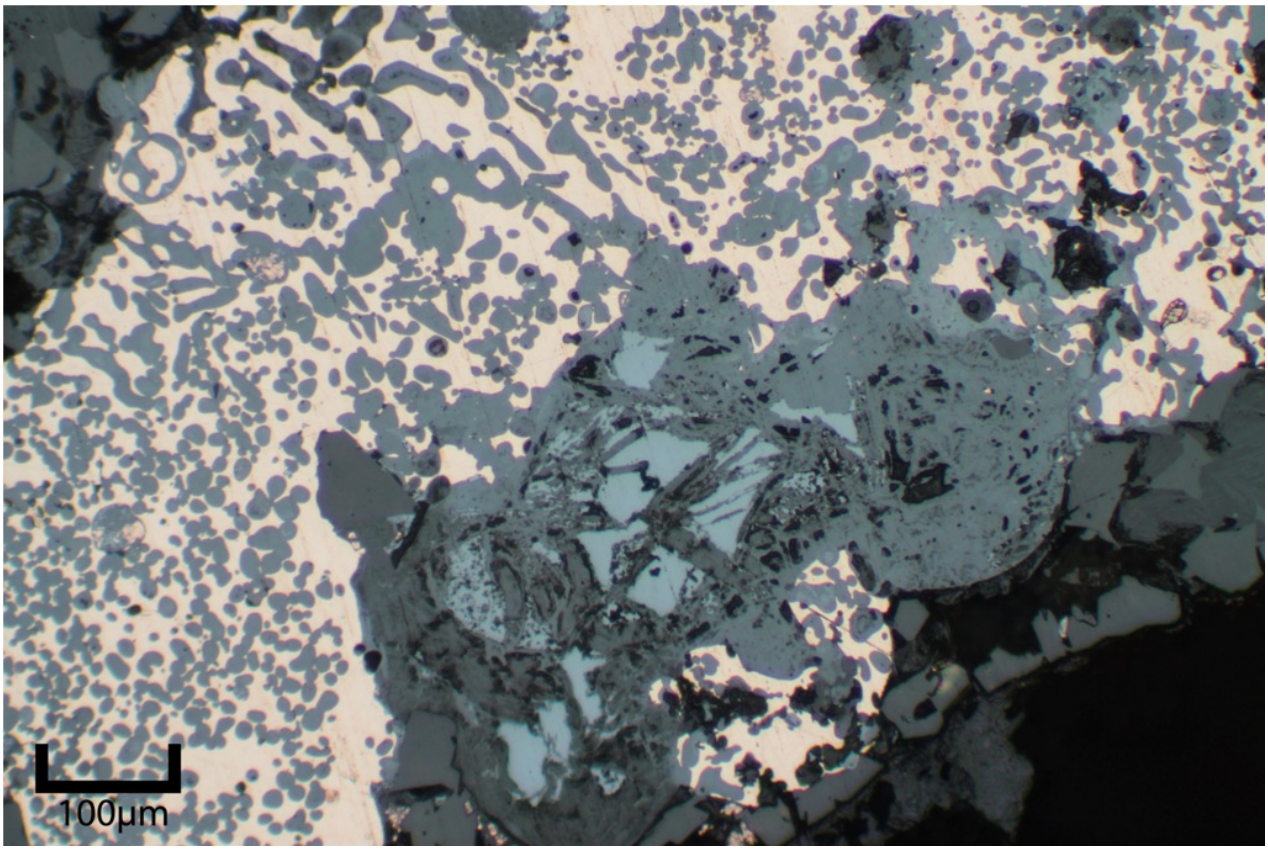
Micrograph 1



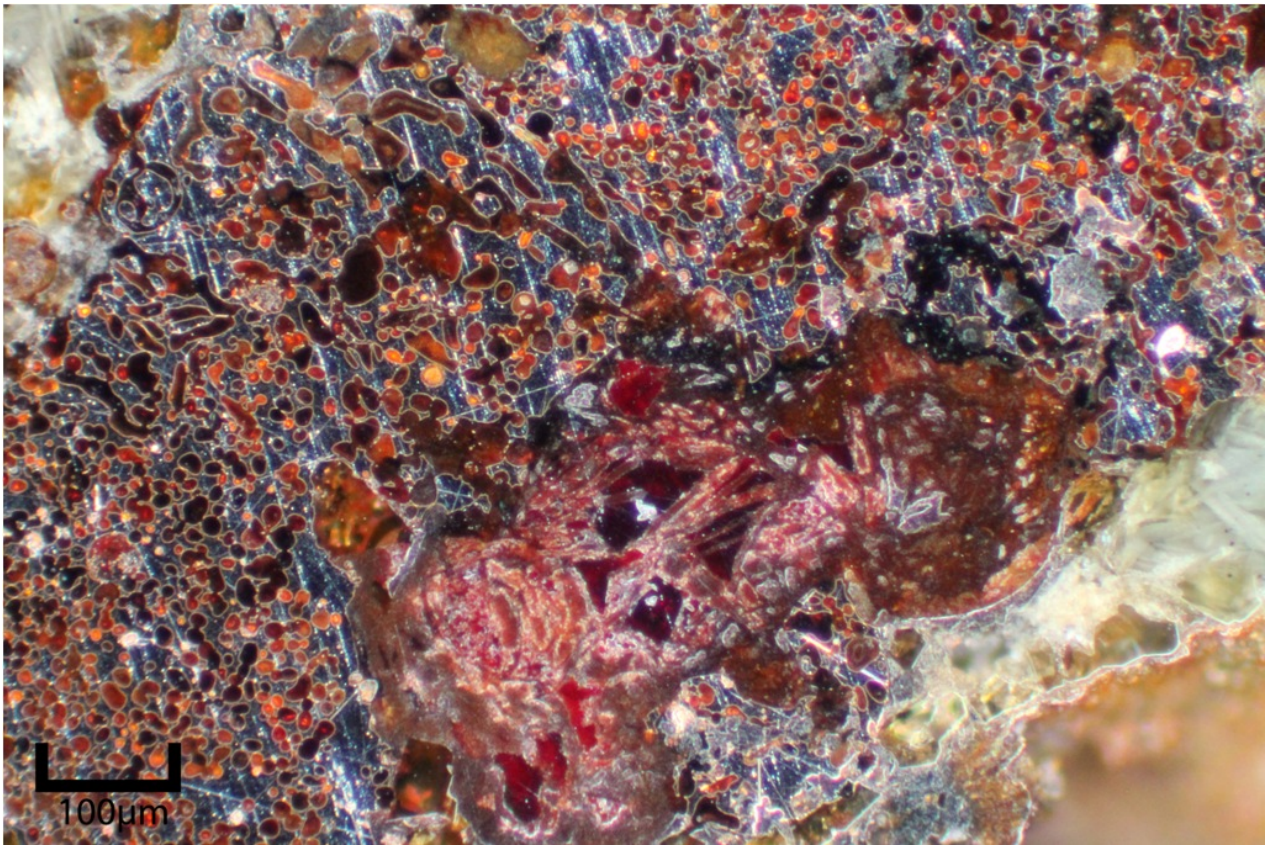
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *STEP2* **Sample** *223* **Type** *Slag* **Area** *Grave*

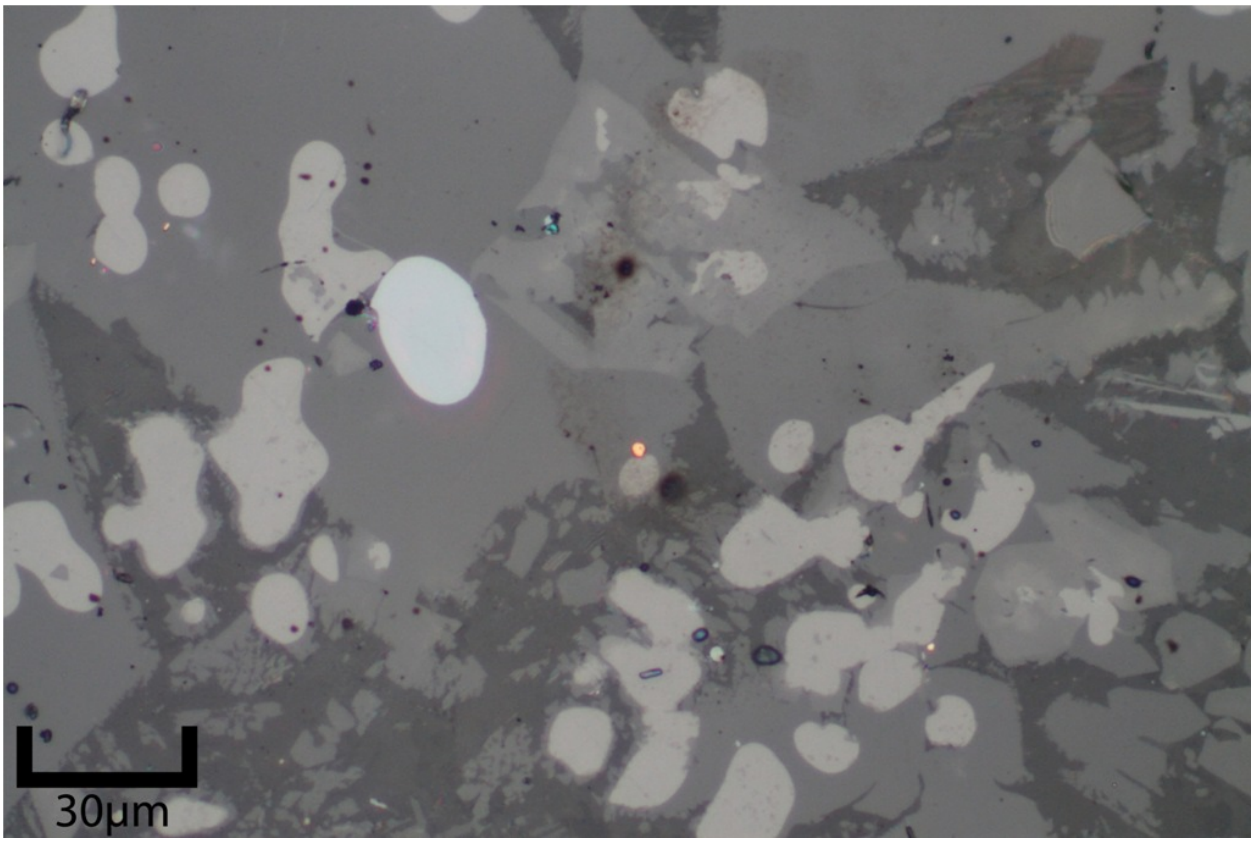
Wustite	*Occasional*
Magnetitie	*Absent*
Lath Fayalite	*Occasional*
Delafossite	
Metallic copper	
Sulphides	
Euheadral fayalite	*Occasional*
Matrix	
Additional Phases	

Additional notes
possible mineral inclusions

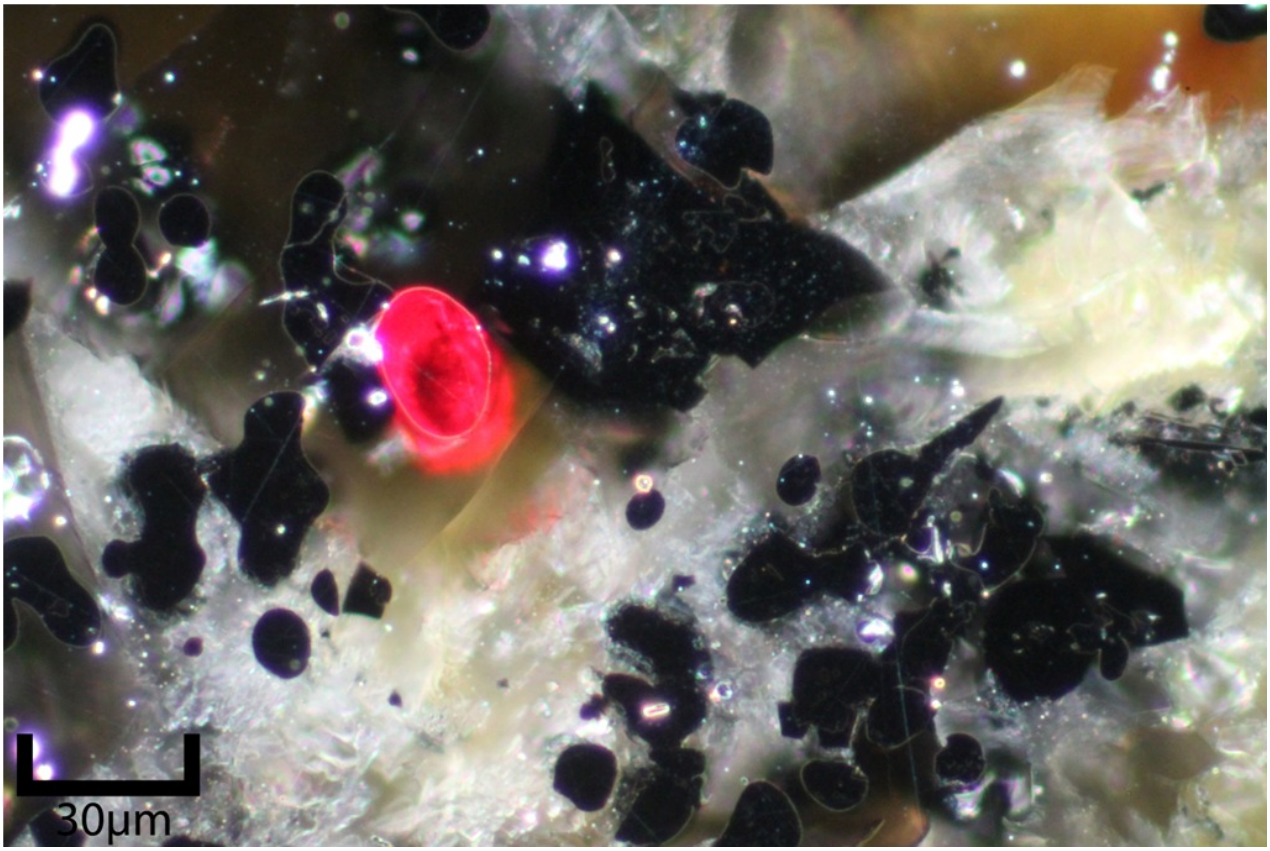
Chromite ***Present*** **Group** *D2*

Hand Specimin

Micrograph 1



Micrograph 2



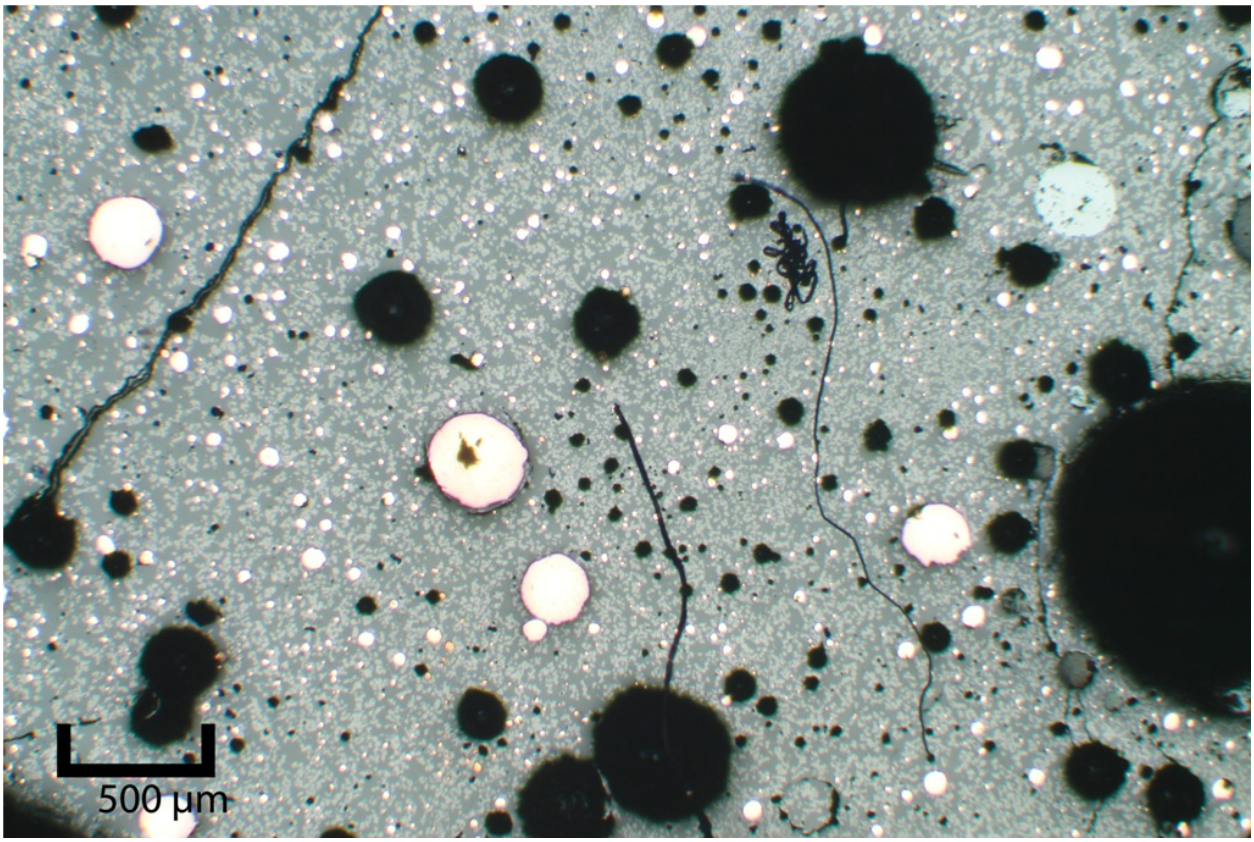
Site Code *STEP2* **Sample** *227.1* **Type** *Slag* **Area** *Grave*

Wustite	*Rare*	**Additional notes**
Magnetitie	*Frequent*	
Lath Fayalite	*Absent*	
Delafossite		
Metallic copper	*Common*	
Sulphides	*Occasional*	
Euheadral fayalite	*Absent*	
Matrix	*Glassy 50-75%*	
Additional Phases		

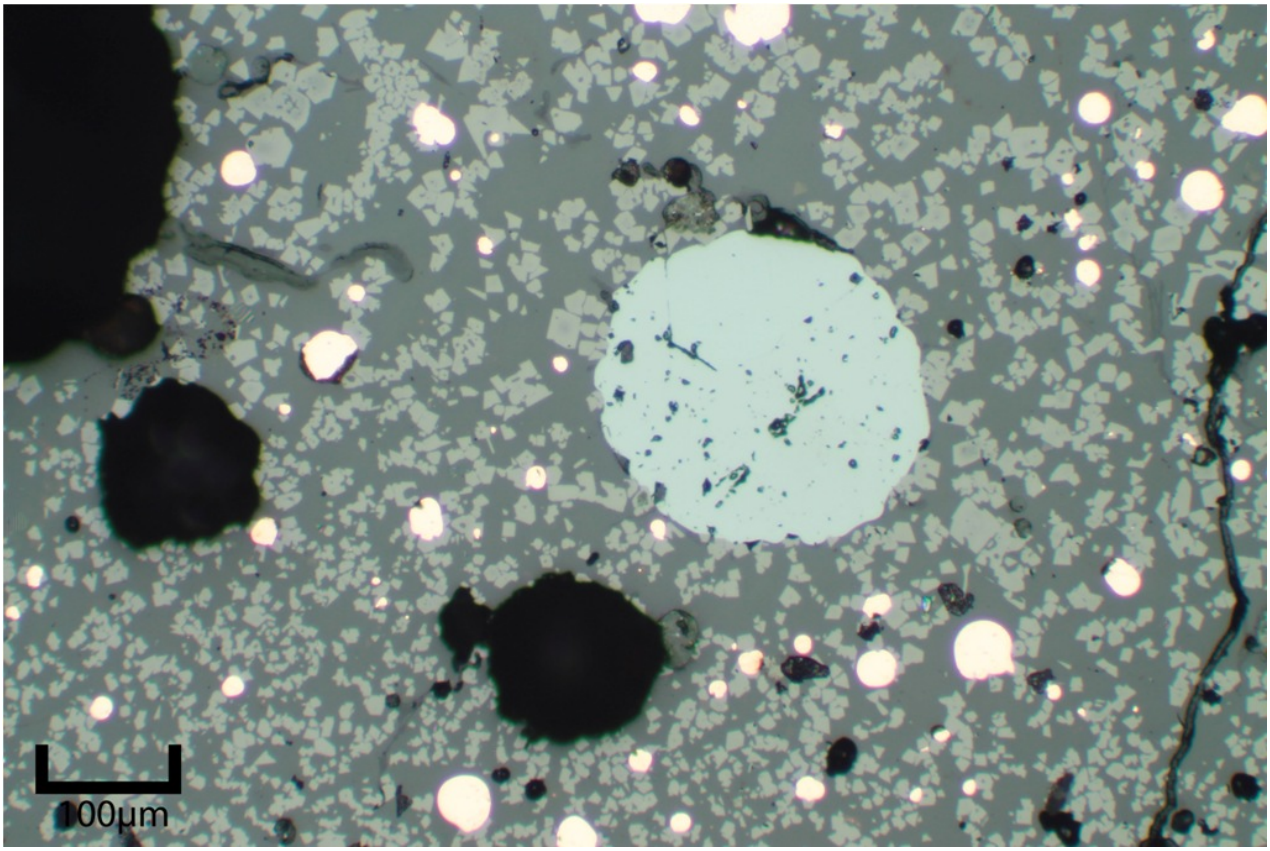
Chromite ***Present*** **Group** *C3*

Hand Specimin

Micrograph 1



Micrograph 2

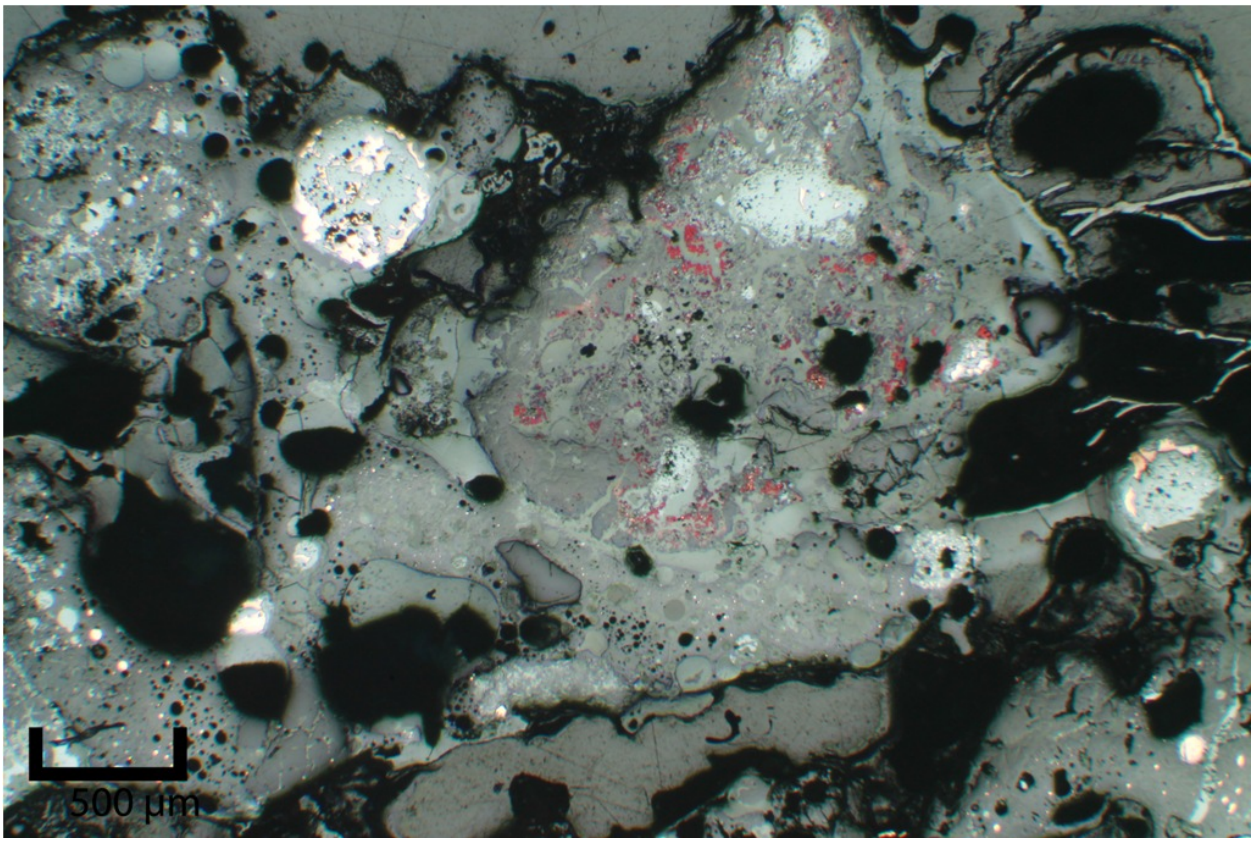


Site Code *STEP2* **Sample** *227.2* **Type** *Slag* **Area** *Grave*

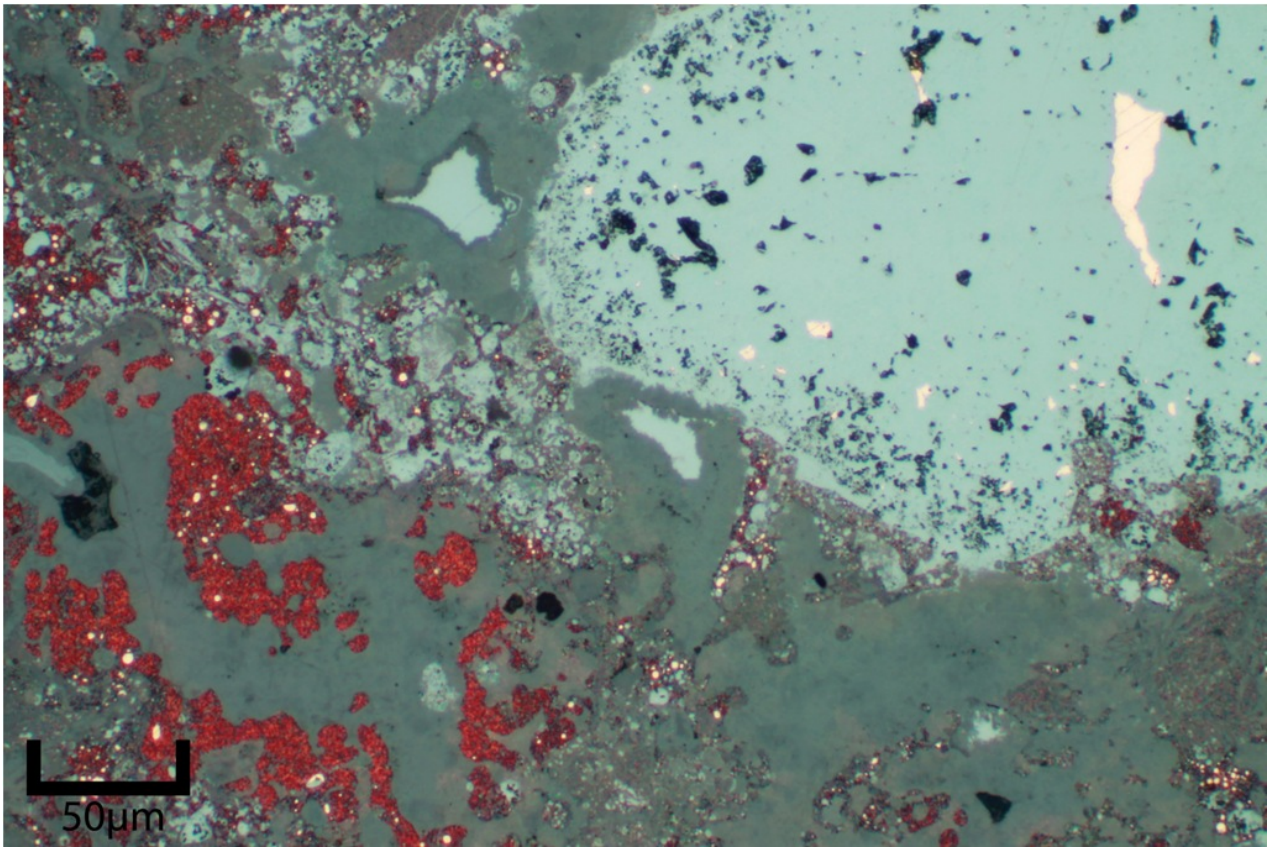
Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

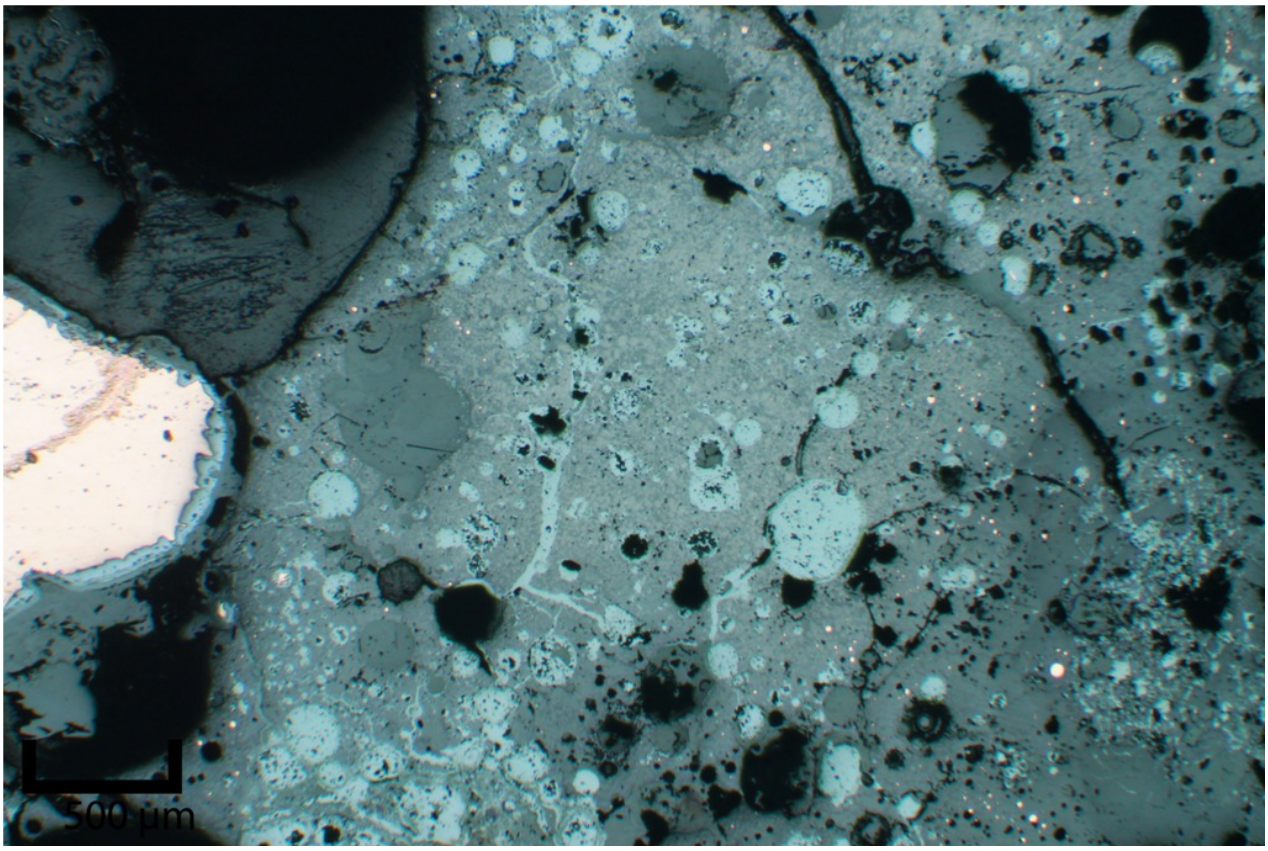
Micrograph 1



Micrograph 2



Micrograph 3



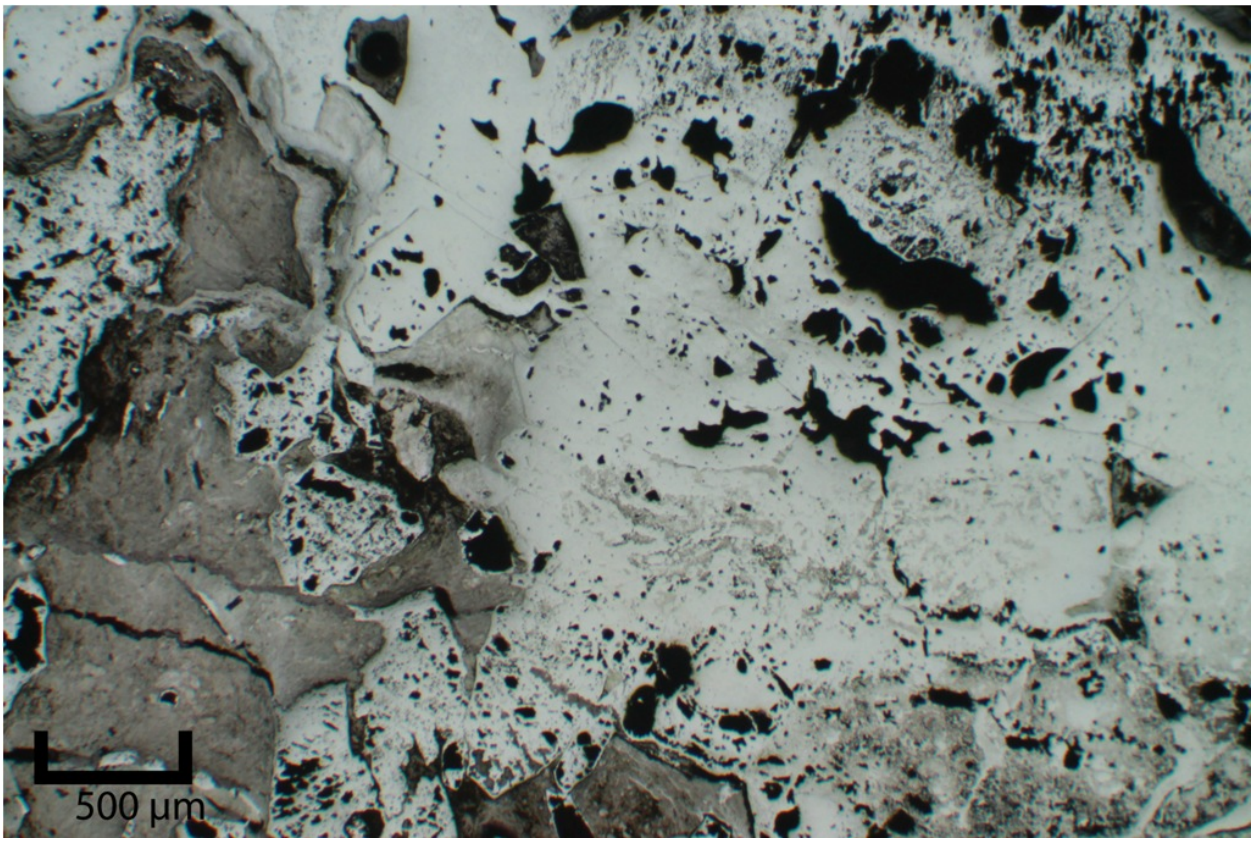
Micrograph 4

Site Code *STEP2* **Sample** *227.3* **Type** *Slag* **Area** *Grave*

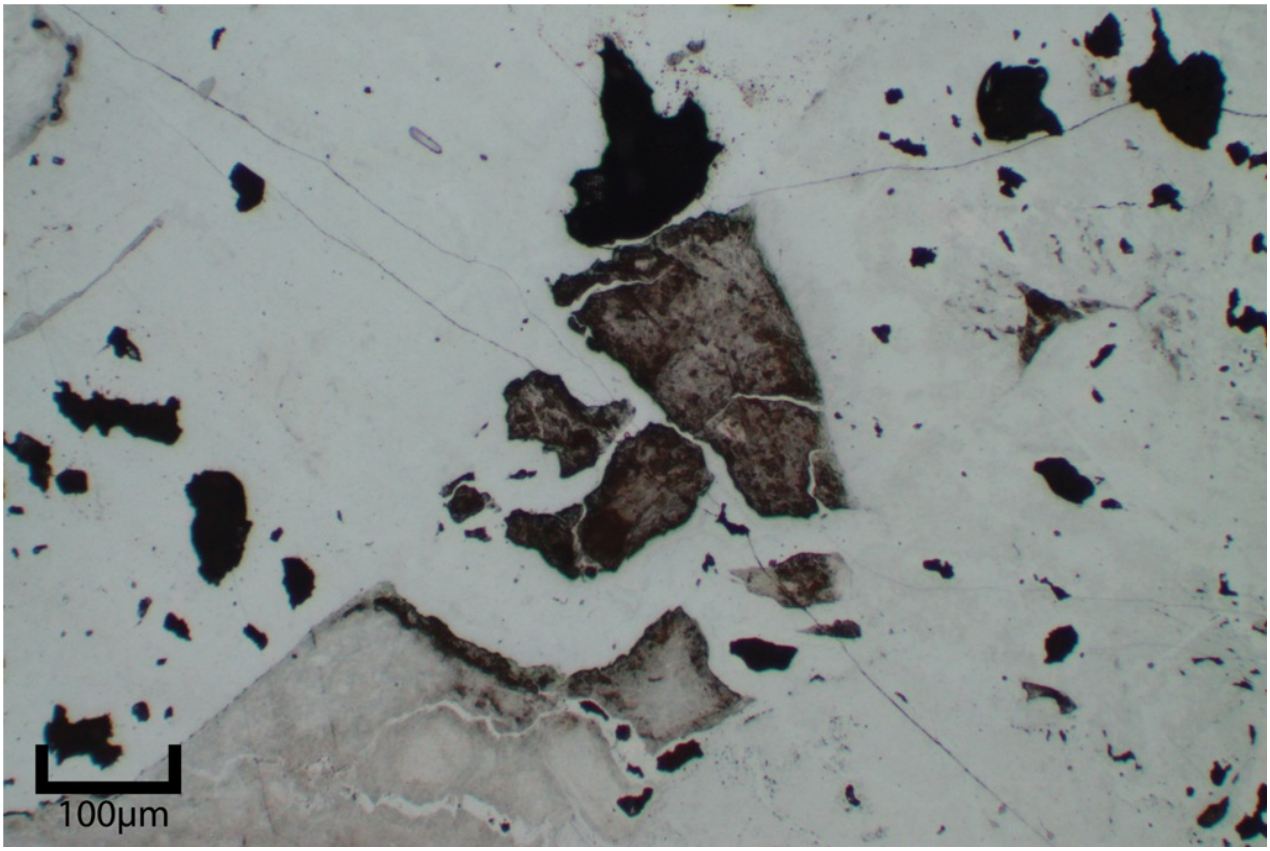
Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

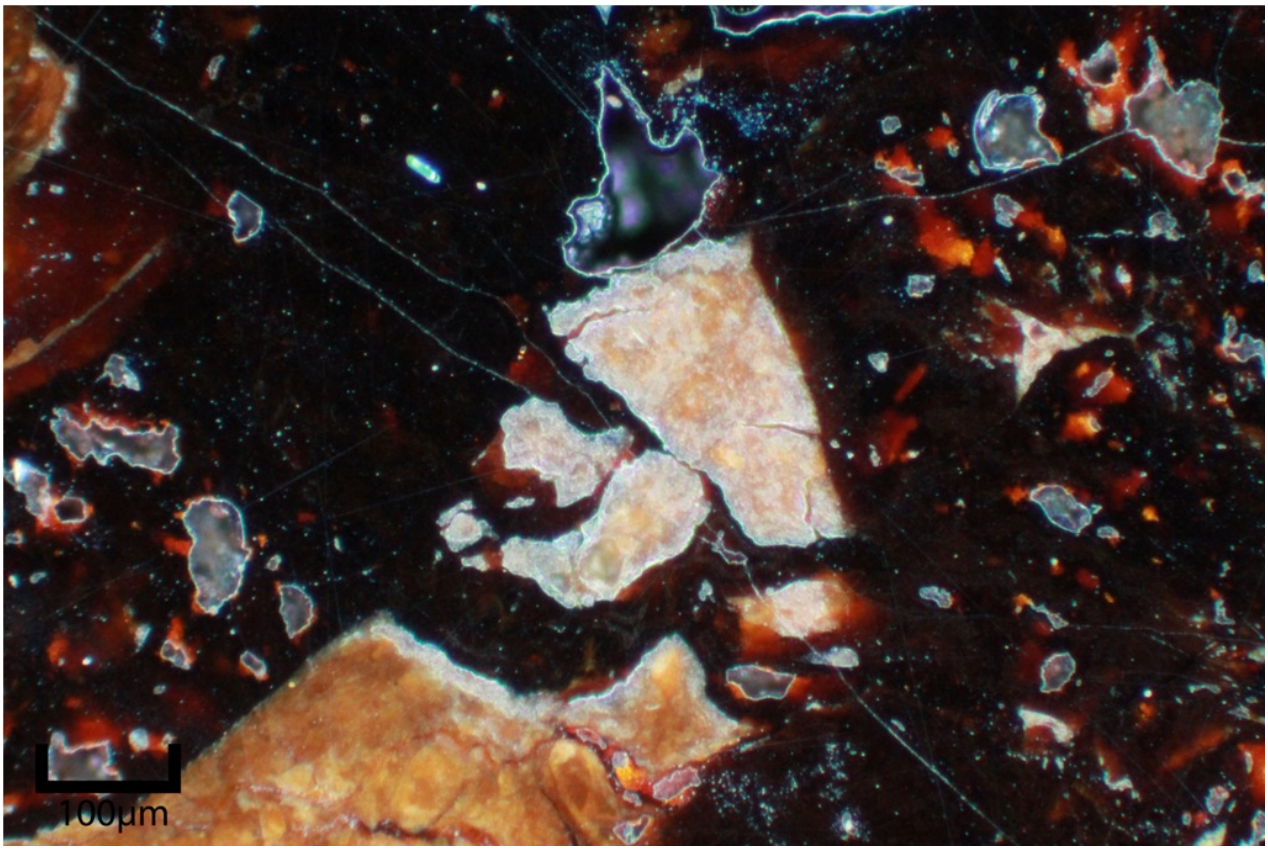
Micrograph 1



Micrograph 2



Micrograph 3



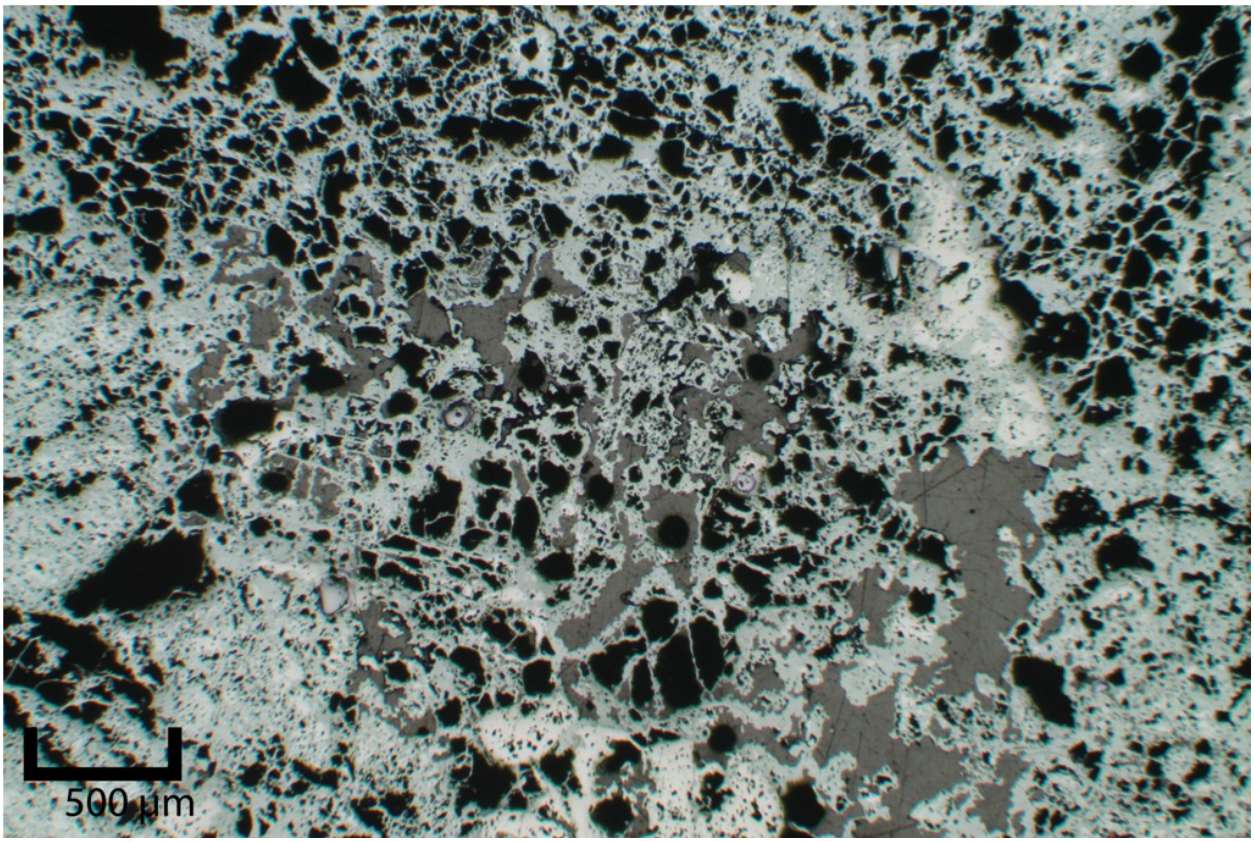
Micrograph 4

Site Code *STEP2* **Sample** *227.4* **Type** *Slag* **Area** *Grave*

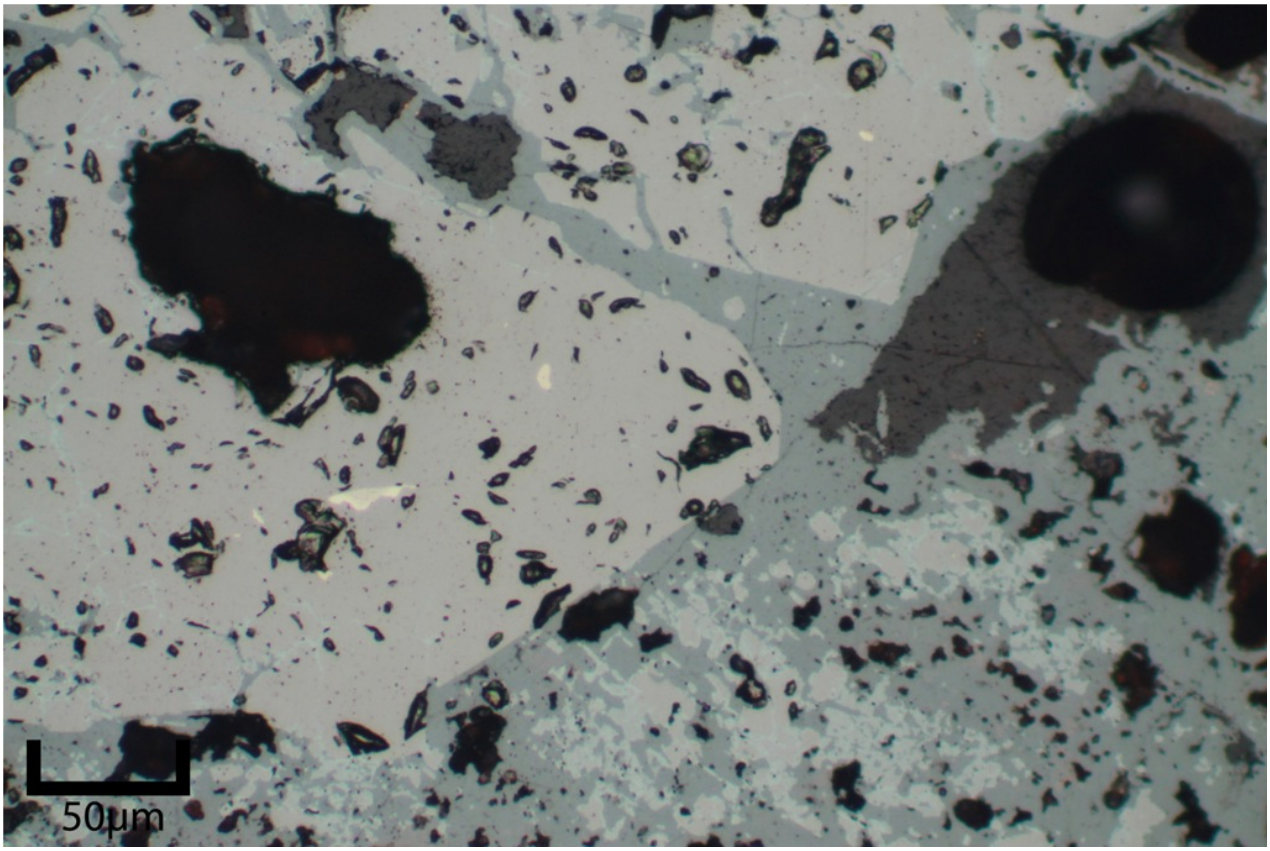
Wustite		**Additional notes**
Magnetitie		
Lath Fayalite		
Delafossite		
Metallic copper		
Sulphides		
Euheadral fayalite		
Matrix		
Additional Phases		
Chromite	***Present***	**Group**

Hand Specimin

Micrograph 1



Micrograph 2

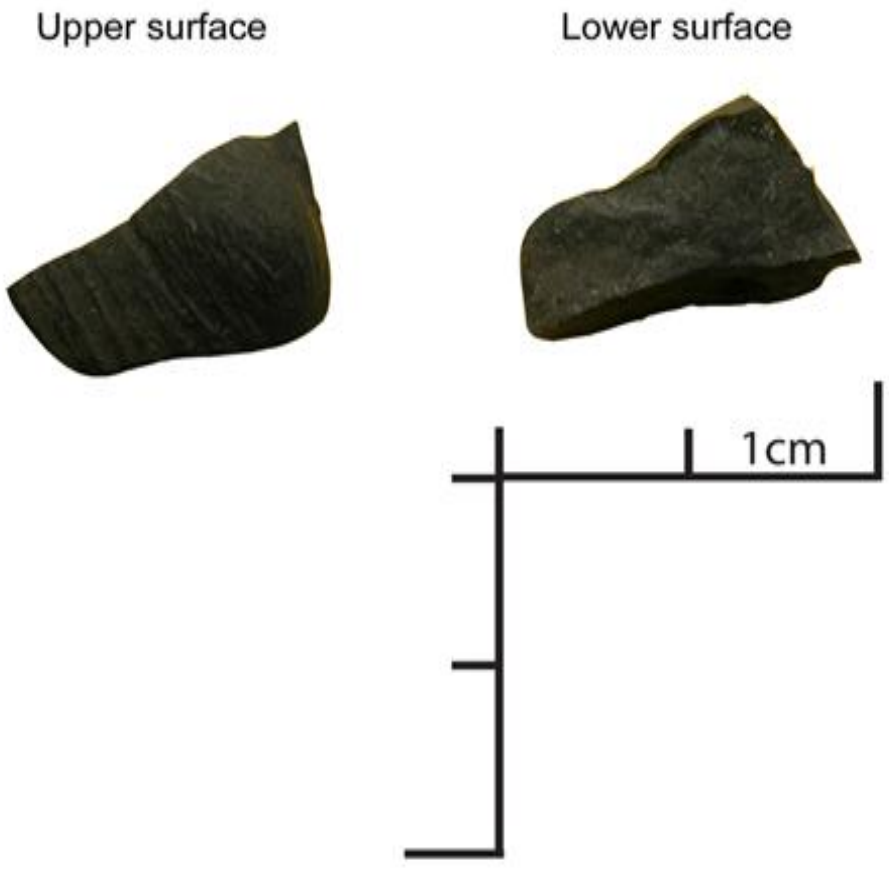


Site Code *UST11* **Sample** *8* **Type** *Slag* **Area**

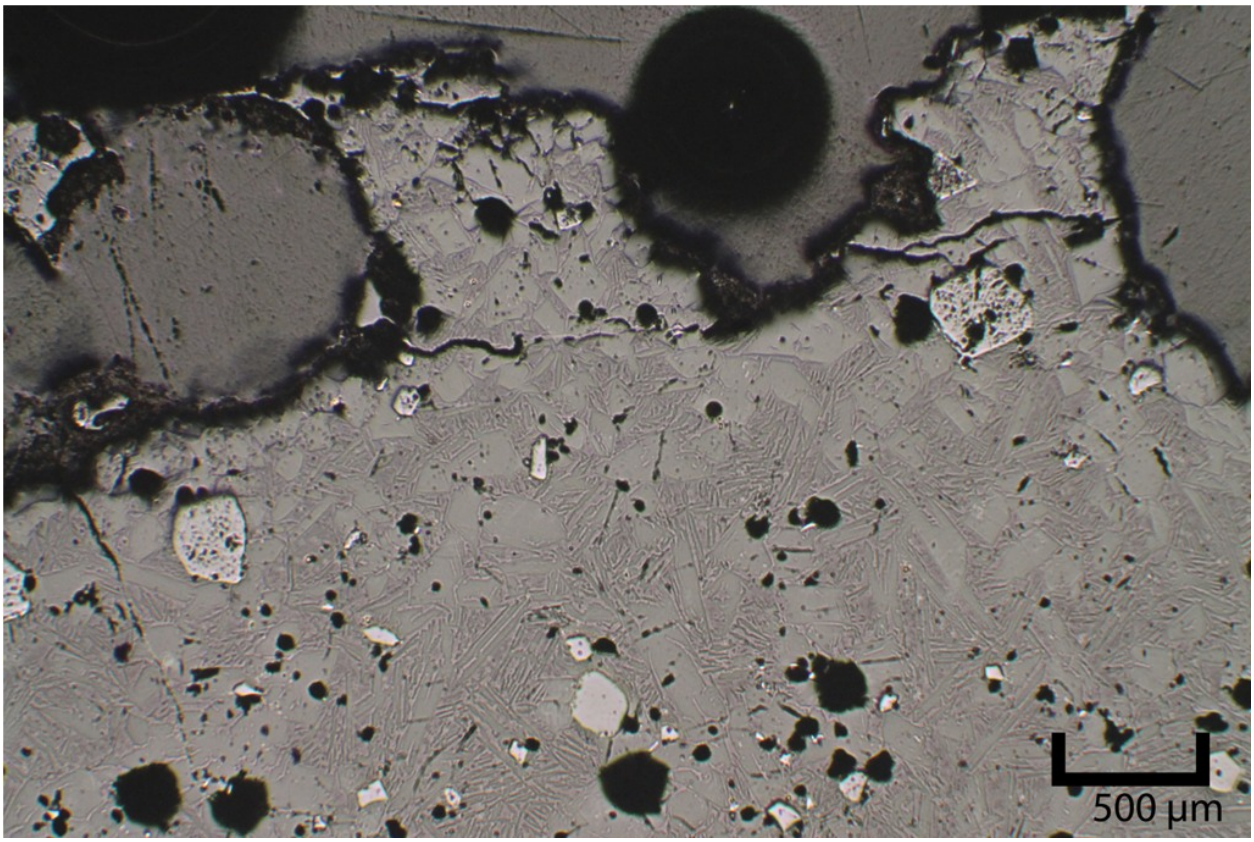
Wustite	*Rare*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Frequent*	
Delafossite	*Rare*	
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 25-50%*	
Additional Phases	*common free silica*	

Chromite ***Present*** **Group** *A2*

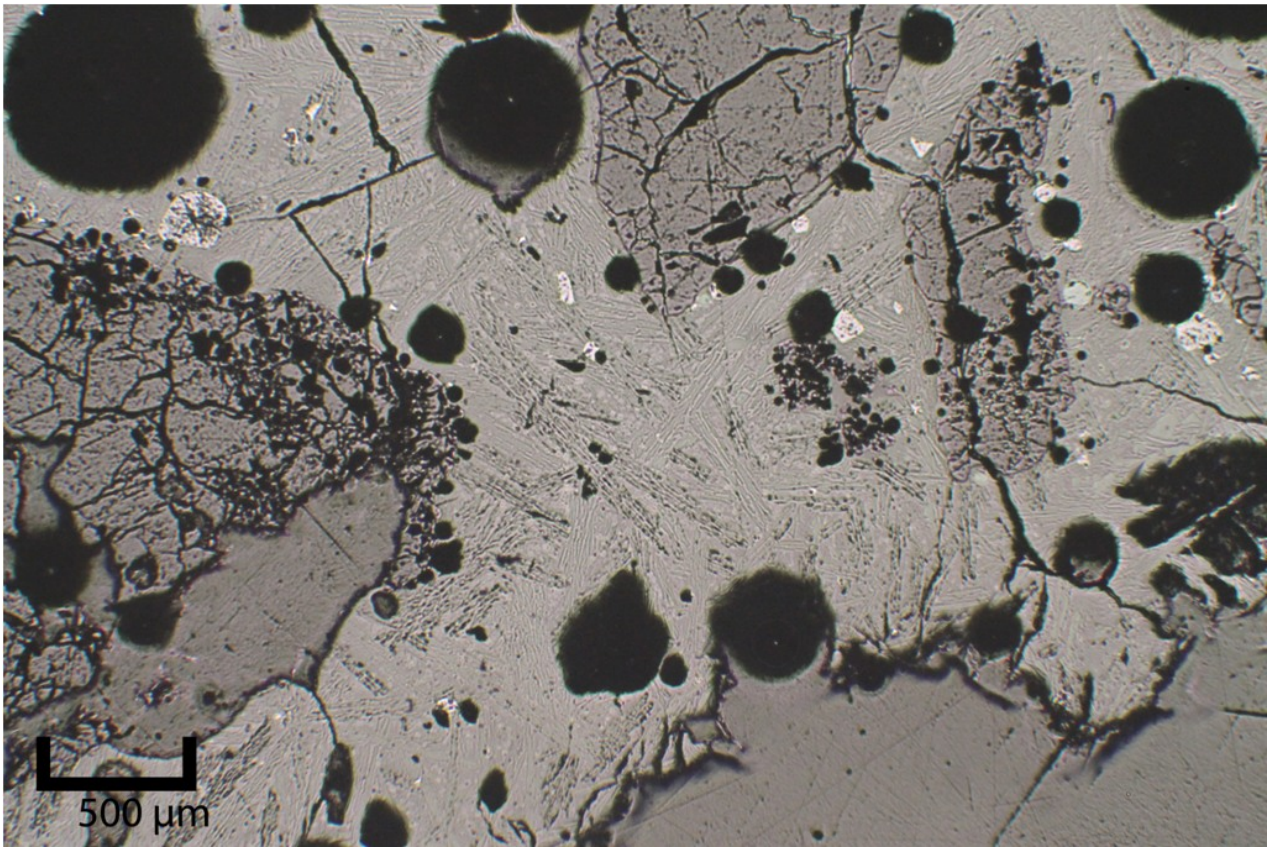
Hand Specimin



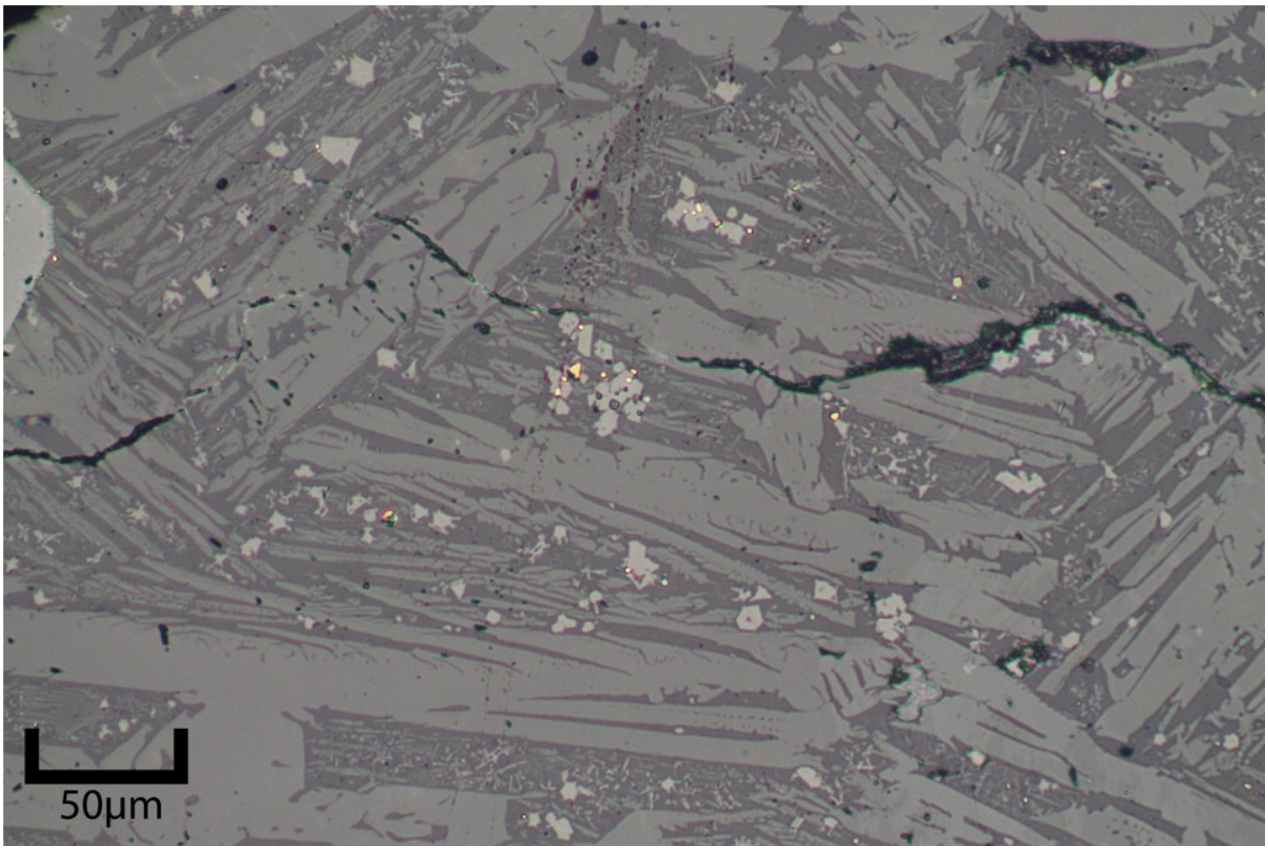
Micrograph 1



Micrograph 2



Micrograph 3



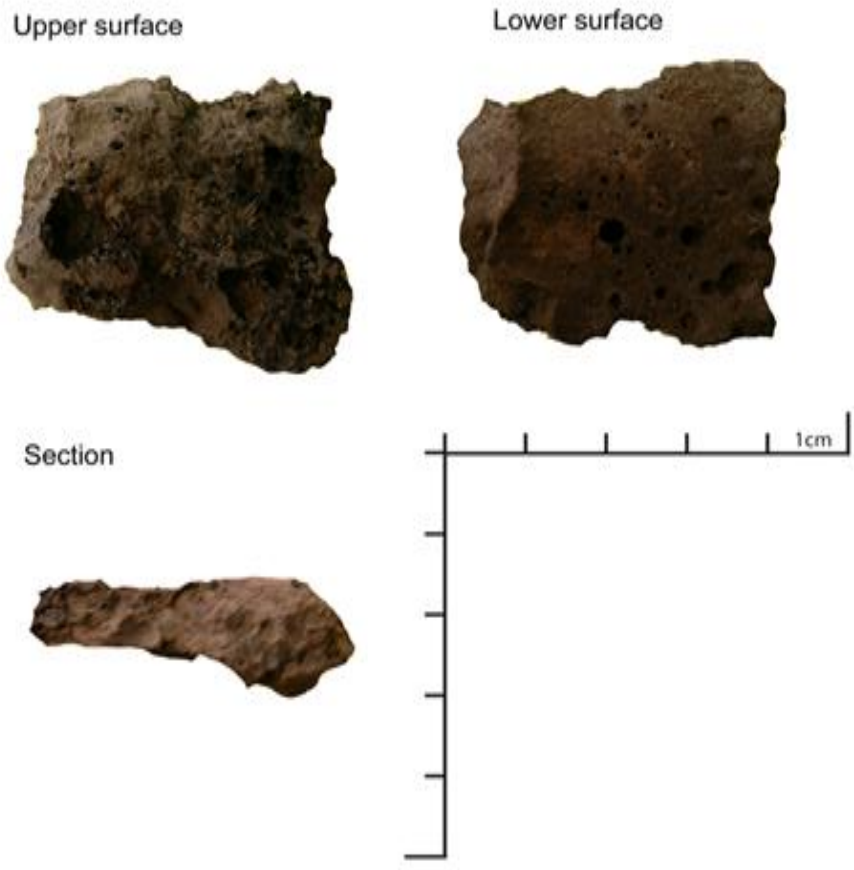
Micrograph 4

Site Code *UST11* **Sample** *62* **Type** *Slag* **Area**

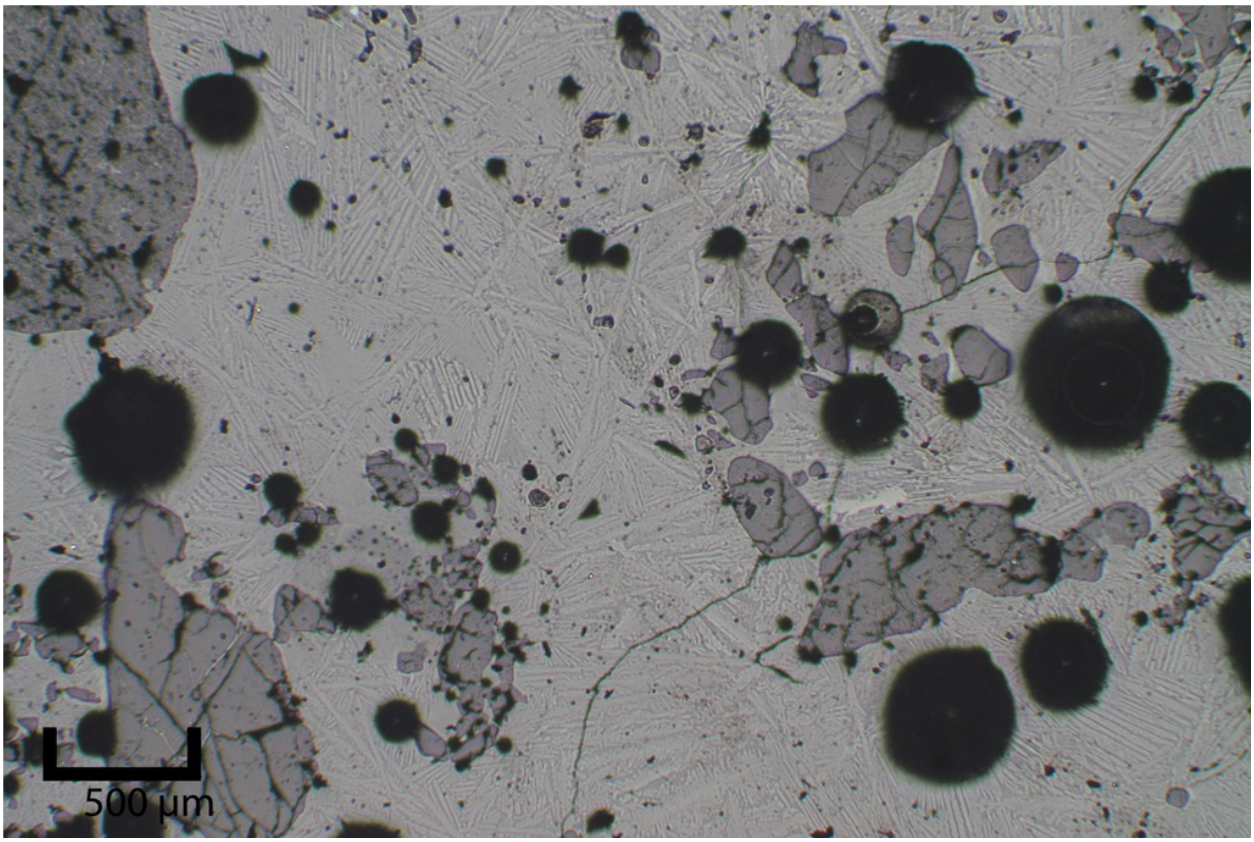
Wustite	*Absent*	**Additional notes**
Magnetitie	*Absent*	
Lath Fayalite	*Dominant*	
Delafossite	*Absent*	
Metallic copper	*Absent*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 25-50%*	
Additional Phases	*common free silica*	

Chromite ***Present*** **Group** *A1*

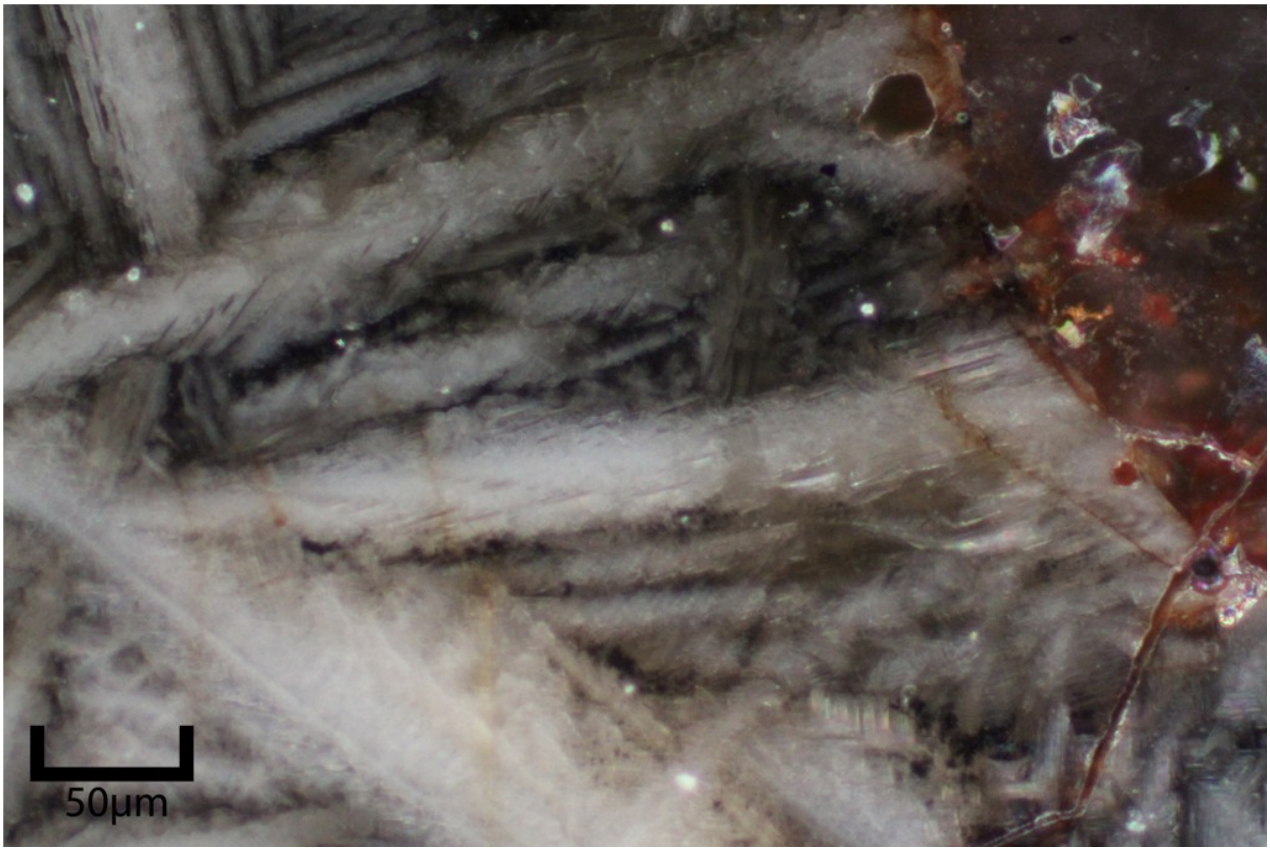
Hand Specimin



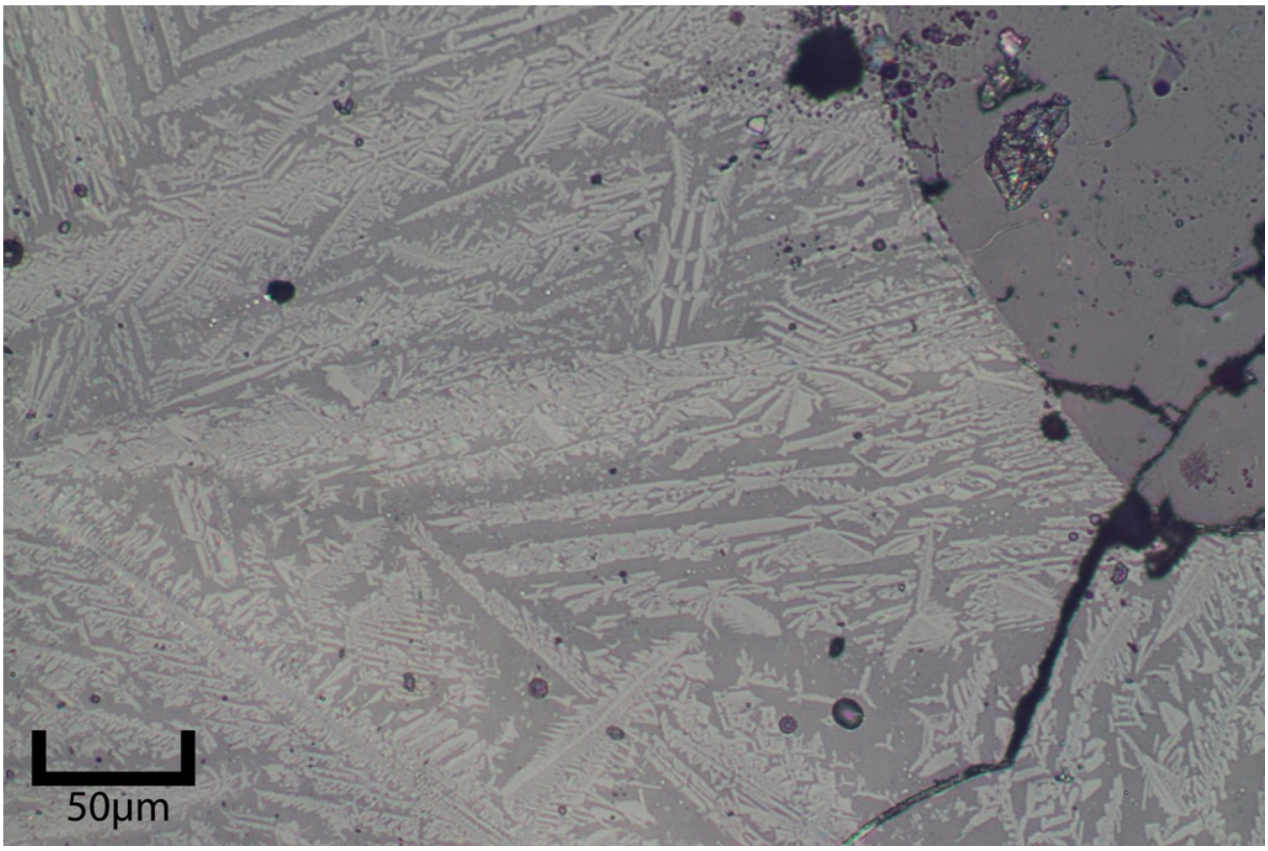
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

Site Code *UST11* **Sample** *64* **Type** *Slag* **Area**

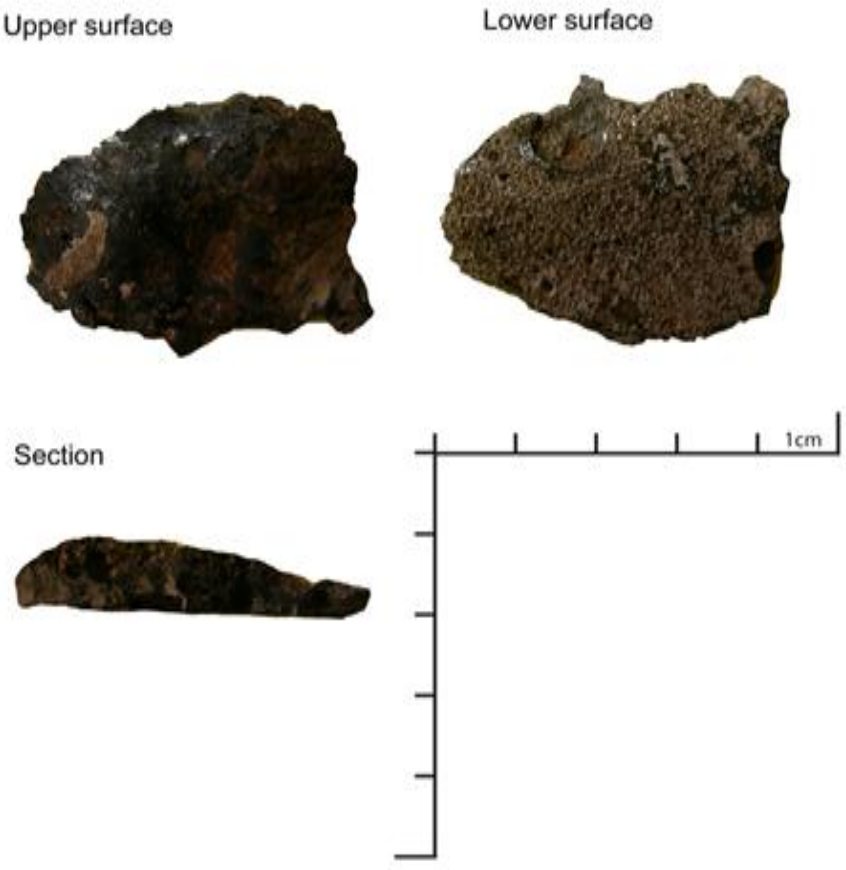
Wustite	*Rare*
Magnetitie	*Rare*
Lath Fayalite	*Dominant*
Delafossite	*Absent*
Metallic copper	*Very rare*
Sulphides	*Absent*
Euheadral fayalite	*Absent*
Matrix	*Glassy 10-25%*
Additional Phases	*some free silica*

Additional notes

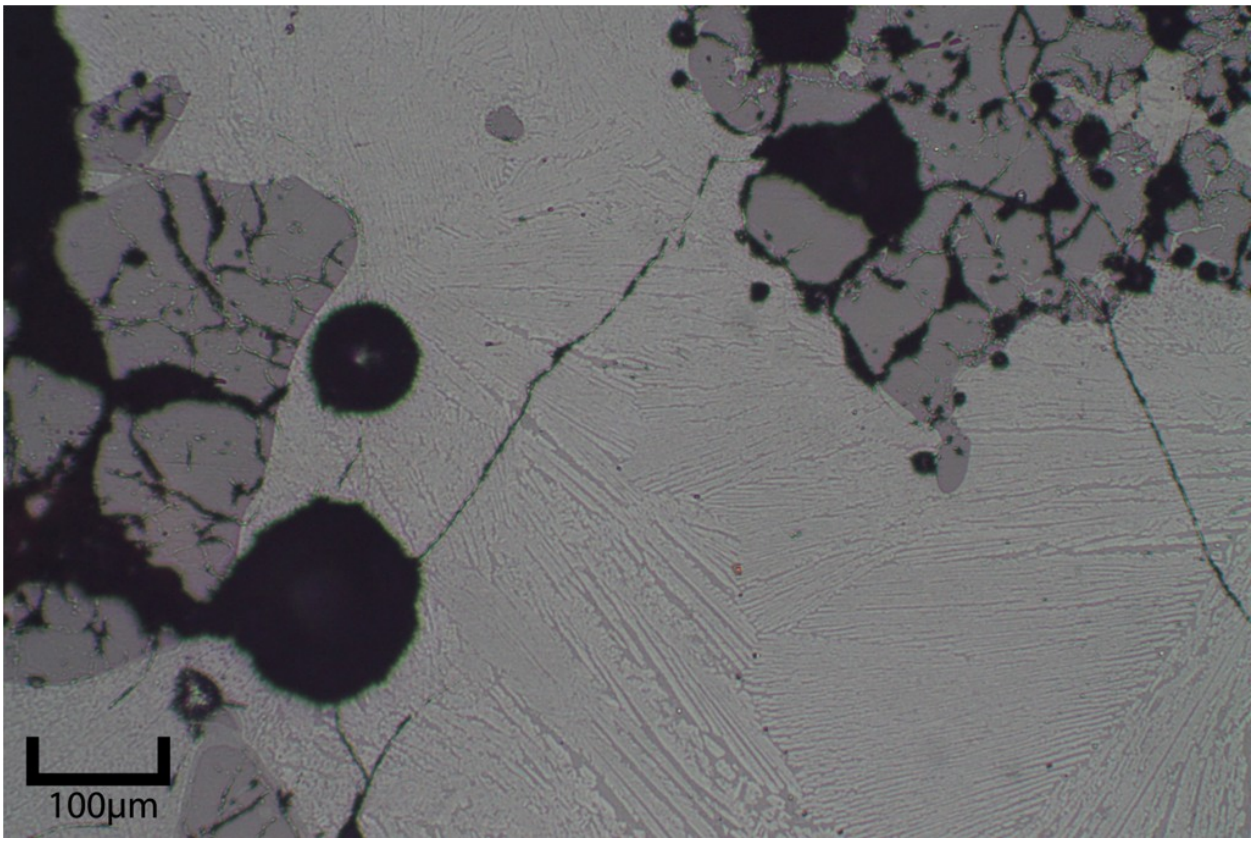
Chromite ***Present***

Group *A1*

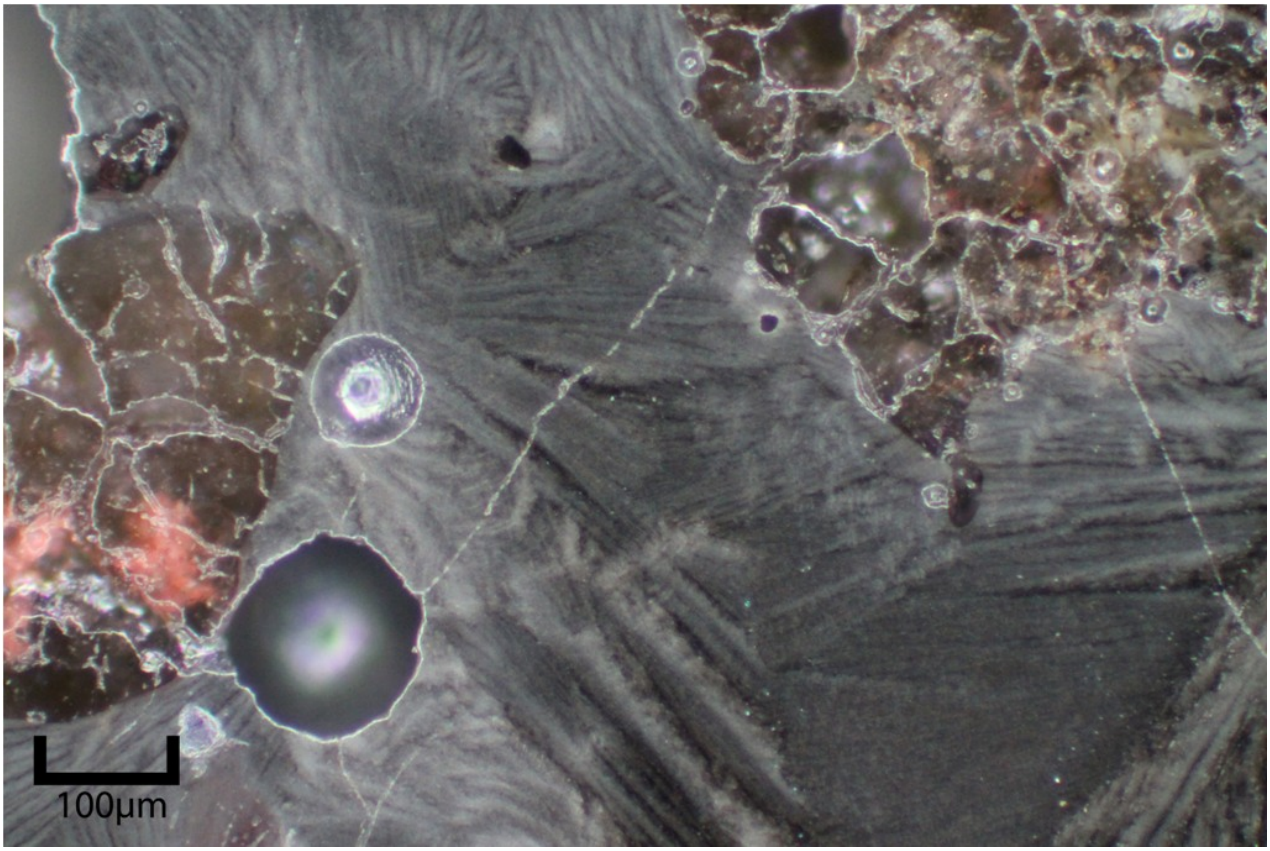
Hand Specimin



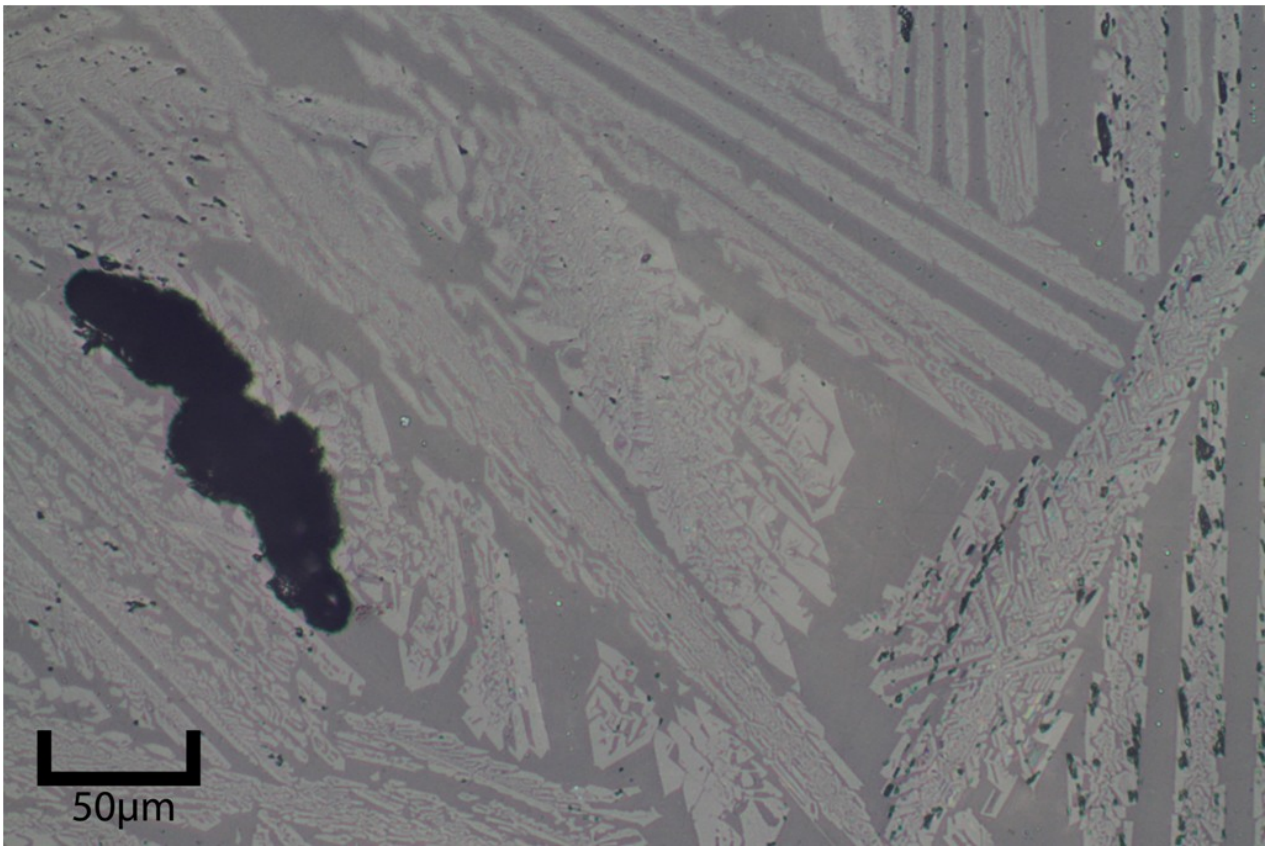
Micrograph 1



Micrograph 2



Micrograph 3



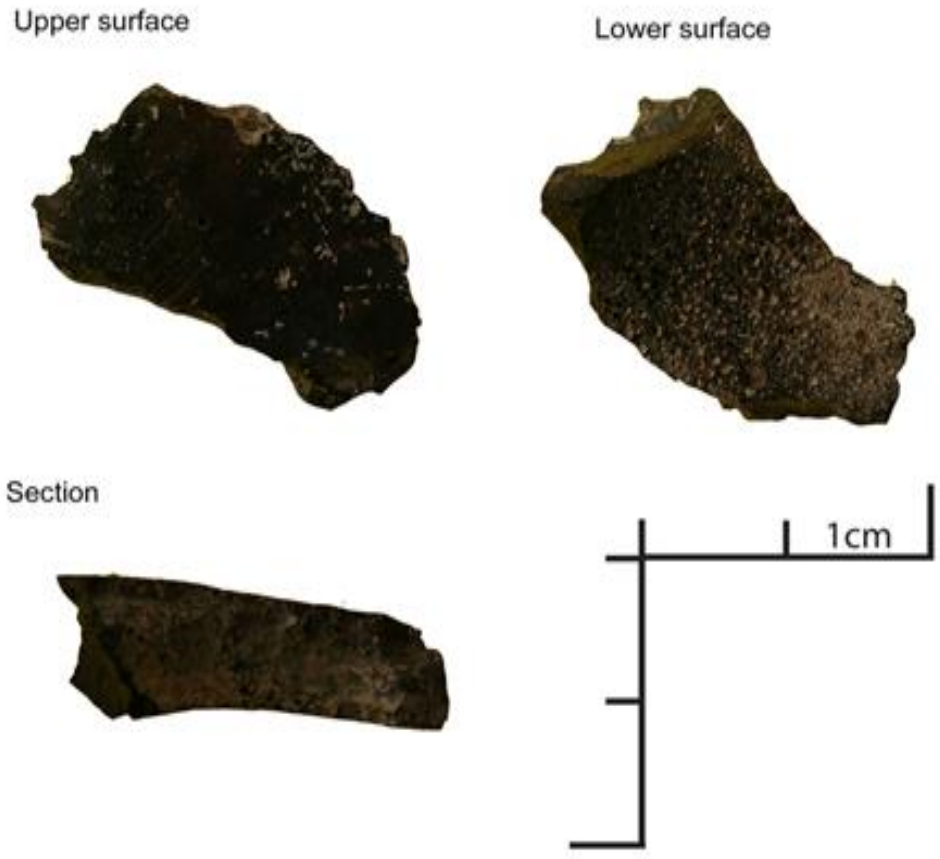
Micrograph 4

Site Code *UST11* **Sample** *69* **Type** *Slag* **Area**

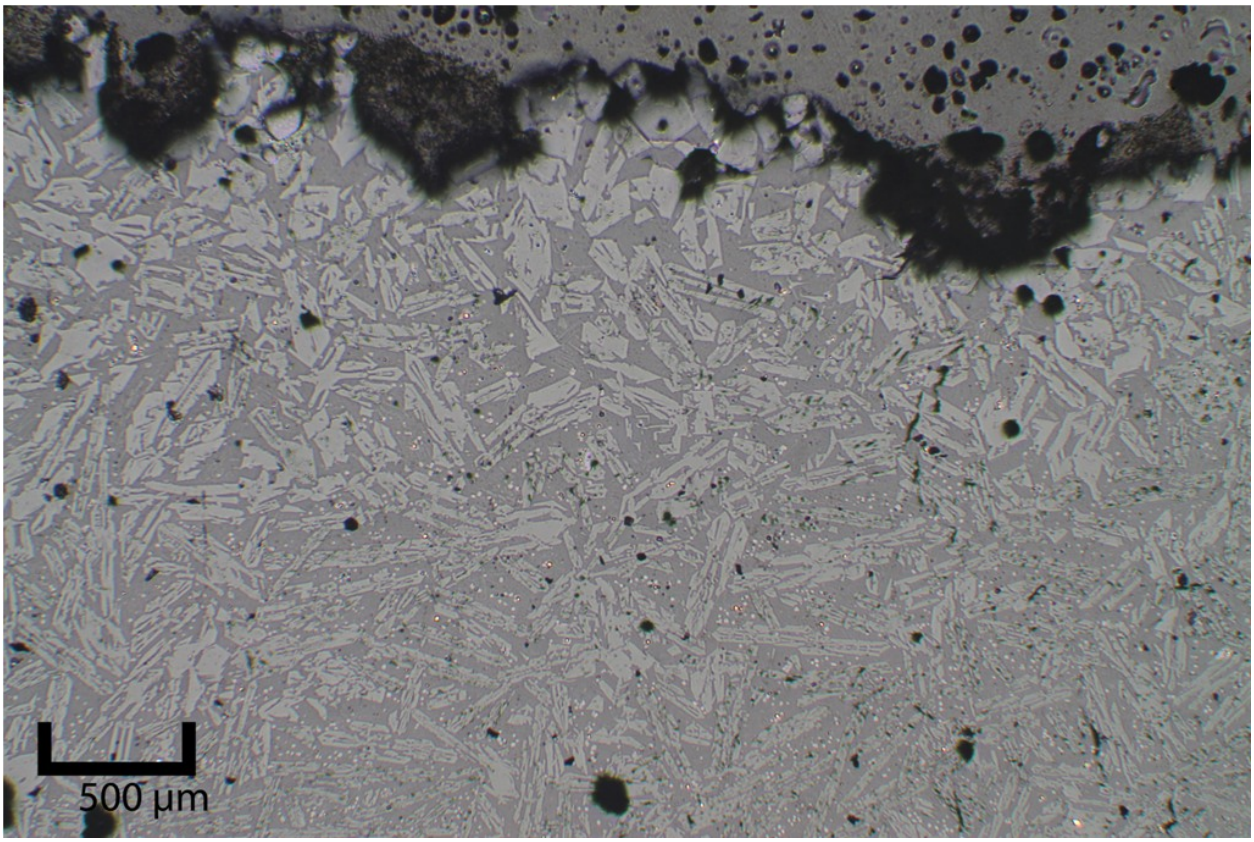
Wustite	*Rare*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Frequent*	
Delafossite		
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Absent*	
Matrix	*Glassy 25-50%*	
Additional Phases	*rare chromites, common free silica*	

Chromite ***Present*** **Group** *A2*

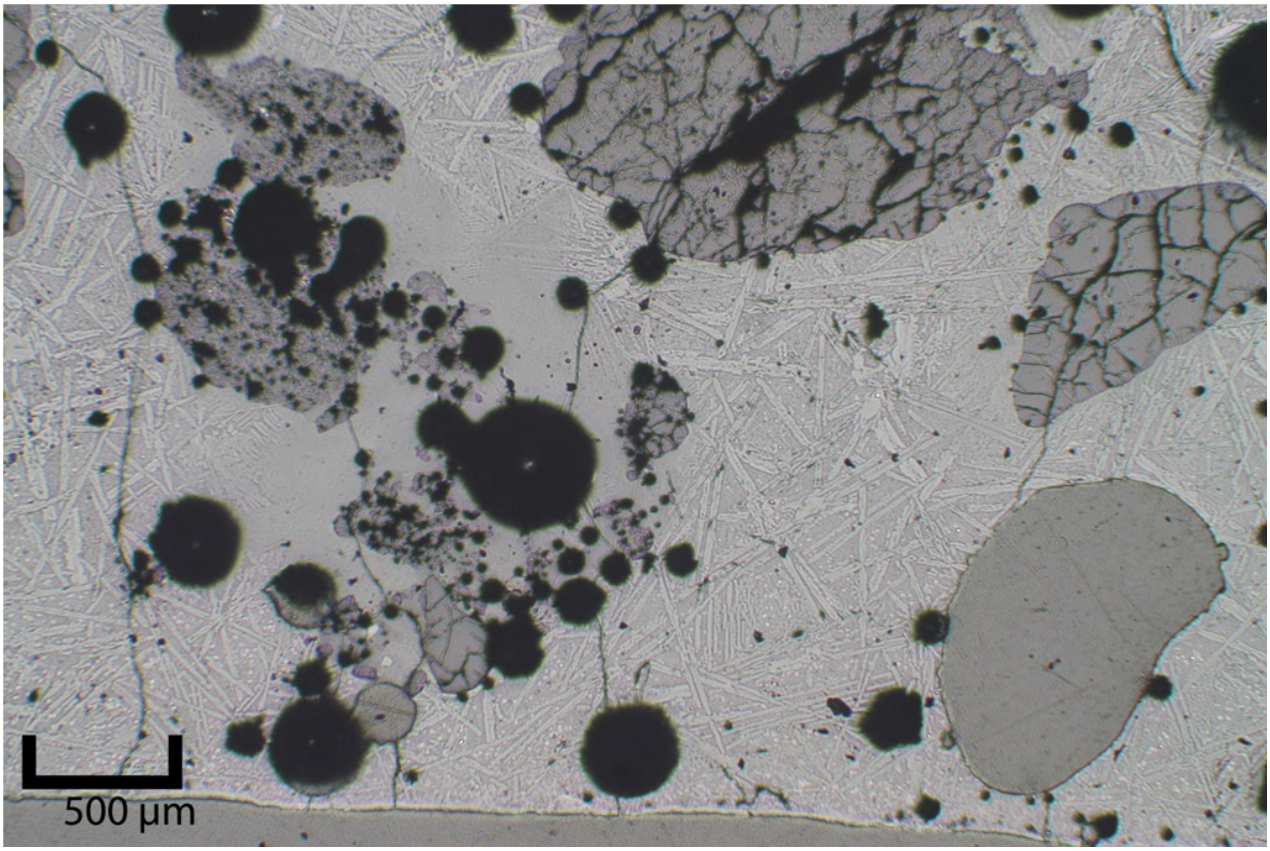
Hand Specimin



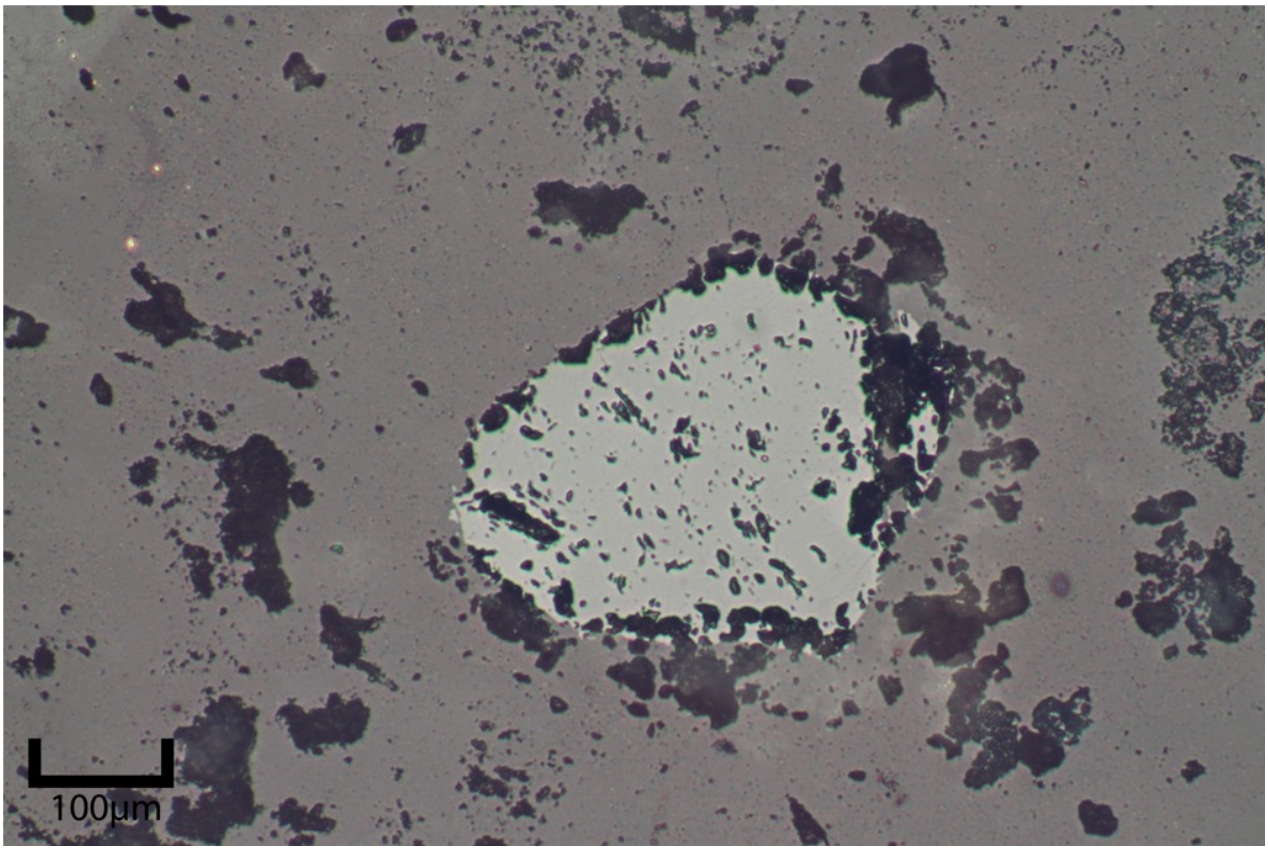
Micrograph 1



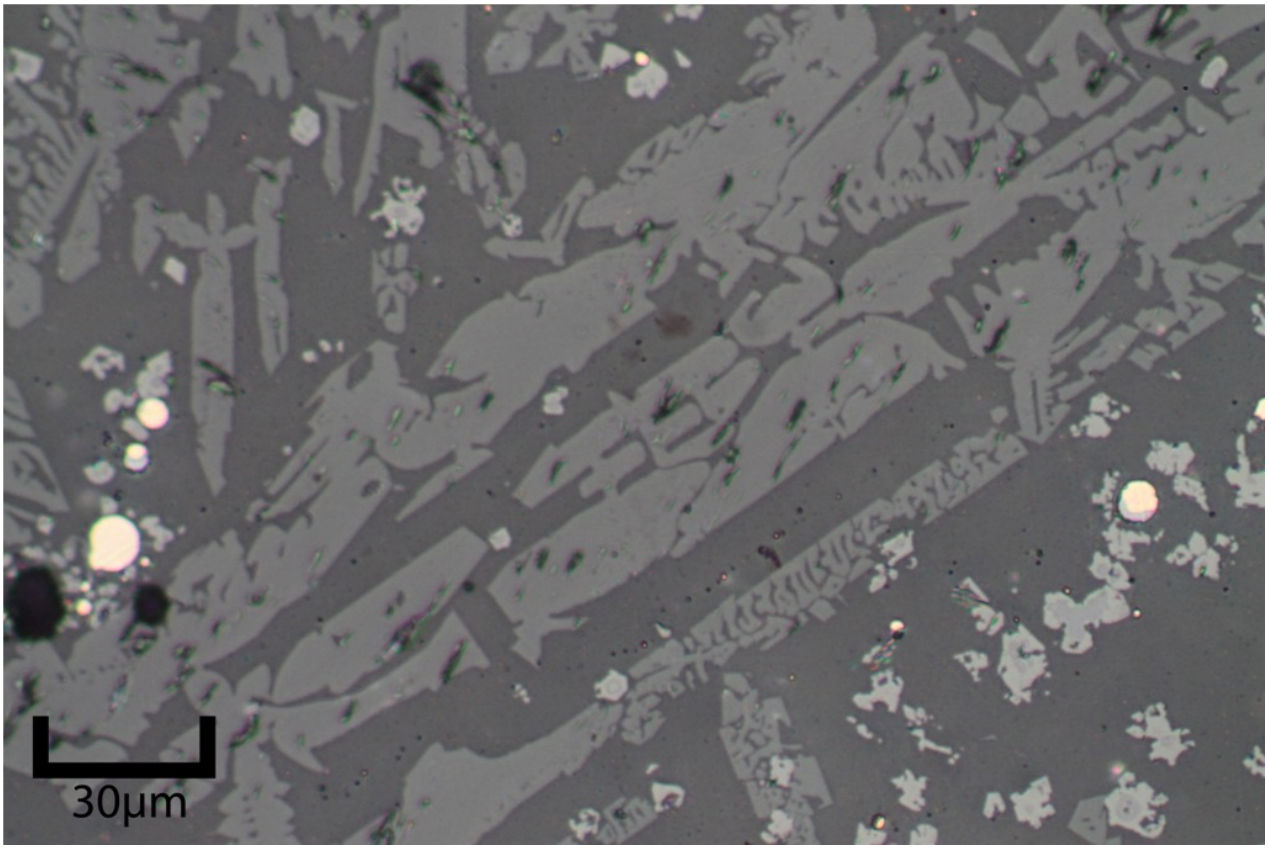
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *UST11* **Sample** *77* **Type** *Slag* **Area**

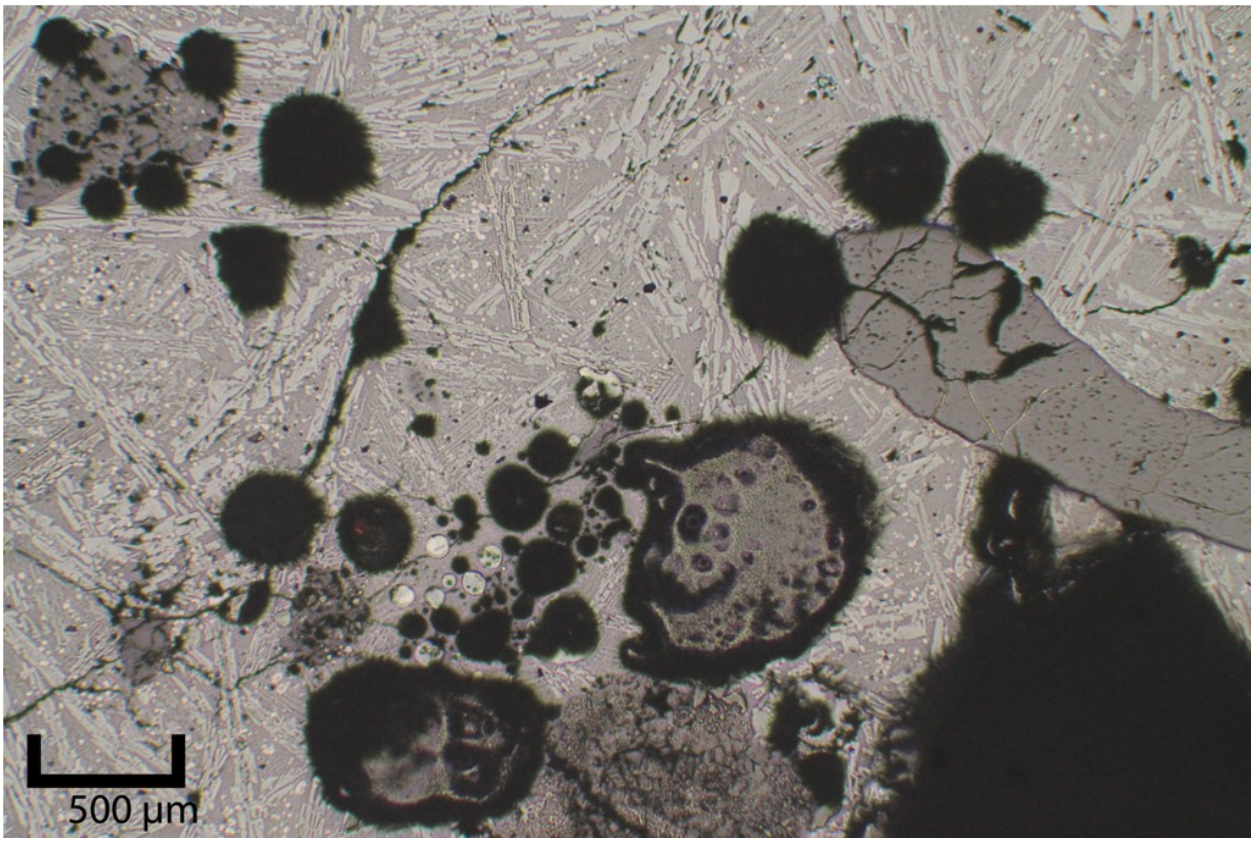
Wustite	*Occasional*
Magnetitie	*Occasional*
Lath Fayalite	*Frequent*
Delafossite	*Rare*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	*ore inclusions*

Additional notes
intermediate iron oxides

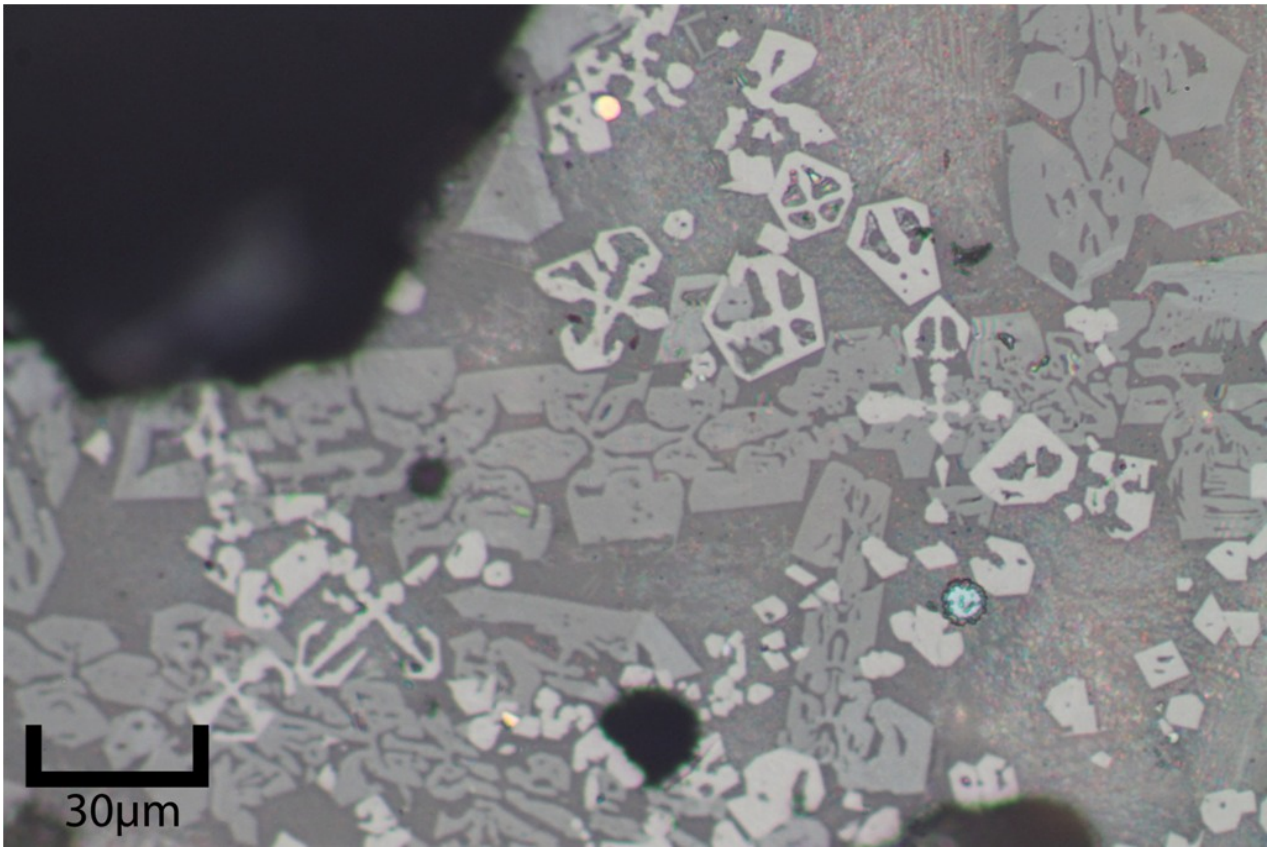
Chromite ***Present*** **Group** *A2*

Hand Specimin

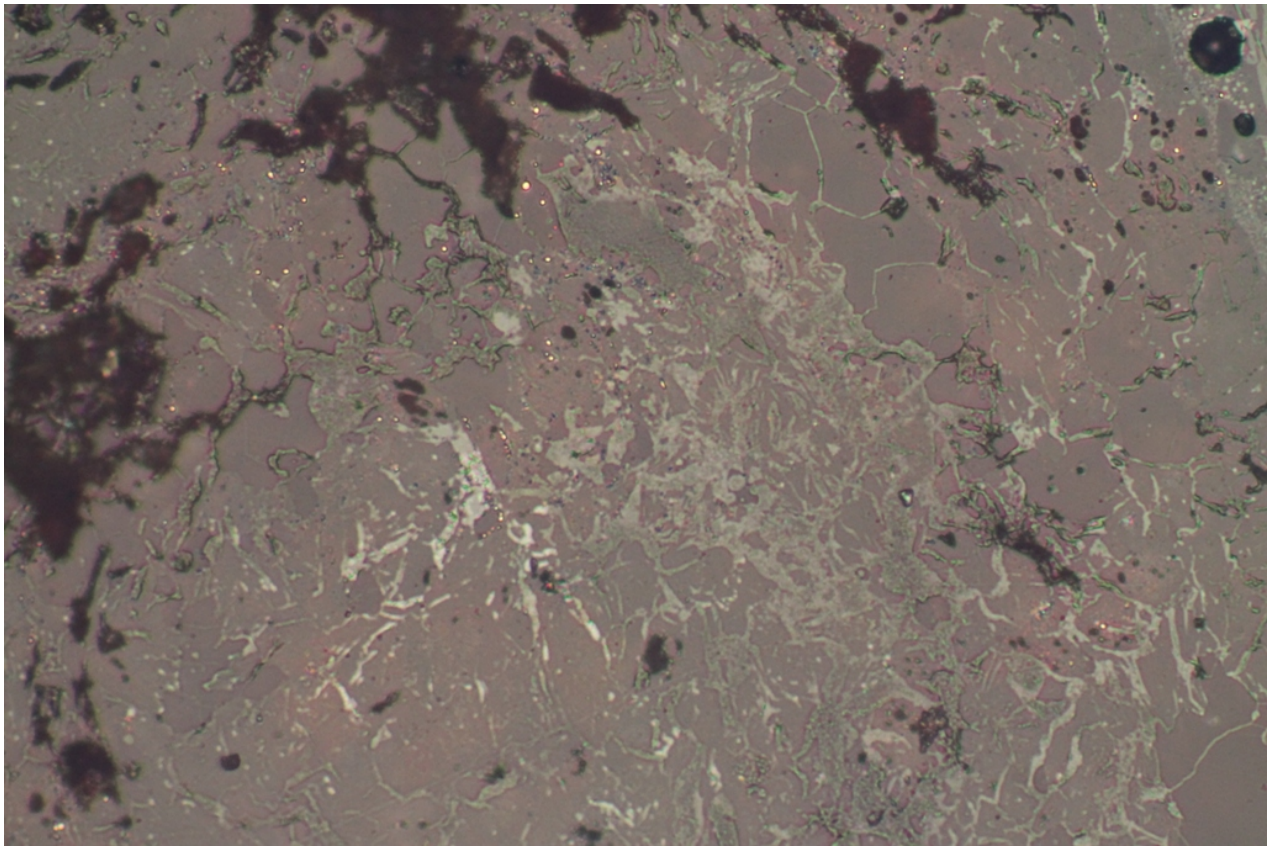
Micrograph 1



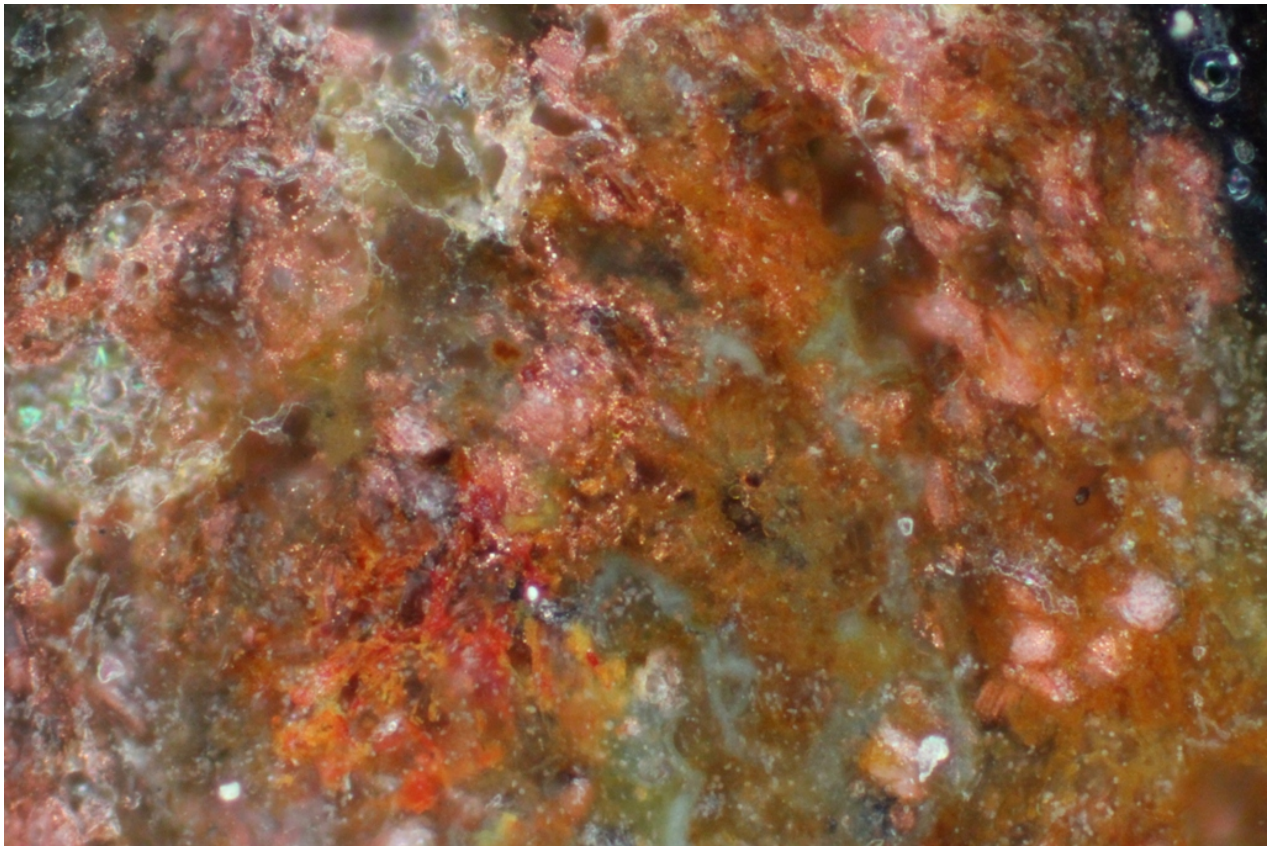
Micrograph 2



Micrograph 3



Micrograph 4



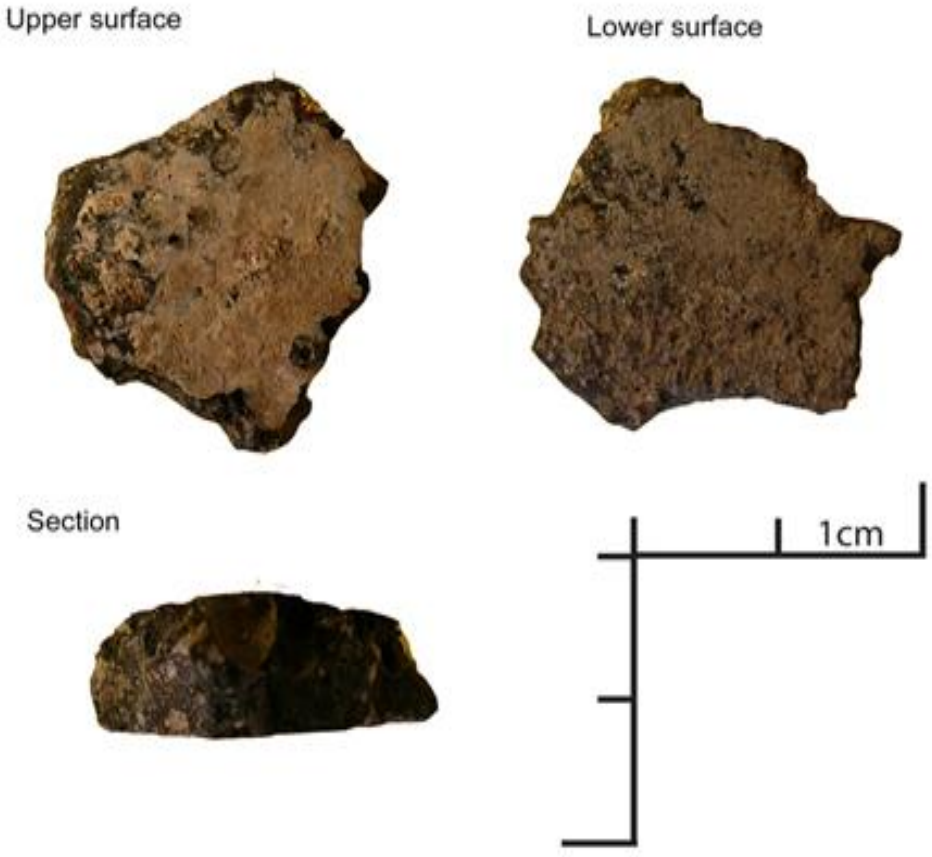
Site Code *UST11* **Sample** *78* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Frequent*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Absent*
Matrix	*Glassy 10-25%*
Additional Phases	*frequent free silica*

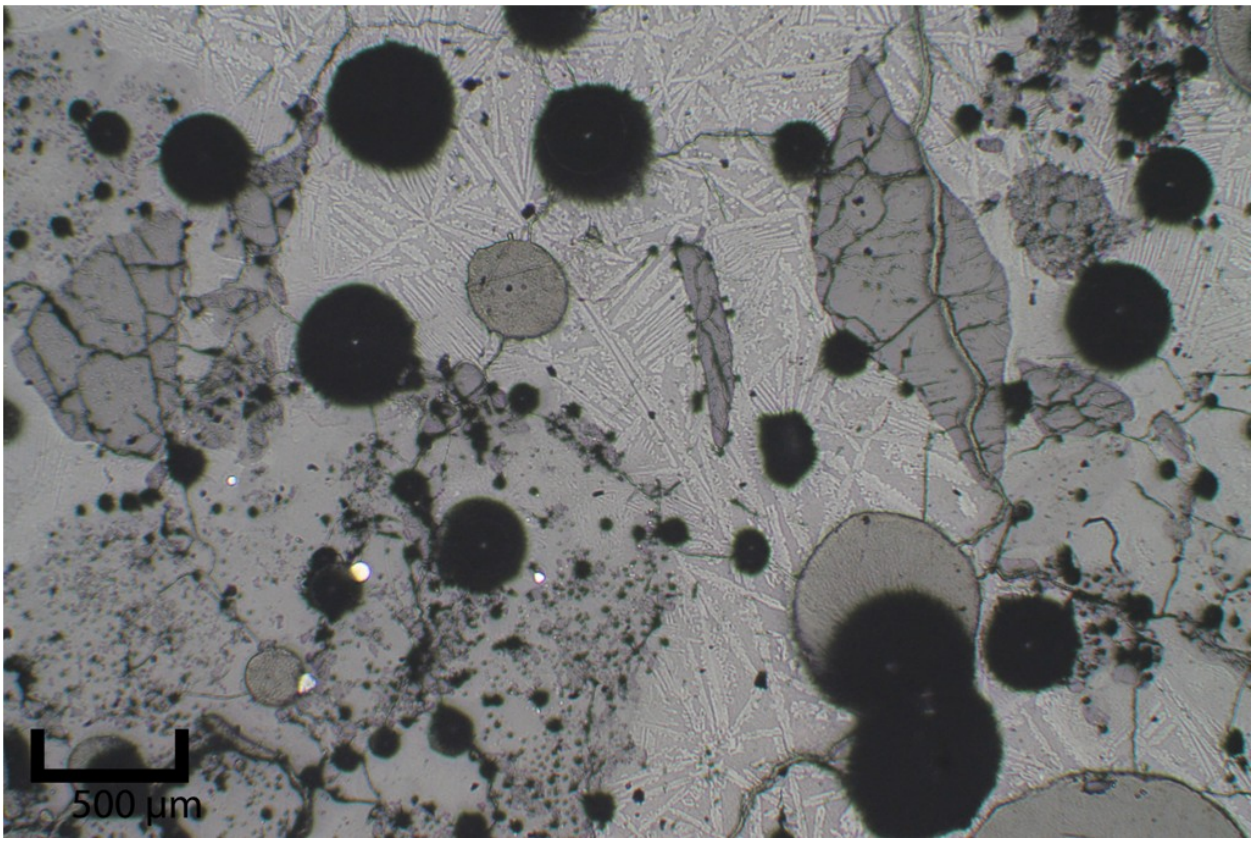
Additional notes
very fine fayalitic matrix

Chromite ***Present*** **Group** *A1*

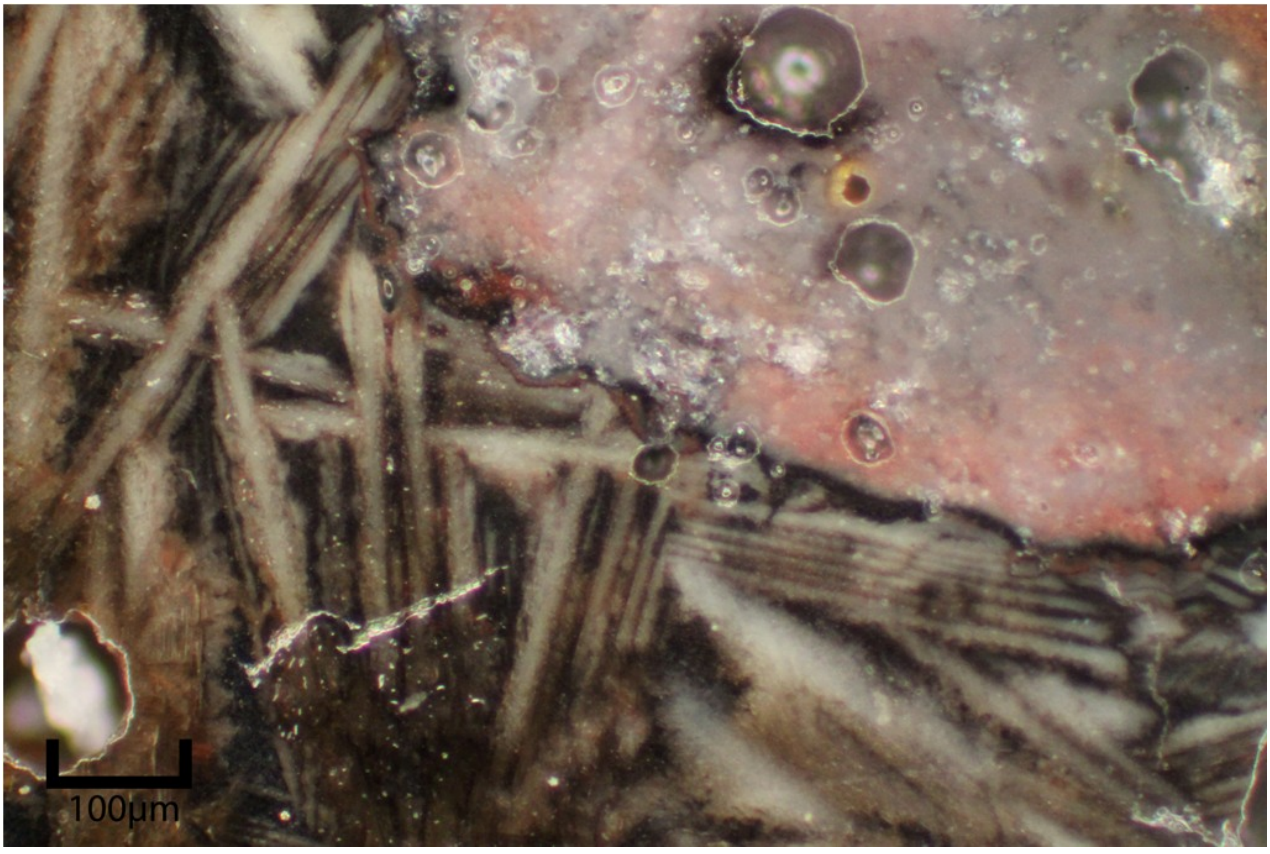
Hand Specimin



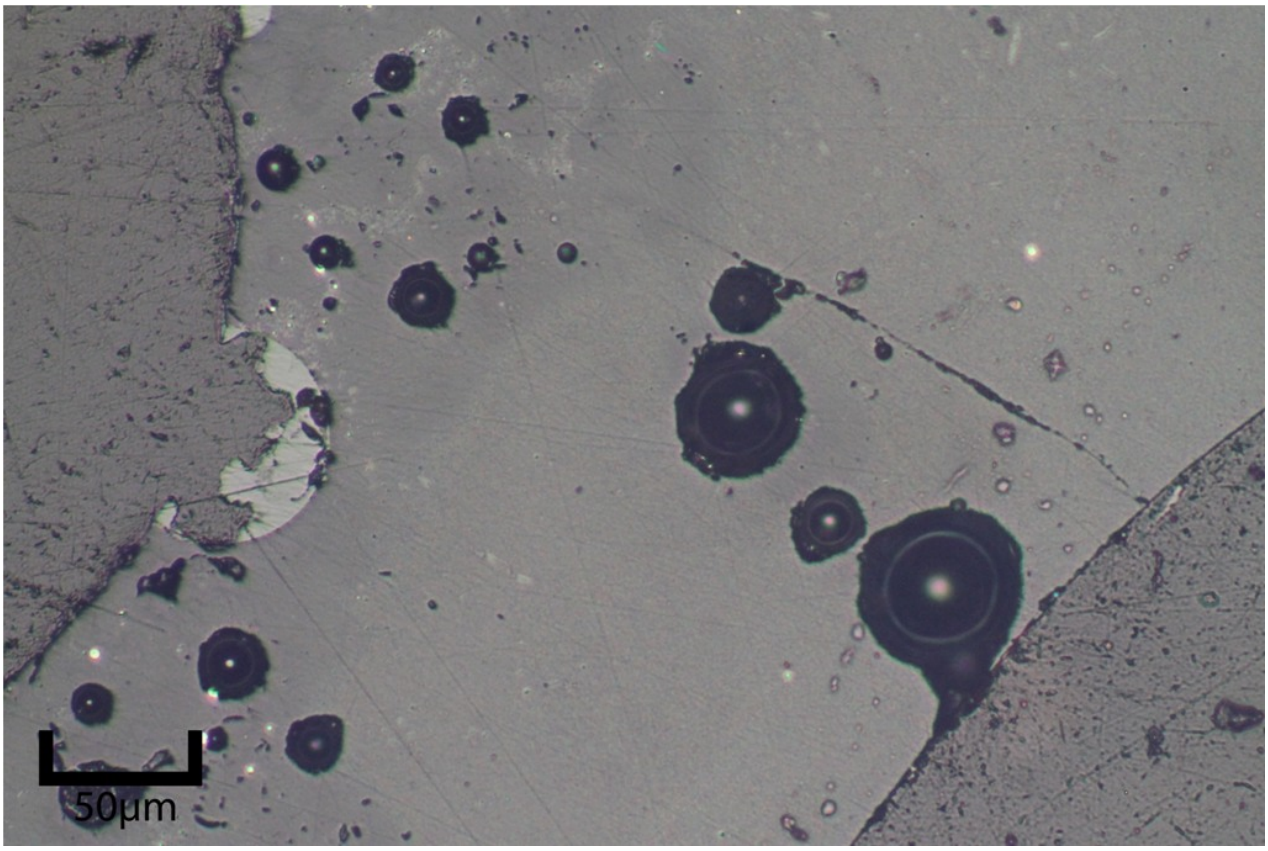
Micrograph 1



Micrograph 2



Micrograph 3



Micrograph 4

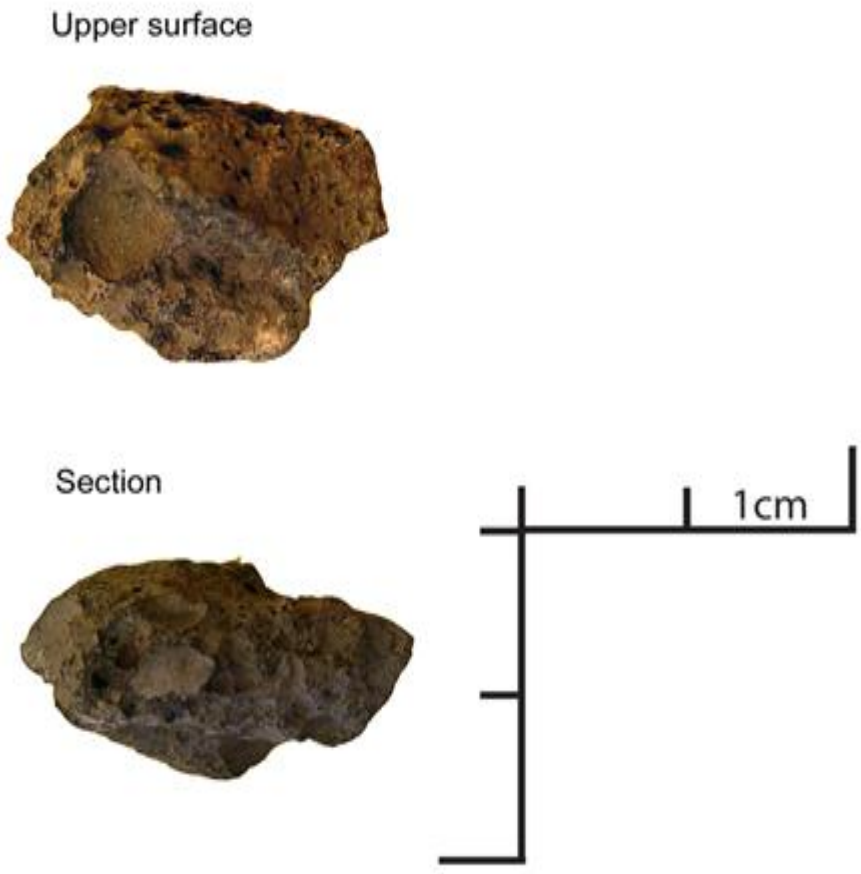
Site Code *UST11* **Sample** *79* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Absent*
Lath Fayalite	*Common*
Delafossite	
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Occasional*
Matrix	*Glassy 25-50%*
Additional Phases	*cuprite in silica,*

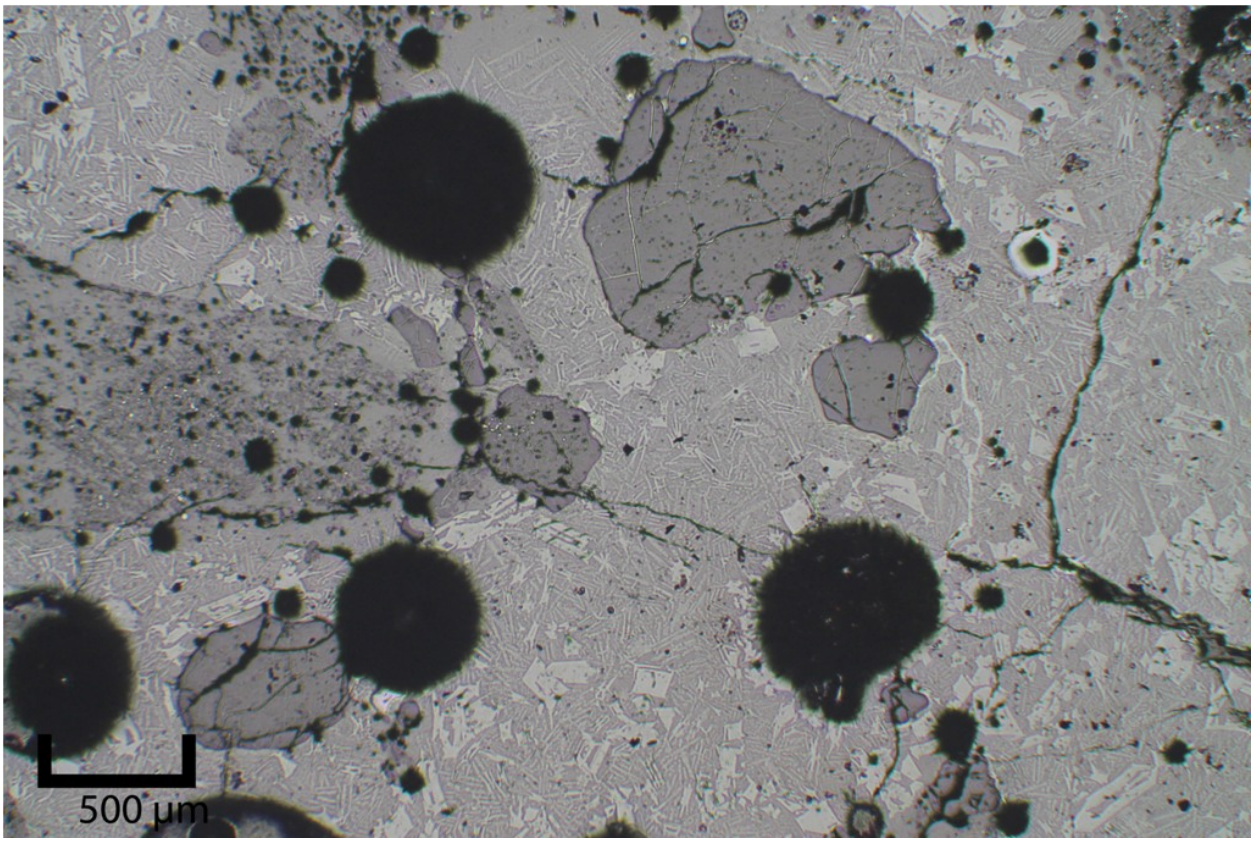
Additional notes
possible ceramic inclusions

Chromite ***Present*** **Group** *D1*

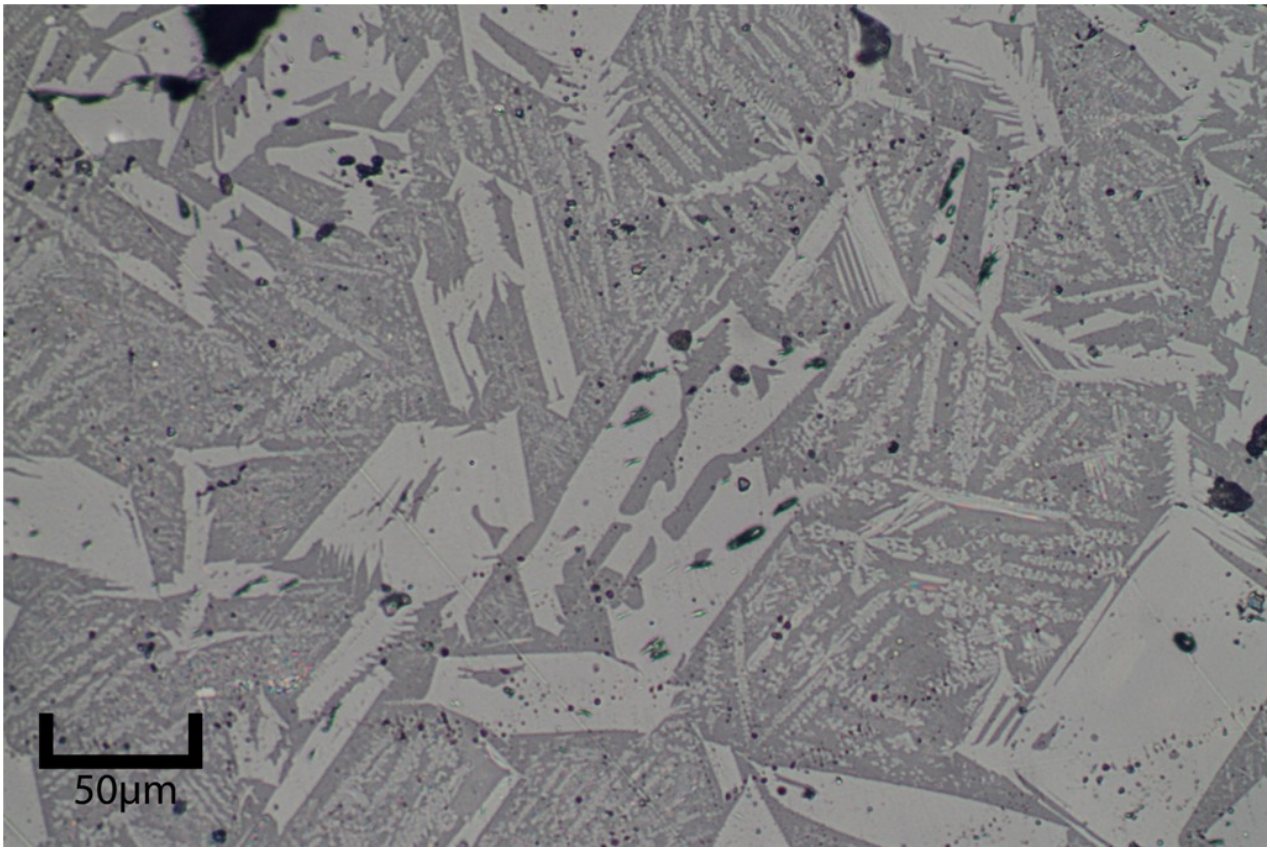
Hand Specimin



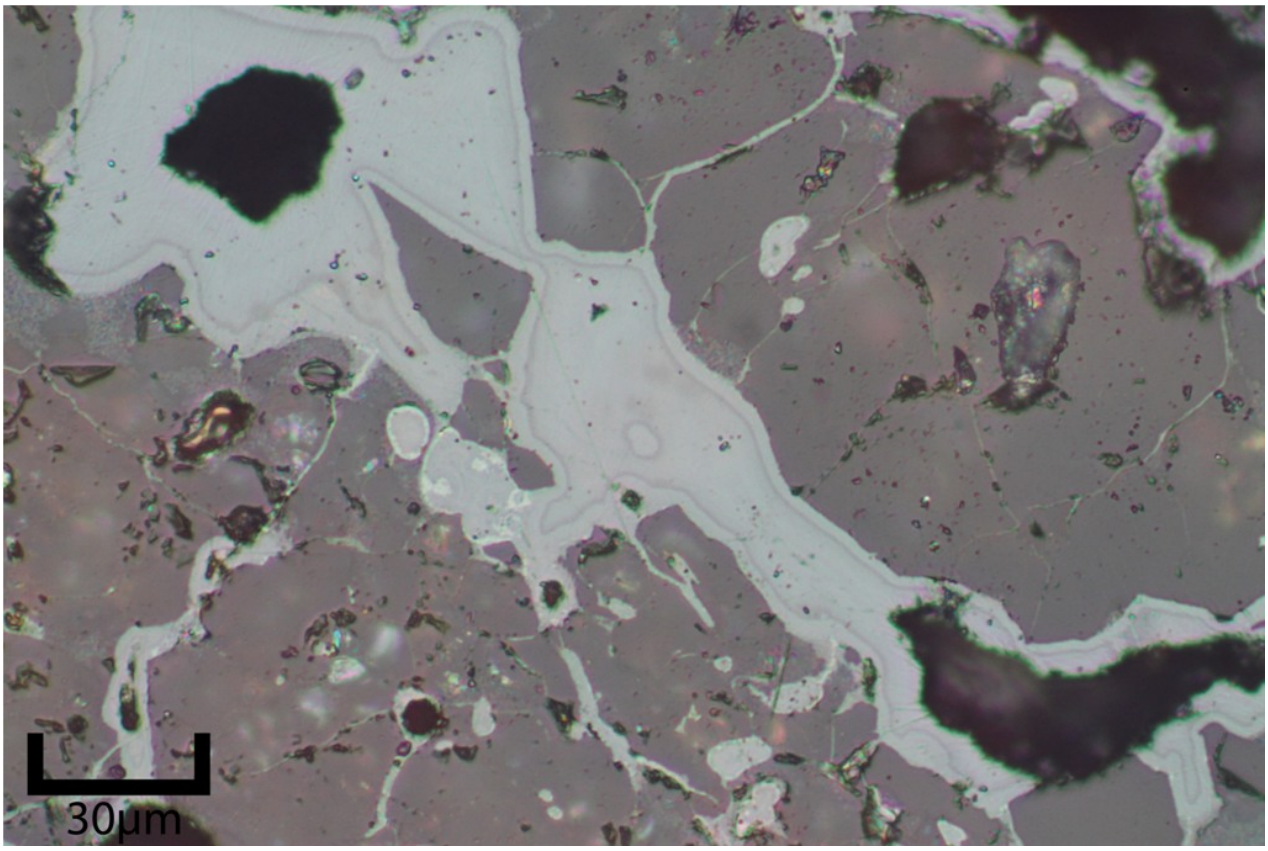
Micrograph 1



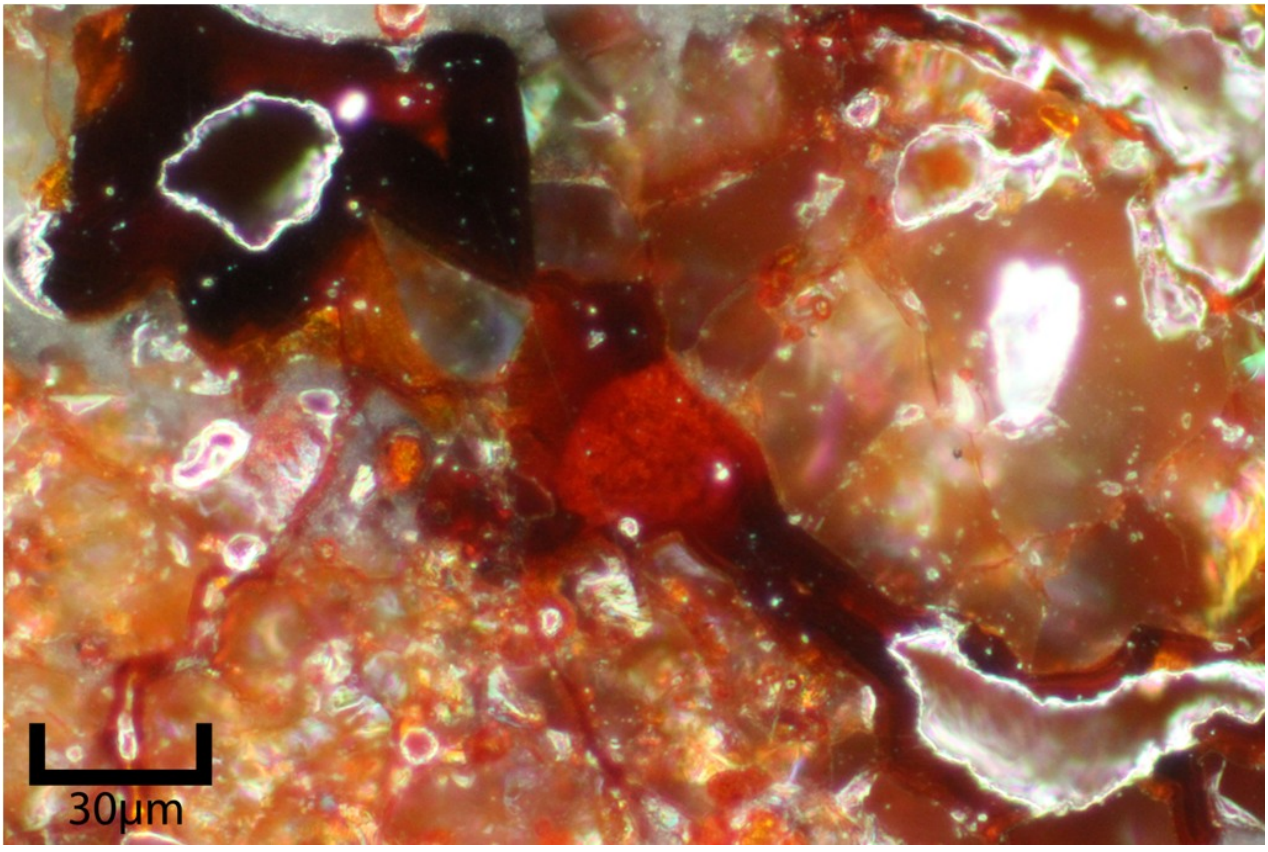
Micrograph 2



Micrograph 3



Micrograph 4

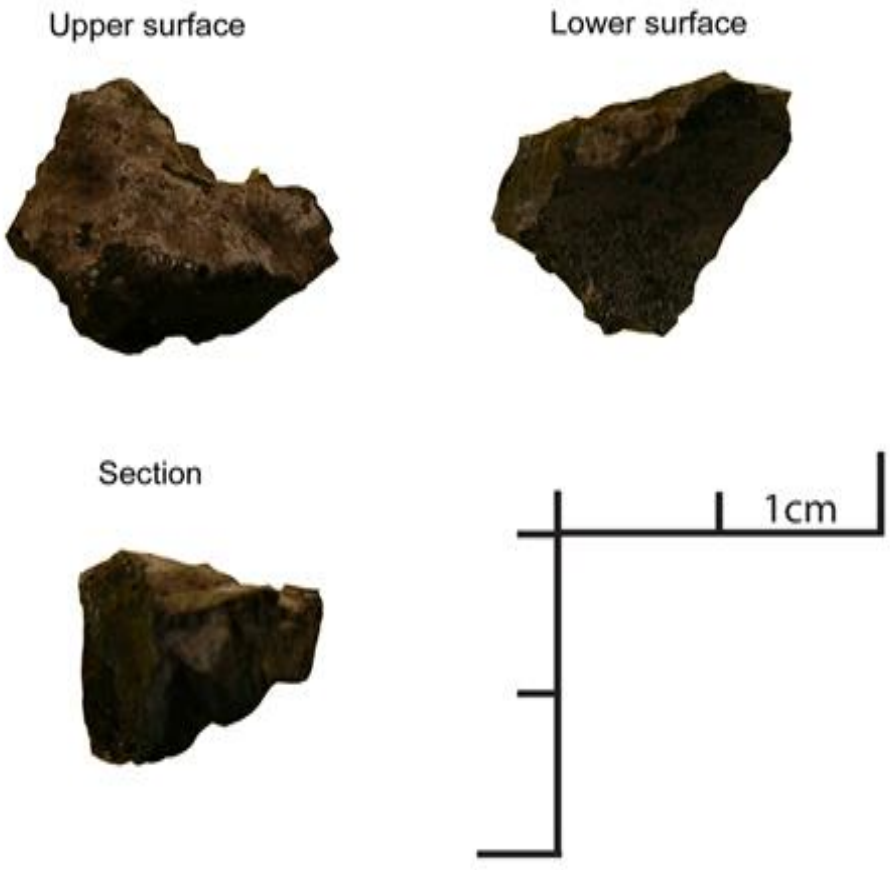


Site Code *UST11* **Sample** *83* **Type** *Slag* **Area**

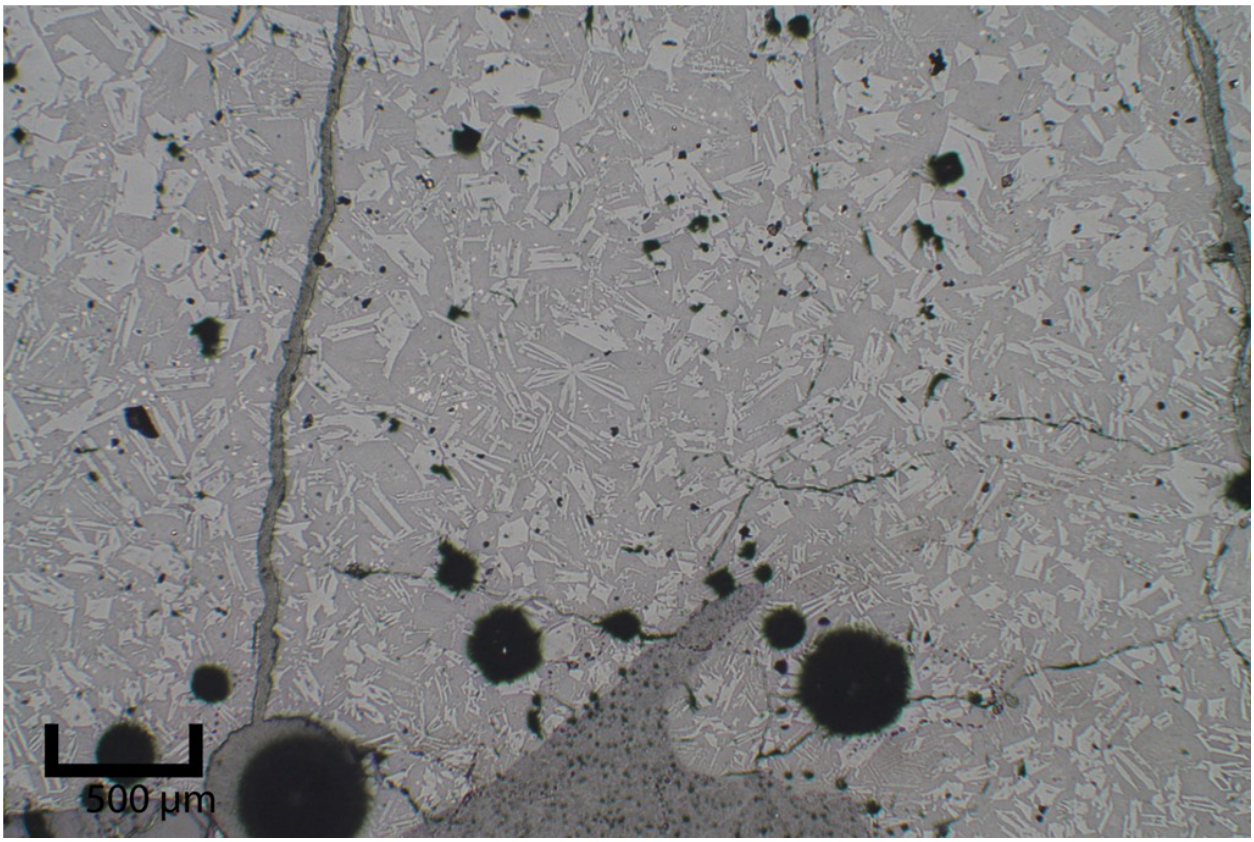
Wustite	*Rare*	**Additional notes**
Magnetitie	*Rare*	
Lath Fayalite	*Common*	
Delafossite	*Rare*	
Metallic copper	*Rare*	
Sulphides		
Euheadral fayalite	*Occasional*	
Matrix	*Glassy 50-75%*	
Additional Phases		

Chromite ***Present*** **Group** *D2*

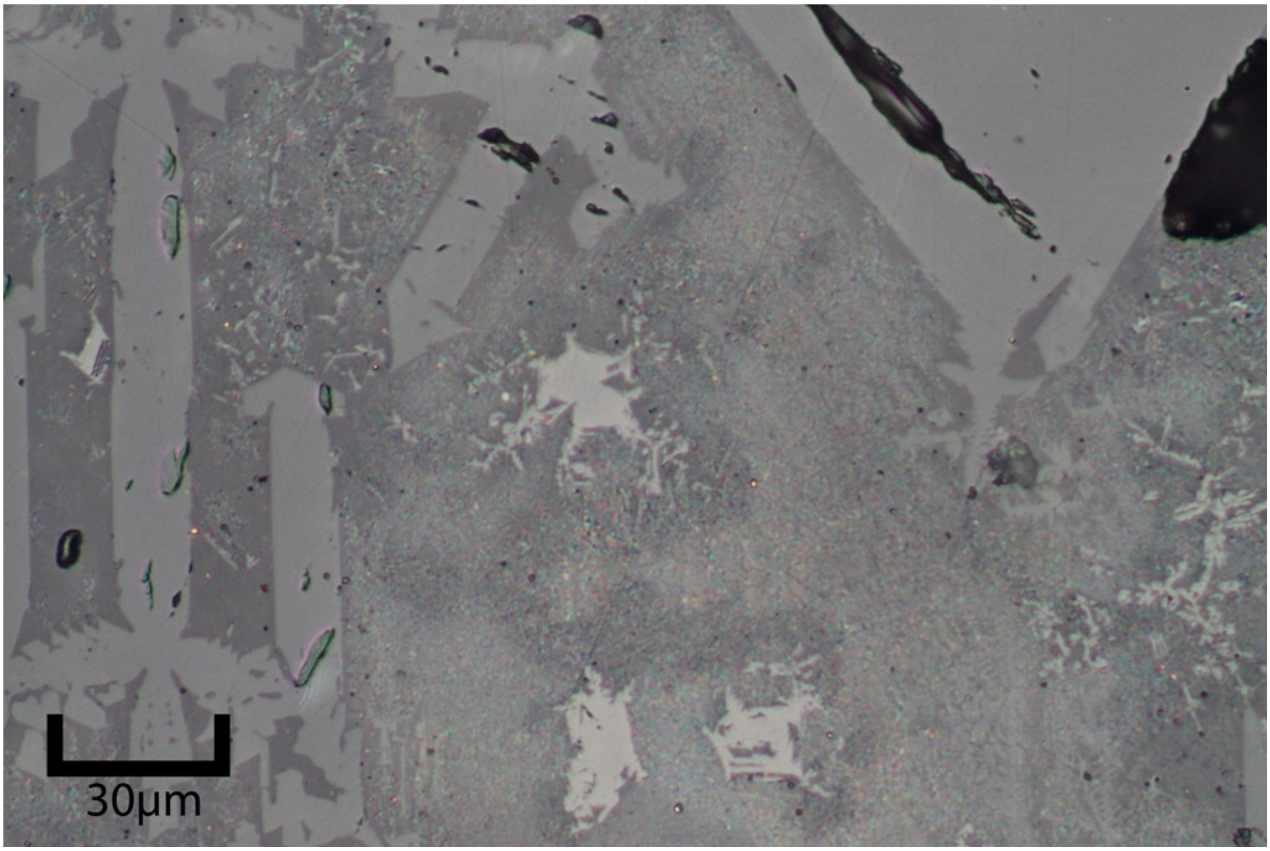
Hand Specimin



Micrograph 1



Micrograph 2



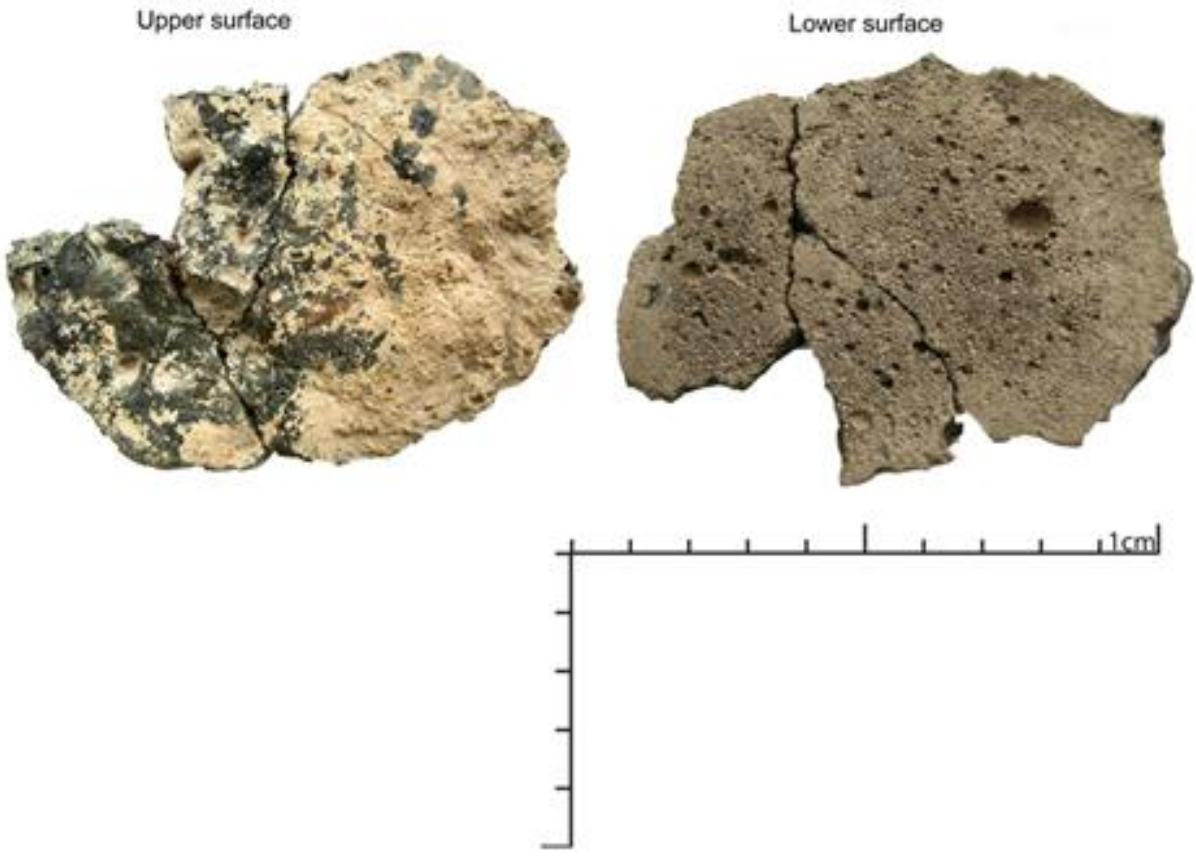
Site Code *UST11* **Sample** *100* **Type** *Slag* **Area**

Wustite	*Rare*
Magnetitie	*Absent*
Lath Fayalite	*Frequent*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	*Rare*
Euheadral fayalite	*Absent*
Matrix	*Glassy 25-50%*
Additional Phases	*common free silica*

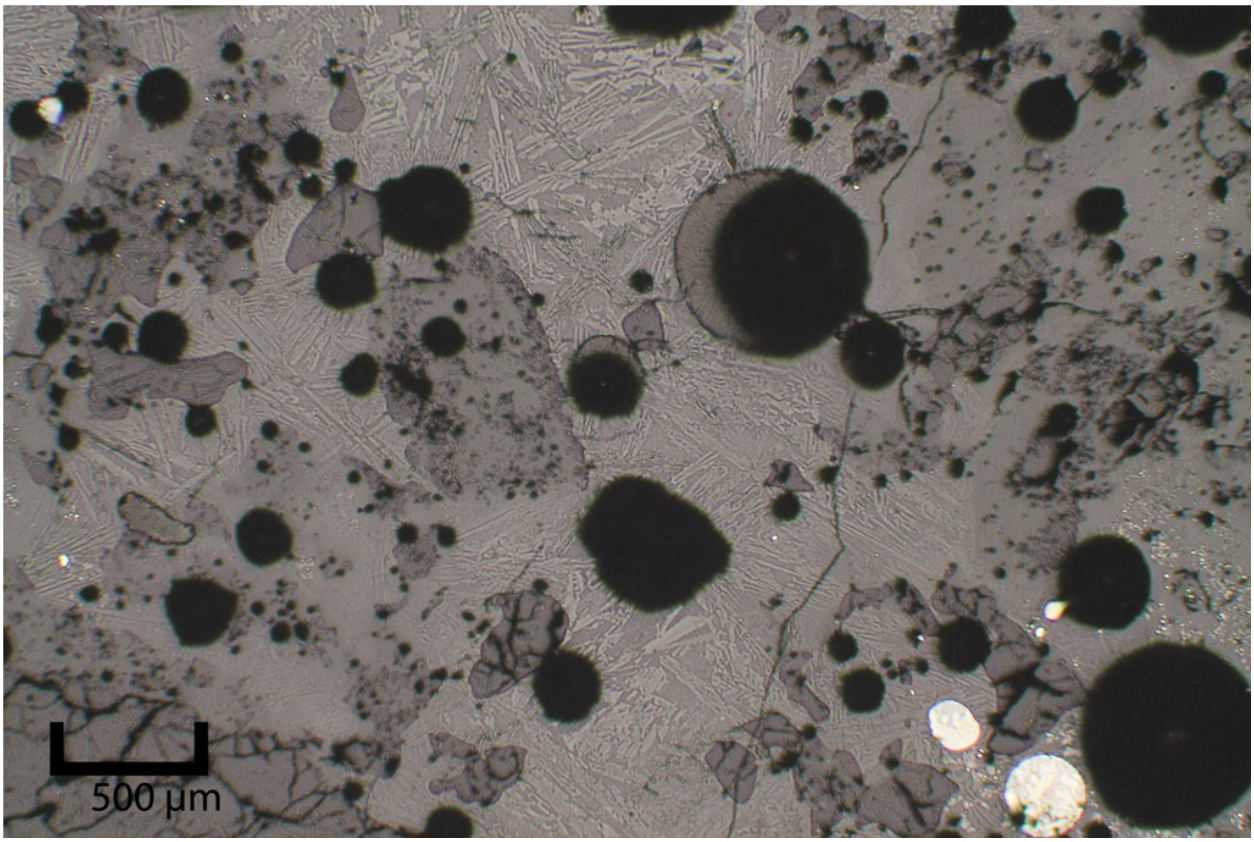
Additional notes
possible ceramic inclusions

Chromite ***Present*** **Group** *A2*

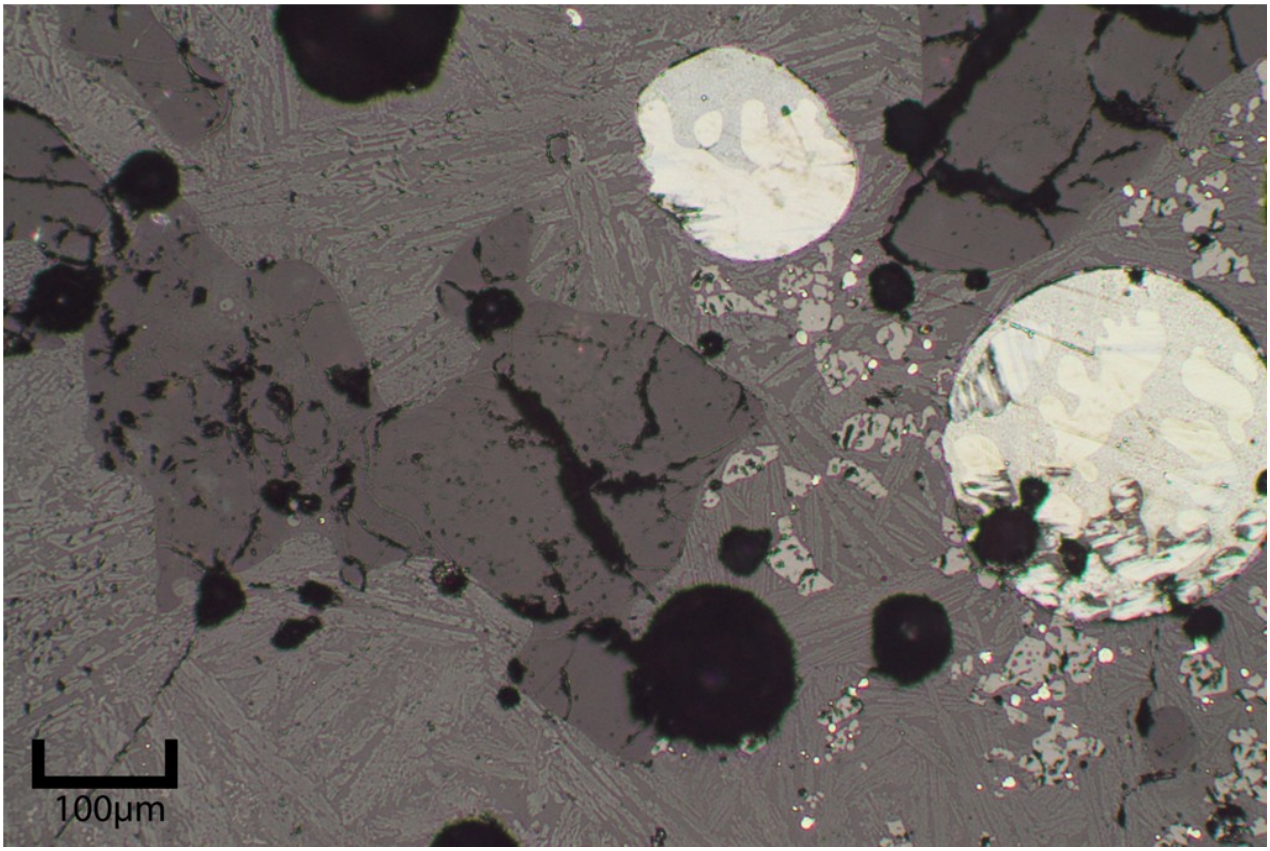
Hand Specimin



Micrograph 1



Micrograph 2



Site Code *UST11* **Sample** *109a* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Rare*
Lath Fayalite	*Occasional*
Delafossite	*Absent*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Common*
Matrix	*Glassy 50-75%*
Additional Phases	*rare cuprite, common free silica*

Additional notes

very glassy in hand specimen, some ceramic inclusions

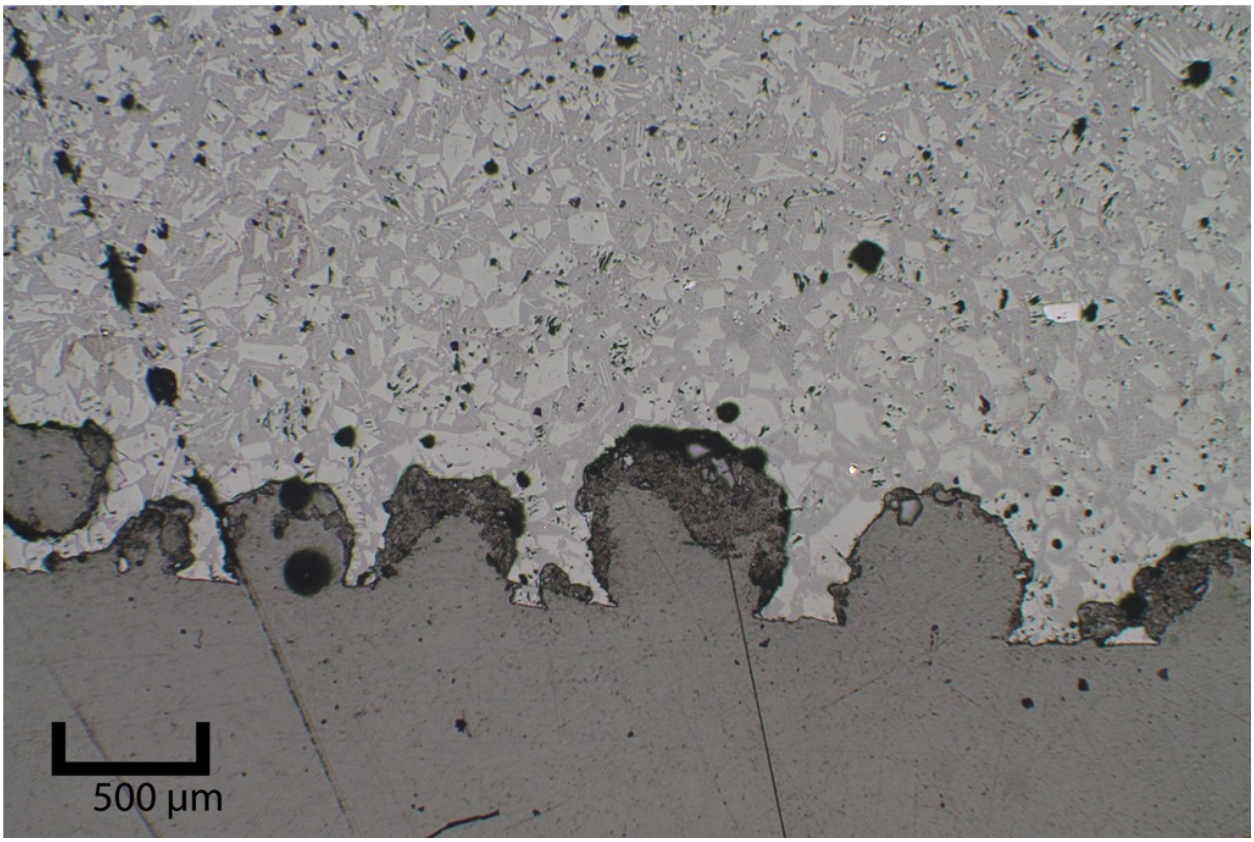
Chromite ***Present***

Group *D2*

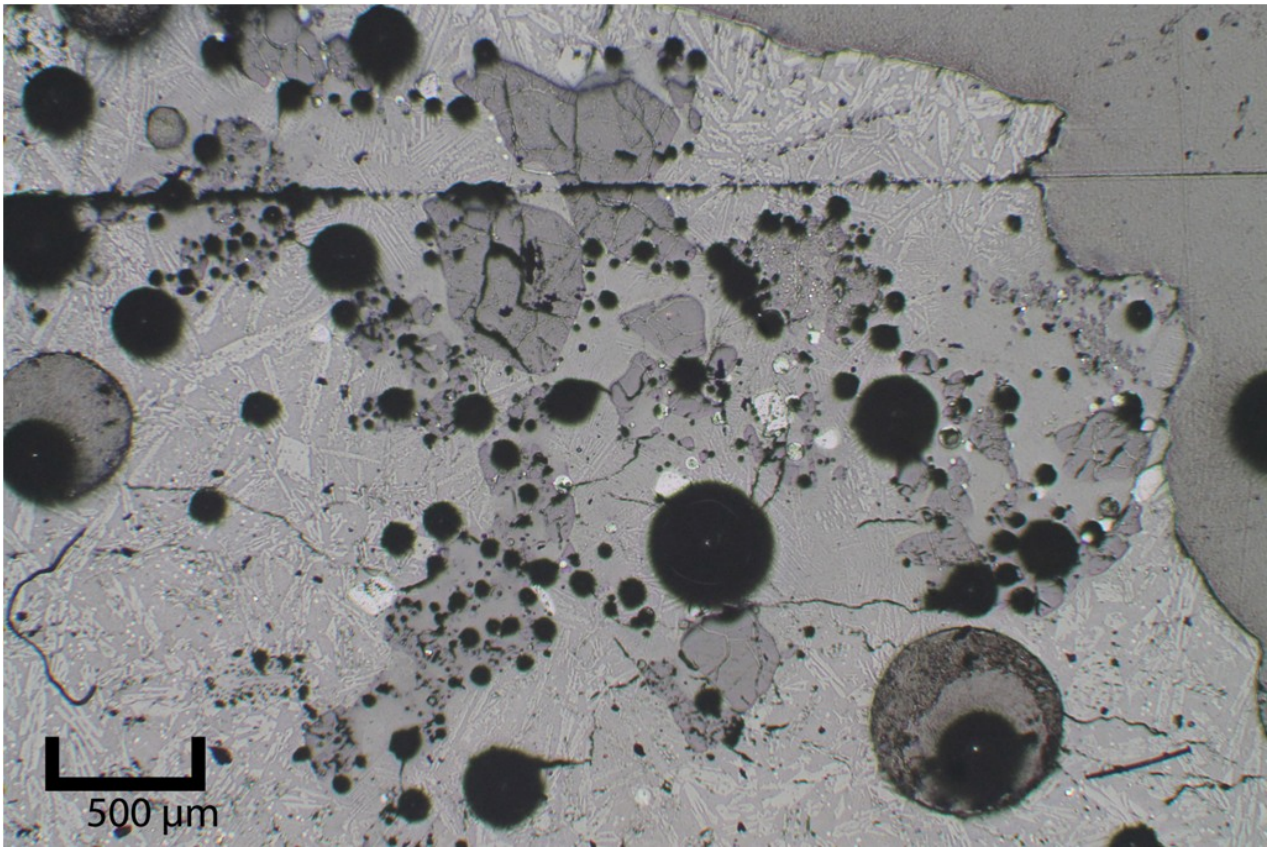
Hand Specimin



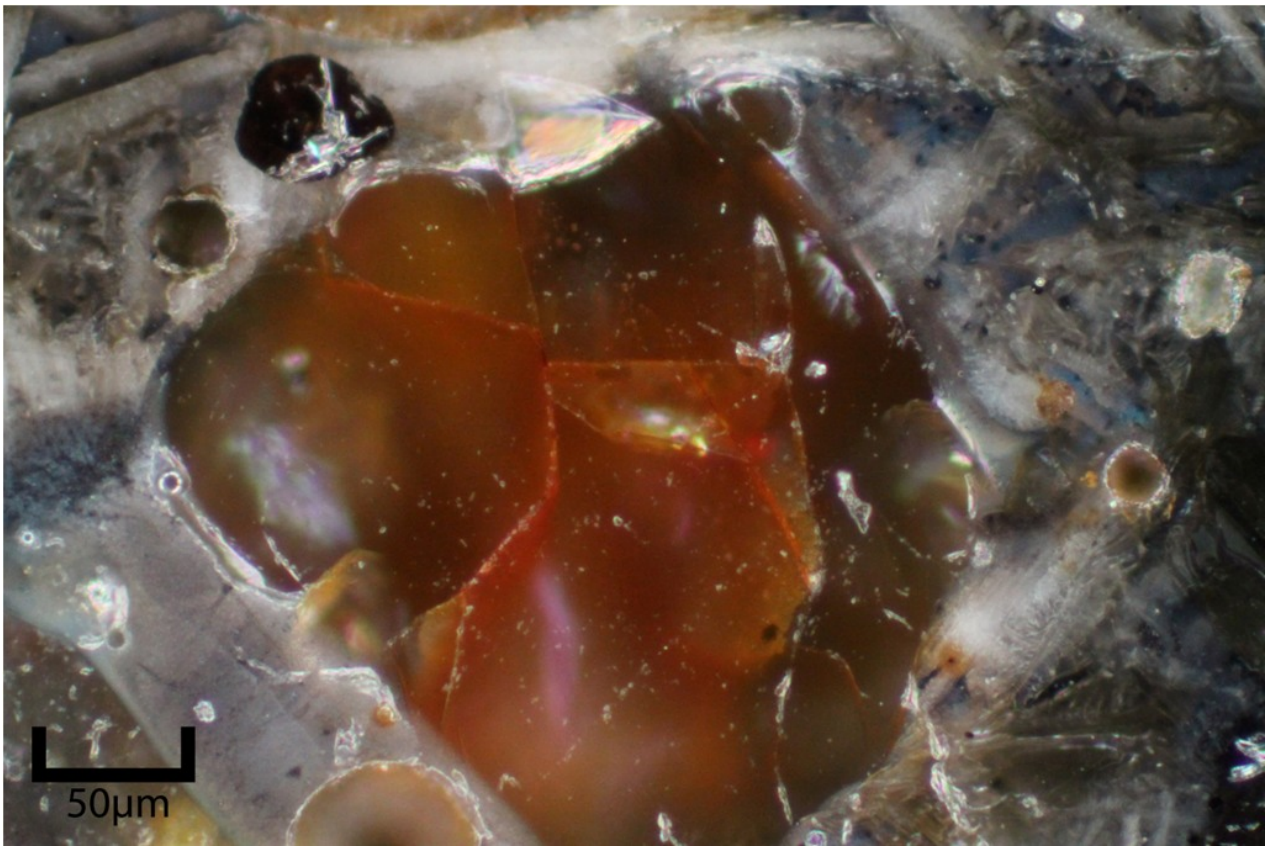
Micrograph 1



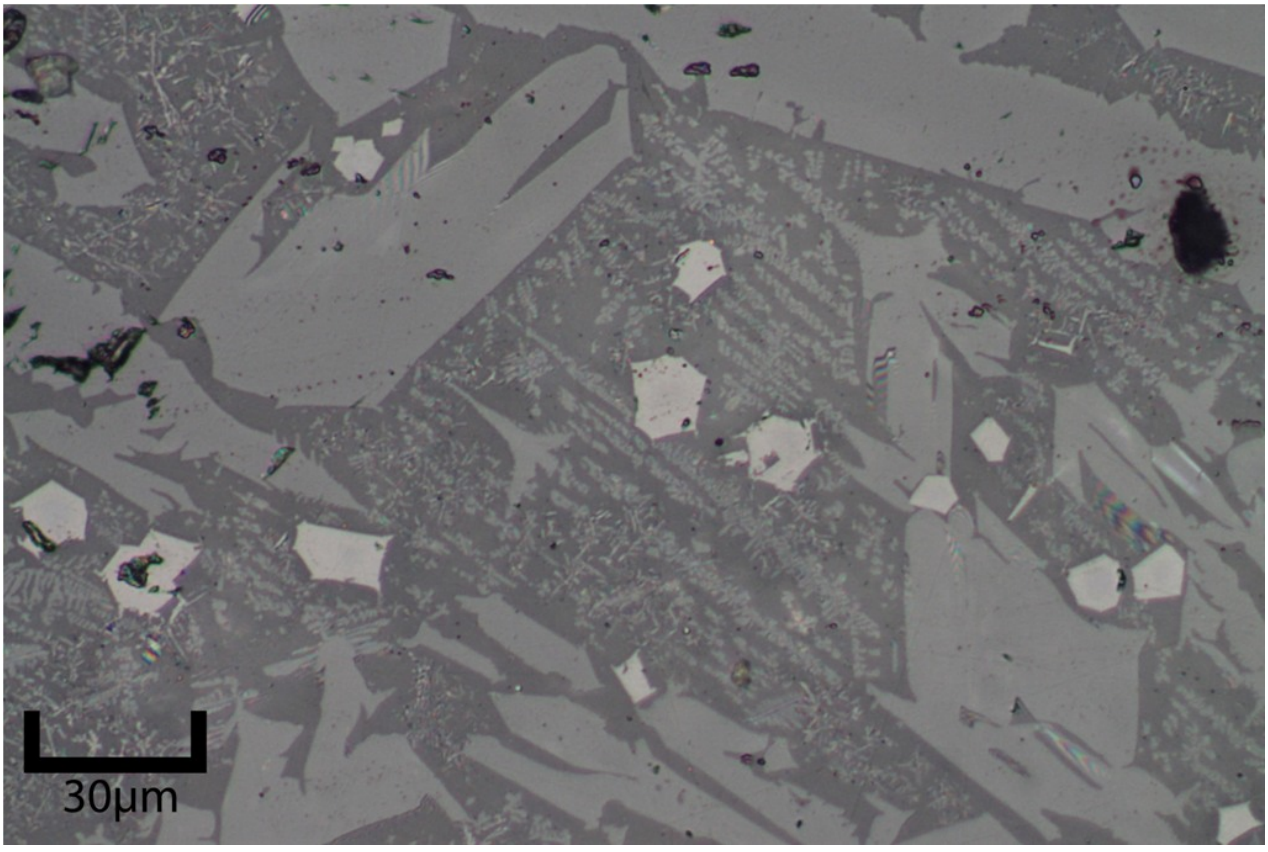
Micrograph 2



Micrograph 3



Micrograph 4



Site Code *UST11* **Sample** *109b* **Type** *Slag* **Area**

Wustite	*Absent*
Magnetitie	*Occasional*
Lath Fayalite	*Common*
Delafossite	*Rare*
Metallic copper	*Rare*
Sulphides	
Euheadral fayalite	*Rare*
Matrix	*Glassy 50-75%*
Additional Phases	

Additional notes
possible talc inclusions

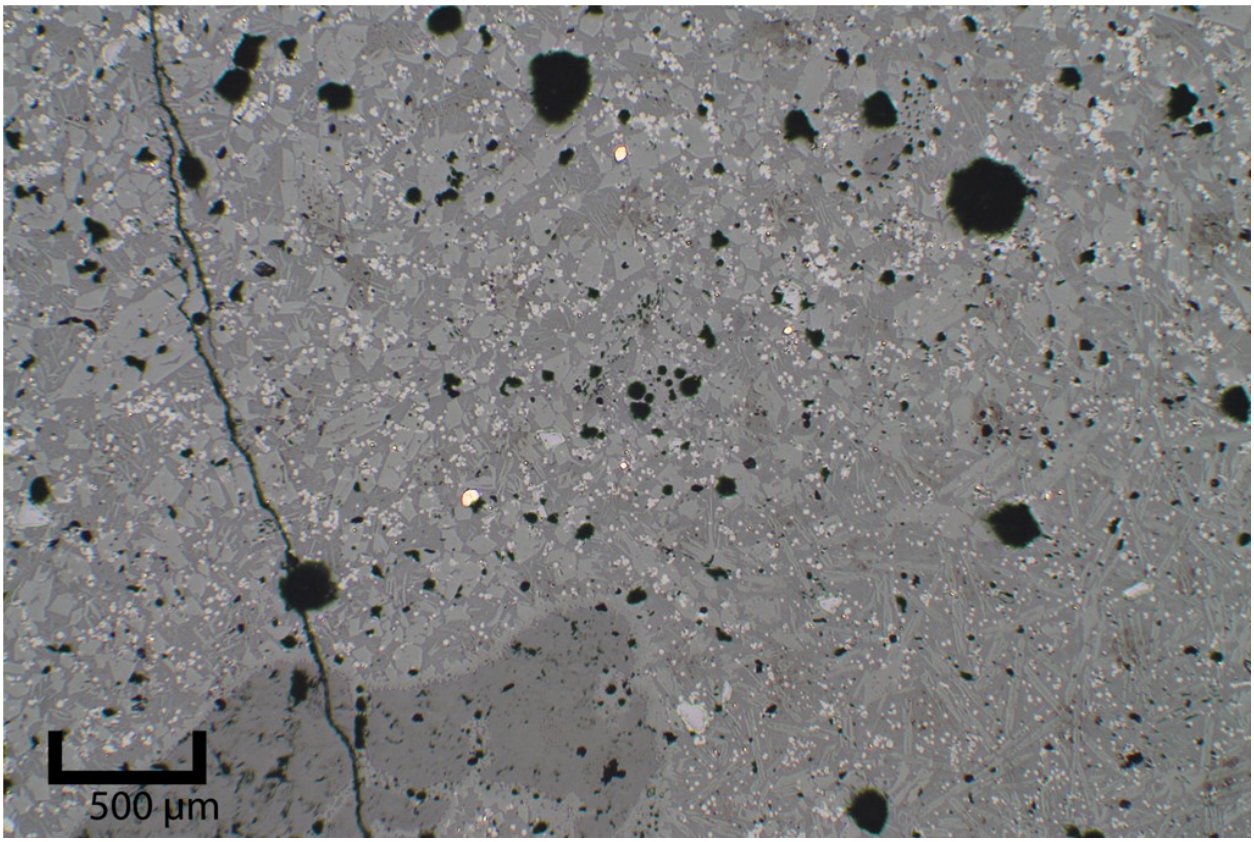
Chromite ***Present***

Group *A2*

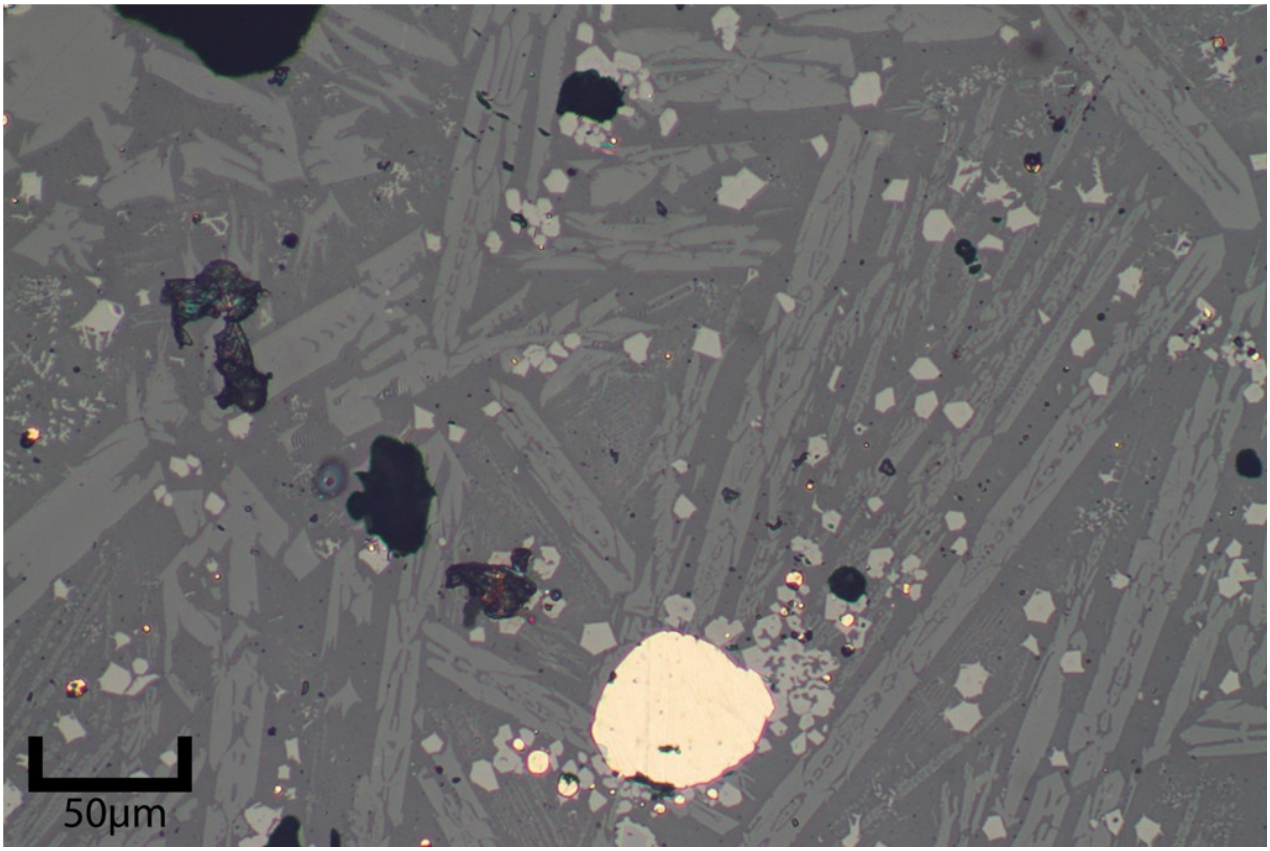
Hand Specimin



Micrograph 1



Micrograph 2



Appendix C

SEM Data

Table C.1 Analysis of silicate phases in the slag
(%wt normalised)

Site	Sample	Spec.	MgO	Al_2O_3	SiO_2	P_2O5	K_2O	CaO	TiO_2	Cr_2O3	MnO	FeO
STEP09	1	1	10.5	n.d.	32.9	n.d.	n.d.	0.2	n.d.	n.d.	0.3	56.1
STEP09	1	2	6.5	n.d.	32	n.d.	n.d.	0.3	n.d.	n.d.	0.3	60.8
STEP09	1	3	1.4	n.d.	29.9	n.d.	n.d.	0.6	n.d.	n.d.	0.3	67.8
STEP09	32	1	3.5	n.d.	29.7	n.d.	n.d.	0.7	n.d.	n.d.	0.4	65.7
STEP09	32	2	1.7	n.d.	29.2	n.d.	n.d.	0.8	n.d.	n.d.	0.6	67.7
STEP09	32	3	2.2	n.d.	29.4	n.d.	n.d.	0.9	n.d.	n.d.	0.5	66.9
STEP09	64	1	23.1	n.d.	34.8	n.d.	n.d.	0.2	n.d.	n.d.	n.d.	41.7
STEP09	64	2	22	n.d.	34.2	n.d.	n.d.	0.2	n.d.	n.d.	n.d.	43.2
STEP09	105.2	1	16.8	0.2	33.4	0.2	n.d.	0.3	n.d.	0.1	0.2	48.6
STEP09	105.2	2	15.8	0.1	33.7	0.2	n.d.	0.5	n.d.	0.2	0.3	48.9
STEP09	105.2	3	16.3	n.d.	33.6	0.2	n.d.	0.3	n.d.	0.1	0.3	49
STEP09	105.2	4	0.3	2.8	31.6	0.7	0.4	3.3	0.1	n.d.	0.2	60.1
STEP09	117	1	9.9	n.d.	31.4	n.d.	n.d.	0.4	n.d.	0.1	0.3	57.9
STEP09	117	2	10.6	n.d.	30.7	n.d.	n.d.	0.3	n.d.	0.7	0.3	57.5
STEP09	x1	1	2.9	0.2	28.8	1	n.d.	0.4	n.d.	n.d.	0.3	65.5
STEP09	x1	2	1.9	0.8	29.7	1.9	0.3	1.9	n.d.	n.d.	0.4	62.2
STEP09	x1	3	3.3	0.4	28.8	1.1	n.d.	0.5	n.d.	n.d.	0.3	64.7
STEP09	x1	4	2.7	0.2	28.9	0.6	n.d.	0.5	n.d.	n.d.	0.4	65.8
UST11	62	1	2.8	2.7	37.1	n.d.	1	0.6	n.d.	n.d.	n.d.	55.7
UST11	62	2	1.6	0.6	28.5	n.d.	0.1	0.3	n.d.	n.d.	n.d.	68.8
UST11	62	3	2	0.2	27.7	n.d.	0.1	0.2	n.d.	n.d.	n.d.	69.8
UST11	69	1	9.6	n.d.	33.2	n.d.	n.d.	0.4	n.d.	n.d.	0.4	56.5
UST11	69	2	6	n.d.	31.6	n.d.	n.d.	0.5	n.d.	n.d.	0.3	61.6
UST11	69	3	11.4	n.d.	32.7	n.d.	n.d.	0.3	n.d.	n.d.	0.4	55.3
UST11	77	1	1	n.d.	29.7	n.d.	n.d.	n.d.	n.d.	n.d.	0.6	68.7
UST11	77	2	0.8	n.d.	30	n.d.	n.d.	n.d.	n.d.	n.d.	0.6	68.6
UST11	77	3	1	n.d.	32.6	n.d.	n.d.	n.d.	n.d.	n.d.	0.7	65.7
UST11	83	1	7.3	n.d.	31.5	0.4	n.d.	0.2	n.d.	n.d.	0.8	59.8
UST11	83	2	8.1	n.d.	32	0.3	n.d.	0.4	n.d.	n.d.	0.6	58.6
UST11	83	3	8.6	n.d.	31.4	0.6	n.d.	0.2	n.d.	n.d.	0.6	58.7
161y	3290	1	17.3	n.d.	33.3	0.7	n.d.	n.d.	n.d.	n.d.	n.d.	48.7
161y	3290	2	17.5	n.d.	33.8	0.4	n.d.	n.d.	n.d.	n.d.	n.d.	48.3
161y	3290	3	19.9	n.d.	34.1	0.5	n.d.	n.d.	n.d.	n.d.	n.d.	45.5
161y	5076	1	4.5	0.8	31.9	0.5	0.3	0.3	n.d.	n.d.	0.3	61.5
161y	5076	2	5	1	32	0.4	0.3	0.4	0.1	0.1	0.3	60
161y	5076	3	3.4	0.5	30.9	0.3	0.4	0.5	n.d.	n.d.	0.4	63.3
161y	6452	1	6.5	0.1	30.2	0.5	n.d.	1.1	n.d.	n.d.	0.3	61.3
161y	6452	2	6.8	0.1	30.4	0.3	n.d.	1.2	n.d.	n.d.	0.3	60.9

Table C.1 Analysis of silicate phases in the slag (%wt normalised) continued.

Site	Sample	**Spec.**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O5**	**K_2O**	**CaO**	**TiO_2**	**Cr_2O3**	**MnO**	**FeO**
161y	6452	3	2.6	1.6	30.6	1.8	1.1	3.2	n.d.	n.d.	0.3	58.9
161y	10007	1	6.3	0.4	31.3	n.d.	n.d.	0.2	n.d.	n.d.	0.5	61.2
161y	10007	2	5.2	0.4	31.2	n.d.	n.d.	0.4	n.d.	n.d.	0.7	62.1
161y	10007	3	7.6	0.2	31.9	n.d.	n.d.	0.2	n.d.	n.d.	0.6	59.5
161y	10007	4	8.3	0.2	31.6	n.d.	n.d.	0.3	n.d.	n.d.	0.5	59.1
161y	10007	5	8	0.7	34.3	n.d.	n.d.	0.5	n.d.	n.d.	0.5	55.9
161y	10397	1	3.1	2.3	33	n.d.	0.8	0.4	n.d.	n.d.	n.d.	60.4
161y	10397	2	2.9	2.5	33.8	n.d.	0.9	0.4	n.d.	n.d.	n.d.	59.5
161y	10397	3	3.6	3.1	33.6	n.d.	1	0.3	n.d.	n.d.	n.d.	58.3

Table C.2 Analysis of iron oxide phases in the slag (%wt normalised)

Site	Sample	Spec.	MgO	Al_3O_3	SiO_2	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO	CuO
STEP09	1	1	n.d.	1.9	2.2	1.2	1	n.d.	n.d.	n.d.	93.3	n.d.	n.d.
STEP09	1	2	n.d.	0.4	0.8	0.2	n.d.	n.d.	n.d.	n.d.	98.5	n.d.	n.d.
STEP09	32	1	n.d.	1.5	n.d.	n.d.	n.d.	n.d.	1.2	n.d.	97.3	n.d.	n.d.
STEP09	32	2	n.d.	1.3	n.d.	n.d.	n.d.	n.d.	0.9	n.d.	97.7	n.d.	n.d.
STEP09	32	3	n.d.	1.3	n.d.	n.d.	n.d.	n.d.	1	n.d.	97.6	n.d.	n.d.
STEP09	105.2	1	0.5	17.2	1.2	n.d.	2.3	0.4	0.2	78.2	n.d.	n.d.	n.d.
STEP09	105.2	2	0.7	18.2	0.8	n.d.	1.9	0.7	6.5	71.1	n.d.	n.d.	n.d.
STEP09	117	1	1.2	6.7	2.8	0.3	1.5	0.4	9.9	n.d.	77.1	n.d.	n.d.
STEP09	117	2	1.3	6.2	4.9	0.6	1.2	0.3	16.9	n.d.	68.6	n.d.	n.d.
STEP09	x1	1	0.7	14.1	0.7	n.d.	0.7	0.4	0.5	n.d.	82.2	0.9	n.d.
STEP09	x1	2	0.6	15.6	0.8	n.d.	0.7	0.4	0.1	n.d.	80.9	1	n.d.
STEP09	x1	3	0.6	14.8	1	n.d.	0.8	0.2	n.d.	n.d.	81.6	1	n.d.
UST11	69	1	1	11.1	7	0.7	1.8	0.4	14.9	n.d.	62	n.d.	0.5
UST11	69	2	0.6	9.1	7.3	0.8	2.4	0.4	4.2	n.d.	74.5	n.d.	n.d.
UST11	69	3	0.7	6.5	4.9	0.6	1.8	0.3	2	n.d.	82.6	n.d.	0.2
UST11	77	1	n.d.	12.6	1.6	n.d.	2.1	2.8	0.9	n.d.	79.4	n.d.	0.6
UST11	77	2	n.d.	11	2.6	n.d.	1.9	2	0.2	n.d.	82.3	n.d.	n.d.
UST11	77	3	n.d.	11.1	1.7	n.d.	2.2	2.3	0.4	n.d.	82.3	n.d.	n.d.
UST11	83	1	0.9	17.5	3.9	0.3	3.1	2.5	5.2	n.d.	63.5	n.d.	2.6
UST11	83	2	1	17.4	0.9	0.1	3.4	3.3	7.1	n.d.	66.7	n.d.	n.d.
161y	6452	1	0.4	3.2	1	0.5	0.5	n.d.	n.d.	n.d.	94.4	n.d.	n.d.
161y	6452	2	0.4	2.7	0.6	0.1	0.3	n.d.	n.d.	n.d.	96	n.d.	n.d.
161y	6452	3	0.5	2.6	0.6	0.1	0.3	n.d.	n.d.	n.d.	95.9	n.d.	n.d.
161y	10397	1	0.7	16.8	6.9	0.2	3	1.3	0.6	n.d.	70	n.d.	n.d.
161y	10397	2	0.8	20.5	9.2	0.3	3.6	1.6	0.3	n.d.	62.7	n.d.	n.d.
161y	10397	3	0.9	20.1	2.5	0.1	2.9	1.6	1.1	n.d.	70.3	n.d.	n.d.

Table C.3 Analysis of ithe matrix in the slag (%wt normalised)

Site	Sample	Spec.	Na_2O	MgO	Al_2O3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO
STEP09	1	1	0.7	n.d.	16.9	36.8	3.9	0.6	4	14.7	0.5	n.d.	21.6	0.1	0.2
STEP09	1	2	0.8	n.d.	11.4	34.3	3.4	0.5	3.3	10	0.3	n.d.	35.6	0.4	n.d.
STEP09	1	3	0.6	n.d.	10.9	33.7	2.6	0.3	2.7	10.6	0.2	n.d.	37.7	0.3	0.3
STEP09	32	1	n.d.	n.d.	14.2	33.1	3.8	n.d.	2.7	13.2	n.d.	n.d.	33	n.d.	n.d.
STEP09	32	2	n.d.	n.d.	15.6	31.6	5	n.d.	3.1	14.9	n.d.	n.d.	29.7	n.d.	n.d.
STEP09	32	3	n.d.	n.d.	13.8	31.7	5.1	n.d.	3.2	13.9	n.d.	n.d.	32.3	n.d.	n.d.
STEP09	64	1	0.7	0.4	15.8	46.6	0.7	n.d.	2	7.1	0.7	n.d.	25.7	0.3	n.d.
STEP09	64	2	0.6	0.5	14.2	45	0.6	n.d.	1.7	6.3	0.9	n.d.	30.2	0.1	n.d.
STEP09	105.2	1	1.4	n.d.	13.4	37.8	2.1	n.d.	2.8	13.8	0.3	n.d.	28.1	0.3	n.d.
STEP09	105.2	2	1.6	n.d.	14.6	39	2.1	n.d.	2.9	14.8	0.2	n.d.	24.6	0.1	n.d.
STEP09	105.2	3	1.4	n.d.	13.2	36.9	2.1	n.d.	3	13.1	0.3	n.d.	29.9	0.1	n.d.
STEP09	x1	1	0.5	n.d.	12.7	37.2	6.7	n.d.	1.7	10.9	n.d.	n.d.	29.1	0.4	0.9
STEP09	x1	2	0.5	n.d.	14.8	36.5	6.2	n.d.	1.6	10	n.d.	n.d.	29.2	0.2	1
STEP09	x1	3	0.4	n.d.	14.7	39.2	6.3	n.d.	1.5	10.8	n.d.	n.d.	26.1	0.2	0.8
UST11	62	1	n.d.	n.d.	11.6	49.1	n.d.	n.d.	2.5	2	0.3	n.d.	34.3	0.1	n.d.
UST11	62	2	n.d.	n.d.	14	48.2	n.d.	n.d.	2.1	3.8	0.8	n.d.	30.1	0.7	n.d.
UST11	62	3	n.d.	n.d.	12.5	50.7	n.d.	n.d.	1.7	5.1	0.7	n.d.	27.7	1.1	n.d.
UST11	69	1	n.d.	0.27	11.39	44.25	0.77	n.d.	3.61	5.3	0.71	0.18	32.89	0.62	n.d.
UST11	69	2	n.d.	0.42	12.76	44.86	1.32	n.d.	3.64	7.36	0.51	0.16	28.58	0.41	n.d.
UST11	69	3	n.d.	0.93	11.06	43.74	1.06	n.d.	2.92	6.14	0.35	0.27	32.88	0.65	n.d.
UST11	77	1	n.d.	n.d.	20.09	39.93	1.67	n.d.	4.27	1.63	0.96	0.18	30.42	0.84	n.d.
UST11	77	2	n.d.	n.d.	17.59	43.13	2.79	n.d.	3.25	3.37	0.9	0.22	28.37	0.38	n.d.
UST11	77	3	n.d.	n.d.	17.82	44	2.27	n.d.	2.92	3.68	0.76	0.31	27.88	0.35	n.d.
UST11	83	1	n.d.	0.32	18.22	42.09	2.01	n.d.	6.12	3.73	0.66	0.18	26.57	0.09	n.d.
UST11	83	2	n.d.	0.51	12.08	36.93	1.63	n.d.	2.84	3.88	0.6	0.32	40.9	0.31	n.d.
UST11	83	3	n.d.	0.7	13.63	40.08	1.56	n.d.	3.49	3.86	0.6	0.36	35.24	0.46	n.d.
161y	3290	1	0.6	0.56	16.26	50.95	1.44	n.d.	3.3	5.47	0.58	n.d.	20.08	0.76	n.d.
161y	3290	2	0.86	0.69	13.93	46.84	1.09	n.d.	3.01	4.41	0.51	n.d.	25.95	2.7	n.d.
161y	3290	3	0.87	0.96	12.33	46.92	1.14	n.d.	2.53	5.05	0.37	n.d.	29.24	0.6	n.d.
161y	5076	1	n.d.	0.49	14.7	42.34	1.36	0.1	3.18	4.84	0.78	0.24	31.39	0.43	n.d.
161y	5076	2	n.d.	0.55	17.89	48.46	0.86	0.07	4.75	3.73	0.72	0.14	22.02	0.73	n.d.
161y	5076	3	n.d.	1.68	10.42	47.38	0.65	0.1	3.32	1.99	0.41	0.14	33.39	0.27	n.d.
161y	6452	1	0.47	0.97	4.25	33.06	3.96	n.d.	3.51	10.17	n.d.	n.d.	43.27	0.34	n.d.
161y	6452	2	0.45	1.02	4.09	34.28	3.8	n.d.	3.48	10.71	n.d.	n.d.	41.31	0.87	n.d.
161y	6452	3	0.65	0.31	5.35	34.13	5.1	n.d.	4.48	14.86	n.d.	n.d.	35.07	0.04	n.d.
161y	10007	1	0.76	0.07	19.59	31.77	2.71	0.57	4.86	6.78	1.3	0.13	31.02	0.46	n.d.
161y	10007	2	0.18	0.46	11.66	34.2	1.88	0.25	2.58	5	0.7	0.4	42.57	0.13	n.d.
161y	10007	3	0.42	0.45	10.69	37.03	1.9	0.27	2.07	6.81	0.82	0.39	38.98	0.18	n.d.
161y	10397	1	n.d.	n.d.	18.93	43.34	0.76	n.d.	5.23	1.58	1.11	n.d.	29.05	n.d.	n.d.
161y	10397	2	n.d.	n.d.	20.45	45.72	0.71	n.d.	5.54	1.58	1.18	n.d.	24.82	n.d.	n.d.
161y	10397	3	n.d.	n.d.	21.68	47.83	0.59	n.d.	6.14	1.44	1.17	n.d.	21.15	n.d.	n.d.

Table C.4 SEM-EDS bulk slag analysis (%wt normalised)

Site	Sample	Spec.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	CuO	ZnO
STEP09	1	1	n.d.	2.43	5.25	29.84	1.13	0.7	2.5	n.d.	0.13	0.17	57.34	0.51	n.d.
STEP09	1	2	n.d.	1.16	7.21	29.59	1.22	1.01	3.3	n.d.	0.16	0.21	55.9	0.25	n.d.
STEP09	1	3	n.d.	4.5	4.06	29.96	0.69	0.4	1.54	n.d.	0.16	0.22	58.2	0.27	n.d.
STEP09	1	4	n.d.	2.51	5.87	30.33	0.99	0.84	2.9	n.d.	0.14	0.2	55.84	0.38	n.d.
STEP09	1	5	n.d.	4.21	3.93	30.12	0.72	0.46	1.76	n.d.	0.25	0.31	58.02	0.21	n.d.
STEP09	32	1	n.d.	1.08	4.53	20.51	1.05	0.24	1.84	n.d.	0.55	n.d.	69.82	0.37	n.d.
STEP09	32	2	n.d.	1.18	4.45	20.65	0.77	0.35	1.76	n.d.	1.07	n.d.	69.33	0.45	n.d.
STEP09	32	3	n.d.	1.14	4.96	20.57	0.91	0.47	2.32	n.d.	0.42	n.d.	68.82	0.4	n.d.
STEP09	32	4	n.d.	1.17	4.11	19.63	1.32	0.19	1.5	n.d.	0.78	n.d.	70.37	0.92	n.d.
STEP09	32	5	n.d.	1.16	4.34	19.73	1.33	0.41	2.18	n.d.	0.89	n.d.	69.33	0.62	n.d.
STEP09	64	1	n.d.	5.13	8.95	38.09	n.d.	0.85	3.54	0.43	0.3	n.d.	42.05	0.64	n.d.
STEP09	64	2	n.d.	6.77	8.78	32.18	n.d.	0.61	2.56	0.23	8.84	n.d.	39.4	0.63	n.d.
STEP09	64	3	n.d.	6.89	8.09	37.5	n.d.	0.75	3.11	0.4	0.61	n.d.	42.05	0.59	n.d.
STEP09	105.2	1	0.67	4.75	6.04	32.72	0.66	0.97	4.25	n.d.	0.31	0.23	48.93	0.47	n.d.
STEP09	105.2	2	0.63	4.78	5.75	32.13	0.75	0.95	4.12	n.d.	1.85	0.24	48.42	0.37	n.d.
STEP09	105.2	3	0.6	3.79	6.33	33.33	1	1.1	4.66	n.d.	0.17	0.3	48.33	0.37	n.d.
STEP09	117	1	0.55	3.62	5.51	38.39	0.43	0.96	3.9	n.d.	0.32	0.24	45.27	0.81	n.d.
STEP09	x1	1	n.d.	1.24	7.9	27.37	2.89	0.6	3.32	n.d.	n.d.	0.19	54.33	1.14	1.02
STEP09	x1	2	n.d.	1.19	8.24	28.82	2.77	0.76	4.02	n.d.	n.d.	0.21	51.83	1.23	0.92
STEP09	x1	3	n.d.	1.18	8.36	27.79	2.98	0.65	3.57	n.d.	n.d.	0.23	52.36	1.94	0.94
STEP09	x1	4	n.d.	1.17	8.51	29.25	3.09	0.7	4.06	n.d.	n.d.	0.29	51.34	0.65	0.94
STEP09	x1	5	n.d.	1.32	7.68	26.8	3.05	0.71	3.91	n.d.	n.d.	0.18	55.18	0.42	0.75
UST11	62	1	n.d.	0.72	7.88	42.6	0.49	1.47	2.21	0.24	n.d.	n.d.	44.39	n.d.	n.d.
UST11	62	2	n.d.	0.84	7.55	43.33	0.67	1.31	2.44	0.24	n.d.	n.d.	43.62	n.d.	n.d.
UST11	62	3	n.d.	0.7	8	43	0.65	1.53	2.17	0.59	n.d.	n.d.	43.37	n.d.	n.d.
UST11	62	4	n.d.	0.79	8.2	43.15	0.73	1.59	2	0.35	n.d.	n.d.	43.18	n.d.	n.d.
UST11	62	1	n.d.	0.72	7.88	42.6	0.49	1.47	2.21	0.24	n.d.	n.d.	44.39	n.d.	n.d.
UST11	69	1	n.d.	2.66	8.25	40.14	0.76	2.29	3.91	0.27	n.d.	0.34	40.82	0.56	n.d.
UST11	69	2	n.d.	2.65	8.25	40.33	0.71	2.29	3.83	0.3	n.d.	0.35	40.74	0.55	n.d.
UST11	69	3	n.d.	2.35	9.07	40.78	0.8	2.43	4.06	0.33	n.d.	0.35	39.44	0.39	n.d.
UST11	69	4	n.d.	2.47	8.91	39.86	0.85	2.36	4.01	0.3	n.d.	0.31	40.38	0.55	n.d.
UST11	77	1	n.d.	0.24	10.42	36.09	1.05	1.74	0.8	0.42	n.d.	0.4	48.03	0.57	n.d.
UST11	77	2	n.d.	0.23	10.15	34.49	1.23	1.77	1.02	0.37	n.d.	0.38	49.69	0.47	n.d.
UST11	77	3	n.d.	0.27	10.07	36.23	1.17	1.72	0.9	0.39	n.d.	0.45	48.19	0.47	n.d.
UST11	77	4	n.d.	0.29	10.22	37.02	1.05	1.7	0.91	0.4	n.d.	0.4	46.67	0.94	n.d.
UST11	83	1	n.d.	2.73	9.09	35.75	1.02	2.26	2.05	0.41	n.d.	0.48	45.79	0.43	n.d.
UST11	83	2	n.d.	2.47	9.61	36.98	1.05	2.42	2.36	0.43	n.d.	0.49	43.7	0.49	n.d.
UST11	83	3	n.d.	2.36	9.98	36.74	1.22	2.44	2.49	0.43	n.d.	0.48	43.51	0.36	n.d.
UST11	83	4	n.d.	2.21	9.69	36.85	1.06	2.46	2.23	0.45	n.d.	0.49	44.11	0.45	n.d.
UST11	83	5	n.d.	2.26	9.77	36.79	1.13	2.46	2.34	0.38	n.d.	0.44	44.11	0.33	n.d.

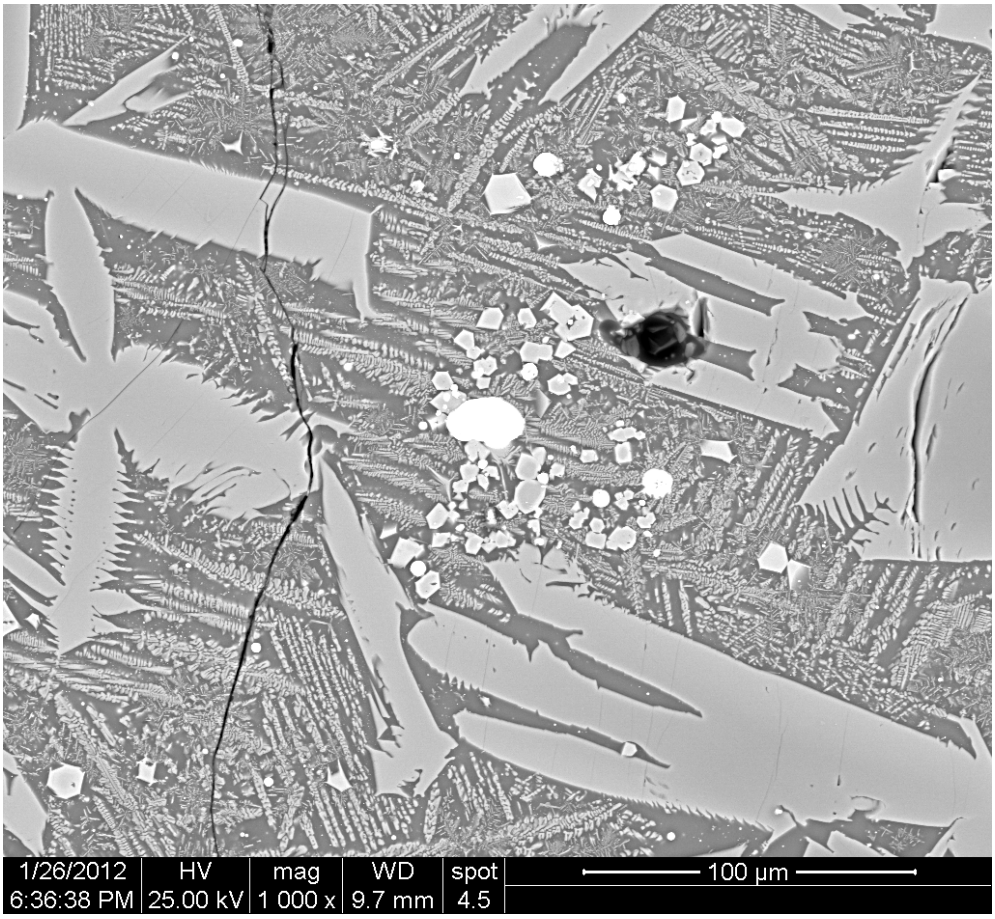
Table C.4 SEM-EDS bulk slag analysis (%wt normalised) continued.

Site	Sample	Spec.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	CuO	ZnO
161y	3290	1	n.d.	5.18	8.02	40.37	0.79	1.55	2.68	0.32	n.d.	n.d.	40.55	0.53	n.d.
161y	5076	1	n.d.	1.54	12.19	39.49	0.84	2.78	2.77	0.5	0.17	0.18	38.62	0.83	n.d.
161y	5076	2	n.d.	1.47	12.32	39.71	0.91	2.85	2.64	0.46	0.04	0.19	38.89	0.41	n.d.
161y	5076	3	n.d.	1.32	13.12	39.79	0.93	2.93	2.87	0.5	0.14	0.19	37.34	0.78	n.d.
161y	5076	4	n.d.	1.38	12.5	43.29	0.7	3.55	2.57	0.42	0.04	0.2	33.76	1.47	n.d.
161y	6452	1	n.d.	2.31	3.14	29.13	2.54	2.02	6.16	n.d.	n.d.	0.25	52.66	1.79	n.d.
161y	6452	2	n.d.	1.86	3.37	28.49	2.55	2.11	6.31	n.d.	n.d.	0.16	54.26	0.88	n.d.
161y	6452	3	n.d.	1.79	3.47	29.69	2.73	2.26	6.86	n.d.	n.d.	0.16	51.95	1.09	n.d.
161y	6452	4	n.d.	1.9	3.34	29.69	2.72	2.29	7	n.d.	n.d.	0.19	52.1	0.77	n.d.
161y	9208	1	0.7	6.91	19.69	54.21	1.25	1.6	2.15	0.96	n.d.	n.d.	12.54	n.d.	n.d.
161y	9208	2	0.65	4.96	18.63	63.45	0.31	2.09	1.27	0.85	n.d.	n.d.	7.79	n.d.	n.d.
161y	10007	1	n.d.	2.71	5.66	30.22	0.9	1.21	1.95	0.27	n.d.	0.46	56.32	0.32	n.d.
161y	10007	2	n.d.	2.07	7.48	31.28	1.11	1.61	2.58	0.35	n.d.	0.46	52.55	0.51	n.d.
161y	10007	3	n.d.	2.3	6.64	29.91	1.09	1.5	2.19	0.28	n.d.	0.5	55.19	0.4	n.d.
161y	10007	4	n.d.	2.63	6.26	30.67	1.04	1.4	2.37	0.25	n.d.	0.48	54.41	0.49	n.d.

Site **161y**

Sample No. **3290**

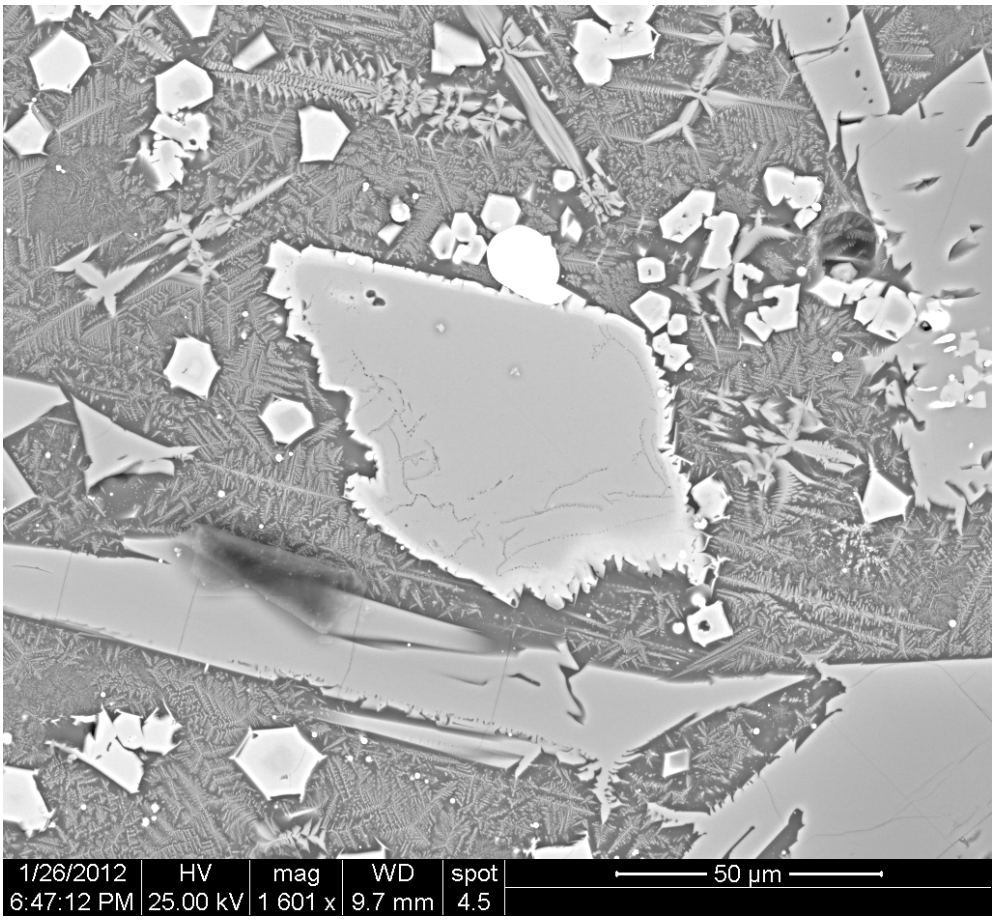
Image No. **1**



Site **161y**

Sample No. **3290**

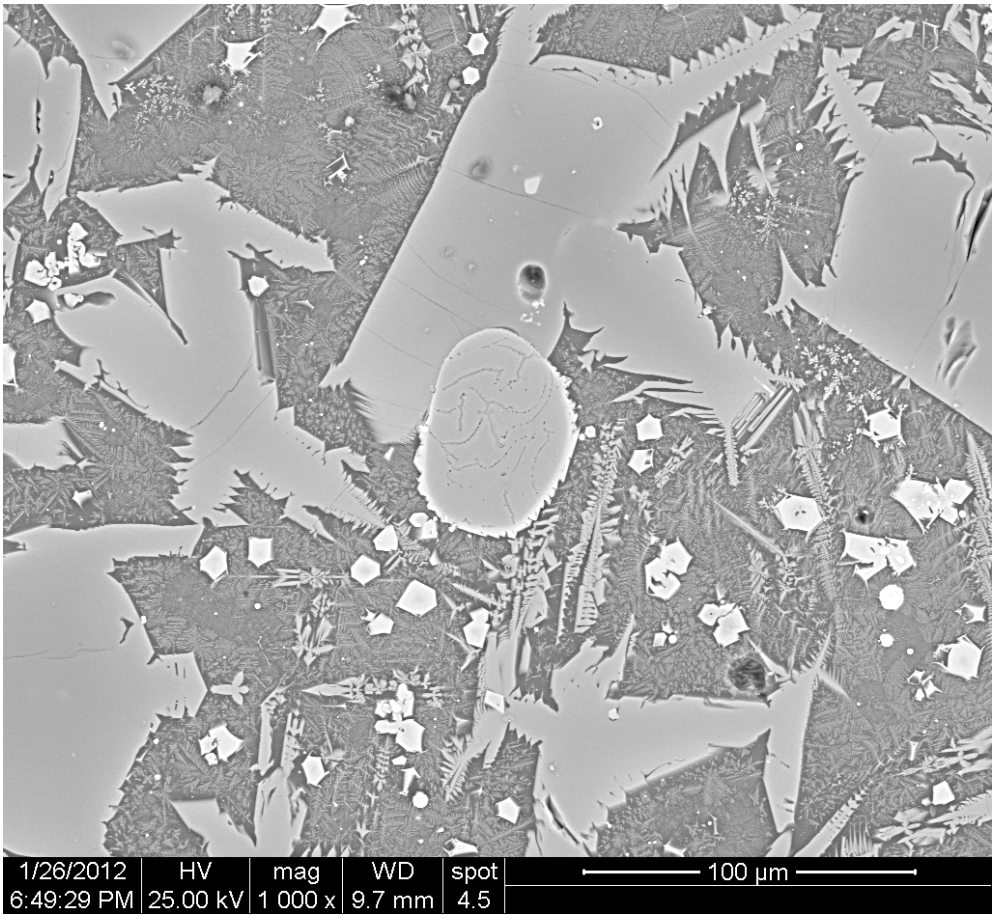
Image No. **2**



Site **161y**

Sample No. **3290**

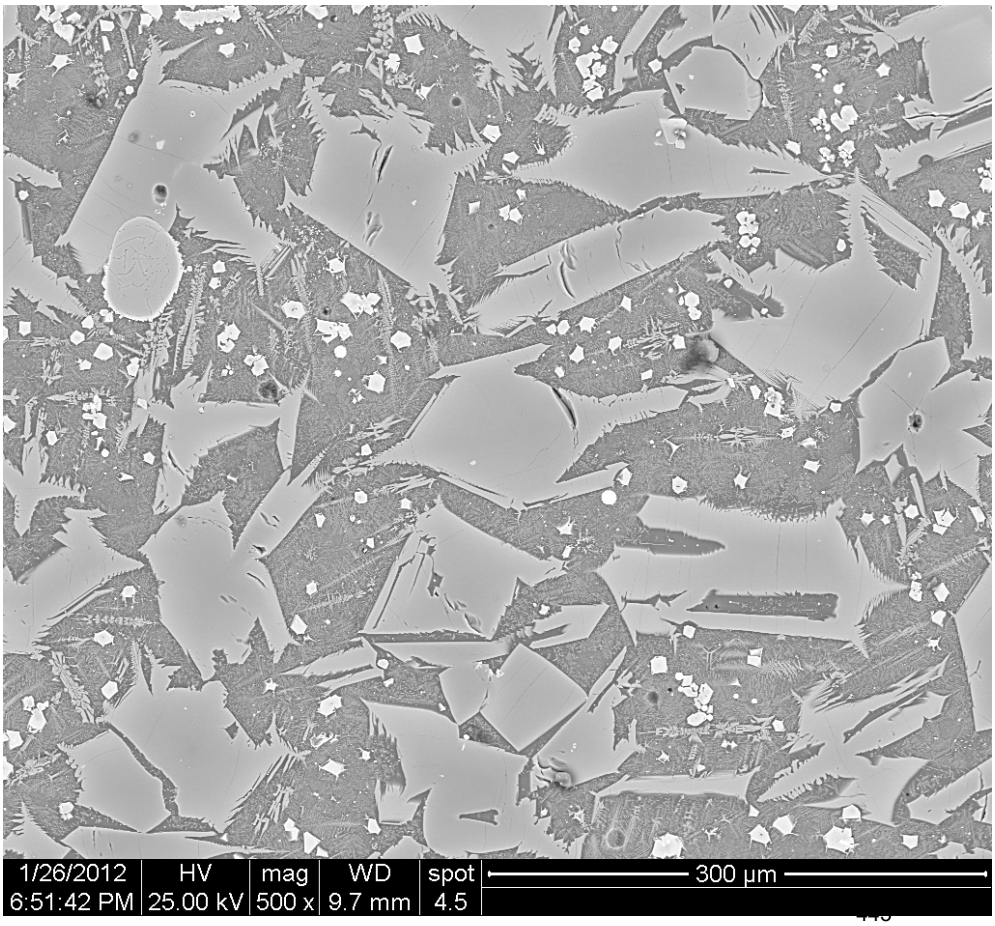
Image No. **3**



Site **161y**

Sample No. **3290**

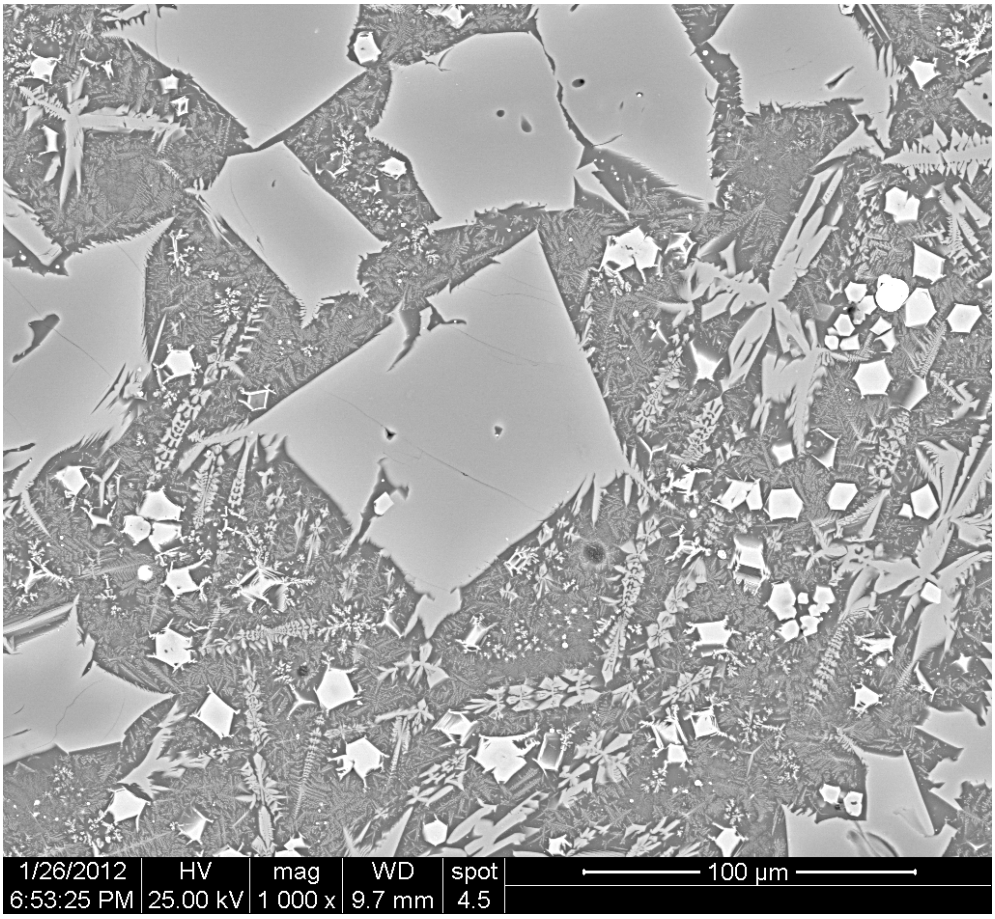
Image No. **4**



Site **161y**

Sample No. **3290**

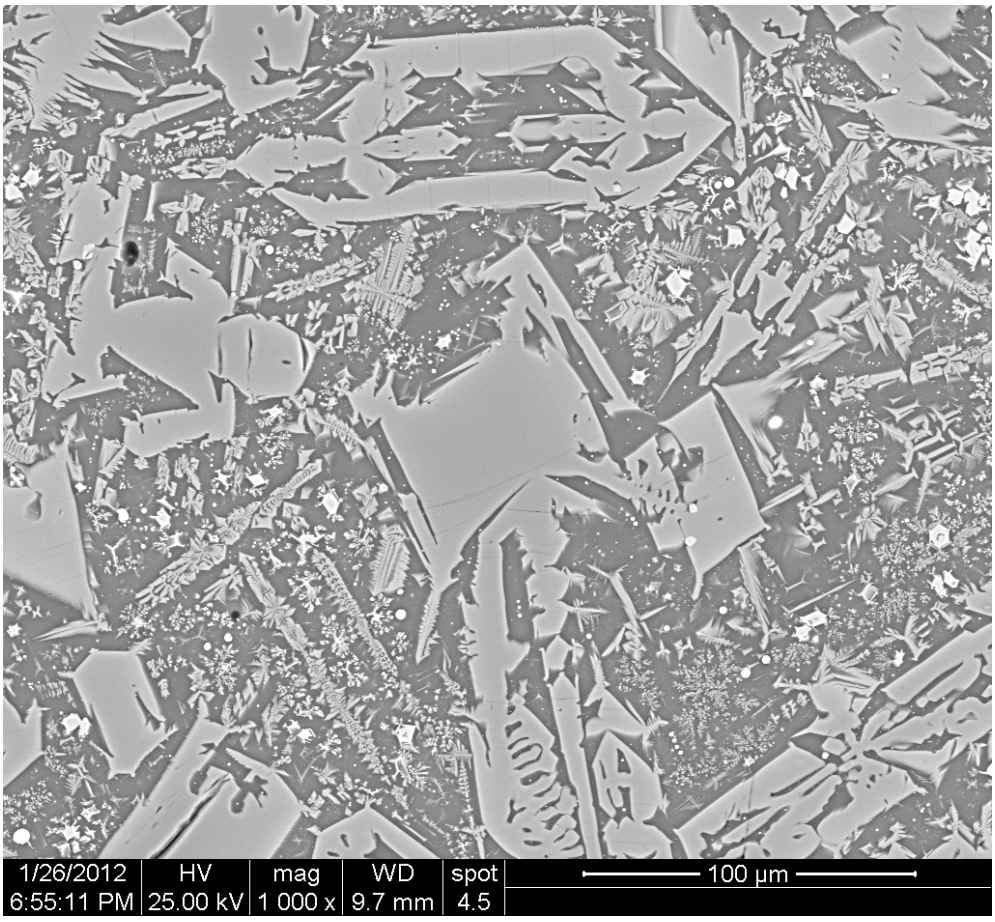
Image No. **5**



Site **161y**

Sample No. **3290**

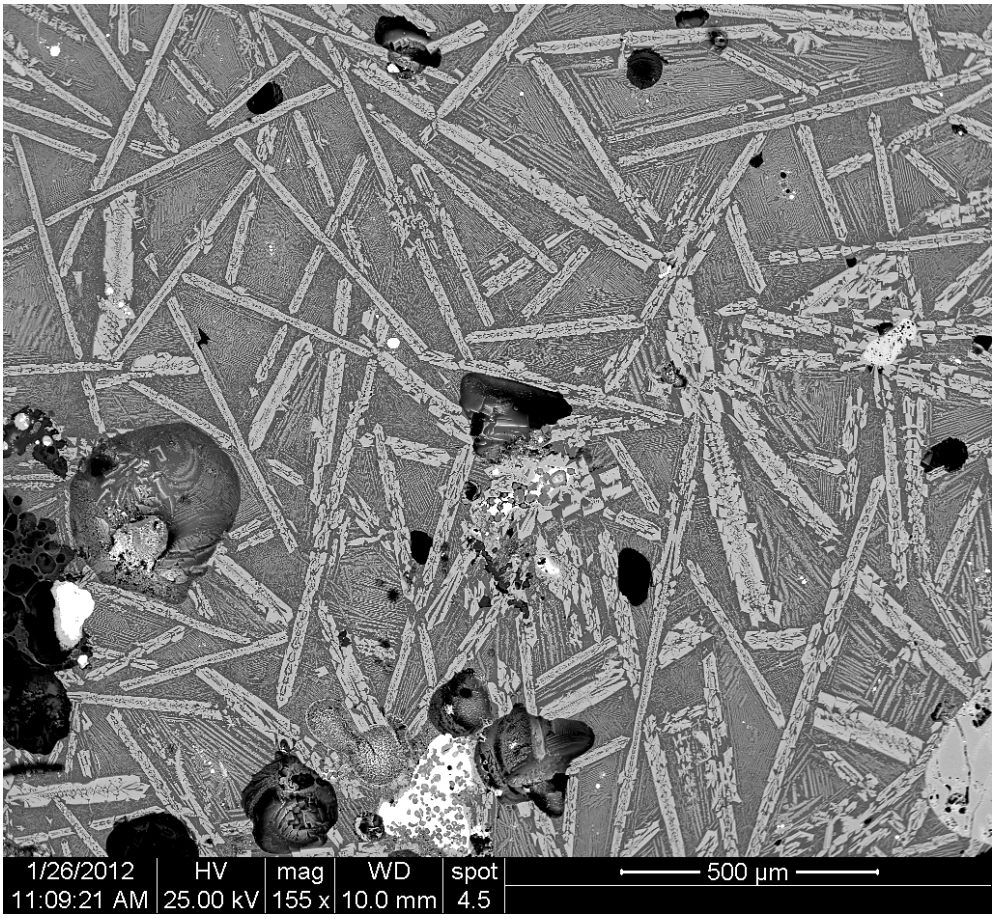
Image No. **6**



Site **161y**

Sample No. **5076**

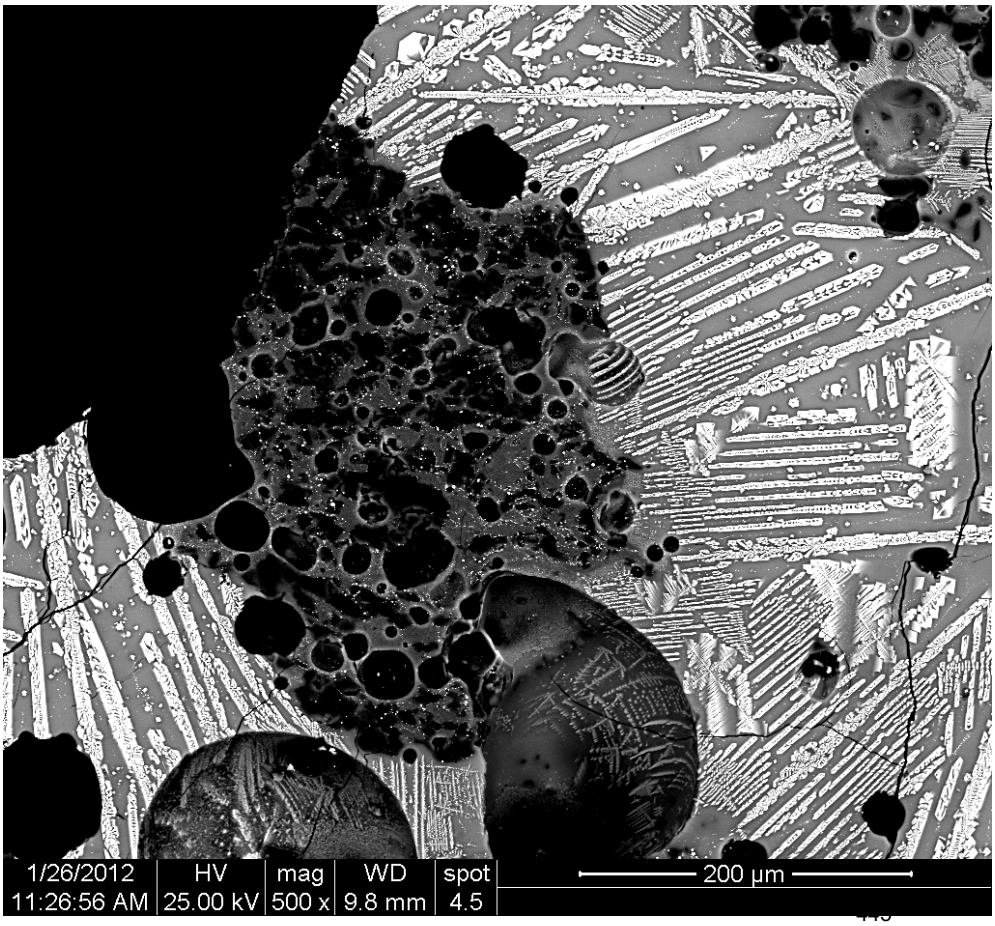
Image No. **1**



Site **161y**

Sample No. **5076**

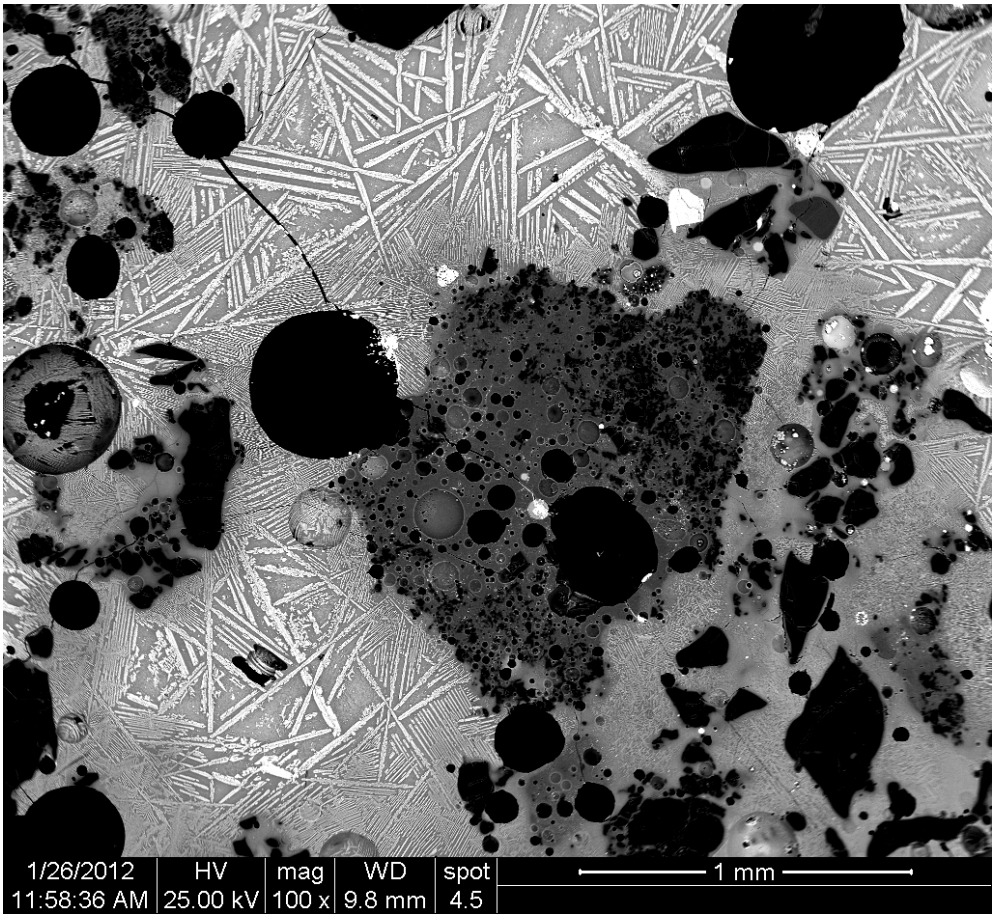
Image No. **2**



Site **161y**

Sample No. **5076**

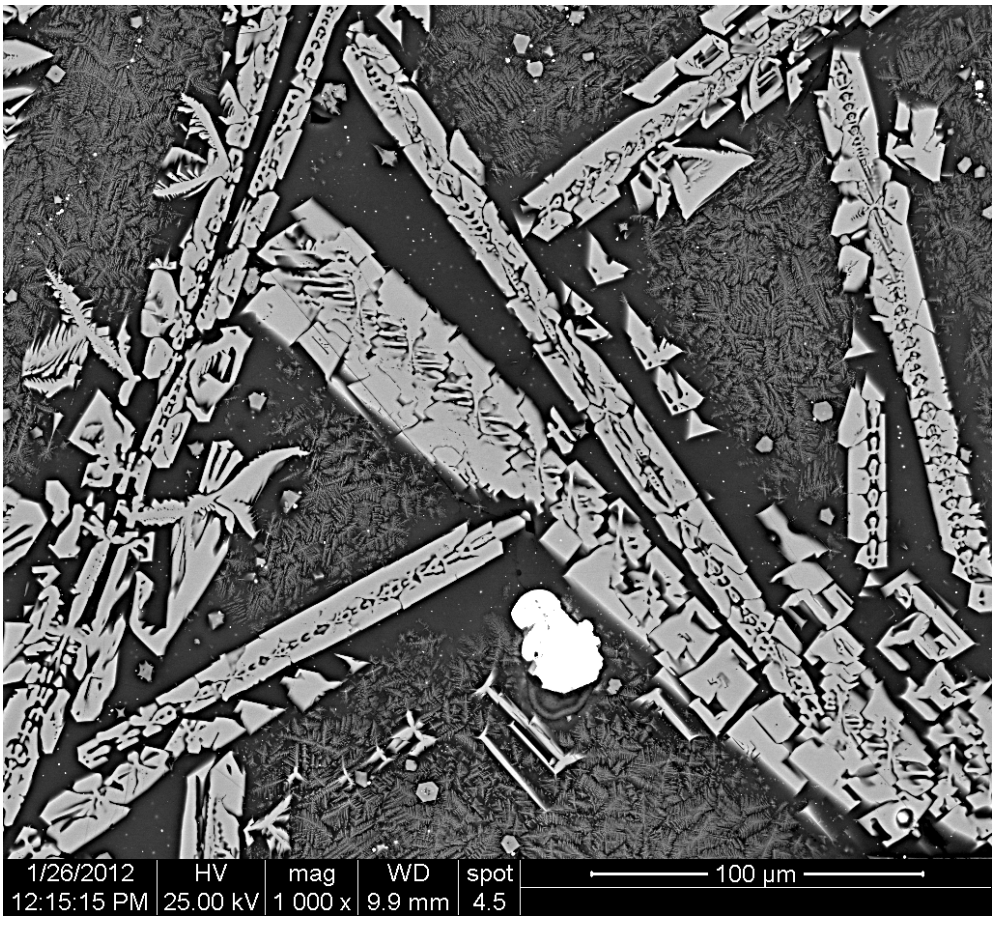
Image No. **3**



Site **161y**

Sample No. **5076**

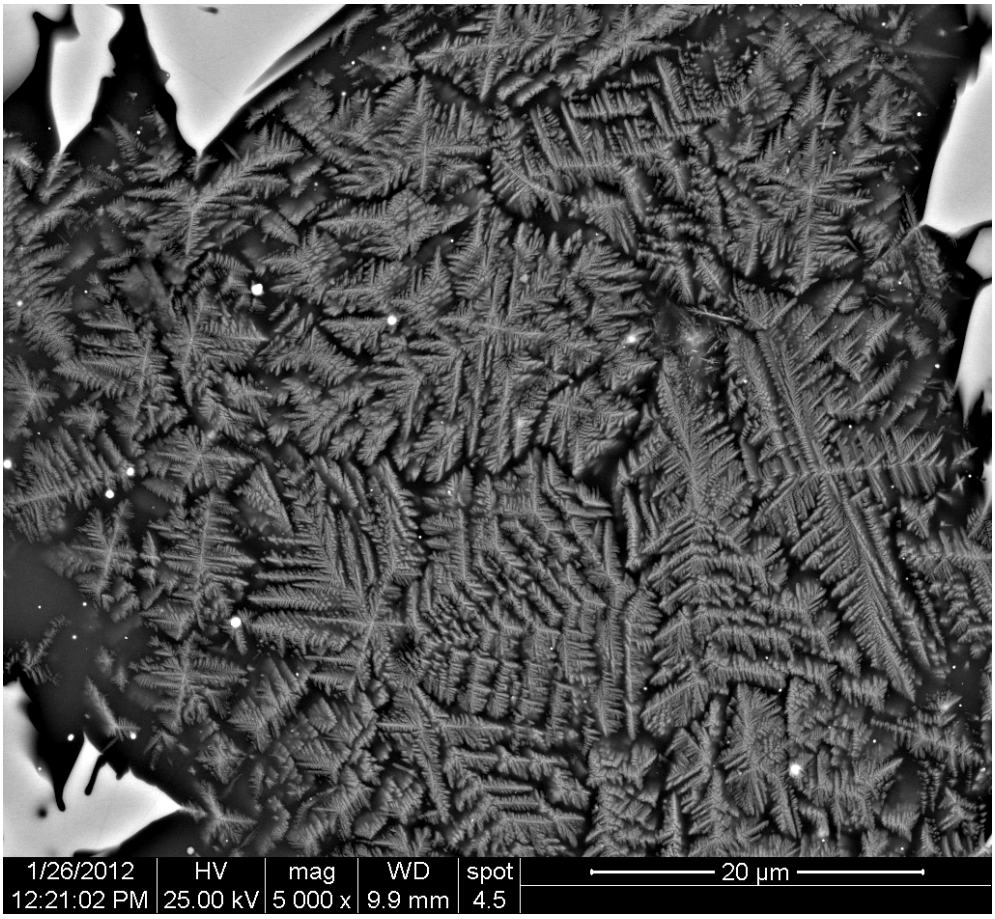
Image No. **4**



Site **161y**

Sample No. **5076**

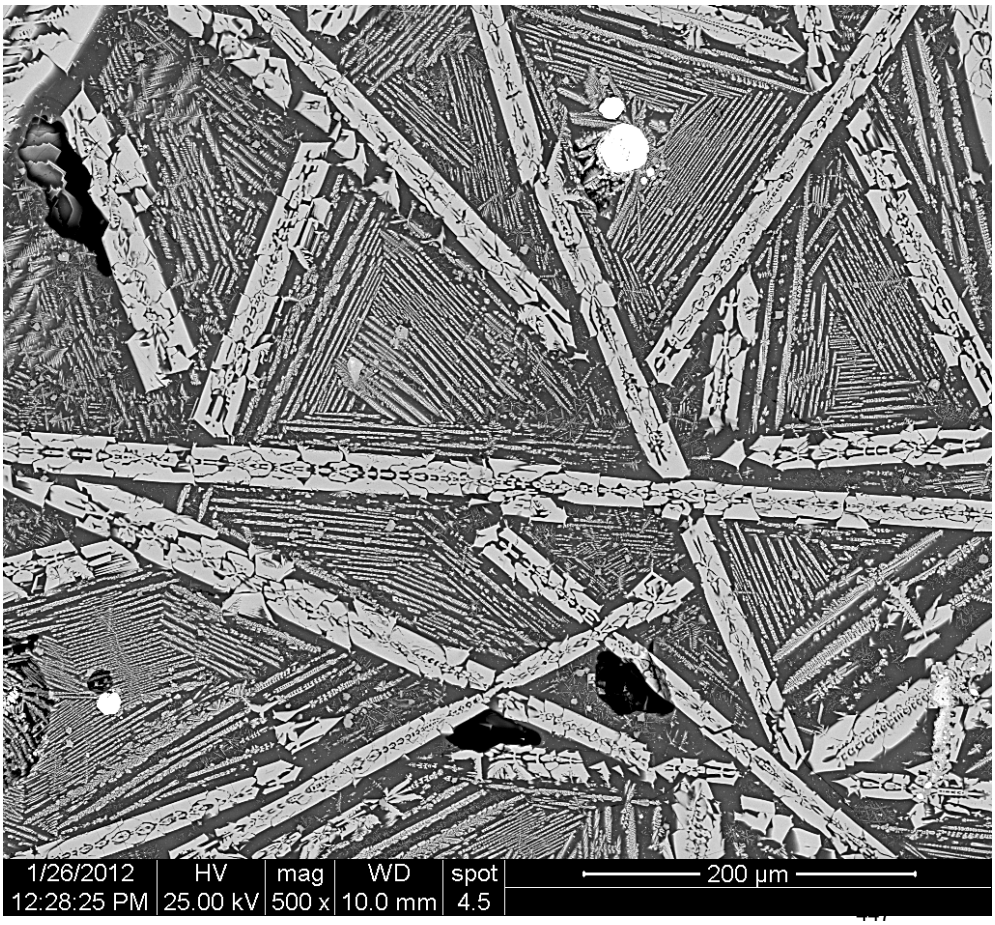
Image No. **5**



Site **161y**

Sample No. **5076**

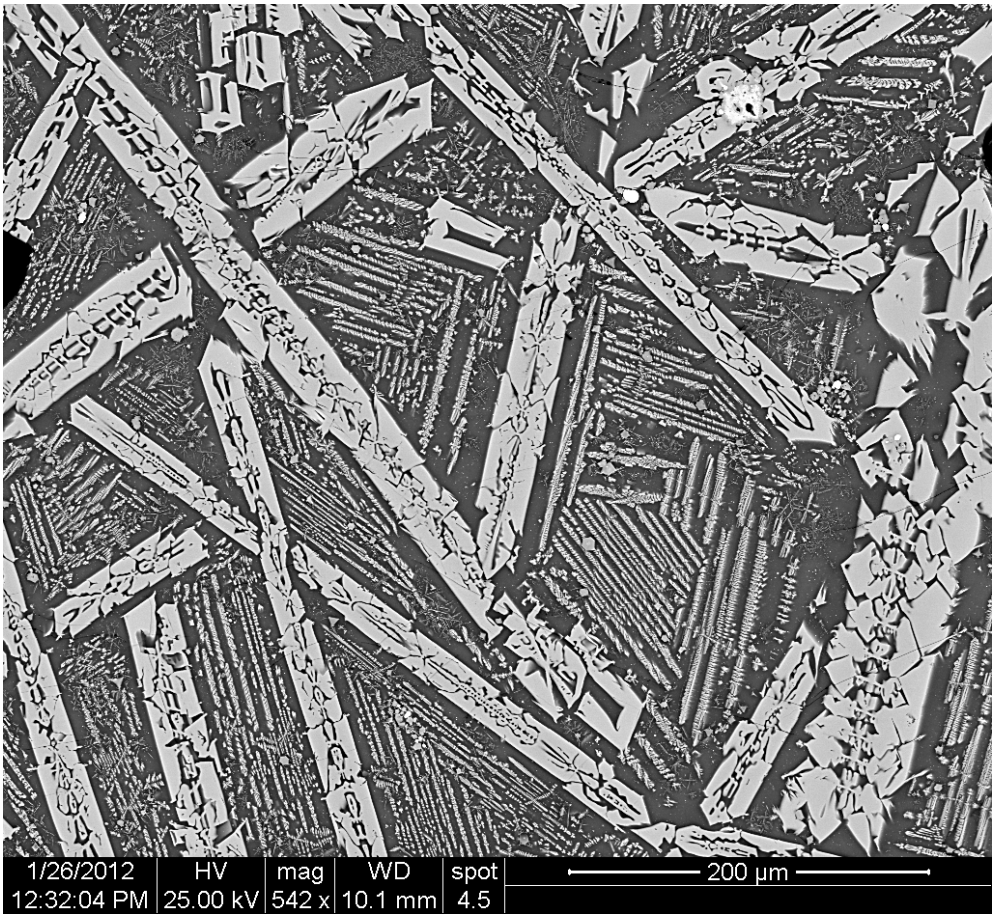
Image No. **6**



Site **161y**

Sample No. **5076**

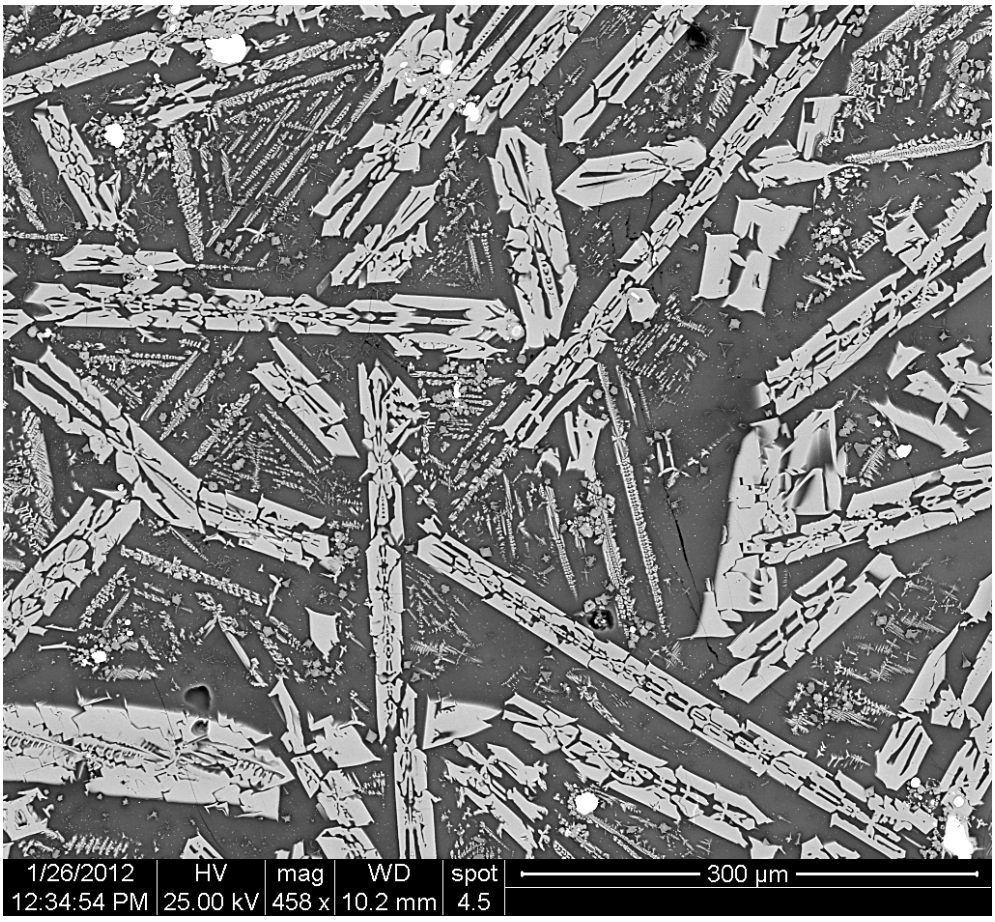
Image No. **7**



Site **161y**

Sample No. **5076**

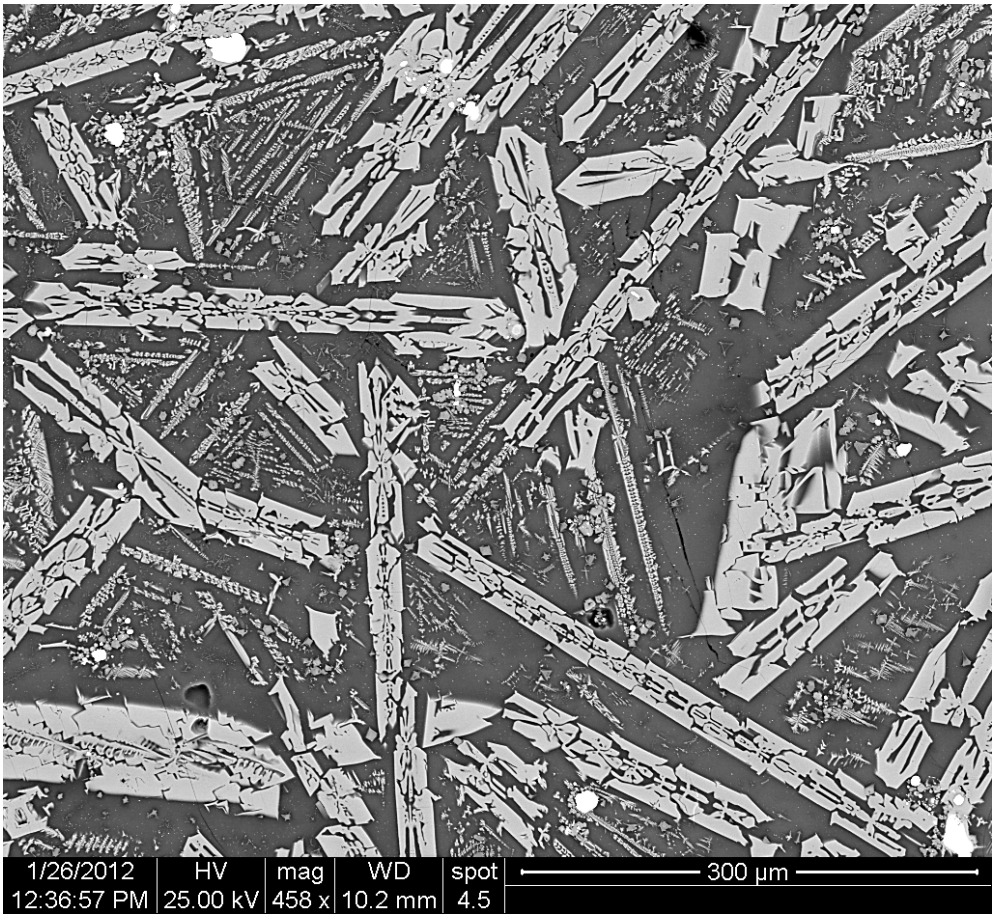
Image No. **8**



Site **161y**

Sample No. **5076**

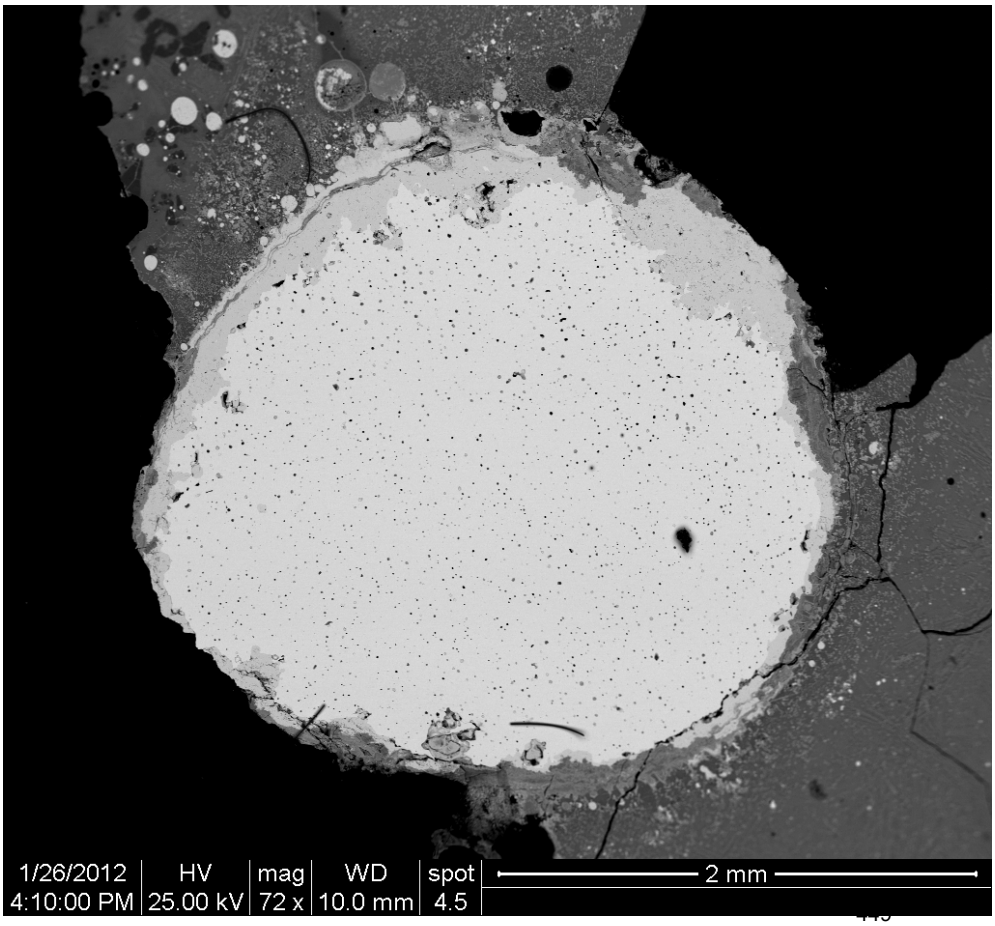
Image No. **9**



Site **161y**

Sample No. **10377**

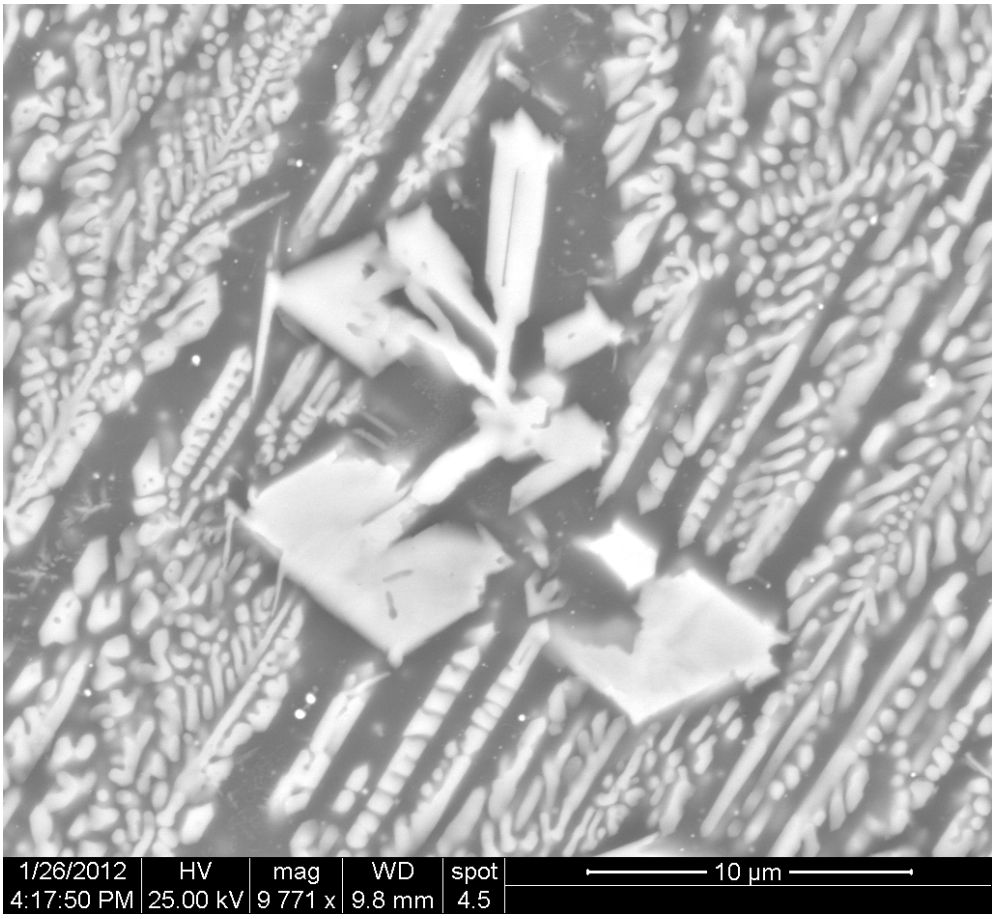
Image No. **1**



Site **161y**

Sample No. **10377**

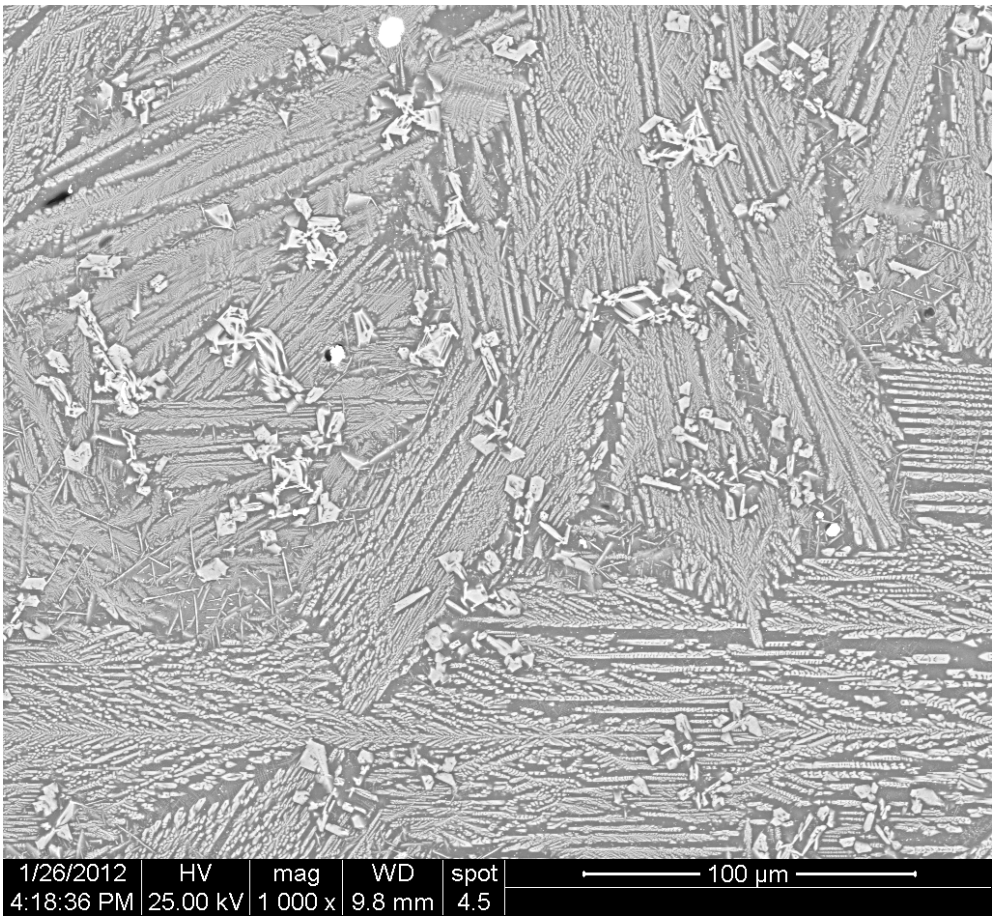
Image No. **2**



Site **161y**

Sample No. **10377**

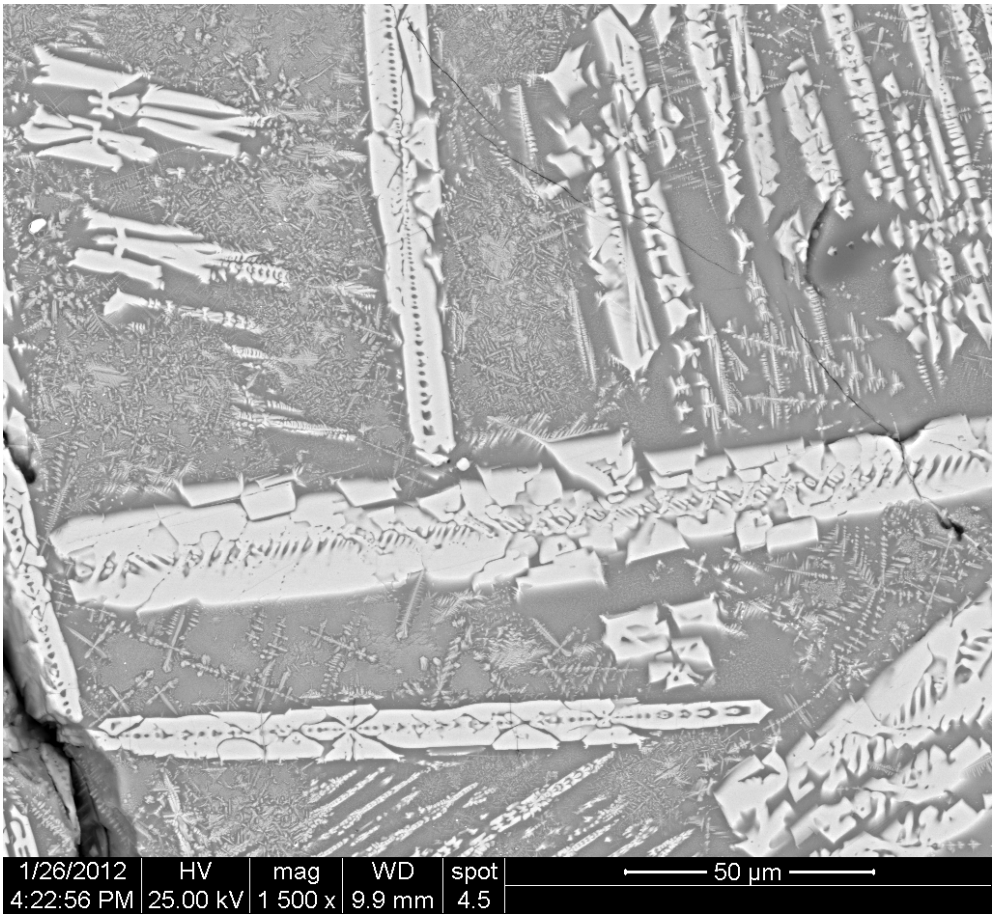
Image No. **3**



Site **161y**

Sample No. **10377**

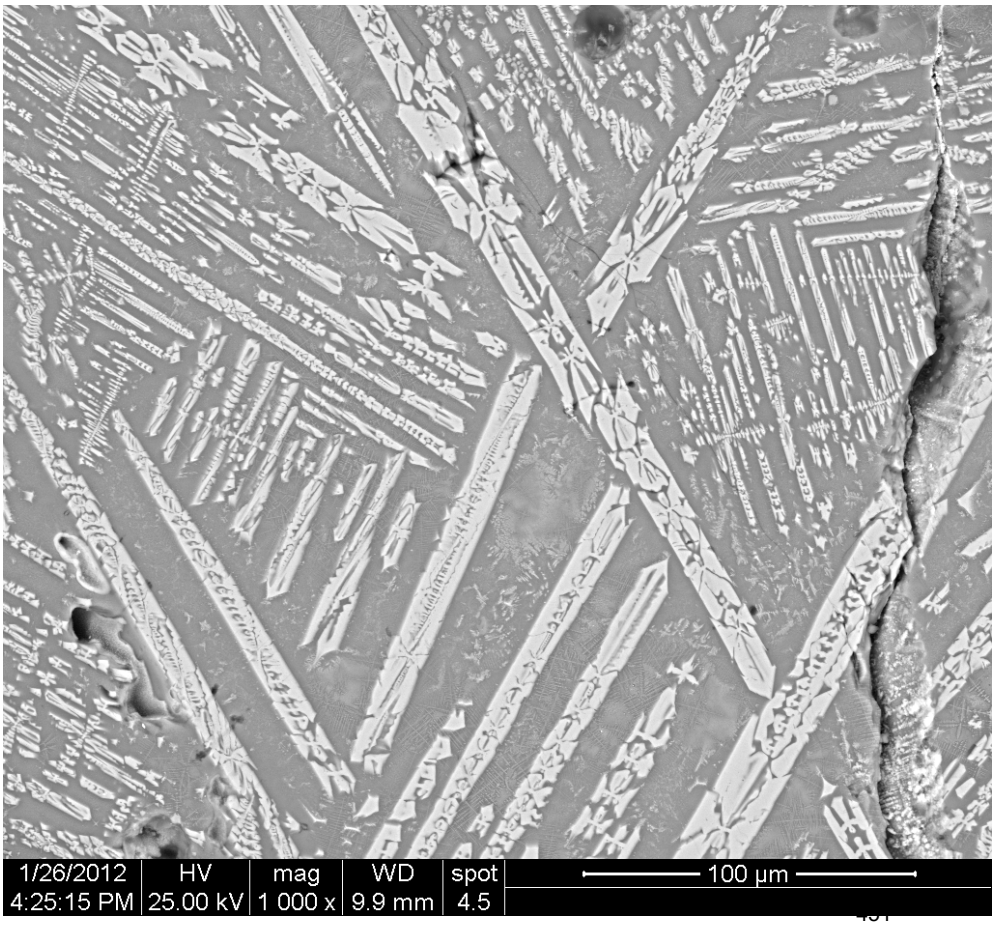
Image No. **4**



Site **161y**

Sample No. **10377**

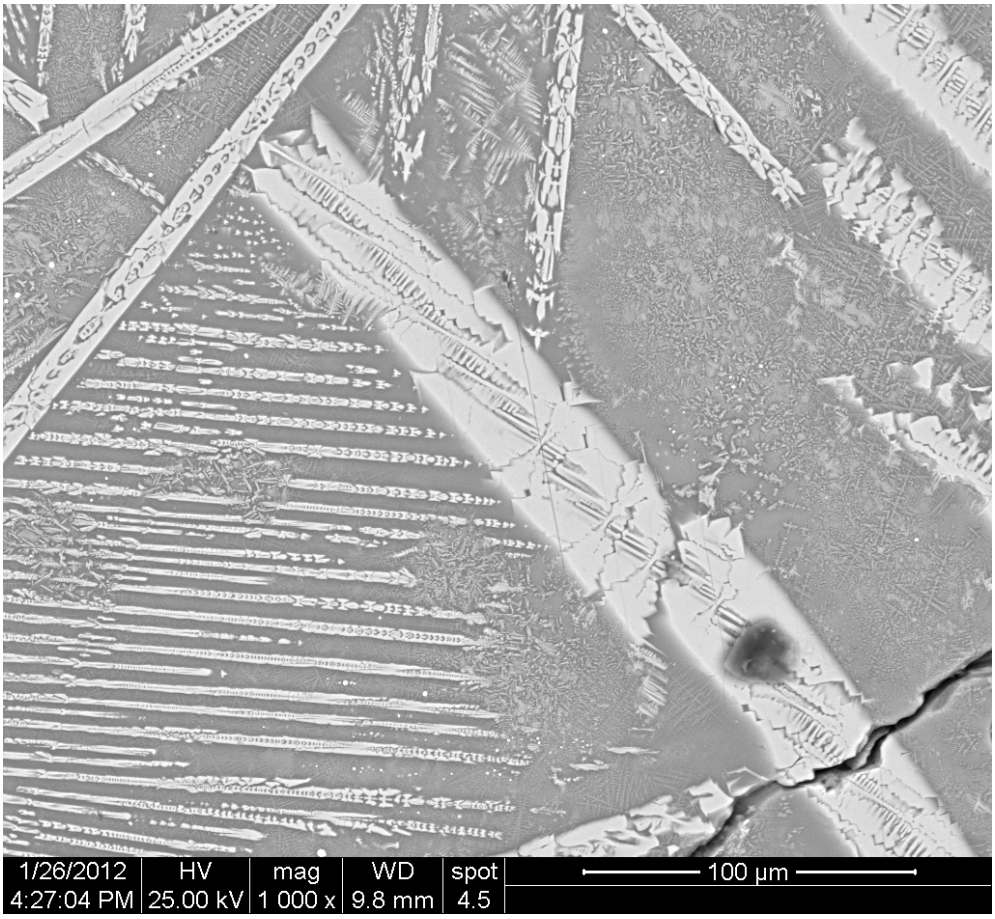
Image No. **5**



Site **161y**

Sample No. **10377**

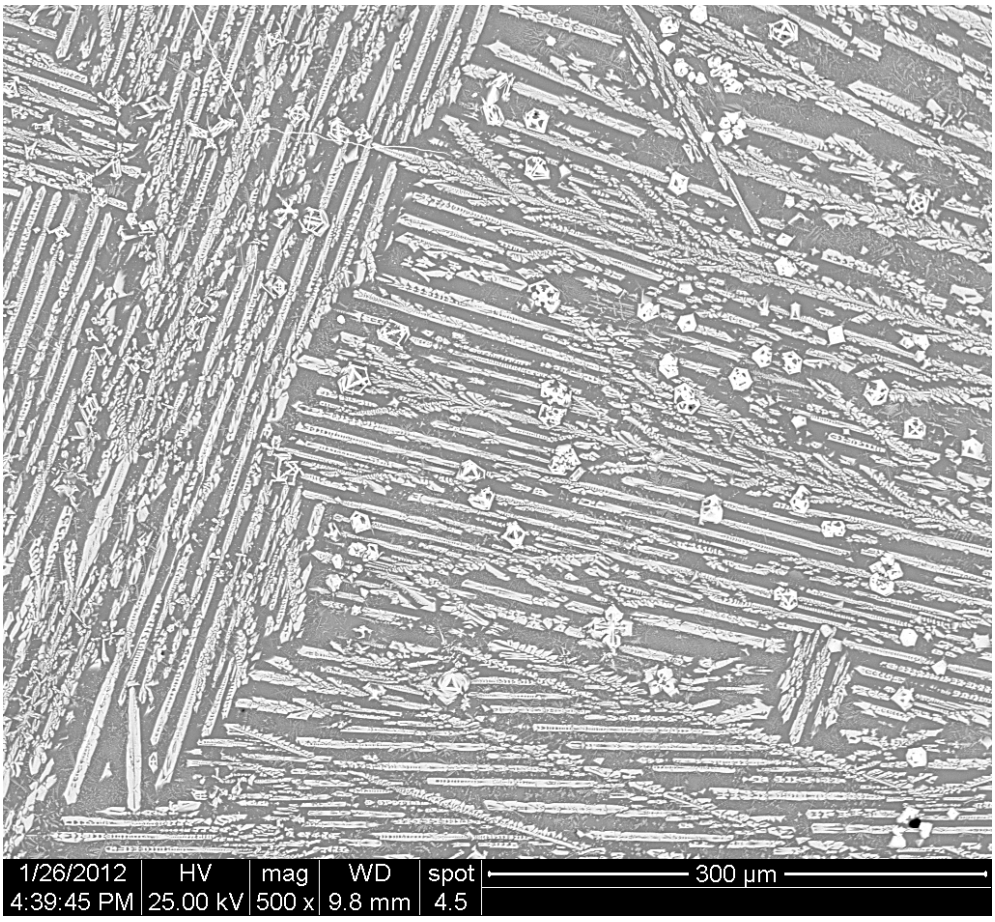
Image No. **6**



Site **161y**

Sample No. **10377**

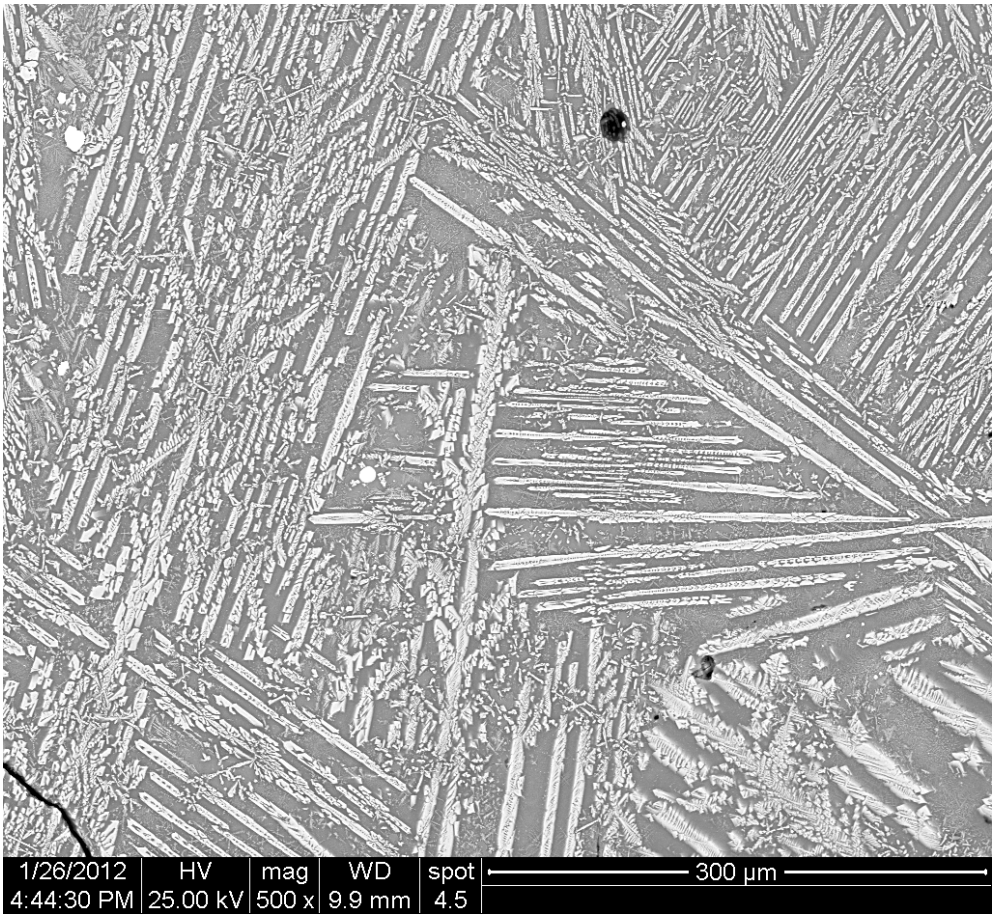
Image No. **7**



Site **161y**

Sample No. **10377**

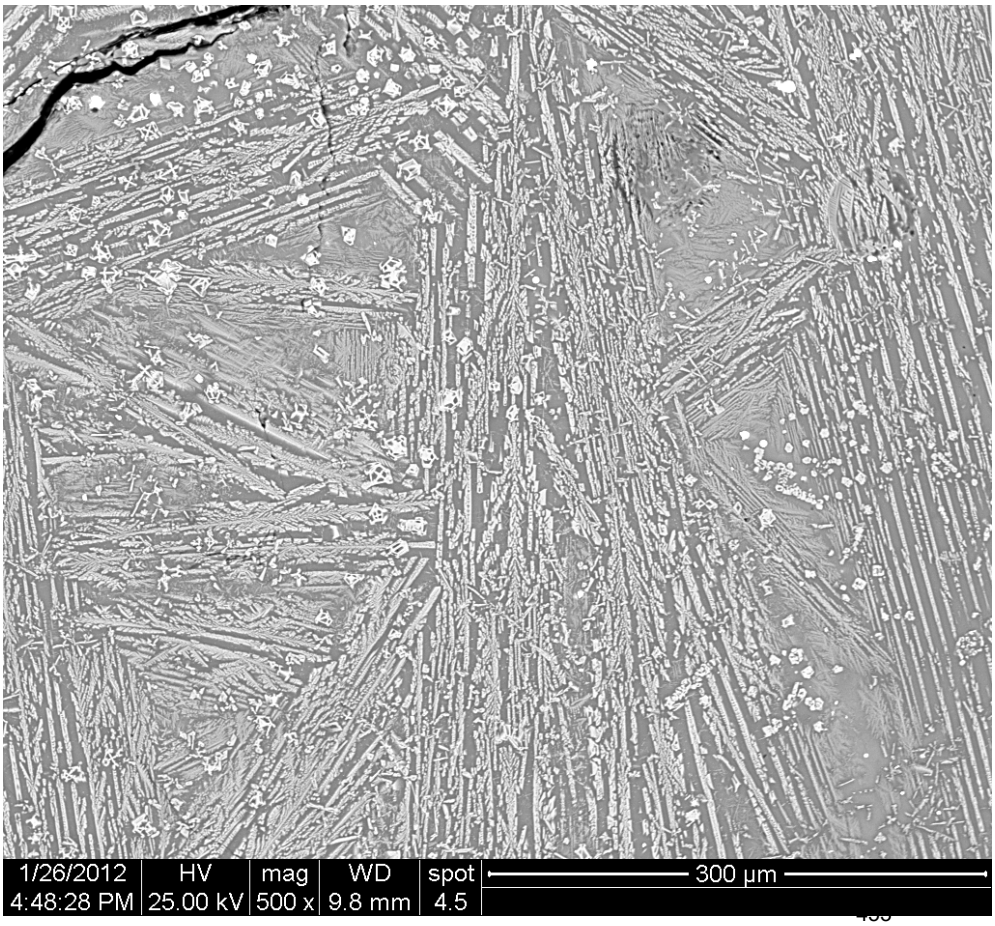
Image No. **8**



Site **161y**

Sample No. **10377**

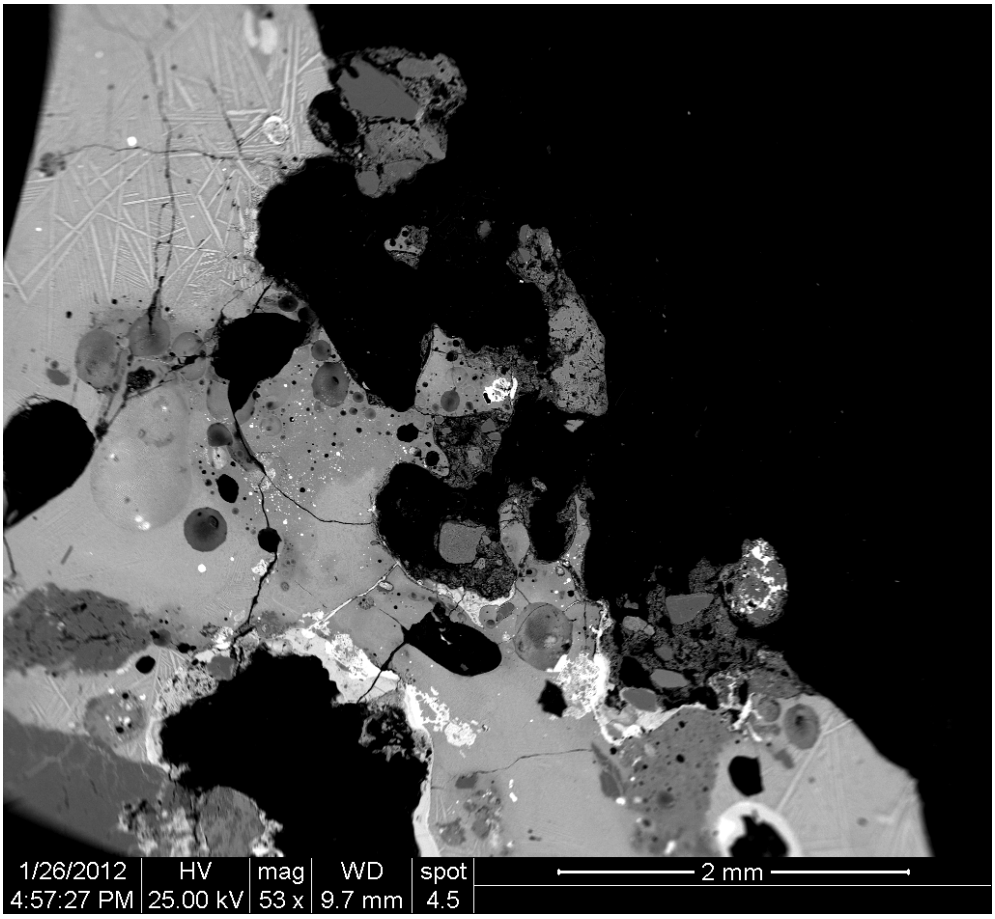
Image No. **9**



Site **161y**

Sample No. **10377**

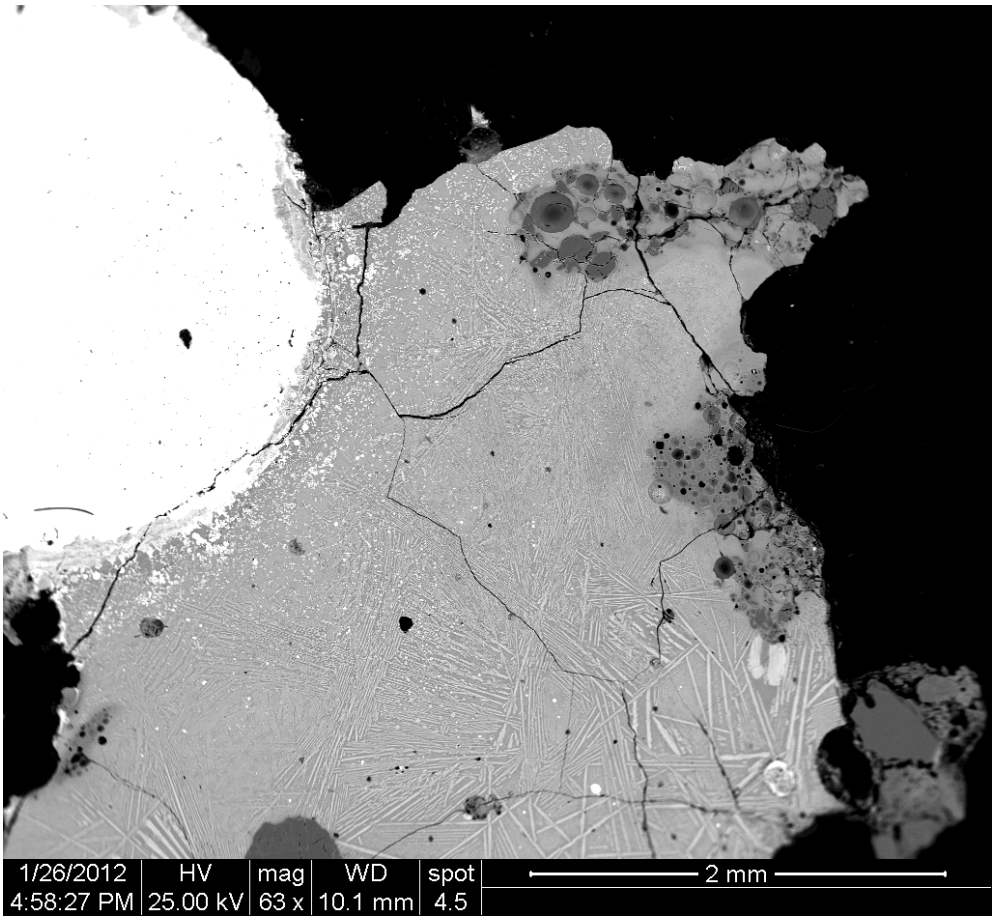
Image No. **10**



Site **161y**

Sample No. **10377**

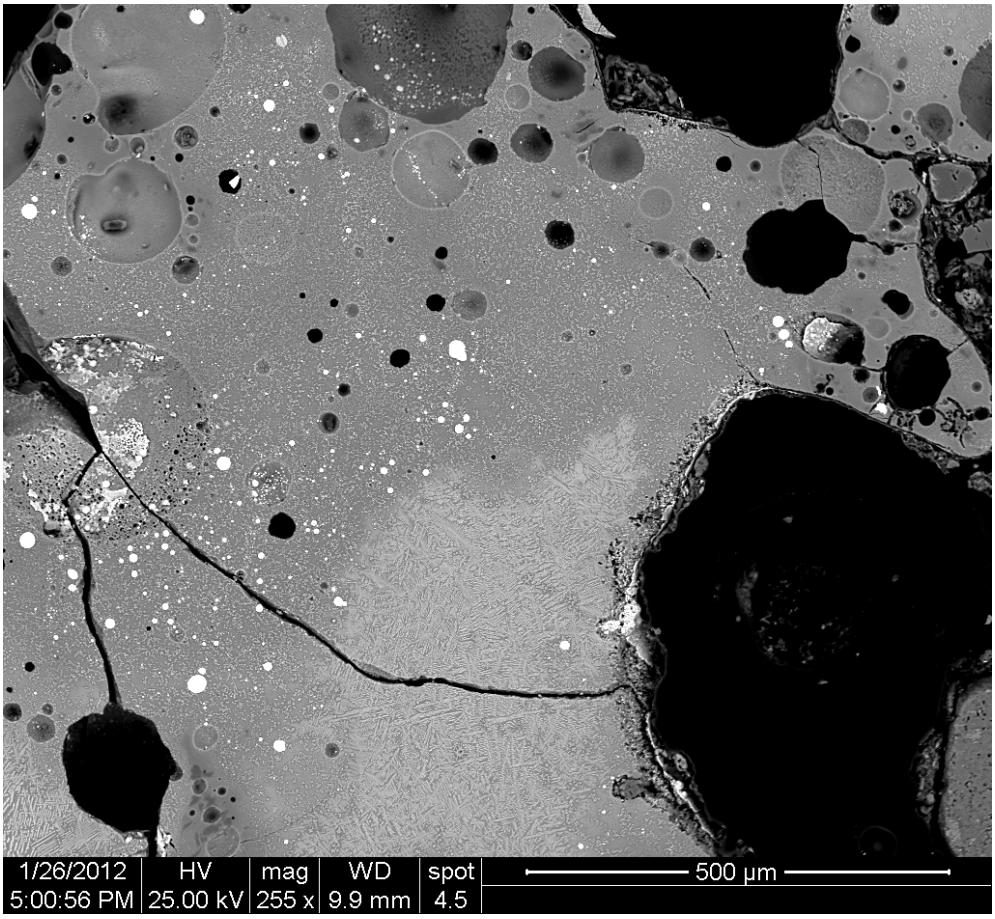
Image No. **11**



Site **161y**

Sample No. **10377**

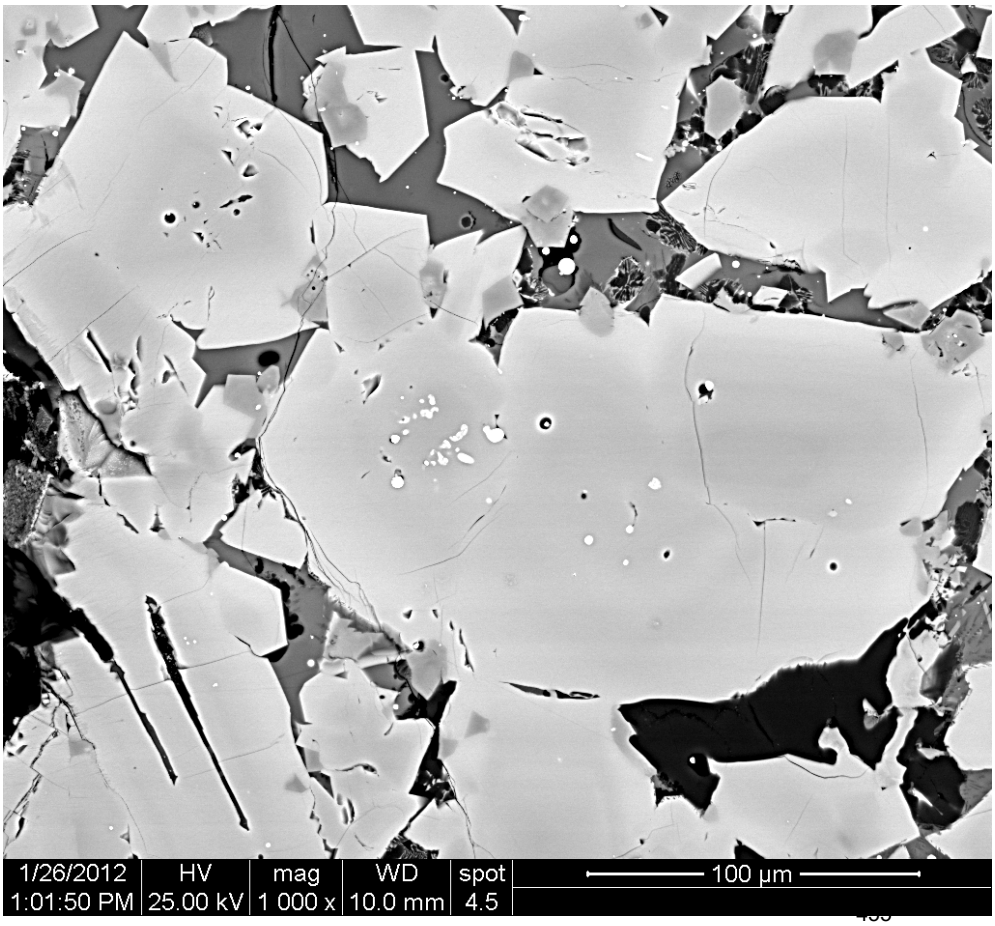
Image No. **12**



Site **161y**

Sample No. **10007**

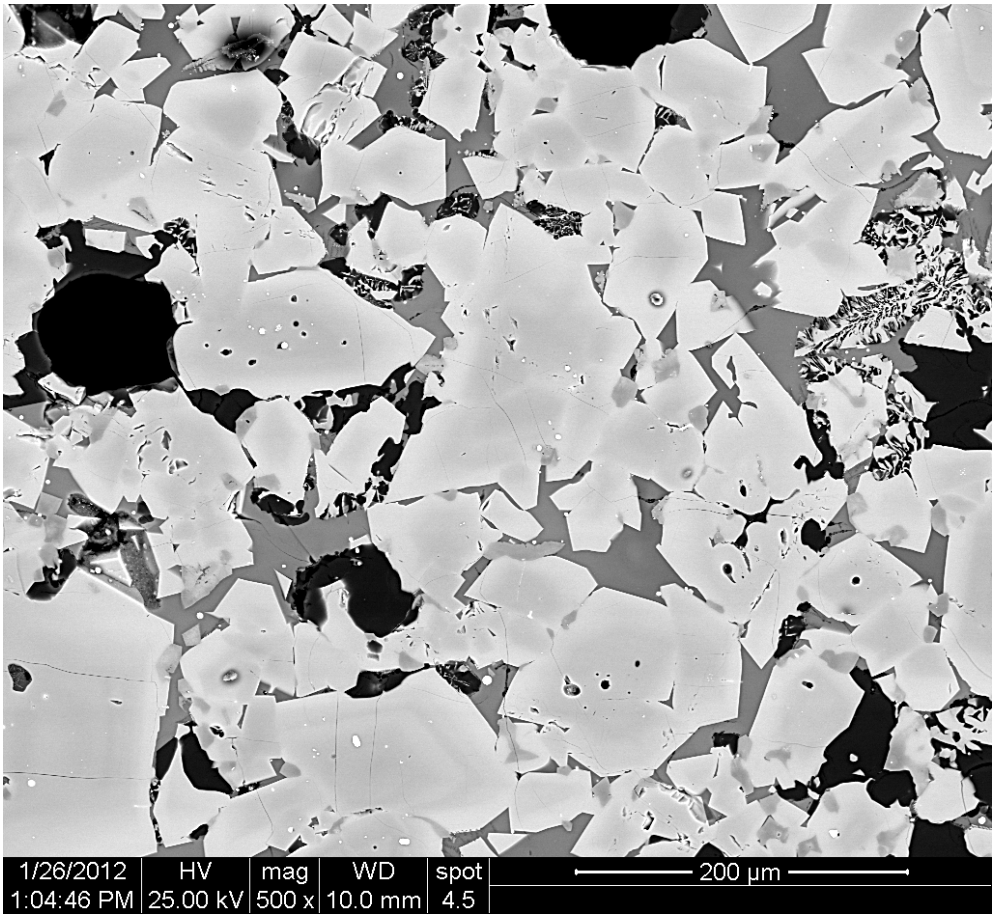
Image No. **1**



Site **161y**

Sample No. **10007**

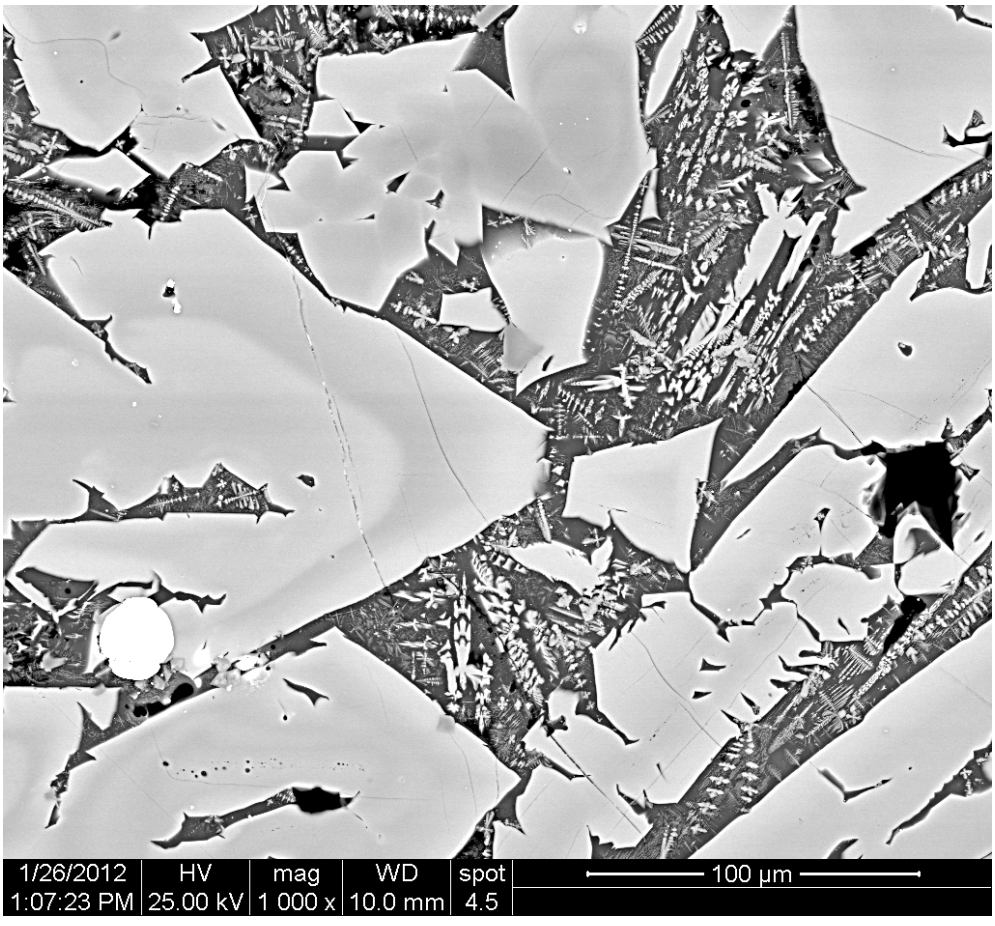
Image No. **2**



Site **161y**

Sample No. **10007**

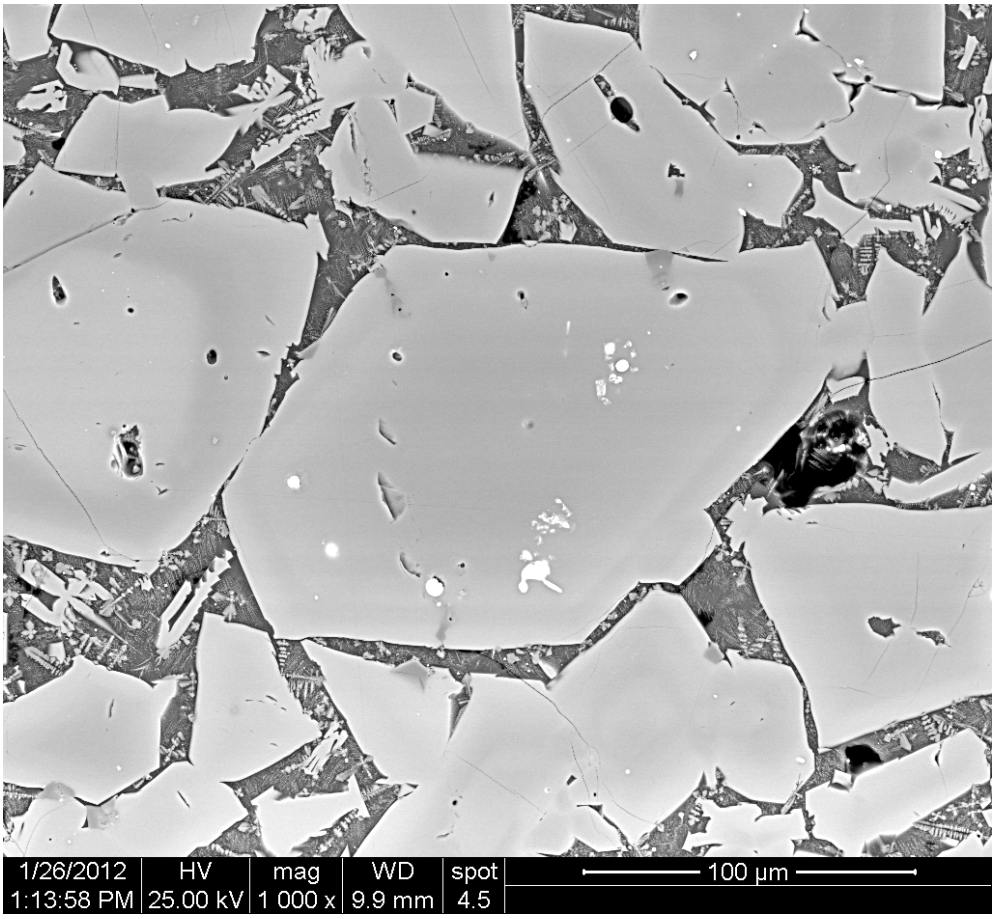
Image No. **3**



Site **161y**

Sample No. **10007**

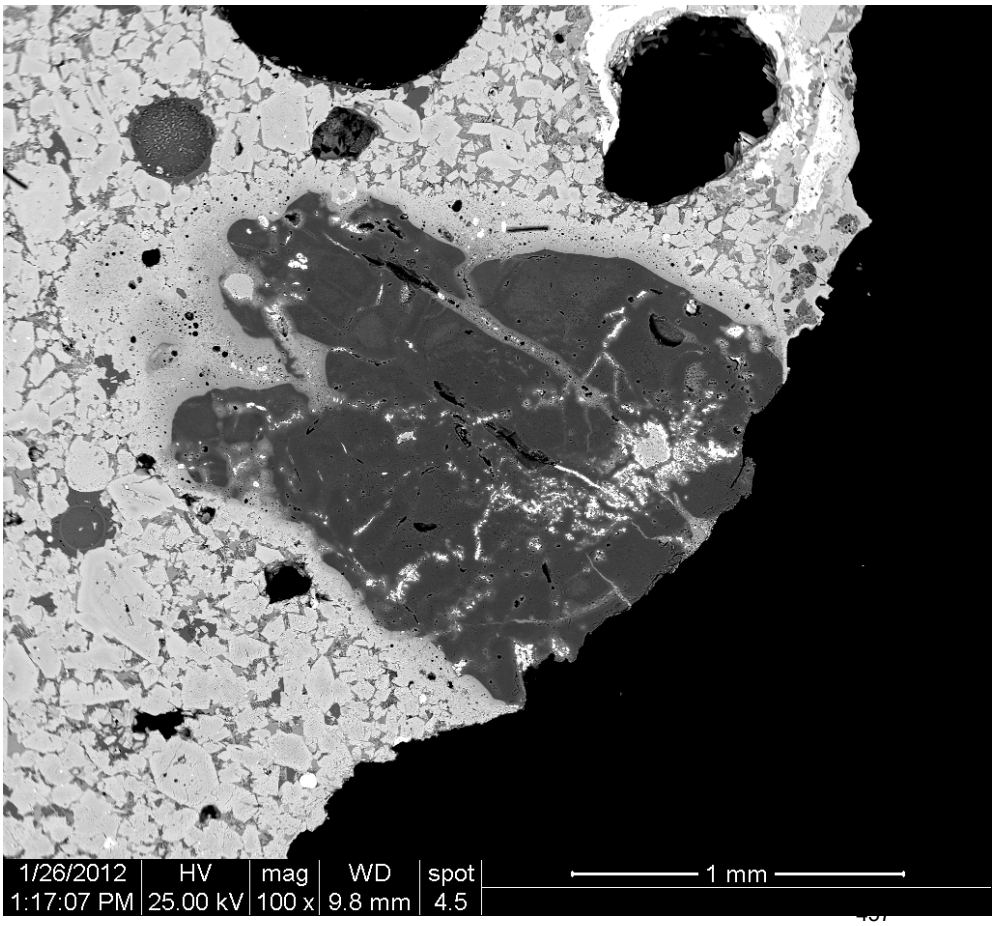
Image No. **4**



Site **161y**

Sample No. **10007**

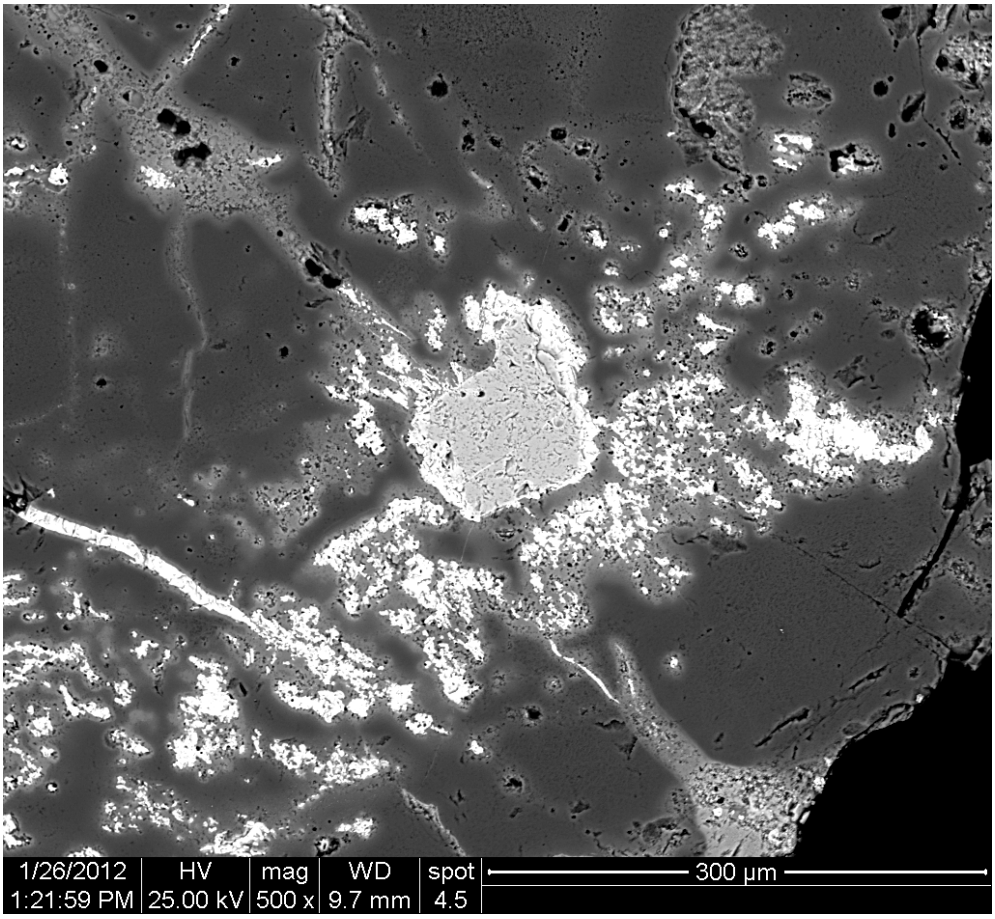
Image No. **5**



Site **161y**

Sample No. **10007**

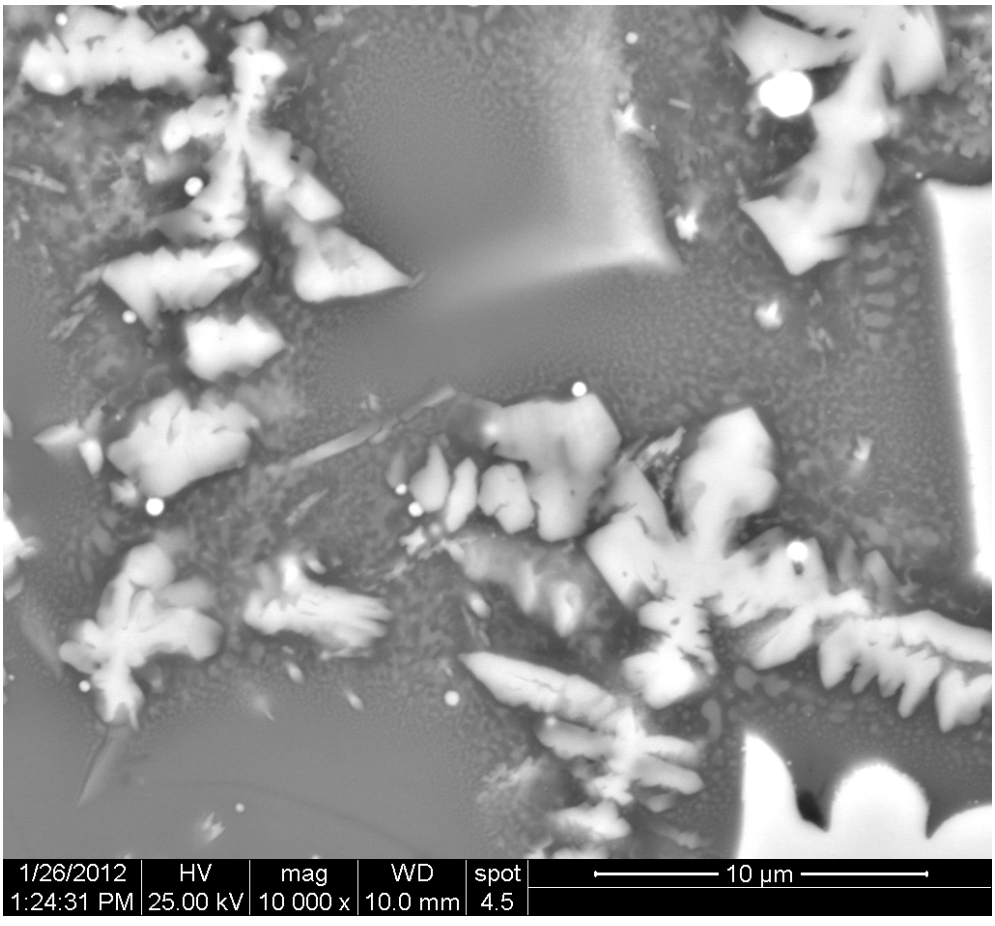
Image No. **6**



Site **161y**

Sample No. **10007**

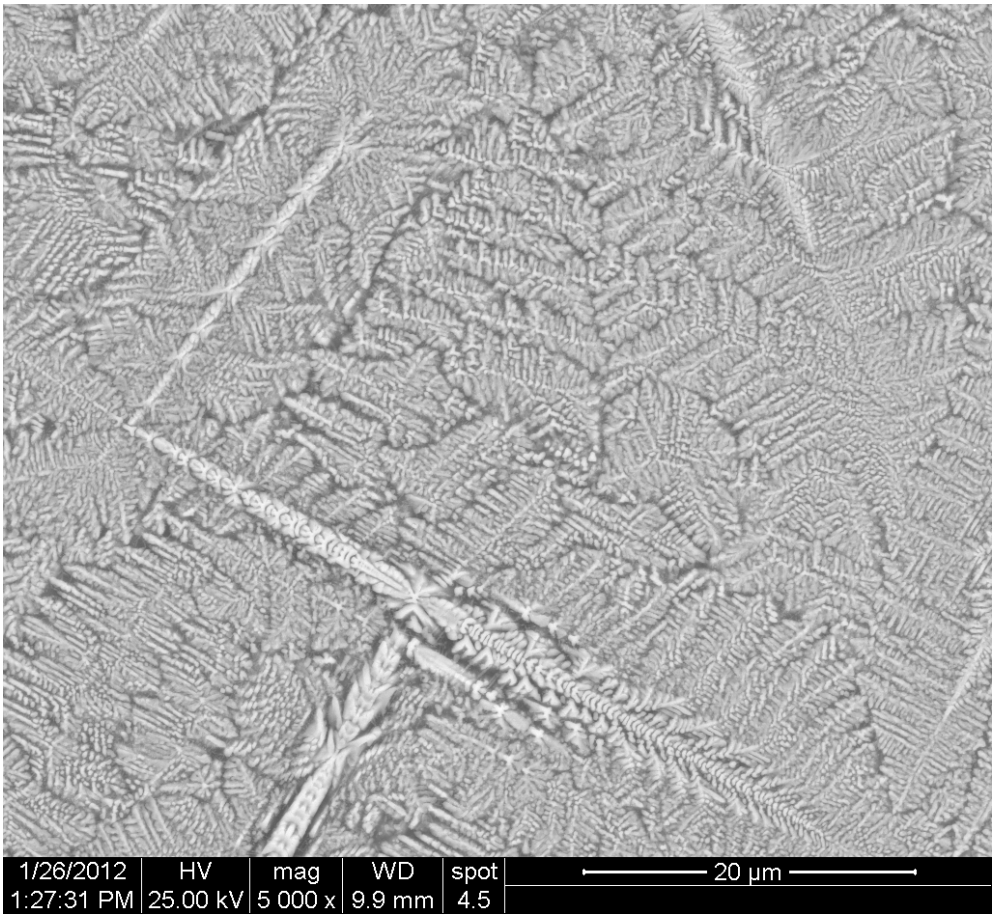
Image No. **7**



Site **161y**

Sample No. **10007**

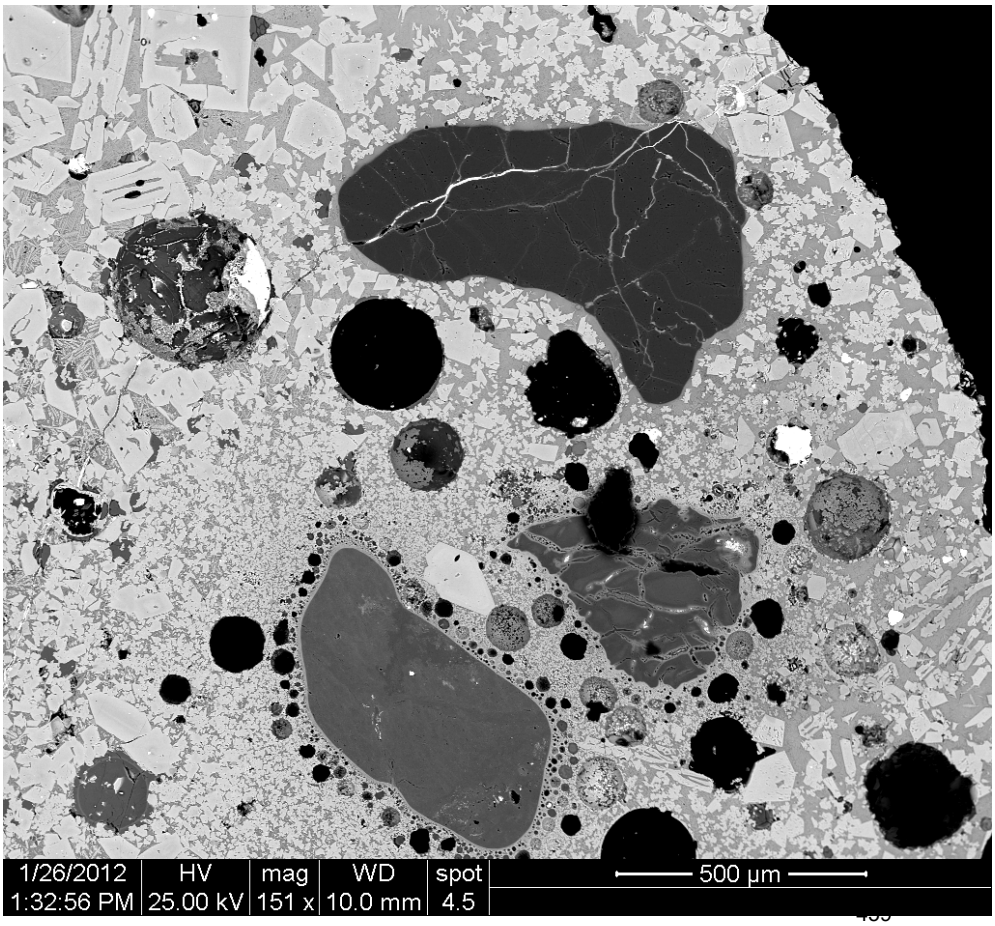
Image No. **8**



Site **161y**

Sample No. **10007**

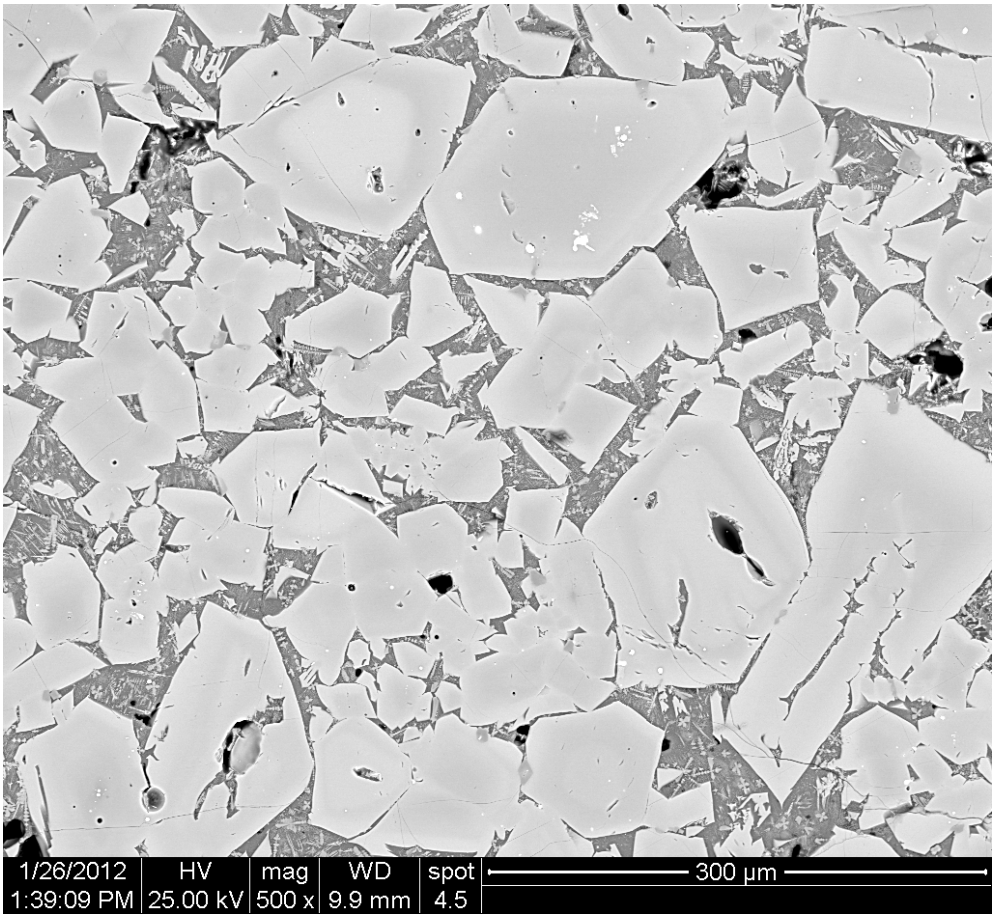
Image No. **9**



Site **161y**

Sample No. **10007**

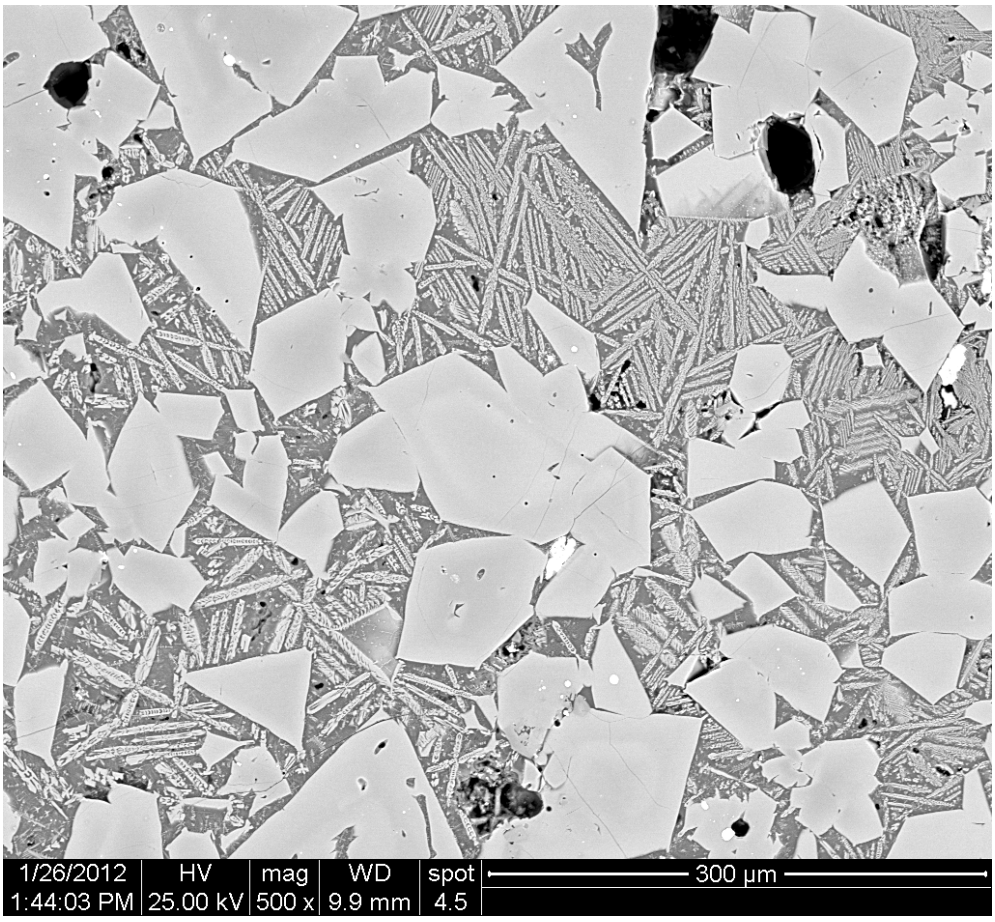
Image No. **10**



Site **161y**

Sample No. **10007**

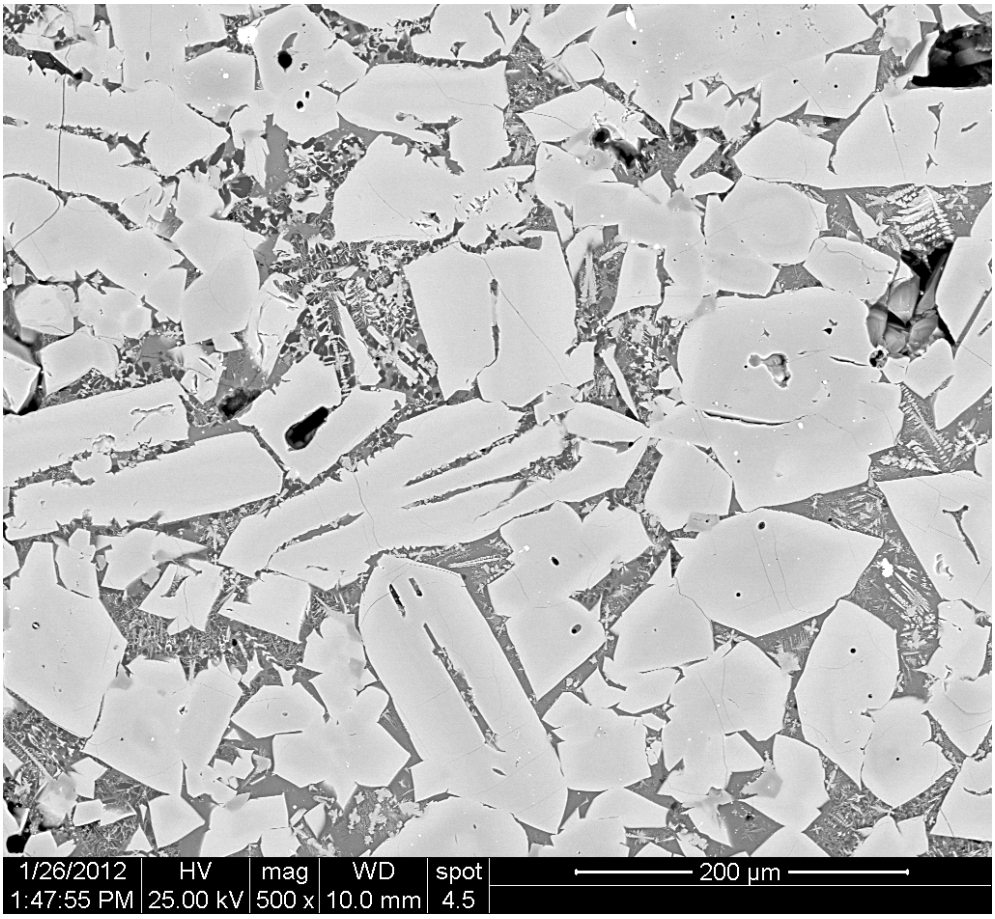
Image No. **11**



Site **161y**

Sample No. **10007**

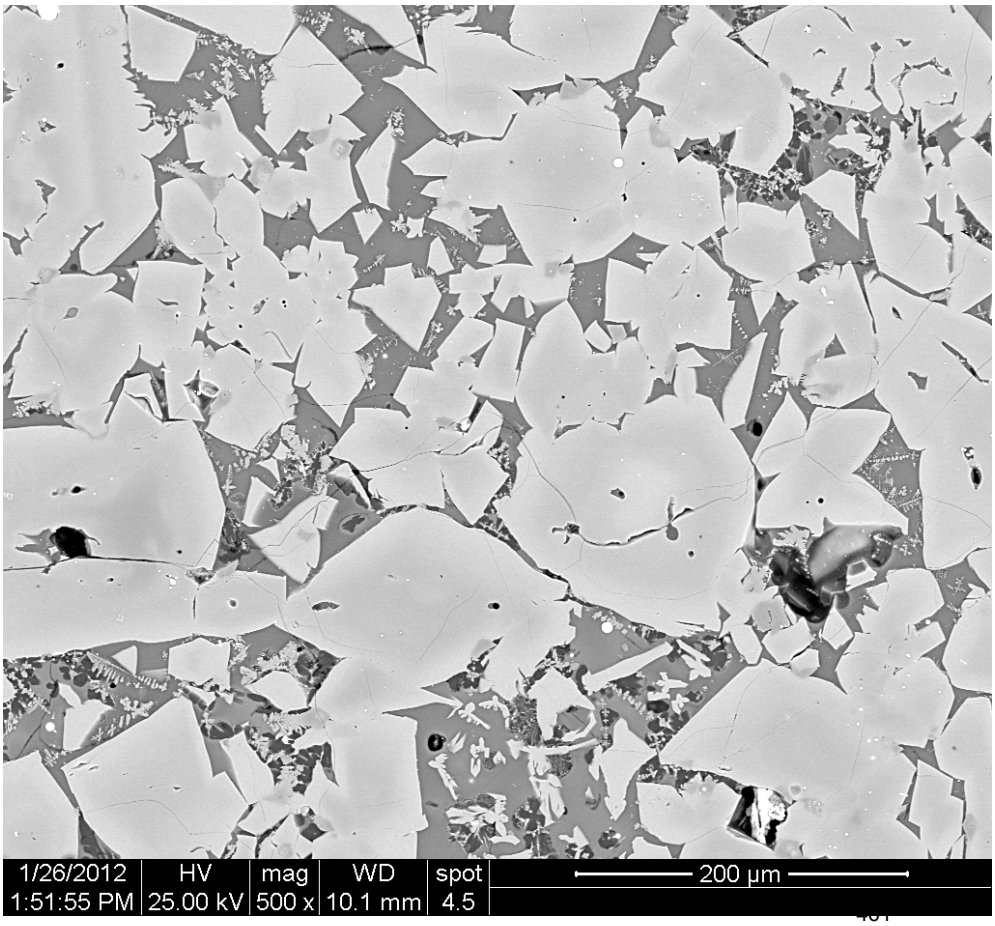
Image No. **12**



Site **161y**

Sample No. **10007**

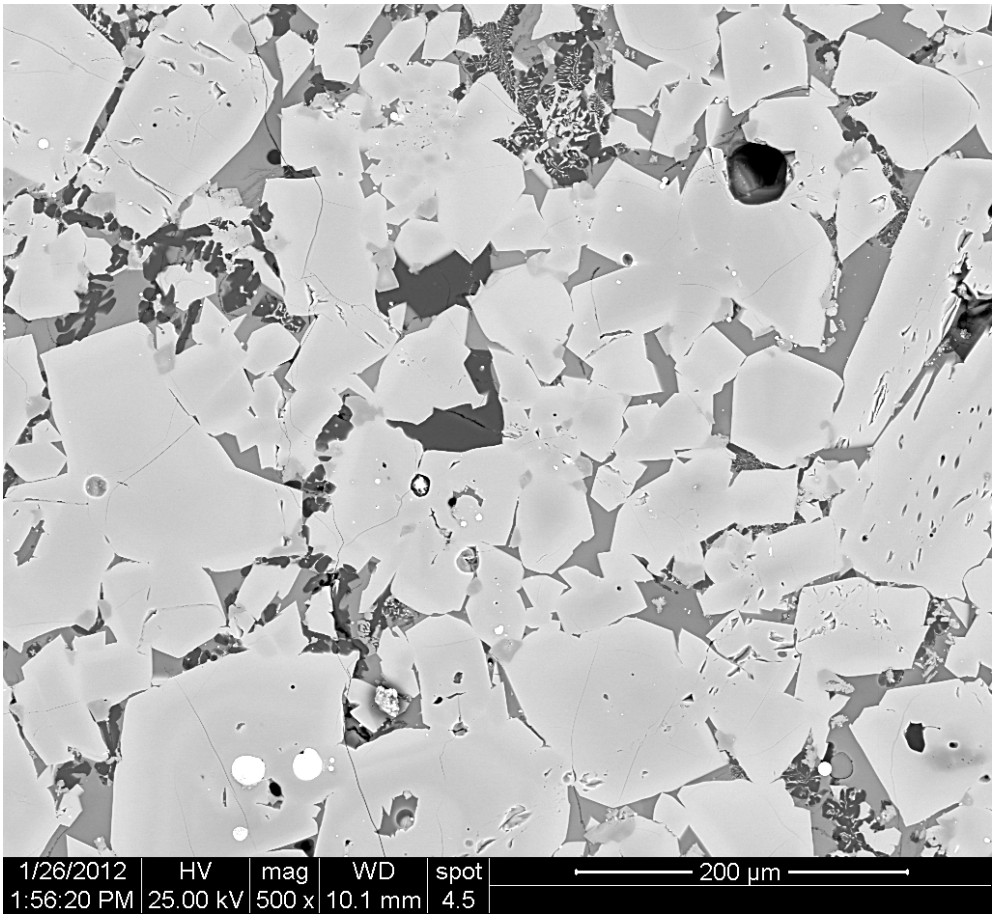
Image No. **13**



Site **161y**

Sample No. **10007**

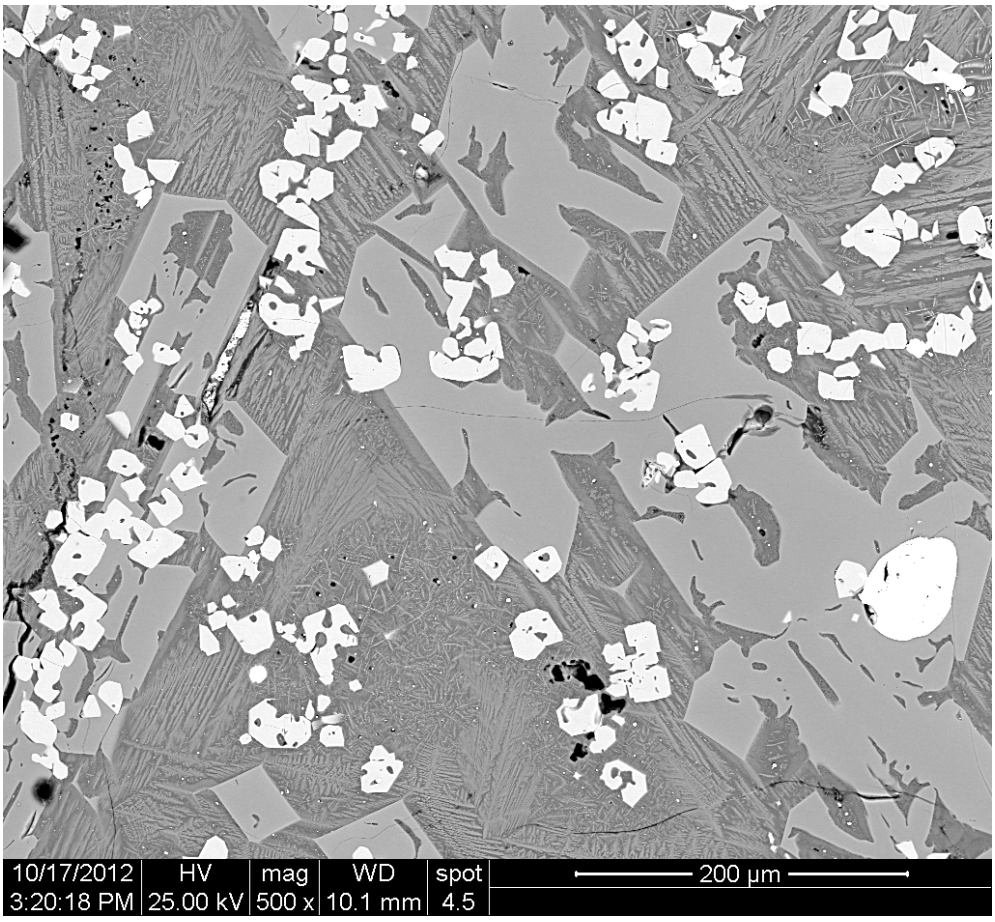
Image No. **14**



Site **161y**

Sample No. **6452**

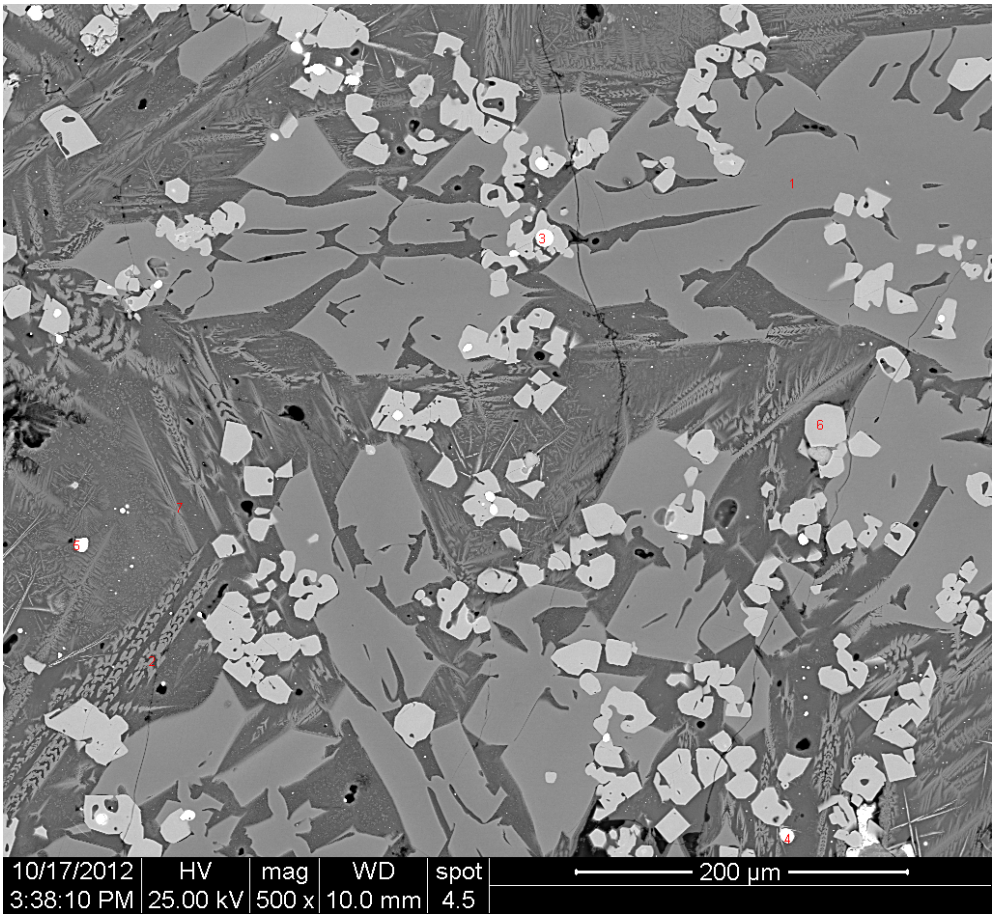
Image No. **1**



Site 161y

Sample No. 6452

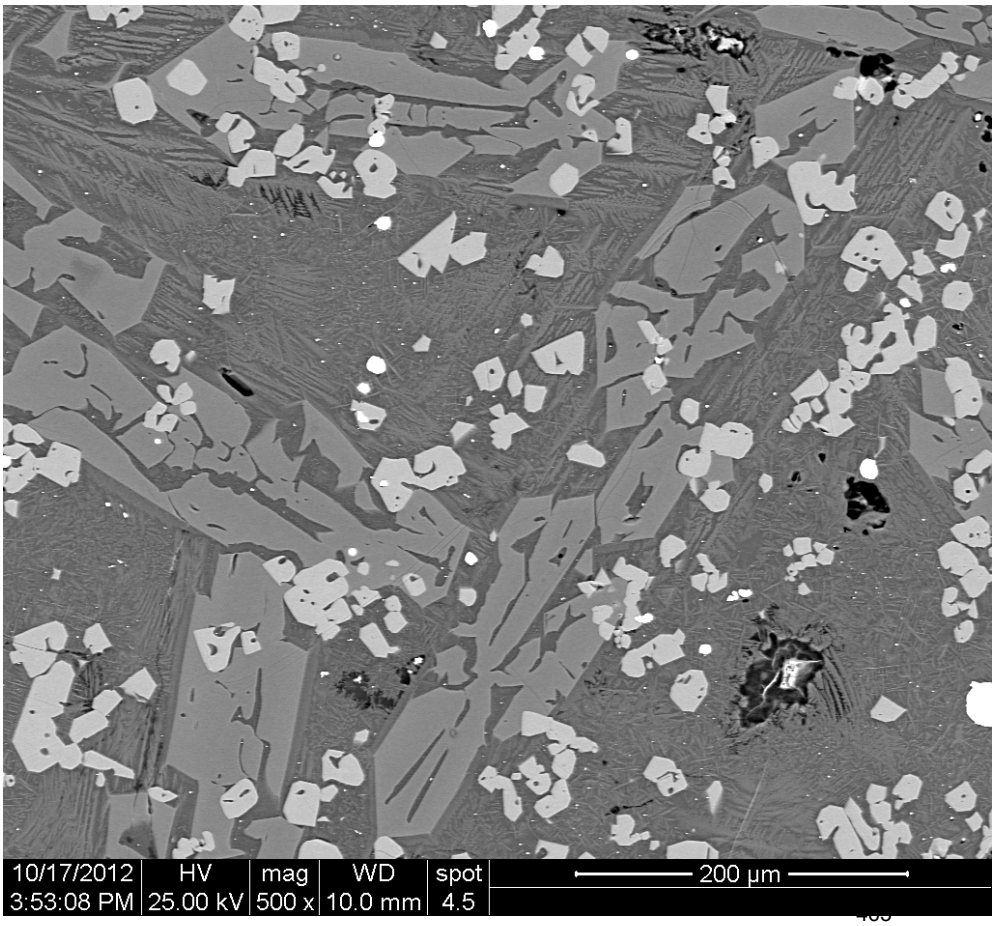
Image No. 2



Site 161y

Sample No. 6452

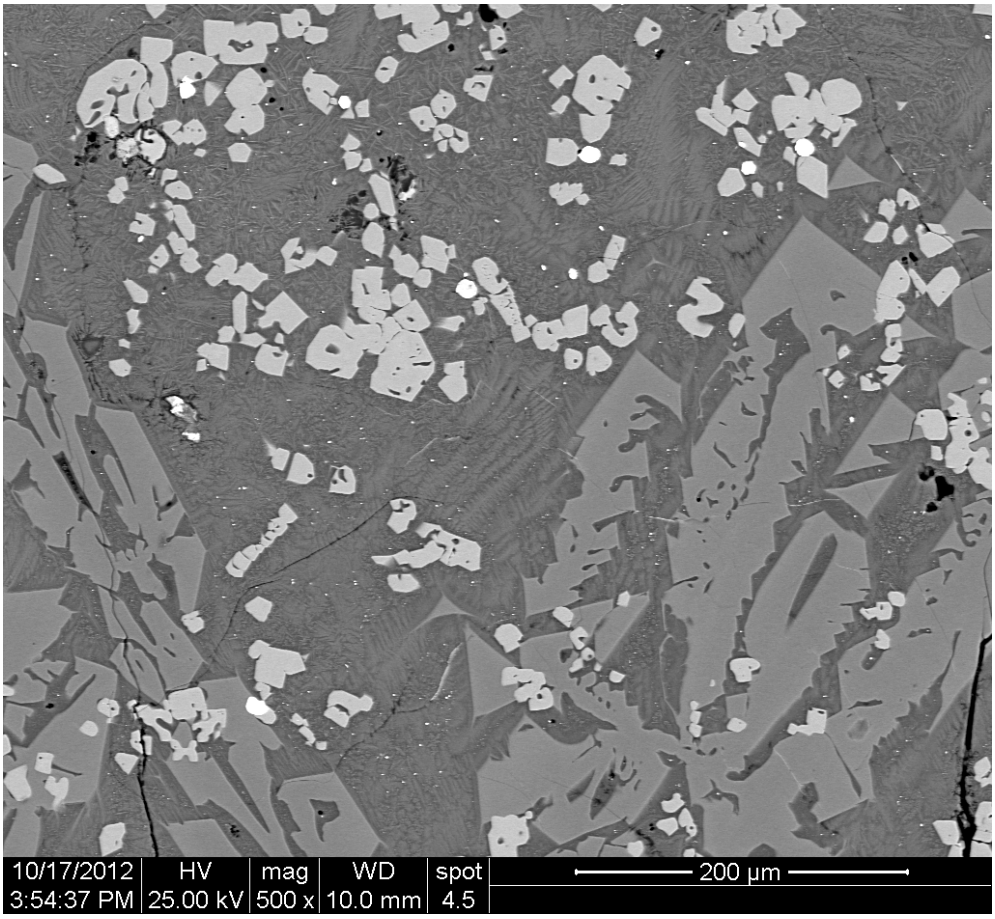
Image No. 3



Site **161y**

Sample No. **6452**

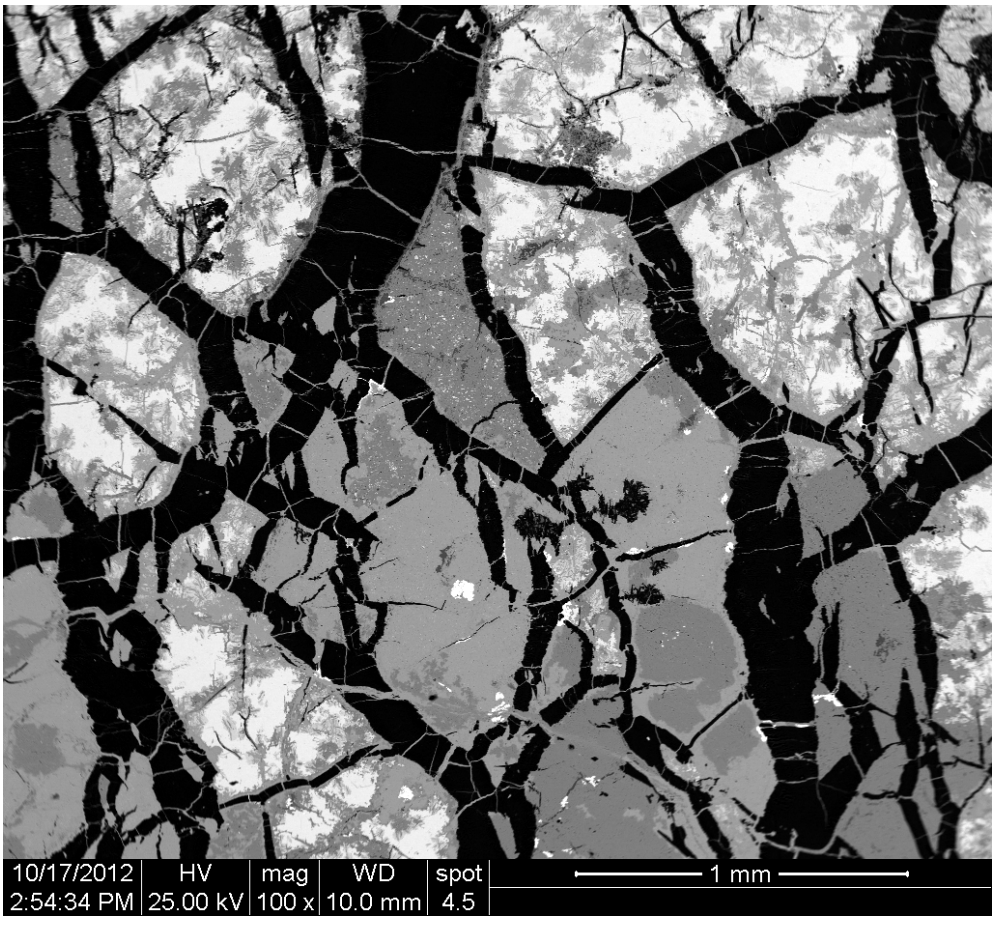
Image No. **4**



Site **161y**

Sample No. **pit 2012**

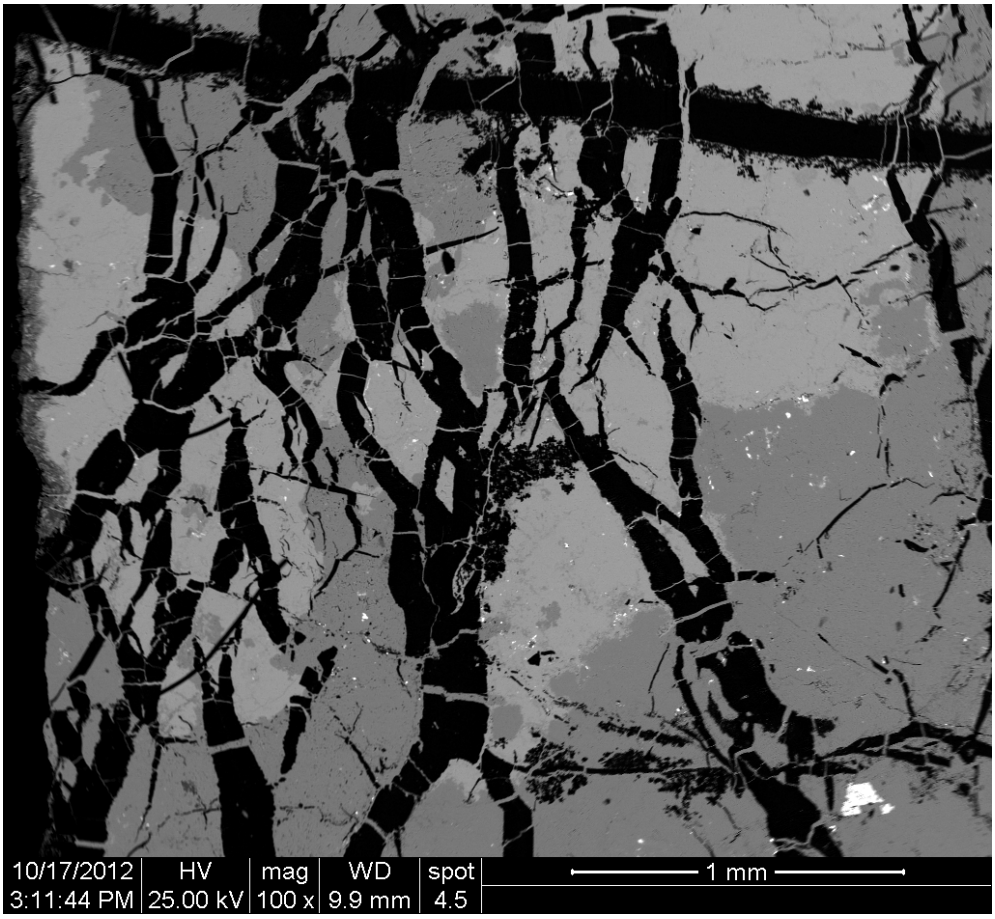
Image No. **1**



Site **161y**

Sample No. **pit 2012**

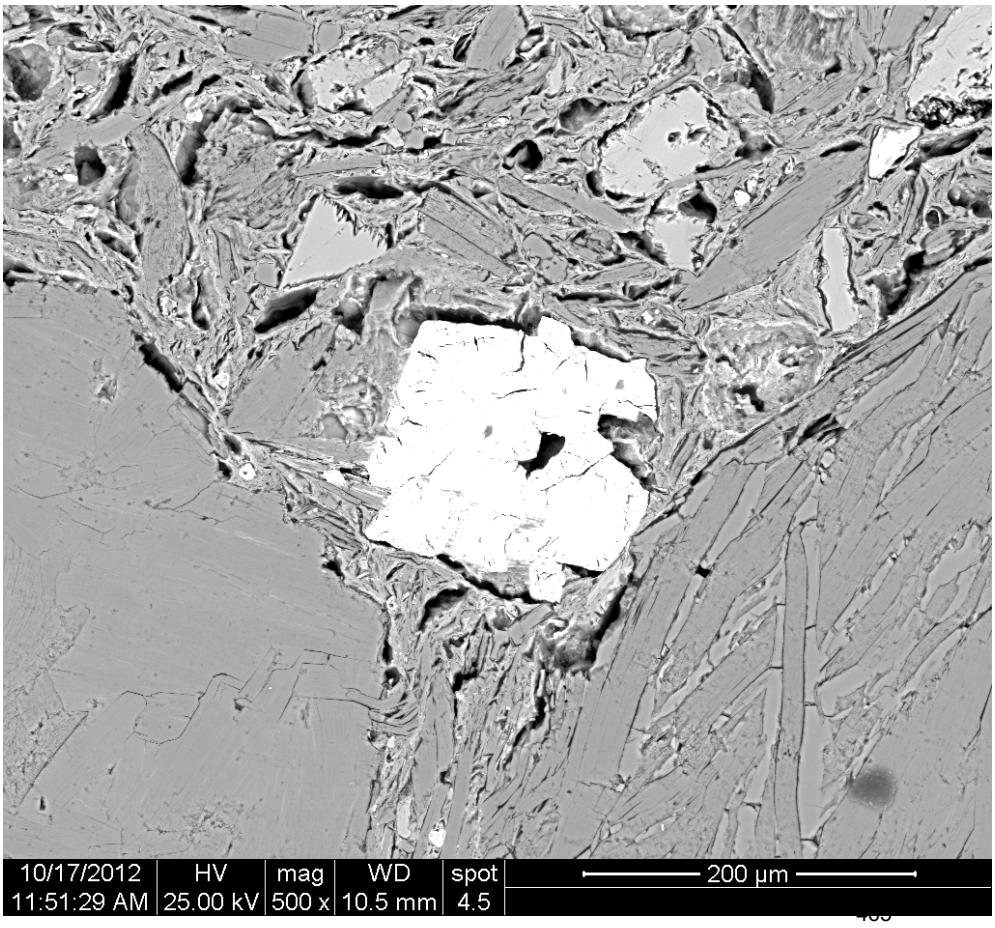
Image No. **2**



Site **161y**

Sample No. **6549**

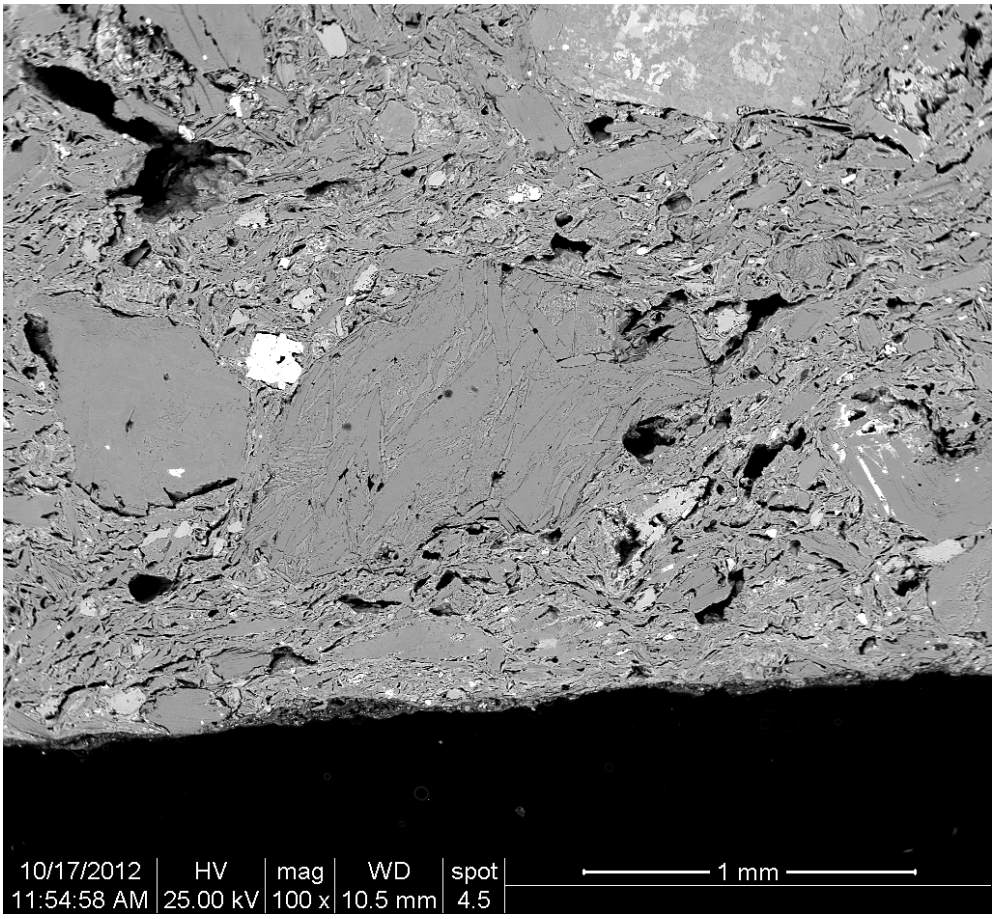
Image No. **1**



Site **161y**

Sample No. **6549**

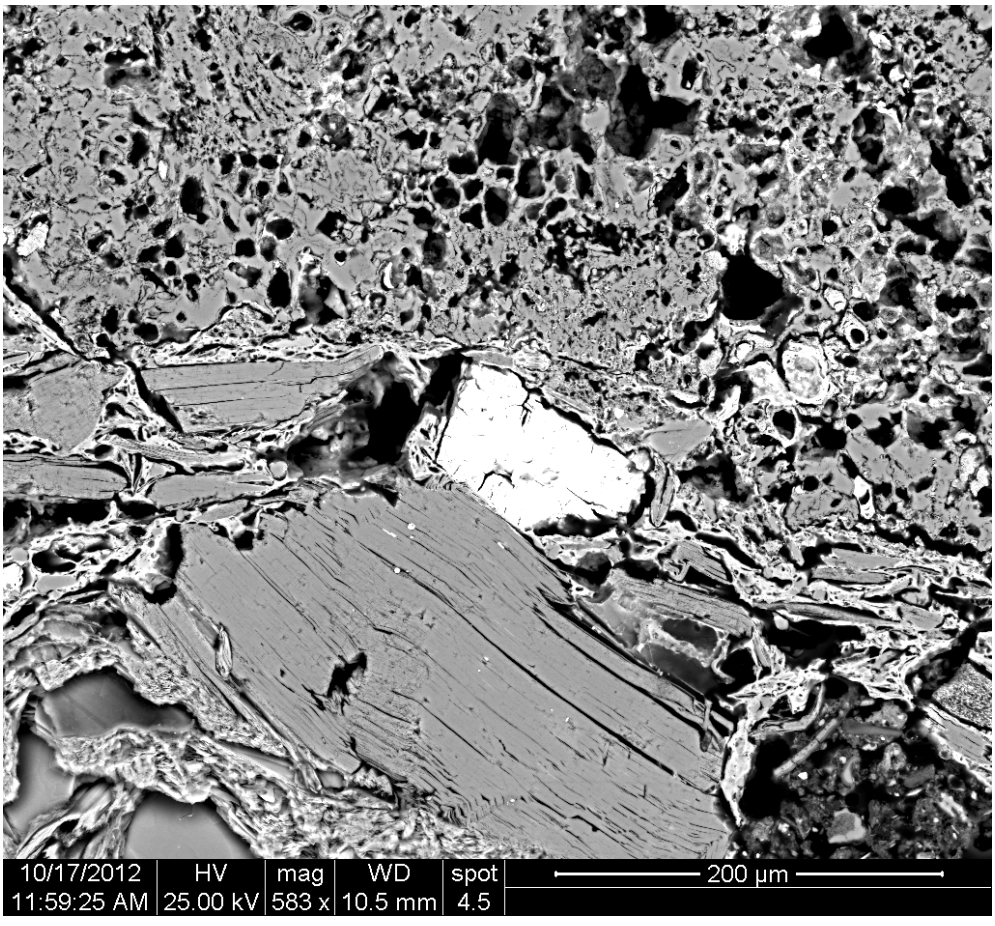
Image No. **2**



Site **161y**

Sample No. **6549**

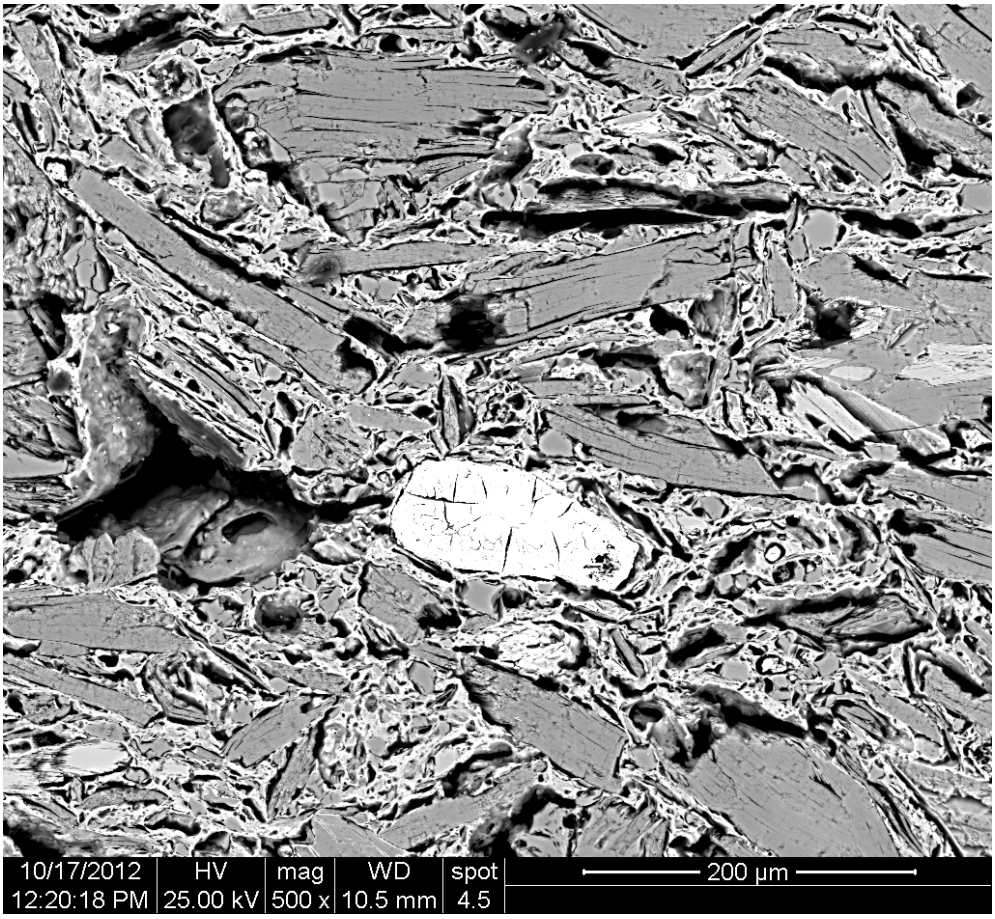
Image No. **3**



Site **161y**

Sample No. **6549**

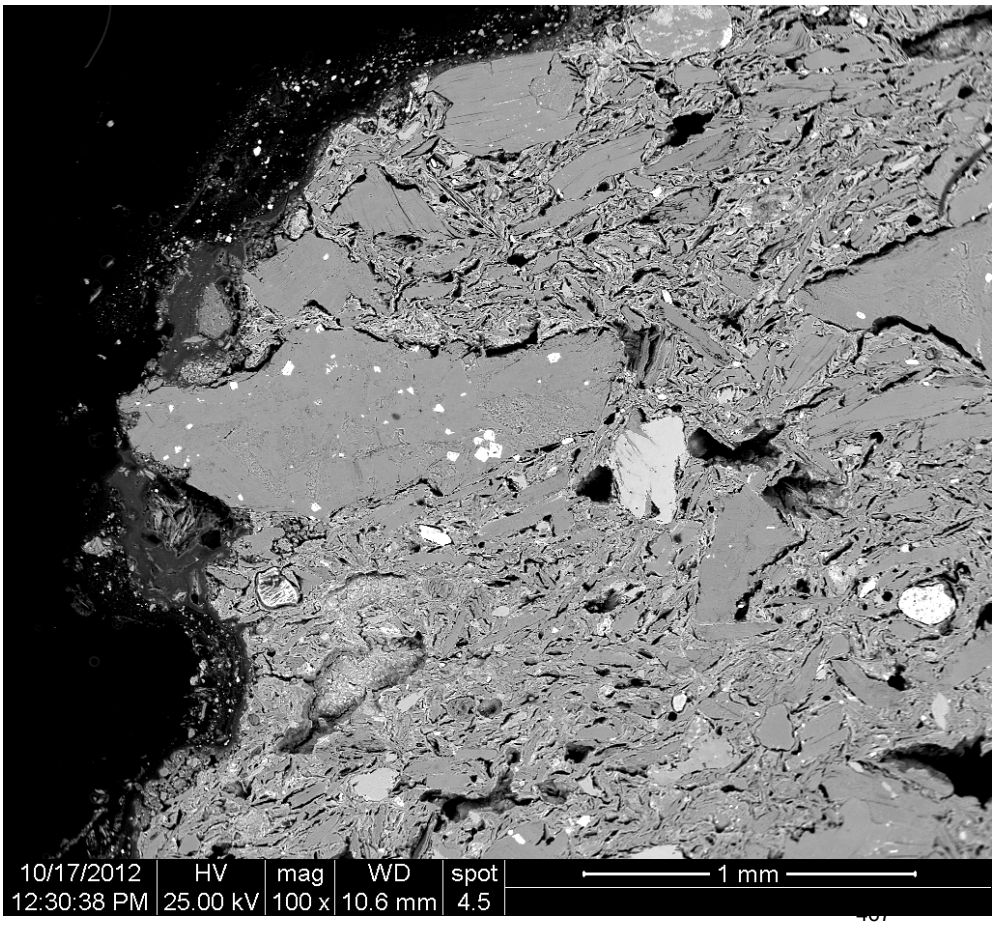
Image No. **4**



Site **161y**

Sample No. **6549**

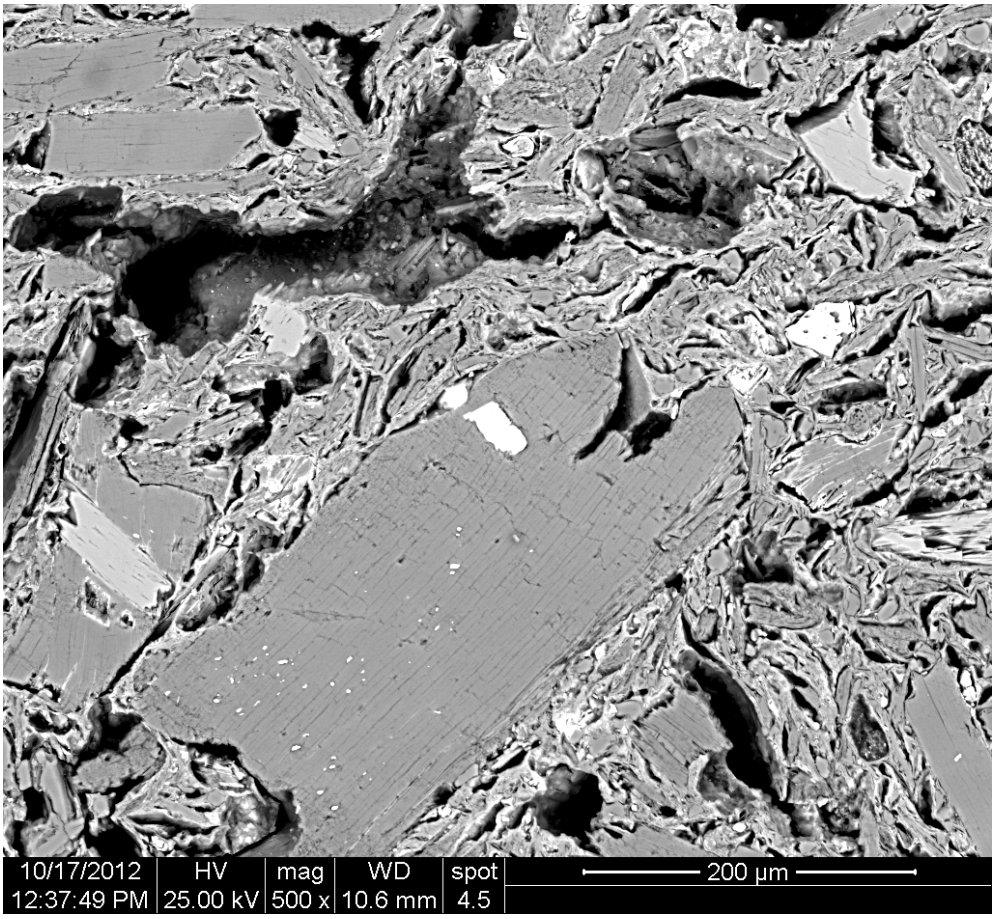
Image No. **5**



Site **161y**

Sample No. **6549**

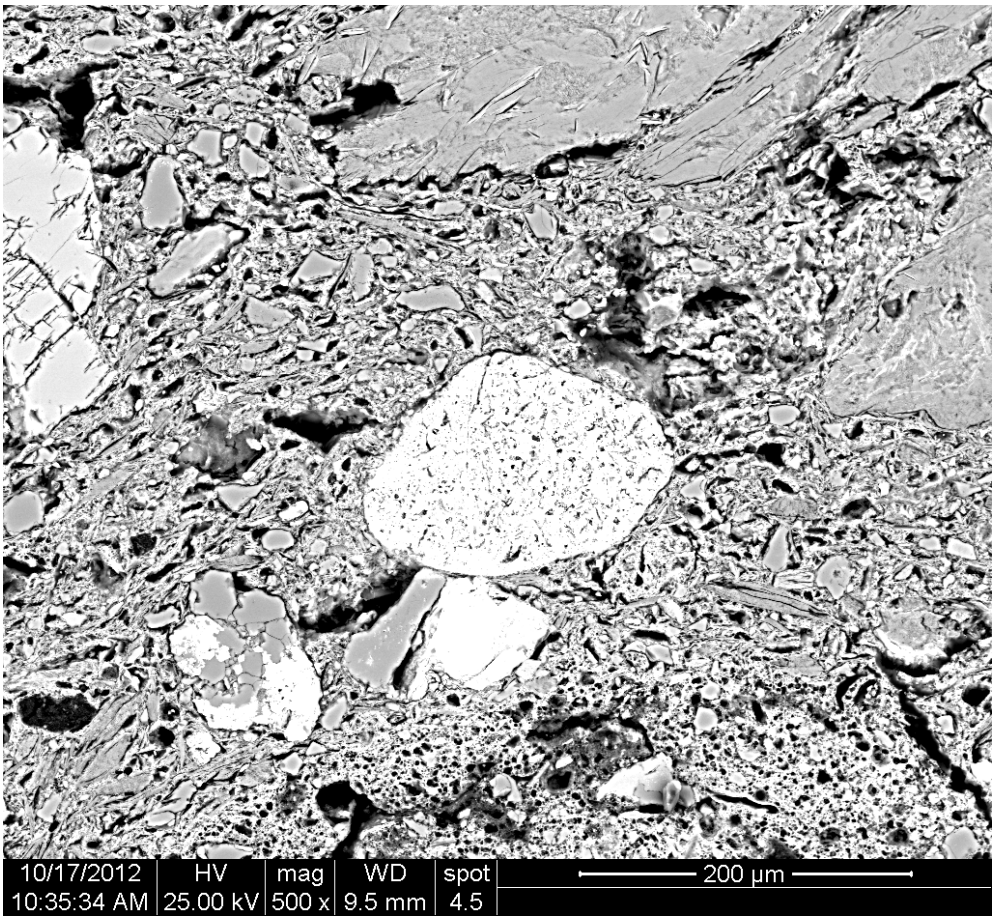
Image No. **6**



Site **161y**

Sample No. **9148**

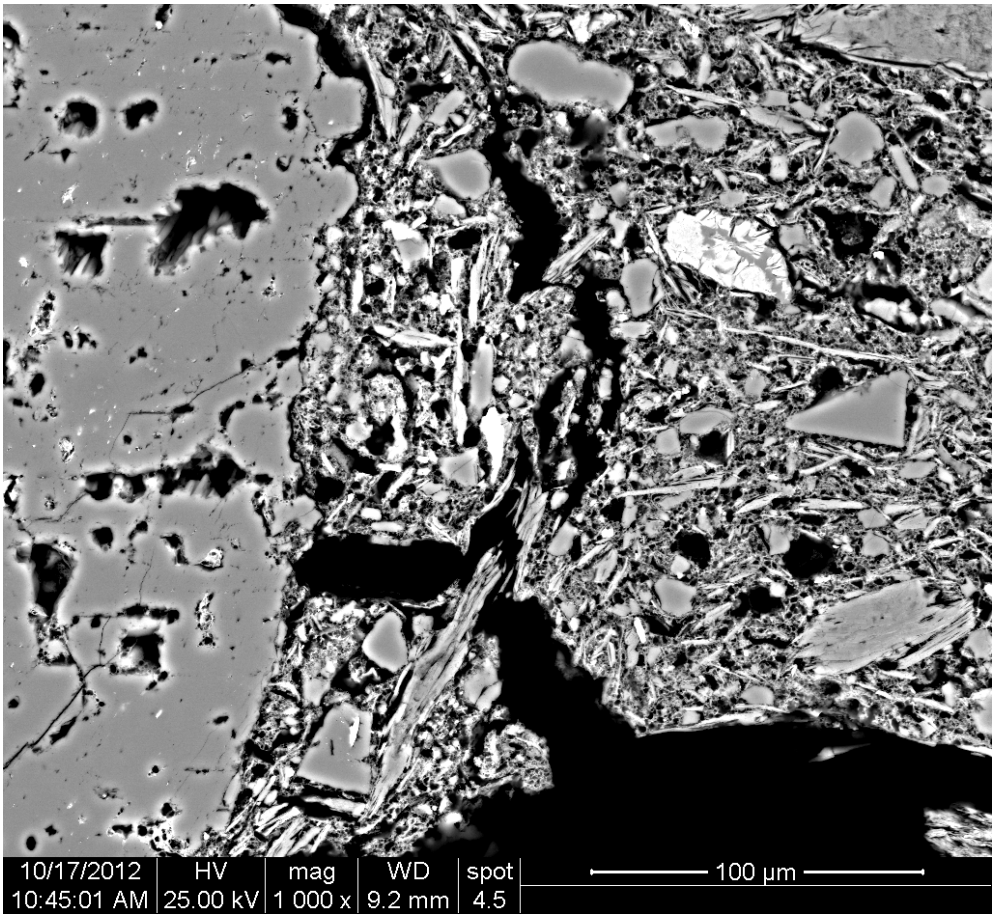
Image No. **1**



Site **161y**

Sample No. **9148**

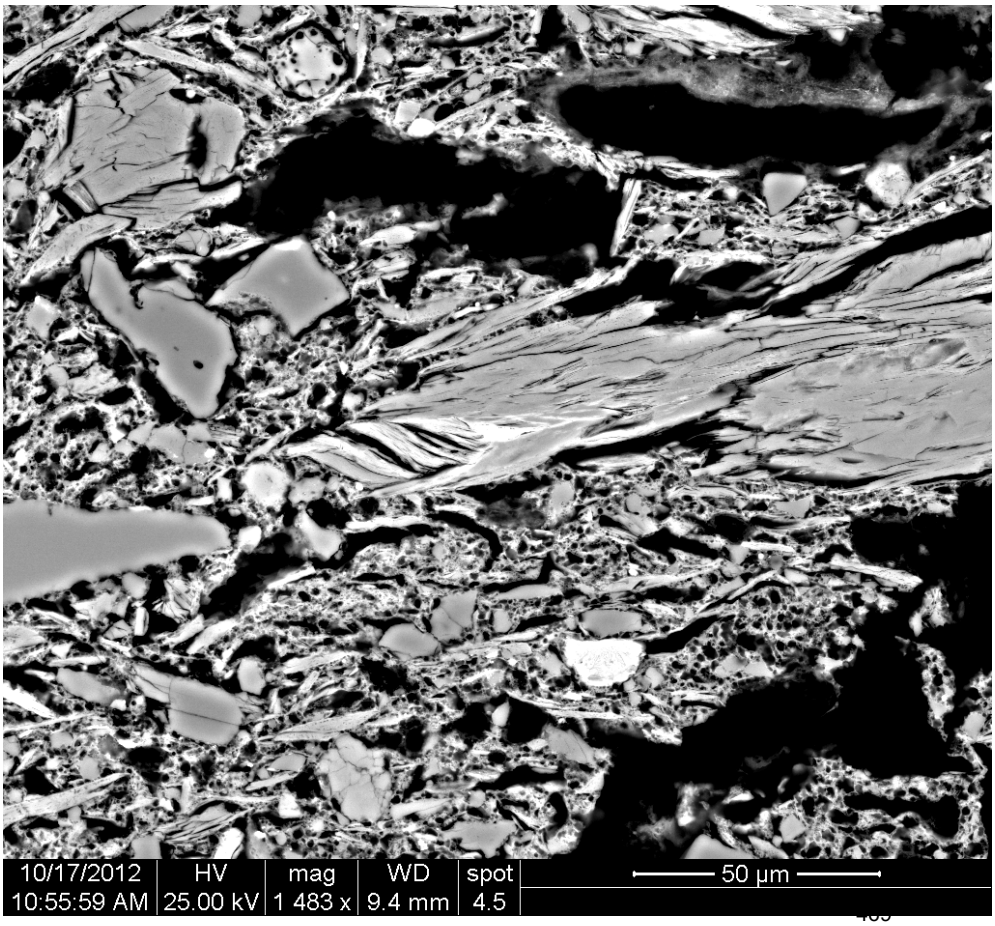
Image No. **2**



Site **161y**

Sample No. **9148**

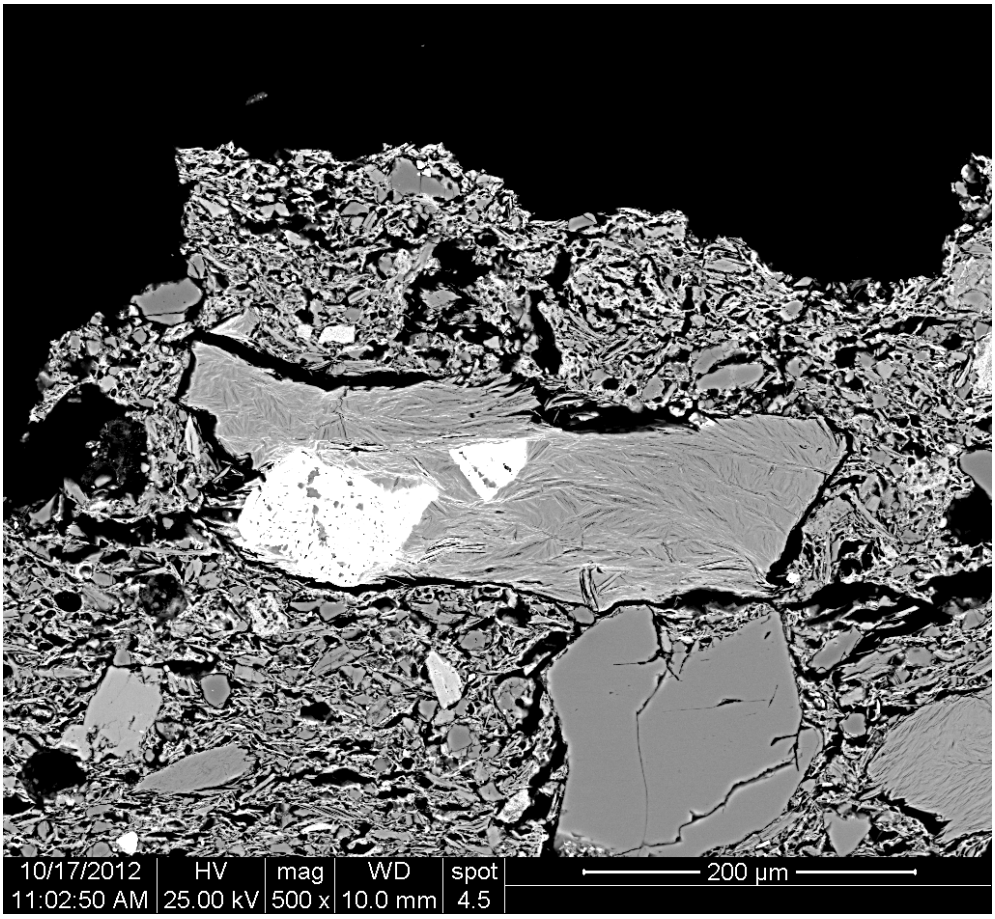
Image No. **3**



Site **161y**

Sample No. **9148**

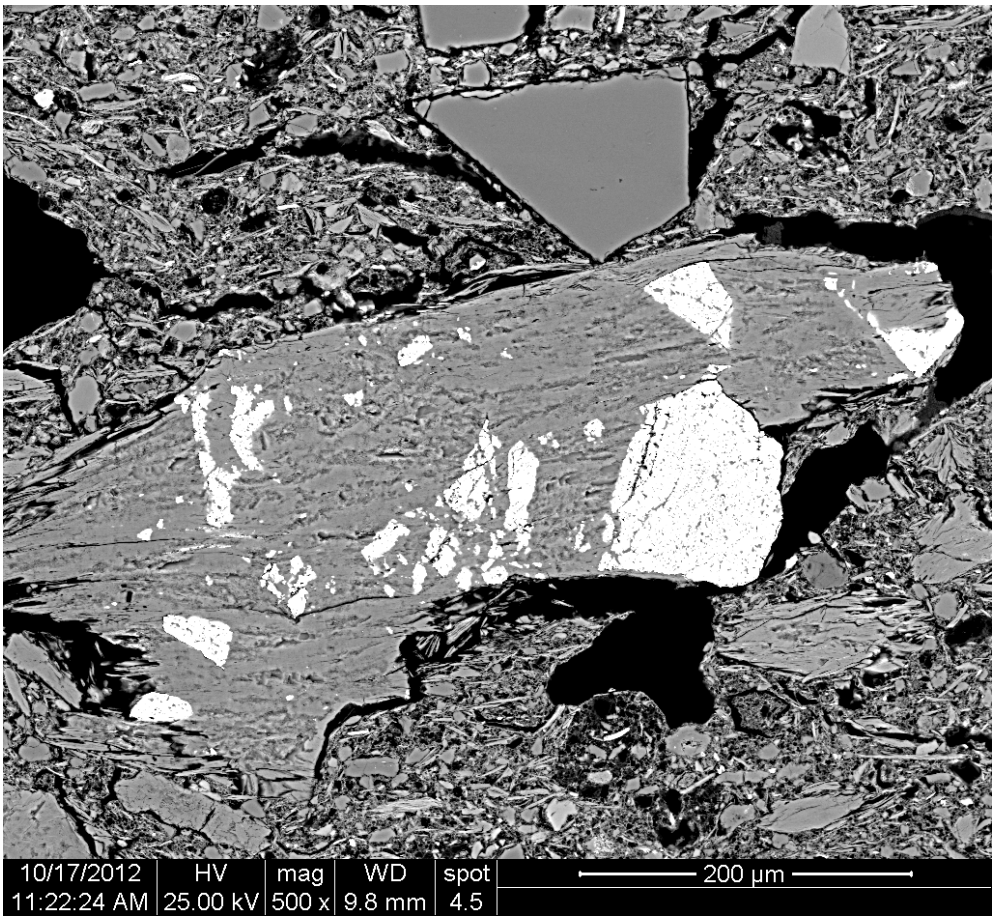
Image No. **4**



Site **161y**

Sample No. **9148**

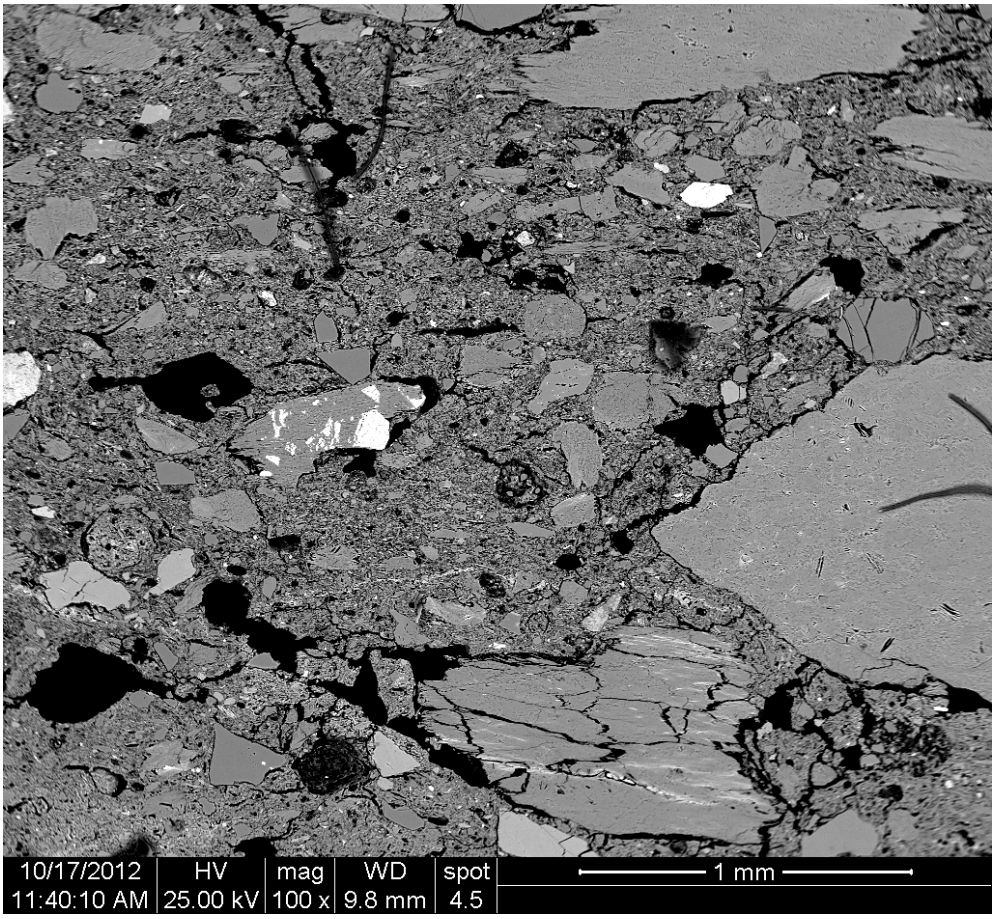
Image No. **5**



Site **161y**

Sample No. **9148**

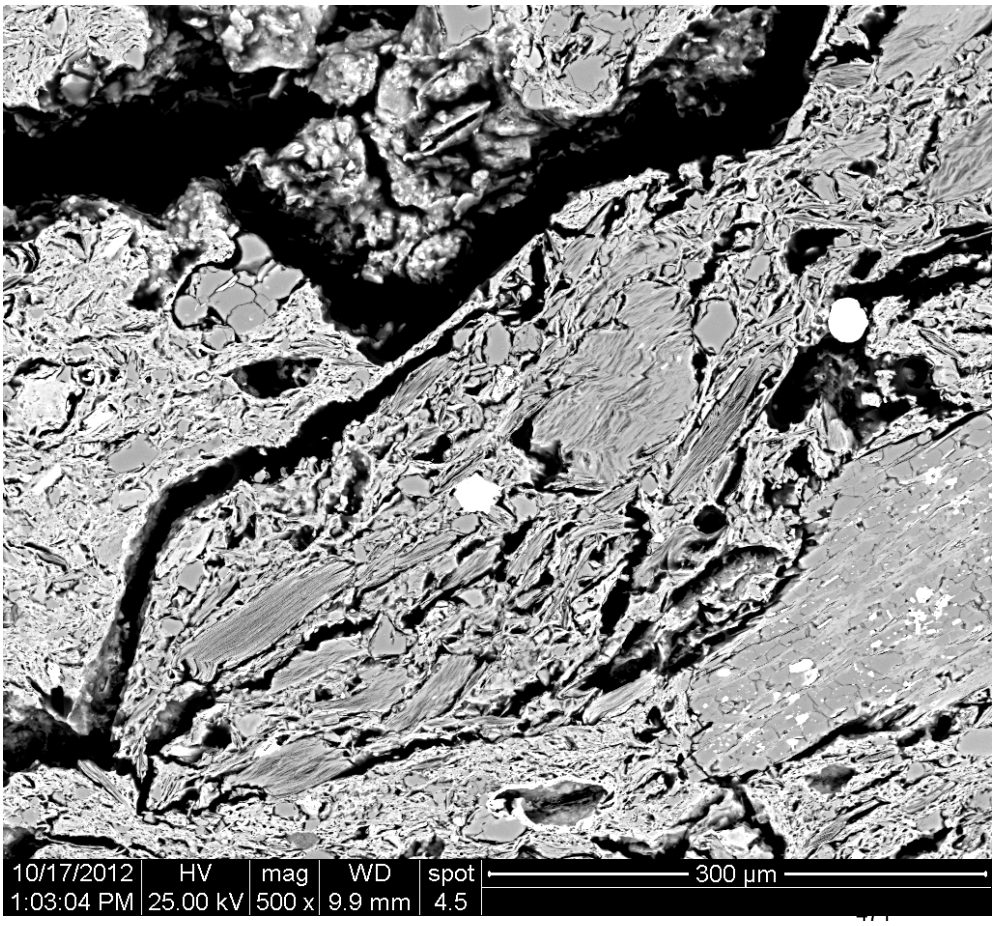
Image No. **6**



Site **161y**

Sample No. **9208**

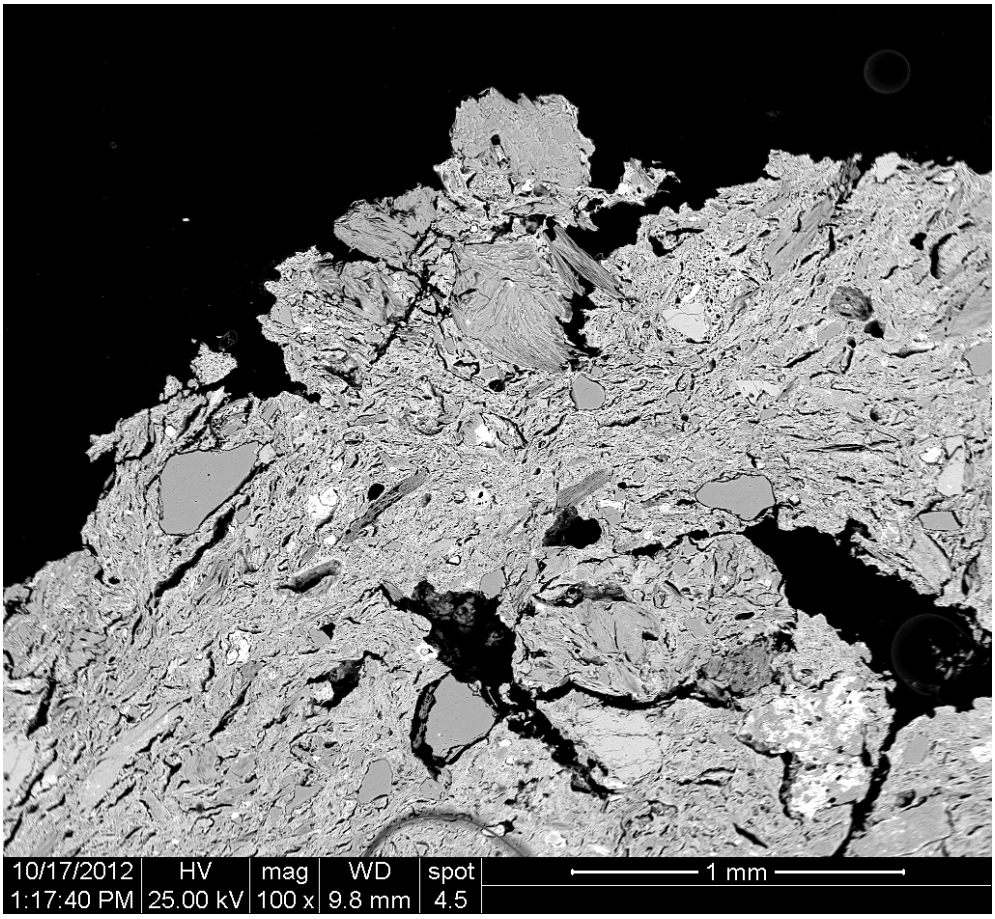
Image No. **1**



Site **161y**

Sample No. **9208**

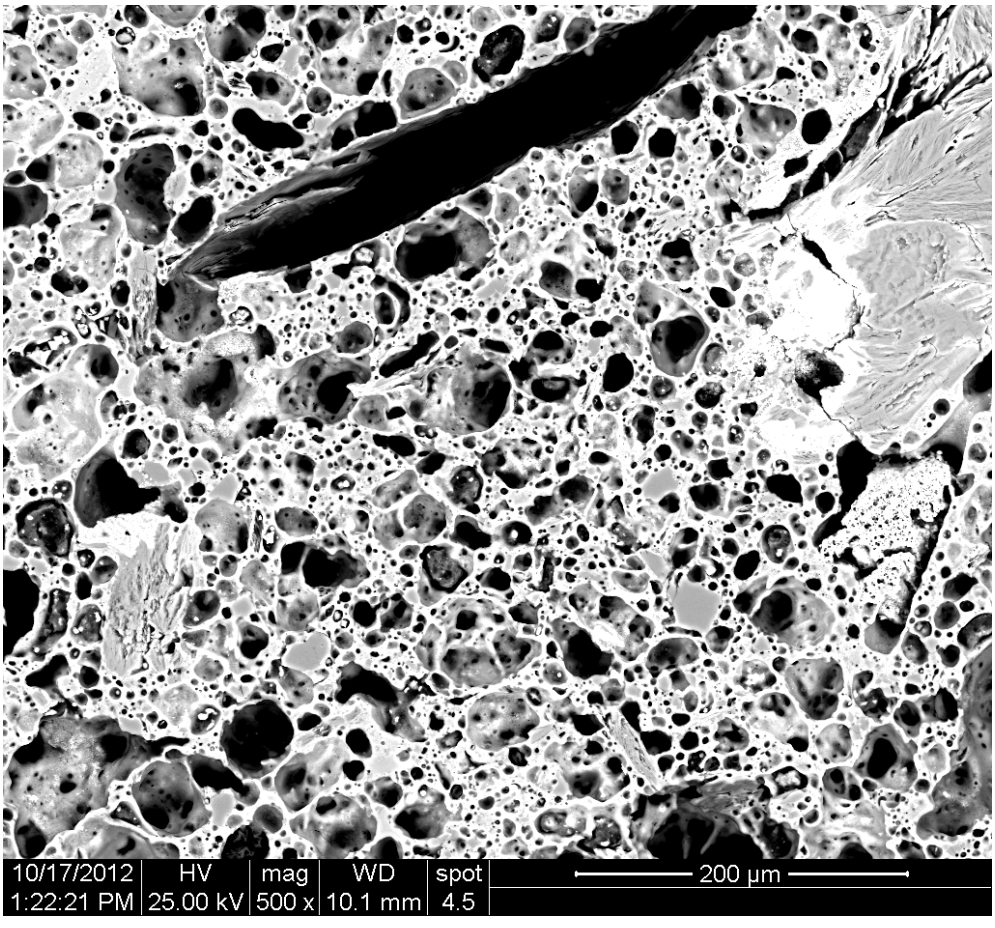
Image No. **2**



Site **161y**

Sample No. **9208**

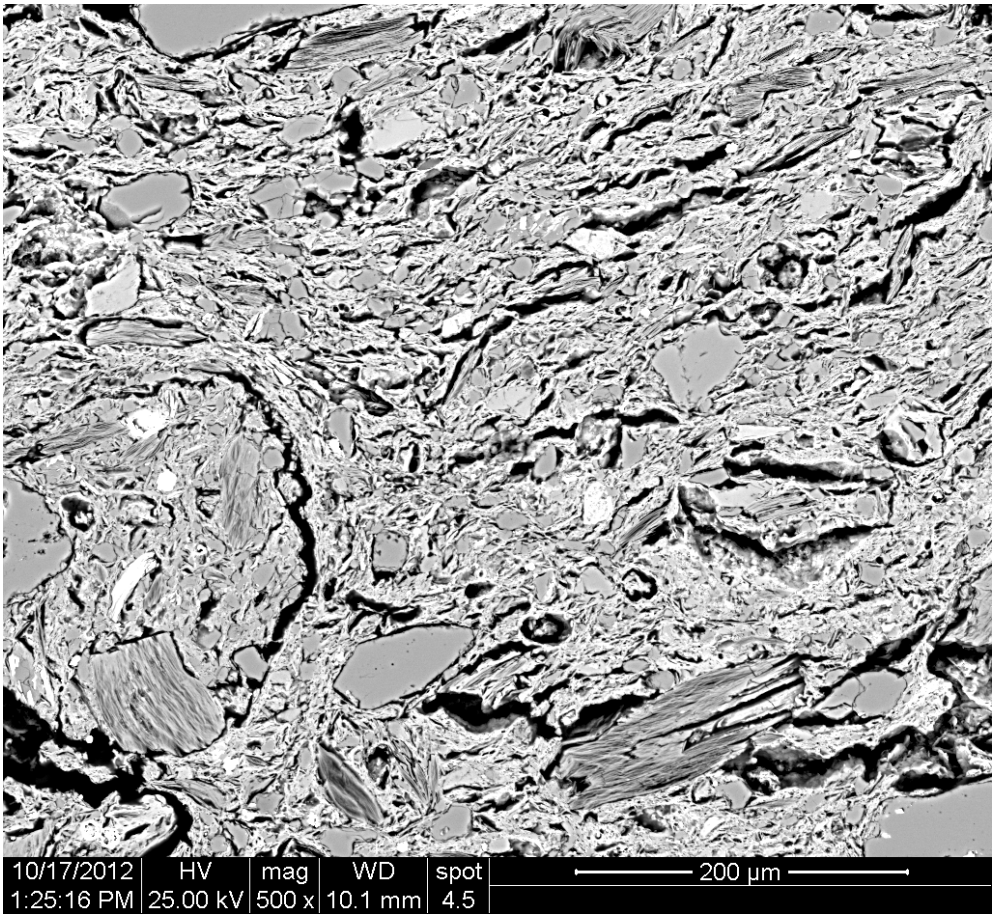
Image No. **3**



Site **161y**

Sample No. **9208**

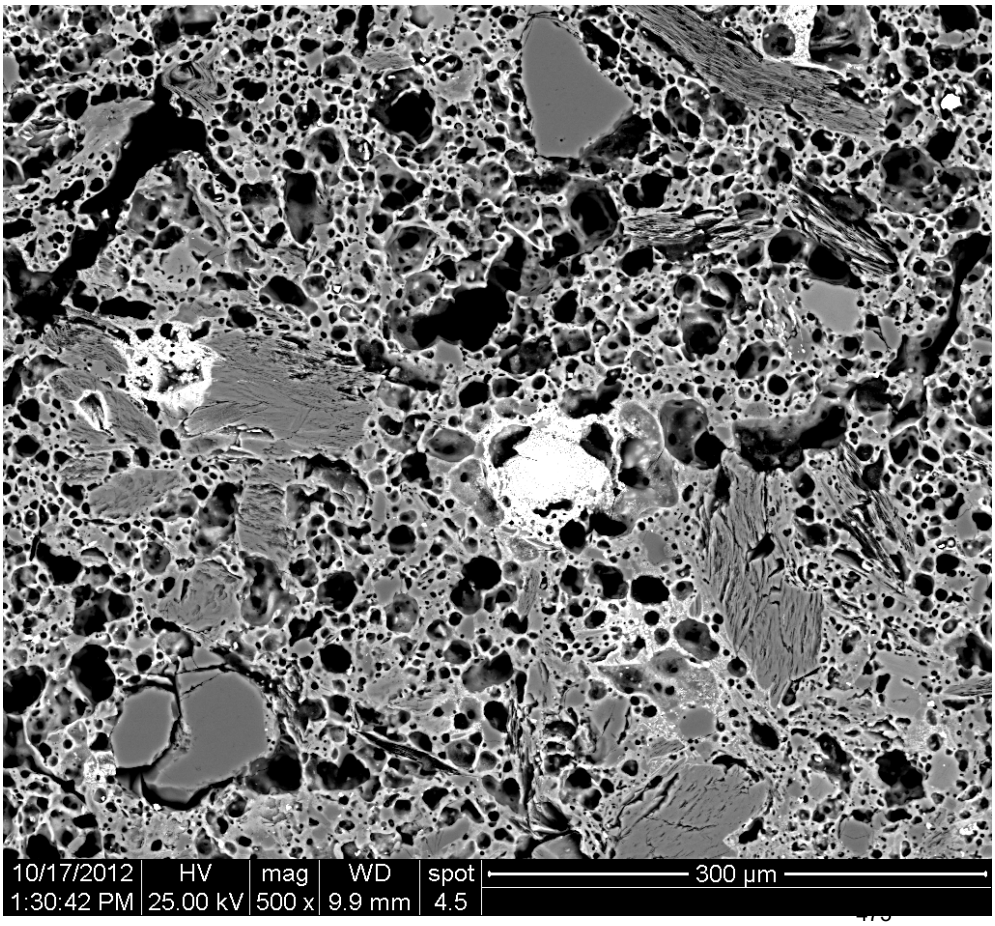
Image No. **4**



Site **161y**

Sample No. **9208**

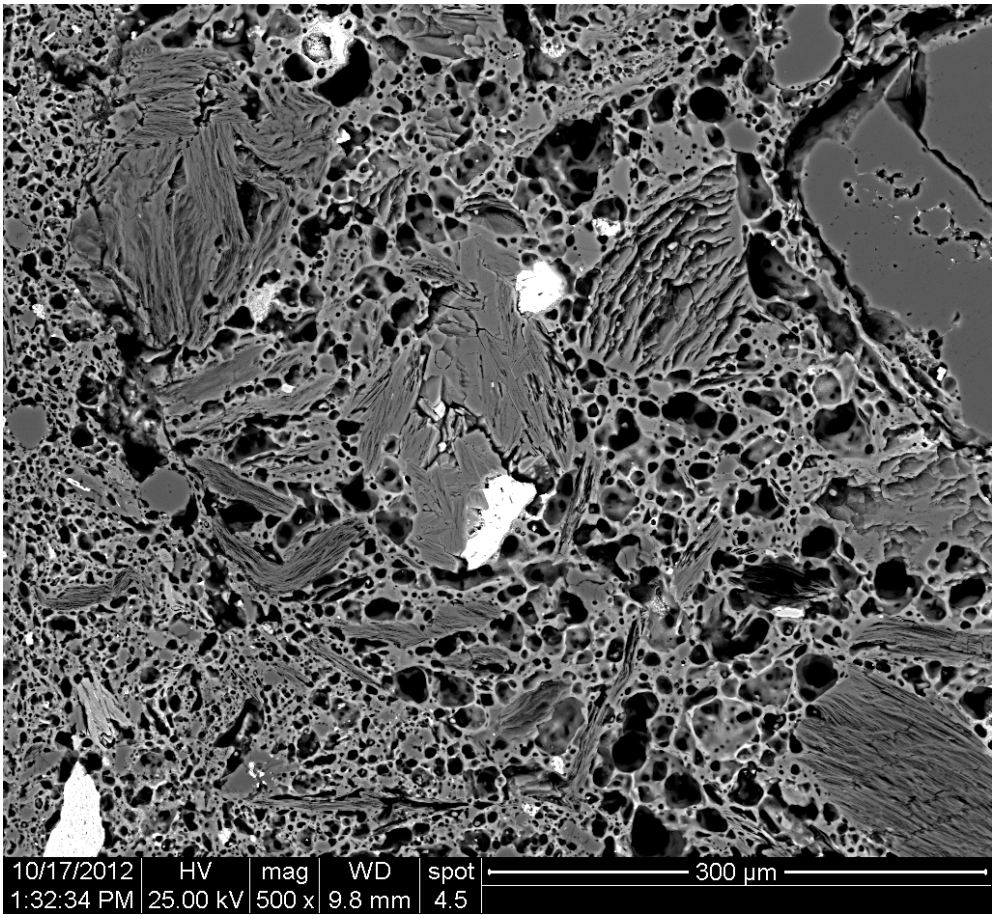
Image No. **5**



Site 161y

Sample No. 9208

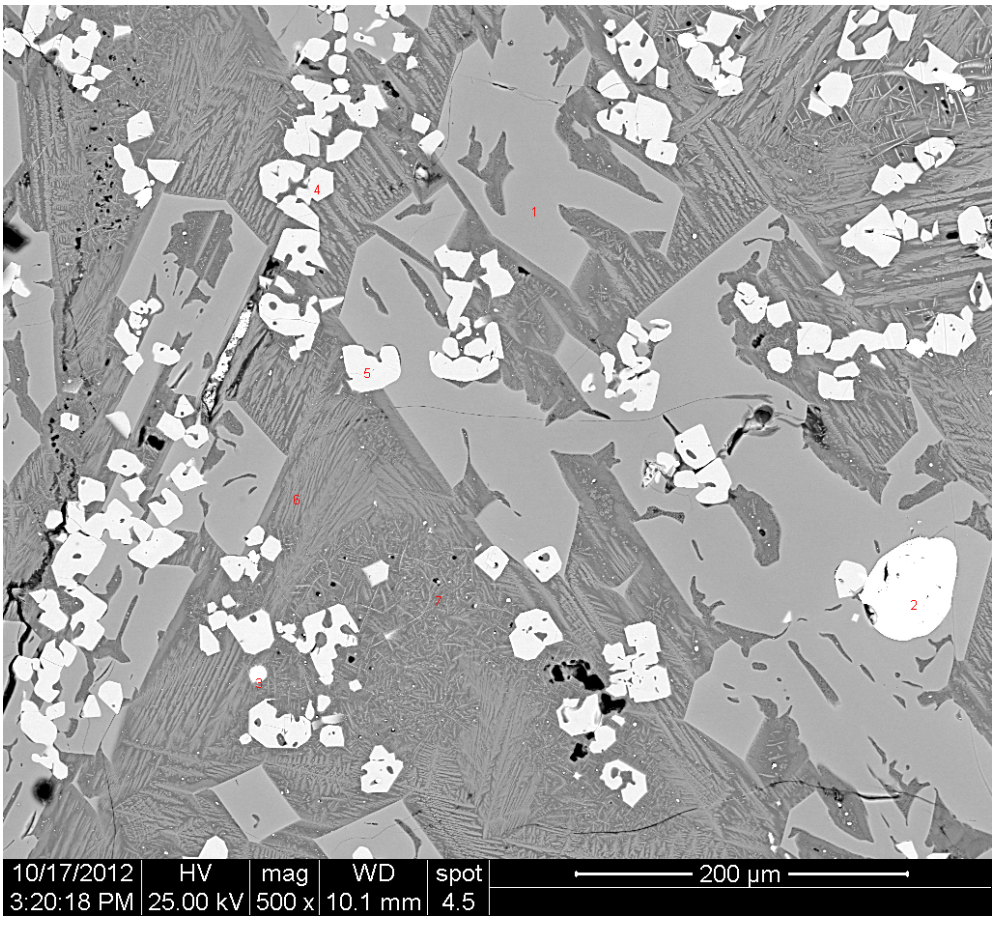
Image No. 6



Site 161y

Sample No. 6452

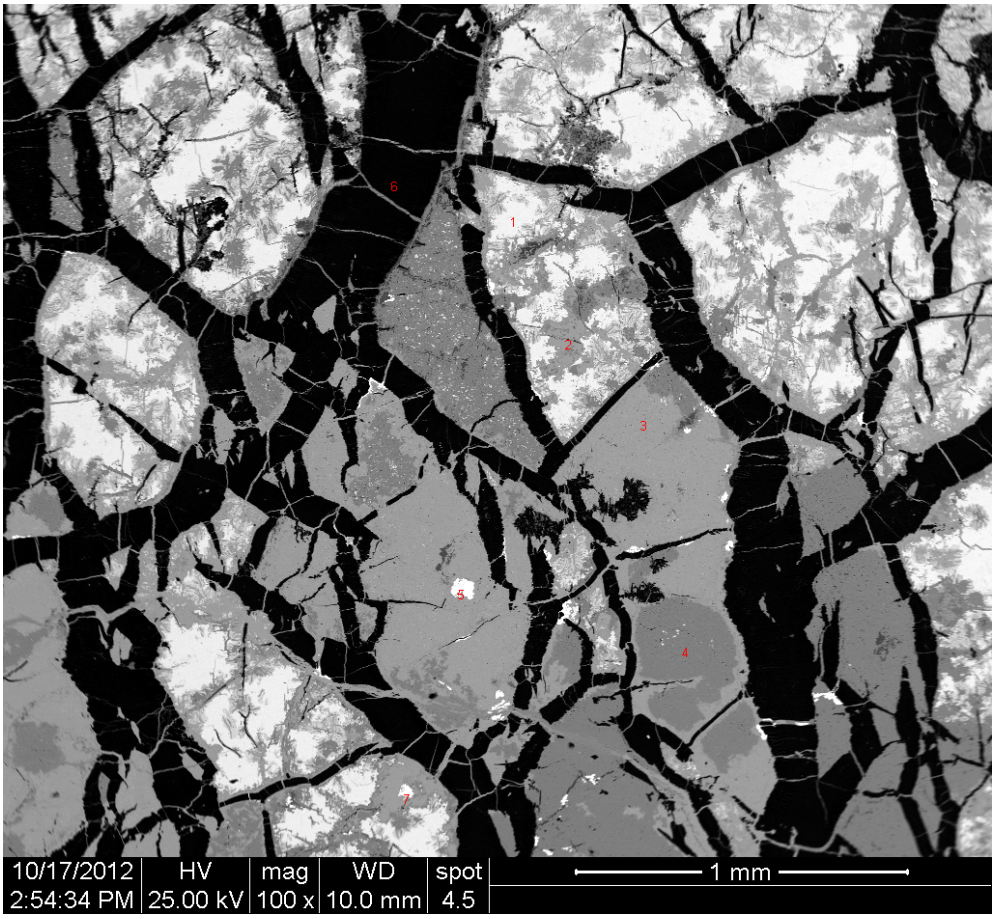
Image No. 1



Site 161y

Sample No. pit

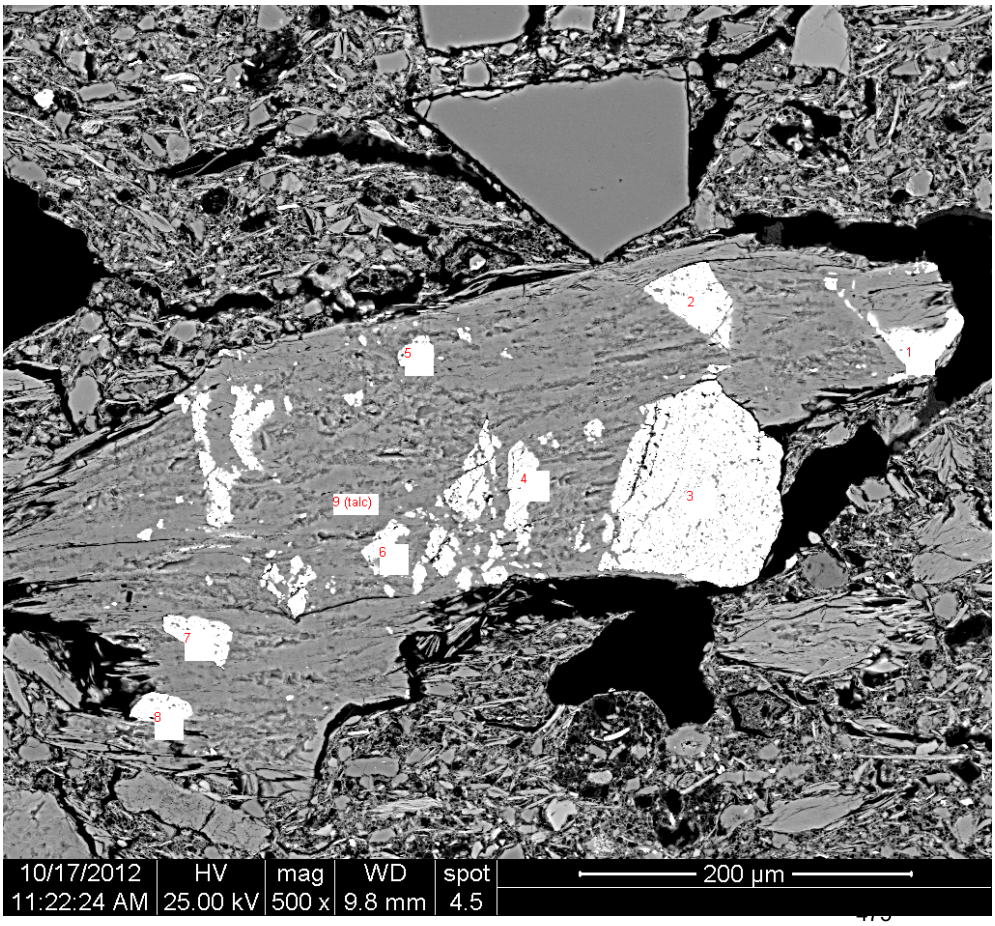
Image No. 1



Site 161y

Sample No. 9148

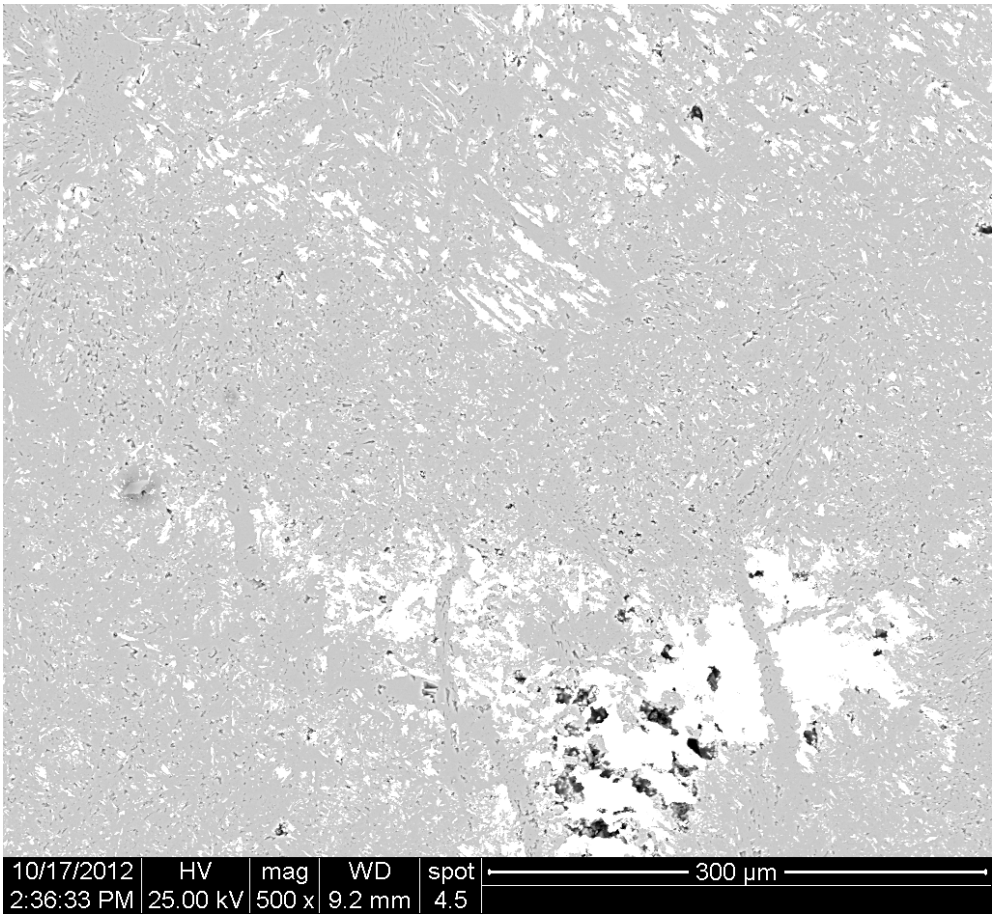
Image No. 5



Site phy

Sample No. 1

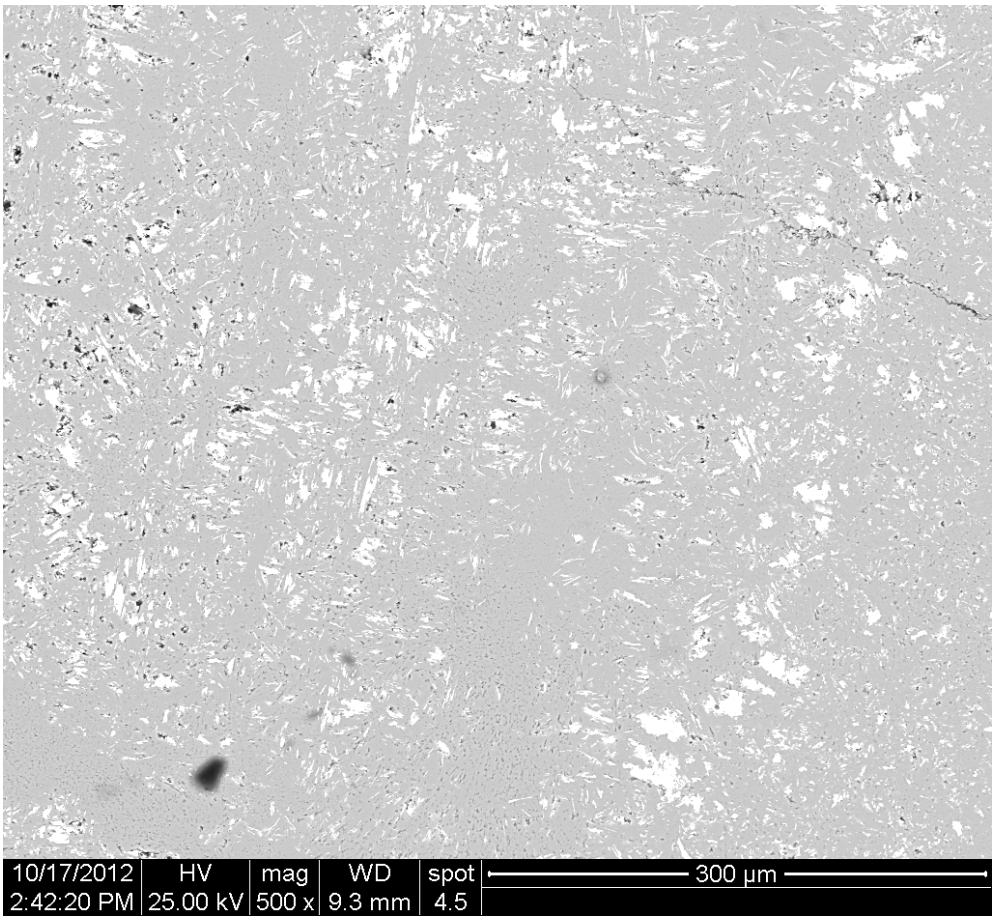
Image No. 1



Site phy

Sample No. 1

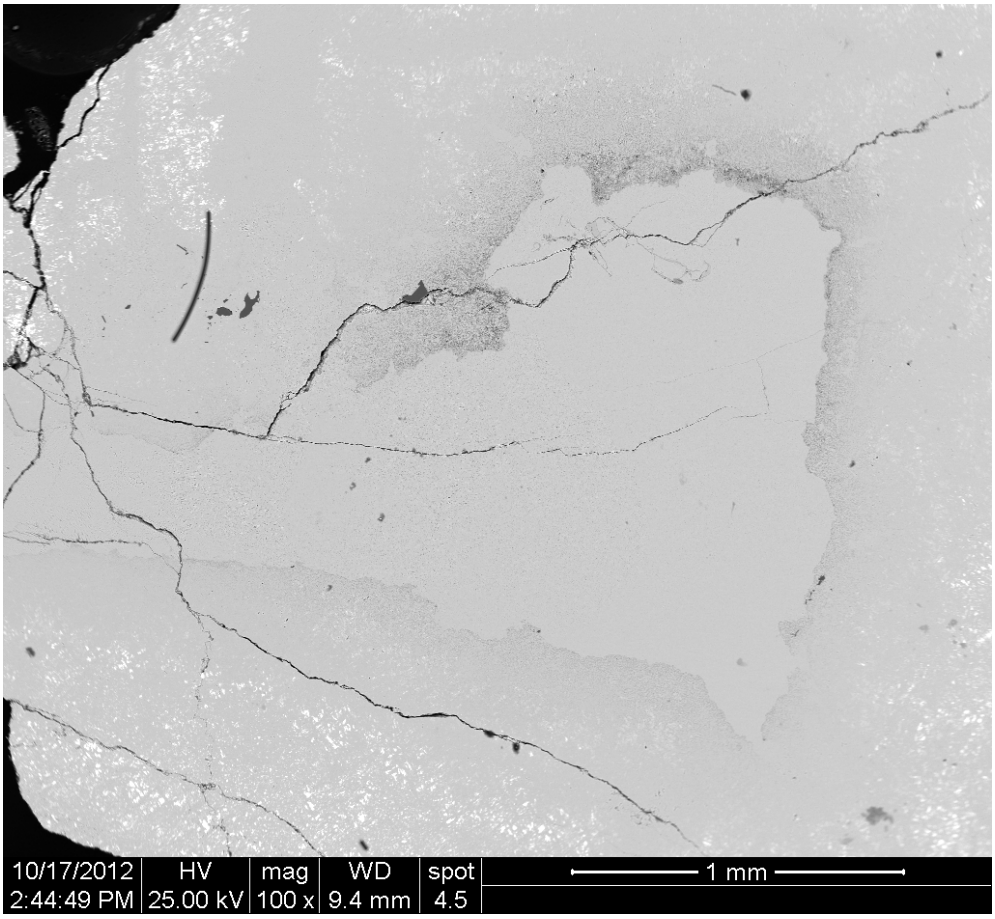
Image No. 2



Site **phy**

Sample No. **1**

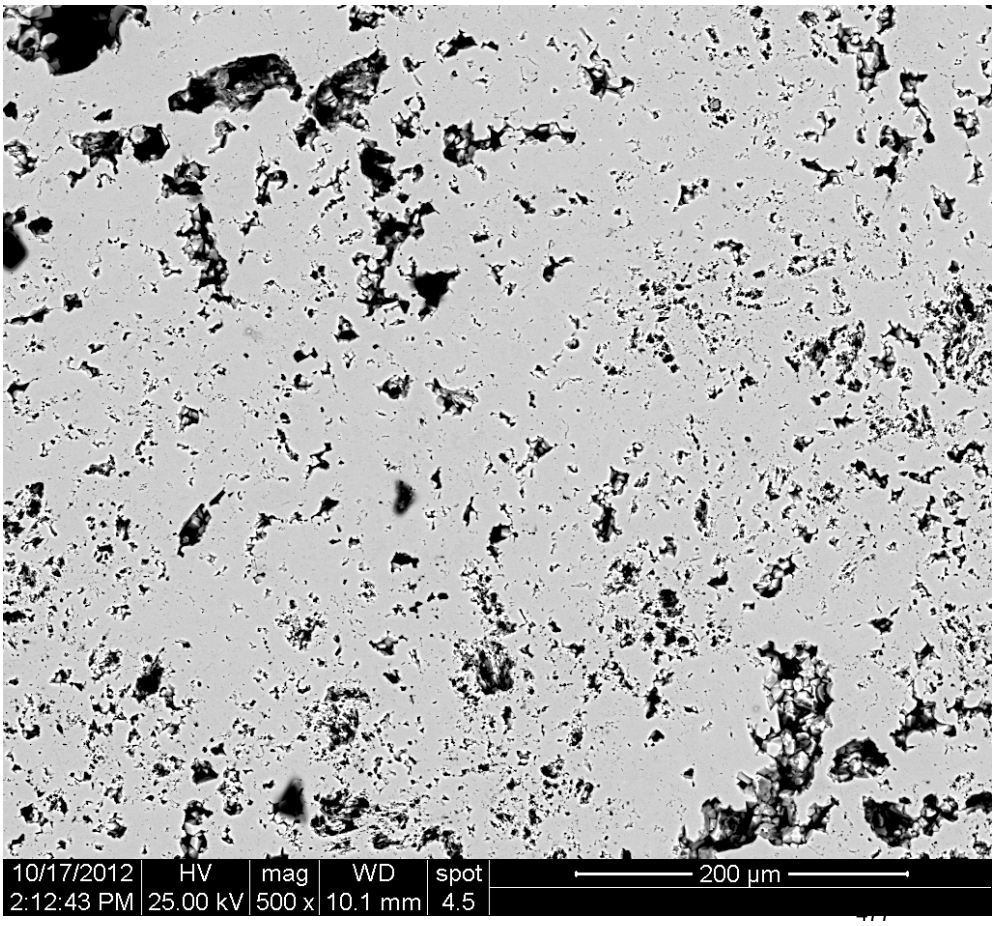
Image No. **3**



Site **pky**

Sample No. **1**

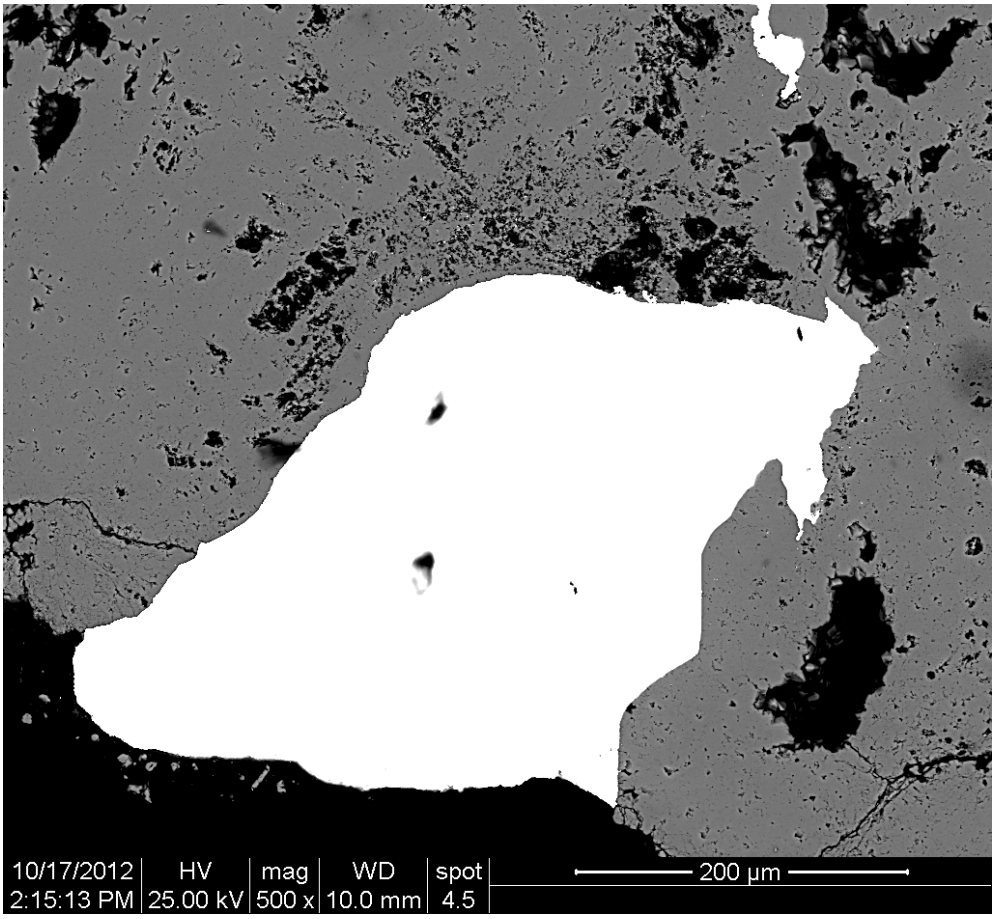
Image No. **1**



Site pky

Sample No. 1

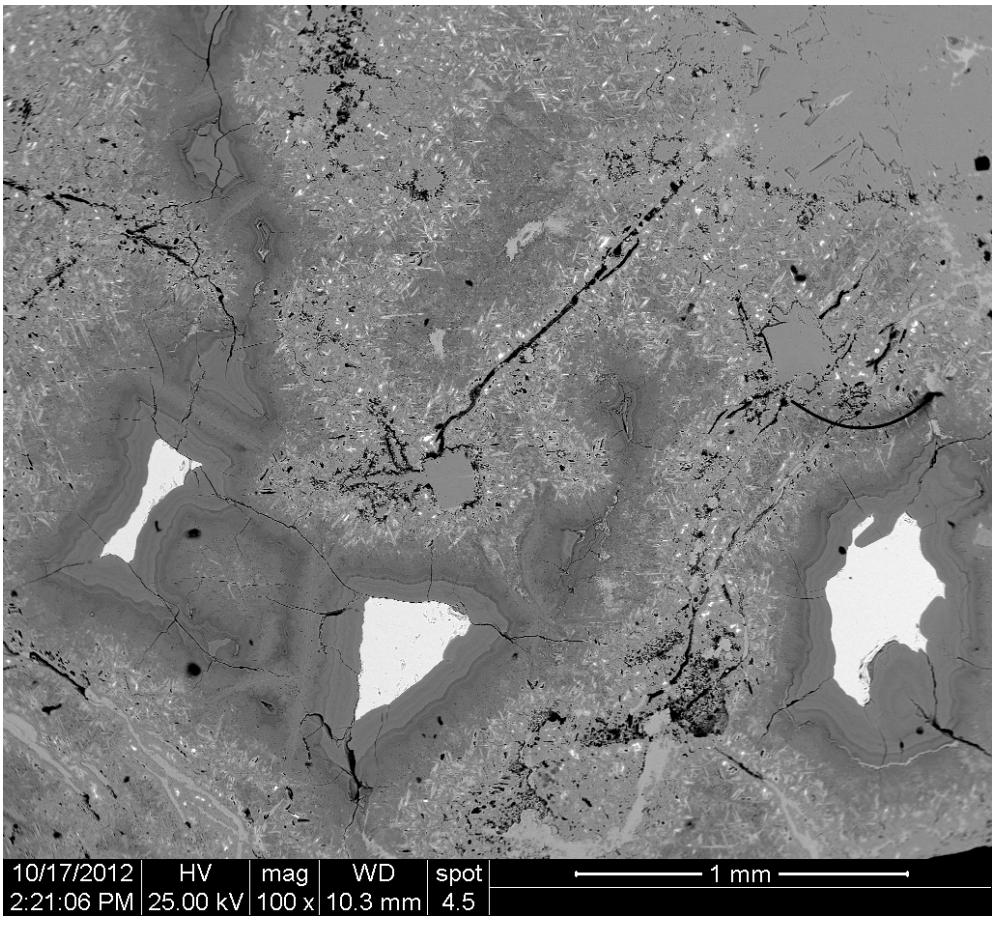
Image No. 2



Site pky

Sample No. 1

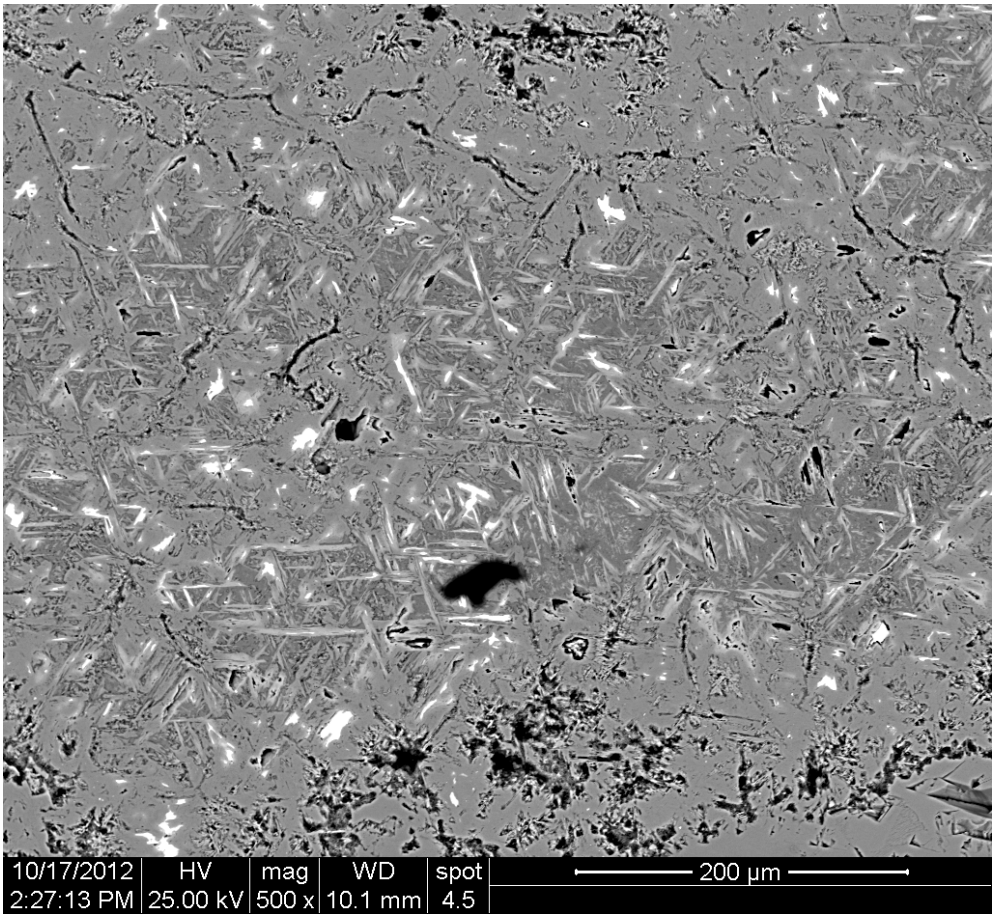
Image No. 3



Site pky

Sample No. 1

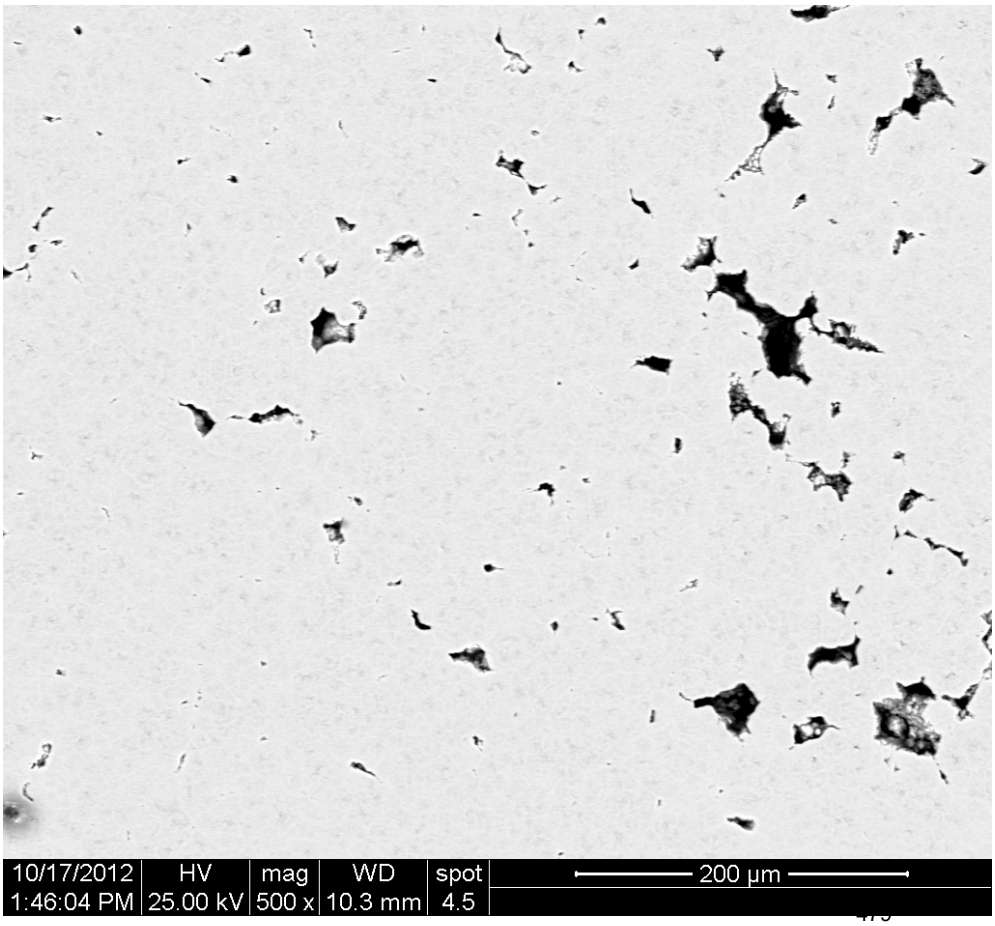
Image No. 4



Site pky

Sample No. 2

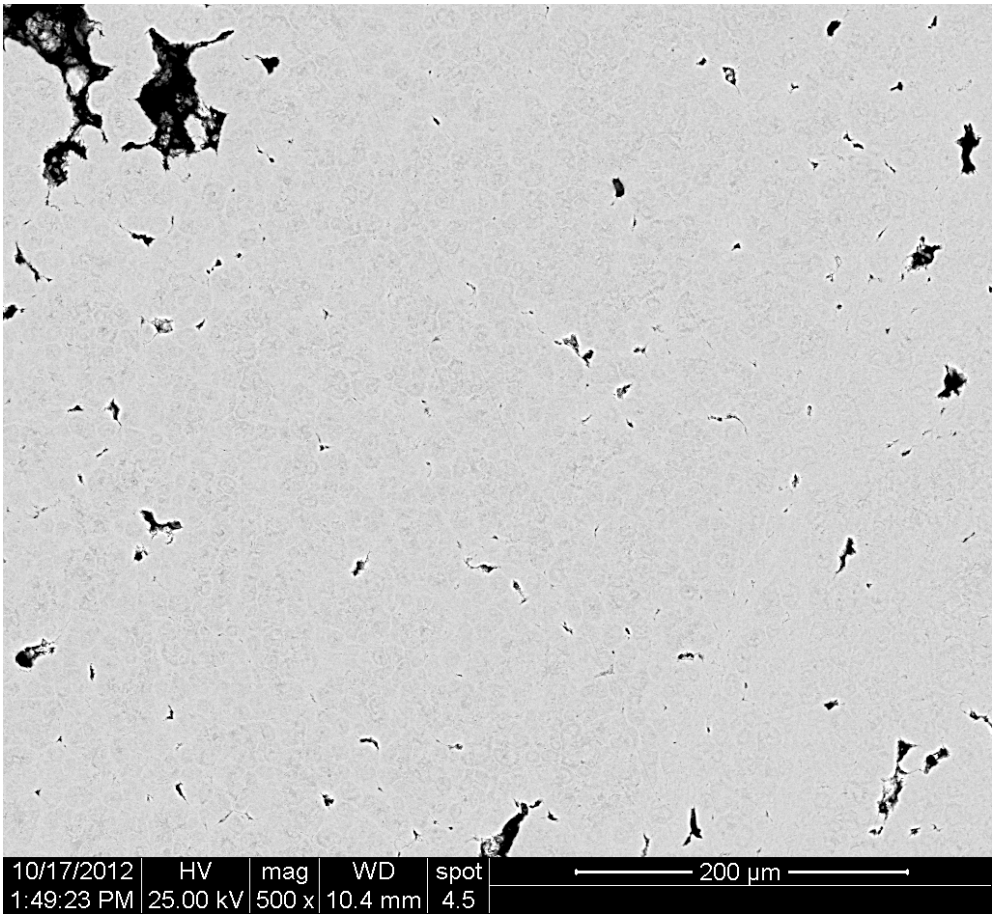
Image No. 1



Site **pky**

Sample No. **2**

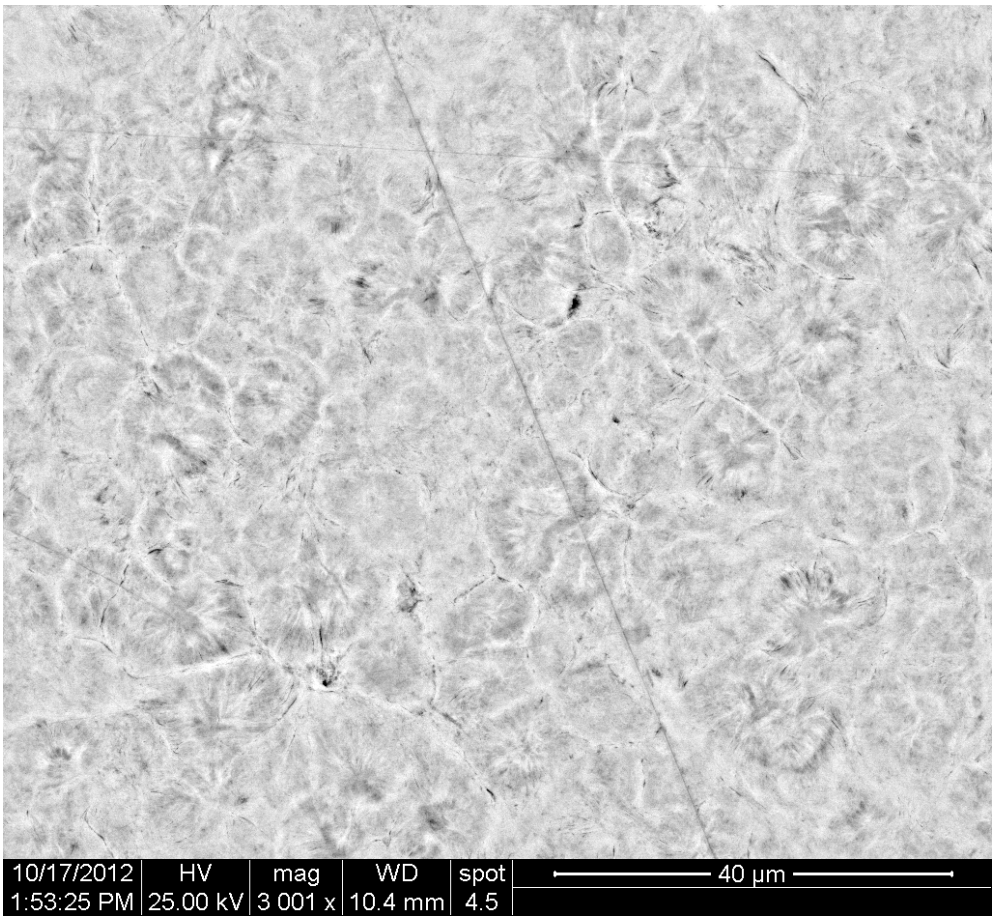
Image No. **2**



Site **pky**

Sample No. **2**

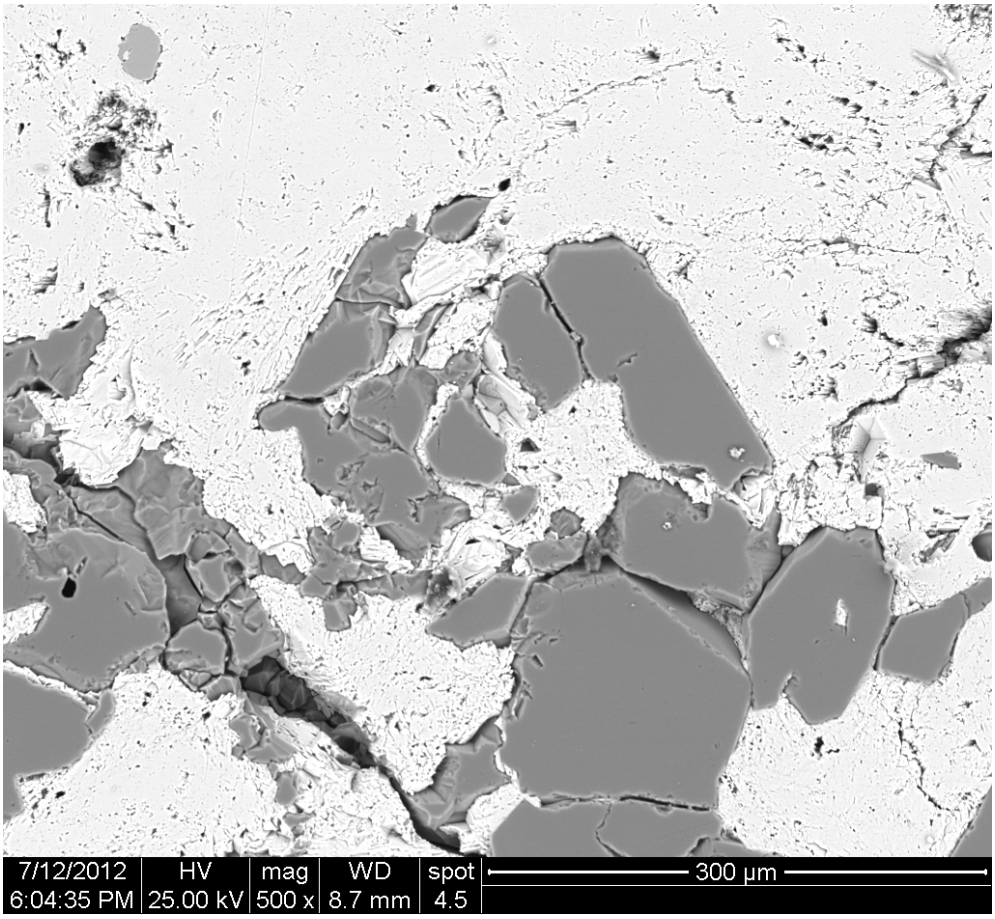
Image No. **3**



Site **sda4**

Sample No. **x3**

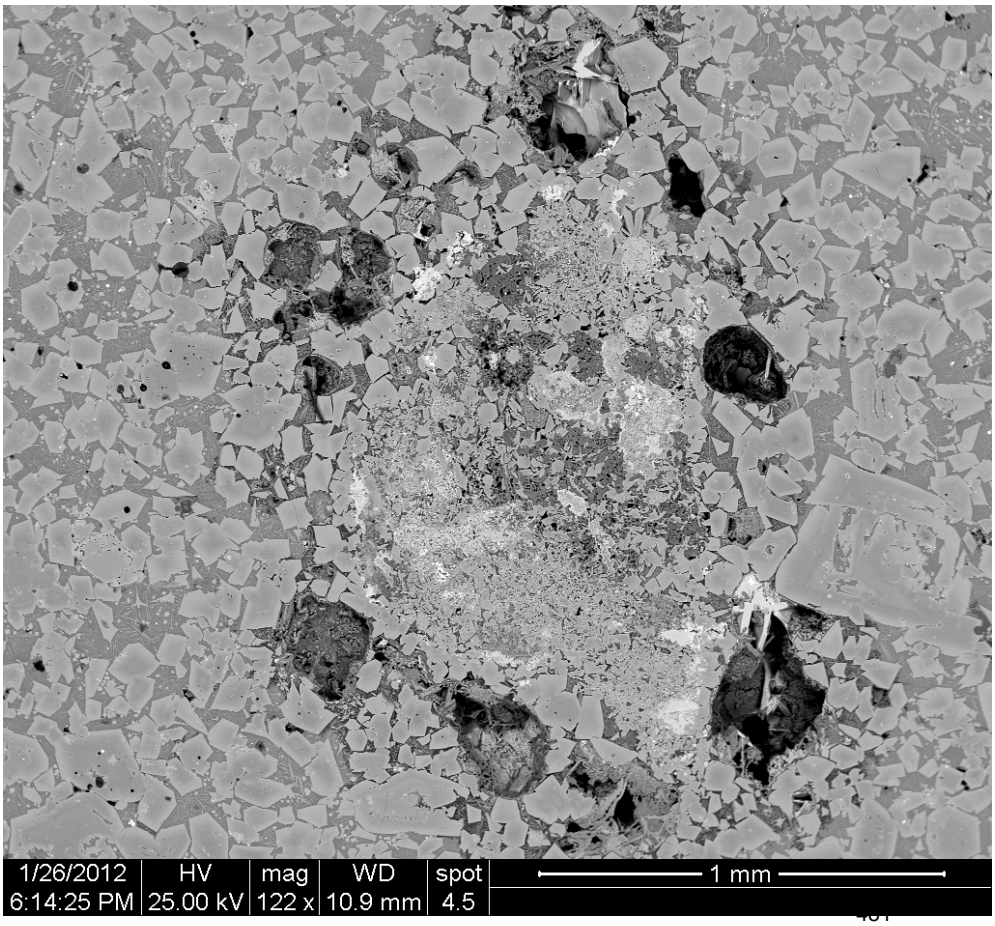
Image No. **8**



Site **step09**

Sample No. **105.6**

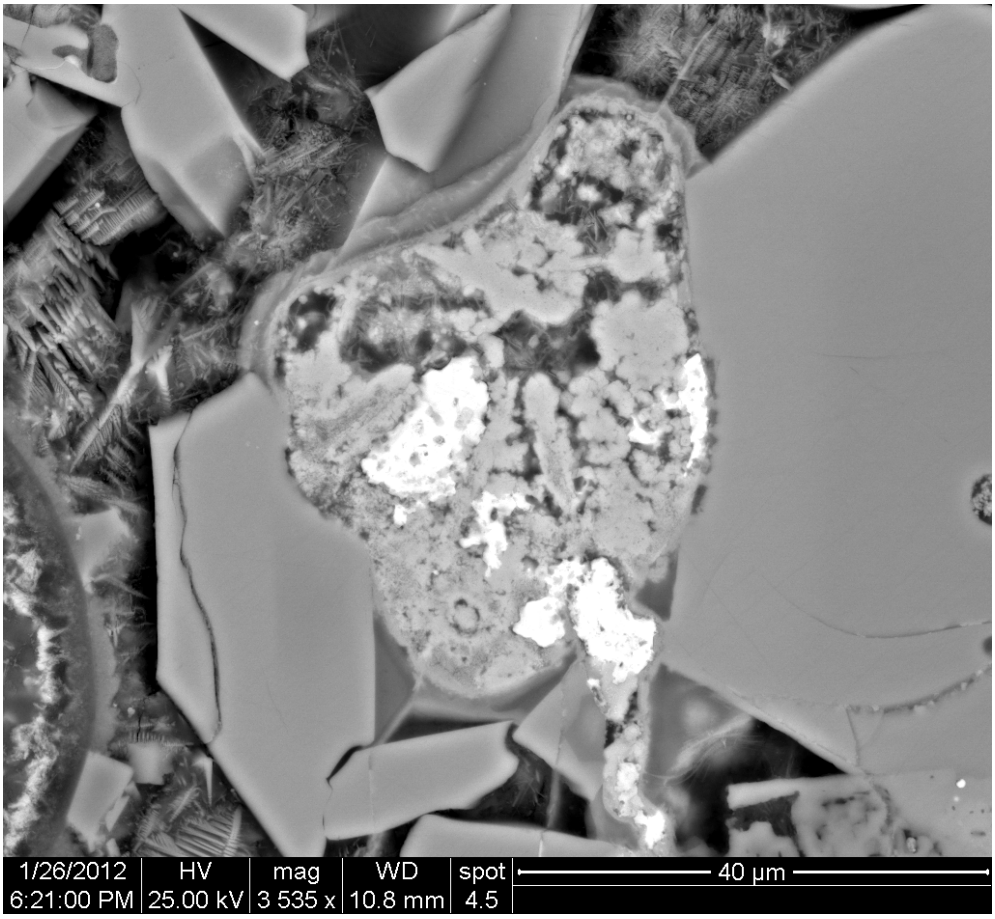
Image No. **1**



Site **step09**

Sample No. **105.6**

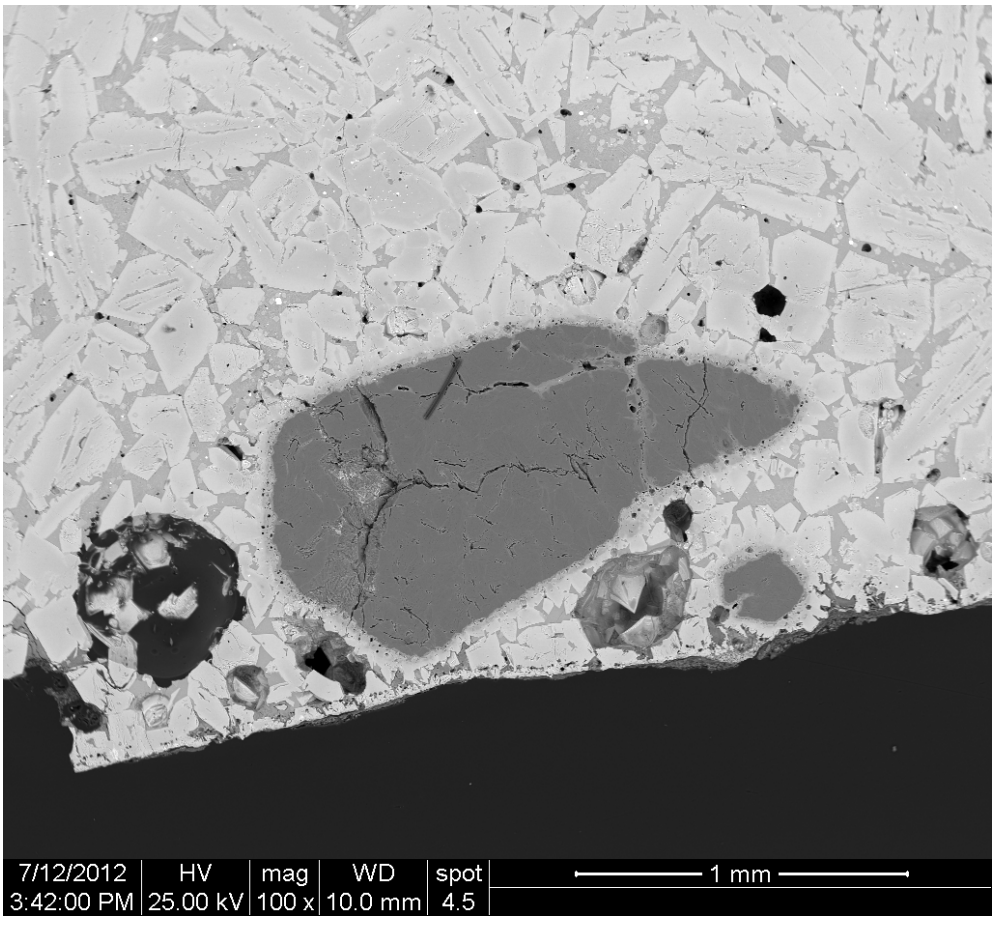
Image No. **2**



Site **step09**

Sample No. **1**

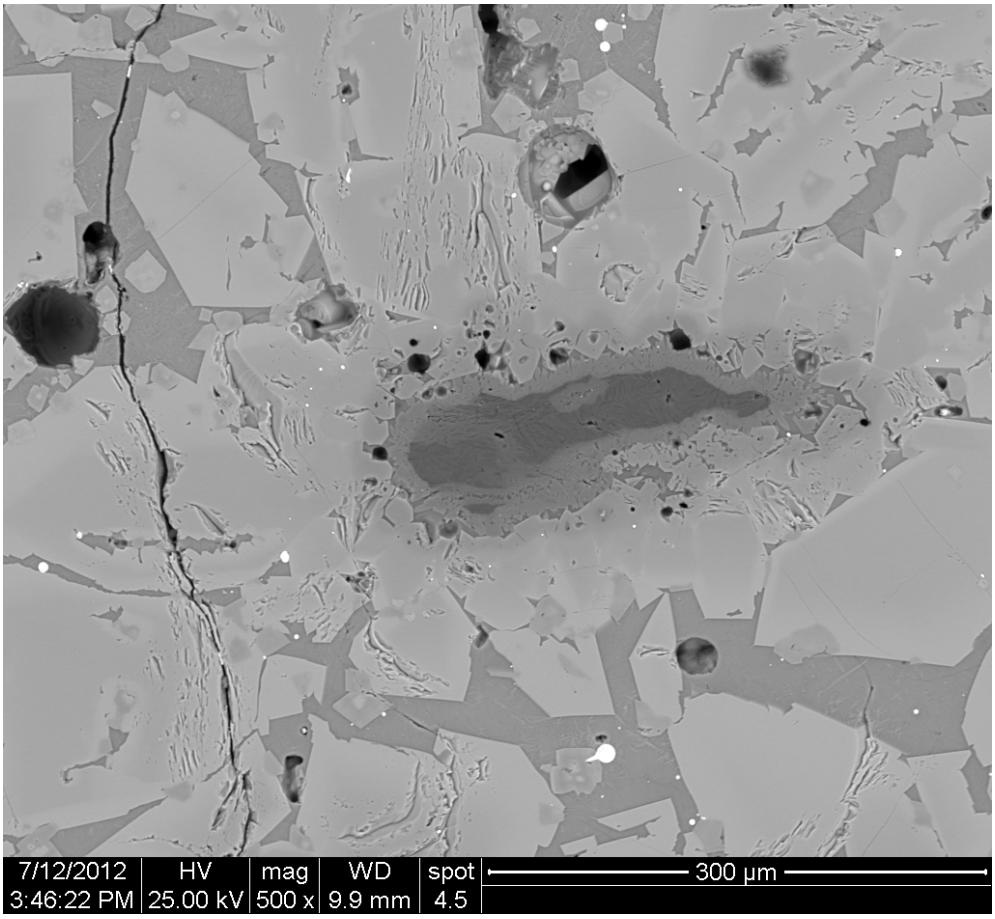
Image No. **1**



Site **step09**

Sample No. **1**

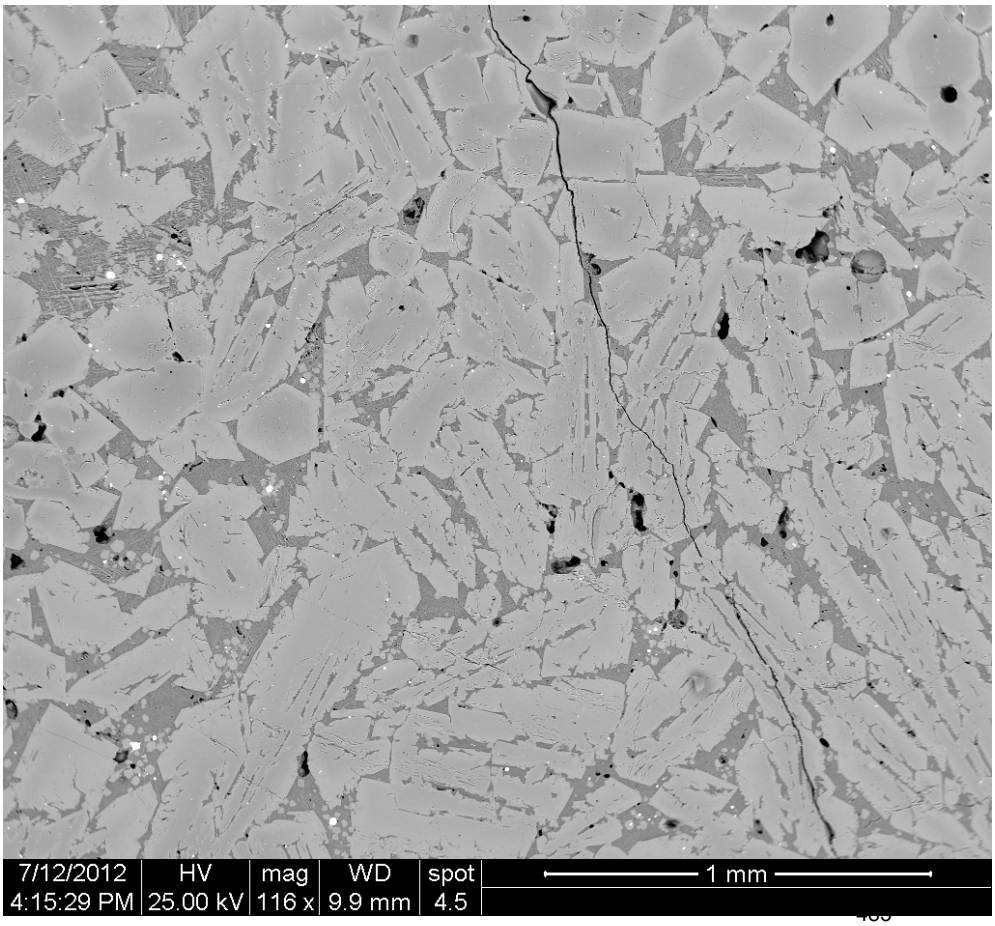
Image No. **2**



Site **step09**

Sample No. **1**

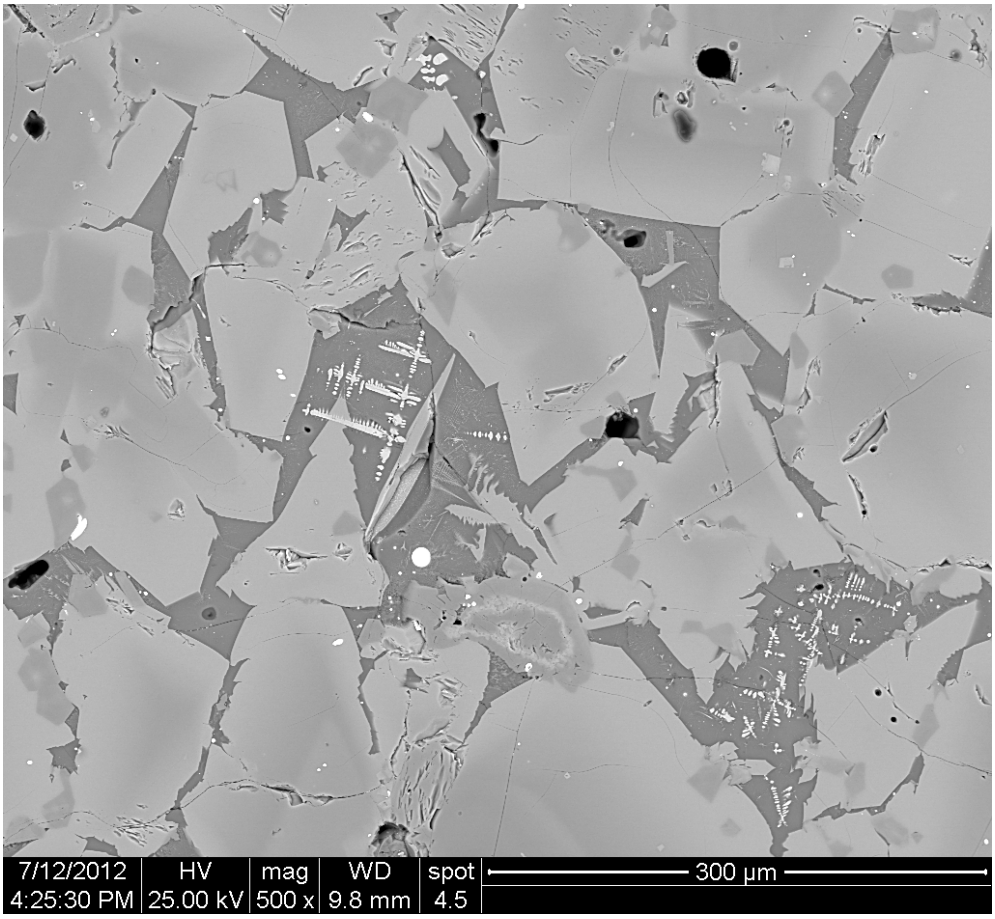
Image No. **3**



Site **step09**

Sample No. **1**

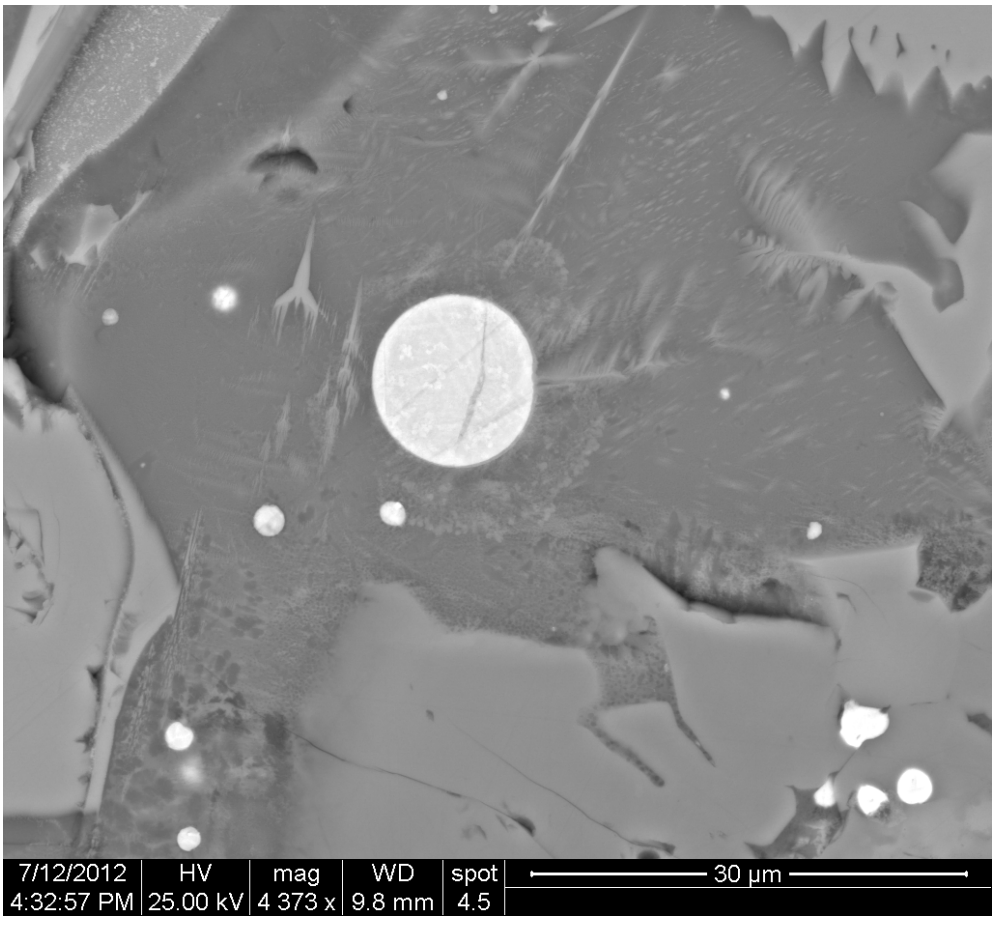
Image No. **4**



Site **step09**

Sample No. **1**

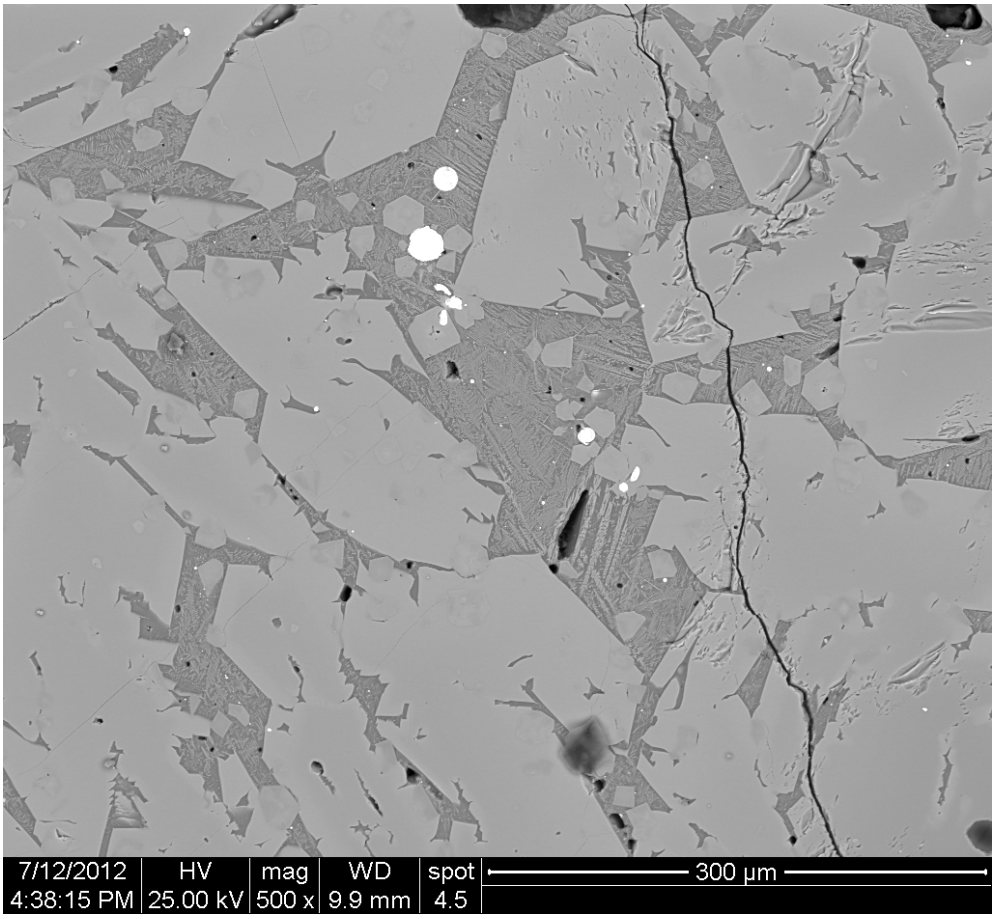
Image No. **5**



Site **step09**

Sample No. **1**

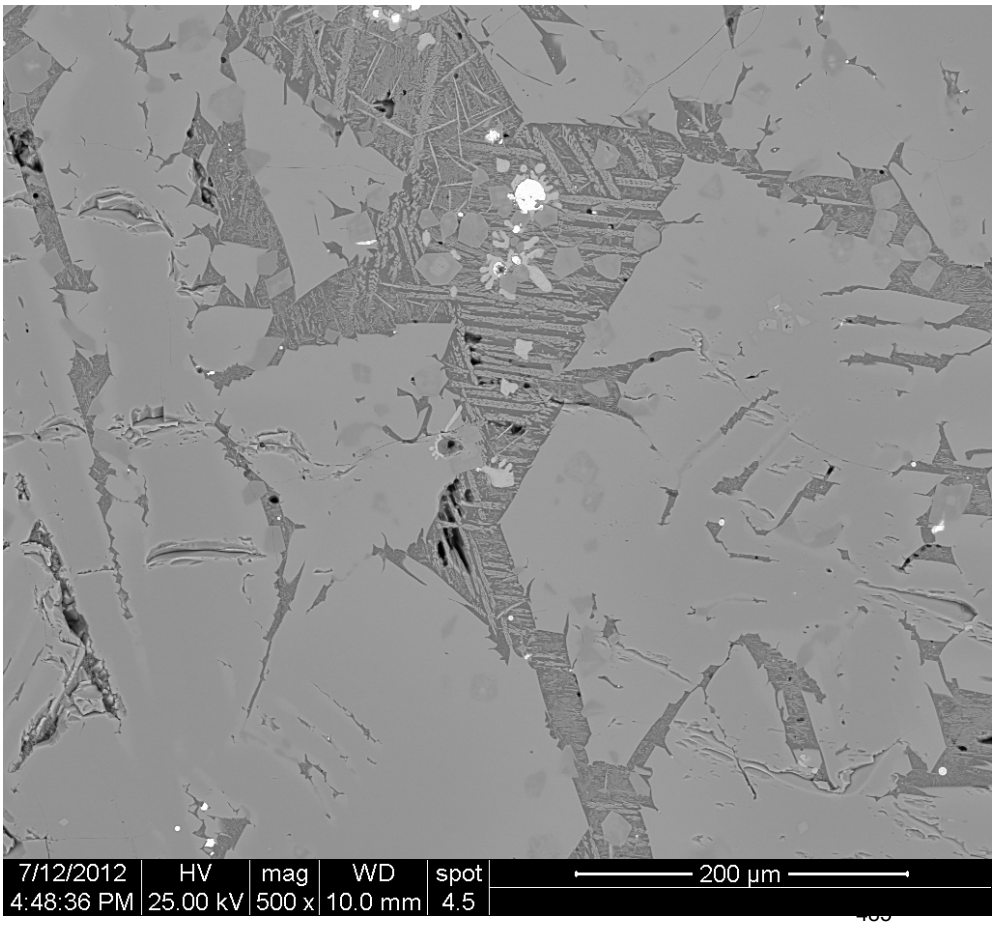
Image No. **6**



Site **step09**

Sample No. **1**

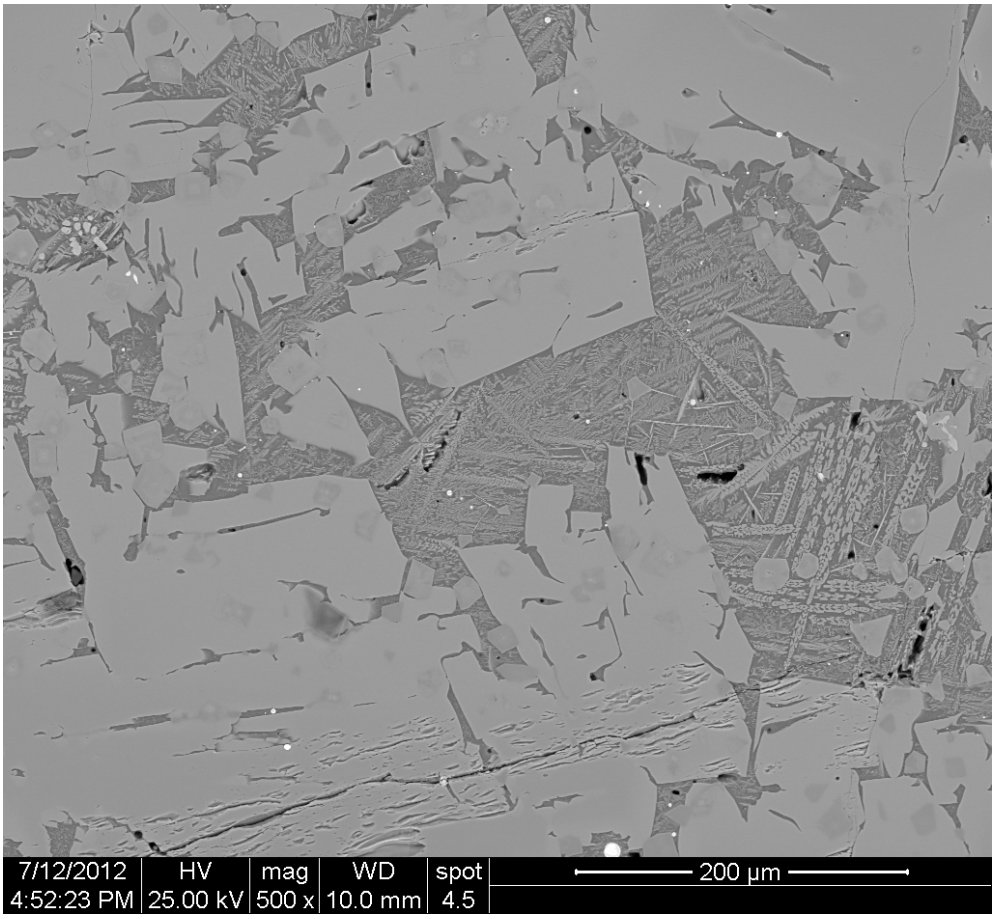
Image No. **7**



Site **step09**

Sample No. **1**

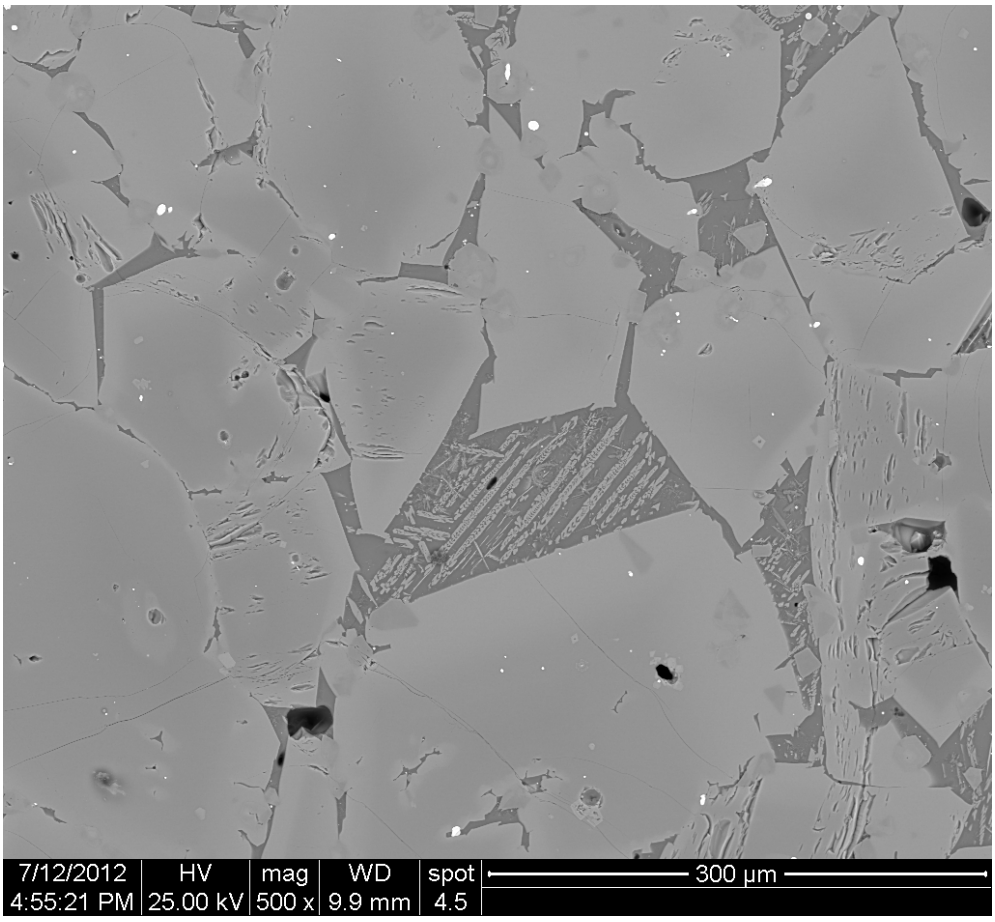
Image No. **8**



Site **step09**

Sample No. **1**

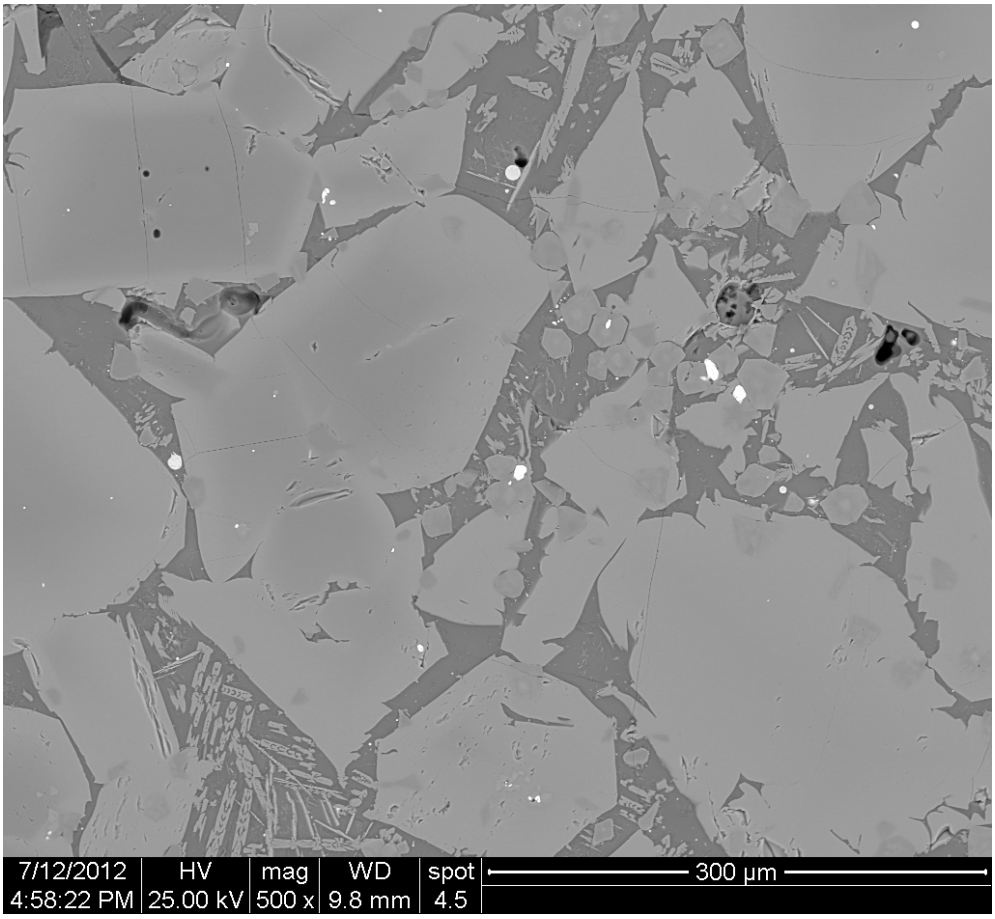
Image No. **9**



Site **step09**

Sample No. **1**

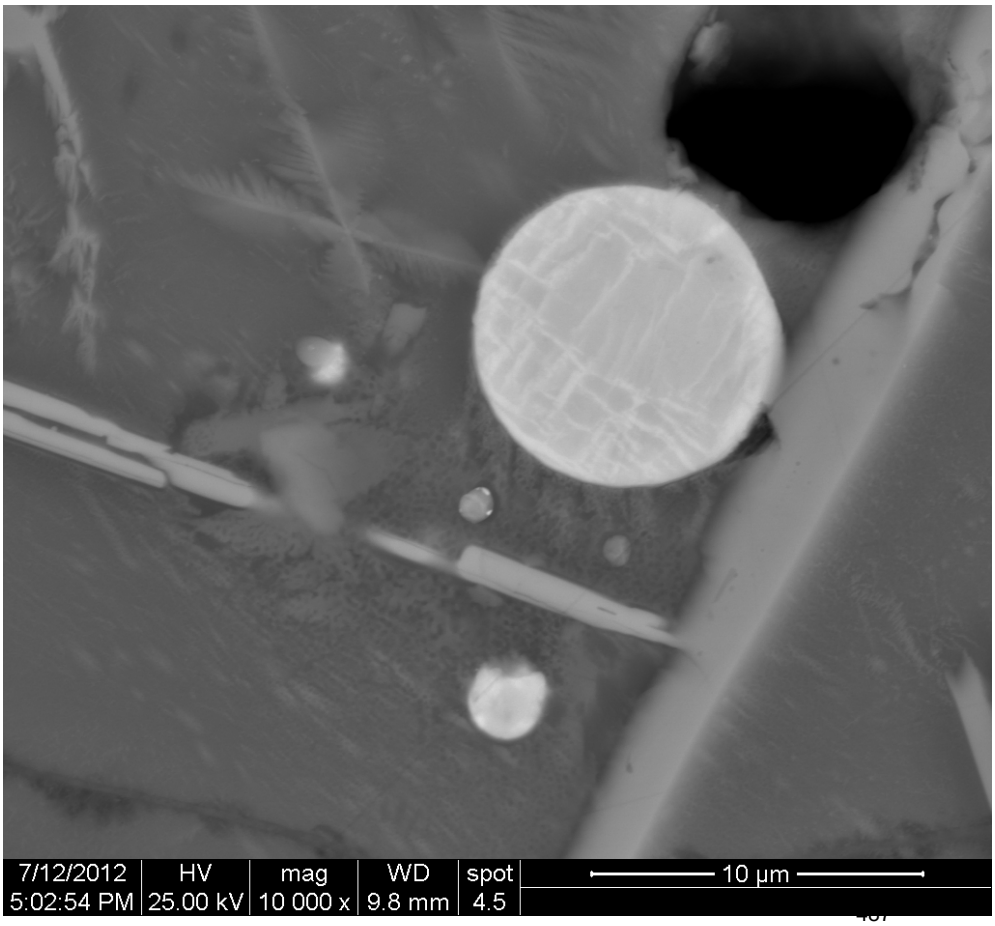
Image No. **10**



Site **step09**

Sample No. **1**

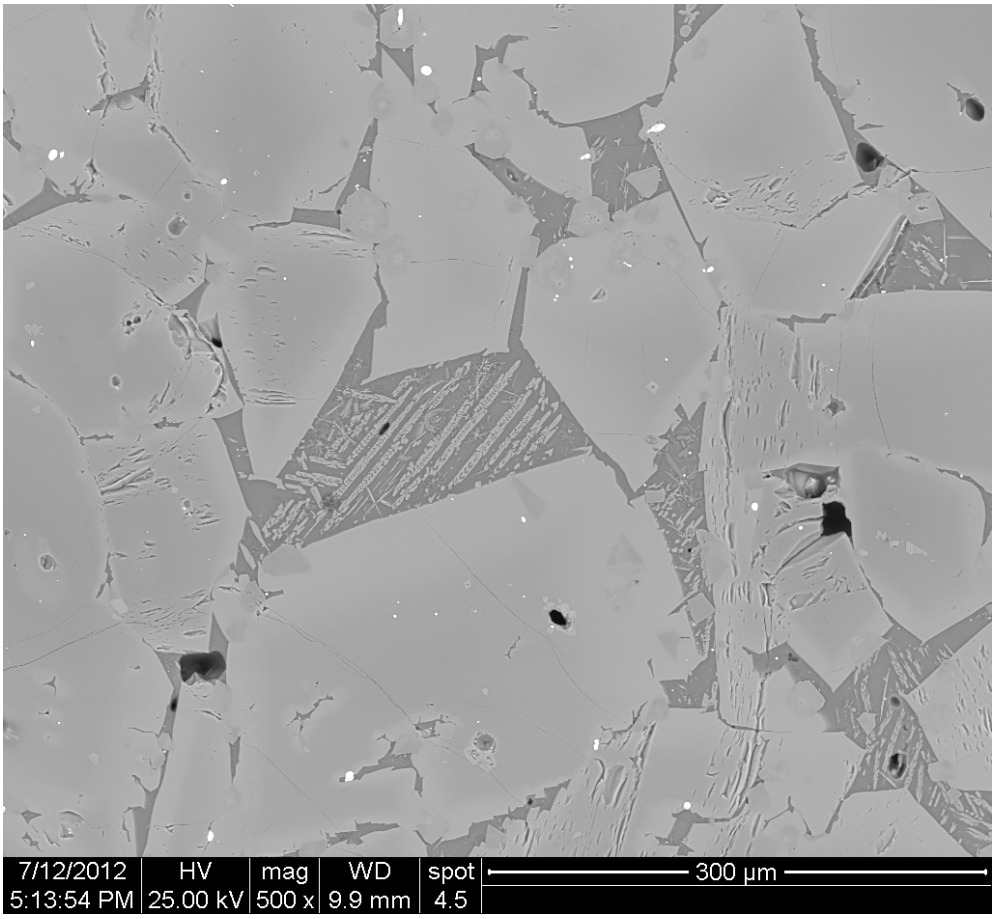
Image No. **11**



Site **step09**

Sample No. **1**

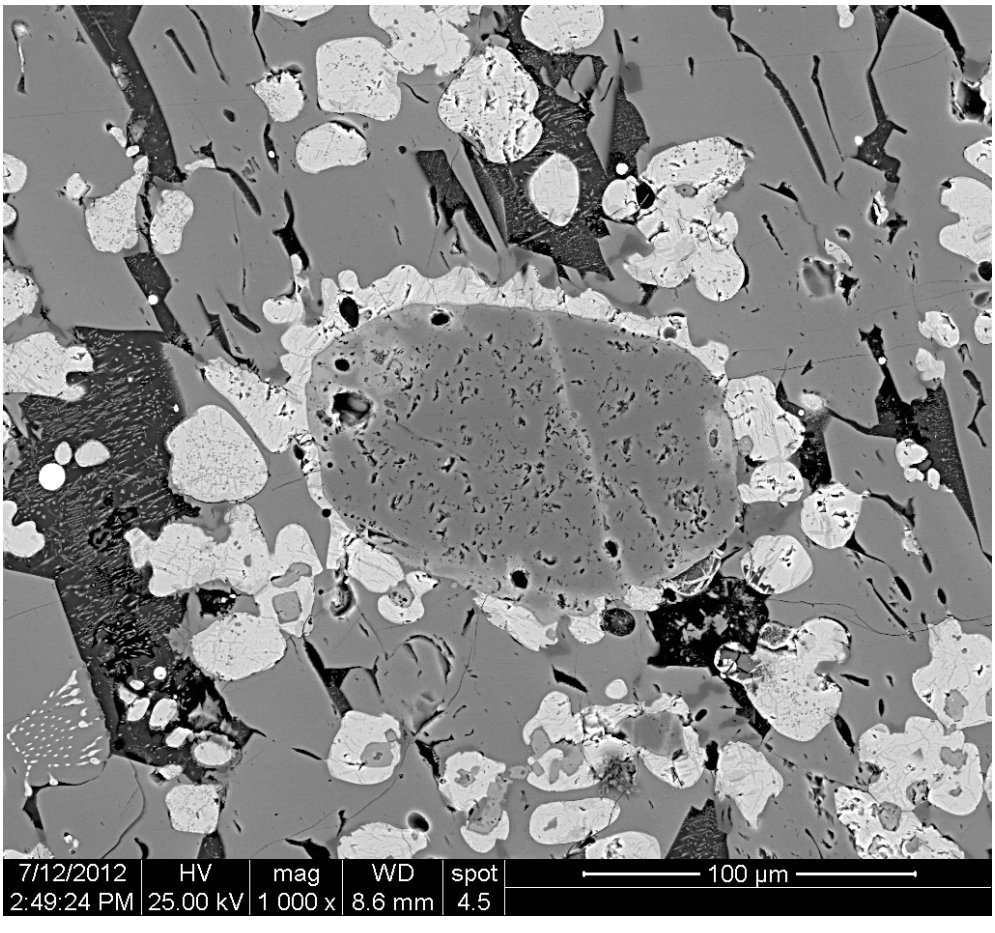
Image No. **12**



Site **step09**

Sample No. **32**

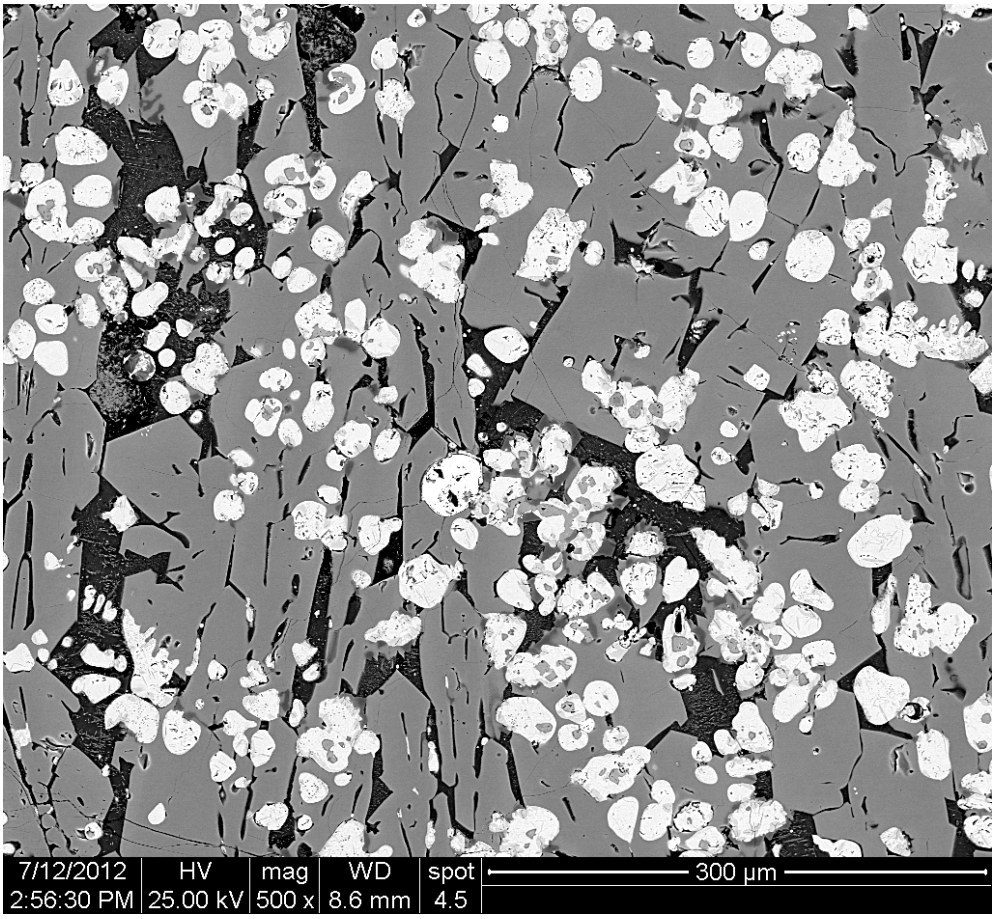
Image No. **1**



Site **step09**

Sample No. **32**

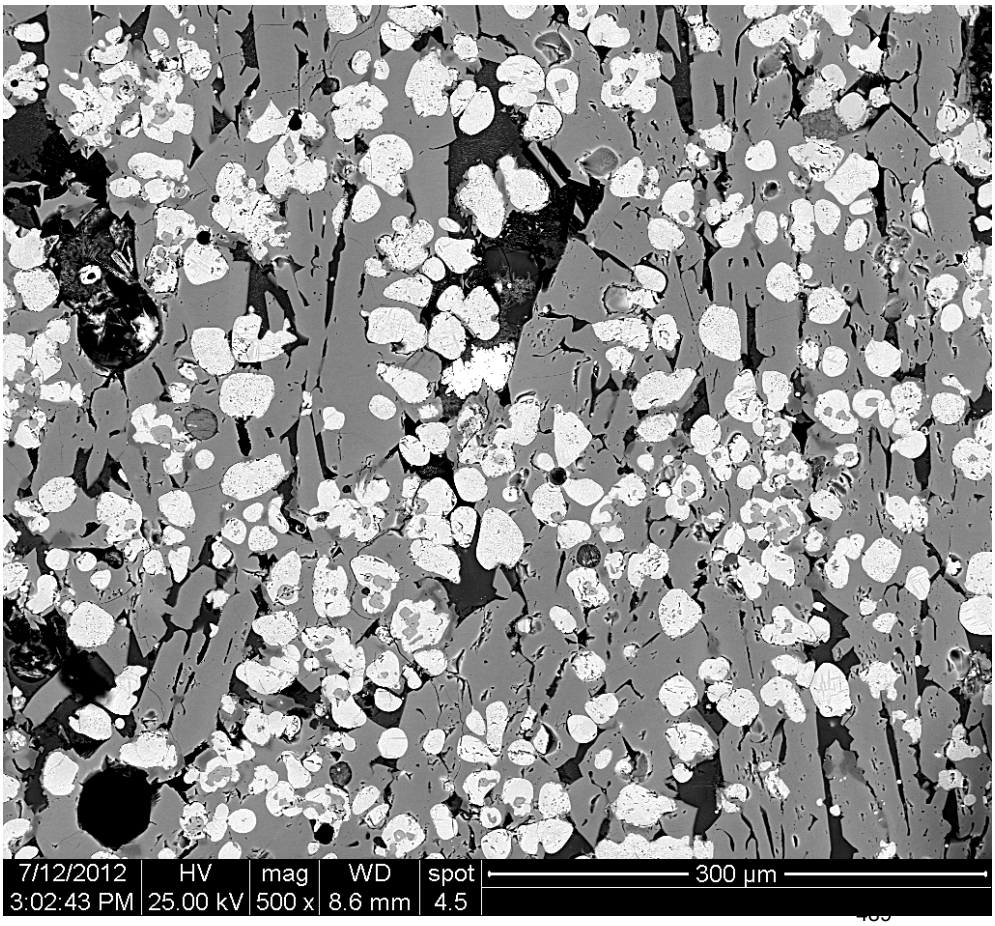
Image No. **2**



Site **step09**

Sample No. **32**

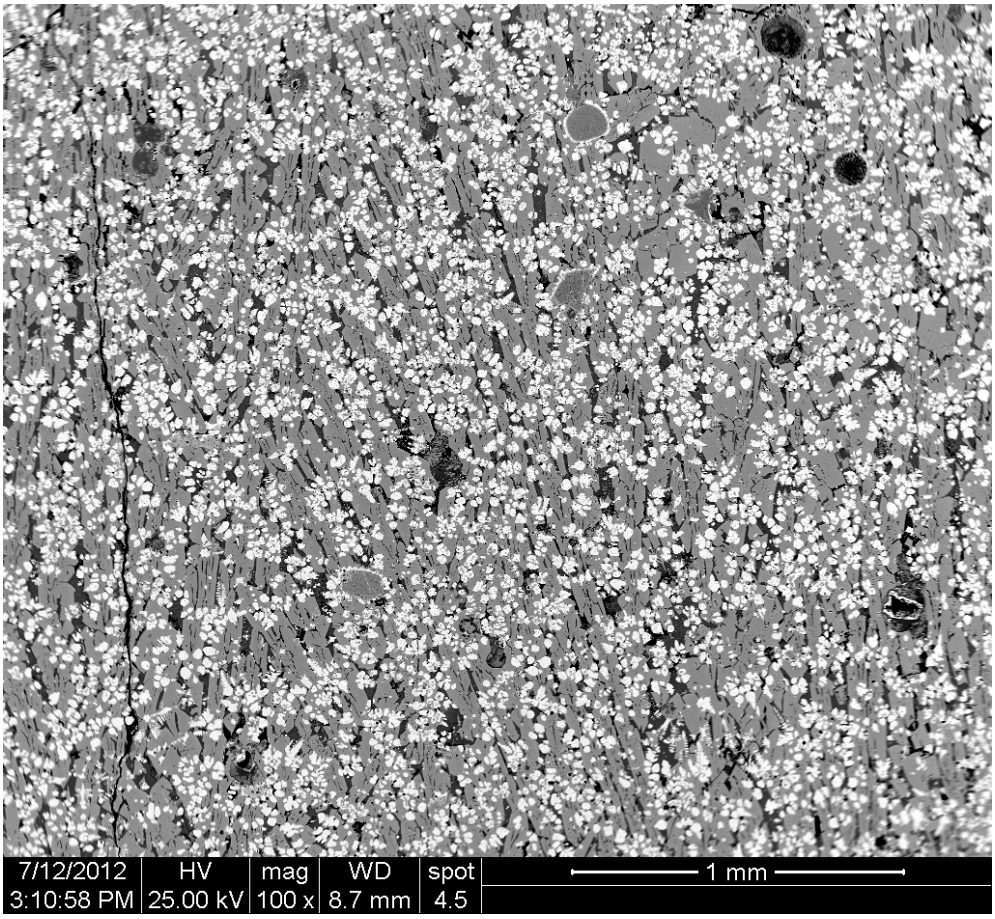
Image No. **3**



Site **step09**

Sample No. **32**

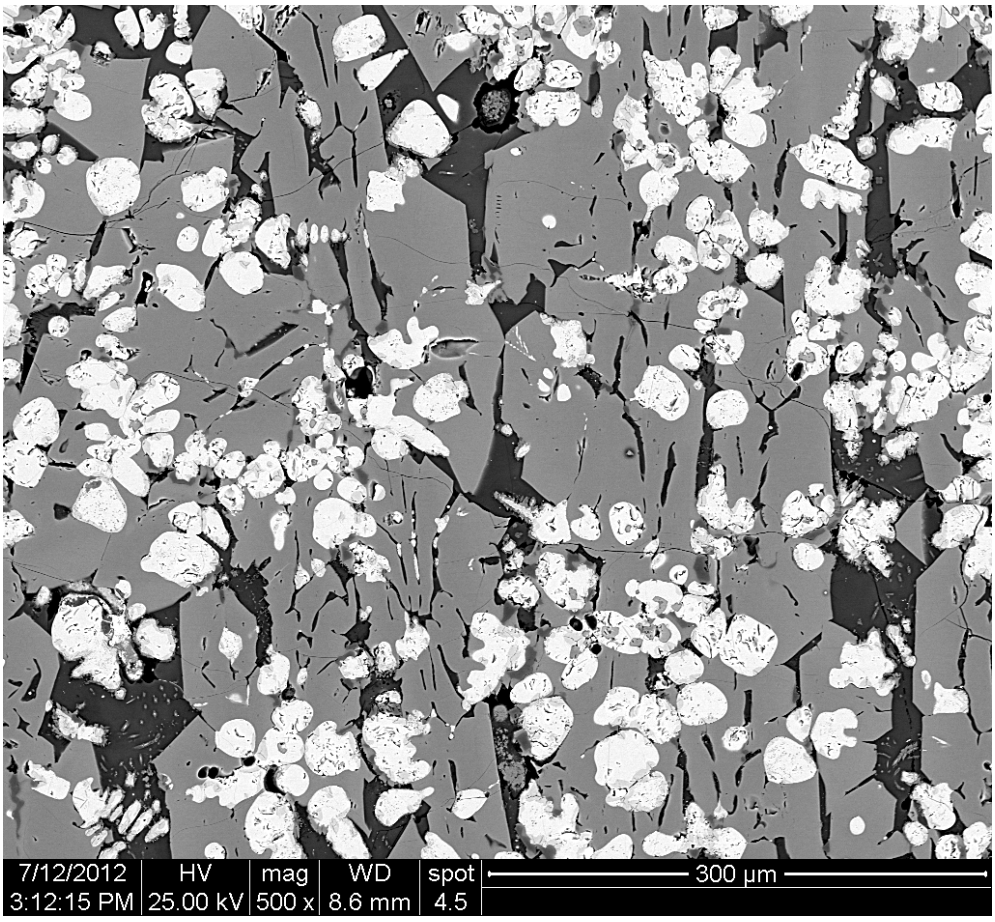
Image No. **4**



Site **step09**

Sample No. **32**

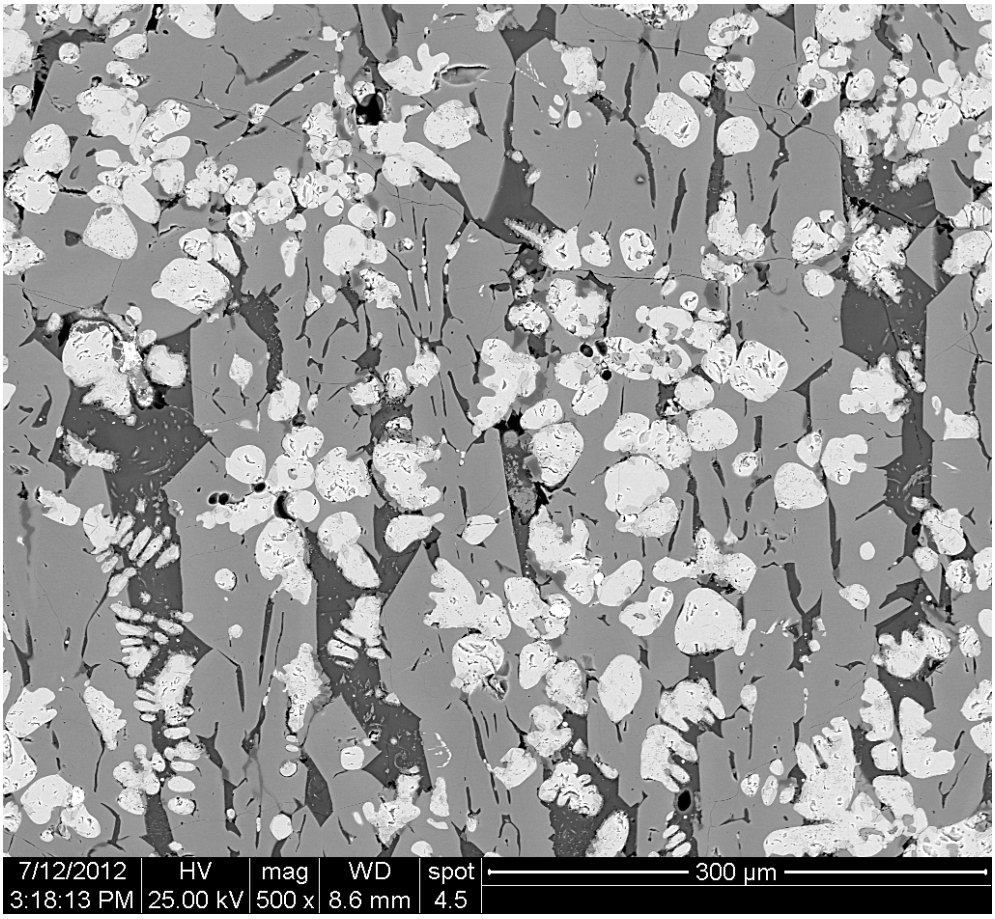
Image No. **5**



Site **step09**

Sample No. **32**

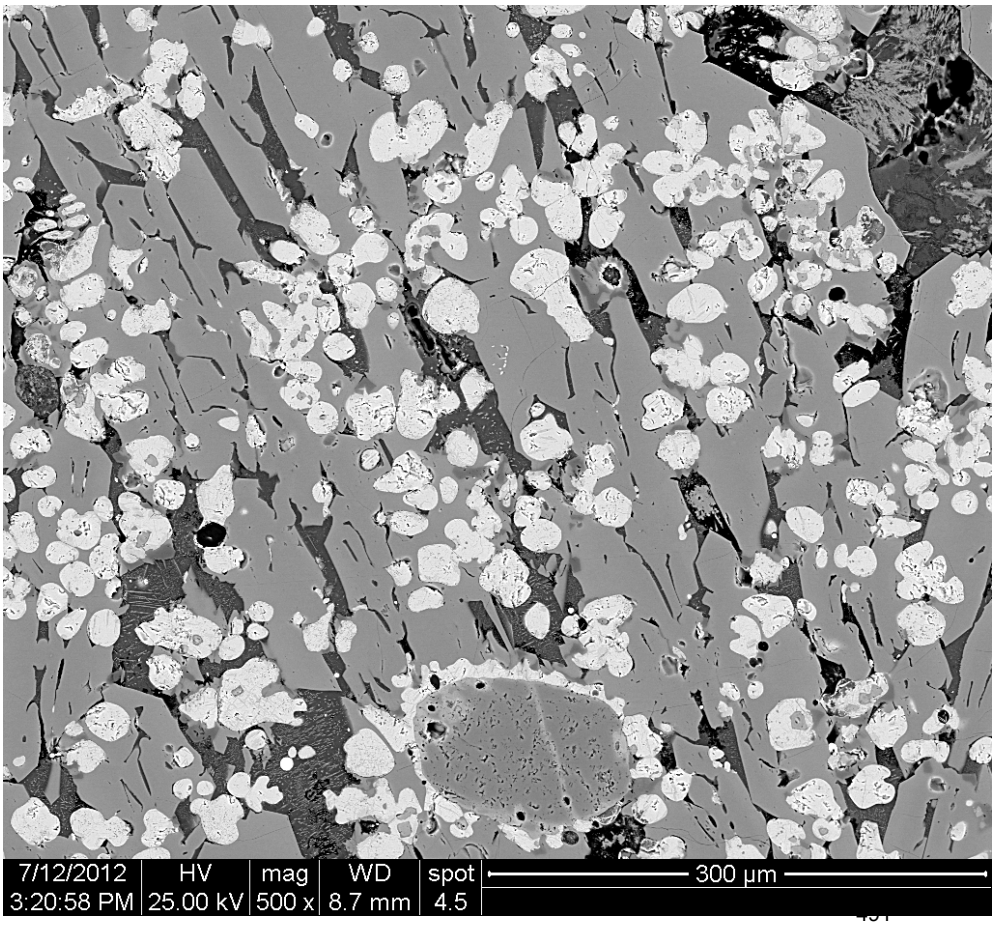
Image No. **6**



Site **step09**

Sample No. **32**

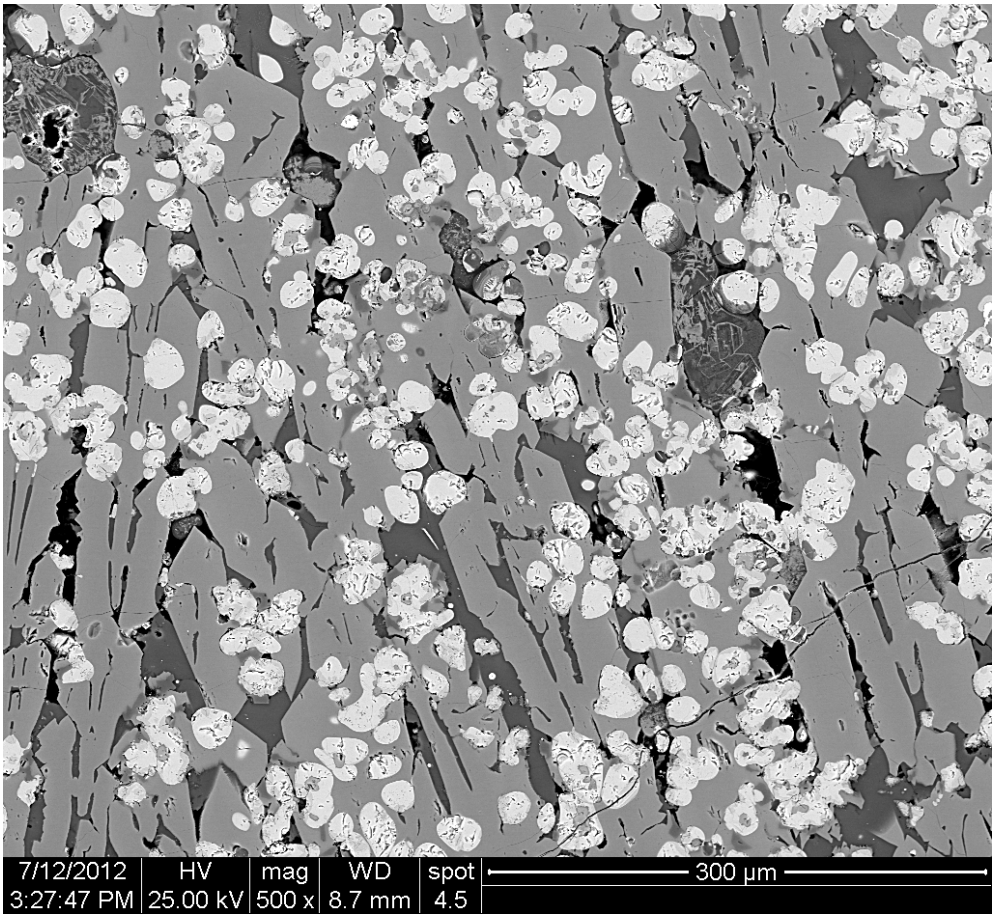
Image No. **7**



Site **step09**

Sample No. **32**

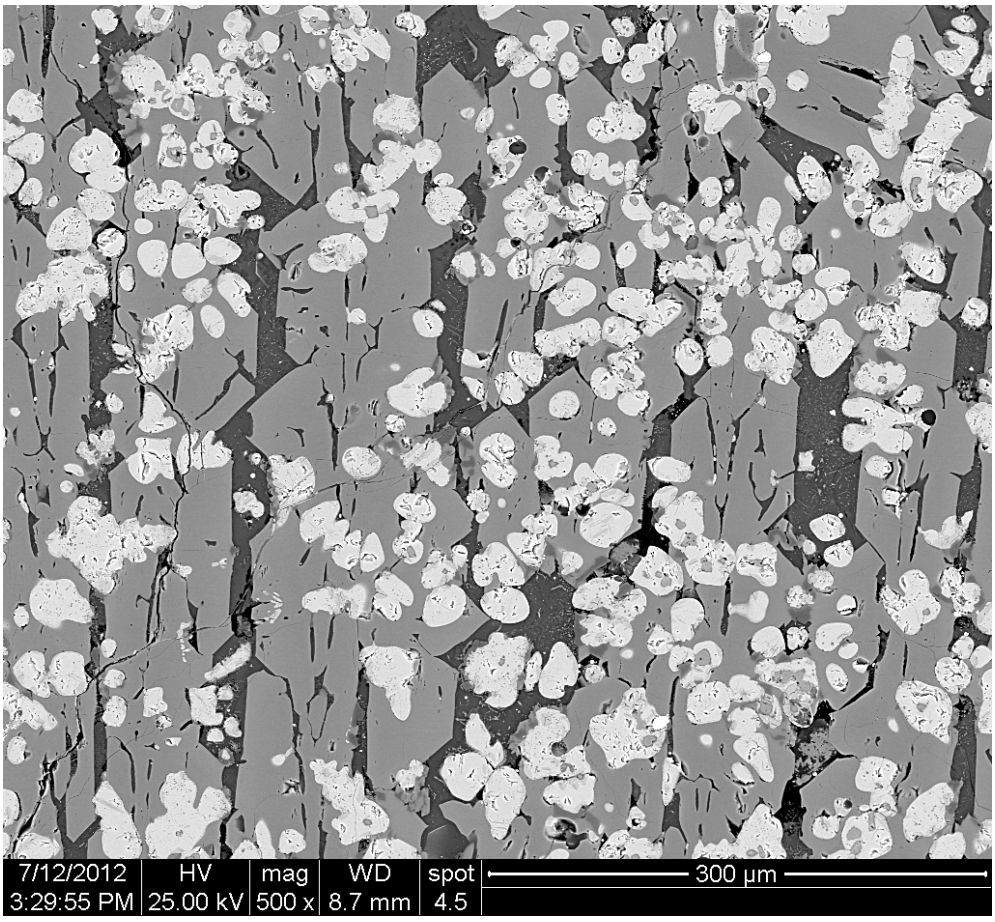
Image No. **9**



Site **step09**

Sample No. **32**

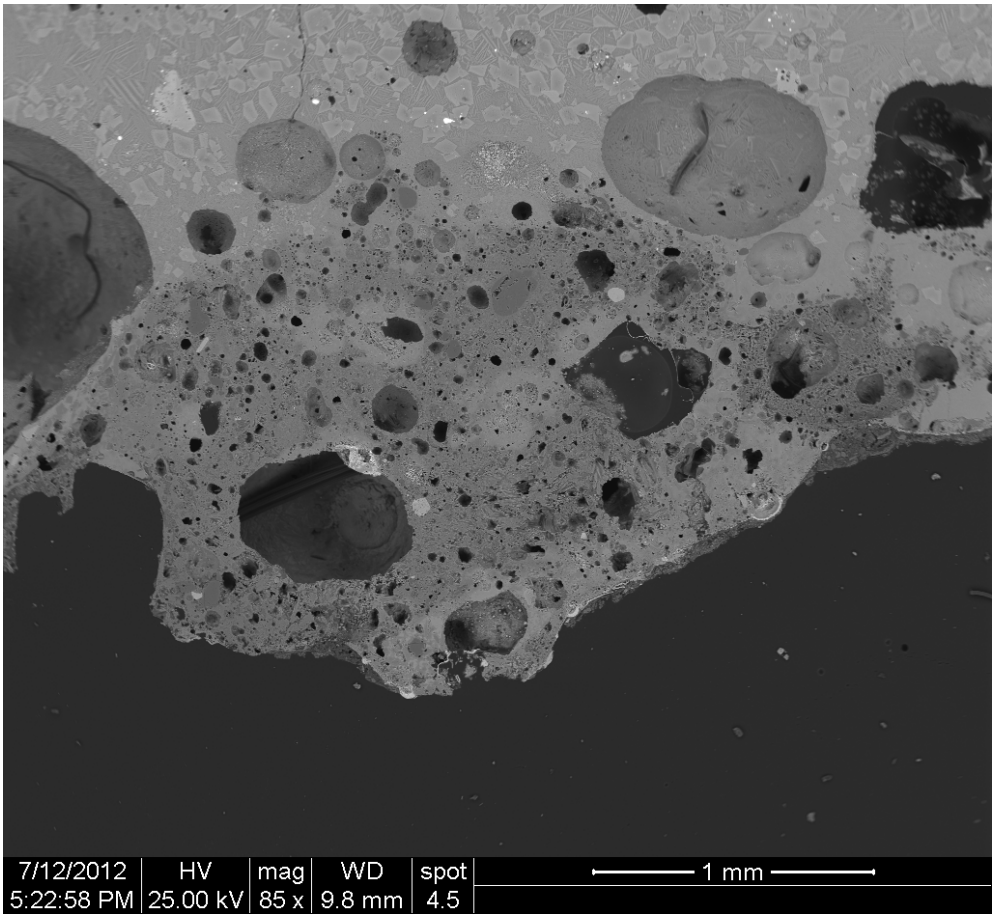
Image No. **10**



Site **step09**

Sample No. **64**

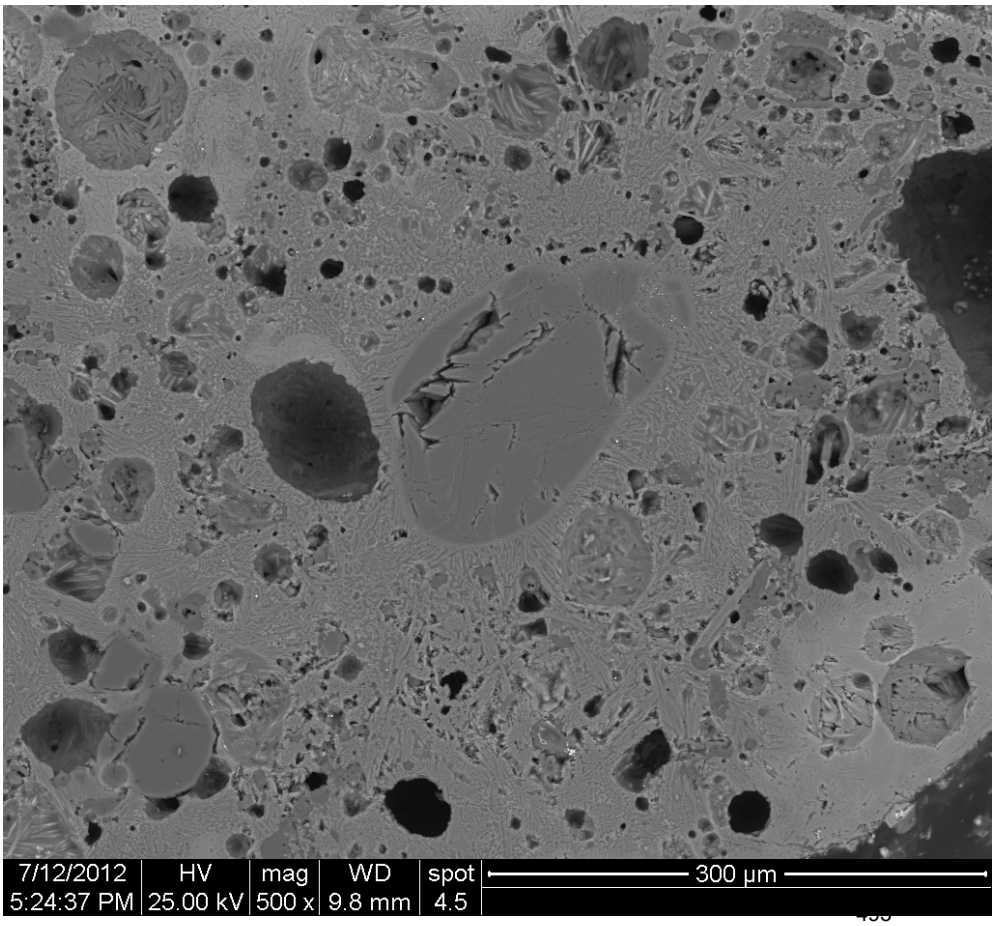
Image No. **1**



Site **step09**

Sample No. **64**

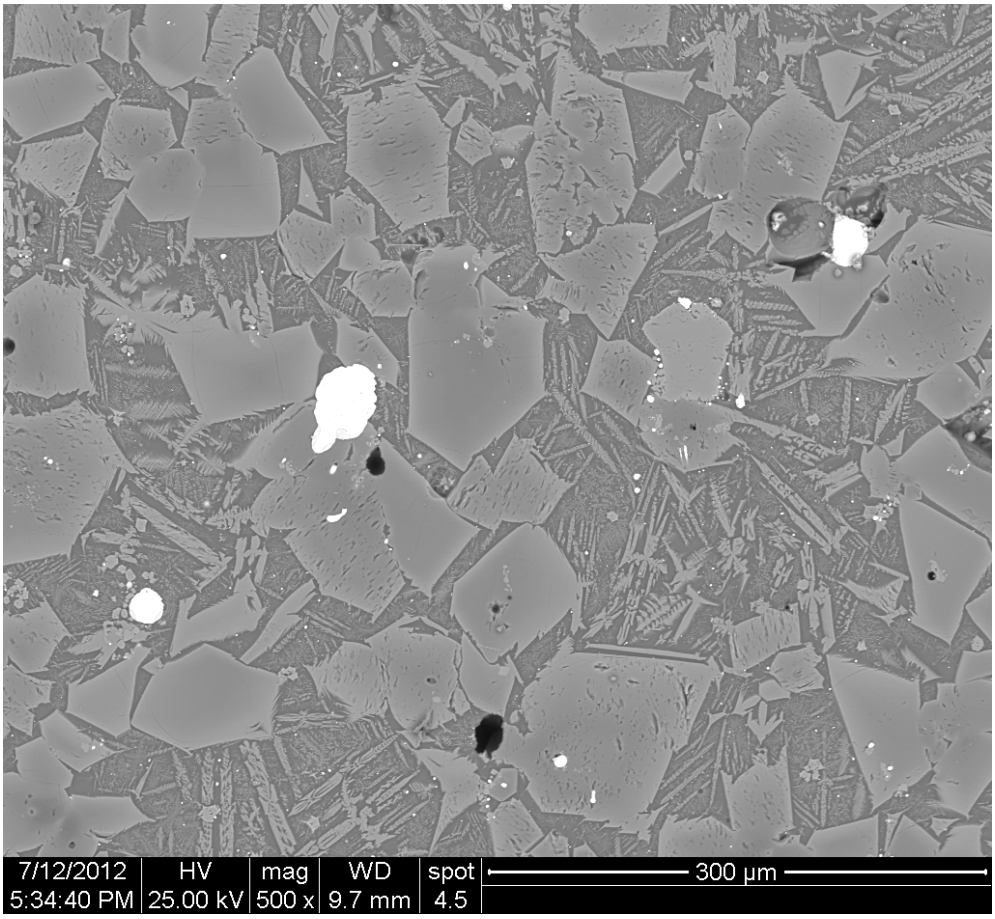
Image No. **2**



Site **step09**

Sample No. **64**

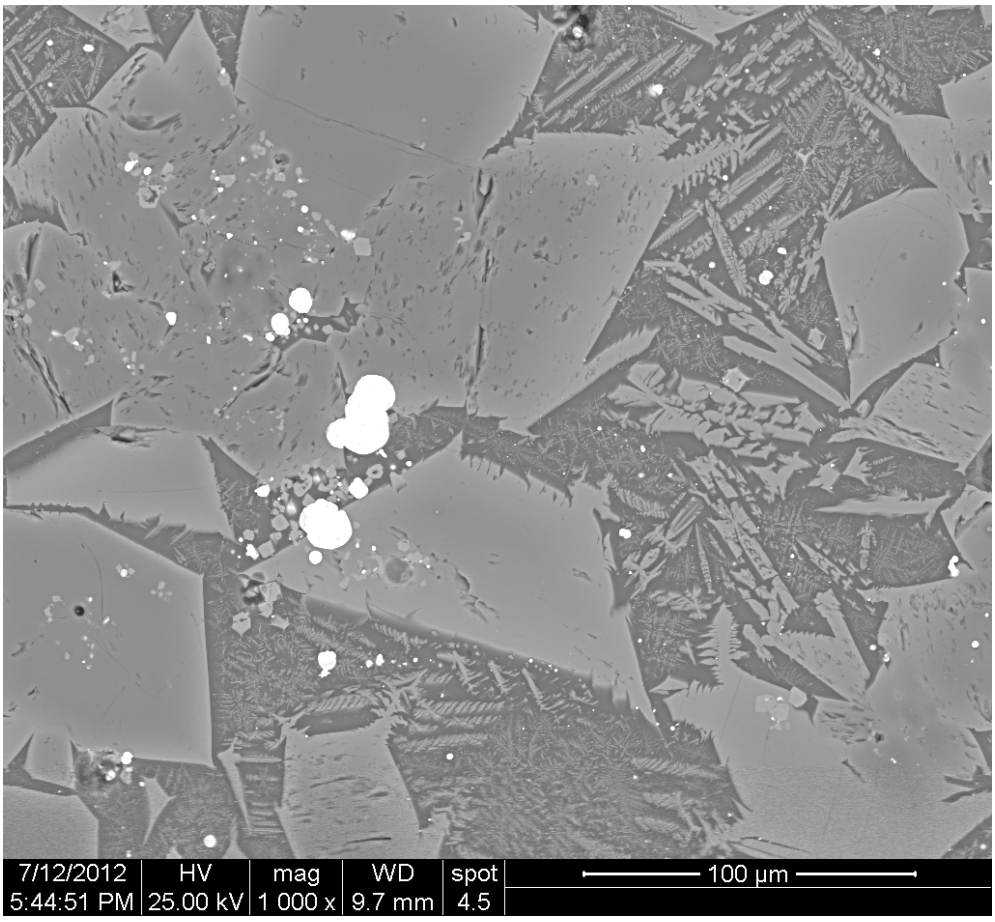
Image No. **3**



Site **step09**

Sample No. **64**

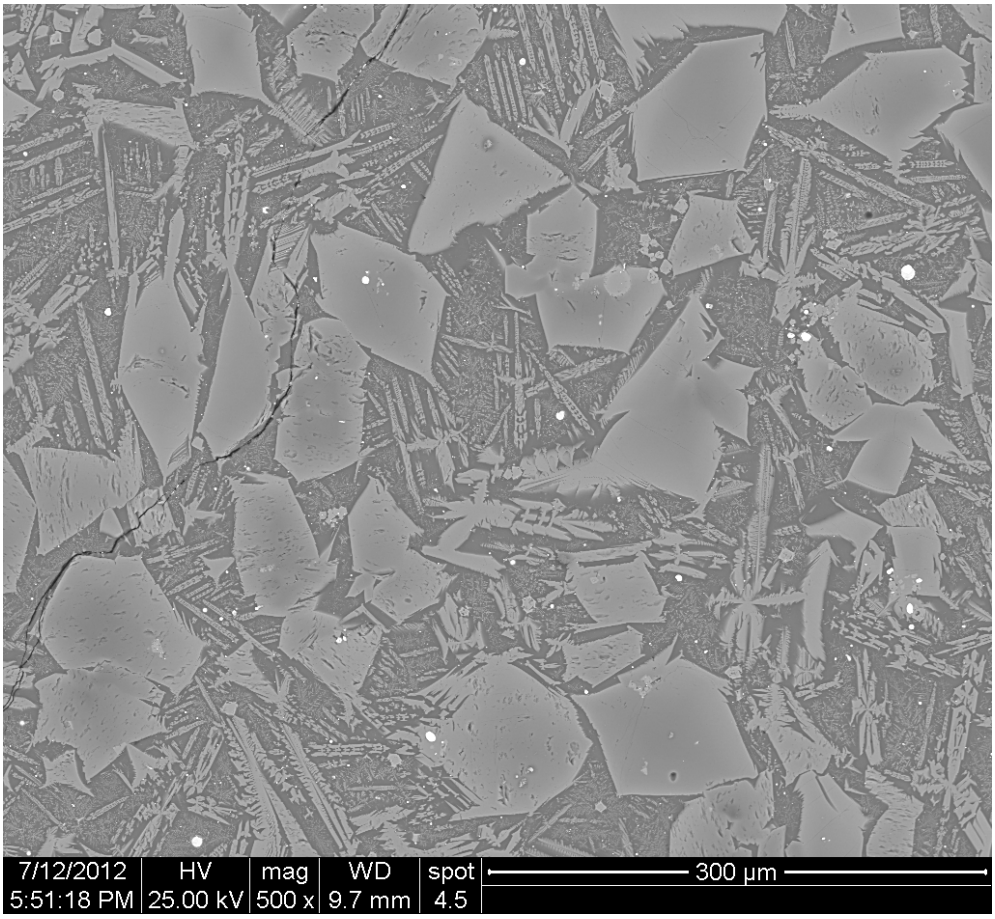
Image No. **4**



Site **step09**

Sample No. **64**

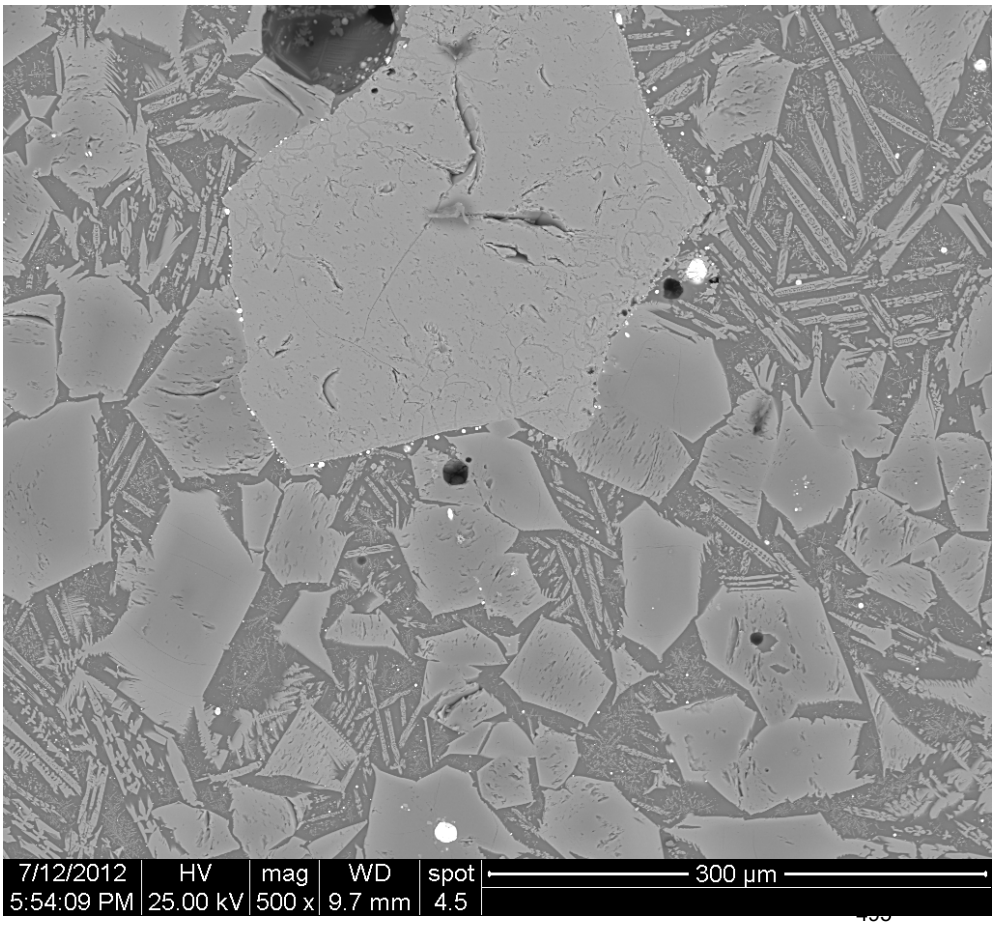
Image No. **5**



Site **step09**

Sample No. **64**

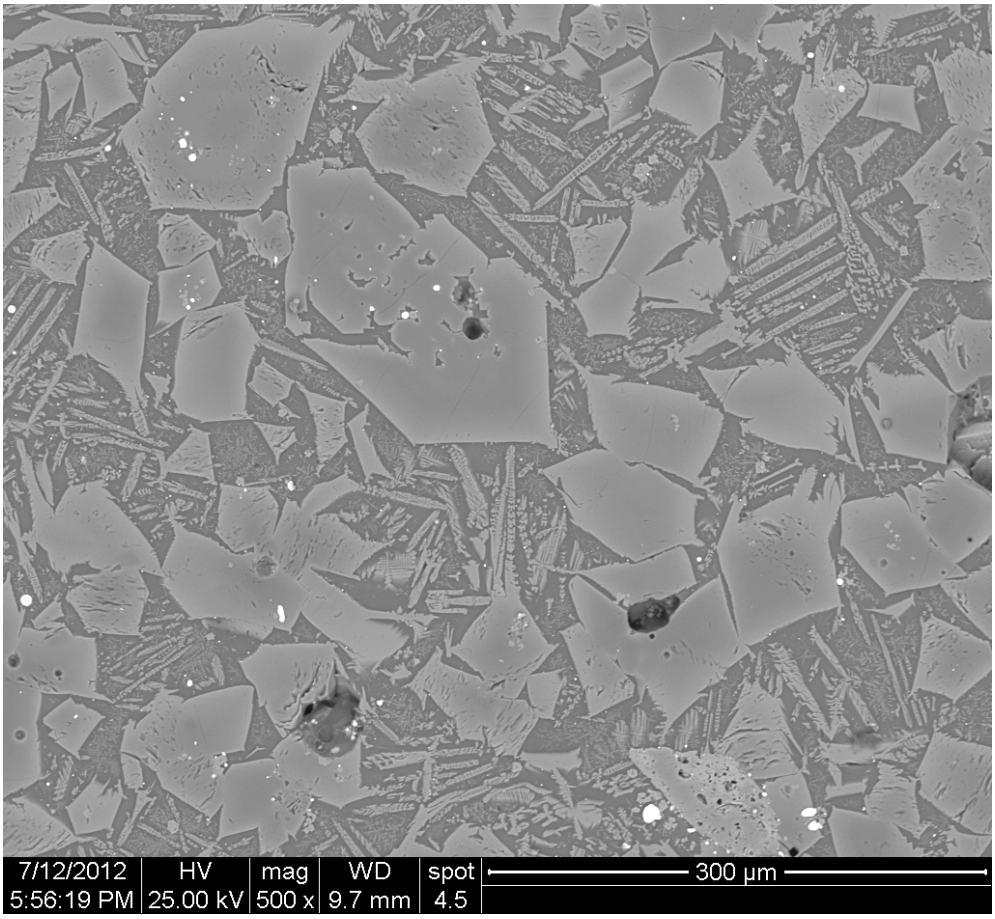
Image No. **6**



Site **step09**

Sample No. **64**

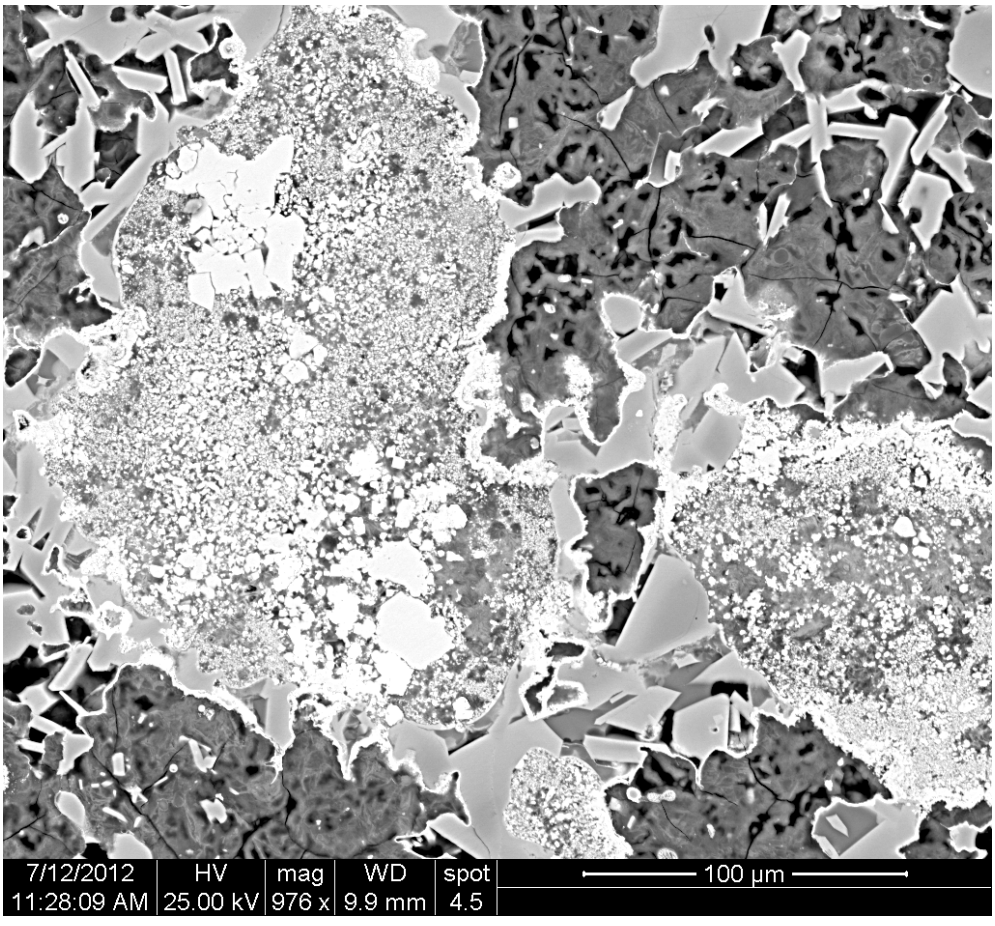
Image No. **7**



Site **step09**

Sample No. **105.2**

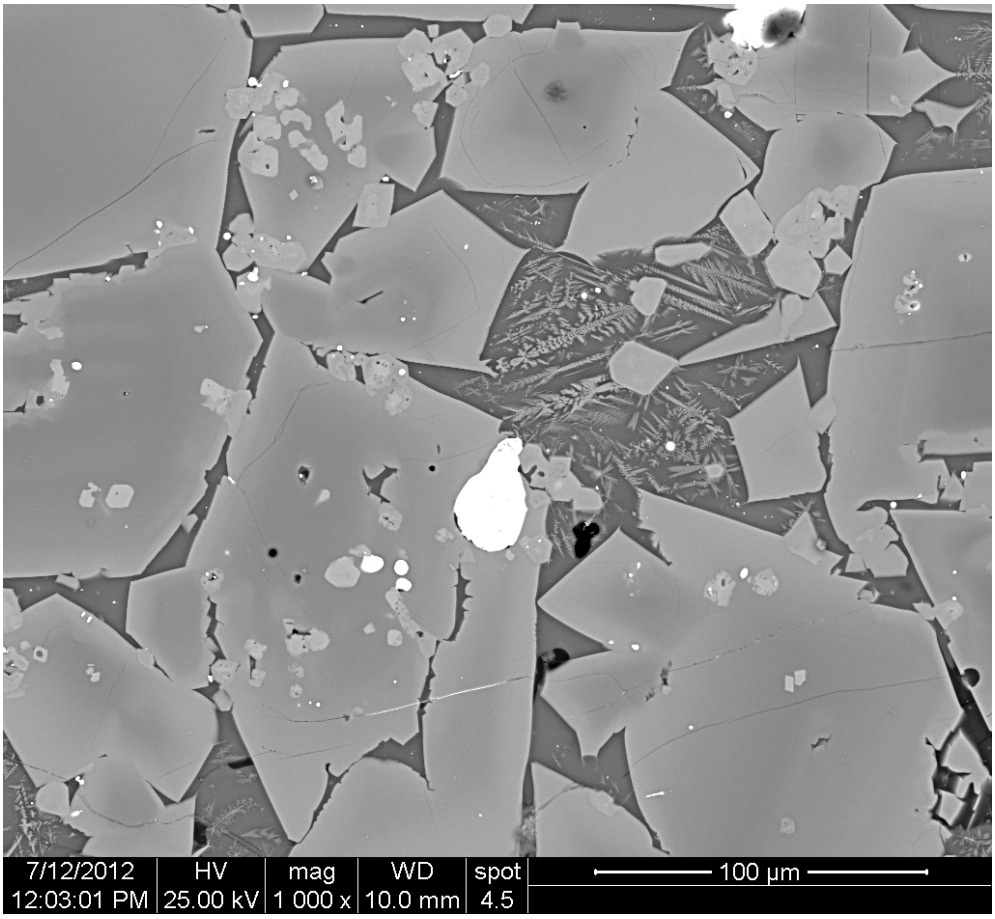
Image No. **1**



Site **step09**

Sample No. **105.2**

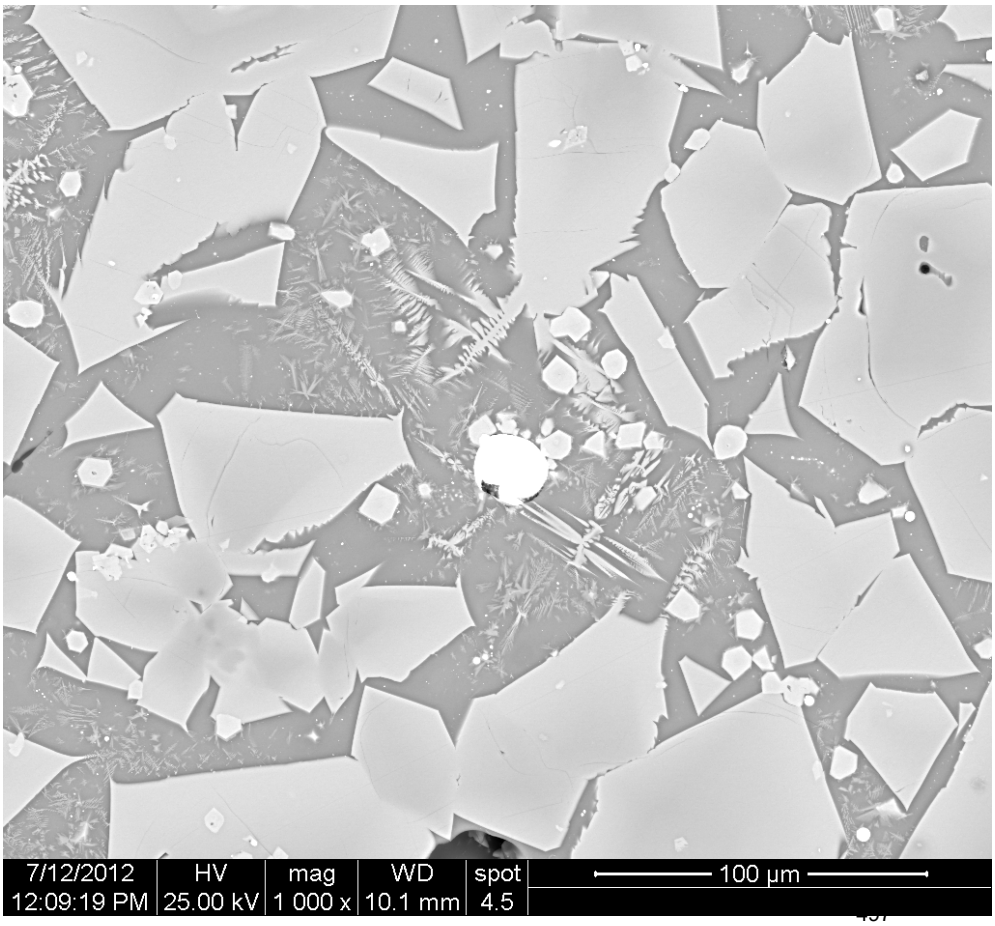
Image No. **2**



Site **step09**

Sample No. **105.2**

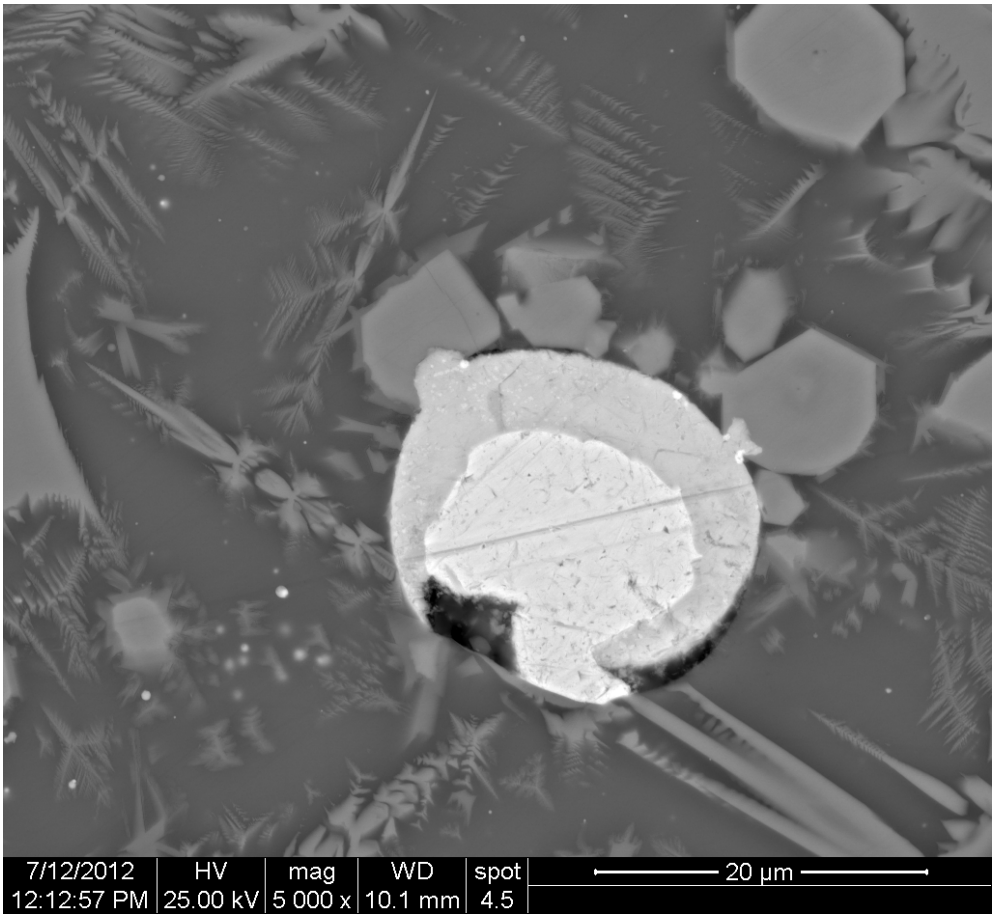
Image No. **3**



Site **step09**

Sample No. **105.2**

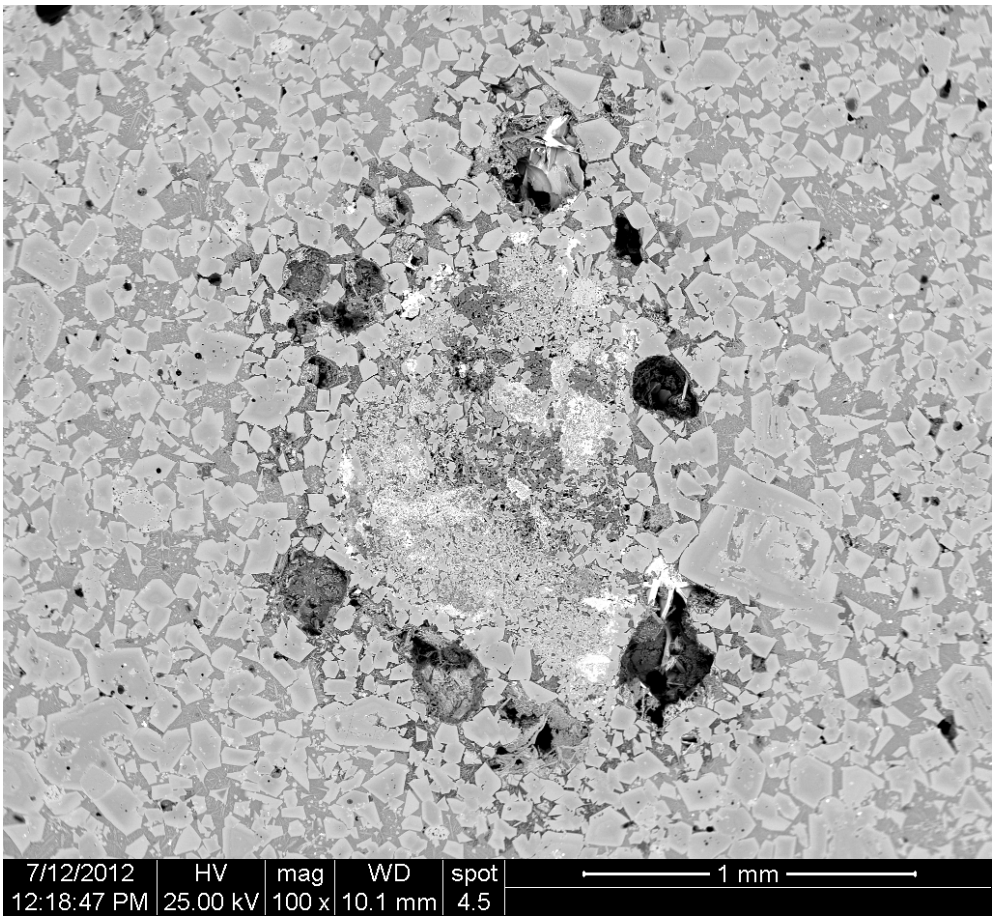
Image No. **4**



Site **step09**

Sample No. **105.2**

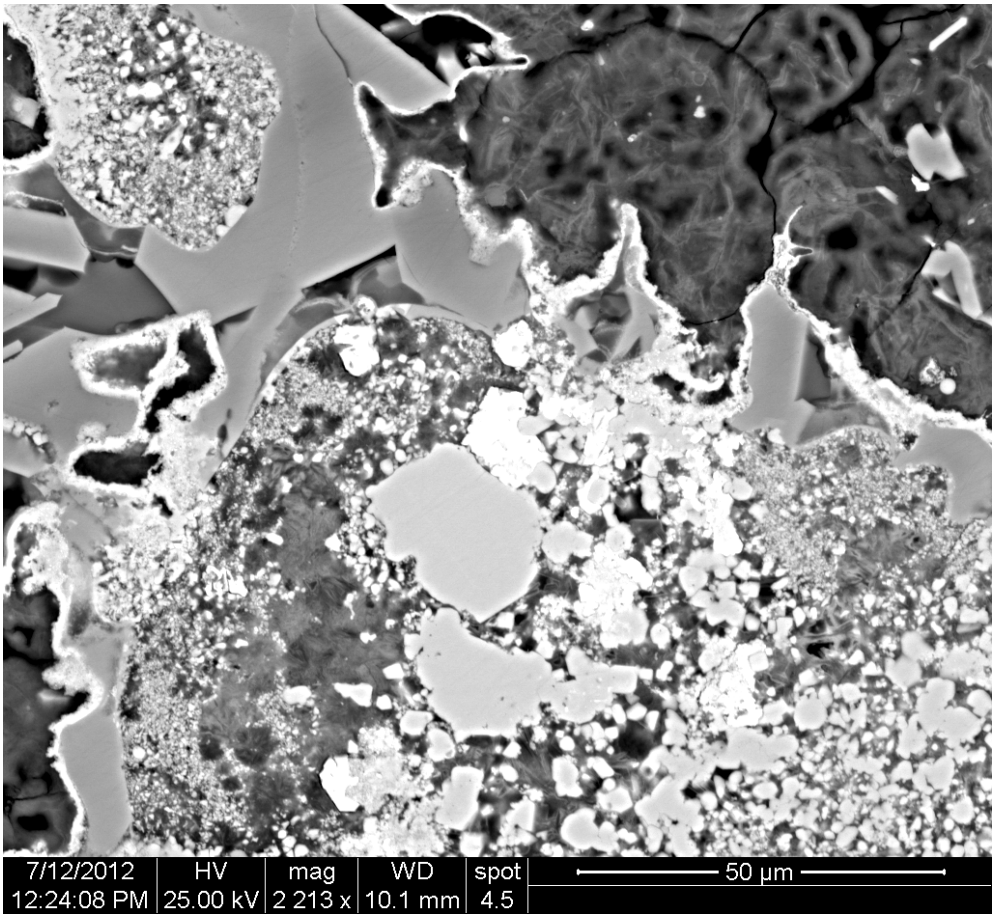
Image No. **5**



Site **step09**

Sample No. **105.2**

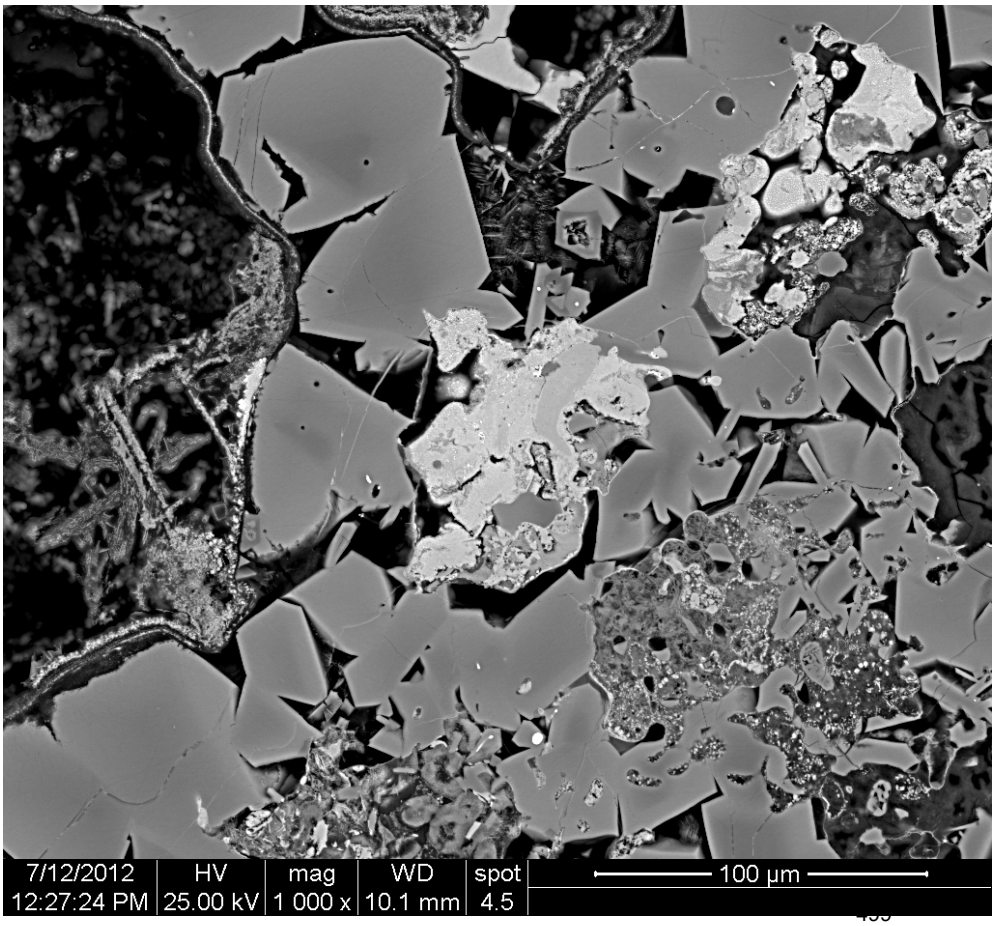
Image No. **6**



Site **step09**

Sample No. **105.2**

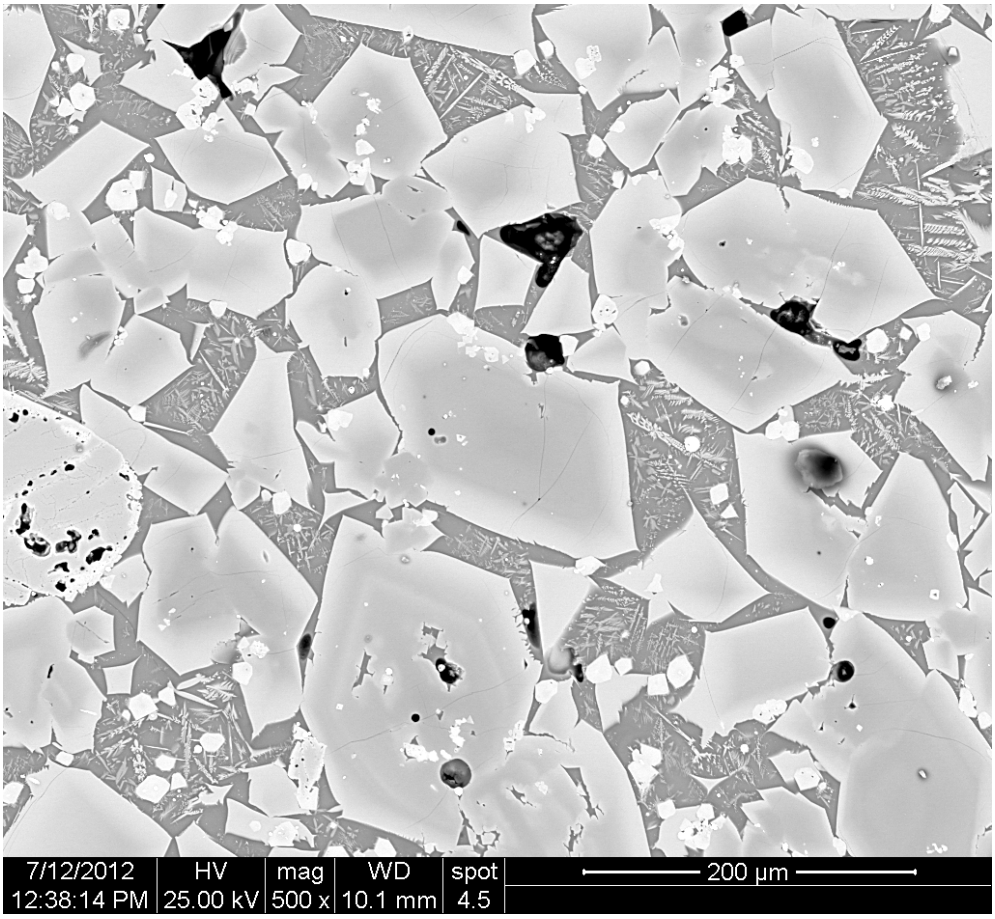
Image No. **7**



Site **step09**

Sample No. **105.2**

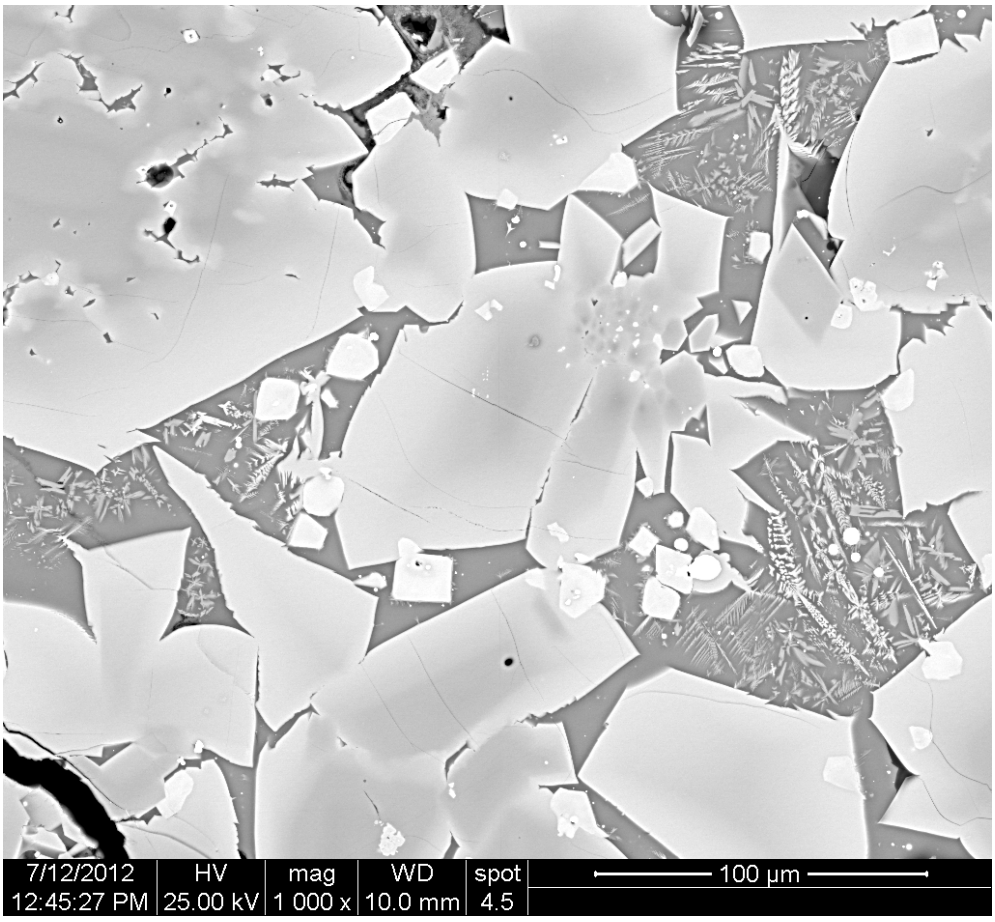
Image No. **8**



Site **step09**

Sample No. **105.2**

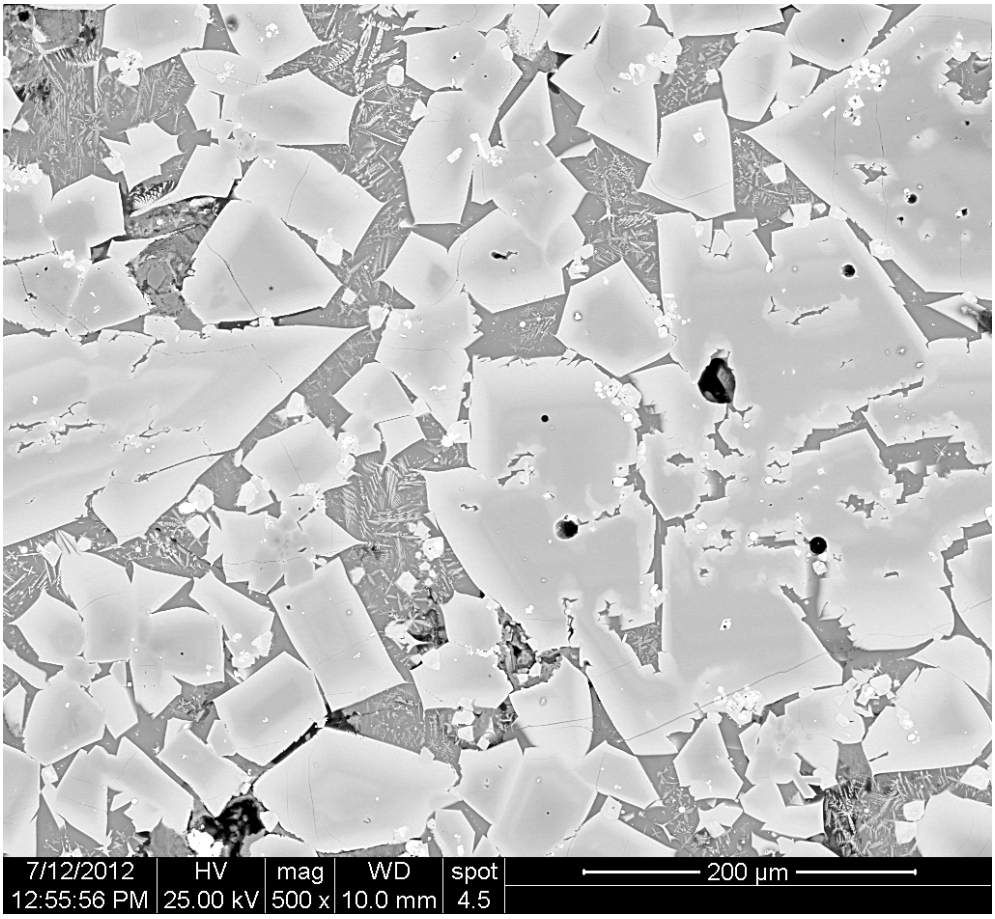
Image No. **9**



Site **step09**

Sample No. **105.2**

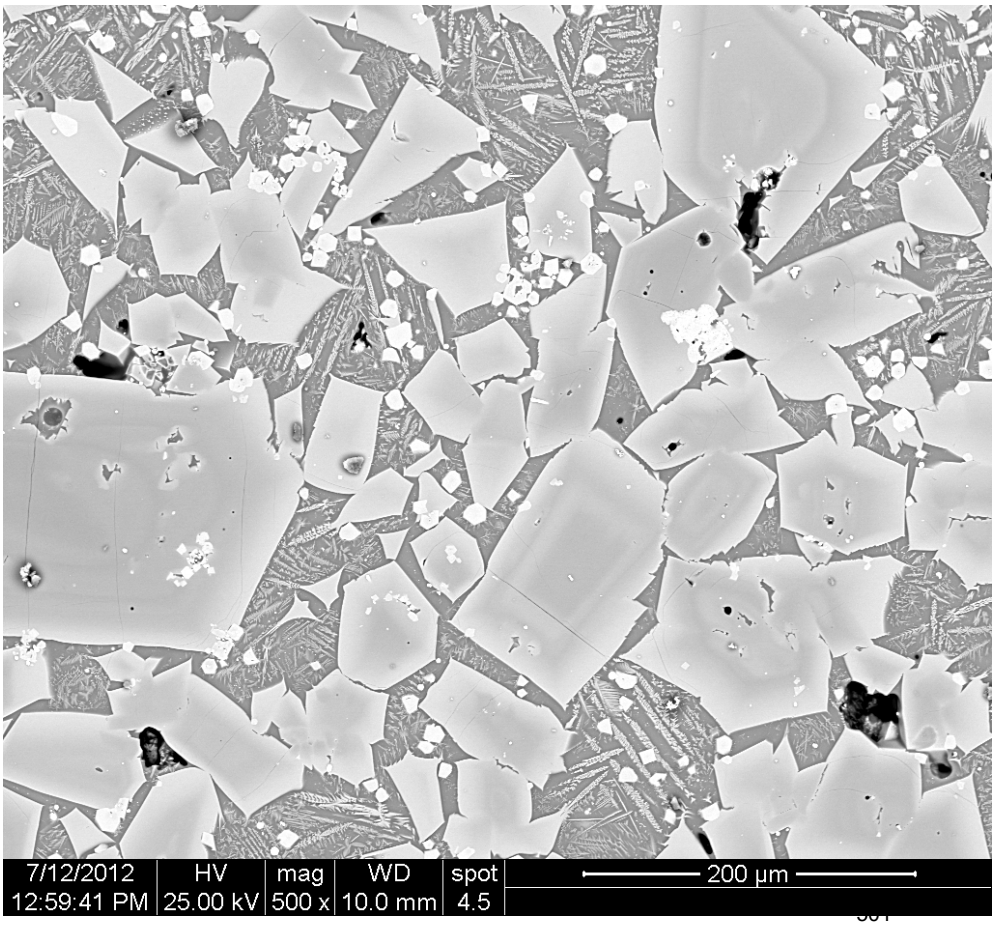
Image No. **10**



Site **step09**

Sample No. **105.2**

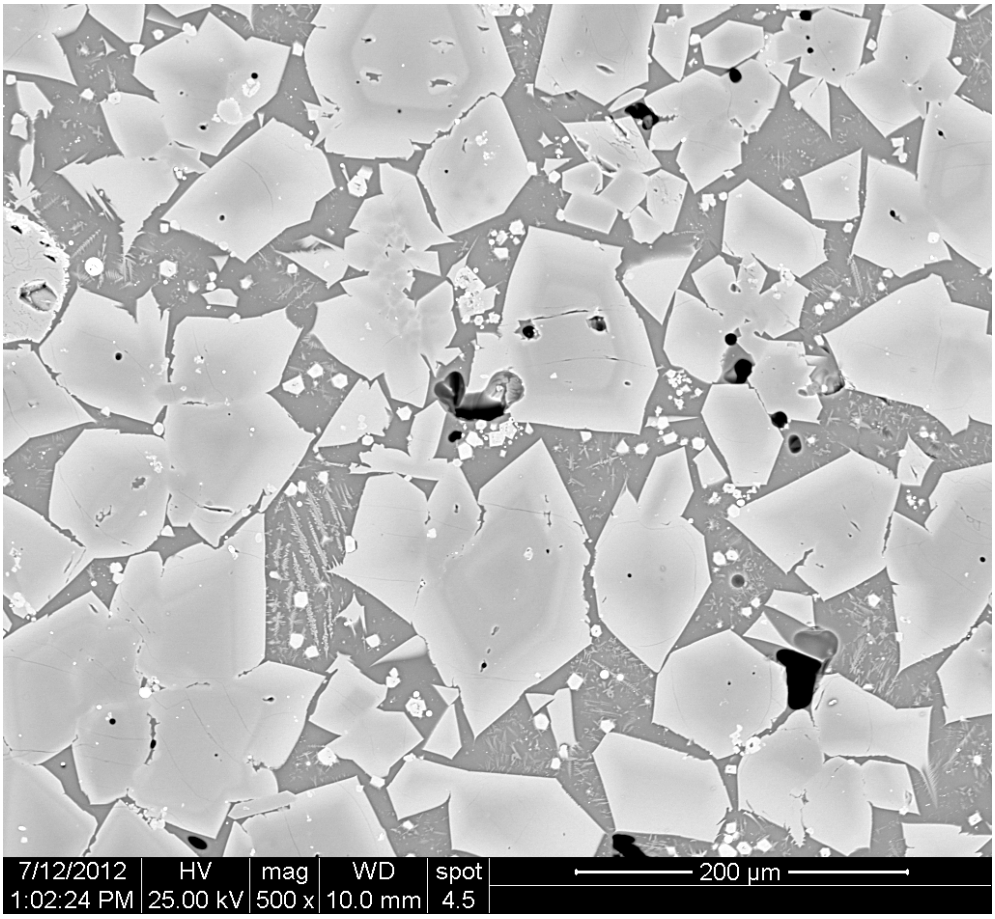
Image No. **11**



Site **step09**

Sample No. **105.2**

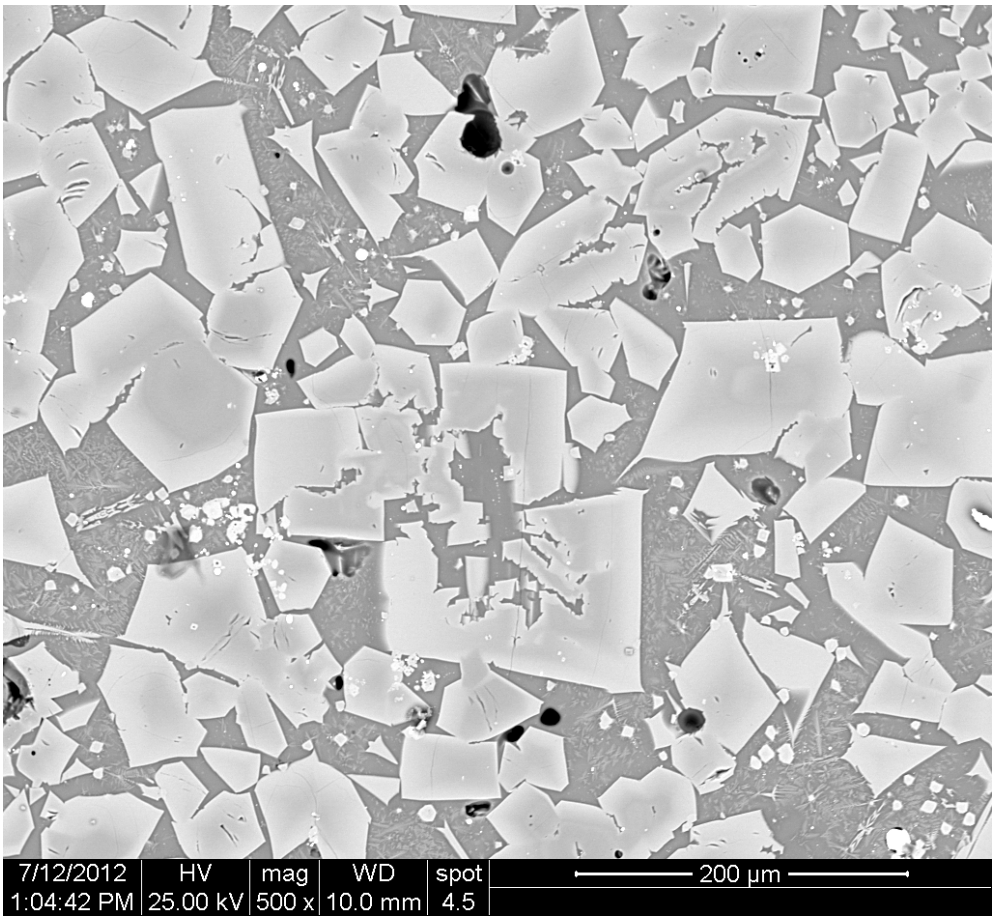
Image No. **12**



Site **step09**

Sample No. **105.2**

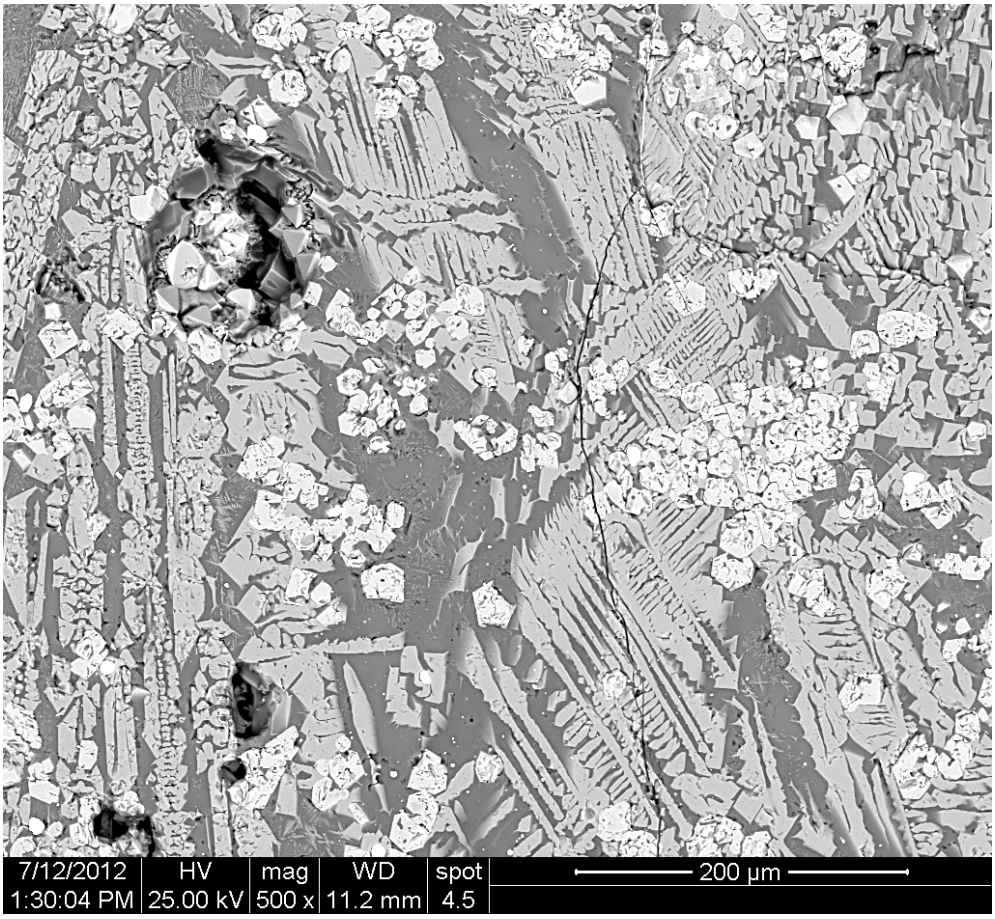
Image No. **13**



Site **step09**

Sample No. **x1**

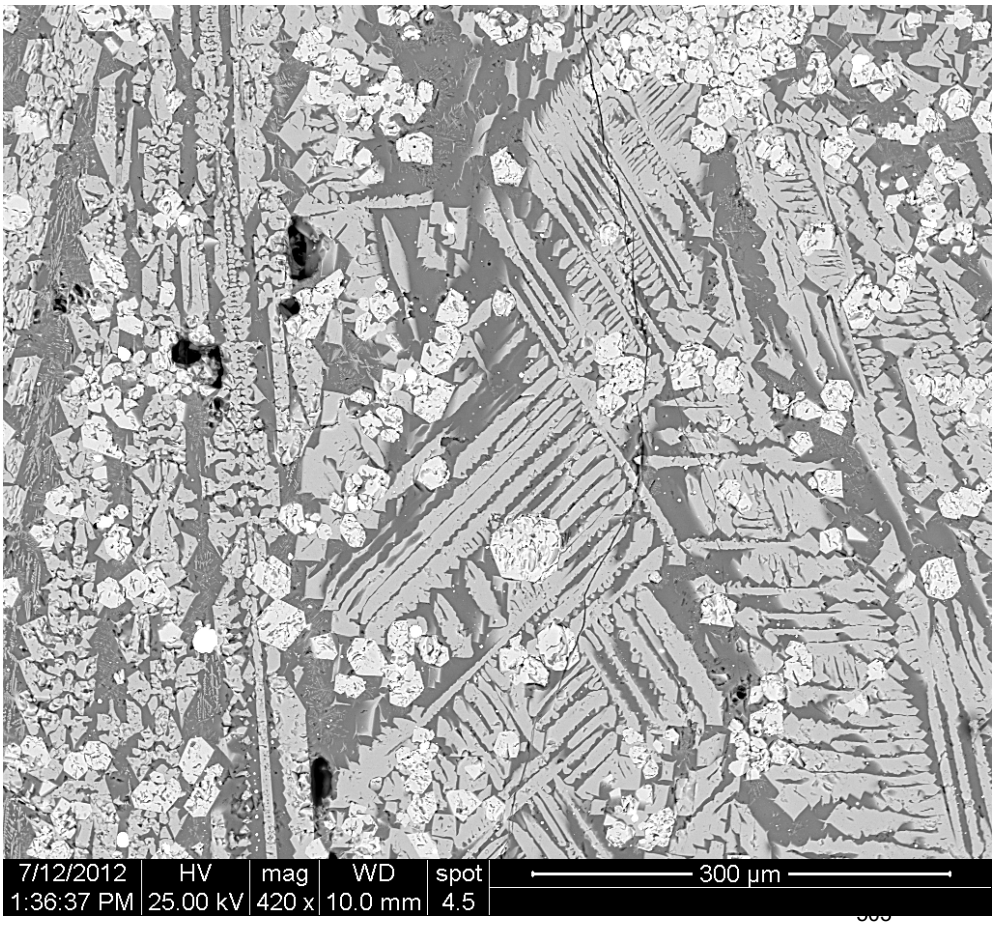
Image No. **1**



Site **step09**

Sample No. **x1**

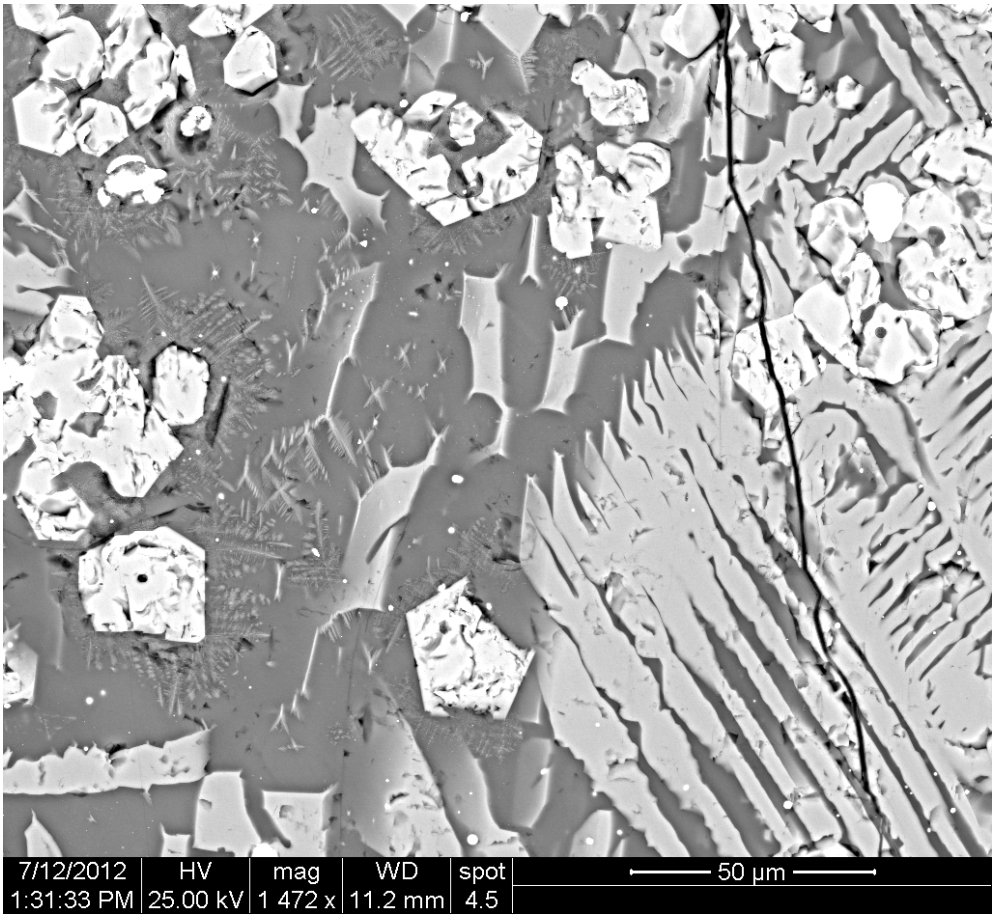
Image No. **2**



Site **step09**

Sample No. **x1**

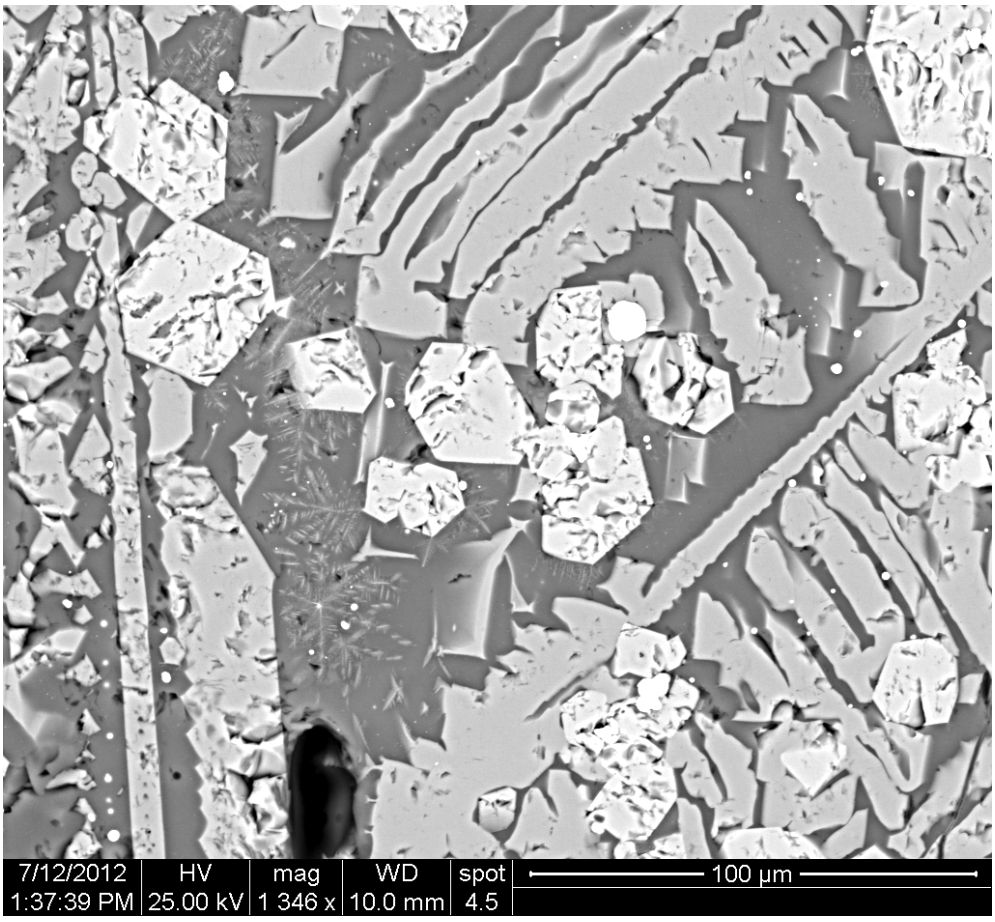
Image No. **3**



Site **step09**

Sample No. **x1**

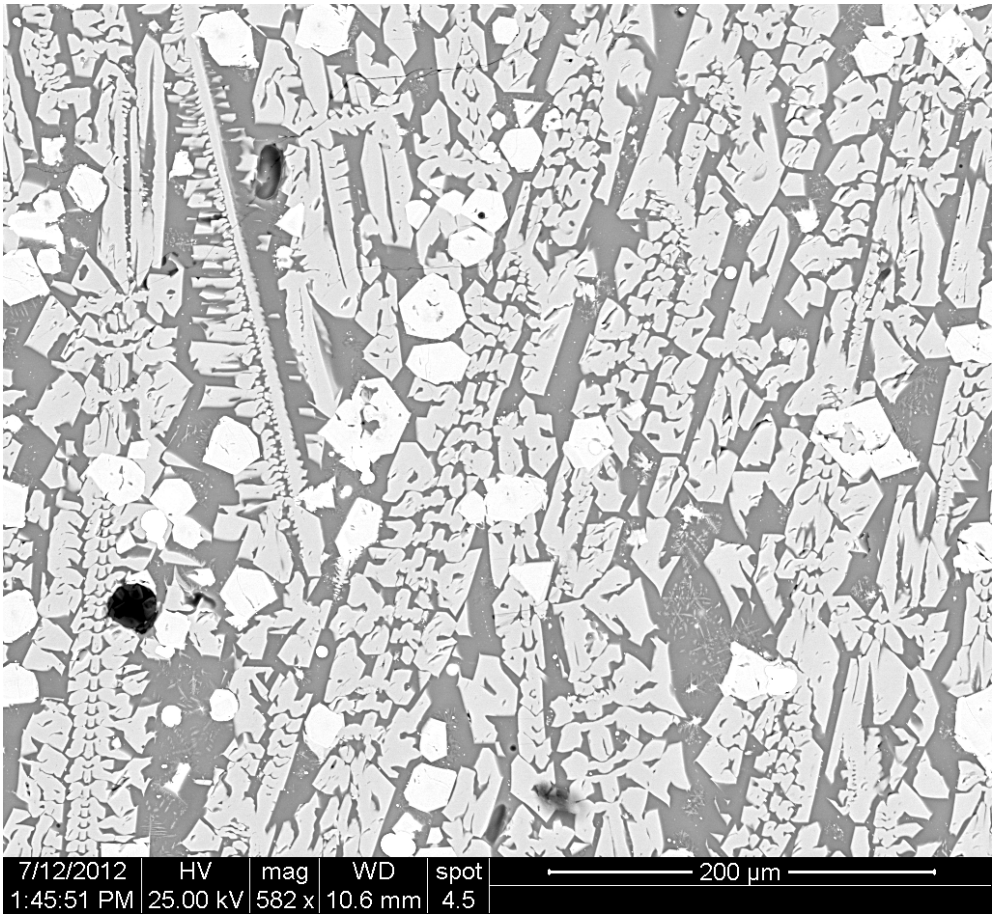
Image No. **4**



Site **step09**

Sample No. **x1**

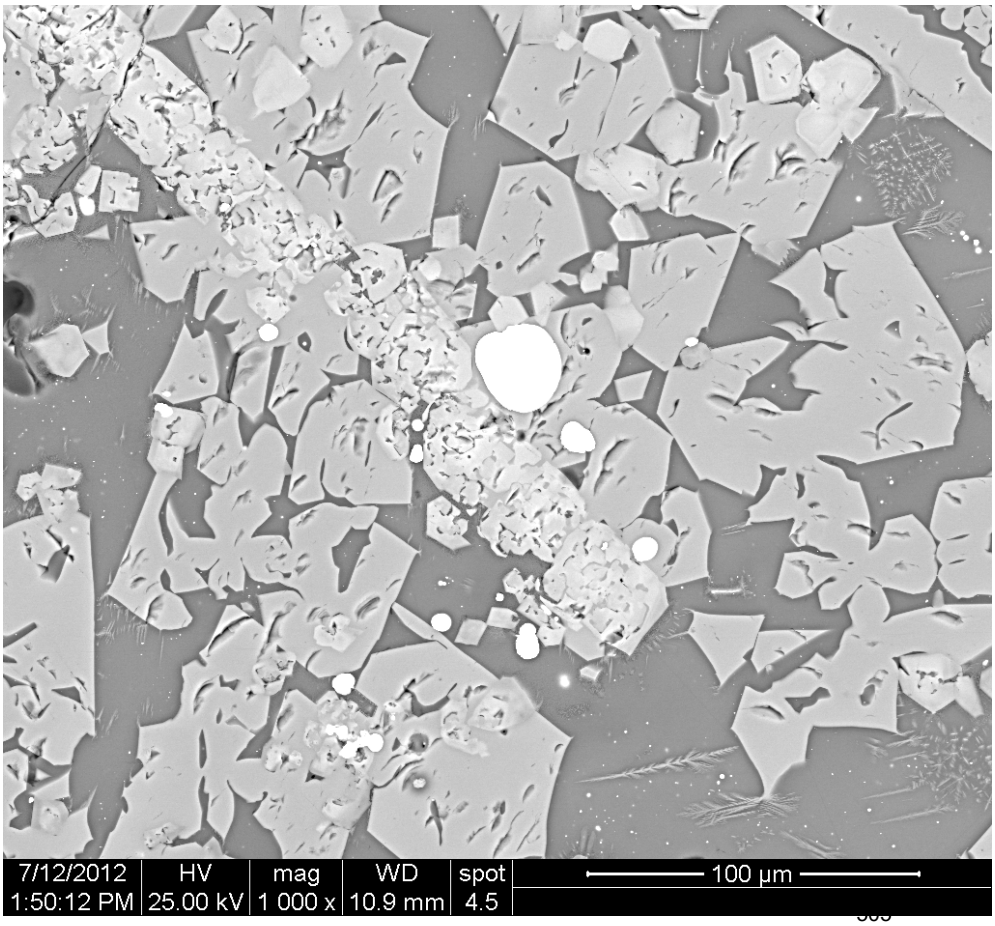
Image No. **5**



Site **step09**

Sample No. **x1**

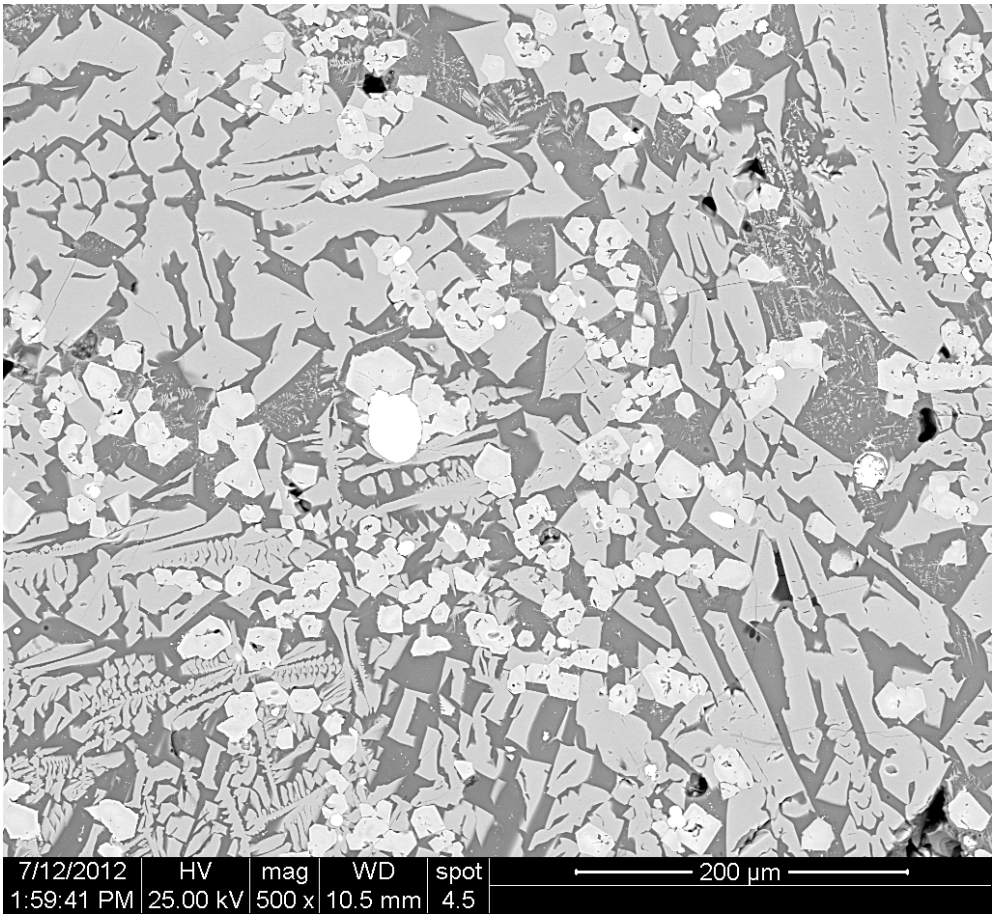
Image No. **6**



Site **step09**

Sample No. **x1**

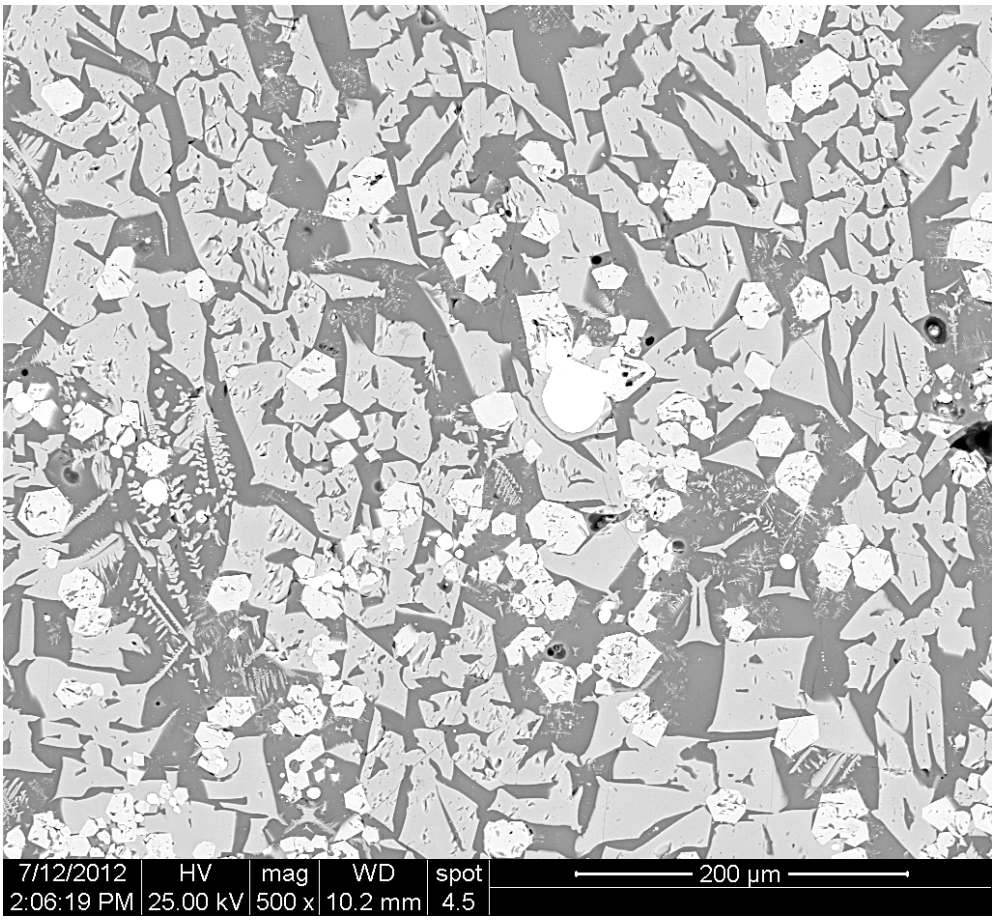
Image No. **7**



Site **step09**

Sample No. **x1**

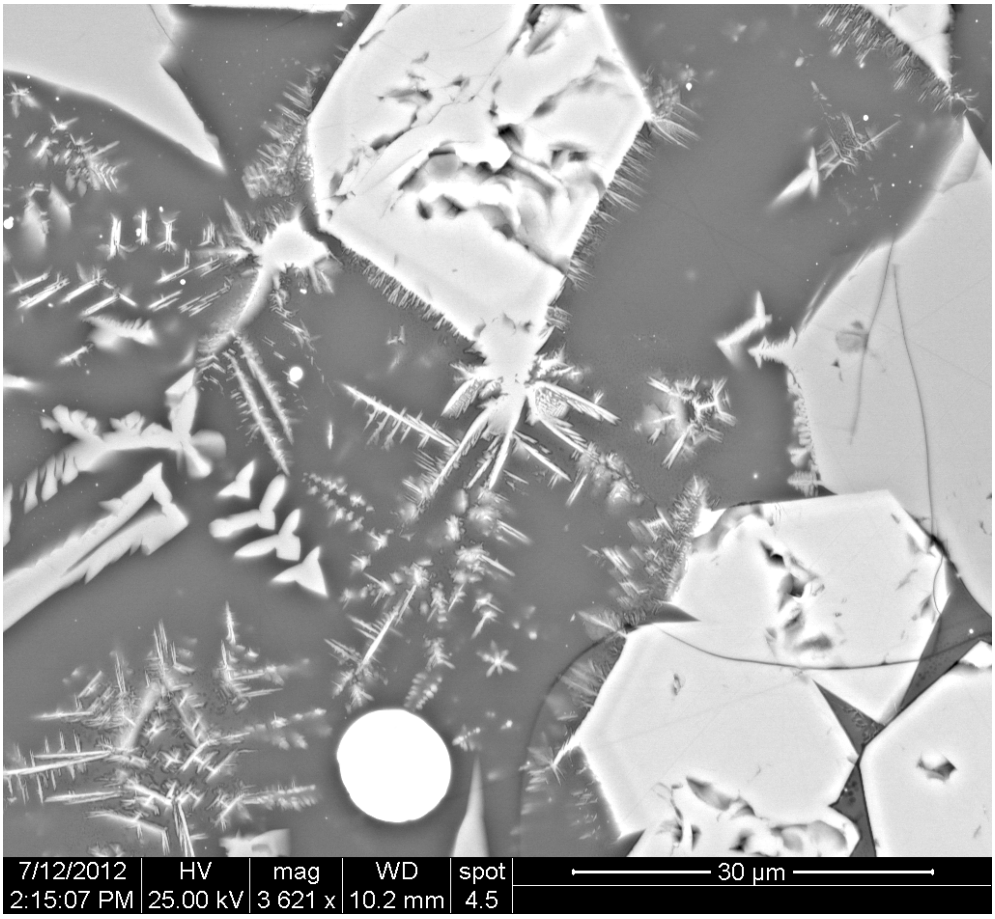
Image No. **8**



Site **step09**

Sample No. **x1**

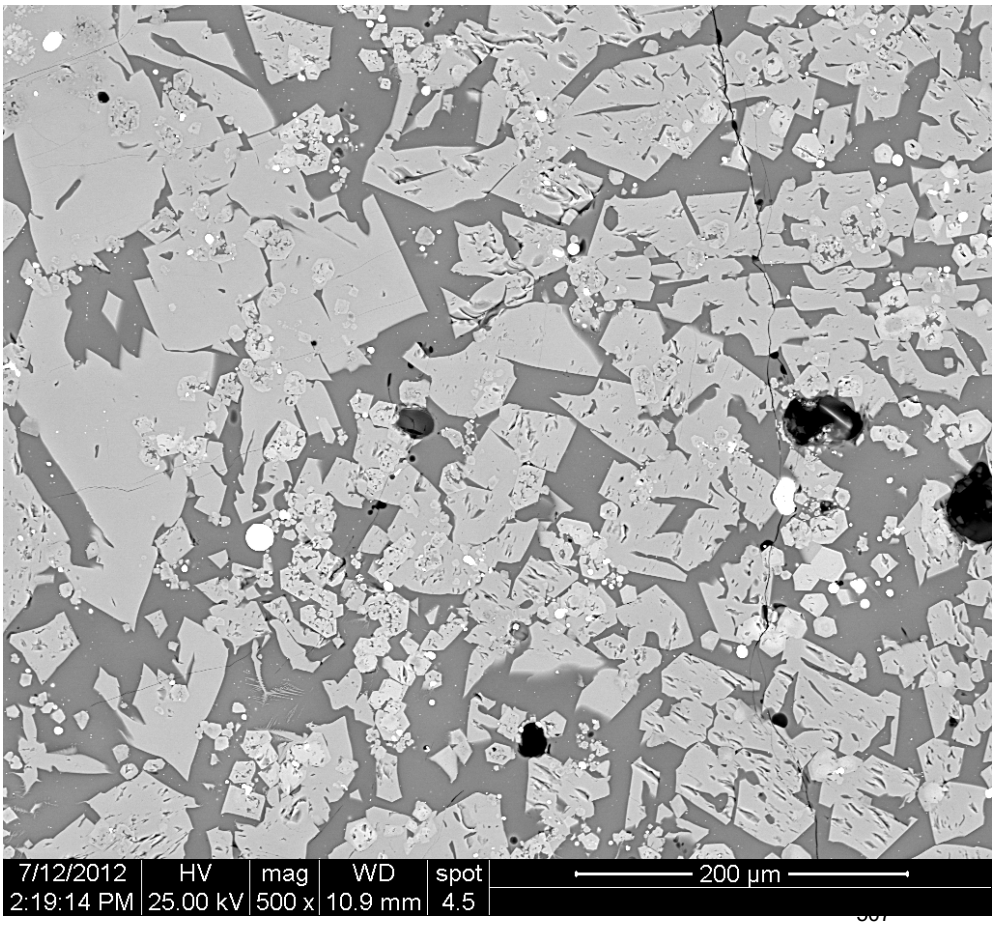
Image No. **9**



Site **step09**

Sample No. **x1**

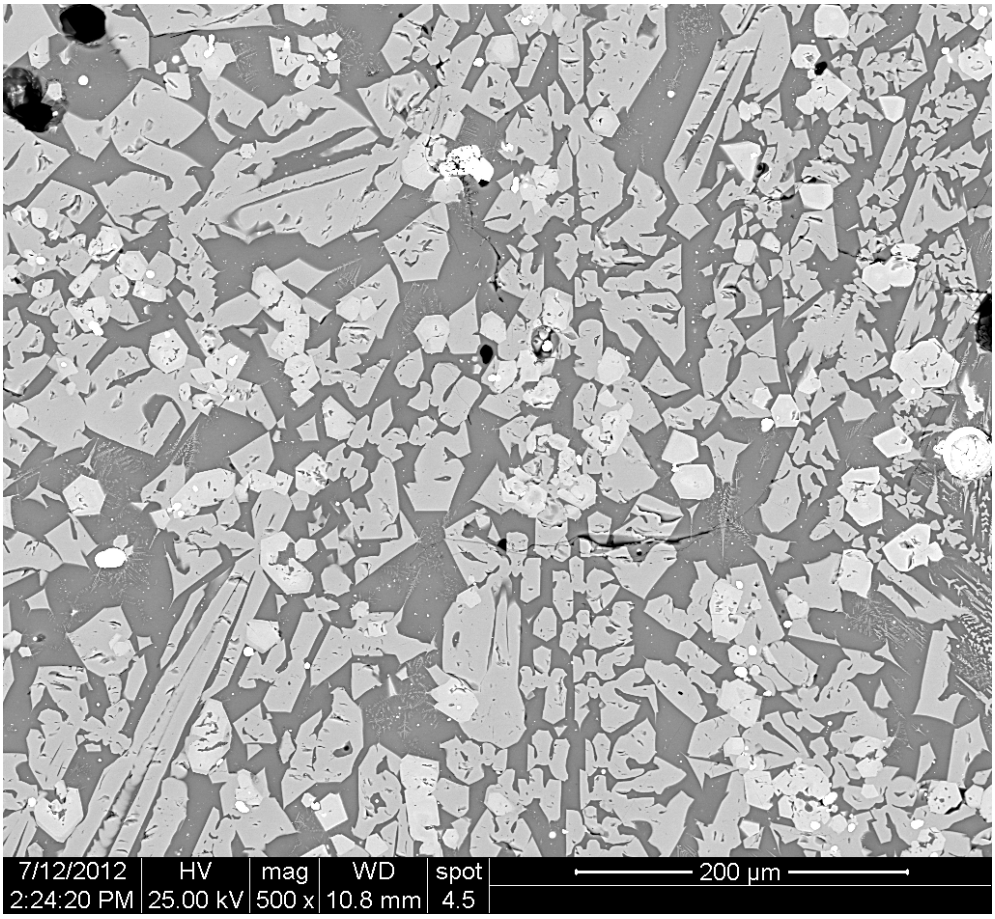
Image No. **10**



Site **step09**

Sample No. **x1**

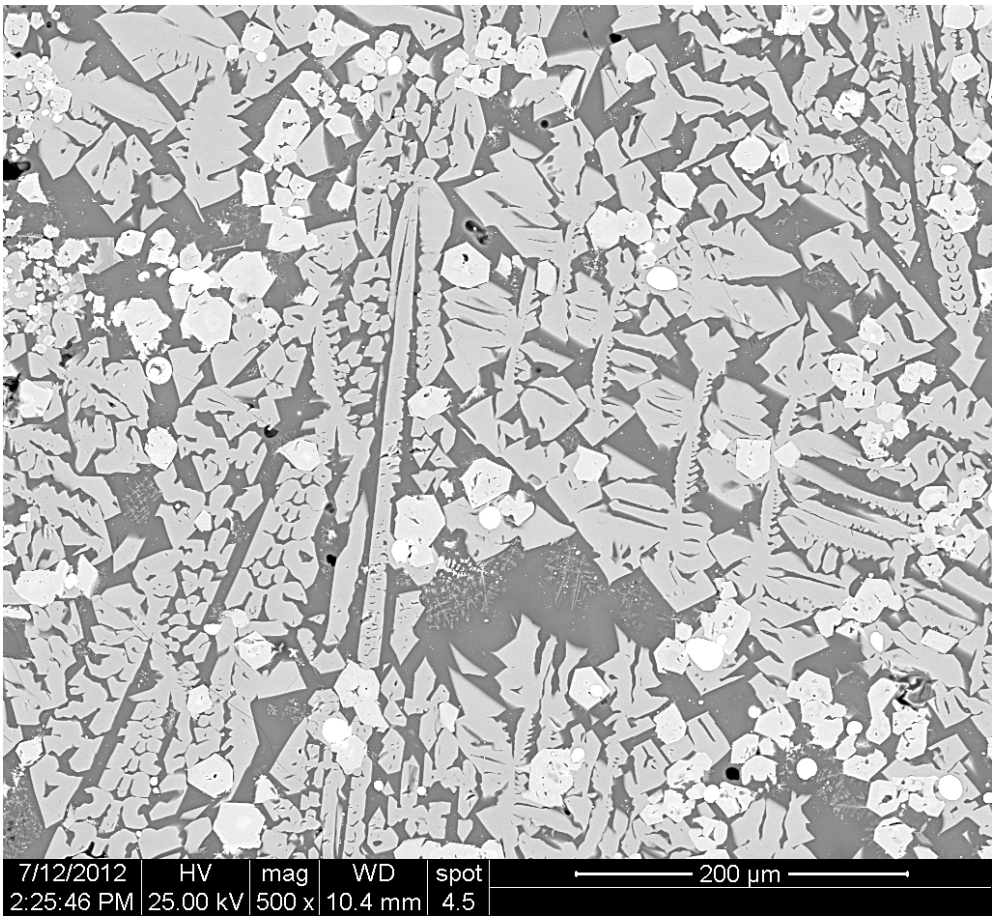
Image No. **11**



Site **step09**

Sample No. **x1**

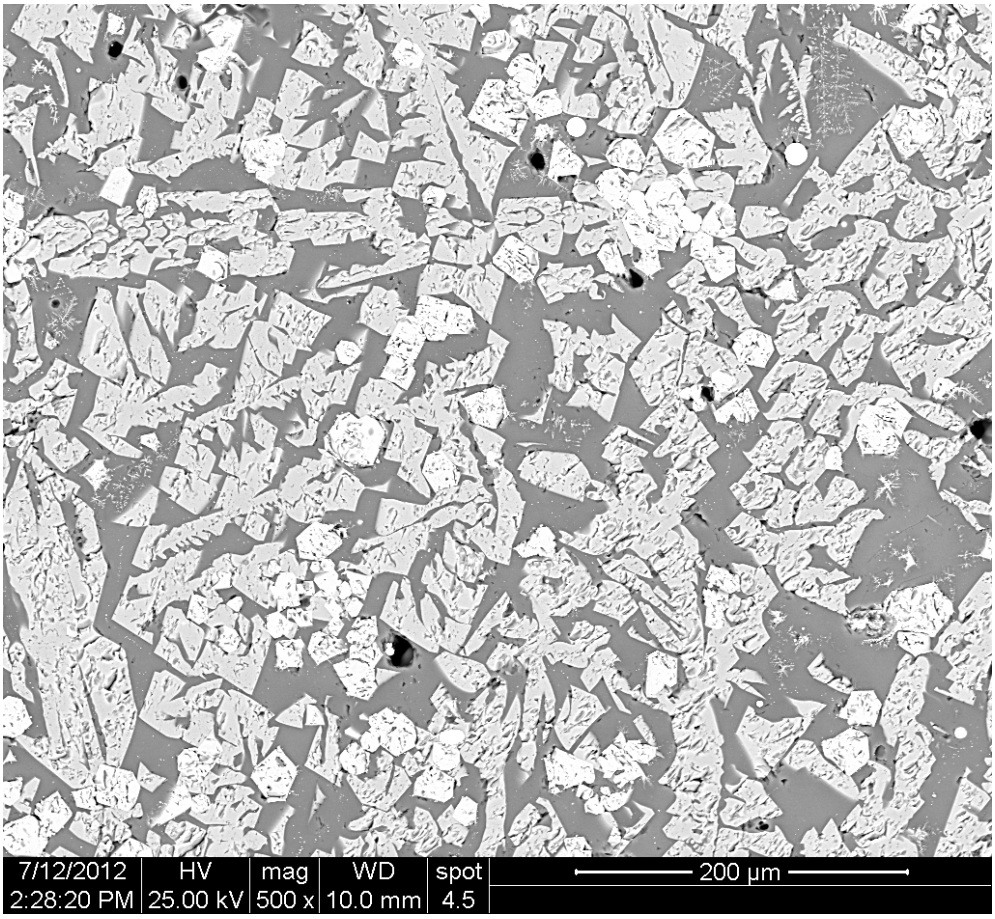
Image No. **12**



Site **step09**

Sample No. **x1**

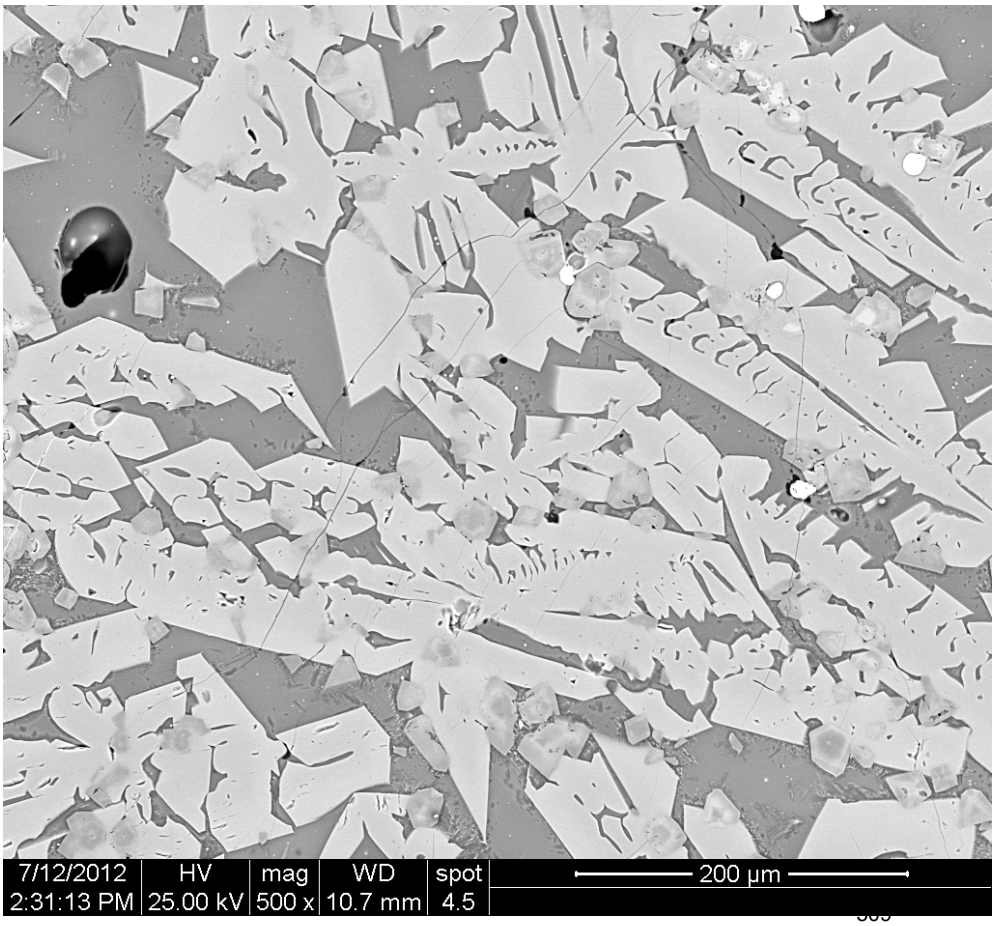
Image No. **13**



Site **step09**

Sample No. **x1**

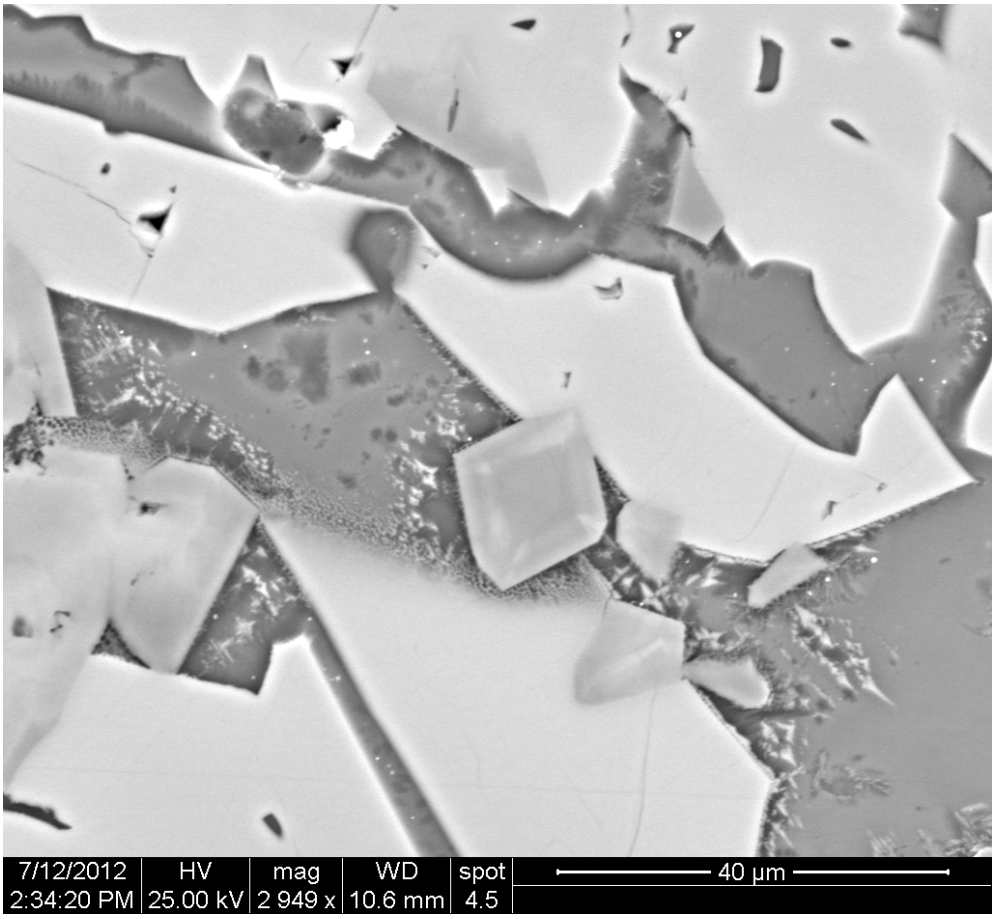
Image No. **14**



Site **step09**

Sample No. **x1**

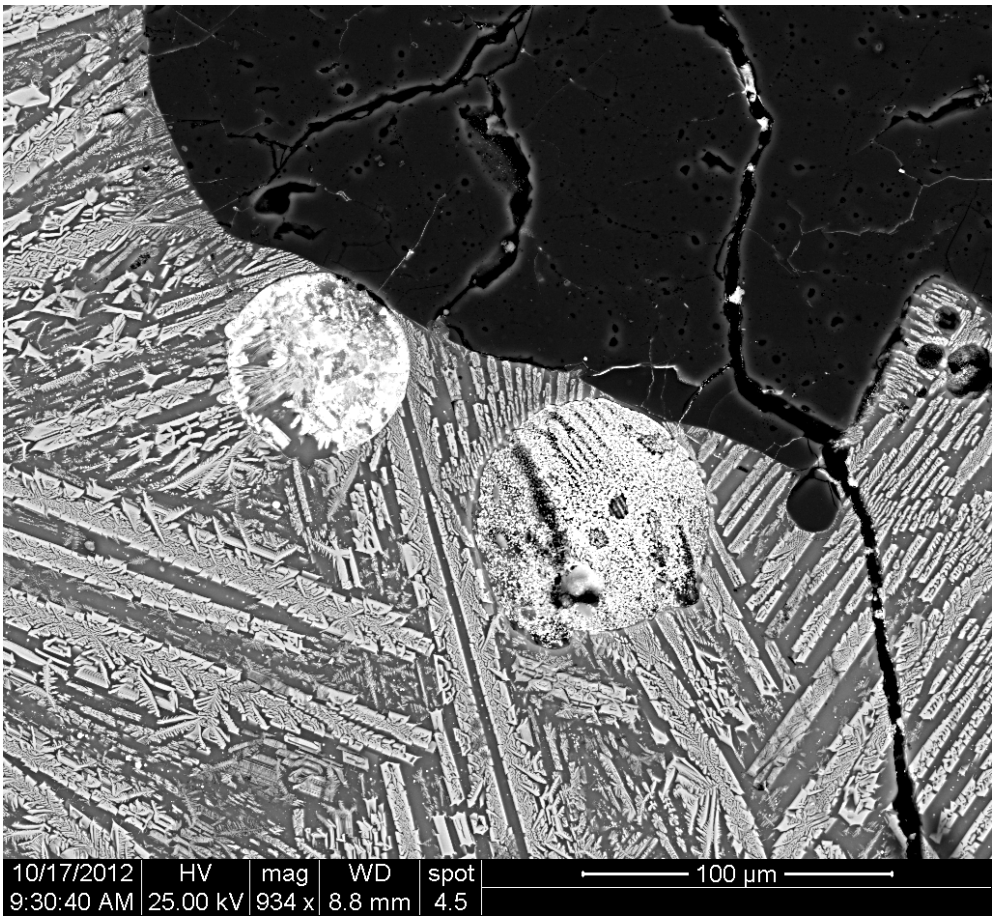
Image No. **15**



Site **step09**

Sample No. **62**

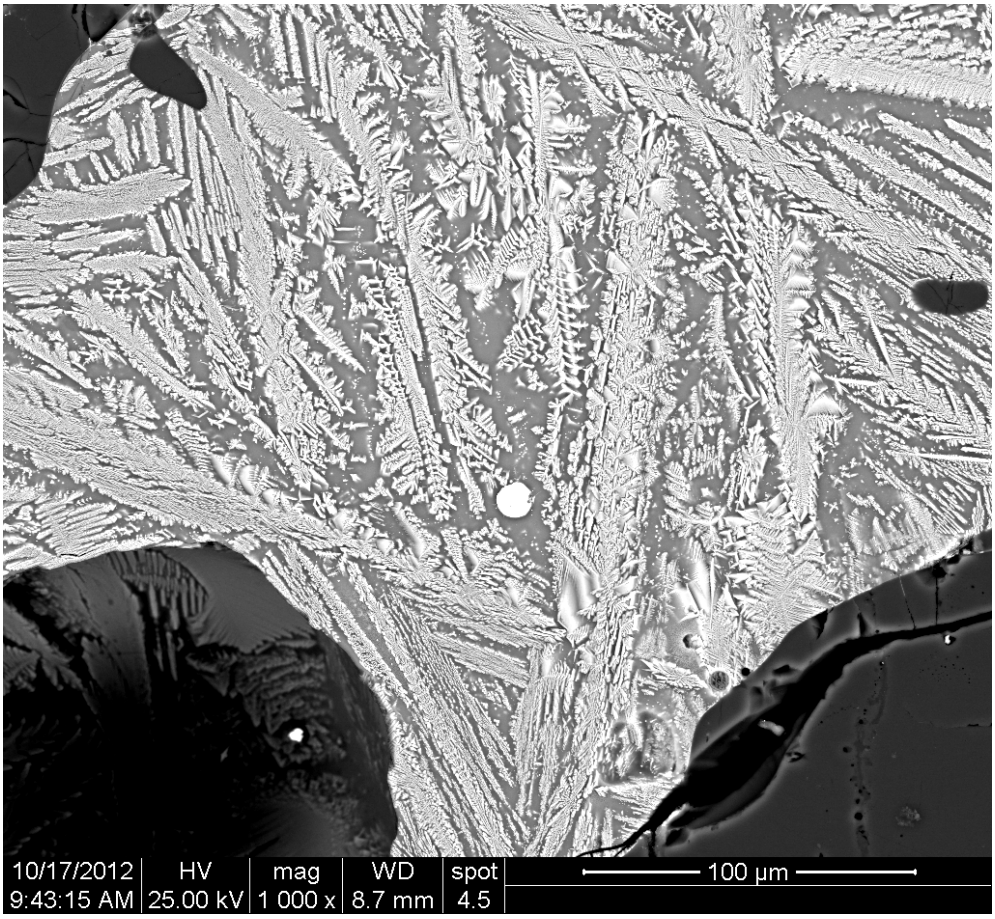
Image No. **1**



Site **step09**

Sample No. **62**

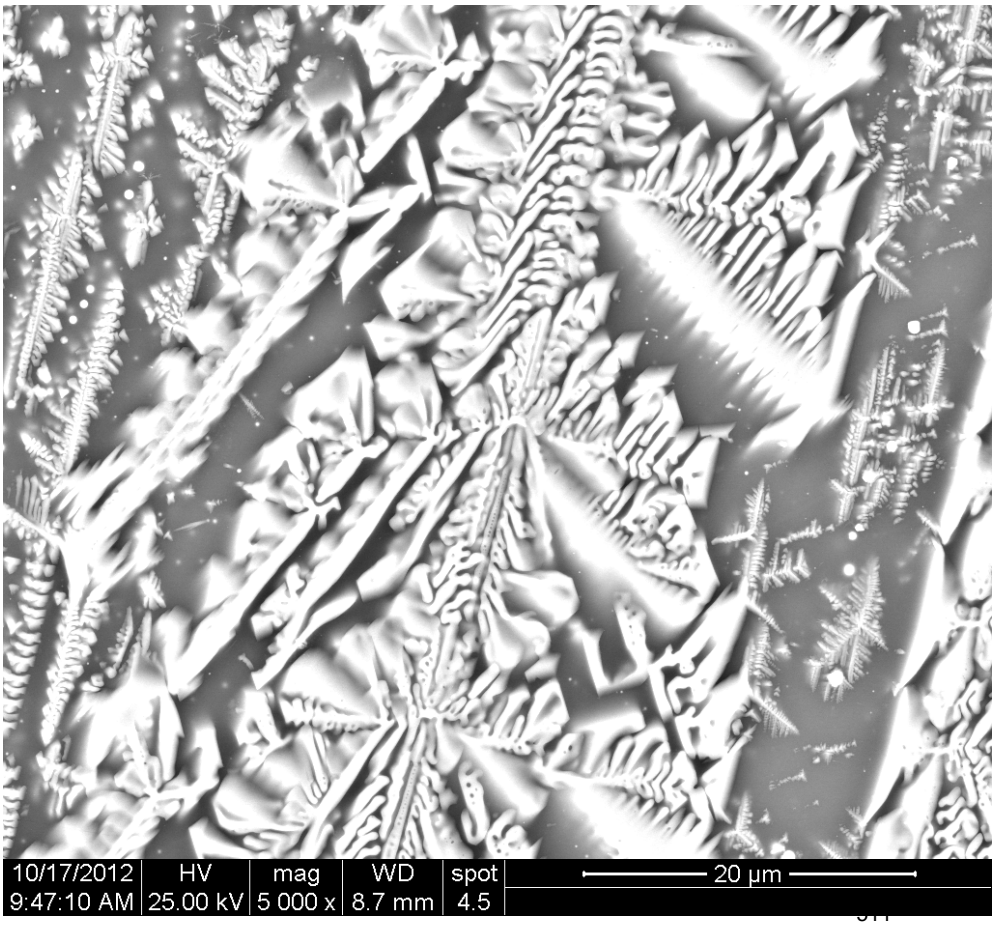
Image No. **2**



Site **step09**

Sample No. **62**

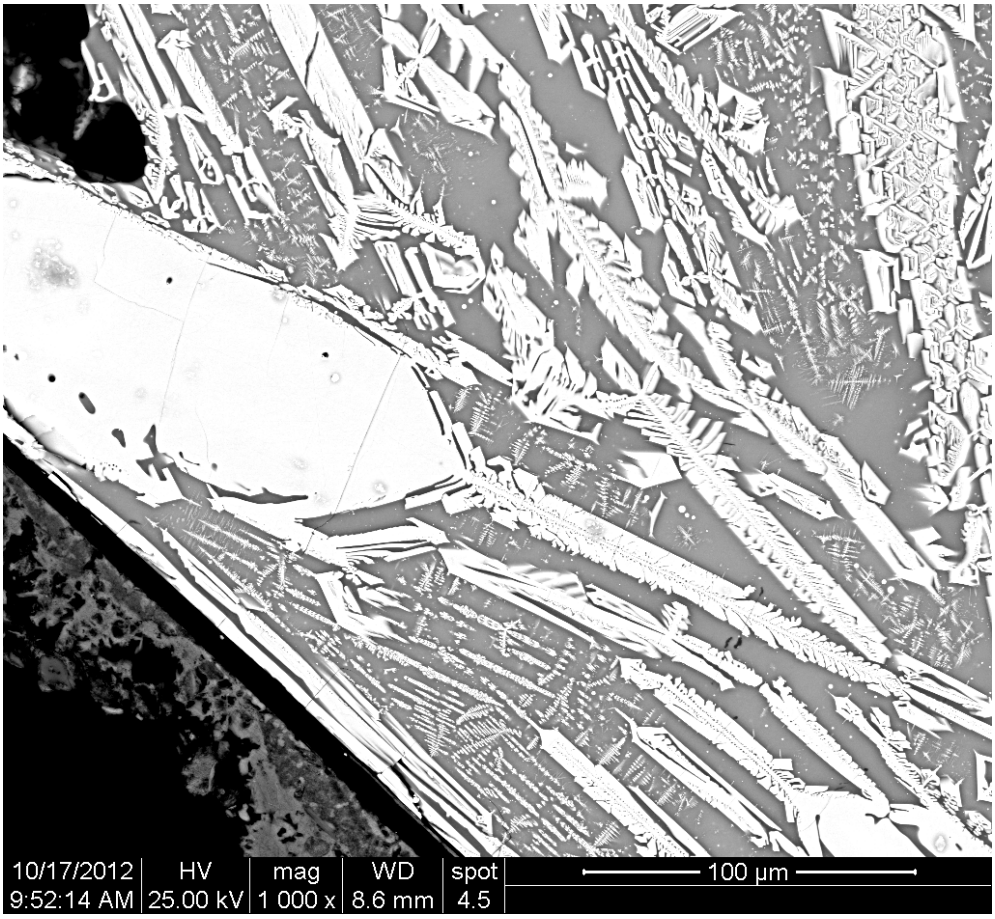
Image No. **3**



Site **step09**

Sample No. **62**

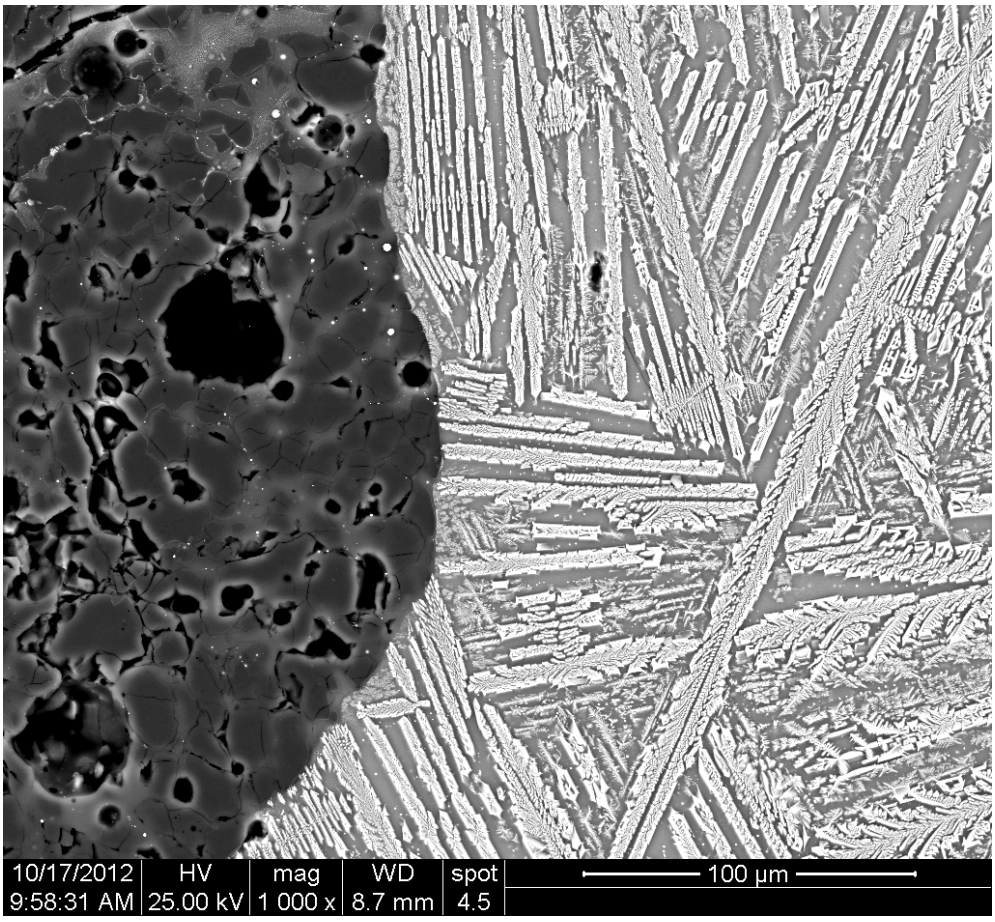
Image No. **4**



Site **step09**

Sample No. **62**

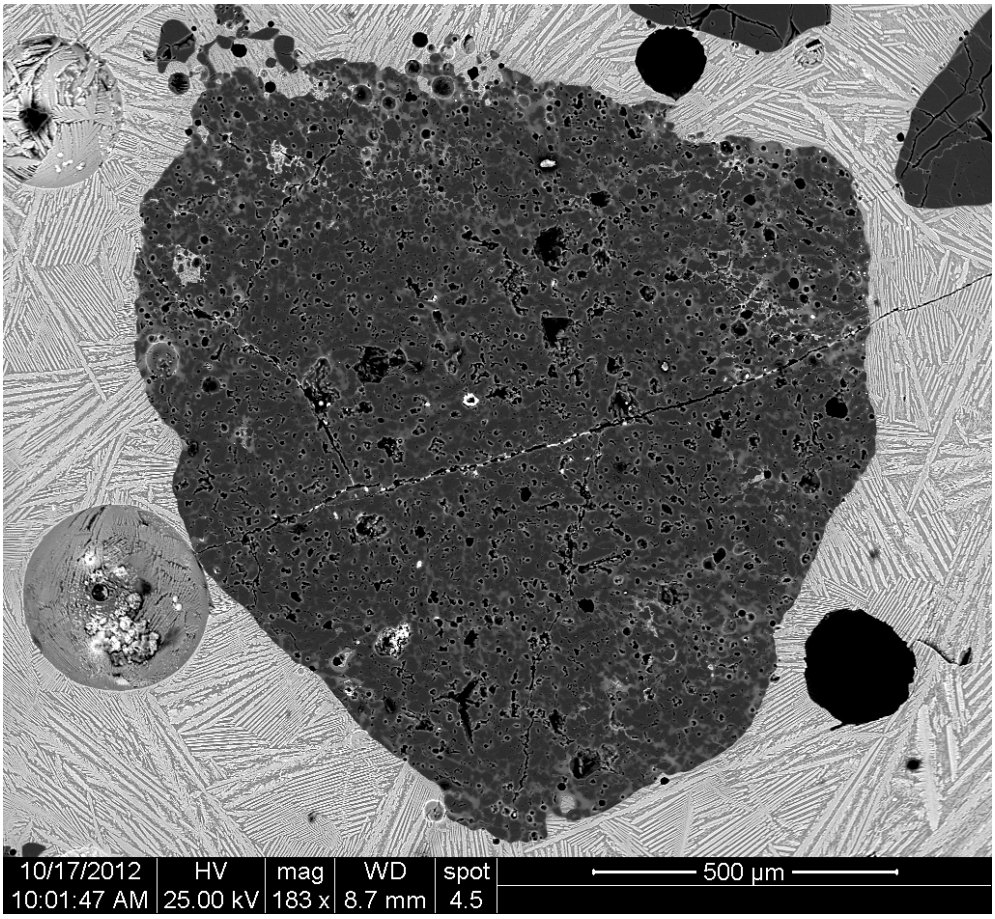
Image No. **5**



Site **step09**

Sample No. **62**

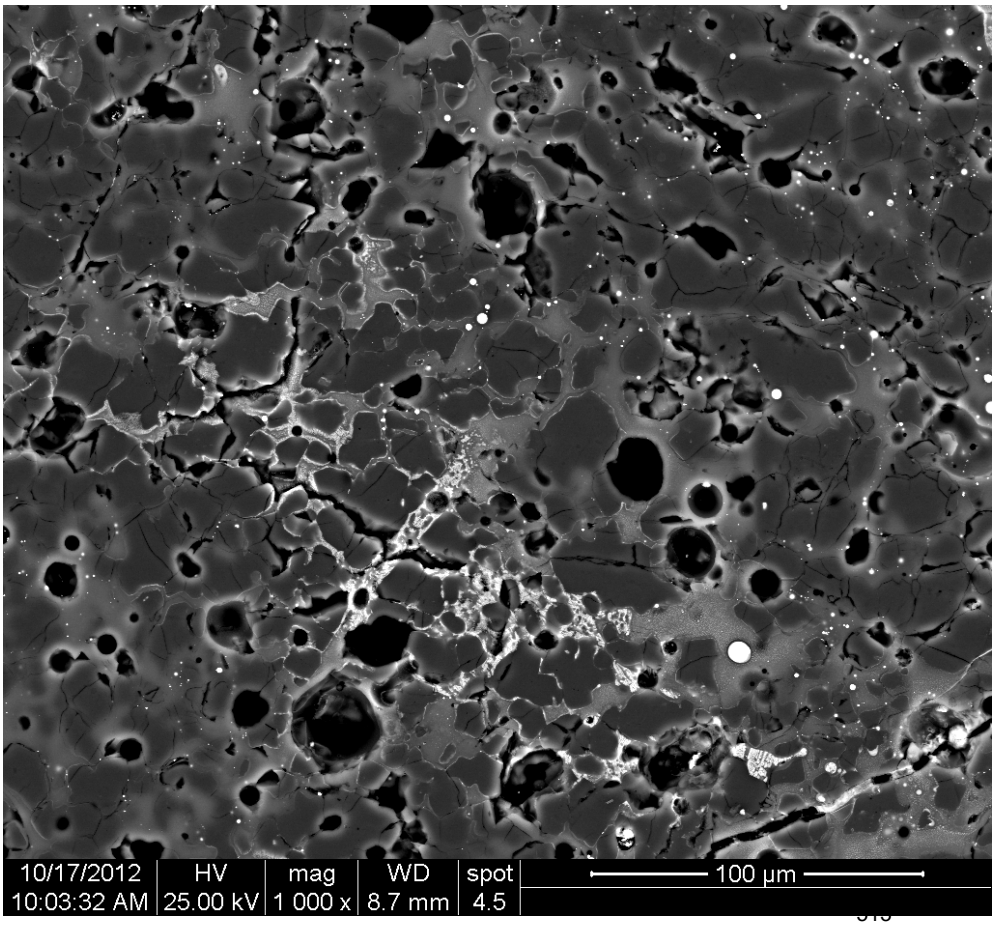
Image No. **6**



Site **step09**

Sample No. **62**

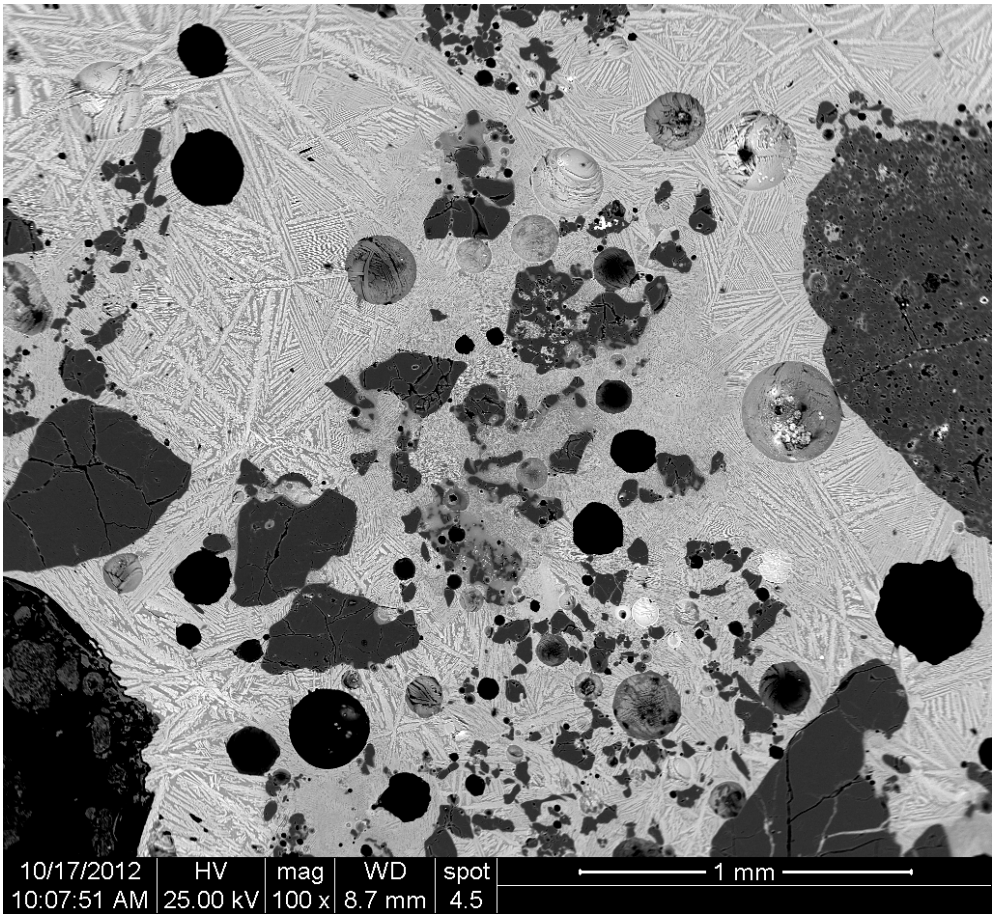
Image No. **7**



Site **step09**

Sample No. **62**

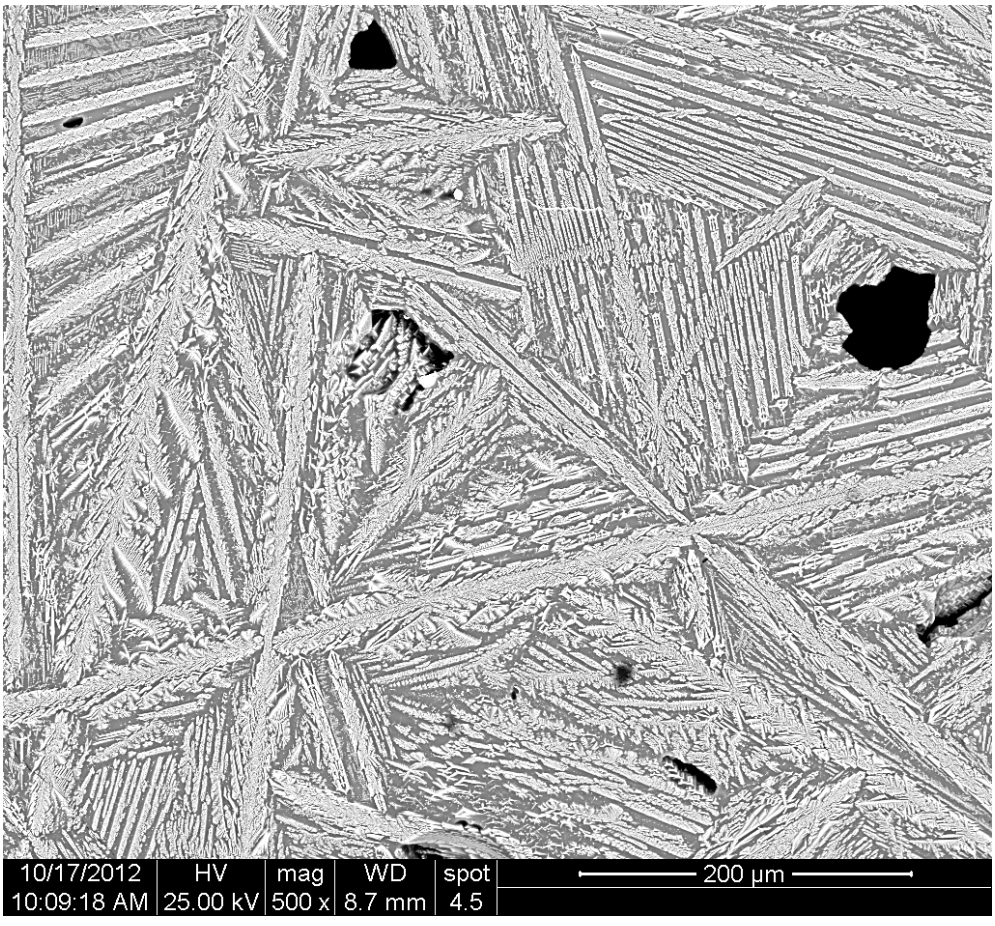
Image No. **8**



Site **step09**

Sample No. **62**

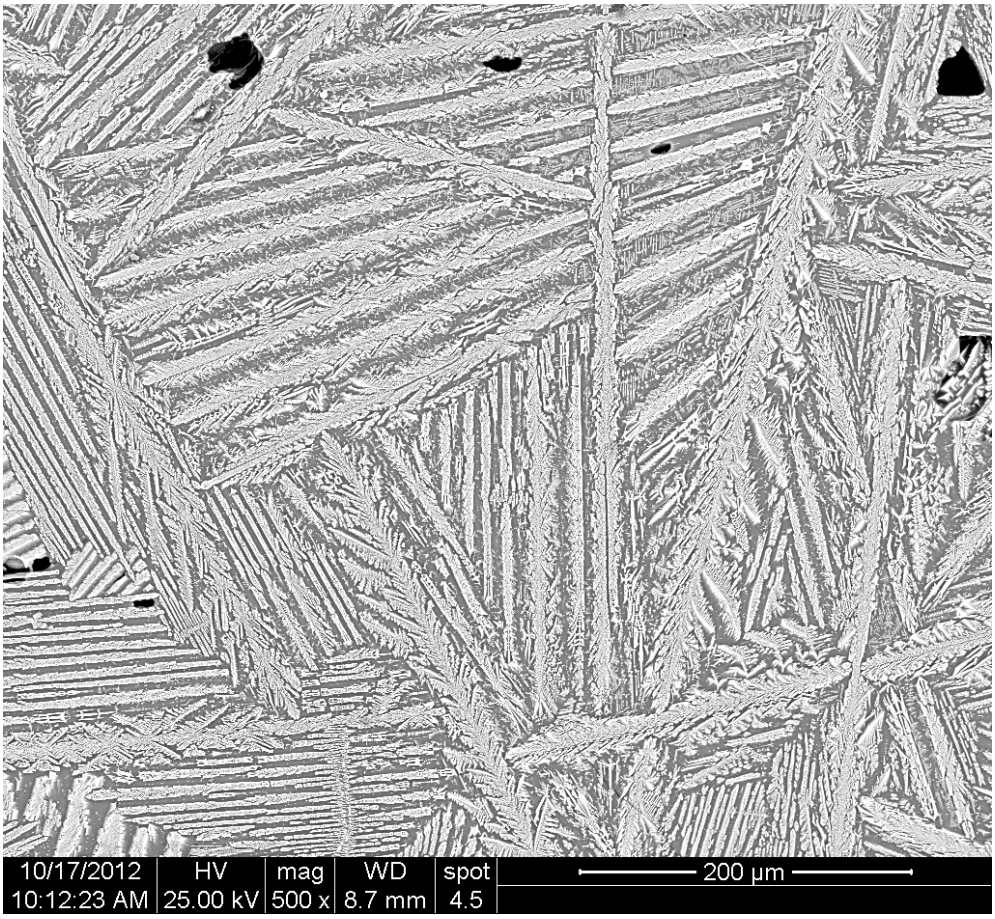
Image No. **9**



Site **step09**

Sample No. **62**

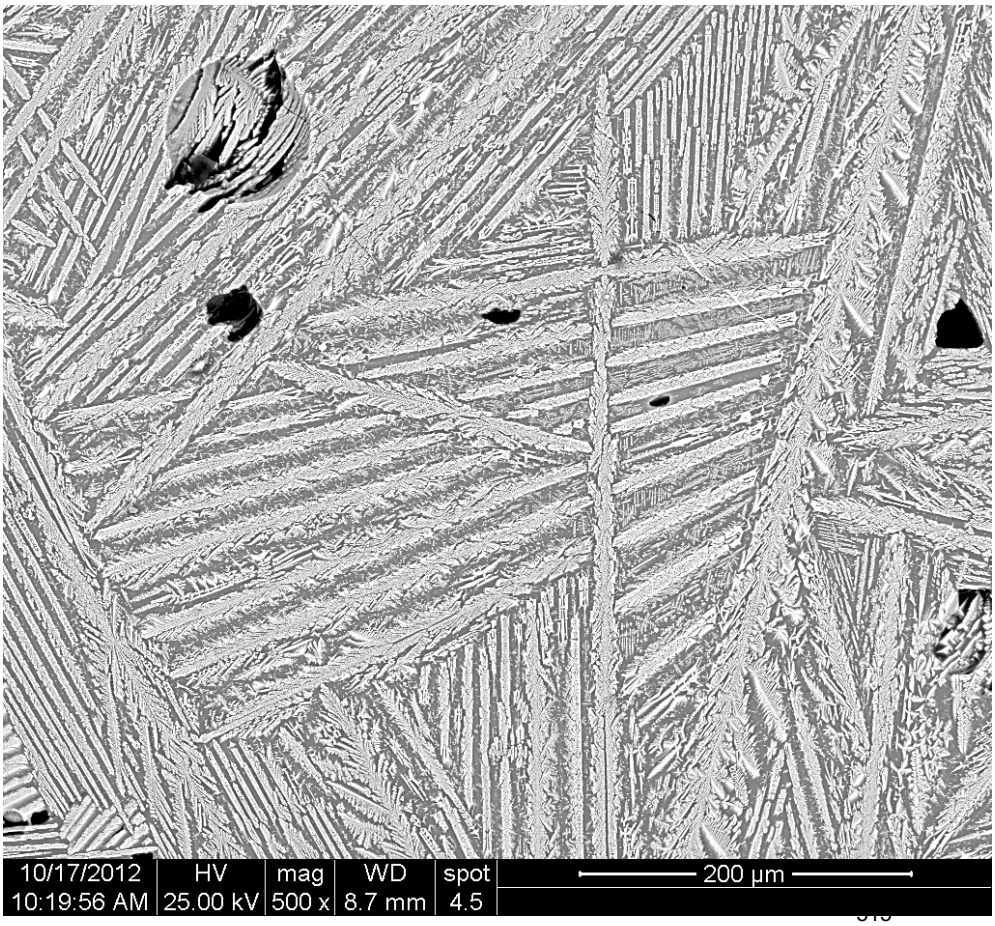
Image No. **10**



Site **step09**

Sample No. **62**

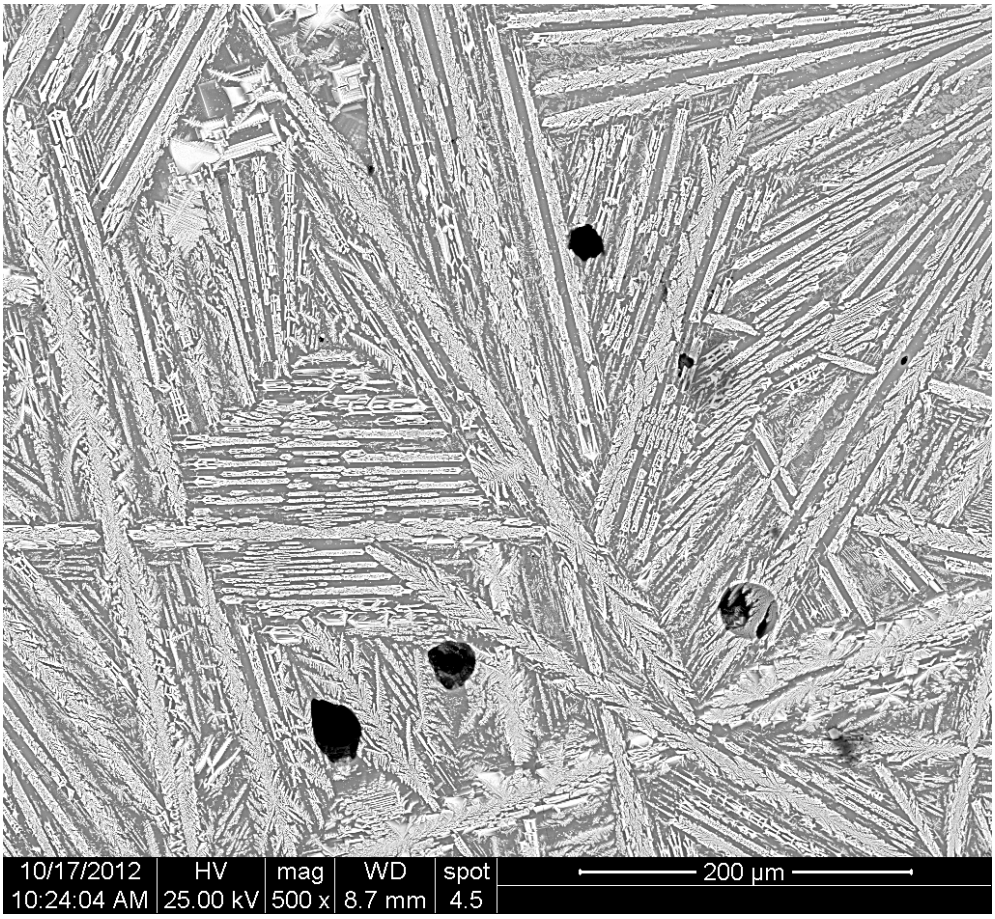
Image No. **11**



Site **step09**

Sample No. **62**

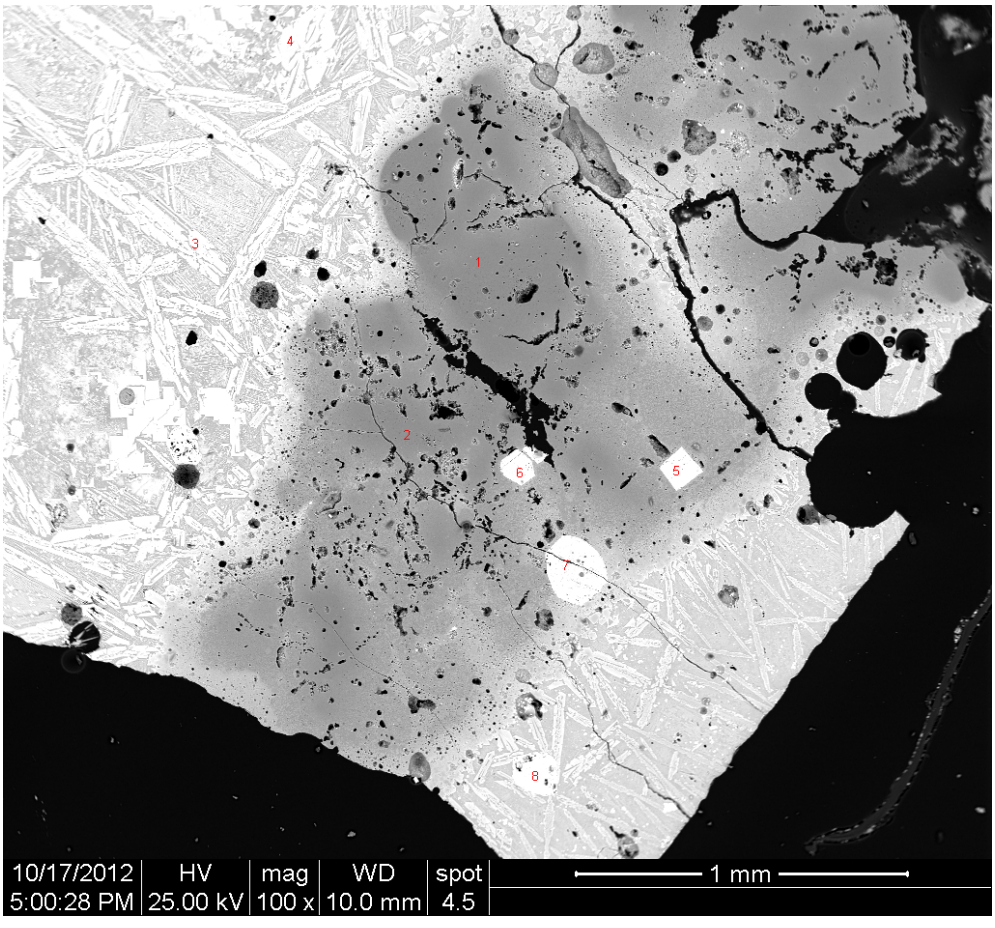
Image No. **12**



Site **step09**

Sample No. **117**

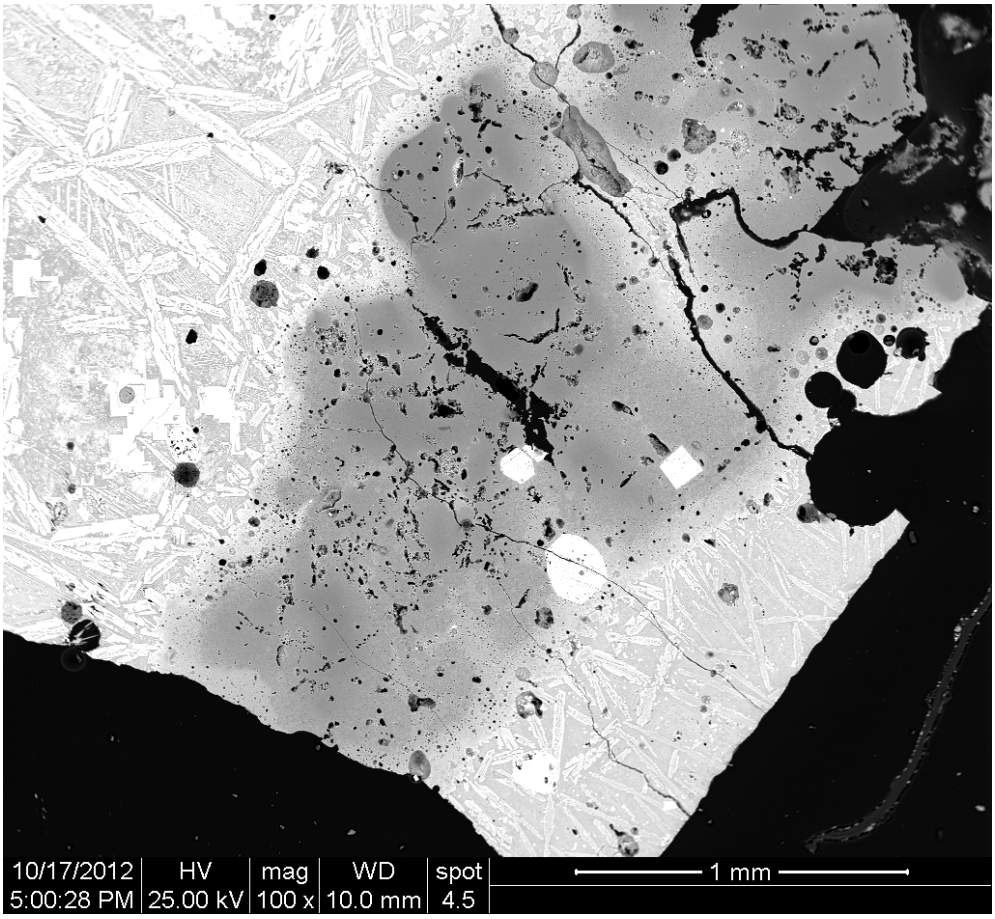
Image No. **1**



Site **step09**

Sample No. **117**

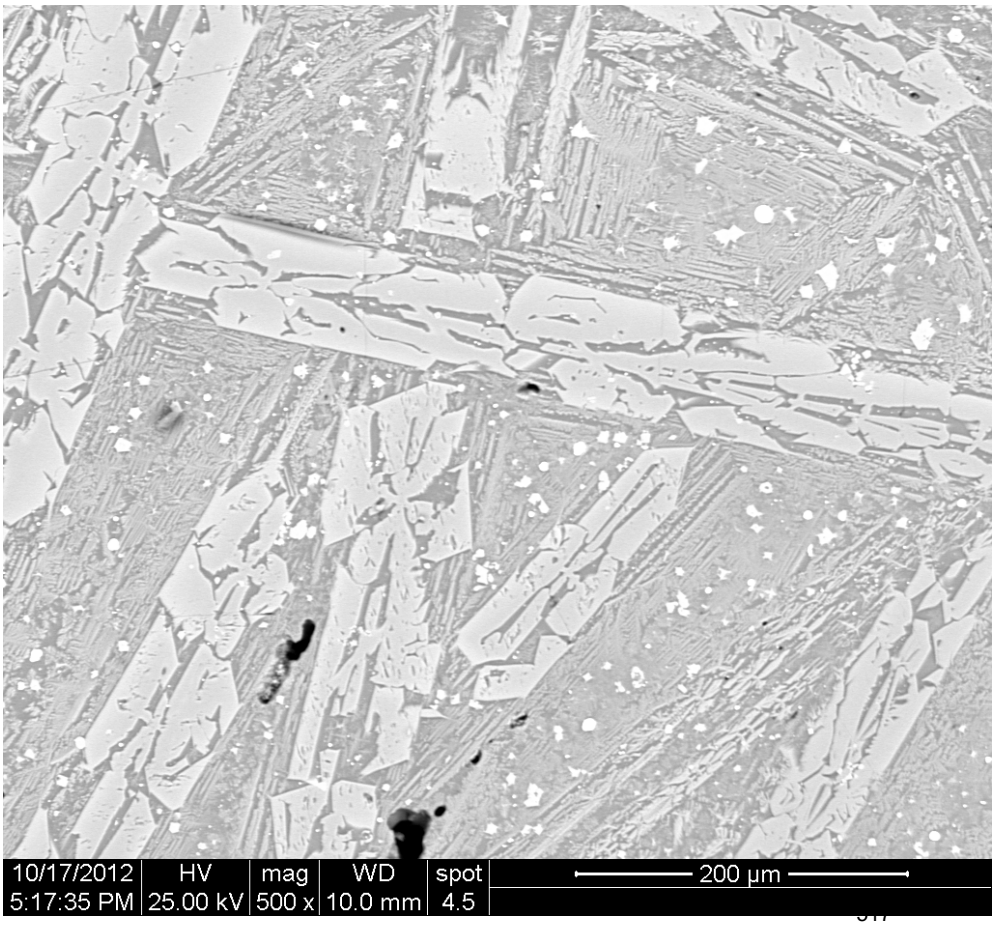
Image No. **1**



Site **step09**

Sample No. **117**

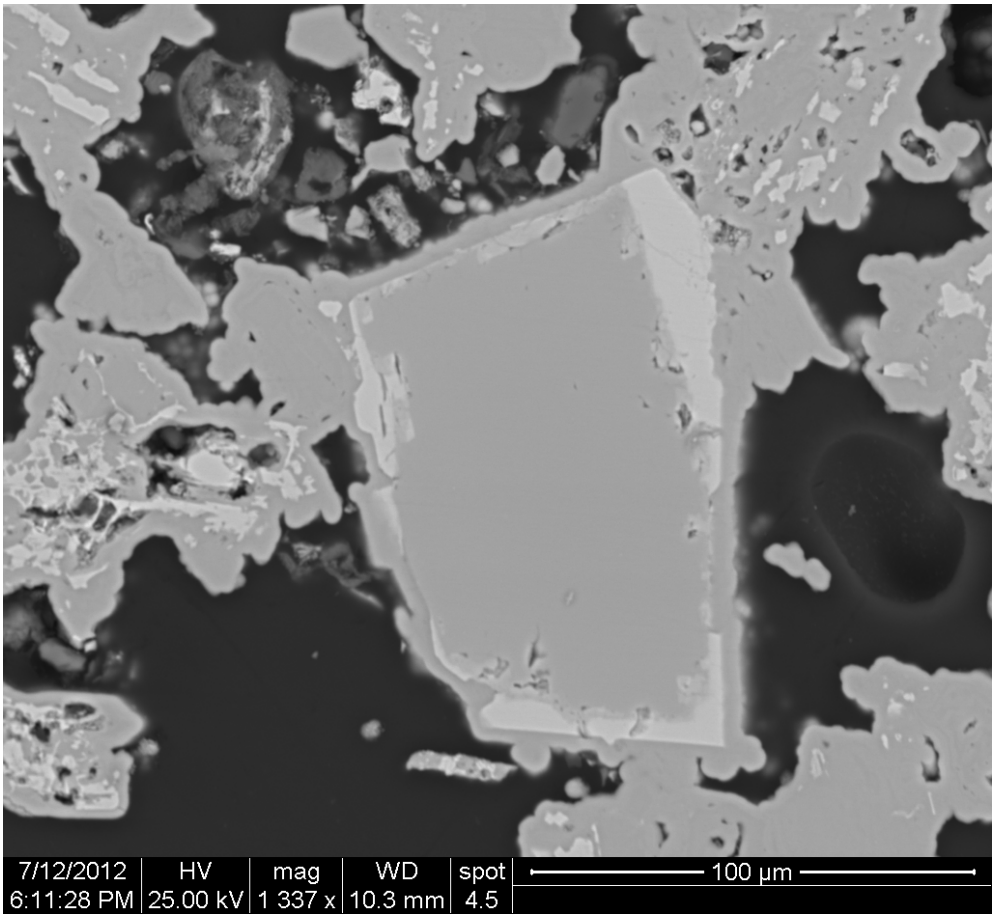
Image No. **2**



Site **step2**

Sample No. **227.4**

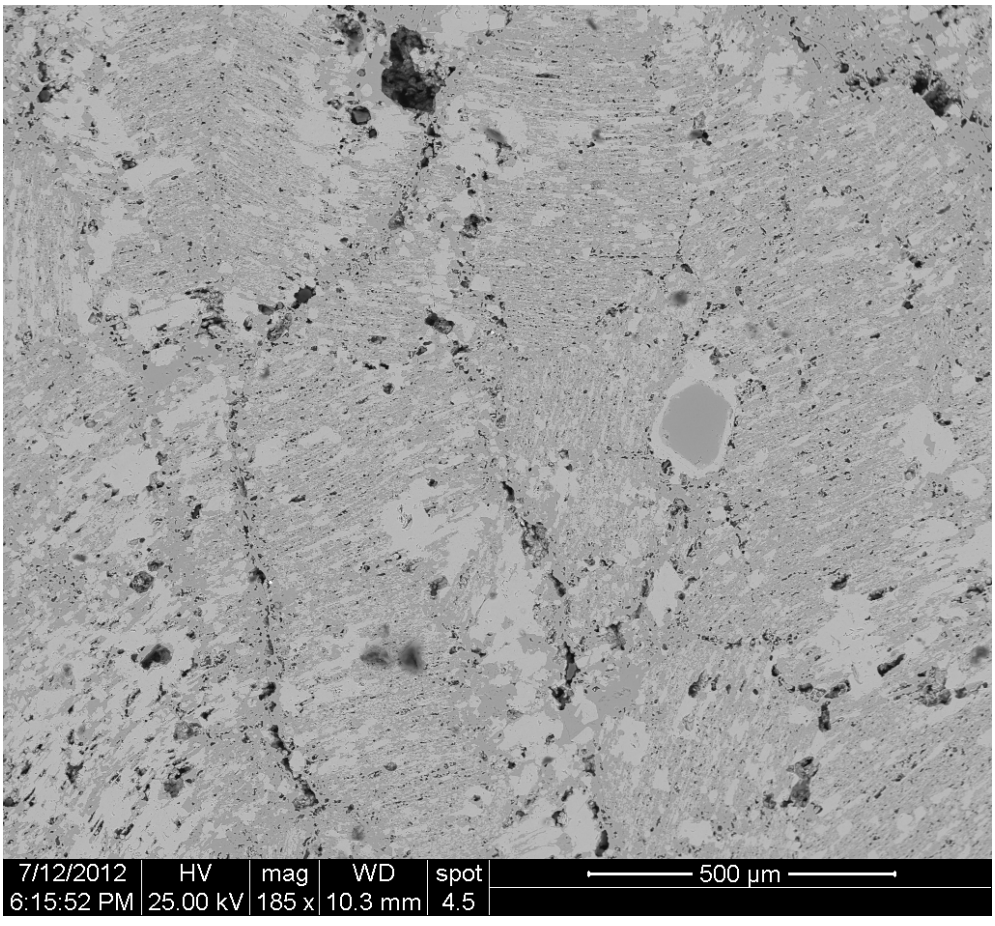
Image No. **1**



Site **step2**

Sample No. **227.4**

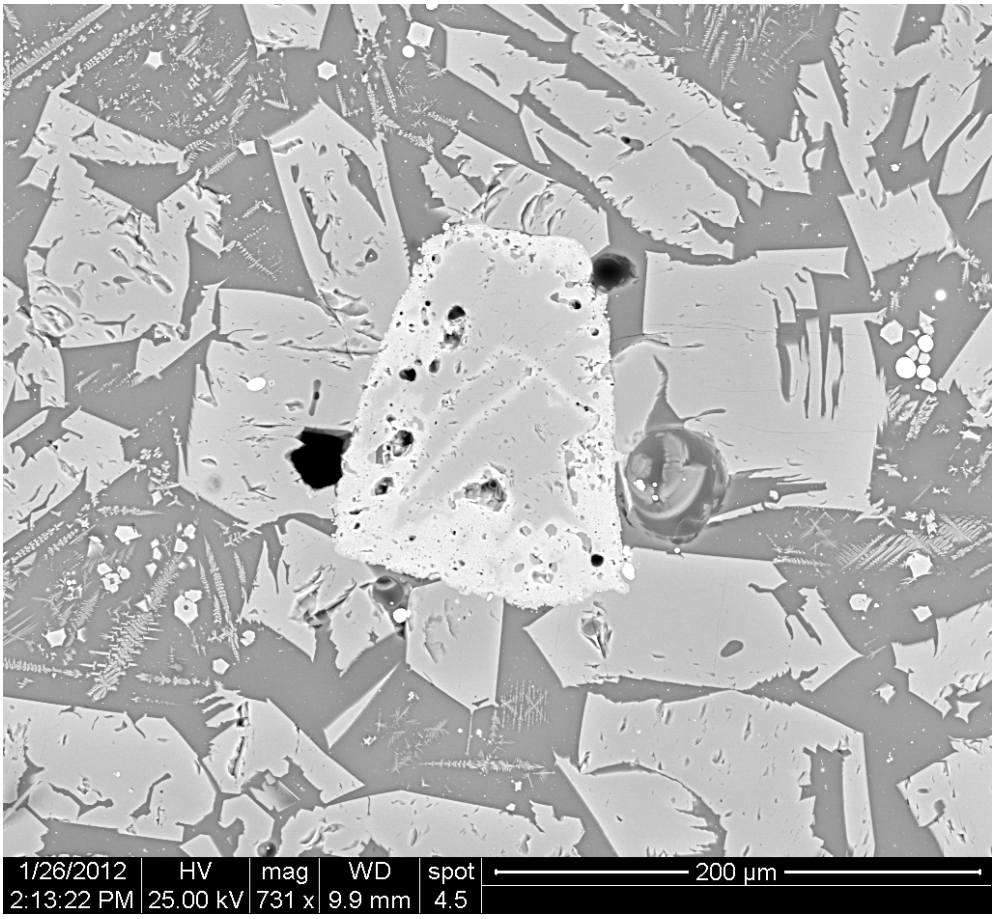
Image No. **2**



Site **ust11**

Sample No. **69**

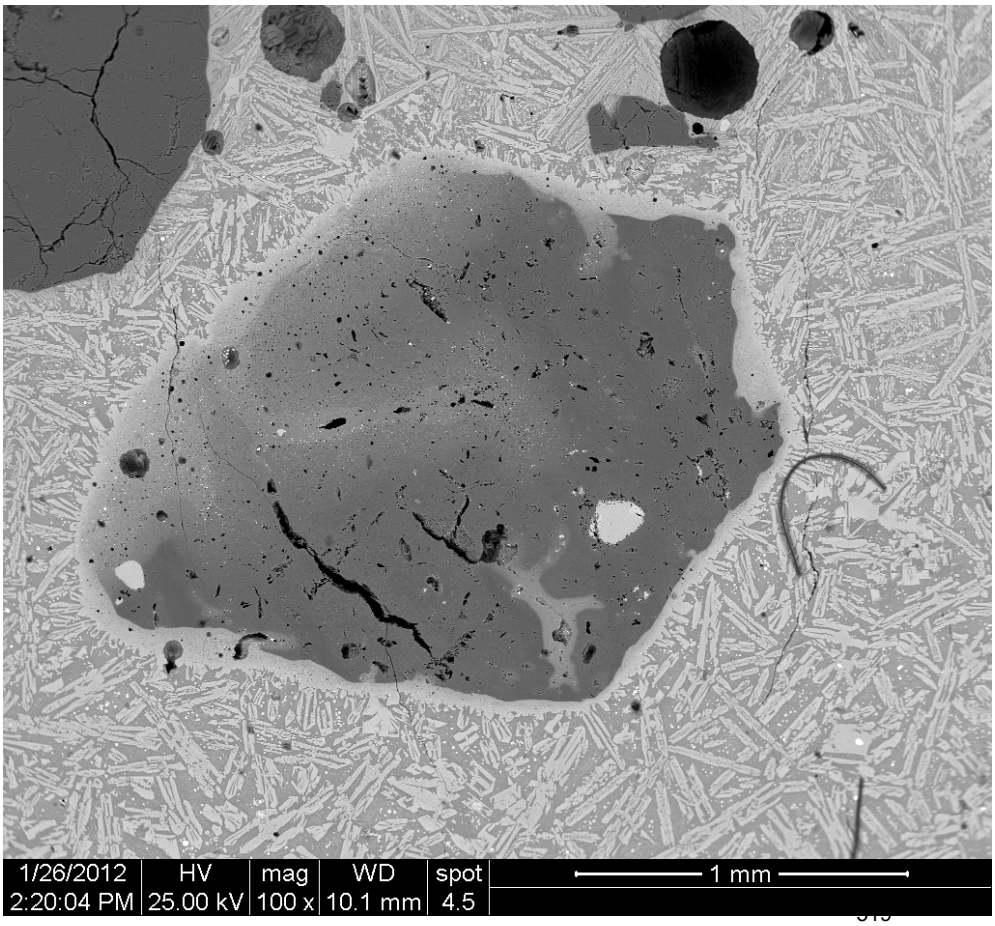
Image No. **1**



Site **ust11**

Sample No. **69**

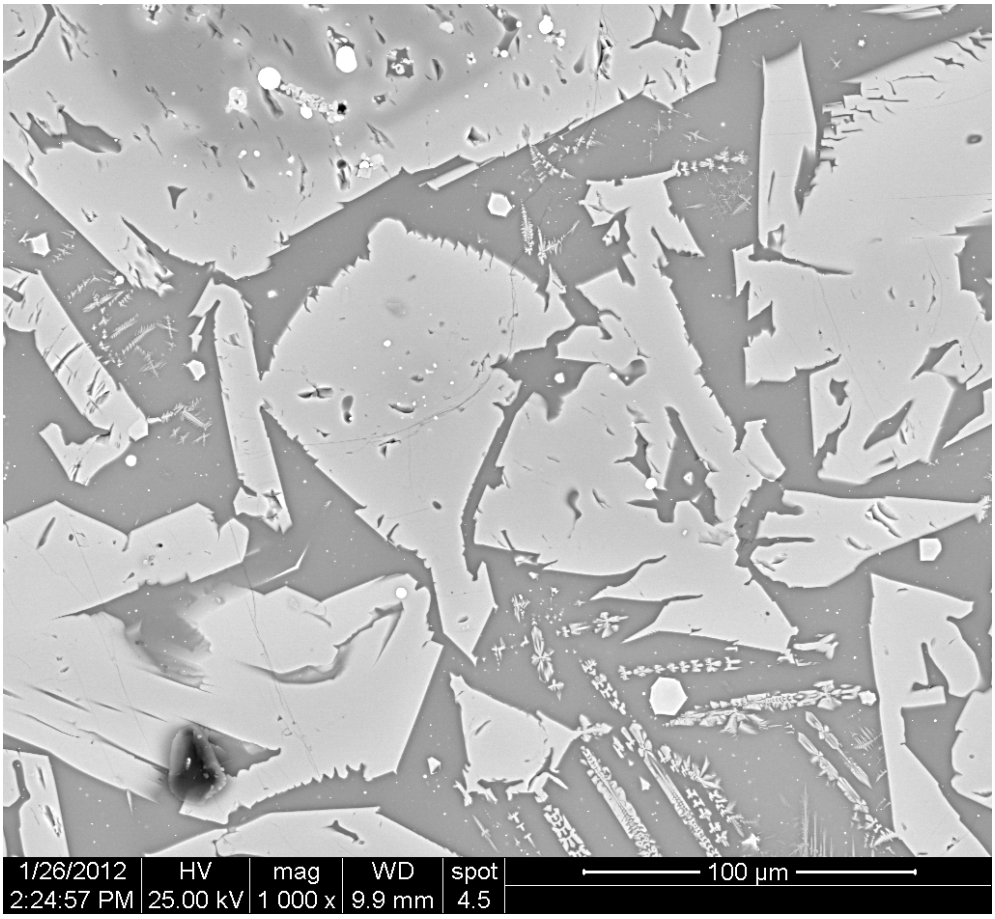
Image No. **2**



Site **ust11**

Sample No. **69**

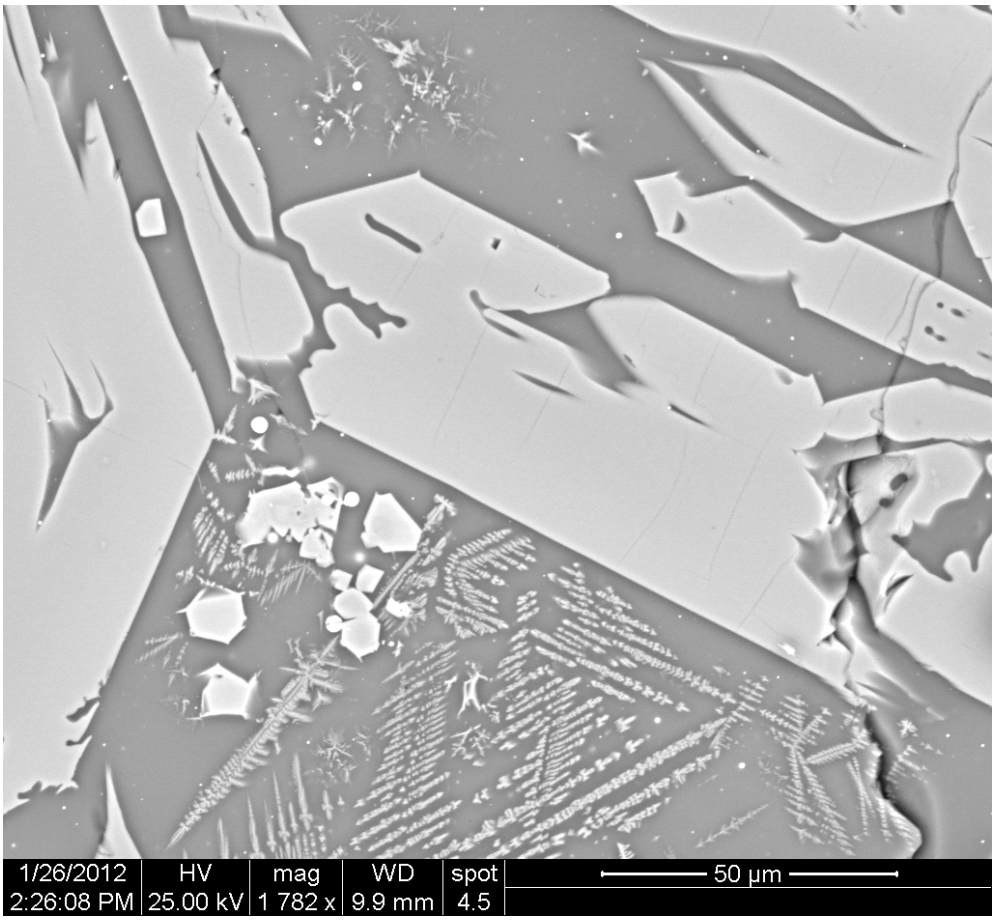
Image No. **3**



Site **ust11**

Sample No. **69**

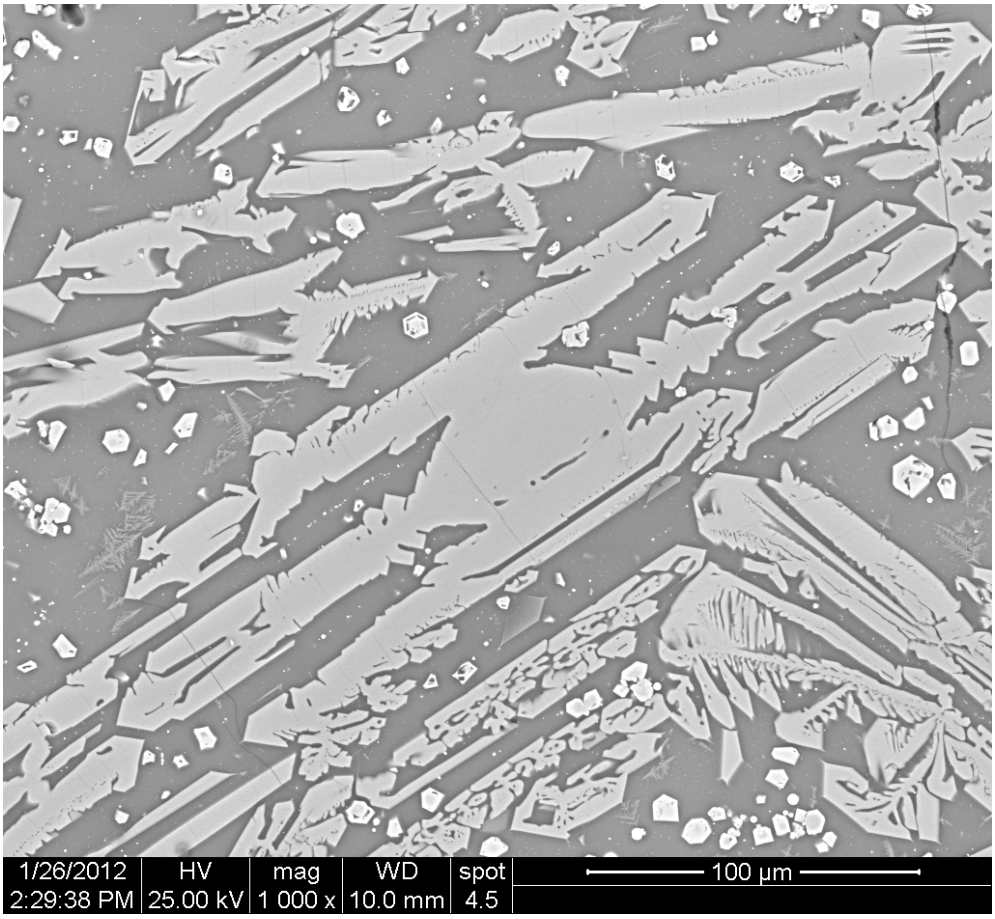
Image No. **4**



Site **ust11**

Sample No. **69**

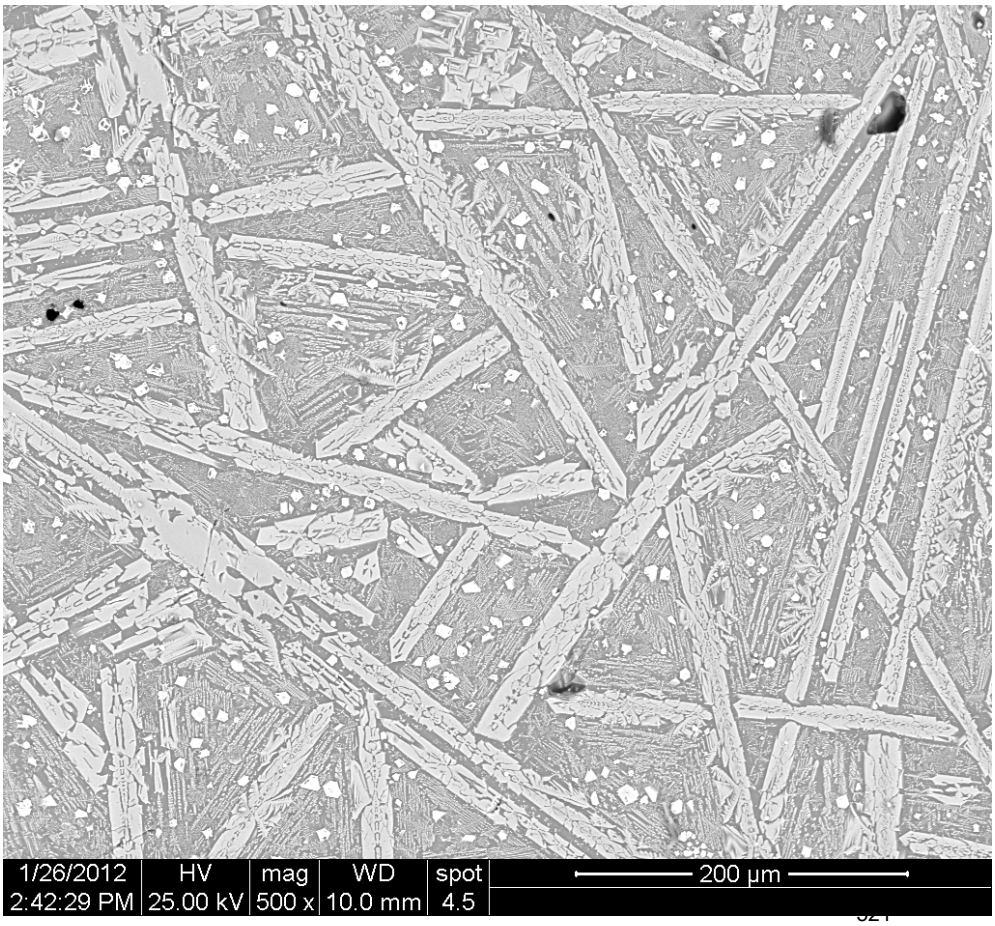
Image No. **5**



Site **ust11**

Sample No. **69**

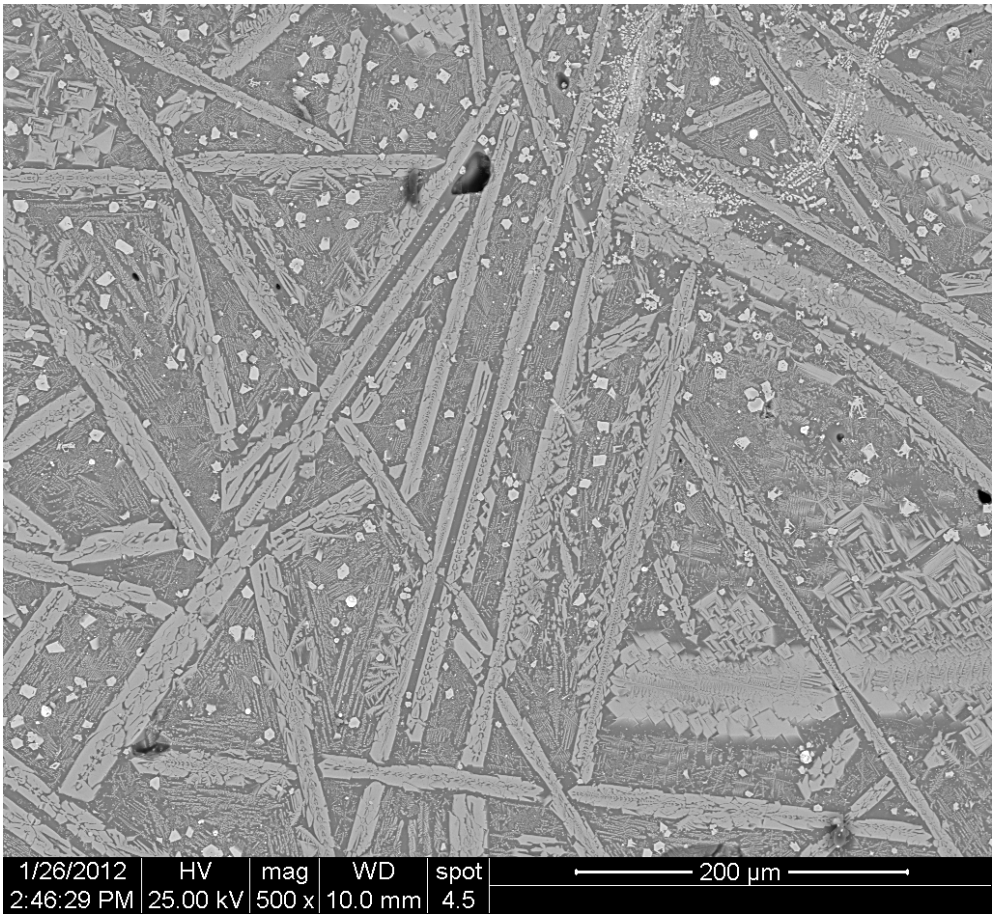
Image No. **6**



Site **ust11**

Sample No. **69**

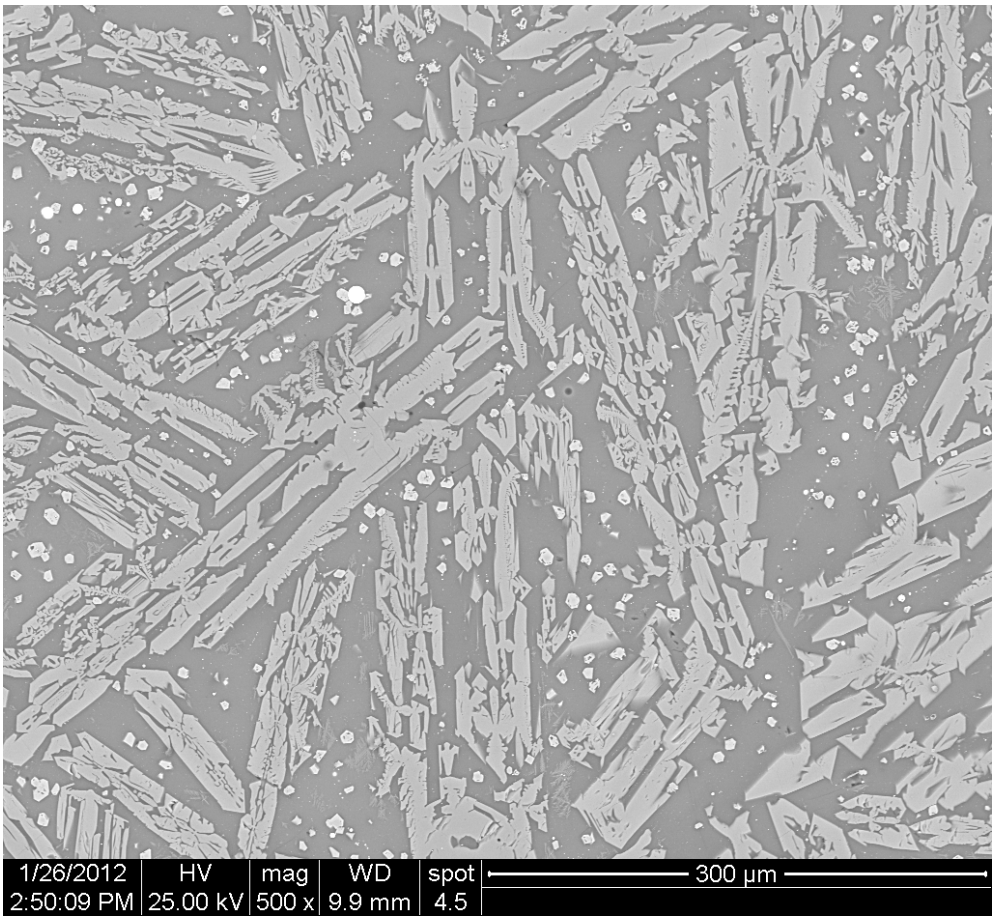
Image No. **7**



Site **ust11**

Sample No. **69**

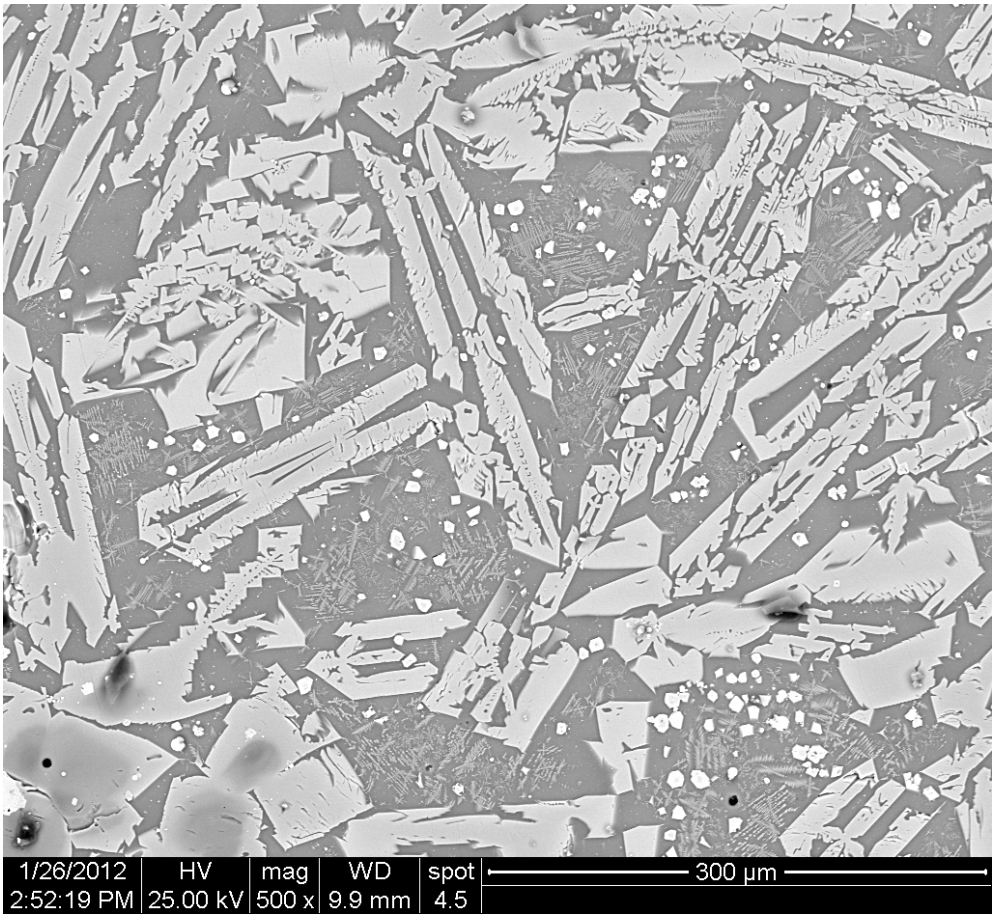
Image No. **8**



Site **ust11**

Sample No. **69**

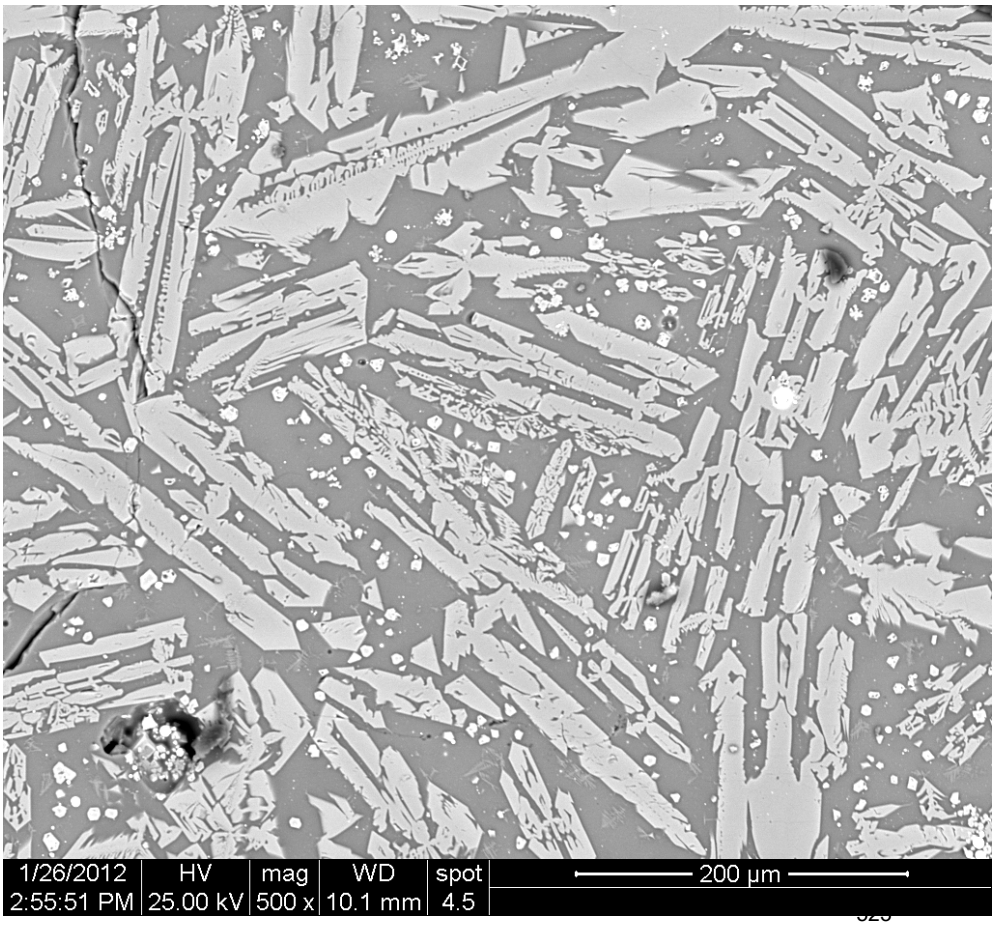
Image No. **9**



Site **ust11**

Sample No. **69**

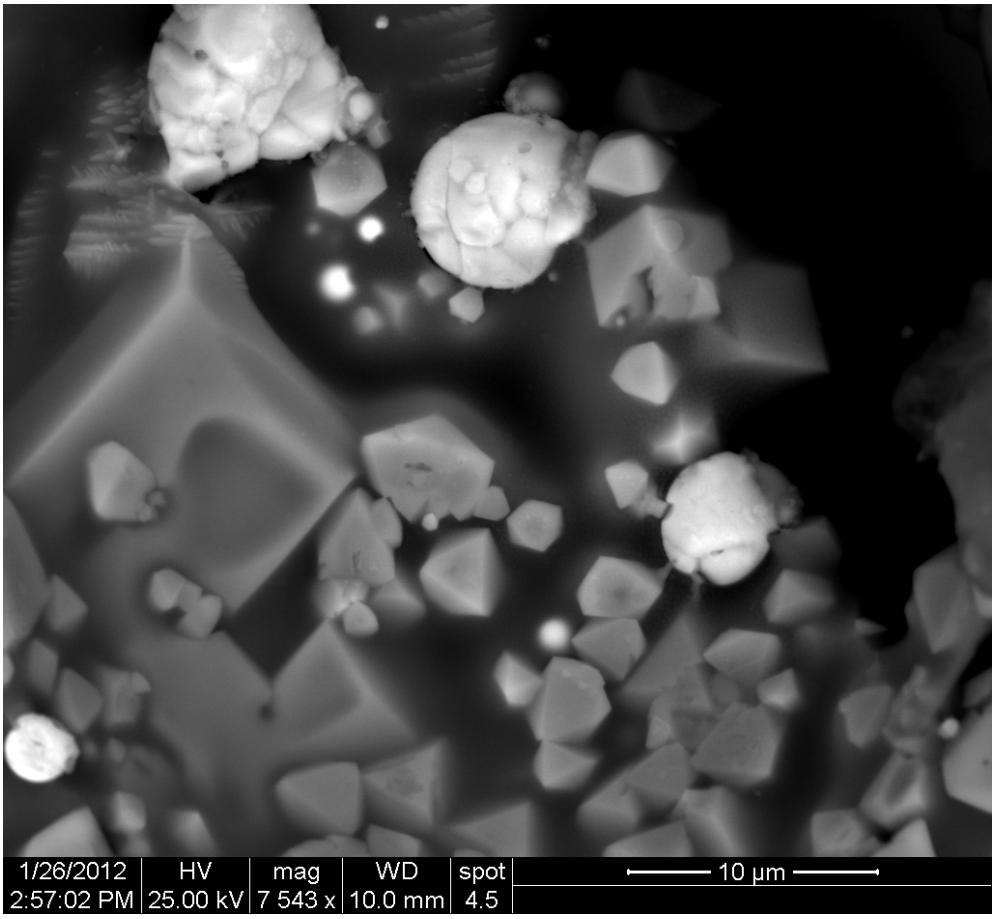
Image No. **10**



Site **ust11**

Sample No. **69**

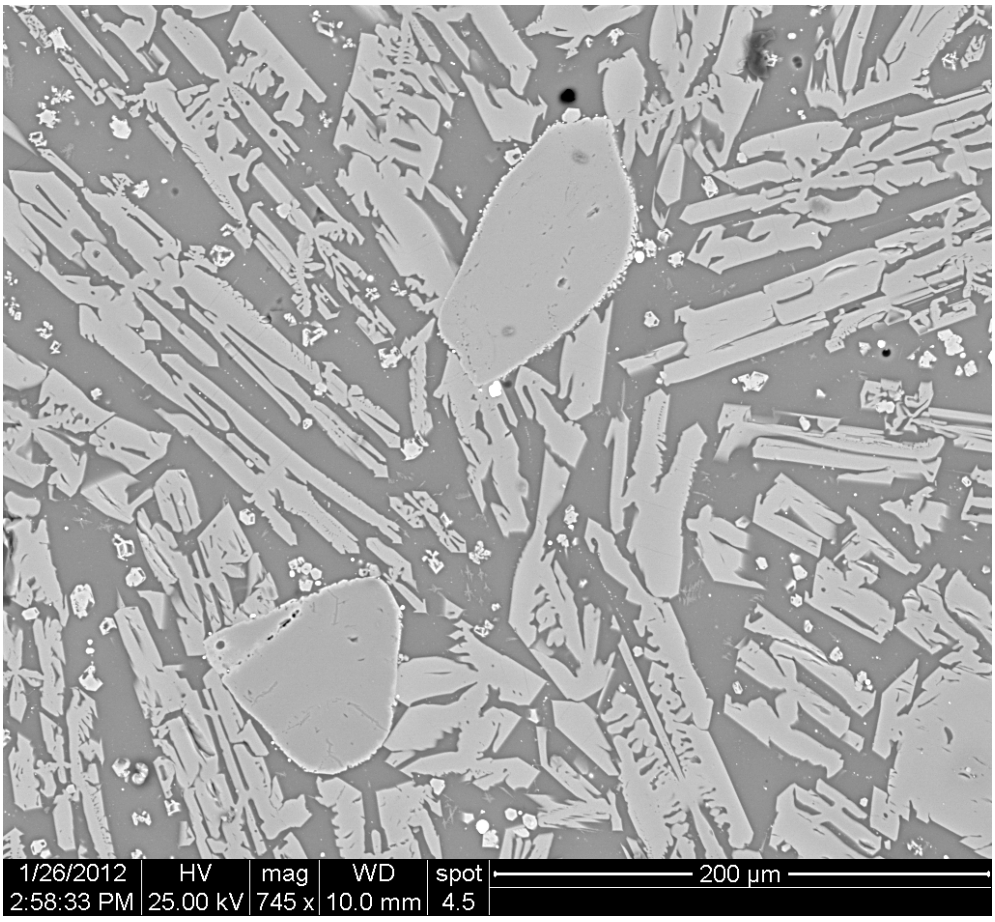
Image No. **11**



Site **ust11**

Sample No. **69**

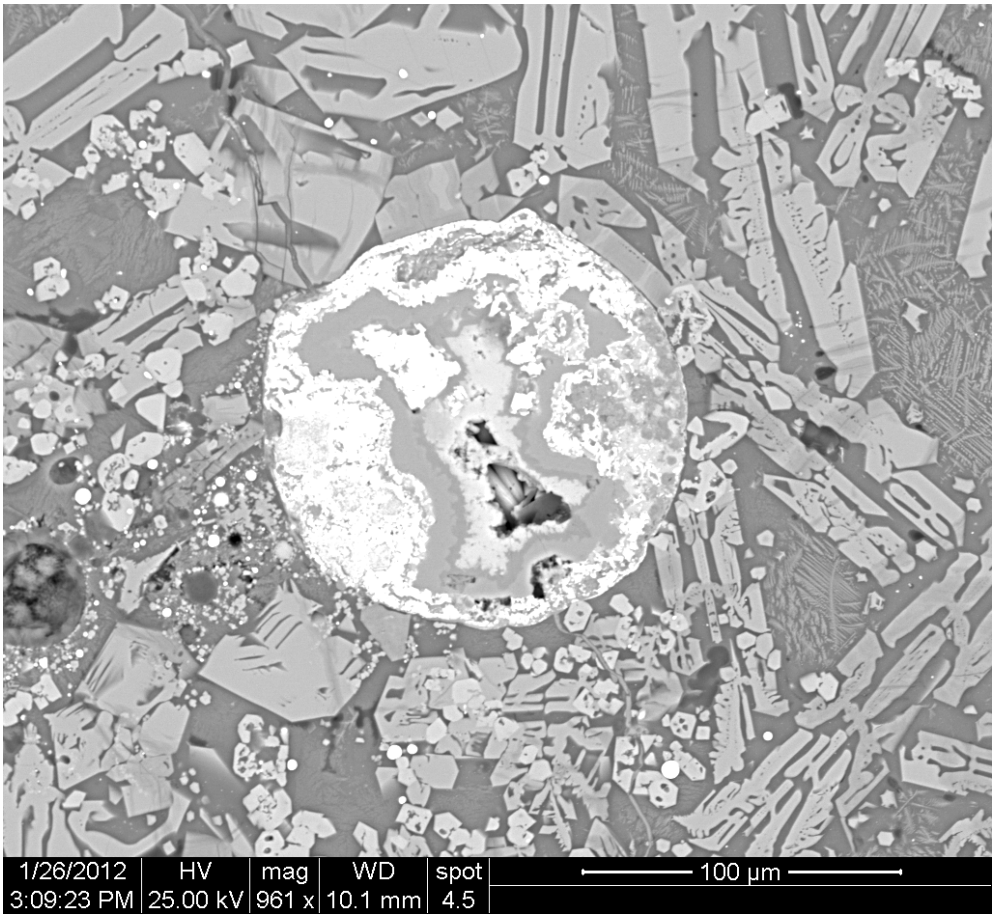
Image No. **12**



Site **ust11**

Sample No. **77**

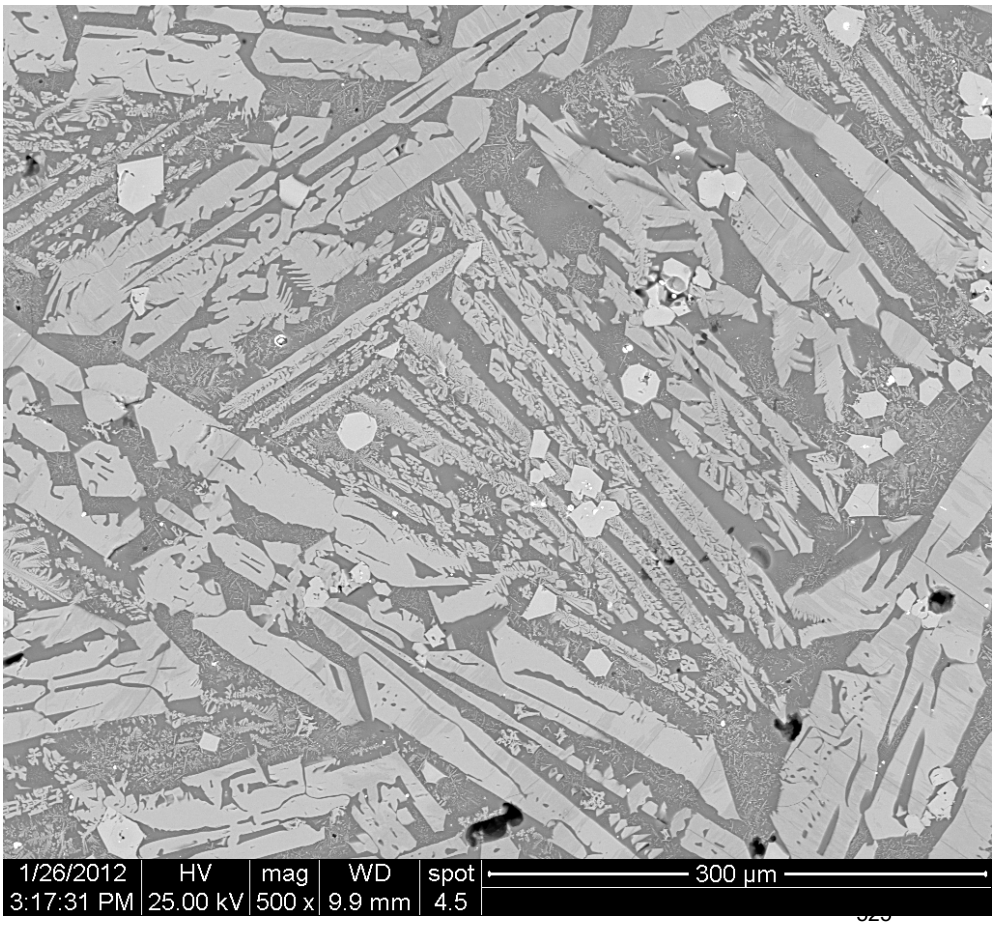
Image No. **1**



Site **ust11**

Sample No. **77**

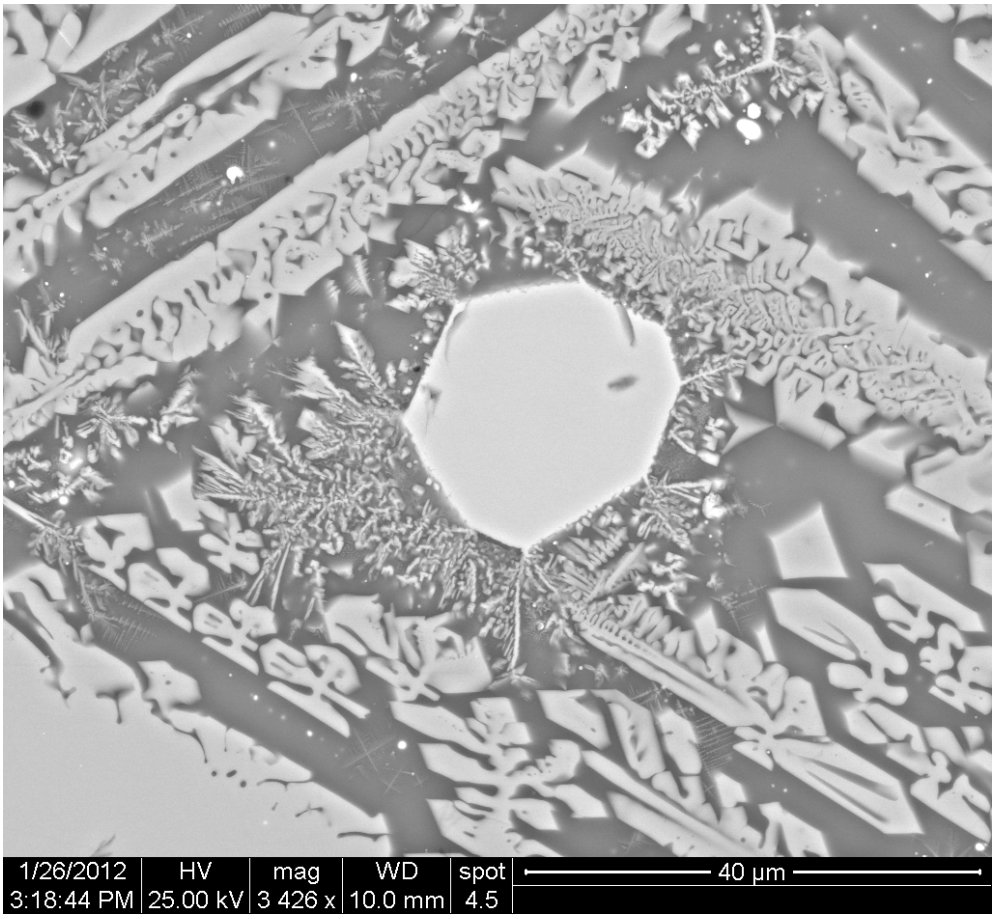
Image No. **2**



Site **ust11**

Sample No. **77**

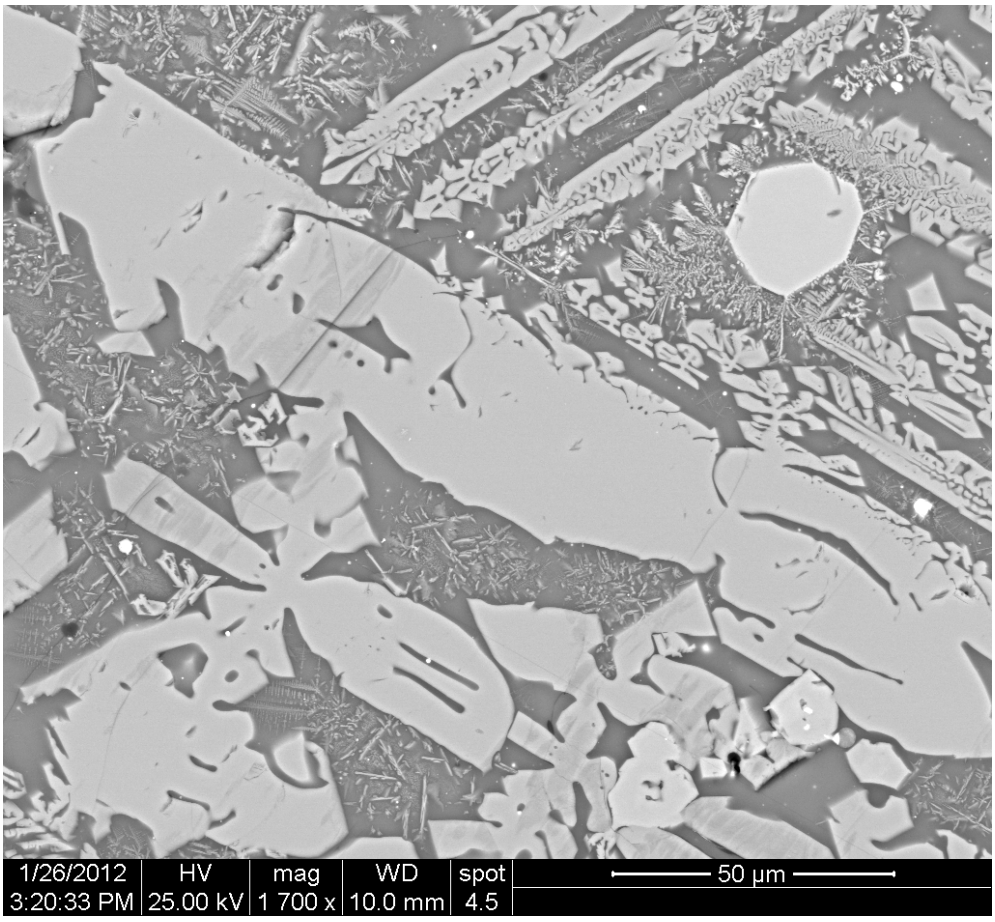
Image No. **3**



Site **ust11**

Sample No. **77**

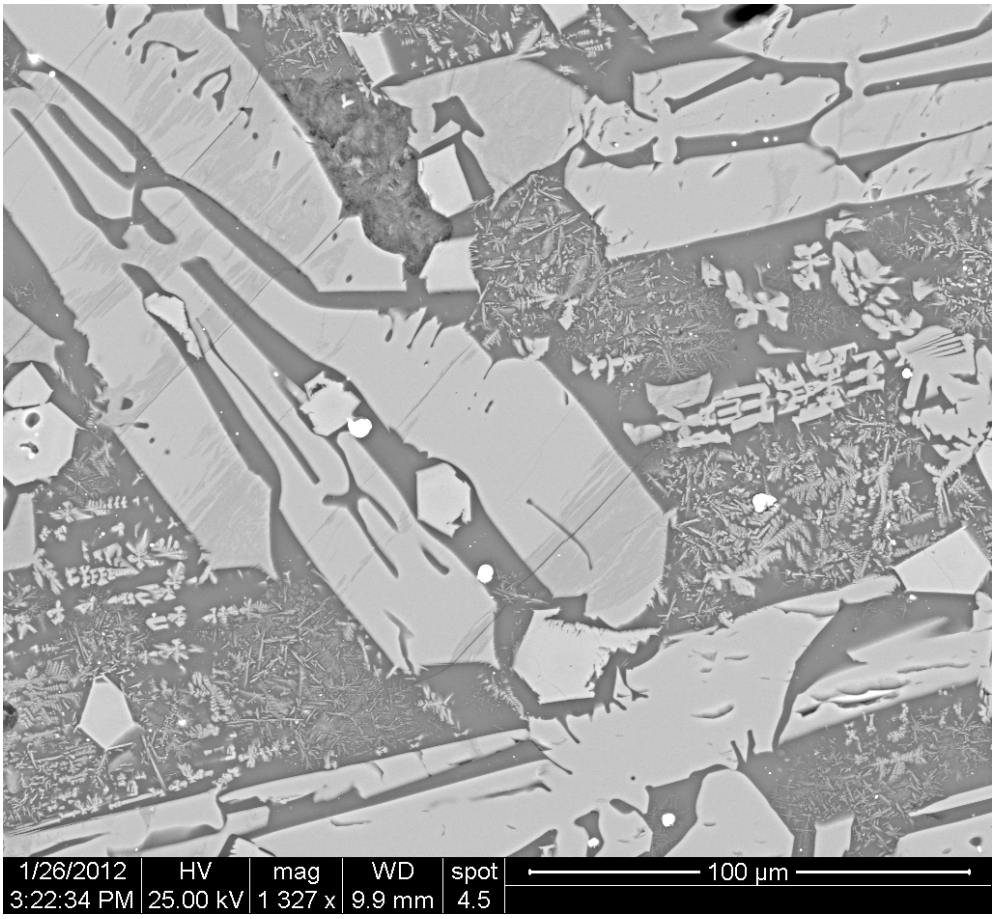
Image No. **4**



Site **ust11**

Sample No. **77**

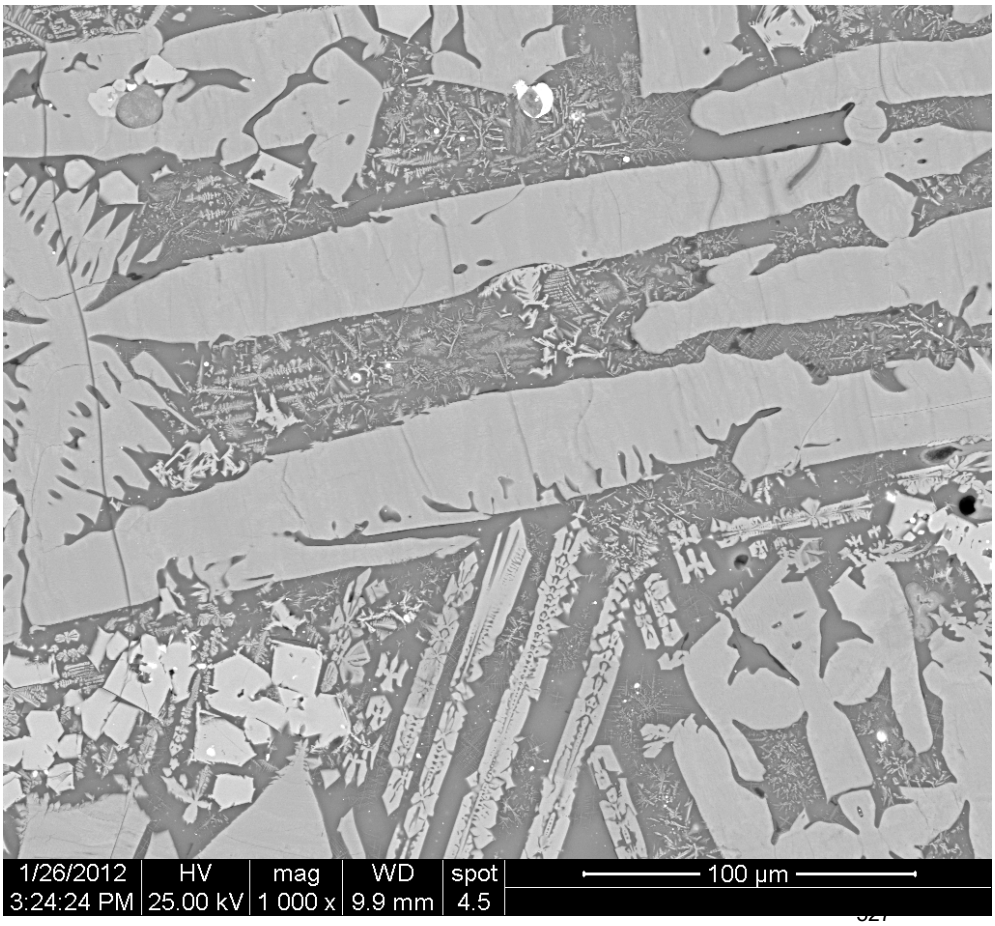
Image No. **5**



Site **ust11**

Sample No. **77**

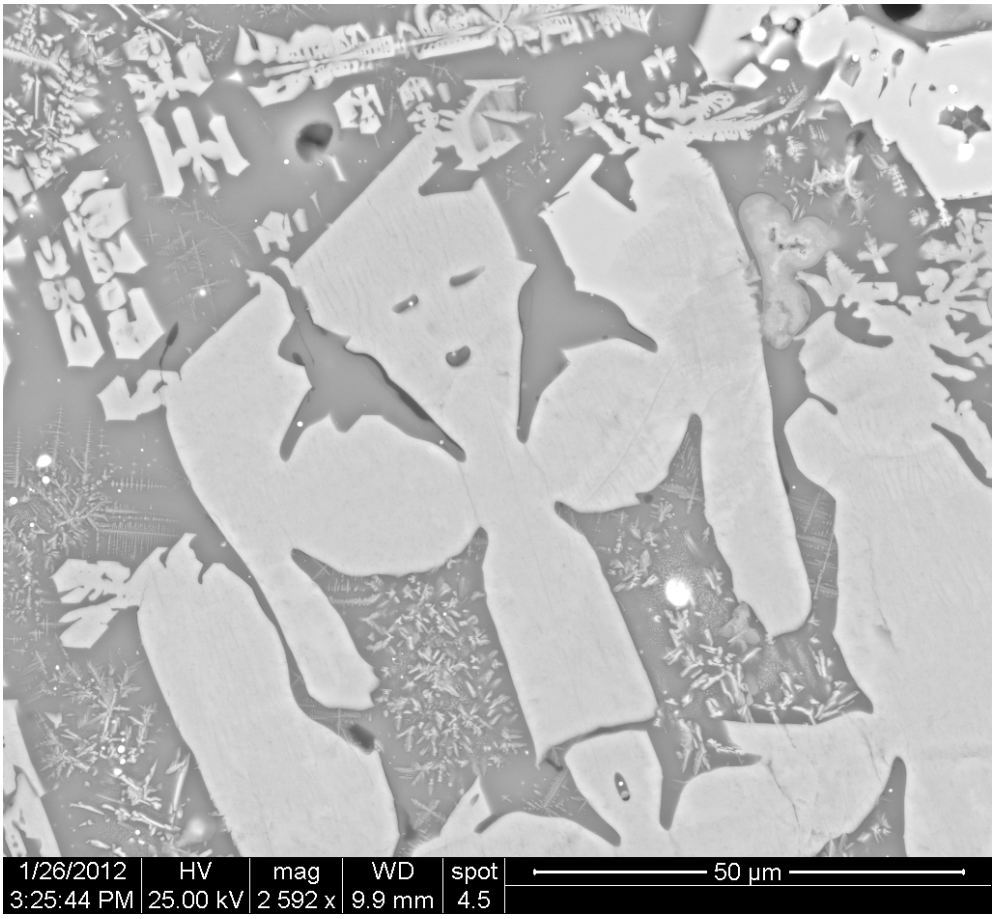
Image No. **6**



Site **ust11**

Sample No. **77**

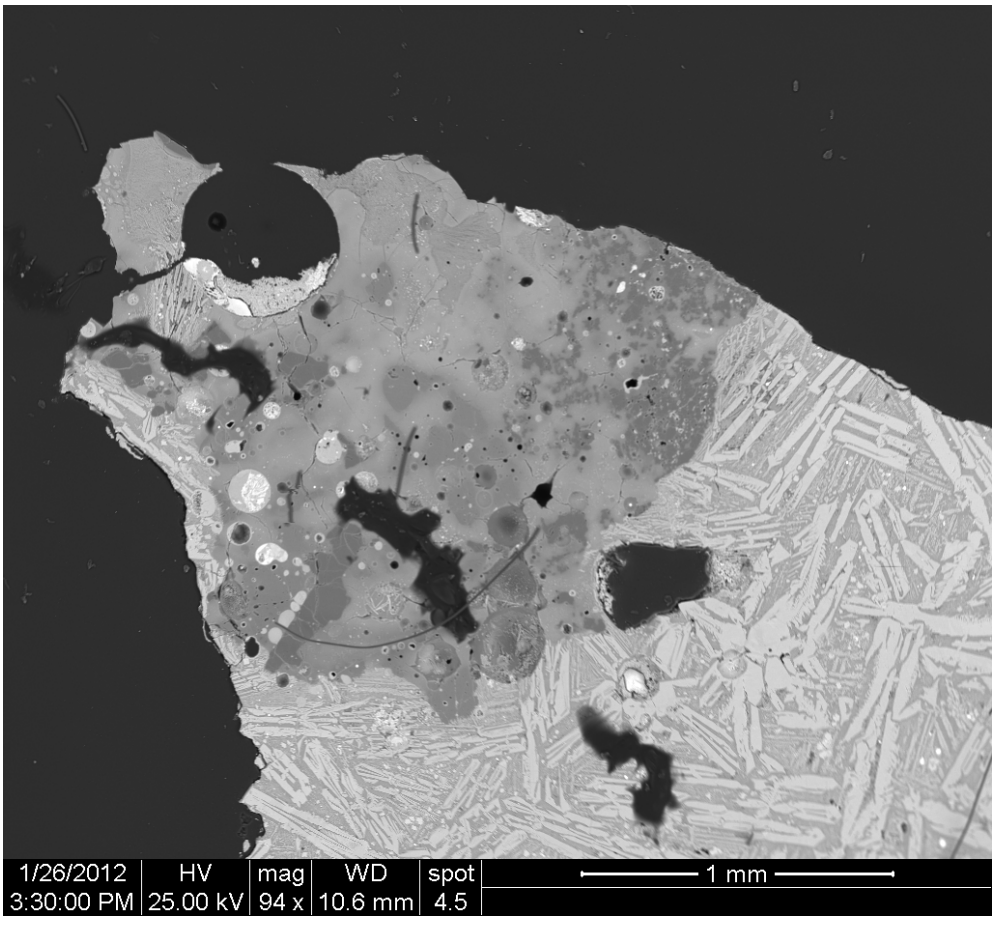
Image No. **7**



Site **ust11**

Sample No. **77**

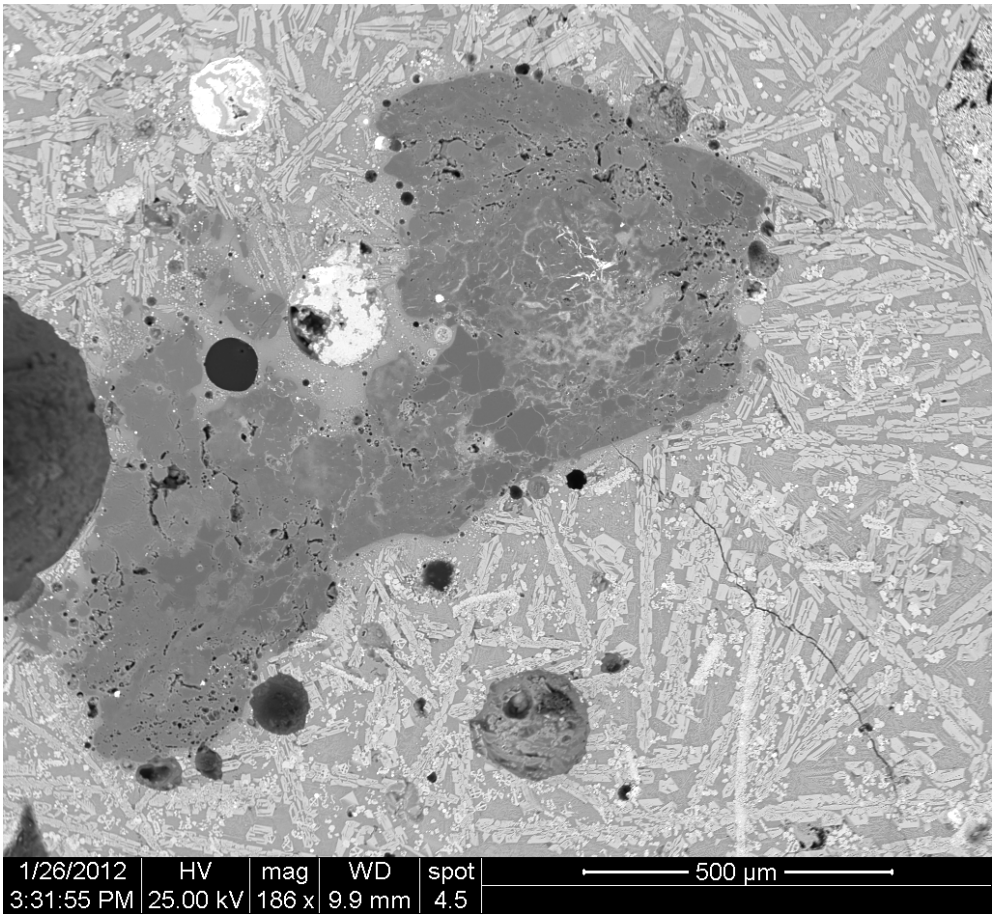
Image No. **8**



Site **ust11**

Sample No. **77**

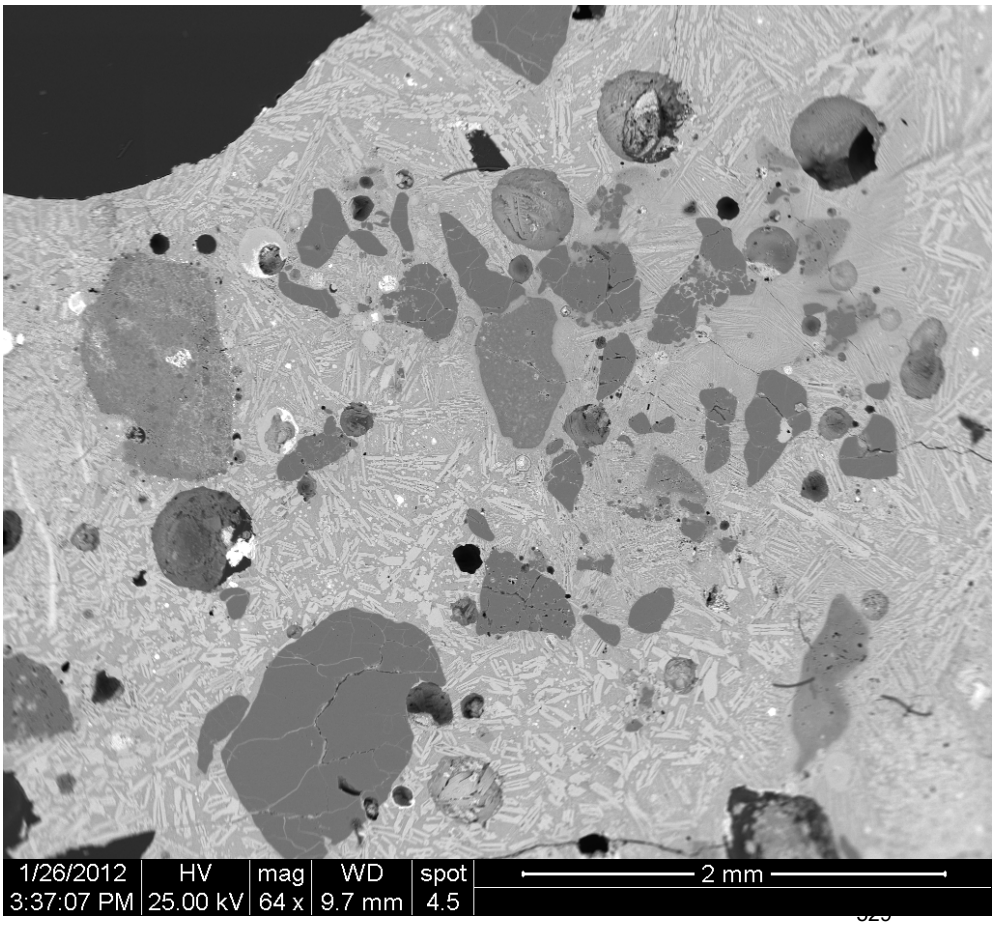
Image No. **9**



Site **ust11**

Sample No. **77**

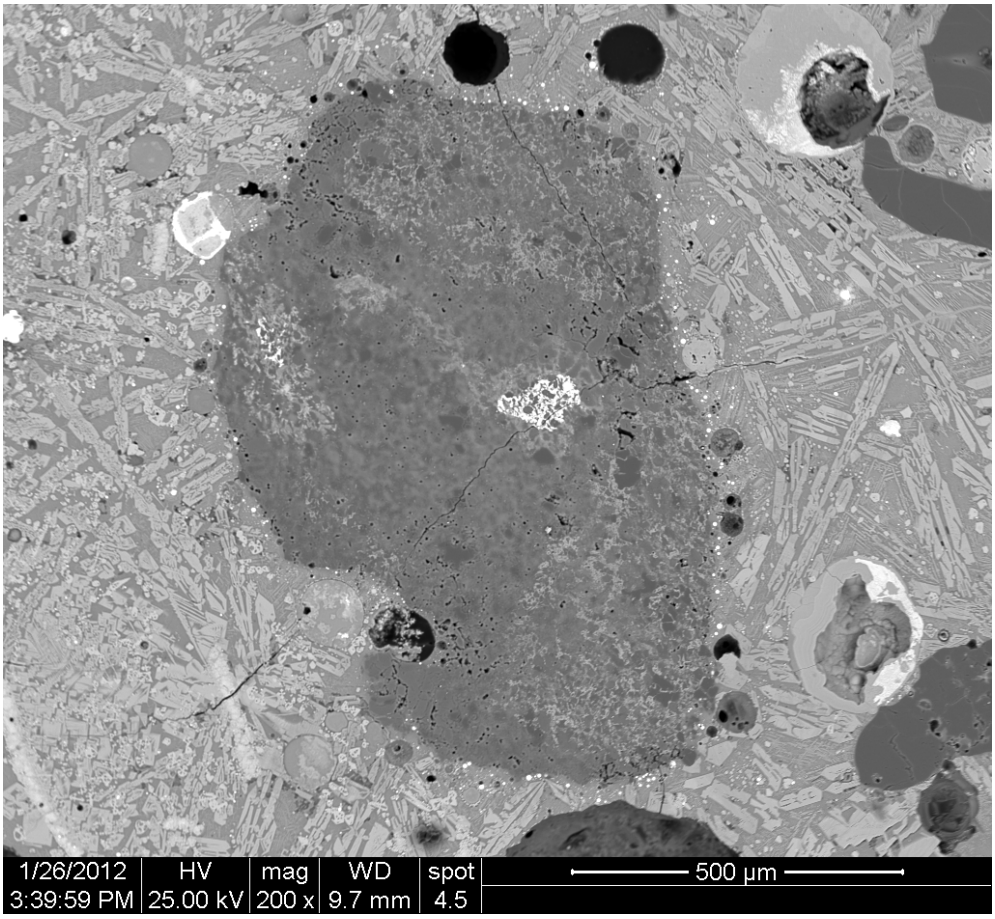
Image No. **10**



Site **ust11**

Sample No. **77**

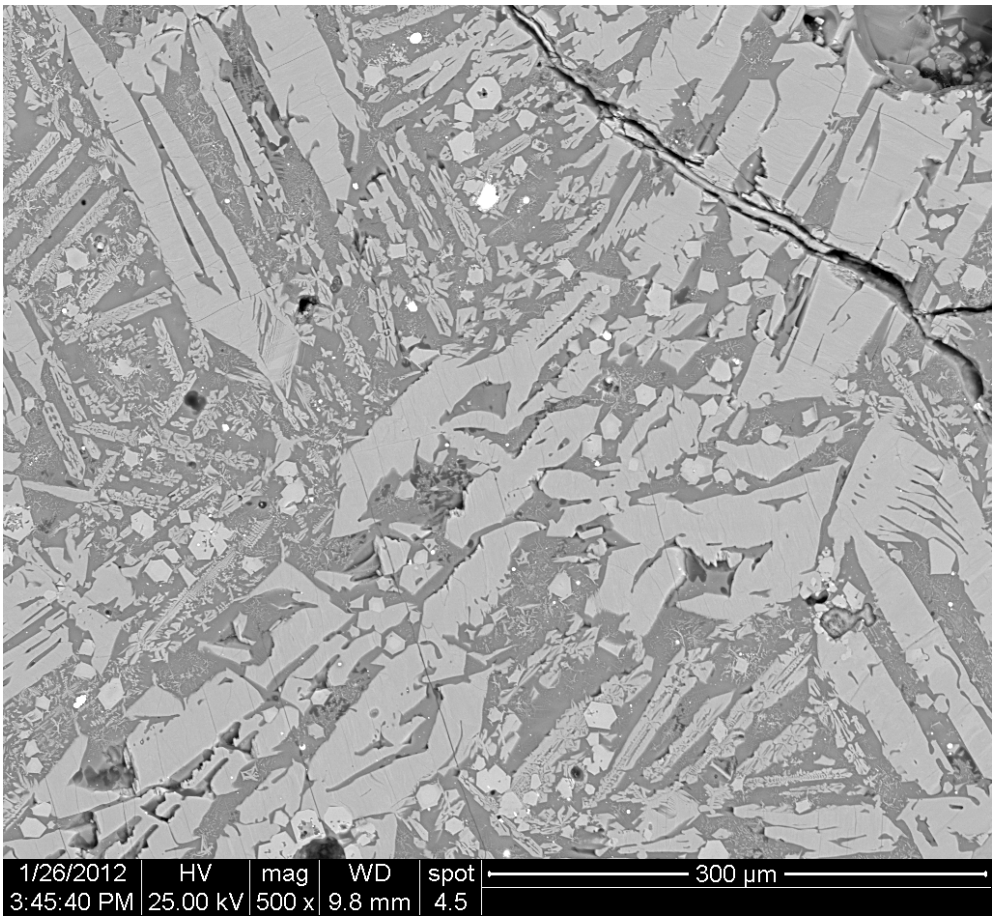
Image No. **11**



Site **ust11**

Sample No. **77**

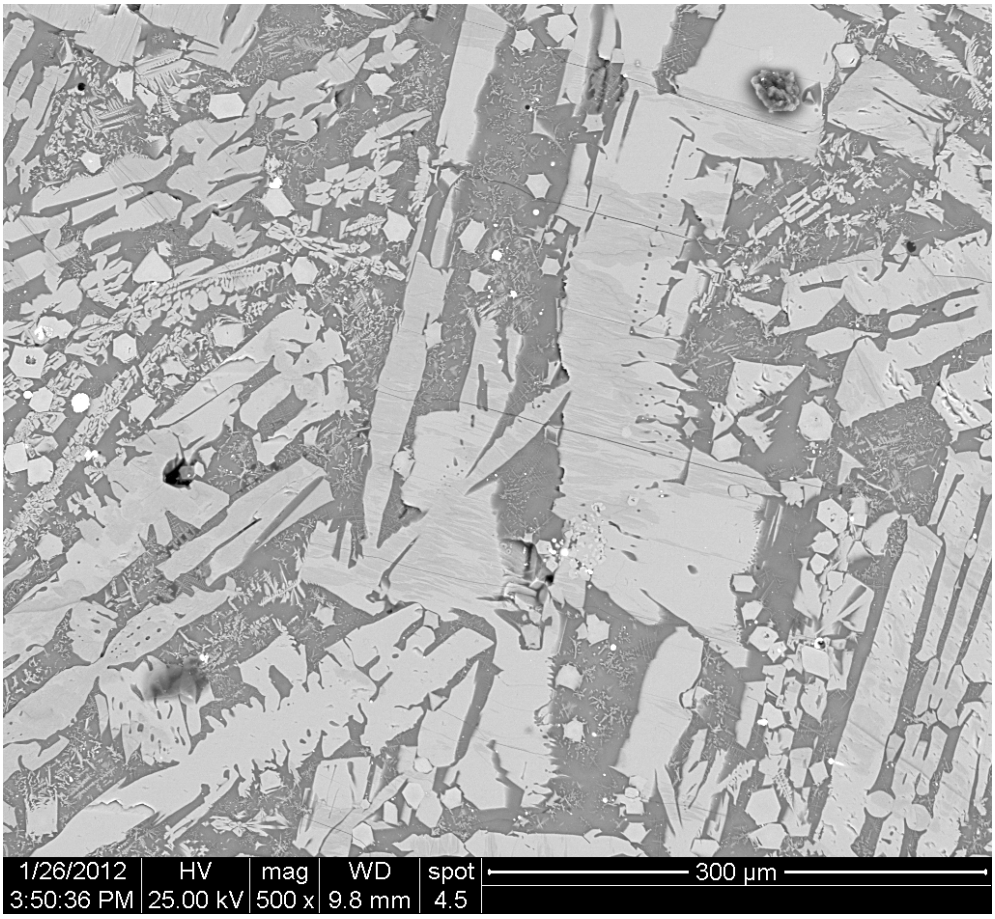
Image No. **12**



Site **ust11**

Sample No. **77**

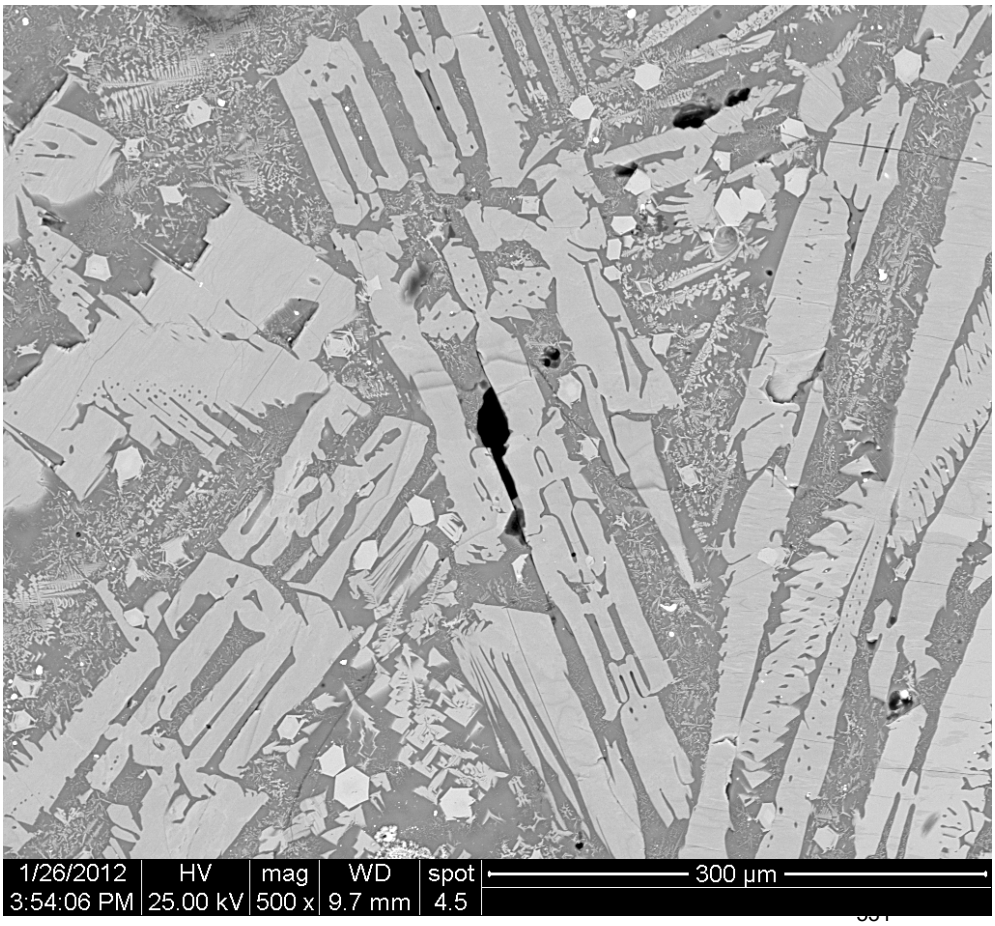
Image No. **13**



Site **ust11**

Sample No. **77**

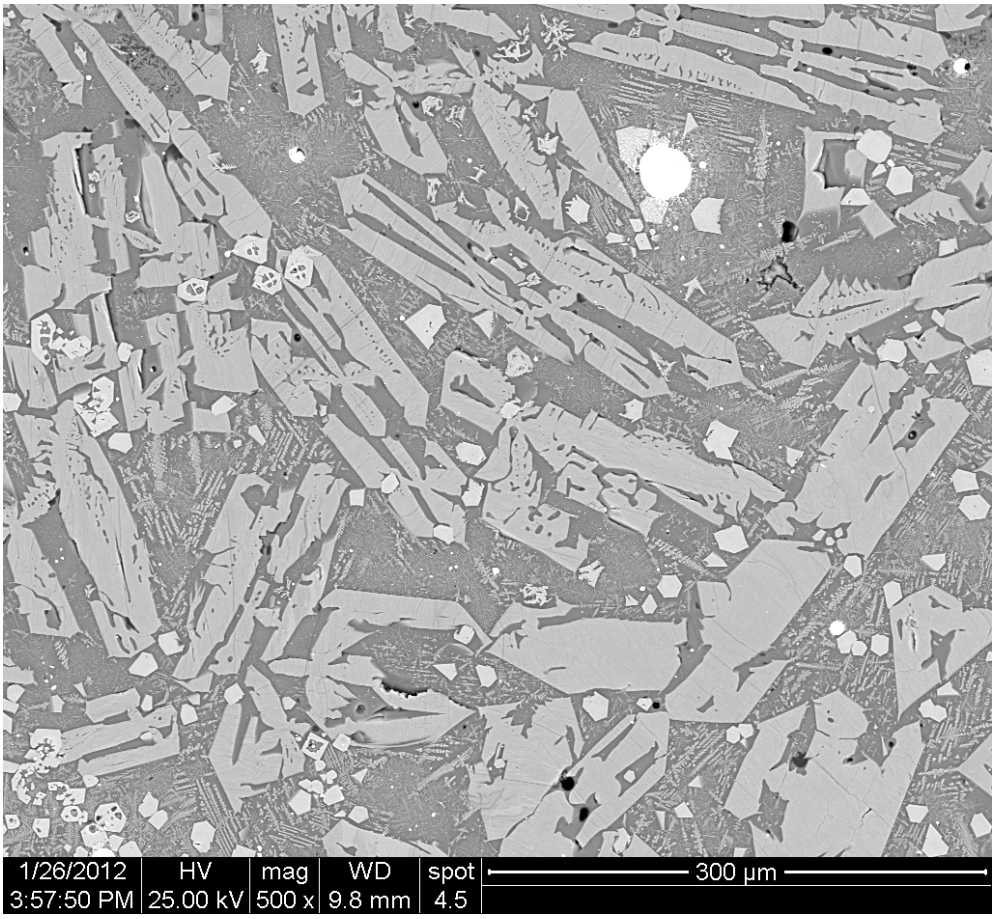
Image No. **14**



Site **ust11**

Sample No. **77**

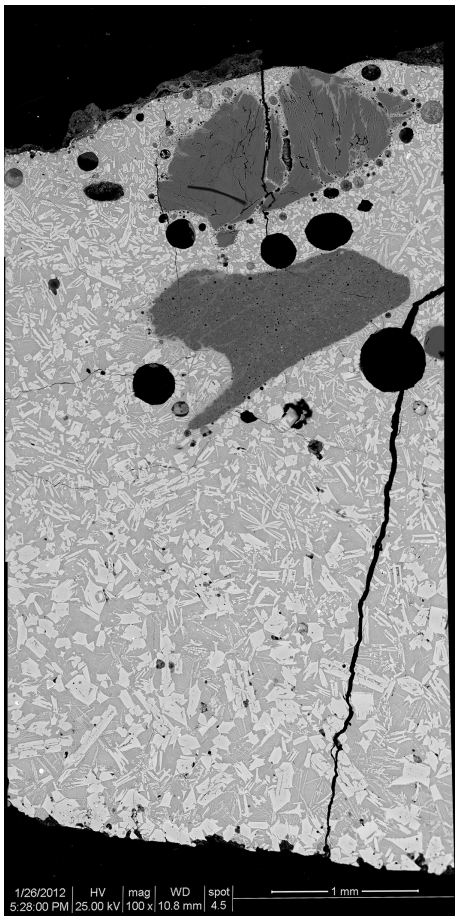
Image No. **15**



Site **ust11**

Sample No. **83**

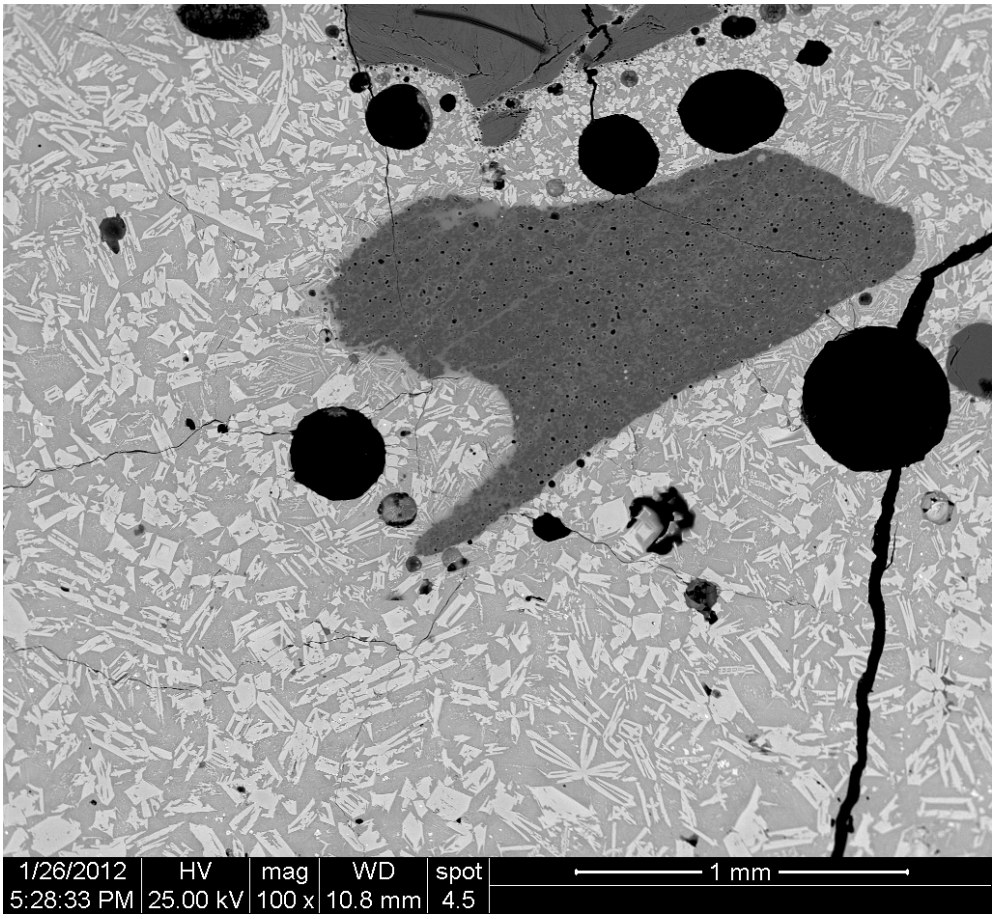
Image No. **1**



Site **ust11**

Sample No. **83**

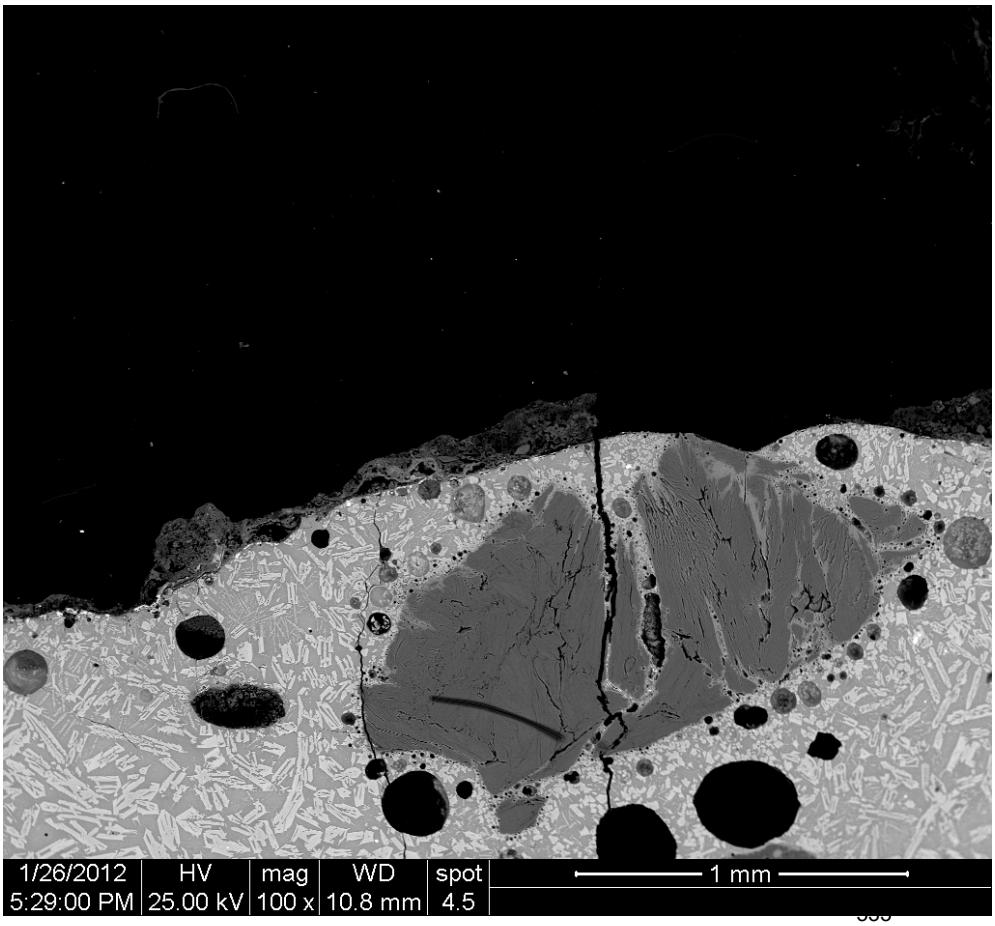
Image No. **2**



Site **ust11**

Sample No. **83**

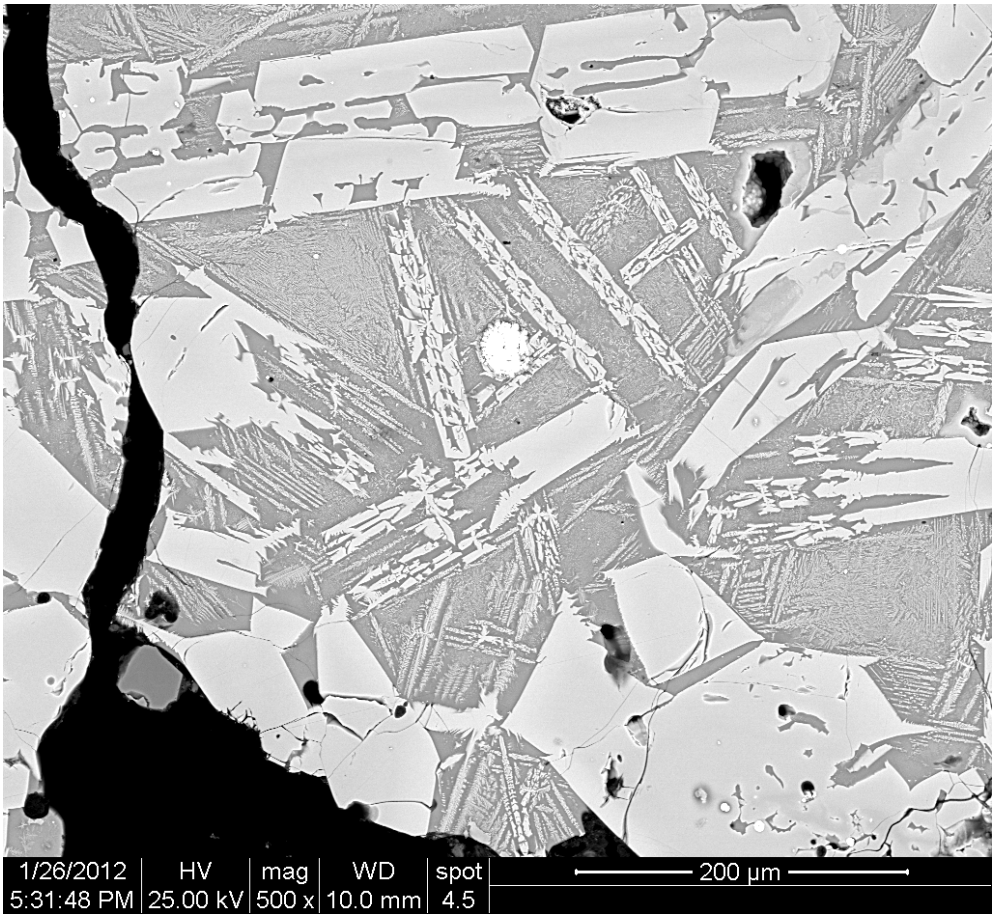
Image No. **3**



Site **ust11**

Sample No. **83**

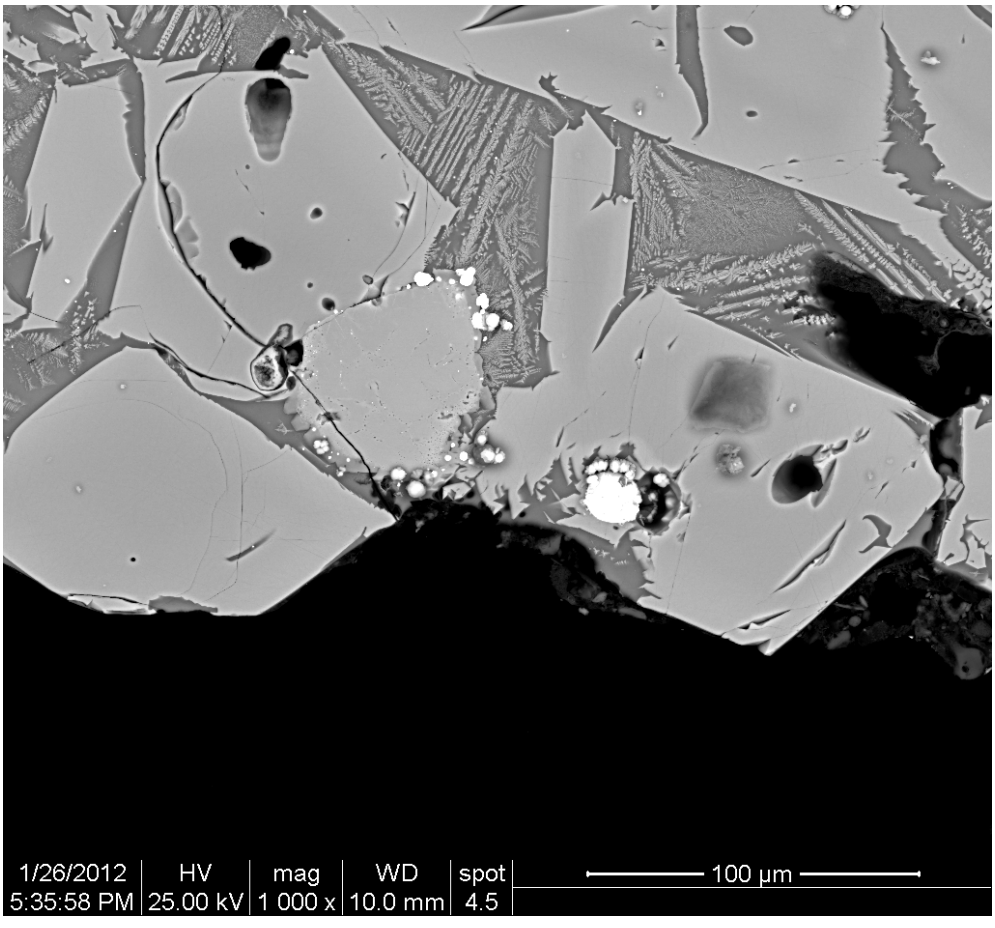
Image No. **4**



Site **ust11**

Sample No. **83**

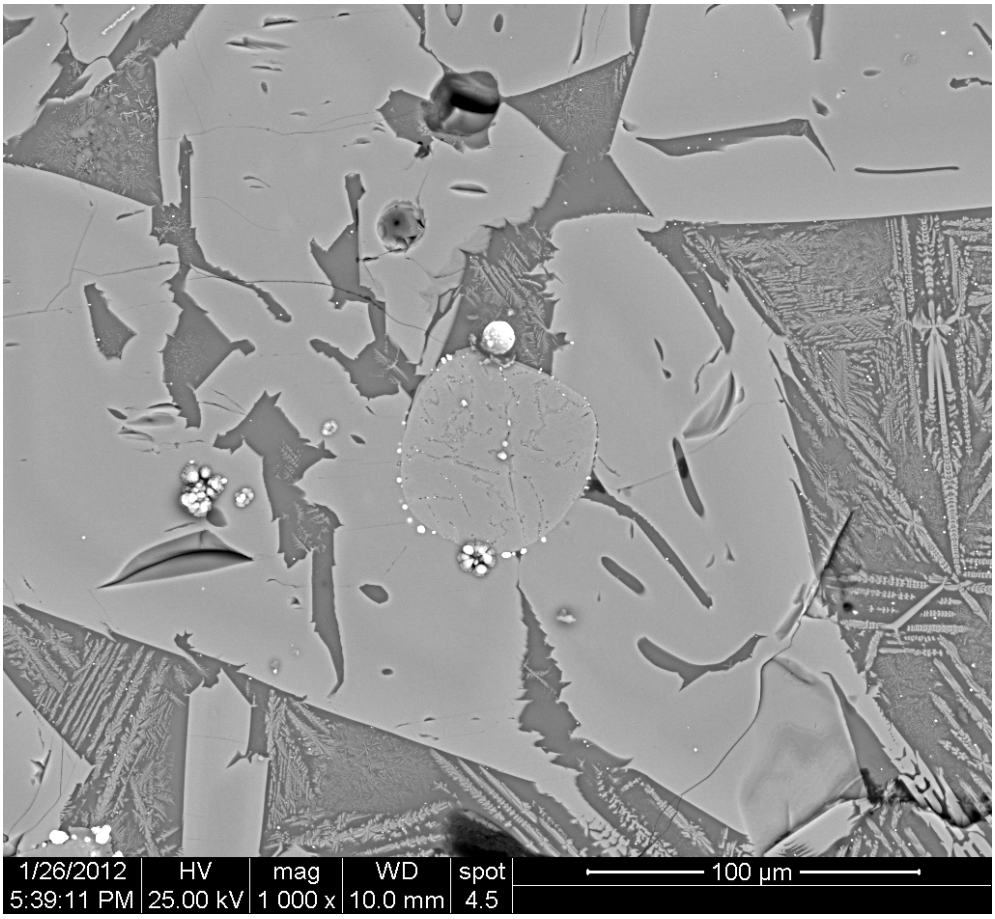
Image No. **5**



Site **ust11**

Sample No. **83**

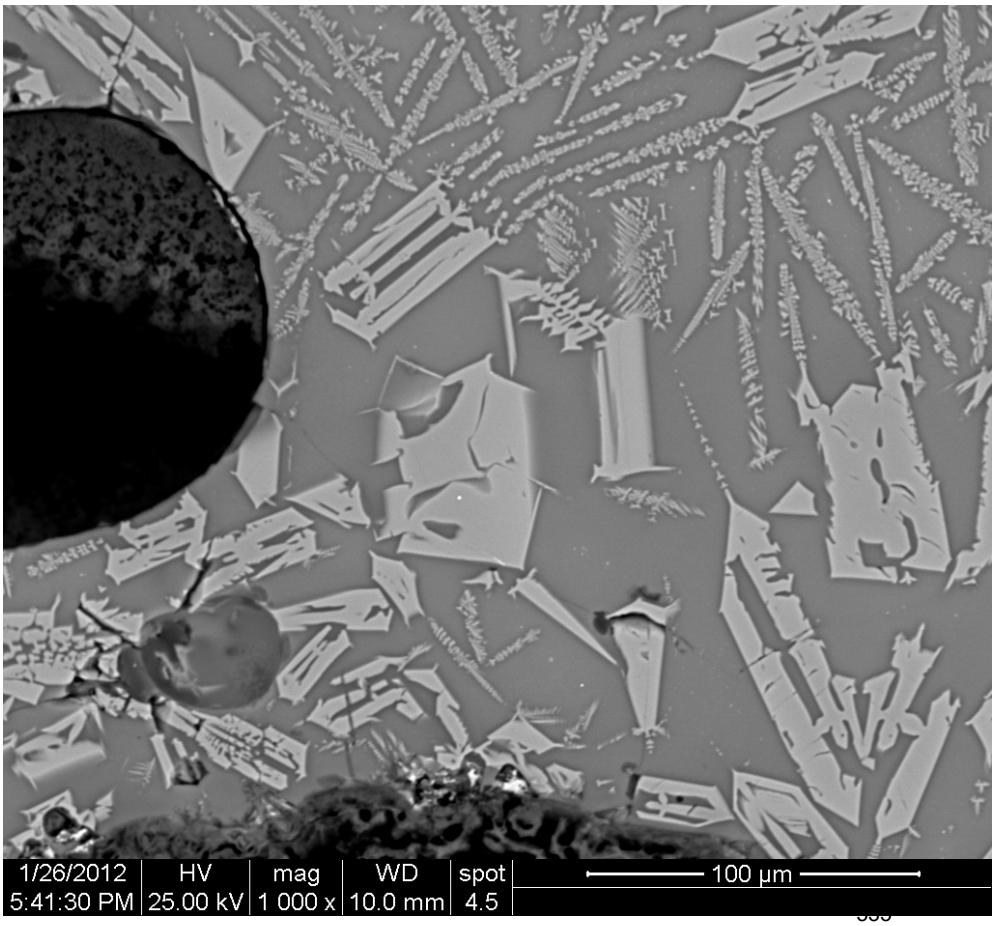
Image No. **6**



Site **ust11**

Sample No. **83**

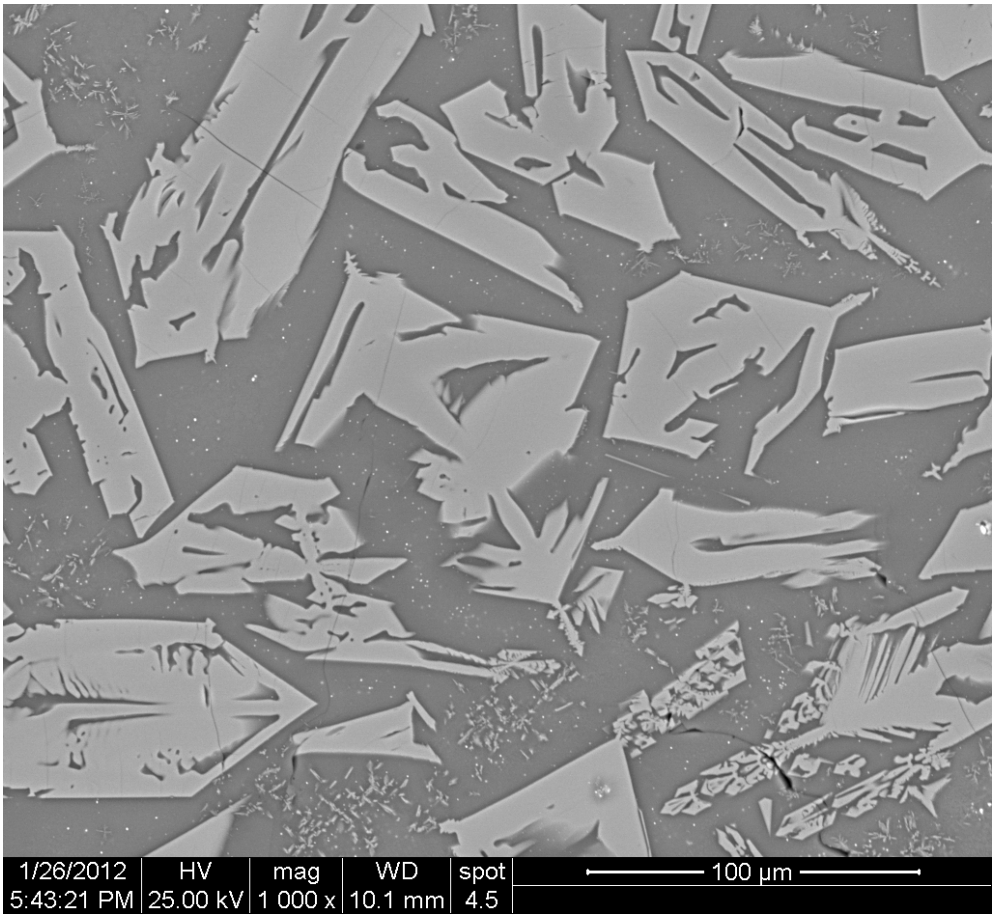
Image No. **7**



Site **ust11**

Sample No. **83**

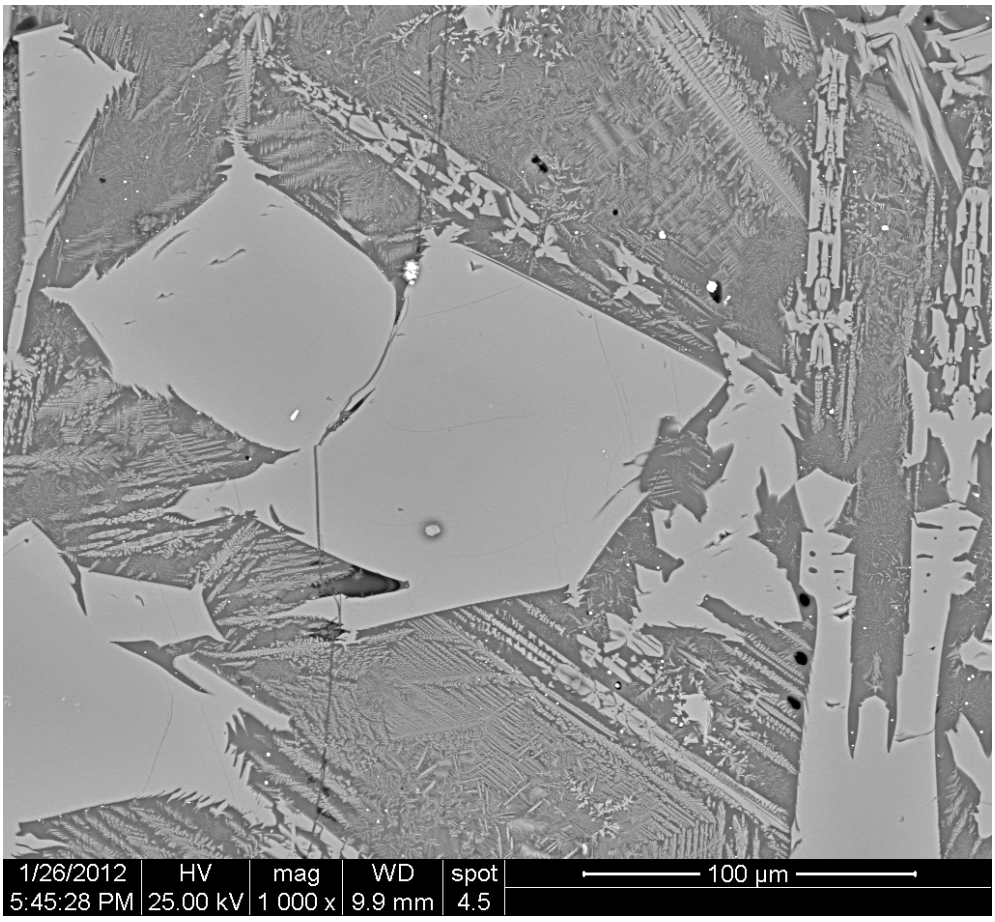
Image No. **8**



Site **ust11**

Sample No. **83**

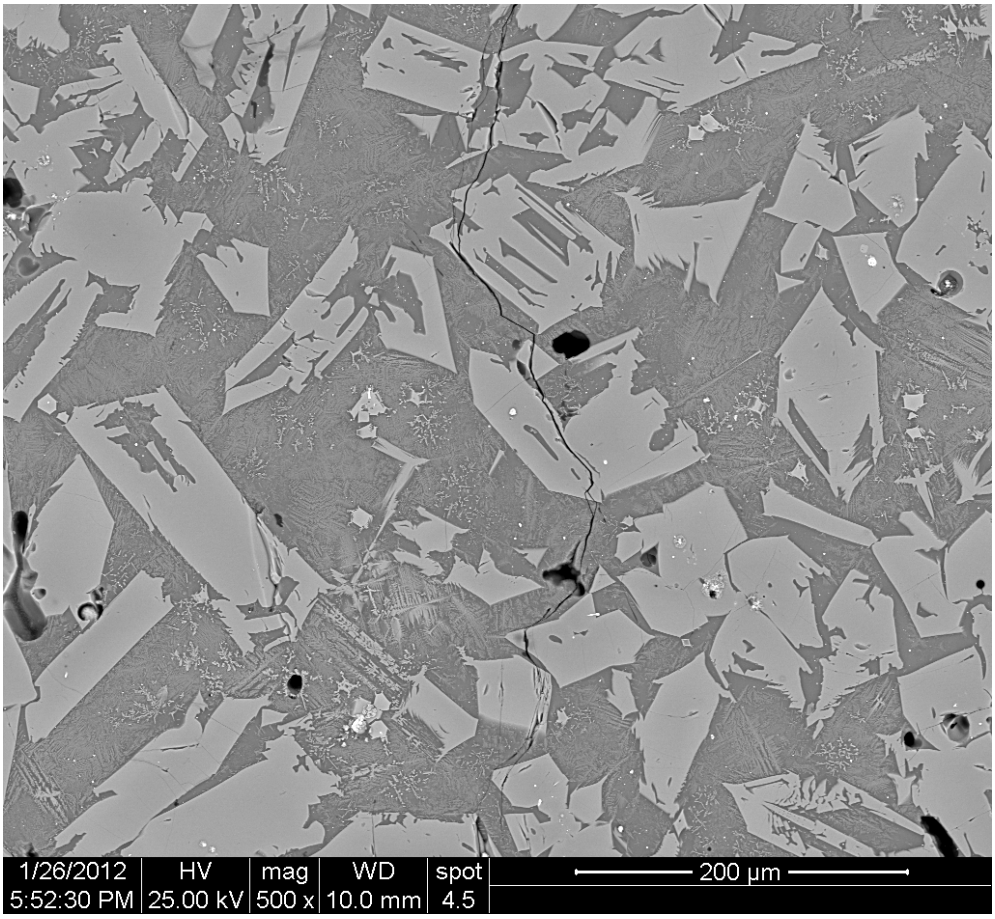
Image No. **9**



Site **ust11**

Sample No. **83**

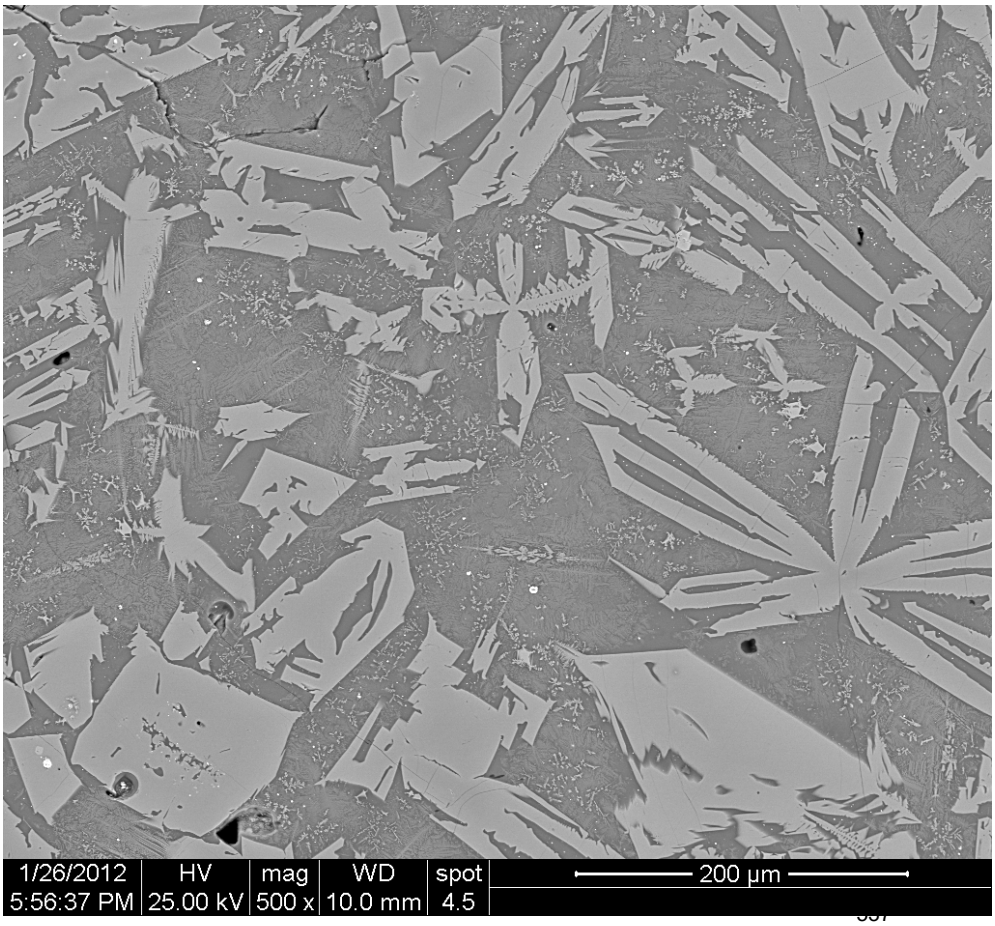
Image No. **10**



Site **ust11**

Sample No. **83**

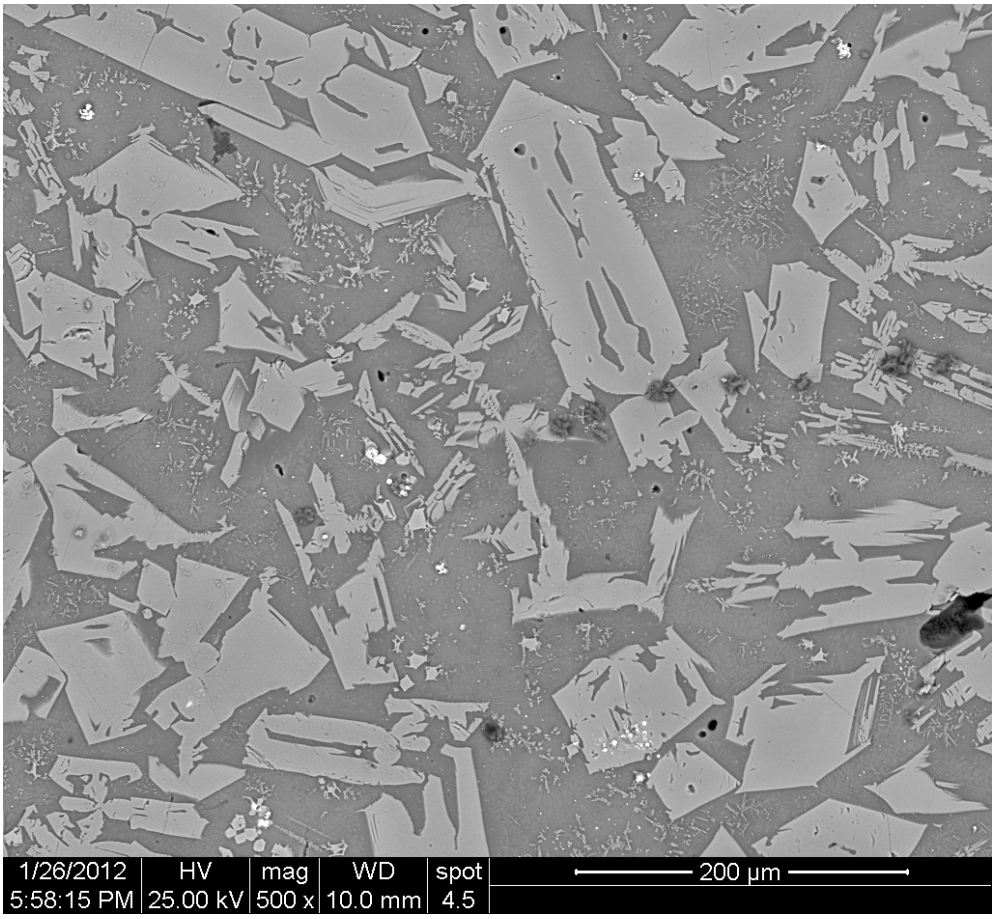
Image No. **11**



Site **ust11**

Sample No. **83**

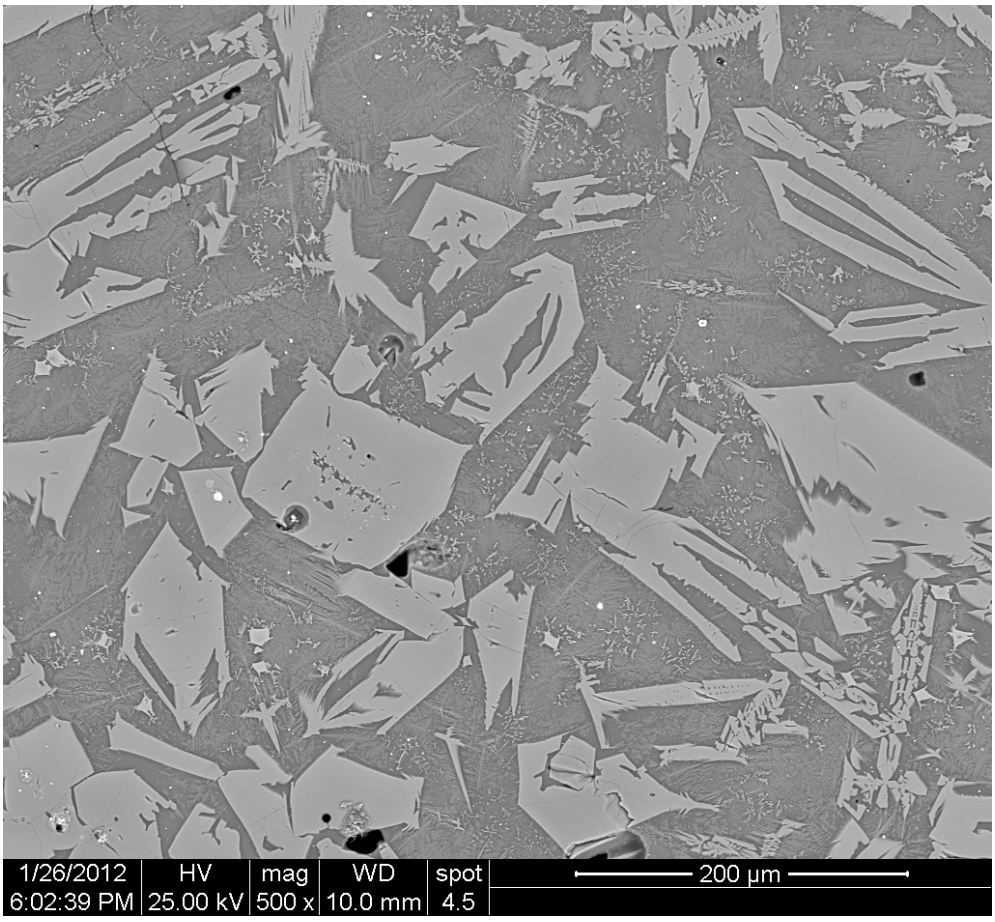
Image No. **12**



Site **ust11**

Sample No. **83**

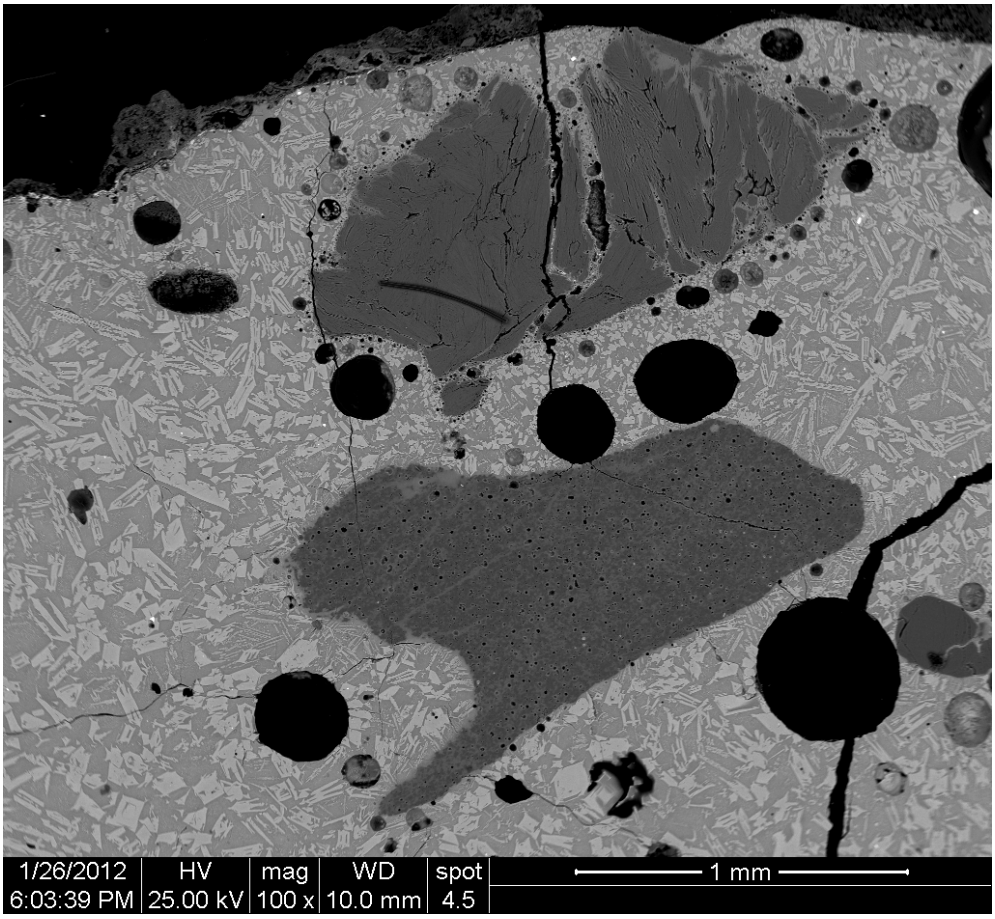
Image No. **13**



Site ust11

Sample No. 83

Image No. 14



Appendix D

XRD Spectra

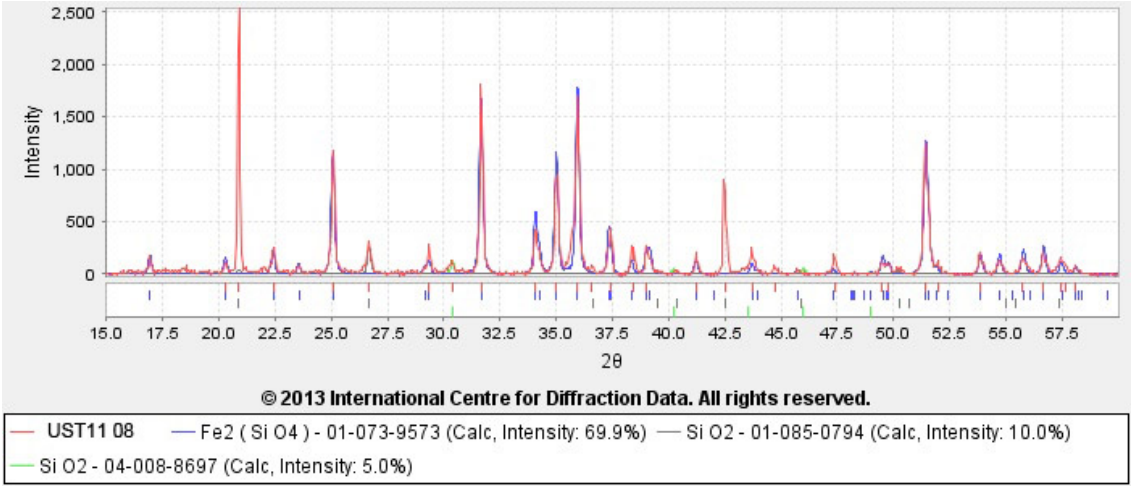


Figure D.1 Diffraction plot for sample UST11 08

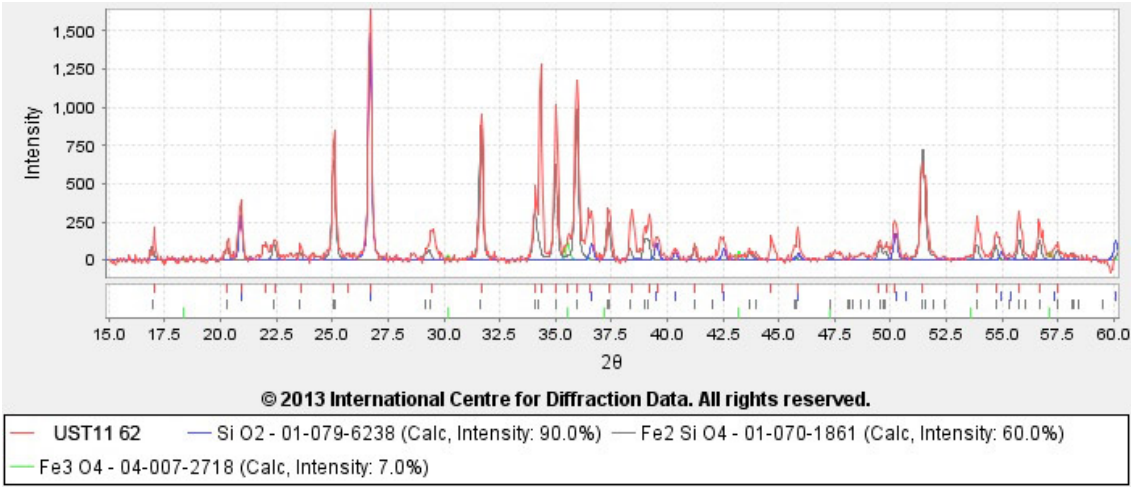


Figure D.2 Diffraction plot for sample UST11 62

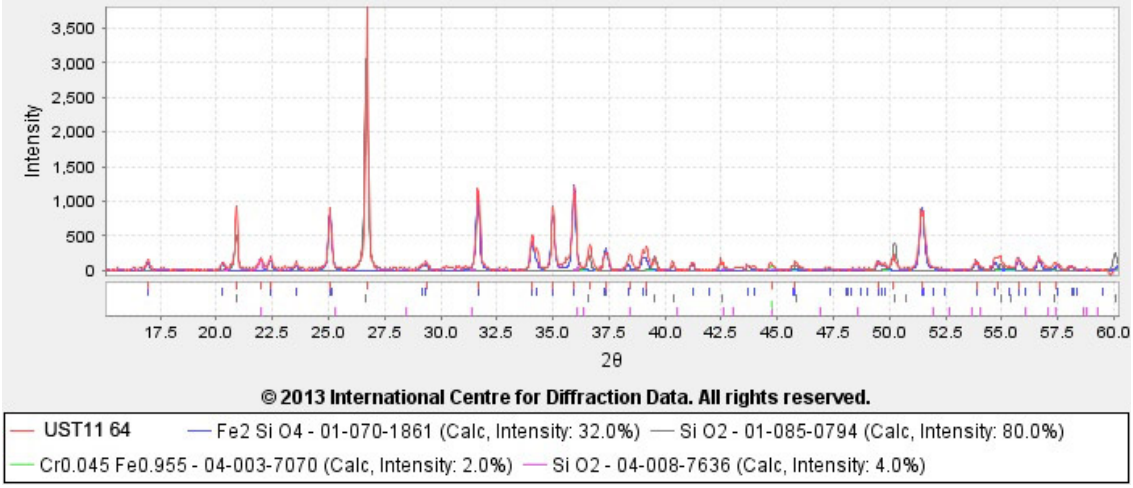


Figure D.3 Diffraction plot for sample UST11 64

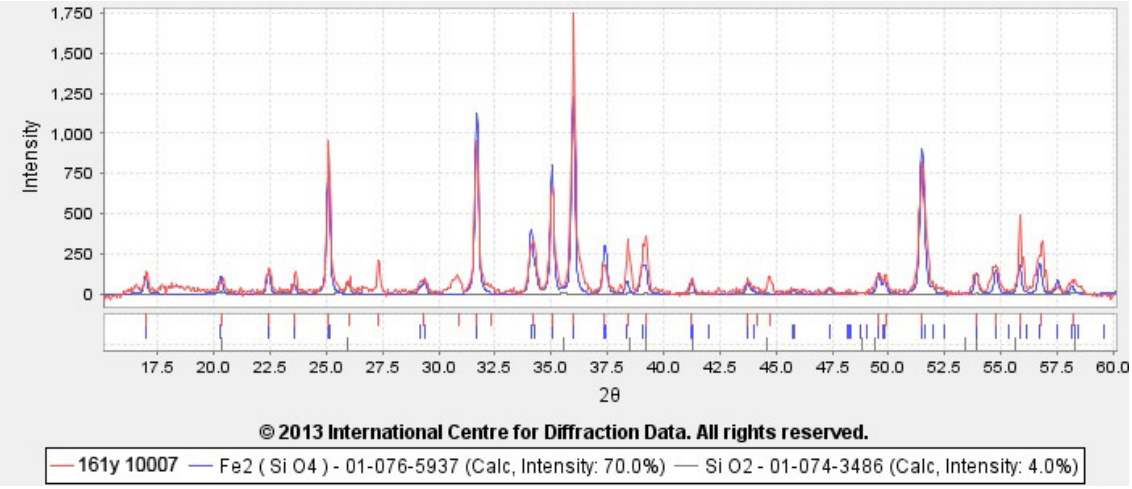


Figure D.4 Diffraction plot for sample 161y 10007

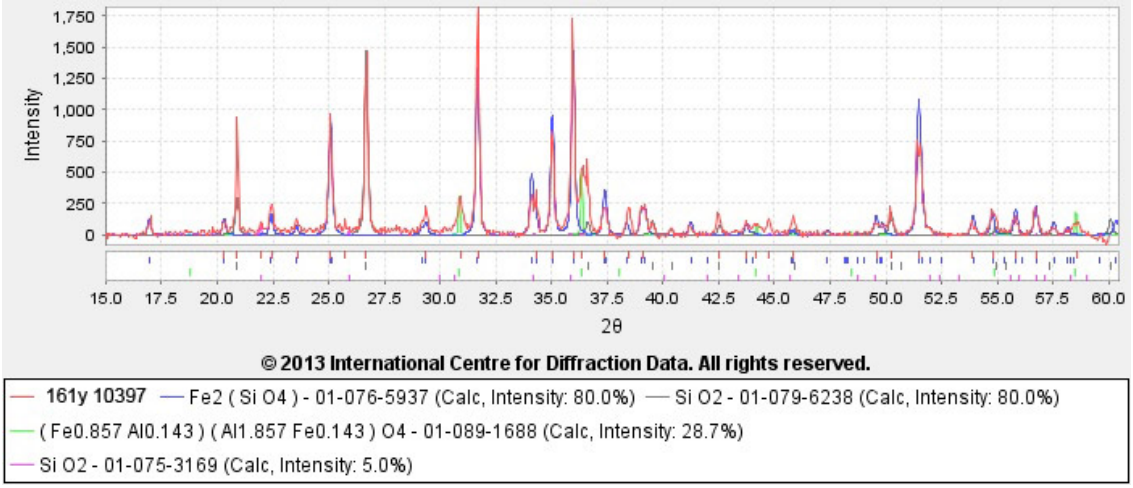


Figure D.5 Diffraction plot for sample 171y 10397

Appendix E

Bulk Chemical Data (XRF PGAA)

Table E. 1 XRF fata form the sheffield series of analysis (%wt)

Site	Code	Sample	FeO	SiO_2	Al_2O_3	CaO	MgO	CuO	SO_3	MnO	ZnO	K2O	SnO_2	As_2O_3	Cr_2O_3
Ust'ye	161y	79	29.66	58.11	8.94	1.24	n.d.	0.50	n.d.	0.06	0.03	n.d.	n.d.	0.10	0.02
Ust'ye	161y	931	33.57	48.04	13.68	1.14	n.d.	0.62	n.d.	0.05	0.02	1.70	n.d.	0.16	0.02
Ust'ye	161y	931	35.28	45.21	13.81	1.18	n.d.	0.75	n.d.	0.04	n.d.	2.87	n.d.	0.29	0.02
Ust'ye	161y	967	98.66	n.d.	n.d.	0.71	n.d.	n.d.	n.d.	n.d.	0.14	n.d.	n.d.	n.d.	n.d.
Ust'ye	161y	1673	37.36	39.84	12.08	1.83	6.98	0.84	n.d.	0.07	n.d.	n.d.	n.d.	0.19	0.04
Ust'ye	161y	2043	27.48	64.50	2.36	2.06	n.d.	0.59	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.04
Ust'ye	161y	3250	57.36	33.51	5.15	2.21	n.d.	1.25	n.d.	0.10	n.d.	n.d.	n.d.	0.01	0.07
Ust'ye	161y	3265	52.84	32.45	7.23	5.33	n.d.	0.38	n.d.	0.44	n.d.	n.d.	n.d.	n.d.	n.d.
Ust'ye	161y	3290	47.87	37.99	6.84	2.29	n.d.	0.95	n.d.	0.08	n.d.	n.d.	n.d.	0.03	0.22
Ust'ye	161y	5076	39.73	41.63	10.24	2.51	n.d.	1.06	n.d.	0.18	0.07	n.d.	n.d.	0.15	0.07
Ust'ye	161y	5131	0.68	42.08	10.54	1.99	n.d.	42.19	n.d.	1.47	0.15	n.d.	n.d.	n.d.	n.d.
Ust'ye	161y	5344	7.32	62.80	n.d.	0.76	n.d.	27.86	n.d.	n.d.	0.07	n.d.	n.d.	0.01	n.d.
Ust'ye	161y	6452	50.13	34.47	2.55	4.99	n.d.	1.75	n.d.	0.12	n.d.	n.d.	0.29	n.d.	0.01
Ust'ye	161y	7235	35.61	37.19	12.52	2.10	n.d.	10.13	n.d.	0.06	n.d.	n.d.	n.d.	0.55	n.d.
Ust'ye	161y	10007	51.53	34.41	9.82	1.80	n.d.	0.73	0.45	0.36	0.02	n.d.	n.d.	0.08	0.01
Ust'ye	161y	10007	54.76	32.78	8.92	1.72	n.d.	0.62	n.d.	0.47	0.02	n.d.	n.d.	0.02	0.01
Ust'ye	161y	10397	39.41	43.82	12.59	1.06	n.d.	0.63	n.d.	0.02	n.d.	1.07	n.d.	0.31	n.d.
Ust'ye	161y	ust11 8	42.34	42.45	12.34	1.24	n.d.	0.46	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.08
Ust'ye	UST11	8	48.45	37.76	11.03	1.49	n.d.	0.55	n.d.	0.05	0.02	n.d.	n.d.	0.03	0.28
Ust'ye	UST11	62	30.68	52.72	6.35	1.98	n.d.	7.22	n.d.	0.09	n.d.	n.d.	n.d.	0.07	n.d.
Ust'ye	UST11	64	50.48	37.99	5.25	1.98	n.d.	0.84	n.d.	0.02	n.d.	n.d.	n.d.	0.05	n.d.
Ust'ye	UST11	69	40.22	43.24	9.35	4.16	n.d.	0.67	n.d.	0.19	0.02	n.d.	n.d.	0.01	0.07
Ust'ye	UST11	77	47.82	36.74	11.72	1.08	n.d.	0.88	n.d.	0.40	0.04	n.d.	n.d.	n.d.	n.d.
Ust'ye	UST11	78	55.78	29.15	1.19	2.66	n.d.	0.61	n.d.	0.44	n.d.	n.d.	n.d.	0.06	n.d.
Ust'ye	UST11	83	43.25	43.03	10.01	2.06	n.d.	0.47	n.d.	0.36	n.d.	n.d.	n.d.	0.01	0.01
Ust'ye	UST11	100	46.06	41.05	10.29	1.40	n.d.	0.53	n.d.	0.11	0.03	n.d.	n.d.	0.02	n.d.
Ust'ye	UST11	109a	44.29	42.04	7.94	2.50	n.d.	0.34	n.d.	0.17	n.d.	n.d.	n.d.	n.d.	0.04
Ust'ye	UST11	109b	41.15	35.33	11.53	1.98	8.03	1.43	n.d.	0.06	0.08	n.d.	n.d.	0.03	0.11
Ust'ye	ust11	ust 11 8	69.87	n.d.	17.41	2.03	n.d.	0.84	n.d.	n.d.	0.03	6.03	n.d.	0.08	2.47
Ust'ye	ust11	ust 11 8	44.91	40.58	11.73	1.54	n.d.	0.53	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.22
Ust'ye	UST11	ust 11 8	49.40	37.61	8.69	1.98	n.d.	0.48	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.27
Stepnoye	step07	a1	54.01	31.20	7.09	2.14	n.d.	0.58	3.76	0.17	0.49	n.d.	n.d.	n.d.	0.02
Stepnoye	step07	a2	65.79	27.63	2.73	1.61	n.d.	0.82	n.d.	0.27	0.53	n.d.	n.d.	n.d.	0.03
Stepnoye	step07	a3	35.20	45.88	15.91	1.56	n.d.	0.64	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.
Stepnoye	step07	a4	58.97	27.74	3.28	3.02	n.d.	1.29	4.62	0.12	0.22	n.d.	n.d.	n.d.	0.06
Stepnoye	step07	a5	27.48	50.11	13.32	2.54	n.d.	3.03	2.78	0.12	0.37	n.d.	n.d.	n.d.	n.d.
Stepnoye	step07	a6	62.87	28.78	4.37	1.78	n.d.	1.08	n.d.	0.07	n.d.	n.d.	n.d.	0.14	0.43
Stepnoye	step07	b1	46.54	41.92	5.94	2.82	n.d.	1.29	0.86	n.d.	n.d.	n.d.	n.d.	0.01	0.14
Stepnoye	step07	b2	45.27	38.12	11.60	2.26	n.d.	0.91	0.83	0.09	n.d.	n.d.	n.d.	0.01	0.08
Stepnoye	step07	b3	48.09	37.09	12.34	1.63	n.d.	0.54	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.06
Stepnoye	step09	1	53.21	31.97	6.71	1.97	n.d.	0.35	5.21	0.17	0.11	n.d.	n.d.	n.d.	0.03
Stepnoye	step09	2	66.10	21.66	6.18	2.30	n.d.	1.91	n.d.	0.71	0.33	n.d.	n.d.	0.03	n.d.

PbO	P_2O_5	Cl	Ba	Co	Sr	W	Ni	Ag	Sb	Ti	Bi	V	Zr	Se	Mo	Cd	Rb	Nb
n.d.	n.d.	0.81	0.39	n.d.	0.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.00	n.d.	0.01	0.00
n.d.	n.d.	0.49	0.38	n.d.	0.07	n.d.	0.03	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	n.d.	n.d.	0.01	0.00
n.d.	n.d.	0.46	n.d.	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	n.d.	n.d.	0.01	n.d.
n.d.	n.d.	0.48	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
0.01	n.d.	0.65	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	0.00	n.d.
0.01	n.d.	2.82	n.d.	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.01	n.d.	0.01	n.d.	n.d.	0.01
n.d.	n.d.	0.21	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	0.84	0.15	n.d.	n.d.	0.31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	n.d.	n.d.
0.02	n.d.	3.56	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.01	n.d.	n.d.	0.00
n.d.	n.d.	3.63	0.53	n.d.	0.14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.01	n.d.	0.01	n.d.	0.00	0.01
n.d.	n.d.	0.78	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	0.00	n.d.
n.d.	n.d.	1.14	n.d.	n.d.	0.03	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	0.00	n.d.	n.d.	n.d.
0.00	1.33	4.18	n.d.	n.d.	0.17	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	0.16	1.47	n.d.	n.d.	0.18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.00	n.d.	0.00	0.00
n.d.	0.24	0.37	n.d.	n.d.	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	0.01	0.01	n.d.	n.d.	n.d.
n.d.	0.20	0.31	n.d.	n.d.	0.14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.00	0.01	0.00	n.d.	n.d.	n.d.
n.d.	n.d.	0.51	0.46	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.02	n.d.	n.d.	n.d.	0.00	0.00
n.d.	n.d.	0.65	0.28	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	0.19	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.00	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	0.62	n.d.	n.d.	0.21	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.01	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	3.12	n.d.	n.d.	0.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.05	0.01	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	1.42	0.44	n.d.	0.17	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	n.d.	0.00
n.d.	0.12	0.11	0.94	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.01	n.d.	0.00	n.d.	n.d.	n.d.
n.d.	n.d.	9.23	n.d.	0.38	0.22	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	0.08	0.02	n.d.	0.02	n.d.	n.d.	0.02
n.d.	0.00	0.29	0.36	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.00	n.d.	n.d.	n.d.
n.d.	n.d.	n.d.	0.32	n.d.	0.14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	2.54	n.d.	n.d.	0.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	n.d.	n.d.	n.d.	0.00
0.00	n.d.	0.15	n.d.	n.d.	0.06	n.d.	0.04	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	0.08	0.41	0.09	n.d.	0.17	n.d.	n.d.	n.d.	n.d.	0.22	0.01	0.24	0.01	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	0.32	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	n.d.	0.00
n.d.	n.d.	1.42	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	n.d.	n.d.
0.01	0.21	0.24	n.d.	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.00	n.d.	n.d.	n.d.
0.01	0.11	0.40	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00	n.d.	n.d.	n.d.
n.d.	n.d.	0.70	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.00	n.d.	0.00	0.00
0.00	0.12	0.38	n.d.	n.d.	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	n.d.	0.00
0.01	n.d.	n.d.	n.d.	n.d.	0.18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.03	n.d.	0.00	n.d.
n.d.	n.d.	0.39	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.37	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	0.01	n.d.	n.d.	n.d.
n.d.	n.d.	0.39	0.29	n.d.	0.14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.14	n.d.	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.18	n.d.	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.00	n.d.	n.d.	0.00
0.00	0.54	0.12	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.01	n.d.	n.d.	0.00

Table E. 1 continued

Site	Code	Sample	FeO	SiO_2	Al_2O_3	CaO	MgO	CuO	SO_3	MnO	ZnO	K2O	SnO_2	As_2O_3	Cr_2O_3
Stepnoye	step09	14	61.04	27.64	5.51	2.60	n.d.	0.55	n.d.	0.23	0.24	n.d.	n.d.	n.d.	0.03
Stepnoye	step09	21	66.08	26.55	3.80	1.96	n.d.	0.80	n.d.	0.26	0.27	n.d.	n.d.	n.d.	0.03
Stepnoye	step09	22	49.49	39.36	6.63	1.73	n.d.	1.55	n.d.	0.53	0.41	n.d.	n.d.	0.03	0.05
Stepnoye	step09	23	59.44	26.58	7.52	3.45	n.d.	0.91	n.d.	0.06	0.79	n.d.	n.d.	0.01	n.d.
Stepnoye	step09	32	71.03	21.63	3.73	1.84	n.d.	0.82	n.d.	0.24	0.13	n.d.	n.d.	n.d.	0.07
Stepnoye	step09	57	61.38	25.11	7.66	2.98	n.d.	0.80	n.d.	0.74	0.57	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	64	35.92	37.55	8.68	2.26	13.40	1.15	n.d.	0.10	n.d.	n.d.	n.d.	0.03	0.33
Stepnoye	step09	83	55.50	18.64	20.39	1.34	n.d.	2.23	n.d.	n.d.	0.77	n.d.	n.d.	0.06	n.d.
Stepnoye	step09	89	2.13	n.d.	n.d.	0.84	n.d.	96.99	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	90	51.55	35.53	6.19	3.22	n.d.	0.93	n.d.	0.08	0.87	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	99	49.96	39.63	3.12	5.17	n.d.	0.83	n.d.	0.11	n.d.	n.d.	n.d.	0.01	0.06
Stepnoye	step09	104.1	50.54	38.43	5.34	2.90	n.d.	2.10	n.d.	0.11	0.06	n.d.	n.d.	0.03	0.06
Stepnoye	step09	105.1	50.98	32.86	5.93	2.77	6.25	0.52	n.d.	0.19	0.04	n.d.	n.d.	n.d.	0.16
Stepnoye	step09	105.2	51.57	37.72	6.09	2.97	n.d.	0.55	n.d.	0.19	0.05	n.d.	n.d.	0.01	0.11
Stepnoye	step09	115	24.47	58.41	11.41	4.01	n.d.	0.94	n.d.	0.08	0.15	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	117	44.27	44.38	4.33	2.51	n.d.	0.69	n.d.	0.17	0.03	n.d.	n.d.	n.d.	0.53
Stepnoye	step09	118	24.57	46.80	20.41	5.21	n.d.	1.72	n.d.	0.10	0.55	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	118.2	10.00	54.84	9.89	2.66	n.d.	22.07	n.d.	n.d.	0.27	n.d.	n.d.	n.d.	0.01
Stepnoye	step09	120	55.34	33.23	6.06	3.24	n.d.	0.74	n.d.	0.20	0.36	n.d.	n.d.	n.d.	0.03
Stepnoye	step09	131	46.39	31.41	2.37	1.26	16.55	1.47	n.d.	0.05	n.d.	n.d.	n.d.	0.03	0.11
Stepnoye	step09	136	20.79	59.49	12.70	3.65	n.d.	2.11	n.d.	0.07	0.42	n.d.	n.d.	n.d.	n.d.
Stepnoye	step09	140.2	50.70	39.14	4.36	2.97	n.d.	1.85	n.d.	0.07	0.04	n.d.	n.d.	n.d.	0.07
Stepnoye	step09	180	15.06	n.d.	n.d.	0.52	n.d.	62.93	21.0	n.d.	n.d.	n.d.	n.d.	0.08	n.d.
Stepnoye	step09	196	32.78	51.64	10.73	1.04	n.d.	1.97	n.d.	n.d.	n.d.	n.d.	n.d.	0.10	n.d.
Stepnoye	step09	105.2	53.80	34.69	6.87	3.07	n.d.	0.57	n.d.	0.19	0.08	n.d.	n.d.	0.01	0.16
Stepnoye	step09	119	48.57	33.66	6.19	2.33	7.62	0.65	n.d.	0.17	0.04	n.d.	n.d.	0.01	0.17
Stepnoye	Step09	1x	54.40	29.18	8.45	2.48	n.d.	1.75	0.96	0.21	0.94	n.d.	n.d.	n.d.	n.d.
Stepnoye	step2	220	50.59	35.47	4.02	3.16	n.d.	5.59	n.d.	0.13	0.39	n.d.	n.d.	0.03	0.02
Stepnoye	step2	223	57.48	28.08	8.09	3.14	n.d.	0.79	n.d.	0.14	0.51	n.d.	n.d.	0.02	0.02
Stepnoye	step2	277.1	27.29	31.50	24.71	1.95	n.d.	13.04	0.22	n.d.	0.91	n.d.	n.d.	n.d.	n.d.
Stepnoye	step2	277.2	86.34	10.19	n.d.	0.79	n.d.	1.42	0.52	n.d.	0.05	n.d.	n.d.	0.23	0.01
Stepnoye	step2	277.4	95.08	0.23	n.d.	0.81	n.d.	1.32	0.75	0.10	n.d.	n.d.	n.d.	1.00	0.03
Stepnoye	step2	220	40.50	38.99	5.73	4.28	9.36	0.53	n.d.	0.05	0.20	n.d.	n.d.	n.d.	0.04
Stepnoye	step2	220	56.13	33.53	3.52	3.49	n.d.	1.69	n.d.	0.11	0.27	n.d.	n.d.	0.01	0.03
Stepnoye	step2	220	42.91	28.62	1.20	4.39	n.d.	18.61	n.d.	0.06	0.35	n.d.	n.d.	0.16	n.d.
Stepnoye	step2	277.2	25.40	15.77	16.19	0.99	n.d.	37.91	1.34	n.d.	1.02	n.d.	n.d.	0.06	n.d.

PbO	P_2O_5	Cl	Ba	Co	Sr	W	Ni	Ag	Sb	Ti	Bi	V	Zr	Se	Mo	Cd	Rb	Nb
0.00	0.19	0.23	1.56	n.d.	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.00	n.d.	0.01	n.d.	n.d.	0.00
0.00	0.04	0.12	n.d.	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	0.00	n.d.	n.d.	n.d.
0.03	n.d.	0.08	n.d.	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.00	n.d.	0.00	n.d.	n.d.	n.d.
0.00	0.68	0.39	n.d.	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.00	n.d.	0.01	n.d.	n.d.	0.00
n.d.	0.18	0.22	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	0.00	n.d.	n.d.	n.d.
0.00	0.56	0.07	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	0.01	n.d.	n.d.	0.00
n.d.	n.d.	0.46	n.d.	n.d.	0.08	n.d.	0.03	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	n.d.	n.d.	n.d.	n.d.
0.02	0.67	0.23	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	0.06	n.d.	n.d.	0.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	n.d.	n.d.	n.d.	n.d.
0.03	1.08	0.32	n.d.	n.d.	0.16	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	0.00	n.d.	n.d.	n.d.
n.d.	n.d.	0.89	n.d.	n.d.	0.14	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
0.00	n.d.	0.24	n.d.	n.d.	0.13	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.17	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.61	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
0.01	n.d.	0.12	0.27	n.d.	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	n.d.	0.01
n.d.	n.d.	2.84	n.d.	n.d.	0.13	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.01	n.d.	0.01	n.d.	n.d.	0.00
0.05	n.d.	n.d.	0.34	n.d.	0.15	n.d.	0.05	n.d.	n.d.	n.d.	n.d.	0.03	0.01	n.d.	0.02	n.d.	0.00	0.01
0.04	n.d.	n.d.	n.d.	n.d.	0.10	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	0.00	0.01
0.01	0.13	0.55	n.d.	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.00	n.d.	n.d.	0.00
n.d.	n.d.	0.23	n.d.	n.d.	0.05	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
0.04	n.d.	0.17	0.37	n.d.	0.10	n.d.	0.03	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.01	n.d.	0.00	0.01
0.00	n.d.	0.59	n.d.	n.d.	0.11	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.	n.d.	n.d.
0.01	n.d.	0.34	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.02	n.d.	n.d.	n.d.
n.d.	n.d.	1.20	0.43	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	0.02	n.d.	0.01	n.d.	0.00	0.00
n.d.	n.d.	0.43	n.d.	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.46	n.d.	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
0.02	1.07	0.19	n.d.	n.d.	0.31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.01	n.d.	0.00	n.d.	n.d.	0.00
0.01	0.07	0.25	n.d.	n.d.	0.13	n.d.	0.08	n.d.	0.04	n.d.	n.d.	0.01	0.00	n.d.	0.00	n.d.	n.d.	n.d.
0.00	1.31	0.23	n.d.	n.d.	0.16	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.01	n.d.	n.d.	0.00
0.05	n.d.	0.18	n.d.	n.d.	0.06	n.d.	0.05	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.03	n.d.	0.00	0.01
n.d.	n.d.	0.30	n.d.	n.d.	0.02	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	n.d.	0.52	n.d.	n.d.	0.03	n.d.	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
n.d.	0.03	0.17	n.d.	n.d.	0.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.00	n.d.	0.00	n.d.	n.d.	n.d.
0.00	0.19	0.87	n.d.	n.d.	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01	n.d.	0.01	n.d.	n.d.	0.00
0.01	0.13	3.07	n.d.	n.d.	0.20	n.d.	0.14	n.d.	0.09	n.d.	n.d.	0.03	0.01	n.d.	0.01	n.d.	n.d.	0.01
0.05	0.01	0.93	n.d.	n.d.	0.03	0.15	n.d.	0.06	n.d.	n.d.	0.05	0.01	0.00	n.d.	0.03	n.d.	n.d.	0.00

Table E. 3 PGAA data %wt (left), PPM *italic* (right).

Site	Sample	CaO	SiO2	Al2O3	MgO	FeO	MnO	TiO2	K2O	P2O5	Cu
Ust'ye	161Y-10007	1.91	32.00	3.78	0.00	58.97	0.46	0.29	1.32	0.00	0.77
Ust'ye	161Y-10397	1.31	45.36	12.53	0.00	34.98	0.06	0.61	4.33	0.00	0.39
Ust'ye	161Y-3265	6.69	25.40	4.09	0.00	61.44	0.57	0.18	1.27	0.00	0.28
Ust'ye	161Y-6452	5.82	26.71	2.82	1.51	58.75	0.19	0.14	2.05	0.00	1.42
Ust'ye	161Y-7235	1.52	43.44	12.02	0.00	37.52	0.11	0.51	2.80	0.00	1.56
Ust'ye	161Y-931	1.08	46.26	9.72	0.00	35.21	0.11	0.37	3.58	2.40	0.71
Ust'ye	161Y-967	0.41	4.58	1.77	0.00	91.41	0.05	0.00	0.00	0.00	0.00
Ust'ye	UST11-62	2.43	47.47	6.27	0.00	38.60	0.10	0.31	1.64	0.00	2.67
Ust'ye	UST11-64	1.82	49.73	6.38	0.00	38.62	0.10	0.28	1.78	0.55	0.53
Ust'ye	UST11-77	0.87	39.17	7.95	0.00	43.45	0.35	0.28	1.58	0.00	4.79
Ust'ye	UST11-78	1.68	49.13	7.72	0.00	34.39	0.32	0.41	3.05	2.59	0.38
Ust'ye	UST11-8	1.30	35.77	5.83	0.00	53.36	0.07	0.32	1.77	0.00	0.50
Stepnoye	STEP09-02	4.44	22.42	6.18	0.00	64.69	0.69	0.13	0.58	0.00	0.76
Stepnoye	STEP09-105.2	3.62	29.77	4.42	5.04	54.57	0.22	0.21	0.84	0.00	0.63
Stepnoye	STEP09-117	2.68	35.75	4.95	4.29	48.70	0.21	0.23	0.87	0.00	0.74
Stepnoye	STEP09-120	3.20	29.96	5.18	3.46	56.25	0.24	0.14	0.61	0.00	0.52
Stepnoye	STEP09-131	1.54	30.44	2.40	10.18	52.73	0.09	0.12	0.51	0.00	1.32
Stepnoye	STEP09-196	0.76	57.66	10.62	0.00	25.70	0.03	0.52	3.67	0.00	0.71
Stepnoye	STEP09-23	3.83	24.67	6.03	0.00	63.45	0.16	0.10	0.00	0.00	0.75
Stepnoye	STEP09-57	3.48	22.23	6.55	0.00	64.00	0.61	0.19	2.01	0.00	0.57
Stepnoye	STEP09-64	2.42	34.38	6.06	8.24	45.36	0.16	0.33	0.63	0.00	0.86
Stepnoye	STEP09-99	5.24	27.36	3.43	4.93	54.29	0.19	0.23	1.24	1.69	1.03
Stepnoye	STEP2-220	5.07	32.20	3.86	4.67	50.42	0.18	0.10	1.26	0.00	1.91
Stepnoye	STEP2-223	3.87	22.71	4.81	0.00	66.80	0.20	0.11	0.45	0.00	0.83

As	H	B	S	Cl	Sc	V	Cr	Co	Ni	Nd	Sm	Gd	Au
0	591	25	0	735	0	436	1281	208	1352	100	12	14	126
1344	1187	37	0	76	45	601	0	92	836	78	12	18	0
0	140	54	0	81	0	231	0	0	0	66	8	9	70
0	1421	41	0	3800	0	68	401	124	0	29	2	4	14
1093	733	30	0	49	50	534	0	121	2447	98	13	18	0
1730	1001	32	0	82	15	451	793	106	1299	62	6	10	19
0	17173	7	0	82	0	0	0	0	0	85	20	21	198
423	752	29	1083	1359	91	1215	0	101	0	31	5	7	0
0	383	27	0	52	71	1232	0	121	0	27	4	7	31
0	2505	26	0	11514	33	678	0	496	0	167	19	17	96
0	635	35	1074	58	15	299	0	90	846	79	10	12	84
0	463	23	0	690	49	833	8259	477	0	28	3	5	0
0	429	104	0	232	0	0	0	0	0	177	22	36	94
424	476	32	0	253	0	155	4237	0	1185	27	3	5	42
0	422	28	0	106	0	183	14629	167	168	8	1	1	31
0	208	26	0	63	0	151	3592	170	0	74	8	13	117
0	342	25	1025	294	0	88	4788	0	0	0	0	1	27
0	697	36	1010	42	24	428	0	87	1000	31	6	7	0
0	343	0	0	97	0	0	0	323	1658	118	13	21	71
0	563	63	0	182	0	278	0	402	1512	182	21	34	216
0	180	89	0	53	0	183	14368	90	543	0	1	2	0
0	557	36	0	68	9	161	2783	0	0	0	1	2	34
0	823	31	0	0	0	120	1471	114	396	153	21	35	93
0	224	21	0	72	0	0	0	177	1548	134	15	24	0