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Historical Ecology and Ironworking on the Fifth and Sixth Century Osaka Plain

By

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Committee in charge:

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Abstract

Historical Ecology and Ironworking on the Fifth and Sixth Century Osaka Plain

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Doctor of Philosophy in Anthropology

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This dissertation clarifies the nature of the relationship between a small group of ironworkers and their forest landscape in the fifth and sixth centuries on the Osaka Plain, and in so doing builds a model for investigating the relationship between craft production and landscape change more broadly.

Scholars have long pointed to metallurgical activities as factors in environmental transformations, but these studies have focused on smelting and refining activities, while disregarding smaller scale activities like smithing. Ogata, a large-scale ironworking site of the Middle and Late Kofun Periods located in Kashiwara City, Osaka Prefecture, Japan, has been excavated sporadically since the early 1980s, and the accumulated finds and data offer insight into questions of the reciprocal and knowledgeable influences between ironworkers and their local forest landscape.

This dissertation approaches this issue through reconstructing *chaînes opératoires* of ironworking, and extending them to encompass fuel procurement activities on the landscape. The knowledge involved in each step in a *chaîne opératoire* provides a way to investigate not only the choices that actors make, but also the motivation behind them. However, this is only possible with detailed knowledge of the craft as well as the landscape. In addition to the material characteristics and natural processes of the landscape, an appropriate understanding of the general nature of relationships between human activities and landscape transformation. This project adopted the research program of historical ecology as a lens through which to view the empirical evidence of landscape transformation and ironworking activities.

To facilitate reconstructing useful and accurate ironworking *chaînes opératoires*, this dissertation reviews the physical behavior and characteristics of iron and its alloys, along with charcoal fuel and the fundamentals of premodern ironworking technologies and techniques. It further examines the specific ironworking technologies known from the Kofun Period in the Japanese Archipelago. A close review of paleoclimatic data for the Japanese Archipelago as well as pollen data from other archaeological sites near Ogata establishes that the Osaka Plain in the Kofun Period was climatically much like the twentieth century, and that the area near Ogata was heterogeneously forested by lucidophyllous taxa with some elements of warm temperate deciduous forest as a result of disturbance by human activity. A review of Japanese

lucidophyllous forest disturbance and regeneration dynamics and conservative estimates for rates of charcoal fuel in forge operations is used to estimate sustainable levels of wood harvesting for charcoal production. Next, the results of the main archaeological excavations at Ogata are introduced with an emphasis on artifacts and features related to ironworking.

With these technological, archaeological, and environmental contexts established, analysis of twenty forge slags from four depositional contexts of the 1984-1 excavation is conducted. Since removing artifacts from Japan is difficult, these slags were prepared as petrographic specimens for reflected light microscopy and initially examined and photographed by Suzuki Mizuho through Nippon Steel Technology Co., Ltd. Taxon identification and radiocarbon dating of charcoal fragments extracted from these slags was also conducted. Charcoal identification was conducted by Paleo Labo Co., Ltd, and AMS radiocarbon dating by Beta Analytic, Inc. Four additional pieces of charcoal and a charred peach pit from a possible charcoal kiln feature uncovered in the same excavation were also radiocarbon dated by Beta Analytic, Inc. The internal macrostructure of the forge slags was analyzed using a method pioneered by Vincent Serneels, Sébastien Perret, and Raphaëlle Soullignac allowing for the estimation of the forge slags' formation process. This analysis was supplemented by reflected light microscopy of the slags.

Results of these analyses supported earlier hypotheses about ironworking at Ogata, concerning hardwoods as the preferred fuel, the use of at least some steel as working stock, and forge refining as one of the ironworking processes performed there. New results include the confirmation of metallic copper in slags, indicating that copper was worked in some capacity at Ogata.

These analyses also revealed that the age of trees used for charcoal production increased significantly over time. This demonstrates that there were still some very old trees living nearby Ogata, but also that the need to harvest them arose, most likely due to decreased availability of younger wood from previous sources. At the same time, a new slag form emerged that suggests an increase in the speed of work or at least faster cooling upon completing work. Either possibility would entail somewhat reduced fuel expenditure compared to prior practices.

These changes both indicate a concern with fuel availability for ironworkers, and reflect their prior insufficient management of forest resources, and a choice to economize with respect to fuel. This was not the only option available to ironworkers; they could have continued to use the same amount of fuel, further accelerating the apparent decrease in fuel availability over time, or negotiated for greater access at the expense of other fuel-users. However, it appears that introducing new ironworking techniques was the best way to manage the forest and the competing interests in its resources.

Beyond these results and establishing a *chaîne opératoire* approach as a viable model for investigating human-landscape relationships, this project also revealed several avenues for future research. Mori, the other major Kofun Period ironworking site in Osaka Prefecture, will be an excellent comparative case for Ogata using the same methodology and analytical techniques. At Ogata, additional research is necessary to clarify the role of copper and potentially copper-plated iron artifacts in the production and circulation of iron goods. Finally, this project revealed the

need for additional experimental work on slag formation processes and postdepositional corrosion.

Chapter 1: Introduction

The purpose of this study is to clarify the nature of the relationship between a small group of ironworkers and their forest landscape as a novel case study in how “societies defined by various socioeconomic, political, and cultural criteria impact landscapes in dissimilar ways” (Balée 2006: 76), and in so doing build a model for investigating the relationship between craft production and landscape change. Specifically, I examine the role of fifth and sixth century ironworkers at the Ogata archaeological site in Osaka Prefecture, Japan, in creating anthropogenic changes to the forest landscape, as well as that of the forests in mediating the relationship between the ironworkers and their products.

Alfred Kroeber wrote that “cultures are rooted in nature, and can therefore never be completely understood except with reference to that piece of nature in which they occur,” while in the same paragraph writing that “the immediate causes of cultural phenomena are other cultural phenomena” (1939:1). For environmental archaeologists, this remains a central difficulty. Understanding how people related (and continue to relate) to their environment requires the correct conceptual frame of reference. That is to say, how do we conceive of the “environment?” People act individually and collectively on the biotic and abiotic elements of the world, and in turn these act on people both individually and collectively. Humans are not passive pawns of their environment with actions determined by ecological forces, and neither does our environment statically shrug off human activities. People act under the influences of their environmental circumstances, which are influenced not only by ongoing non-human processes but also by the history of prior human and non-human activities. Furthermore, people act under the deep influence of their cultural ways of being, which are themselves tied to the land and its history. Thus, for all the ecological cycles and processes playing out around and even inside people, human communities’ relationships to their environments are better understood as more than to any “ecosystems” or even “environments,” *per se*, but rather to “landscapes.” Understanding a society’s choices with respect to their environment demands reckoning with specific environmental and cultural histories, and so this dissertation adopts a landscape perspective based in a historical ecological framework rather than an ecological or environmental one.

Early smelting and refining activities have long been implicated in anthropogenic environmental impacts on both the local and global scale (Wertimie 1983, Hong et al 1996, Mighall and Chambers 1997, Eichhorn et al 2013, Jouffroy-Bapicot et al 2007), but the relationship of non-smelting metalwork to landscape change is rarely considered in archaeometallurgy. At the same time, much scholarship surrounding human impacts on landscapes has focused on subsistence activities rather than non-food products (Balée and Erickson 2006, Thompson and Waggoner 2013).

The Middle and Late Kofun Periods on the Osaka Plain provide an ideal case study for understanding these issues of human environmental interaction. The start of the Middle Kofun Period is recognized when the largest tombs cease to be built in Nara and shift to the Osaka plain and is also characterized by a different set of elite grave goods, including highly standardized iron military equipment (Hashimoto 2015). These items are understood to have been manufactured under royal auspices on the Osaka Plain and distributed to distant elites. Iron was a valuable material in this context because it was not being smelted anywhere in the archipelago and had to be imported from the Korean peninsula until some time in the Late Kofun Period (Murakami 1998). Accordingly, iron objects have long been seen as key to the political

economies of the Early and Middle Kofun periods (Tsude [1991] 2006). Relying on imported raw materials, ironworkers made these standardized prestige goods, and consumed vast quantities of charcoal fuel. At the same time, local availability of forest resources was decreasing in alluvial lowlands, and supply networks were expanding in geographic range (Yasuda 1978, Higami 2016, Oba 2017). How did ironworkers choose to deal with these changes, especially in light of their apparent strategic importance to the political order of the Kofun Period? How did ironworkers affect this changing landscape?

This dissertation approaches these questions through reconstructing ironworking *chaînes opératoires* (Sellet 1993, Chazan 2009, Soressi and Geneste 2011) at Ogata, one of two sites in Osaka Prefecture where evidence for large-scale ironworking has been unearthed. These *chaînes opératoires* are constructed based on charcoal recovered from excavated features and extracted from forge slags, as well as reconstructions of forging activities based on mineralogical and chemical examination of forge slags and legacy data from archaeological excavations. The chronology of these *chaînes* is established based on radiocarbon dating of charcoal recovered from the same features and forge slags, and their differences are examined in light of vegetation changes on the landscape inferred from a synthesis of legacy paleoenvironmental and climatic data.

Chapter 2: Theoretical and Methodological Framework

Introduction

Before examining evidence for the human-environmental interactions of ironworkers at Ogata, it is important to establish the framework for inquiry. That is to say, what are the operative concepts and foundational assumptions for interpreting patterns in the data? This chapter serves to situate this project with respect to the field of environmental archaeology and studies of past technology to approach the broad question of how researchers can understand peoples' technological choices on their landscape. To that end, I draw particular attention to the insights and assumptions of the research program of historical ecology (Balée 2006) as well as some potential pitfalls and lacunae in historical ecological research to this point. I also introduce the concept of the *chaîne opératoire* as an analytical tool and describe a novel use for it in historical ecology.

Historical Ecology as a Social Environmental Archaeology

Despite increased recognition of environmental archaeology's importance in the so-called Anthropocene (Braje et al 2014), its old reputation for environmental determinism and latent processualism has been difficult to shed (Arponen et al. 2019). Archaeologists have long acknowledged that "the environment" must not be treated as an independent variable or worse, a constant, in understanding past societies (e.g. Butzer 1982), but research emphasis on environmental adaptation and equilibrium, which seem to preclude social explanations for cultural change, remained mainstream into the 1990s.

Since then, environmentally oriented archaeologists and anthropologists have sought ways to better account for the dynamism and complexity of human-environmental interactions in their research (Crumley 1994; McGlade 1995). For archaeologists, the relationship between human activities and the non-human aspects of their environments has become something that requires explanation, rather than something that explains other phenomena. To be acceptable as explanations, correlations between environmental trends and human activity must be accompanied by mechanisms articulating their connection (Arponen et al. 2019 and following commentary; Dincauze 2000).

Efforts to incorporate social factors in environmental archaeology have been somewhat slower. Taking cues from landscape archaeology, mainstream formulations now include elements of environmental perception (Dincauze 2000). John G. Evans' (2003) work to create an environmental archaeology that recognizes social engagement via the environment prior to any biological engagement with it is a noteworthy contribution, but his approach is rarely replicated. Despite mutual influence and many self-described environmental archaeologists' adoption of landscape (as opposed to "environment" or "ecosystem") concepts, environmental archaeology and landscape archaeology generally remain distinct fields of inquiry.

Amid and as part of these changes, the research program of historical ecology (Balée 2006) emerged from the work of archaeologist Carole Crumley (1994, Marquardt and Crumley 1987) in the mid-1990s. Since then, it has found utility as a theoretical framework for archaeologists and other social scientists engaging with issues of human environmental interaction, especially those interested in human impacts (Crumley 2015). Historical ecology contains four straightforward core postulates: virtually all environments have been affected by human activity, human activity is neither inherently positive nor negative with regard to environmental parameters, the kinds of effects visited upon landscapes by societies differ

according to those societies' socioeconomic, political, and cultural organization, and human-environmental interactions in various contexts can be studied as integrative phenomena (Balée 2006).

Beyond these postulates, historical ecologists take a historical as opposed to evolutionary view of environmental change, which is not to deny the roles of natural selection and other evolutionary mechanisms, but to emphasize the role of human agency in creating landscapes with specific histories, rather than humans unthinkingly adapting to environments through naturally "rational" behaviors (Balée 1998). This in turn combines with a conception of time derived from the Annales school, albeit one focused on the *longue durée*, and a developed concept of landscape (Balée 1998, 2006, Crumley 2003). Taken together these ideas constitute a framework particularly amenable to integration with social theoretical insights from other areas of archaeology and social science, even though they do not "privilege the importance of social knowledge over ecological information" (Maher 2019: 1014-1016). This is an especially notable feature of the landscape concept for historical ecologists.

Landscape in Historical Ecology

The growth of landscape archaeology as a subfield has led to numerous conceptions of landscape, so it is important to articulate what is meant both in historical ecology generally and in this project in particular in relation to other formulations. An accounting of all the various archaeological approaches to landscape is beyond the scope of this chapter, but it is significant to mention that virtually all agree that in addition to physical features and characteristics, landscapes are constituted socially through place- and meaning-making activities, resulting in intangible features and characteristics (David and Thomas 2008). Which aspects are emphasized or given ontological priority varies between investigators, but in historical ecology the landscape as a unit of analysis is a resolutely physical entity with spatial and temporal dimensions (Balée 1998, 2006; Balée and Erickson 2006; Crumley 1994, 2015, Marquardt and Crumley 1987).

To historical ecologists, the physical aspects of landscapes do not simply coexist with the intangible social aspects. Rather, the physical features have come to be constituted by the social aspects over time (Balée 1998, 2006; Crumley 1994). The landscape is the physical manifestation of the ongoing dialectical relationship between human acts and acts of nature (Marquardt and Crumley 1987: 1, Crumley 1994: 9). Landscapes have history, and features of the landscape are historiographic indices (Balée 2006: 77). These indices have been "inscribed in a subtle, physical sense by learned, patterned behavior and action....Culture is physically embedded and inscribed in the landscape as nonrandom patterning, often a palimpsest of continuous and discontinuous inhabitation by past and present peoples" (Balée and Erickson 2006: 2). These actions range from small, cumulative management techniques of landscape domestication to highly visible landesque capital investments such as terracing (Balée 2006: 79). Crumley notes that the landscape records evidence of the maintenance or modification of practices and decisions that were made (1994: 9); they are "theatres of conflict over resources and values" (2015: 5), and they can be understood as "congealed politics" (2010: 10).

Although unconscious actions and unintended consequences of actions are certainly recorded in the landscape alongside the intended results of purposeful actions (Kidder 2013), the landscape is nevertheless a built environment akin to architecture in its intentional creation (Balée and Erickson 2006). In other words, the landscape is a palimpsestic record of the human intentionality and agency in land use and resource management (Balée and Erickson 2006).

Hurdles in Practical Application

Despite the flexibility of this framework for accommodating analysis of societies with varying political organizations and its grounding in the importance of human action in landscape histories, historical ecological research often entails assumptions that can lead to overstatements. Specifically, in evaluating particular human impacts on vegetation, historical ecology research frequently invokes the intermediate disturbance hypothesis (Balée 2006: 83-85), which states that species diversity will be maximized when disturbance frequencies and/or intensities in an environment are at an intermediate level (Fox 2013a). Since pollen records and other paleoenvironmental indicators can often disclose histories of disturbance at various levels, this is an appealing hypothesis for researchers.

However, in recent decades, the intermediate disturbance hypothesis has come under serious criticism on both theoretical and empirical grounds: critics find that only when explicitly modeling nonlinear or nonadditive systems, or in explanations relying on competition-colonization tradeoffs can the intermediate disturbance hypothesis hold (Fox 2013a, 2013b, Chesson and Huntly 1997), and reviews of empirical research find that the supposed relationship can rarely be found (Mackey and Currie 2001, Hughes et al 2007). Defenders argue that theoretical refutations only narrow the acceptable range of acceptable explanations for the hypothetical phenomenon, or that research reviews misunderstand the interconnection between diversity and productivity, leading to poor performance of the hypothesis (Sheil and Burslem 2013, Huston 2014). Regardless of the merits of each side's arguments, archaeologists and historical ecologists need to approach the effects of intermediate disturbance cautiously, as a hypothesis to be carefully tested rather than as an explanatory mechanism.

A harder problem is that of intent. Actions have intentional and unintentional results, and both leave their mark on landscapes. In other frameworks where human modifications to environments are explicitly theorized, such as niche construction theory (Laland and O'Brien 2010, Wallach 2016), intent is much less important than outcomes, but since historical ecologists are expressly concerned with humans as intentional agents of landscape transformation (Balée 2006, Balée and Erickson 2006), researchers need to identify intention.

Balée and Erickson (2006: 2) contend that researchers can use archaeological, paleoecological, and other data to reverse engineer landscapes and infer human actions and intentions through deconstructing their historical formation processes, but they prescribe no methodology, tools, or procedures. Kidder (2013: 178–182) notes the ease with which scholars can overlook the purpose and intent in small-scale societies' transformations of their landscapes, and even when researchers acknowledge the likelihood of deliberate, albeit subtle, transformations, there are cases in which the intentionality of some transformations is uncertain. Recognizing that the issue of scale complicates such investigations, he (Kidder 2013: 178) advocates for a high-resolution microhistorical approach alongside the investigation of the *longue durée*. I suggest that the *chaîne opératoire* is an exceptional tool not only for constructing such microhistories but also for linking them to larger-scale historical ecological trajectories.

A *Chaîne Opératoire* Approach

Defined by Perlès (1987: 23, translated in Sellet 1993: 106) as the “succession of mental operations and technical gestures, in order to satisfy a need (immediate or not) according to a preexisting project,” the *chaîne opératoire* is a concept that has found myriad applications since its introduction to anglophone archaeology (Schlanger and Sinclair 1990). The concept emerged in French lithic archaeology in the 1980s based on ideas first found in research by André Leroi-

Gourhan (1964) and Pierre Lemonnier (1983), strongly influenced by Marcel Mauss (1948).

Though Leroi-Gourhan spent formative time studying with Ainu people in Japan in the 1930s, much of his experience there was not explicitly published until after his death (Leroi-Gourhan and Leroi-Gourhan 1989). Perhaps for this reason, though his best-known work *Le Geste et La Parole* was translated into Japanese in 1973 (Goto 2012), decades before it received an English translation, Leroi-Gourhan's work and others' later developments of the *chaîne opératoire* concept had little impact on Japanese archaeology (Nishiaki 2000, 2004, Nakao 2012) until Yamanaka Ichiro (2007, 2009a) brought it renewed attention. Since then, *chaîne opératoire* approaches in Japan have largely remained the province of devotees like Yamanaka Ichiro (2009b) and Oba Masayoshi (2013, 2015), but a few other archaeologists have found it useful (Awada 2017, Hirakawa and Nakazono 2019), and so its popularity may eventually rise to levels seen in anglophone and French archaeology.

Although it is most commonly applied in studies of lithic technologies, the range of studies making use of a *chaîne opératoire* approach has expanded to encompass nearly every kind of material culture. Ceramics, textiles, cultivated plants and numerous other technologies are well represented in recent literature utilizing the *chaîne opératoire*. For some scholars, the concept is merely shorthand for "stages of production" as part of other discussions, but for others, the full *chaîne opératoire* concept (Chazan 2009; Soressi and Geneste 2011) provides opportunities to explore such diverse ideas as past mental states (Schlanger 1994), social agency and meaning-making (Dobres 2001), phylogenetic approaches to lithic tool assemblages (Riede 2006) and production (as opposed to "technology") (Kohring 2006).

These provocative investigations are possible because the *chaîne opératoire* is not just a sequence of physical steps. Based on Cresswell's (1983) approach, Pierre Lemonnier's (1992) methodology for recording *chaînes opératoires* involves the setting, elements, technological relations, and social relations of each step of the *chaîne*. Separately, he notes that techniques are constituted of matter, energy, objects, gestures, and specific knowledge (1992: 5–6), but other scholars have productively collapsed this to three levels of analysis: the material objects involved, the gestures and technical sequences involved, and the technical knowledge necessary (Schlanger 1994: 146; Sellet 1993: 107). The technical knowledge component can be further divided into the abstract knowledge necessary (*connaissance*) and the actual ability or know-how to perform the sequence (*savoir faire*) (Chazan 2009). To further elaborate on the knowledge component, the *chaîne opératoire* developed by a researcher is a description of something that plays out in the mind and actions of a maker that is both sequential and an integrated whole (Chazan 2009: 471). The maker must have a concept or template of the process, not just or necessarily the object itself, in mind to work through, but it must be flexible enough to account for variation in the materials being manipulated (Schlanger 1994: 148).

In order to understand the physical constraints involved, a researcher should ideally have some knowledge of working the material medium at the center of a *chaîne opératoire*-based investigation. However, since gestures and especially knowledge are culturally and historically specific, an archaeologist has no hope of obtaining an emic perspective on an extinct tradition. Consequently, any reconstruction will sacrifice some precision to maintain accuracy. That is to say, rather than reconstructing the specific gestures and knowledge involved, in many cases a researcher should settle for inferring the *kinds* of gestures and knowledge that may have been involved. For example, this might involve a knowledgeable researcher trained in metalwork noting that an ancient metalworker must have known the how, and some reasoning behind that how, of some technological process, such as drawing out wire, without commenting on what the

reasoning behind that how was. The reason for that reticence would be that both the how and its reasoning are more heavily constrained by the tools and modern tradition the researcher has joined in order to become knowledgeable than by the material itself.

Because constructing a *chaîne opératoire* requires investigators to consider the knowledge necessary for each step, it insists that they examine the technological choices available to and indeed made by the craftsperson. In his related approach, Lemonnier (1992: 6) explicitly frames makers' knowledge as choices: the choice of tools, materials, processes, and gestures all reflect the specific knowledge mobilized in a technological activity. Examining the contingency of past makers' actions, that is to say their socialized choices, through careful analysis of archaeological residues can reveal those makers' intentions and goals with respect to their media (Schlanger 1994).

Conneller (2006) has pointed out that *chaînes opératoires* are not isolated or individual, but rather multiple and networked across the landscape. Keeping in mind that at least archaeologically, the *chaîne opératoire* is inevitably a reconstructed approximation and thus better treated as an analyst's tool than an actual phenomenon, Conneller's (2006) insight can be reframed: researchers can combine multiple *chaînes*, or seek their intersections to reveal aspects of social structure as much as physical transformations (cf. Dobres 2010). Similarly, researchers can expand or contract *chaînes* to suit their needs. Consequently, although a *chaîne opératoire* usually begins with raw material procurement and terminates with discard at the end of an object's use life, there is no reason the *chaîne* might not be expanded on either end or branched out wherever additional objects or people enter the pattern, creating multilinear *chaînes*.

Chaînes Opératoires of Landscape Transformation

Just as archaeologists seek cognition and meaning along with economic arrangements arising through making using a *chaîne opératoire* approach (Dobres 2010; Schlanger 1994), by using such an expanded *chaîne opératoire* approach, archaeologists might also seek cognition and meaning in practices of making not just on the landscape, but of making the landscape.

Some archaeologists have already integrated the *chaîne opératoire* into environmental and landscape archaeologies, though their approaches differ in important ways to the expanded approach proposed here. Environmental archaeologist John G. Evans (2003) advocates for the use of *chaînes opératoires* to examine social expression and accumulations of meaning on the landscape, and Conneller (2006) has examined how lithic production links places and in so doing creates the landscape. Maher (2019) has combined historical ecological concepts, a *chaîne opératoire* approach, and theories of situated learning and communities of practice to explore the social role of technology in understanding landscapes as well as landscape learning, the processes by which communities acquire, share, and maintain knowledge of their landscape, and make places meaningful (Rockman and Steele 2003). These approaches all at least implicitly acknowledge physical engagement with the landscape, but all also primarily use the *chaîne opératoire* to investigate the intangible social aspects of landscape that emerge through that physical engagement.

I submit that for researchers in historical ecology, a *chaîne opératoire* approach permits investigating not only intangible social relations of the landscape but also ecological relations and landscape transformations, and encourages a more detailed analysis of the landscape across both spatial and temporal scales. The landscape itself is a built environment, so it is amenable to a *chaîne opératoire* analysis. Of course, a landscape is created by many people over generations, and though the pace of its production and transformation may vary over time, it can never be said

to be completed as an end product. In that way, the *chaîne opératoire* of a landscape differs from that of other technologies, but the sequences of actions nevertheless involve particular gestures, objects and knowledge.

A landscape is created not just by activities primarily intended to alter it, but also through activities where alteration of the landscape is secondary to some other purpose. Felling lumber for construction seems an obvious example, but research into traditional resource and environmental management have documented numerous reasons beyond immediate subsistence for intentionally modifying and managing plants and plant communities on scales from individual trees to small patches of land, to entire landscapes (Anderson 2005, Armstrong et al 2018, Lightfoot et al 2013, Lightfoot and Lopez 2013, Turner et al 2009). These activities, too, are technological and subject to *chaîne opératoire* analysis.

By linking and expanding *chaînes* as they unfold spatiotemporally, archaeologists can trace even subtle effects of various practices on the landscape. In so doing, they can make explicit the mechanisms expected to accompany correlations and conclusions of causal relation in mainstream environmental archaeology (Dincauze 2000).

Equally important is the way that *chaîne opératoire* analysis exposes the choices made by actors to a thoughtful analyst; the reconstruction of *chaînes opératoires* requires the investigator to engage with the intentions and knowledge of past actors. Such analysis in fact foregrounds the intentions of actors even in small-scale societies, where Kidder (2013) has found it easy for researchers to overlook or inadvertently disregard them. A *chaîne opératoire* approach not only foregrounds the existence of past intentions, it also enables their analysis. Where multiple strands of *chaînes* intersect and different individual actors perform technical actions, their differing sets of required knowledge shift in and out of the *chaîne*, as do their intentions. The patterns of these shifts may reveal the landscape impacts not only of a society generally, but of specific groups or communities within that society. Similarly, the knowledge and intent of impacts on the landscape may be discontinuous across the *chaîne*. Such findings should invite deeper scrutiny of political economy in landscape transformation processes as well as the ways that ecological risks, costs and benefits can be enacted, ignored, absorbed or externalized by different segments of society.

The advantages of a *chaîne opératoire* approach for studying technologies directly extend to studying landscape transformation and ameliorate some of the principal conceptual difficulties in historical ecological archaeology. Accordingly, this project adopts a *chaîne opératoire* approach as a tool for parsing archaeological and paleoecological evidence within the theoretical framework of historical ecology.

Conclusions

This chapter has introduced several important concepts for this project. It has introduced and situated the research program of historical ecology, which provides a framework of fundamental assumptions to guide inquiry and interpretation of evidence for the interactions between ironworkers at Ogata and their local landscape. It follows that their landscape was inherently anthropogenic, with a specific history prior to the arrival of ironworking that influenced their own historical trajectory on that land. The effects of their activities on that landscape are not a foregone conclusion: they may have been positive or negative, in both their own evaluation and that of later observers. Furthermore, their relationship to the landscape can be studied as an integrative phenomenon. This relationship played out over multiple spatial and temporal scales on the Osaka Plain.

It is particularly important to theorize landscape given the plurality of definitions in archaeology. For the purposes of this study, the landscape is a palimpsest-like built environment constituted by the intentional and unintentional effects of the ongoing interaction between human and nonhuman actions and processes that entails senses of place and meaning irrecoverable or only dimly glimpsed archaeologically. But what can be recovered is nevertheless valuable for understanding past lives in that place.

Despite the enduring presence of monumental tombs, the landscape of the Osaka Plain has transformed immensely since the fifth century. Even below the extensive concrete and asphalt surfaces of modern urban development, agricultural activities and intensive hydraulic engineering, fluctuating population levels, and early modern urbanization alongside sea level changes, and the actions of meandering rivers and their varying deposition and erosion regimes all obscure the traces of the Kofun and earlier periods. What do remain to modern researchers are of course buried archaeological assemblages, but notably also paleoenvironmental records, especially pollen samples taken during archaeological excavations.

These are powerful datasets that can provide evidence of disturbance and landscape changes, but how we understand that data, especially with only limited access to other lines of evidence is fraught. Even when striving to culturally contextualize pollen data (Richer and Gearey 2017), we may rely on the oft-repeated but scientifically questionable intermediate disturbance hypothesis (Balée 2006, Fox 2013a). In the absence of, or at least the only very cautious application of such heuristic understandings of anthropogenic effects on species diversity, we must think through human activities and their effects very carefully.

Researchers in historical ecology must also consider the intentions of past actors carefully. Without written or oral accounts of past activities, intent in the transformations of past landscapes can be overlooked, or may be subject to unsystematic speculation. In this chapter I introduced a novel extension of *chaîne opératoire* analysis, which is normally used as a tool for understanding the technology of portable artifacts, to the landscape by recognizing its status as an artifact of sorts, as well as the flexibility of a *chaîne opératoire* analysis to involve multiple actors, intentions, and branching pathways. For historical ecologists, this analytical tool foregrounds the intentions of past actors in a systematic and empirical way.

In combination, these ideas provide a core framework for investigating the interrelationships between ironworkers at Ogata, their technological choices, and the landscape they dwelt on. Despite some careful explorations of caveats pertaining to this project and the incorporation of a new (to historical ecology) analytical tool, this project fundamentally fits within the research program of historical ecology.

Chapter 3: Ironworking Fundamentals

Introduction

Linking the ironworking technology to landscape management at Ogata with an extended *chaîne opératoire* approach requires a detailed understanding of ironworking processes and archaeometallurgical investigation methods in the abstract, as well as both the broad context of the archaeology of ironworking in the Japanese archipelago and the dynamics of forest landscapes on the Osaka Plain. This chapter provides the essential scientific background to explore the archaeology of Kofun Period ironworking in general and later the evidence from Ogata specifically. Given the methodological movement to expand the *chaîne opératoire* of ironworking to link it to landscape management practices, the definition and scope of ironworking are important considerations. Ironworking can be thought of as all the technological processes relating to the purposeful procurement and transformation of iron and its alloys. In this study, ironworking does include environmental management practices related to fuel procurement and use, but background information on Japanese forest dynamics and management will be covered in Chapter 5.

This chapter is essentially divided into two sections: the first is a description of ferrous alloys and their properties, and the second covers ironworking technologies and techniques. However, before proceeding, I must make a brief note about terminology and present an additional goal for this chapter. The “general” set of ironworking procedures tends to be discussed in English terms derived from the specific history of ironworking in Europe from the late medieval period onward. Because of the way English has become the hegemonic language of science, these specific historic terms are difficult to avoid even in “objective” scientific description of the material properties and behaviors of alloys in laboratory conditions. Historic terms like “cast iron” and “steel” now have specific scientific meanings that make them difficult to avoid, but the use of these terms need not be accompanied by ones that have not acquired status as widely accepted scientific and industrial nomenclature.

This is important because as seemingly immutable as the chemistry and physics of ferrous metallurgy are, the processes and techniques used to cause and control these material transformations are not. They are in fact highly variable temporally and geographically, and force-fitting these technologies into European frameworks, or at best always implicitly comparing them to the European historical trajectory through the use of that terminology, at a minimum does a disservice to the ingenuity and skills of non-European metalworkers and often additionally invites imprecision, confusion, or misunderstanding of these technologies. Terms like “wrought iron” and “refining” are everywhere in the discourse of historic metallurgy, and a decolonized or decolonizing vocabulary has yet to emerge. The most precise descriptions are of course the historically and culturally particular, but these are too particular for a general discussion meant to set the stage for discussion of the particularities, and furthermore are often unknown to the researcher as a simple matter of temporal distance: no one knows anymore. At the same time, detailed descriptions in scientific language are excellent for explaining processes with the desired level of precision, but they are unwieldy to repeat in extended discussions and lack a convenient shorthand. In the interest in both accuracy and generality, I will attempt to develop a less Eurocentric nomenclature for examining ironworking processes, and adopt a tripartite classification of ironworking technologies to better account for variations in past divisions of labor. Finally, while some concepts and processes covered in this chapter benefit from some discussion with concrete contexts, much here is the presentation or description of

established science or very general description of technologies. I have therefore omitted citations for much of this “textbook” knowledge, and would direct interested readers to more detailed sources, such as Callister and Rethwisch 2010, Verhoeven 1975, Verhoeven 2007, and Samuels 1980.

Ferrous Alloys, their Phases, and Properties

Debate continues around the circumstances of the initial adoption and eventual widespread use of metallic iron as a material (Thornton and Roberts 2014). Initially it may have been attractive for its rarity, but in other places and times the ubiquity of its ores or availability as a trade good seem to have played a role. In still other circumstances, its unique material properties surely contributed to its adoption. Regardless of the reasons, *chaînes opératoires* of ironworking cannot be understood without reference to these material properties, the underlying physical structures that give rise to them, and the conditions for physical transformations between physical structures. This section provides an overview of this important background information, covering the common phases and allotropes of ferrous alloys, the effects of common alloying elements, as well as a brief discussion of grain size and its effects. Because carbon is the primary alloying element in pre-modern ferrous alloys, discussion of its role is interwoven throughout this section.

Cast iron is relevant to this study insofar as it may have been imported to the Japanese archipelago as raw material, and would need to be decarburized before it could be worked. Accordingly, a full treatment of cast irons is omitted, and only the most salient information is presented. Additionally, for the plain carbon alloys under discussion here, the material properties most associated with metal implements (especially in the Kofun Period), hardness, strength, and toughness, correlate well with each other. Since high hardness correlates with high strength and low toughness, only the hardness of these constituents will be mentioned, as relative strength and toughness can thereby be inferred.

Iron, Steel, and Cast Iron

Somewhat unintuitively, the terms iron, steel, and cast iron refer to alloys of iron and carbon of increasing carbon composition with notably different material characteristics. In modern materials science and industry, “iron” technically refers to very pure iron, which is covered below, however, it is often used as shorthand for the historical term “wrought iron.” “Wrought iron” itself invites some confusion because most specifically it refers to a very low carbon ferrous alloy that has been decarburized through processes called fining or puddling, but is also often used to refer to very low carbon alloy produced through a solid state smelting process called “bloomery,” described below. Regardless, alloys can be reasonably referred to as iron if they contain 0.05% carbon or less, which is too low to permit hardening through quenching to martensite. Iron also has a very high melting point, which was exceedingly difficult to reach prior to modern industrial innovations.

Steel refers to iron-carbon alloys with carbon content higher than the aforementioned iron, up to 2.14%, but in practice usually up to about 1.2%. Microstructurally, these alloys may contain ferrite, cementite, and/or pearlite in the annealed or normalized state, and can be quenched to form martensite or bainite. The ability for ironworkers to induce these changes as well as alter their properties through a variety of means makes steels superior to iron in many applications. Steels have very high melting points, though not as high as iron.

Cast irons contains more than 2.14% carbon and are so named because their high carbon content results in a melting temperature that could be achieved in non-industrial settings, and could therefore be cast to form. Cast irons are much more brittle than steels, and generally cannot be worked by forging, nor can their microstructures be transformed to martensite or bainite through quenching. Cast irons are smelted directly from ore using so-called blast furnaces that operated at higher temperatures and could raise the carbon content of the metal high enough to bring the melting temperature in line with the operating temperature of the furnace. Cast irons so produced have some direct applications, but various techniques, such as fining and eventually puddling in Europe also existed to decarburize cast irons to “wrought” iron or less commonly to steel for use in forging applications.

Pure Metallic Iron

At normal atmospheric pressures pure iron can exist in multiple phases depending on its temperature. At room temperature it is a magnetic solid with a body-centered cubic (BCC) crystal structure called alpha ferrite. Above 1538 degrees Celsius it melts into a liquid, between 911 degrees Celsius and 1394 degrees Celsius it takes the form of a solid with a face-centered cubic crystal structure (FCC) called austenite, and between 1394 degrees Celsius and 1538 degrees Celsius it forms delta ferrite (BCC), which is similar to alpha ferrite in the absence of alloying elements.

Extremely pure iron is vanishingly rare outside of laboratories; it usually has some other elements incorporated into its structure, even if only at minuscule levels. Carbon is probably the most important for most archaeometallurgical discussions. When mixed into iron even in very small quantities, carbon has profound effects on the properties of the resulting alloy. Iron-carbon alloys like steel or cast iron have significantly different properties from “pure” iron. First, the temperatures at which iron melts begins to decrease as carbon content increases, but the temperatures at which austenite and ferrite form also change. Additionally and significantly, new phases, such as cementite and other carbides, pearlite, or ledeburite can form. This is summarized on the iron-carbon equilibrium phase diagram (figure 1). The equilibrium phase diagram assumes temperature changes happen at under equilibrium conditions, but even more phases, like martensite, troostite, and bainite can form if hot steel is cooled at different rates, and the properties of these phases also change according to carbon content. These constituents all have different properties suitable for different applications, and are discussed in more detail below.

Ferrite

Ferrite is the BCC phase formed by pure iron at room temperature, but just like most iron in general, most ferrite is not pure iron. Even so, it is relatively close to pure, since ferrite has limited solubility for interstitial and substitutional alloying elements. Ferrite is ferromagnetic below 768 degrees Celsius and paramagnetic above it. When cooled under equilibrium conditions from the austenite phase, hypoeutectoid steels (those containing less than 0.76% carbon) will form at least some ferrite outside of the grains of pearlite. Though precise hardness of ferritic materials will depend on factors like grain size and dislocation density, ferrite is the softest constituent of ferrous alloys, and is softer than many bronzes, especially if the bronze is work hardened (Scott 2013).

Austenite

Austenite, also known as gamma iron, has FCC crystal structure and is paramagnetic. Iron-carbon alloys containing 2.14% carbon or less will transform to this phase above the A_3 or A_{cm} temperature, which vary with carbon content (see figure 1). Alloys with carbon contents above this carbon solubility limit but under 4.30% will transform into austenite in combination with other constituents above 727 degrees Celsius. In the absence of other alloying elements, above 4.30% carbon, austenite does not form at any temperature. Austenite is not stable at room temperature in the absence of high concentrations of additional alloying elements, so when it is cooled below its formation temperatures at equilibrium, it will transform into other constituents depending on the carbon content. Heating a ferrous alloy containing up to 2.14% carbon to transform it to austenite, then controlling its cooling it is the main way for ironworkers to produce other phases in the metal, such as pearlite, cementite, martensite, or bainite. Not all austenite may be transformed during a quenching heat treatment to produce martensite, leaving behind what is termed “retained” austenite, which is not desirable under most circumstances since it leads to lower hardness than a fully martensitic steel.

Cementite and Other Carbides

Cementite, Fe_3C , is the most common iron carbide and one of the constituents of pearlite. When present at room temperature outside of pearlite, the overall alloy is hypereutectoid (containing a carbon content in excess of 0.76%). Under equilibrium cooling conditions, hypoeutectoid alloys will transform into grains of ferrite, with excess carbon beyond the solubility limit becoming arranged as cementite within grains of pearlite. Under equilibrium cooling conditions, hypereutectoid alloys will transform into pearlite, and excess carbon will form cementite at grain boundaries. Depending on heat treatments and alloy composition, cementite may be present inside or outside of ferrite or pearlite grains, as granules, plates, or as larger masses. Other carbides can also occur, especially ϵ -carbide, which forms in slightly tempered martensite and in lower bainite, among other places (Samuels 1980: 11). These other carbides may also precipitate from austenite as proeutectoid constituents (Samuels 1980: 11). Carbides are much harder than ferrite and contribute to the overall hardness of the areas they occur in ferrous alloys.

Pearlite

Pearlite is a two-phase eutectoid constituent of ferrous alloys that may appear at room temperature in alloys containing more than 0.02% carbon. The two phases present are ferrite and cementite, and they are organized in a lamellar structure inside grains. The lamellar structure results from equilibrium cooling, but several factors can affect the integrity of this structure and aspects such as the lamellar spacing. These factors include alloying elements, especially small austenitic grain size, very slow cooling rates, and the presence of incompletely dissolved cementite (Samuels 1980: 24). Cementite lames can be degraded and will eventually transform into spheres if pearlite is held at high temperatures below 727 degrees Celsius for prolonged periods. The lamellae of cementite in pearlite give it a significantly higher hardness than ferrite, even in its annealed state.

Martensite

Martensite technically refers to type of structure rather than a phase of steel specifically, but the term is commonly used to refer to steel transformed into this structure through the rapid cooling of austenite. When cooling under equilibrium conditions, austenite decomposes to ferrite

and cementite (pearlite), but rapid cooling prevents diffusional transformation (Samuels 1980: 14). Martensite may actually take two forms in steels: lath martensite and plate (sometimes called acicular) martensite depending on the carbon content of the alloy. Laths are the predominant form in steels up to 0.6% carbon, though they do exist up to about 1%, and above 1% carbon, martensite is almost exclusively found in the plate form.

Martensite is a metastable transition structure, and is relatively easily transformed after formation through additional heat treatment, called tempering. The transformation brought on by tempering is structural, but varies according to the degree of tempering. Accordingly, tempered martensite is called just that, and does not have a different term in current usage. Early works may refer to heavily tempered martensite as either sorbite or troostite, but these terms are obsolete and may also refer to very fine pearlite. Even when tempered, martensitic steel is several times harder than unquenched steels of equivalent alloy composition.

Bainite

Bainite is a generic term for products of nonequilibrium cooling of austenite that takes place too fast to form pearlite, though not fast enough to form martensite. It is a two-phase constituent consisting of ferrite and carbides, but distinct from pearlite. Bainitic structures are typically categorized into upper bainite, which forms at higher temperatures, and lower bainite, which forms at cooler temperatures. Bainite is rarely found in premodern objects due to the complexity of controlling cooling rates, but is occasionally seen in objects like swords (Scott 2013). Bainite is much harder than pearlite, but not as hard as martensite.

Graphite

Graphite, a form of pure carbon, is only formed in alloys with very high carbon content, such as cast irons, and only when cooled from liquid slowly or otherwise thermally treated. Cast irons in which the carbon has formed graphite are called grey cast irons, whereas ones where the carbon has formed cementite are termed white cast irons. Mottled cast irons are those containing both graphite and cementite. Graphite may appear in a variety of distributions, forms, and sizes. Graphite itself is soft, but only appears in cast irons, which are very hard, if brittle.

Inclusions

In addition to the above alloy constituents and phases, metal objects may contain inclusions of other materials. In modern industrial steels these are often manganese sulfides, but inclusions in alloys produced through premodern means are likely to be slag. Inclusions are generally deleterious to the alloy's toughness because they provide sites for the initiation and subsequent propagation of cracks. Accordingly, lower levels of inclusions are generally desirable, however slag melting out of a ferrous alloy can be useful during welding operations where it may act as a flux, preventing oxidation of the welding surface. The amount of slag present in metal depends on how it was smelted and subsequently processed, which will be covered in a later section.

Grain Size and Dislocations

As seen above, heating and cooling affects the constituents present in a ferrous alloy, and at the same time it can also produce changes in the sizes of the crystal grains that make up the microstructure of a ferrous alloy object. As iron changes from one phase to another due to temperature changes, these phase changes do not simultaneously reorganize every atom

throughout the metal into a single crystal with a single orientation, nor do they start in one location and proceed atom-by-atom until the entire mass is converted to a single crystal with a single orientation. Rather, the phase changes begin nearly simultaneously at many points throughout the mass, with many crystals of the new phase nucleating and beginning to expand, reorganizing atoms of the old phase as they do. The directional orientation of these new crystals is not identical, and as they expand they eventually come in contact with each other as the phase transformation completes, resulting in boundaries between them defined by discontinuities resulting from the differing orientations of the neighboring crystallites. These many crystallites in the mass are called grains.

Within each grain, atoms are aligned with each other, but not every space in the grain's crystal lattice is occupied by an atom. These empty spaces are called dislocations, and the movement of these dislocations within the body of an object is what allows for the deformation of the metal. Perhaps counterintuitively, the higher the density of dislocations in a material, the stronger it is. This is because dislocations become barriers to the movement of other dislocations, thereby preventing plastic deformation. It is also difficult for dislocations to travel across grain boundaries. This means that in general, the smaller the grain size in a metal, the less dislocations can move, and so the stronger it is. Smaller grain size also reduces hardenability somewhat (Siebert et al 1977). Dislocation density and grain size in ferrous alloys can be influenced by ironworkers through heat treatments and mechanical working.

Alloying Elements

The ability to manipulate the properties of an object by changing its phase composition through alloying and heat treatment is one of the reasons ferrous alloys are attractive materials for many applications even today. As evident from the preceding description of alloy constituents and phases, the amount of carbon in ferrous alloys is key to understanding and manipulating their phase compositions, especially in premodern metallurgy. That said, carbon not only affects what phases are possible, but also the properties of those individual phases. Other alloying elements or impurities (depending on your perspective) have important effects on ferrous alloys as well.

In general, the presence of alloying elements affect the A_1 and A_3 critical temperatures as seen on the phase diagram as well as the carbon percentage of the eutectoid. Effects on A_1 and A_3 are disparate, but alloying elements almost uniformly lower the carbon percentage at the eutectoid. With respect to transformations, all alloying elements except cobalt, which is rare in archaeological ferrous alloys, delay the start and finish of transformation in cooling treatments (Samuels 1980: 53-57). These properties were probably not important to premodern smiths who may recognize that iron from different sources had different behaviors but had limited ability to change them, and the effects themselves were comparatively minor in the absence of modern industrial temperature controls. Rather, alloying effects on the final and working properties of the metal would be more immediately recognizable and understood. These will be the focus of the following descriptions of alloying elements/impurities. Other elements besides the ones described here occasionally appear in premodern ferrous alloys, but the following are of greatest interest.

Carbon

As shown in the equilibrium phase diagram, carbon content lowers the melting point of the alloy up to 4.3% before it begins increasing again. Similarly, the austenitizing temperature falls as

carbon content increases to the eutectoid of 0.76% before increasing again. The formation of non-ferrite constituents is also dependent on the presence of carbon. That is to say that very low carbon alloys cannot be quenched to form martensite or bainite, and will not form pearlite due to the necessary carbon content of those constituents.

Carbon content also affects the hardness of the alloy regardless of which phase it is in. The hardness of steels in annealed or normalized states rises with increasing carbon content up to about 0.6%, but above that hardness is approximately constant (Samuels 1980: 171). The hardness of untempered martensite also rises with carbon content up to at least 1.0 percent (Grange et al 1977).

Phosphorus

Phosphorus strongly affects the hardness of ferrous alloys; in small quantities its effects can be beneficial, improving strength, especially compared to very low carbon ferritic metal, but higher amounts quickly lead to brittleness, especially at low temperatures. In finished objects, this brittleness may only be apparent in cold weather, but while forging, alloys containing notable amounts of phosphorus are cold short (Rostoker and Bronson 1990: 22). That is, the smith must be careful to keep the metal at higher than usual temperatures or else it may crack or crumble when struck. Not only does phosphorus harden iron simply by its presence, it also improves its capacity for work hardening, and in the presence of carbon, it also improves the quench hardenability of the alloy, though it also impedes efforts to carburize the metal (Rostoker and Bronson 1990: 22). Phosphorus can be added directly to molten cast iron to depress its freezing temperature, but historically it more often arrived in a metal as a result of its presence in the ore smelted (Rostoker and Bronson 1990: 22). Phosphorus is generally viewed as a contaminant in modern industry, but ironworkers in the past may have enjoyed some of its effects, especially when its incorporation was difficult to avoid due to ore availability and the absence of higher carbon steels.

Sulfur

Sulfur is generally regarded as undesirable in modern steel, even at levels as low as 0.03 percent (Rostoker and Bronson 1990: 21). The reason for this is that it causes hot shortness, or the tendency to crack when struck at high temperatures. Smiths confronted with raw material containing sulfur must forge at temperatures below 988 degrees Celsius, which is inefficient with respect to fuel and labor, since the metal will need to be reheated more often than other stock, and the temperature must be monitored very closely (Rostoker and Bronson 1990: 21). This tendency can be counteracted with large additions of manganese, but this was neither directly understood nor generally possible in premodern contexts. Sulfur also strongly affects cast irons, promoting the formation of white cast iron instead of grey cast iron (which may or may not be desirable), and improving castability (Rostoker and Bronson 1990: 22). Even at as little as 0.05%, sulfur is seen as an impurity in modern cast irons, much like modern steels (Rostoker and Bronson 1990: 21). Sulfur can enter ferrous alloys either through its presence in iron ores, or through the use of sulfurous fuels such as coal or coke for smelting or other processing.

Copper

Like sulfur, copper makes ferrous alloys significantly hot short. In historic times it was rarely added to steel to produce visual effects on the surfaces of Japanese swords (Smith 1960: 52), and is a component of some special purpose modern alloy steels (McGannon 1964: 1089),

but it is generally regarded as having deleterious effects on the properties of steels. Copper bearing minerals can be reduced under iron smelting conditions, so ores bearing both iron and copper may result in iron or steel contaminated by copper (Rostoker and Bronson 1990: 20). There is evidence that both the malign effects of copper and their source in certain ores was known historically in renaissance Europe (Rostoker and Bronson 1990: 20-21). In addition to the ore route, pure copper could of course be added to molten cast iron.

Manganese

Manganese significantly improves hardenability in steels, especially above 0.8% (Siebert et al 1977: 86), making it a desirable alloying element in any hardened application. The typical route for manganese to enter ferrous alloys in premodern contexts was through smelting. Generally, any cast iron smelting furnace operated under conditions that could reduce manganese oxides in ores (Rostoker and Bronson 1990: 19-20). Depending upon their operating temperatures, bloomery furnaces may or may not have been able to reduce manganese oxides. If operating at the minimum temperature to reduce iron ores, manganese oxides would not be reduced, but rather would be carried away in the smelting slag, however, hotter furnaces could and evidently did produce blooms with significant manganese content (Rostoker and Bronson 1990: 19-20).

Nickel

Nickel is occasionally found in preindustrial ferrous alloys and may have arrived there through smelting ores containing nickel, since nickel can also be reduced even in an iron bloomery furnace. That said, such ores are comparatively rare, and most high-nickel alloys from premodern contexts are actually meteoric in origin rather than smelted (Rostoker and Bronson 1990: 20). Nickel does improve hardenability, though not as much as manganese (Siebert et al 1977). Nickel has been used both historically and in the present for decorative effect in etched steel surfaces.

Nitrogen

Like carbon, nitrogen increases strength, hardening capacity, and hardenability, however, it is difficult to introduce into iron. If nitrogen were added to ferrous alloys historically, it was probably through treatments intended to add carbon but also incidentally included ingredients bearing monatomic nitrogen (Rostoker and Bronson 1990: 23).

Silicon

In premodern contexts, silicon is unlikely to have been deliberately added to ferrous alloys, but it does appear in historic cast irons at as much as 1.5%, where it promotes solidification as grey cast iron (Rostoker and Bronson 1990: 22-23). At the high temperatures in a cast iron smelter, silica, which is practically ubiquitous in ores, is also reduced to elemental silicon, which could diffuse into the liquid metal (Rostoker and Bronson 1990: 23). As for bloomery furnaces, fineries, and puddling furnaces, even when they reached high temperatures in some zones, most silicon would reoxidize to silica on contact with oxide-rich slags in lower temperature areas (Rostoker and Bronson 1990: 23).

Summary

The material properties of ferrous alloys arise from their chemical composition and physical structures. A variety of microstructural constituents, each with their own properties, may be present depending primarily on the metal's carbon content and its history of heating and cooling. Heating and cooling also affect the size of crystal grains, which contribute to an object's material properties, including how heating and cooling affects its microstructural phase composition. While carbon content is the most significant determinant of premodern iron alloy properties and behavior, other elements, too, are commonly found in archaeological ferrous alloys. These additional elements have various effects on both an alloy's material properties at ambient temperatures, and its response to heating and cooling. Though they did not understand the physics behind these variables and their relationships to material properties as modern scientists do, and may have valued those properties differently than modern metallurgists, past ironworkers were nevertheless able to produce ferrous alloys and manipulate their properties through an array of techniques and processes. These technologies are understood through a combination of established modern scientific principles alongside ethnographic and archaeological investigations. These technologies and their archaeological study are the topic of the next section.

Ironworking Technologies and Techniques

The preceding discussion, while touching on how different properties may be achieved in a ferrous alloy, was a primer for the discussion of the general procedures of ironworking, which must be understood in order to grasp the variation in those procedures visible to archaeologists. Heather Miller, describing metalworking more generally, divides processes into the four categories of raw material procurement, materials preparation, primary production, and secondary production (Miller 2007: 145-146, fig 4.11) that together make up a general *chaîne opératoire* for ironworking. Taken together, these categories are useful for demonstrating the basic scope of ironworking, but not the internal breakdown of the field in all places and all times. In Miller's formulation, each of these categories (except primary production) contains multiple general categories of processes, each of which in turn encompasses a myriad of variations as practiced in different places and times. However, these variations do not map neatly to one another between cultures. One culture's single process may yield a similar final result to a sequence of multiple processes in another culture, or available raw materials in one place may necessitate additional processes to achieve the desired results. History and human ingenuity have produced many ways to work iron within the hard constraints of physics and chemistry.

The sheer diversity of past ironworking technologies makes categorizing activities within "general procedures" difficult, and doing so creates a predisposition toward a singular standard procedure, against which variations are unintentionally positioned as unusual or exotic, with all the associations that frequently accompany those terms. Given the material constraints of ores, fuels, ceramics, and of course ferrous alloys themselves, some aspects of ironworking can be generalized enough to avoid this error. However, much as modern Western science and industrial technologies have become standard around the globe replacing preceding local ways of knowing and doing, historical ironworking procedures based in the Western European trajectory of metallurgical development have come to constitute the standard model for describing "general" ironworking, particularly in Anglophone scholarship. These procedures do not necessarily capture the intended inputs and outputs of processes used elsewhere, and furthermore, they may not adequately capture prehistoric processes. This is particularly evident in descriptions of metal processing occurring after smelting but before forging.

As noted in Chapter 2, *chaînes opératoires* can be extended in all directions, branch out, or be truncated to suit the needs of a researcher. This dissertation is only concerned with investigating part of the ironworking *chaîne*, excluding smelting, any prior activities, and potentially some afterward. However, these activities have effects on later stages of the *chaîne*, and so necessitate some description despite their limited direct relevance to the central questions of this project. This section will provide a generalized background on the materials and processes of ironworking, develop a more neutral vocabulary for its description, and detail the archaeological residues and analytical techniques available to researchers.

Smelting Operations

Since metallic iron and alloys thereof exist natively almost exclusively as meteorites, generally, ferrous alloys must be produced from ores, which are any rocks containing an economically viable amount of iron-bearing minerals. This process is called smelting. There are a many technologies that have accomplished this task around the world, and even more that are theoretically possible. Since this study is focused on post-smelting aspects of ironworking, this section will give only a cursory overview of the theoretical aspects of smelting and outline the relevance it has for other ironworking practices.

Ores consist of some quantity of iron mineral and other materials, which are called gangue. Prior to the nineteenth century, generally only iron oxide minerals were exploited for iron smelting (Rostoker and Bronson 1990: 42). Smelting separates the gangue materials from the iron oxides, and reduces the iron oxides to metallic iron. Depending on the composition of the gangue, element other than iron may also be reduced and to greater or lesser degree become incorporated into the metallic iron as well. Impurities arising from the fuel composition can behave similarly. However, in addition to producing metallic iron, smelting results in slag, which is waste in the final product, but serves to protect the metallic iron from oxidation and most impurities during the smelting process.

All this is achieved with both high temperatures and a strongly reducing atmosphere in the smelting furnace. These two features are in opposition to a degree, as vigorous combustion producing high heat results in more carbon dioxide than carbon monoxide, yet it is carbon monoxide, a product of inefficient combustion that is required to reduce iron oxides to metallic iron. Successful smelting depends on appropriate furnace design and air flow, carefully selected and prepared ores and fuels, and practical knowledge of furnace operation and management procedures to achieve and maintain high temperatures with a sufficiently reducing atmosphere.

At the lowest temperatures hot enough to maintain a liquid slag (1000-1100 degrees Celsius), iron oxides will not be reduced unless the ratio of carbon monoxide to carbon dioxide in the furnace is 4:1 or more (Killick 2014: 29-32). At these temperatures in such an atmosphere and up to a carbon monoxide to carbon dioxide ratio of 97:3, the resulting product will be a very low carbon iron. With carbon dioxide at one to three percent, steel can hypothetically be produced, and carbon monoxide at still higher levels will result in the production of cast iron (Rostoker and Bronson 1990: 89). In practice, maintaining the furnace atmosphere required to smelt directly to steel is extremely difficult, very rarely achieved, and even when it was achieved, the product was usually unsatisfactory (Rostoker and Bronson 1990: 136). Instead, when steel was produced directly in a smelting furnace in nonindustrial settings, it was because either cast iron was produced in part of the furnace, and iron in another, which mixed, or because the furnace made one product and then the other in the same smelting campaign, again mixing

(Rostoker and Bronson 1990). In most smelting systems, either iron or cast iron was produced, and both the metal and the slag resulting from each system differed significantly.

Solid-State Smelting

Unlike cast iron production, which involves liquid metal, systems that produced very low carbon iron are entirely solid-state processes. In these systems, carbon monoxide reacted with iron oxides to produce tiny pieces of solid metallic iron, which fell into the liquid slag, slowly sank through it, and sintered to other pieces of metallic iron beneath the slag. The slag itself is composed of material from the gangue, fuel ash, the furnace walls, and iron oxides from the ore. Chemically, the bulk of the non-iron oxide material is silica with much smaller quantities of other oxides like calcium oxide, manganese oxide, magnesium oxide, and aluminum oxide. Much of the iron oxide in the ore actually melts into the slag rather than being reduced. This is what allows the melting temperature of the slag to be low enough to remain liquid during operations, but it does mean that the iron recovery rate is low. Furnaces reducing metallic iron in a solid state like this typically produce slags that are 60% iron oxide or more. Higher temperatures can lead to better iron recovery, and as alluded to above, this kind of smelting system can produce small amounts of liquid cast iron in part of the furnace and/or during part of the smelting run. That said, the bulk of metal produced was not cast iron, and so never liquid at the furnace temperatures. The product of this system is a spongy mass of (typically very low carbon) ferrous alloy that contains many pockets of entrapped slag.

In English, this mass is typically called a bloom, the iron stock consolidated from this mass bloomery iron, the furnace a bloomery furnace, and the process bloomery production. Some confusion can arise from these terms since bloom can also refer to the product of a decarburization process called puddling, and some smelting systems, such as the early modern Japanese *tatara*, operate primarily on bloomery principles but through particular furnace design and operation were used to create large amounts of cast iron and steel bloom in addition to low carbon iron bloom. That said, there is no clear alternative nomenclature for the products and processes of archaeological smelting systems with no extant documentation or living tradition. Bloom, as a term for the spongy mass of iron product will do in spite of its covalence, but “bloomery” invites the conflation of a product, a furnace, and a process. In spite of the alliteration, where possible I adopt the term “solid-state smelting” to force specificity about what is and is not the subject of discussion.

Cast Iron Smelting

Smelting to cast iron occurs under more reducing conditions than solid-state smelting. However, when these conditions are reached, the iron oxides that would become part of the slag in a solid state smelting system also begin to reduce, raising the temperature required to maintain a liquid slag. In practice, temperatures above about 1300 to 1350 degrees Celsius must be maintained to ensure good functioning of the slag (Rostoker and Bronson 1990: 102-104). At this temperature, the carbon monoxide to carbon dioxide ratio required for reduction to liquid cast iron is lower than in a solid-state smelting furnace, below nine to one (Rostoker and Bronson 1990: 102). Ironworkers may or may not add specific substances, such as lime (calcium oxide) to help maintain the liquid slag. In any case, since most if not all the iron oxides in the ore (and slag, should they melt before being reduced) are reduced, the slag composition in a cast iron smelting system is markedly different than slag from a solid-state smelting system. Cast iron smelting slags tend to be composed primarily of silica, calcium oxide, and aluminum oxide, with

smaller amounts of magnesium oxide, manganese oxide, and sometimes some iron oxide (Rostoker and Bronson 1990). The liquid cast iron sinks below this slag and can be directly cast into final molds from the smelting furnace, or cast into intermediate forms (often called pigs in English, leading to the term pig iron) for later processing.

Heat and carbon from the fuel is the key to smelting operations, so choice of fuel is important. The necessary temperatures for smelting are hard if not impossible to achieve with fuels like wood or other uncharred plant material, but they may be used to preheat a smelting furnace. Outside of modern industrial settings, actual reduction of iron oxides relies on fuels that are primarily carbon, that is to say charcoal, coal, or in later periods, coke. The reasoning behind the choice of charcoal or coal in past smelting systems is a broad topic beyond the scope of this project, but suffice it to say, both charcoal and coal were used as fuels for smelting in various parts of China and the Korean Peninsula by the start of the Kofun Period in the Japanese Archipelago (Rostoker and Bronson 1990 (pg 66), citing Read 1939-40). In terms of effects on the products of smelting, coal contains considerable amounts of sulfur, which will be absorbed by the iron, leading to hot shortness while forging. Charcoal, while more difficult to produce and transport, and providing less heat than coal, contains fewer contaminants that can affect the metal.

Though considerable efforts were required to smelt metal, from locating, procuring, and preparing ore, to doing the same for fuel, and constructing a furnace from suitable materials, neither the immediate product of solid-state smelting nor of cast iron smelting was suitable for forging, the technology used to form iron implements in the Japanese Archipelago during the Kofun Period.

Secondary Processing

Miller (2007) groups all ironworking processes aside from smelting as “secondary production,” including both the processes required to make smelting products forgeable, and forging itself. Rostoker and Bronson (1990) refer to some of these processes as “secondary smelting.” Both of these classifications imply particular (but opposite) divisions of tasks and by extension labor, though the authors all acknowledge that this need not be the case, and certainly was not always so. A tripartite classification of smelting, secondary processing, and fabrication seems to better handle the differences between divisions of tasks and labor, defining processes according to what they accomplish rather than where or by whom they are performed. This is still not satisfactory, as some tasks, such as carburization, may actually be performed after some fabrication activities. Additionally, it does not solve the polyvalence of the term “refining,” which in both English and Japanese can refer to very different processes, all of which fall into the class of secondary processing. This section covers the variety of activities involved in preparing smelting product for fabrication via forging specifically, and will address the issue of refining according to each process.

Forge Refining

Solid-state smelting produces a sponge-like lump of ferrous alloy that has entrapped a lot of the iron oxide and silica slag during its formation. This material is not suitable for forging into iron implements because the entrapped and adhering slag gives it markedly inferior qualities compared to iron containing no slag. In other words, slag needs to be removed from the bloom before it can be used. A bloom is also to greater or lesser extent only tenuously held together. A single activity can improve the bloom on both counts.

When the bloom is heated above the melting temperature of the slag, it is consolidated by hammering (forging) it, not necessarily forcefully, which squeezes much of the liquid slag out and fuses the metal together. So long as the bloom is consolidated, this process can be continued to varying degrees to eliminate varying degrees of slag, though removing all of it is high impossible, and approaching that limit is only economical for applications demanding the best metal. The reason for this is that the yield of metal from a fresh bloom is often in the range of only half of the bloom's initial mass (Rostoker and Bronson 1990: 94). In many applications, highly slag-free iron is unnecessary, so purposely further reducing its mass makes little sense, especially when mass is lost not just from the slag, but also from the oxidation of the metal itself at high temperatures. Furthermore, additional entrapped slag can be expelled during later forging operations, and entrapped slag can act as a flux for welding operations as well. When this consolidation and slag removal process is prolonged, say by cutting, folding, and rewelding the material back together to better remove slag inclusions deep inside the bloom, there are additional affects. The first is that the remaining slag inclusions become increasingly fine and homogeneously distributed through the material, stretched in the direction of forging. Second, if the bloom had any areas of higher carbon content resulting from varying furnace conditions during smelting, that carbon becomes increasingly homogeneously distributed through the metal. This is not only because of the potential for splitting up and relocating the higher carbon areas, but because of carbon diffusion through the metal at high temperatures. Oxidation at the metal's surface may lead to a loss of carbon, though.

Because this process removes impurities (slag inclusions, but not elements like phosphorus), it is a kind of refining, sometimes called forge refining. The degree to which ironworkers engaged in other activities also conduct this forge refining can vary substantially. For example, consolidating and forge refining the bloom when it is still hot immediately after it is withdrawn from the smelting furnace can be efficient with respect to fuel and time, since reheating it later requires additional fuel and labor. Furthermore, processing the bloom immediately into iron stock allows it to be more easily commodified. Yet there are many cases in which this was not done; the bloom steel from at least some early modern Japanese *tatara* furnaces was broken up and sorted by hand for distribution instead of being consolidated (Rostoker and Bronson 1990). In other cases, blooms could be processed to remove at least some slag without hammering. Simply heating the bloom and allowing slag to melt out of it before consolidating it rather than hammering it out was apparently practiced in parts of India (Rostoker and Bronson 1990: 95, citing Atkinson 1890), though it is difficult in the twenty-first century to identify any advantage of this procedure, as it seems to require more fuel and time than forging the slag out, while requiring equal effort to actually consolidate the bloom.

Processing the products of solid-state smelting requires both consolidation and removing large amounts of slag. The methods for accomplishing these goals: heating, forging, and potentially cutting, folding, and welding, are fundamentally forging techniques, hence the term forge refining. Accordingly, they can be performed to various degrees by ironworkers at different points in a *chaîne opératoire*, from smelters themselves, to specialist refiners associated with the smelting location, to the smiths who eventually fabricate objects from the metal by forging.

Decarburization of Cast Iron

In contrast with the products of solid-state smelting systems, cast iron from the smelting furnace contains practically no slag and a large quantity of carbon, so preparing it for forging is

an entirely different task. The obstacle to overcome is the carbon content, which makes the cast iron too brittle to withstand forging. There are numerous historically documented methods for decarburizing cast iron, but they can reasonably be classified into liquid metal and solid-state processes. Liquid metal processes involve remelting the cast iron and decarburizing it from that state, while solid-state decarburization processes do not. The upshot for the study of archaeological forging practices is that with the exception of the Westphalian fining process used to make small amounts of stock for drawing music wire (Goodway and Odell 1984, Schubert 1957), liquid metal decarburization results in a product with inclusions of slag composed mainly of iron oxides and silica, like the raw product from solid-state smelting (Rostoker and Bronson 1990). Additionally, since these processes cannot be controlled precisely enough to produce steel, the product is very low carbon iron, which when produced via a so-called puddling process, is called wrought iron in English.

Solid-state decarburization can only be performed on white cast iron, but could lead to products of varying carbon content, microstructure, and carbon morphologies, including steel, that like the original cast iron, did not contain slag inclusions. Solid-state decarburization was used to produce steel for weapons and tools in China as early as the Early Han Period (202 BC-AD 9) (Scott 2013, Rostoker and Bronson 1990, Bronson 1999).

Decarburization of cast iron to forgeable ferrous alloys is also called refining since it removes unwanted carbon. While decarburization of cast iron is strongly associated with large operations supplied by blast furnaces, like forge refining, both liquid metal and solid-state decarburization could potentially be performed by ironworkers at different points in a *chaîne opératoire*, from smelters, to specialist refiners, to smiths. To be clear, while there are historically attested liquid metal and solid-state decarburization processes that either were used, or easily could have been to different scales and divisions of labor, not every single process was amenable to different scales of operation and divisions of labor. A brief discussion of examples of each kind should nevertheless be sufficient to demonstrate the potential for small and medium-sized preindustrial ironworking contexts.

With respect to solid state decarburization, smiths know that without paying attention to creating a reducing atmosphere in their forging hearth, heated ferrous alloys will decarburize little by little. This could easily be applied to cast irons to decarburize them, except that without exceptionally fine control over just how oxidizing the atmosphere is, either the process will proceed too slowly to be practical, or the metal itself will oxidize leading to very low final yields. One solution to this was employed in eighteenth and nineteenth century Europe: Pack decarburization involved sealing the cast iron (often already cast to its final shape) in a closed container packed with materials like hammer scale (mostly Fe_3O_4) that when heated would produce an atmosphere that would decarburize the metal without oxidizing it (Rostoker and Bronson 1990: 1490-150). In Japan, white cast iron would be packed with charcoal in a container that was not sealed from air to create a similarly decarburizing atmosphere (Rostoker and Bronson 1990, citing Rein 1889).

Liquid metal decarburization is also a technique employed by traditional sword smiths in Japan (Saito 2014). The process and product is called *oroshi tetsu*, but like many terms in ironworking, it can refer to other processes and products. Here, the smith constructs an aboveground furnace fuelled with charcoal, which is blown via a tuyere positioned to direct airflow into metal that accumulates in the bottom after melting down from the top of the furnace where it was charged above the charcoal (Saito 2014). The antiquity of this technique is

uncertain, but it is simple enough that something like it could have been employed in many different settings historically.

Carburization

Another kind of secondary processing is the carburization of low carbon alloys to make steel. Carburization is essentially the opposite of decarburization, though possible techniques are essentially all solid-state processes due to the very high temperatures needed to melt low carbon alloys. Even so, there is a large array of methods, many of which are slight variations on decarburization methods. When the metal to be carburized is low carbon metal that had been decarburized from cast iron, this could rightly be called a form of tertiary processing, but classing it as secondary processing is consistent with the idea of scalability and flexibility in division of labor characterizing the forge refining and decarburization processes outlined above.

Much as ferrous alloys can be decarburized in an open hearth, so too can they be carburized. By adjusting the forge hearth air flow and fuel to create an area with a reducing atmosphere, a smith can very slowly add carbon to an object. Carbon diffusion will be very slow so this method can only be reasonably used to put a very thin layer of steel on a small iron object, but even that may be useful, say for producing arrowheads. Rostoker and Bronson (1990) contend that until most steel in the world was produced this way until the mid-nineteenth century, but it is hardly the only possible method available.

Carburization by heating an airtight container holding the low carbon alloy, a source of carbon, and a bit of fuel to release carbon dioxide was practiced by American blacksmiths even in the twentieth century (Rostoker and Bronson 1990: 124). That said, it was also performed on an industrial scale as early as the seventeenth century (Rostoker and Bronson 1990: 124). This is a solid-state carburization process, and depending on the particulars (amount and shape of metal stock, carbon source, temperature, time at temperature, etc.), the steel that emerges may have inhomogeneous carbon content, leading to unpredictable characteristics. One approach to rectifying this is to homogenize it by folding and welding, much as done with slaggy iron produced in solid-state smelting. This step too, could be done at different stages in a *chaîne opératoire* by different people; there is no reason it could not be done in an industrial setting right after the carburization process, or equally by a single smith wanting to improve his or her stock before fabrication.

A similar technique resulting in a somewhat different product involves using a sealed crucible that can withstand very high temperatures. Heating the crucible and its contents very hot for a prolonged period of time would raise the carbon content (not to “cast iron” levels) of the metal high enough that it would actually melt at that temperature, and the metal and slag entrapped in the iron stock would separate. When the crucible cooled, the product was a very high carbon steel that contained little to no slag. Though the product eventually melted, the carburization still occurred in a solid state. While this technique could theoretically be employed at a variety of scales under various divisions of labor, until the eighteenth century this kind of steelmaking was essentially geographically limited to India and the Middle East, and is primarily of interest to exclude it as a candidate for ironworking processes in the Japanese Archipelago.

However, several other methods for making steel by carburization are historically known from Japan. Of particular interest is a technique also employed by traditional sword smiths, and also called *oroshi tetsu*. The process is similar to the decarburization process described above, but with slight alterations to the furnace design and air blast. Instead of cast iron, low carbon metal is charged atop the charcoal, which is burned to produce a reducing atmosphere. The metal

is heated to a near-melting temperature and is carburized as it descends through the furnace, finally landing away from the direct blast of the air. The resulting steel is inhomogeneous, but the carbon content has been raised by 0.3-0.7% (Saito 2014: 207-211).

Like smelting, most secondary processing requires fuels that can produce high temperatures, again limiting reasonable choices to charcoal, coal, and coke. In smelting, liquid cast iron or tiny particles of hot low carbon iron can absorb sulfur from fuels, but large consolidated pieces of ferrous alloys will not absorb appreciable quantities of sulfur below its melting point. Accordingly, using coal for solid-state secondary processing will not imbue the metal with poor forging characteristics due to increased sulfur content, but its use for liquid metal processes will. While there is no evidence for the use of coal in the Japanese Archipelago prior to or during the Kofun Period, it was in use for some metallurgical processes in China and the Korean Peninsula (Rostoker and Bronson 1990). Accordingly, ironworkers in the archipelago may have used metal smelted or processed with coal.

Fabrication

Fabrication, processes of forming suitable raw materials into completed objects, can overlap with secondary processing both physically in terms of processes outlined above, and conceptually in terms of imbuing raw materials with the desired characteristics either for working or for the use of the completed object. Even so, though it would be possible, the processes described here are not often performed by ironworkers specializing in smelting or secondary processing outside of modern industry. The division of tasks between secondary processing and fabrication holds in practice due to this division of labor. In terms of fabrication processes themselves, like secondary processing, there are numerous techniques possible to accomplish given goals. Unlike secondary processing, though, there are many more potential goals than adjusting carbon content and removing slag inclusions, so rather than organizing processes according to these goals, it is preferable to classify them into hot working and cold working processes.

Hot Work

As the name implies, hot work is characterized by the necessity of heating the metal in a forge hearth as an early step in the work process. Forge hearth designs can take many forms, but in general they must be fueled by charcoal, coal, or coke subjected to air flowing into the hearth via a tuyere. Once heated, the metal can be manipulated in various ways using an array of generalized and specialized tools. Since these tools are so various, and so few of them are preserved from the Kofun Period (see Chapter 4), it will suffice to say here that these tools minimally include tongs for holding and moving hot metal, hammers and anvils for applying force, and chisels and/or punches and drifts for removing material and opening holes in it.

This set equipment allows the smith to plastically deform ferrous alloys heated to some 700 degrees Celsius or more, up to nearly 1200 degrees Celsius if the metal is not hot short. At these temperatures, ferrous alloys are far more malleable than at ambient temperature, and can be shaped with relative ease. The early stages of forming an object may overlap with secondary processing, specifically forge refining, depending on the raw material a smith is using. Smiths may begin to shape an unconsolidated or partially consolidated bloom into intermediate or final shape specific to the *chaîne opératoire* of the completed object, in the process consolidating the metal and driving out slag, thus combining elements of secondary processing and fabrication. The exact techniques of forging ferrous alloys shape is beyond the scope of this project, but it is

important to mention that working ferrous alloys at these temperatures has two effects besides the intended plastic deformation. When heated, ferrous alloys will begin to decarburize and to oxidize even in the normal atmosphere of the workshop. Decarburization is a problem when making implements with hardened steel parts, since that depends heavily on the presence of sufficient carbon. Smiths may have to grind away decarburized areas prior to quenching to mitigate this.

The second effect is metal loss due to oxidation. At high temperatures, a dark film of iron oxides will form on the surface of the metal during forging. This film flakes off the work piece incidentally while hammering, or it may be removed purposefully by the smith to better see the temperature of the metal, prevent the oxide from being incorporated into the metal during certain processes, or to maintain the desired surface finish of the piece. These flakes of iron oxides are called hammer scale, and are an archaeological residue of smithing operations. More importantly to ironworkers, the formation of scale comes at the expense of the material being worked, so smiths may budget for this loss of raw material.

Flux can also be used to limit the loss of both carbon and metal mass. Fluxes are substances that are applied to the surface of the iron raw material that melt and coat it, absorbing oxides and protecting the metal from further oxidation as well as decarburization. Many substances can be used as fluxes, including quartz rich sand. Raw material with significant slag inclusions may actually be fluxed by the slag inclusions melting out of the metal, which can be particularly useful in forge welding.

Hot work also encompasses notable methods of combining multiple pieces of metal into one object. Forge welding actually combines multiple pieces of metal into a single piece. Ferrous alloys will bond to each other when hammered together at high enough temperatures provided that the mating surfaces are smooth and clean of any oxides or other physical impediments to metal-to-metal contact. Since high temperature operations lead to oxidation, if there is insufficient slag occluded in the metal to act as a flux, a smith may use a flux of their own. The flux coats the mating surfaces, protecting them from oxidation, and when the pieces are hammered together, the flux is squeezed out, leaving a clean and strong weld. Some flux may become entrapped, but in skilled work this is likely no worse for the mechanical properties of the metal than the slag inclusions left from solid-state smelting or liquid metal decarburization processes. Forge welding is used not only to combine small pieces of metal make larger pieces, or to create an object with parts that have different material characteristics by adding a high carbon piece to a low carbon piece. Furthermore, as mentioned above, forge welding is also part of processes to homogenize the carbon content or remove/homogenize slag within the metal, especially when the smith is working directly with an unconsolidated bloom or separate pieces of bloom. In this way, forge welding is not only a technique for fabrication, but potentially for secondary processing.

Riveting is another way to combine pieces of metal, but instead of creating a single solid object, it links multiple pieces together. This can be done to create a rigid structure, like a helmet, but it can also be done to make a mechanical linkage, such as the hinge of a pair of tongs. Depending on the size and characteristics of the materials, some riveting can be performed either as cold work or hot work. The introduction of riveting technology to the Japanese Archipelago for armor making in the Middle Kofun Period, and the role that armor played in statecraft (Hashimoto 2015) makes this technique potentially key to ironworking at Ogata.

Surface decoration is more commonly associated with cold working, but there is one notable hot working technique for applying a bronze surface to an iron base, though some might

reasonably conclude it is a bronze working technique rather than an ironworking technique. Dipping part of an iron object into molten bronze to apply a coating is known from several areas of Eurasia, including China (Scott 2013, Rostoker et al 1984). This technique is not known from the Kofun Period in the Japanese Archipelago, where a cold working technique was used to cover iron with gilt bronze.

The term heat treating is sometimes used to specifically refer to quenching, but is just as often a catch all term for hot working operations that change the microstructure of ferrous alloys, and that is the sense it is used in here. The three most common varieties of heat treatment for steel and low carbon iron are annealing, quenching, and tempering. Smiths may perform some all or none of these operations, but in general annealing is performed before quenching, which is a prerequisite for tempering, but might also conceivably be done to undo the effects of quenching.

Annealing refers to a number of processes, including the modern processes of normalizing, that involve heating the metal and then letting it cool slowly. The precise effects will vary depending on the temperature reached during heating, the duration the metal is held at that temperature, and how slowly the cooling proceeds. Many of these treatments involve heating the metal to transform it to austenite, which has the effect of relieving internal stresses, though some treatments are in the so-called subcritical range, which can still soften the material through changing the carbide structures in the steel to spheres rather than lamellae (spheroidizing). Modern smiths also use various annealing treatments to create a finer grain structure and to assure even carbon distribution at the microscopic scale prior to quenching. In nonindustrial settings, the heating and holding at temperature could be performed in a forging hearth, and cooling could be done in open air or slowed by embedding the hot steel in various materials, such as a bed of ashes.

Quenching is the process of heating steel to transform it to an austenitic microstructure, then cooling it rapidly to transform it into another phase, usually martensite. With the low alloy steels available in nonindustrial settings, this is accomplished by submerging the hot steel in a liquid quenchant, such as water, brine, or oil, the properties of which affect the speed of cooling and thus the final outcome of the phase transformation. Faster transformations, such as those provided by water or brine quenches are at greater risk for causing cracks in the metal, but if successful lead to higher hardness compared to slower quenches. Although not recommended in modern metallurgy, preindustrial smiths also may have allowed the steel to cool somewhat in air before quenching, or remove the steel from the quenchant before the transformation was complete in order to produce a final hardness below that of as-quenched martensite deriving from a mixed microstructure (Williams 2003: 895). Achieving a fully bainitic microstructure requires quenching to an intermediate temperature, which was generally not possible prior to modern industrial engineering. Nevertheless, bainite does appear in small quantities in some archaeological objects in the gradient between martensitic and pearlitic microstructures that arise from the limited hardenability of plain carbon (or nearly so) steels, quenching practices that did not result in complete transformation, or other deliberate steps taken to produce objects with differential microstructures.

This can be accomplished by coating the object to be quenched in an insulating clay of variable thickness, preventing the more thickly insulated areas from cooling fast enough to transform to martensite. This technique is most famously applied in making traditional Japanese swords in historical periods, but the use of clay covering for producing differential hardness may predate that specific tradition, so clay may enter the *chaîne opératoire* at this stage even in the Kofun Period.

Successful quenching results in a martensitic microstructure, which is very hard, but also brittle. Depending on the intended use of the object, a smith may choose to sacrifice some of that hardness to also reduce that brittleness. This is accomplished in a process called tempering. Tempering is exposing martensite to heat to relax its structure, relieving some internal stresses, resulting in physical changes that can be observed metallographically. As with other heat treatments, temperatures and times govern the precise effects of tempering processes, but unlike annealing or quenching, tempering can be done at comparatively low temperatures; effects are seen even below 200 degrees Celsius (Samuels 1980). Tempering can be done in several ways, including embedding the object in warm or hot ashes as in annealing. Another way, requiring considerable skill, is to remove a just-quenched object from the quenchant after it has completed transforming, but before it has cooled to ambient temperature and allow the residual heat in the object to temper the martensite. If a smith grinds or polishes the object before tempering, they can apply a limited amount of heat directly to the object and carefully observe the color of the very thin oxide film that develops, since the color correlates with the degree of tempering.

Cold Work

Cold working techniques are used to accomplish the same kinds of objectives as hot working techniques, though there is limited capacity for altering ferrous alloys' material properties without heat. While these techniques have important roles in and implications for the *chaînes opératoires* of fabricating iron objects in the Kofun Period, they are difficult to detect in Kofun Period archaeology, so their discussion here will be limited. Hammering is much less effective for shaping cold ferrous alloys than hot ones, and regardless of any cold shortness in the raw material, can lead to cracks forming in the metal which can cause failures either during production or during use of the completed object. That said, low carbon alloys in particular can be shaped to some degree using cold hammering. Another affect of cold hammering is the introduction of more dislocations in the crystal lattices of the material, leading to slightly improved hardness. This increase does not compare to what is possible through heat treatment, but it is the only way that cold work can affect the material properties of the metal. As noted above, multiple pieces of ferrous alloys can also be joined together via cold riveting, but much cold work is shaping objects by removing material, either by cutting, scraping, or grinding with saws, edged tools, files, and other abrasives. Shaping also overlaps with surface decoration in polishing, which alters the object's form while bringing it to the desired smoothness and reflectivity.

Surface decoration using cold working techniques was also possible by riveting decorative plating or panels, including ones of different metals, such as gilt bronze, to the base, or by hammering nonferrous metals, like gold or silver into channels cut into the surface and textured with edged tools and files. Etching and patination through the application of acids or other chemicals can enhance the contrast between areas of dissimilar component microstructures, or provide an attractive and protective coating. Some historical processes involve heat, but it is usually the chemicals that are heated rather than the iron and hardly in the temperature ranges of forging.

Charcoal Fuel

Just as smelting and secondary processing, fabrication involving hot working techniques requires hot burning fuel. Since it does not deal in liquid metal, the sulfur content of coal is not an issue for the quality of completed objects. Even so, charcoal is presumed to be the fuel used in

Kofun Period ironworking in the Japanese Archipelago, and is the material at the intersection of the forest landscape and ironworking technology. Accordingly, its characteristics and production warrant a closer look.

Charcoal is the product of pyrolyzing plant matter, particularly wood. Compared to its feed stock, charcoal contains little water or volatile materials, and is composed mainly of carbon, though some ash does remain (Antal and Grønli 2003). The theoretical yield (by weight) of wood pyrolysis is 36.7% charcoal (Antal and Grønli 2003: 1621), but it is difficult to approach 30% under atmospheric pressure conditions (Antal and Grønli 2003: 1623). Traditional methods of production tend to have yields between 8% and 28% (Antal and Grønli 2003, Rostoker and Bronson 1990), and a volatile material content on the order of 30% (Rostoker and Bronson 1990), although some methods can produce charcoal with considerably lower volatile material content.

The yield, final carbon and volatile material content of charcoal is influenced by several parameters of its production; the most relevant to nonindustrial processes are the heating rate and peak temperatures of the wood during pyrolysis (Antal and Grønli 2003). Generally, slower heating results in higher yields, and higher peak temperatures results in less volatile matter and higher carbon content (Antal and Grønli 2003). In terms of final carbon content, very similar results can be achieved regardless of the taxonomic identity of the wood stock (Antal and Grønli 2003), but hardwood and softwood charcoal do seem to have different physical characteristics. In particular, hardwood charcoal is said to be more physically robust and burn slowly, whereas charcoal made from softwood is more friable, and burns quickly (Foley 1986).

Nearly any charcoal will work for ironworking, however, given its importance in the *chaîne opératoire* and the differences in characteristics that can arise from both production technique and feed stock selection, it is not surprising that ironworkers should have preferences. The physical fragility of charcoal presents an issue for ironworking in several ways. First, charcoal must be transported to the ironworking site, and the further the distance it must be brought, the more of it will be lost to incidental abrasion and breaking in transit. For this reason, charcoal production is ideally located as close as possible to its point of use, indeed an Edo Period aphorism states that a smelter's charcoal source must be within three *ri* (11.79 km) of the ironworking site. Beyond this, the friability of charcoal can cause problems for smelting, as charcoal that breaks down into too-small pieces under the weight of ore and other charcoal can choke a smelting furnace, preventing the flow of gases inside (Rostoker and Bronson 1990). That said, Shimohara Shiganaka, the author of a late 18th century treatise on iron production, cautions against charcoal that is too hard (Kawase 2000).

He may be referring to so-called “white charcoal.” In modern Japan, charcoal is classified as either white charcoal, or black charcoal. White charcoal refers to a special charcoal that has existed under various names since at least the Heian Period (AD 794-1185), and may have existed earlier (Kishimoto 1984). This charcoal is made in a kiln, and in the final stage of pyrolysis brought to some 1000 degrees Celsius before being removed from the kiln and extinguished (Kishimoto 1984). This results in a very hard charcoal with a very hard carbon content, perhaps akin to “carbonized charcoal” in scientific literature (Antal and Grønli 2003). White charcoal has many uses, but it is known for burning for a long time at a low temperature (Kishimoto 1984), and is not suitable for metalworking. The process Shimohara describes for producing smelting charcoal, raising the temperature very high (but not as high as for white charcoal) and then extinguishing it by sealing all the kiln vents and allowing it to cool, would also produce a rather hard charcoal with high carbon content that would nevertheless be

classified as “black” in modern Japan. It is also worth noting that other sources indicate that for traditional smelting in Japan, charcoal quantity was more important than quality, and that even incompletely pyrolyzed charcoal was sometimes used (Kawase 2000).

In any case, the distinction between white charcoal and other kiln-fired charcoal is important for disentangling Kofun Period ironworking from the confluence of two poorly supported theories about charcoal in the Japanese Archipelago in the first millennium. The first surrounds two kinds of charcoal mentioned in *mokkan* wooden tags and other records concerning bronze production in the early eighth century. The two types are *arasumi* (荒炭) and *nikosumi* (和炭). Scholars are generally in agreement that *arasumi* was a comparatively hard charcoal fired in a kiln, and *nikosumi* was a comparatively soft charcoal made in the older method of burning wood in a pit or pile and heaping dirt over it (Kishimoto 1984). The question of the use and manufacture of *arasumi* remains, though. *Arasumi* seems to have been used for heating and cooking in elite residences and temples based on harder charcoal’s properties (Kishimoto 1984). A hard charcoal ideal for cooking and heating sounds like white charcoal, and some scholars have made the argument that it was, but as Kishimoto (1984) demonstrates, while there is limited evidence for the existence of white charcoal in the Japanese Archipelago in the eighth century, nothing demonstrates that *arasumi* was indeed that white charcoal. Even so, *arasumi* was probably fired in a kiln, and eighth century *mokkan* wooden tags unearthed at the Naganobori Dōzan copper mine archaeological site in Yamaguchi Prefecture beginning in the 1990s suggest that it was also used in the smelting of copper, while *nikosumi* was used for smithing (Sasaki 2002).

Beginning in the sixth century, a new type of archaeological kiln feature appears in the Kibi Region, and since it overlaps in timing and geographical area with early iron smelting activities, there is a popular theory that these kilns not only produced charcoal for iron smelting, but also that it was white charcoal (Kawase 2000). This theory is attractive in light of the high quality charcoal later used for copper smelting, that some scholars also say is white charcoal, but Kawase (2000) points out that these kilns do not have the tarry residues known from medieval charcoal kilns, casting significant doubt that they were charcoal kilns in the first place. However, the same body of evidence for high quality kiln fired charcoal being used in copper smelting also indicates that smithing was still done with *nikosumi* charcoal in the eighth century. Despite the outsized place of white charcoal in academic studies of charcoal making in the first millennium in the Japanese Archipelago, the available evidence does not suggest white charcoal, or any other kiln fired charcoal, for any aspect of ironworking in the Kofun Period.

Smiths working in fabrication may have different preferences for their fuel than smelters, and evidence from modern traditional smiths in Japan seems to strengthen that possibility. That is not to say that some of the same issues that affect smelters do not affect smiths. The size of charcoal pieces is an important consideration for smelters so as not to choke the furnace while also maintaining atmospheric conditions inside. On the other hand, modern traditional sword smiths want charcoal of a small uniform size to provide uniform heating in the hearth, but will use charcoal of different sizes for different operations: charcoal cut into two to three centimeter pieces is used for most forging work, but pieces half that size are used when heating prior to quenching, as the smaller size makes it less likely that moving the object through the charcoal will dislodge the clay coating (Suzuki 1994).

Another consideration shared with smelters is the problem of material loss in transit due to charcoal’s fragility. This, combined with other factors, may be why until recently, many smiths were said to make their own charcoal from wood they harvested and dried themselves

(Suzuki 1994). Their preferred method of manufacture was simple and without a kiln structure: fill a pit with wood to be pyrolyzed, ignite it, then cover it with dirt to cut off the air supply (Suzuki 1994). Charcoal made this way was already close to where it was needed, and displayed other ideal characteristics for smithing work. Such charcoal is softer than kiln-fired charcoal, which is helpful in heat treating for the same reason that cutting it to a smaller size is. Further, unlike hard, high carbon kiln-fired charcoal, which ignites only at a high temperature and is less reactive, this softer charcoal ignites more easily and is more reactive, in part as a consequence of the lower temperature of pyrolysis (Antal and Grønli 2003).

Foley's (1986) aforementioned observation about the differences between hardwood and softwood also play into traditional Japanese smiths' preferences. Several authors note a preference for pine and/or chestnut tree charcoal (Sato 1983, Suzuki 1994, Kapp, Kapp, and Yoshihara 1987). Charcoal made from these woods are said to respond quickly to changes in air flow in the hearth, allowing the smith to raise or lower the temperature quickly and precisely, which is particularly important for heat treating operations (Sato 1983). That said, chestnut is not a softwood. Sato (1983) explains that its behavior as a charcoal is similar to pine (though the limited data Sato provides seems to indicate chestnut reaches lower maximum temperatures than pine), and preferred for that reason, but also says there are regional preferences for charcoal feedstock, with smiths in the Tohoku and San'in regions preferring pine, and those in Shikoku and Kyushu preferring chestnut. Both pine (*Pinus*) and chestnut (*Castanea*) are widely available across the archipelago, so preference for one or the other presumably does not stem from regional availability. Charcoal feedstock taxon selection may be a result of many factors beyond perceived performance benefits, but the available evidence nevertheless suggests that a preference for charcoal made without a kiln has existed for a very long time in the Japanese Archipelago and is not based on a lack of access to kiln-fired charcoal. Rather, in addition to being efficient with respect to transit losses, simple charcoal like the *nikosumi* of the eighth century produced by the smiths themselves had the desired performance characteristics in the forge. There is no evidence to suggest otherwise for ironworkers in the Kofun Period.

Conclusions

This chapter has introduced the fundamental concepts and technical processes of ferrous metallurgy most relevant to archaeological settings. The physical structures and chemical makeup of ferrous alloys play a large role in how they behave, which ironworkers can exploit to create materials and objects with a wide variety of properties, adaptable to many potential uses. The techniques and social structures involved in ironworking *chaînes opératoires* are highly variable, but always involve smelting metal from ore, processing the smelted metal into workable and desirable forms, and fabricating objects. Wherever possible, this chapter adopts nomenclature that avoids reference to the particulars of the European historical trajectory of ironworking technology. This tripartite classification of activities accomplishes that by decoupling technological activities from traditional divisions of labor, whether European or not.

Chapter 4: Kofun Period Ironworking

Introduction

The archaeology of iron implements and iron technologies has long been an active area of Kofun Period research. The prehistory of iron in the Japanese archipelago is unique in the long period between the initial adoption of iron implements and the beginning of iron smelting within the archipelago. This period overlaps with much of the Yayoi and Kofun Periods, which also saw major changes in social and political structures, including the rise of a central Yamato Authority that would later lead to an early Japanese state. Some scholars see access to iron and ironworking technologies as playing a critical role in changing lifeways and political structures during the period of state formation (Hanada and Sakaguchi 2012), but this opinion is not universally held (Shimogaki 2012). Even so, ensuring access to overseas sources of iron, especially amid the contemporary political and military upheavals on the Korean Peninsula seems to have changed the character of paramount leadership during the Kofun Period (Mizoguchi 2013).

While research on ironworking technology and iron implements are closely intertwined with state formation and other areas of Kofun Period research, this chapter focuses on archaeological finds and research that illuminate the technical procedures of ironworking in the Kofun Period rather than on how those procedures relate to other aspects of Kofun Period society. In order to assess the human-environmental interactions that ironworkers at Ogata were engaged in during the fifth and sixth centuries, this study adopts an extended *chaîne opératoire* approach to closely examine the technological procedures undertaken there. Due in part to issues of partial preservation, discard practices, and the extent of excavation at Ogata, building these *chaînes opératoires* necessarily relies on inferences made in part based on materials not found at Ogata itself. Instead, where unavoidable, generalizations based on investigations of other sites and materials in the Japanese archipelago are mobilized to bridge gaps in the Ogata materials. Additionally, results from other sites serve to contextualize the particularities of Ogata ironworking practices, since as discussed below, ironworking technologies during the Kofun Period were notably diverse.

To this end, this chapter examines the archaeology of ironworking technologies in the Japanese archipelago, especially in the Kofun Period. As detailed in Chapter 3, ironworking is a general category for numerous technical processes that involve the production of metallic iron and its alloys, as well as processing them into usable implements. While this study extends that definition to include environmental management practices related to fuel use, this chapter focuses on prior research into the processes, features, and artifacts more commonly associated with ironworking, and a brief overview of the archaeology of forestry and wood use is included in Chapter 5.

This chapter summarizes existing research on smelting technology, refining and forging technology, forge slags resulting from refining and forging activities, workshop structures, hearth features, charcoal production features, bellows and tuyeres for air supply, ironworking tools, the iron raw materials for forging, and finally metallurgical studies of iron implements themselves. Each of these elements can partially reveal the constraints and affordances available to ironworkers, as well as some of the technological choices ironworkers actually made.

Smelting Technology

Historically, many studies of Yayoi and Kofun Period iron objects explicitly or implicitly assume the production of iron (smelting) accompanied or followed shortly after the introduction

of iron objects (Nojima 2012: 96). Some researchers take the Komaru site (備後小丸遺跡) in Hiroshima Prefecture, where features thought to be the remains of a shaft-type smelting furnace with a 30cm diameter were uncovered surrounded by pottery from the first half of the Late Yayoi Period, as evidence for smelting in the Yayoi Period. However, radiocarbon dating produced results from two time periods, and since a smelting furnace from the Late Kofun Period was found at the same site and Sue Ware was also unearthed along with Yayoi pottery, many researchers do not accept this interpretation. Rather, the mainstream hypothesis is that smelting began in the archipelago in the Kofun Period (Hanada and Sakaguchi 2012 100-101).

Specifically, the earliest known uncontroversial smelting furnace was unearthed at the Senbiki Kanakurodani site in Okayama Prefecture. It was found in association with Sue ware dating to the late 6th century (Suemura TK43). Soon after, numerous smelting sites appear from the late 6th century onward from sites in the Kibi region and northern Kyushu, such as the Ozoike Minami site, Midoriyama site, Okitaoku site, and Misonoo site also in Okayama Prefecture, the Imasayayama site and Hamori No.3 site in Shimane Prefecture, the Shirakesako site, To-no-Maruyama site, and Sera-gun Kanakuro-dani site in Hiroshima Prefecture, and the Kashiwara M site in Fukuoka prefecture (Uwagaki 2000, Matsui 2001, Murakami 2007). By the end of the 6th century and into the early 7th century smelting spread to the Kinki region, evidenced by sites such as the Endokoro site in Kyoto Prefecture and the Furuhashi site in Shiga Prefecture (Nojima 2012).

Through the end of the Kofun Period, smelting furnaces in the Kibi region have a few forms. Most have bases that are rectangular (albeit nearly square) or nearly circular (Nojima 2012), though it is thought that there were also furnaces with elliptical bases, about twice as long in the long axis as in the short axis (Kawase 1995), and in the Bingo area there is a variant with a circular heated substructure as well (Uwagaki 2000, Anma 2007). Within sites, they are built on slopes in lines at the same elevation (Nojima 2012). Air is supplied through multiple holes through one or both of the longer sides, and slag is drained from holes near the base on the left, right or both of the shorter sides of the furnace (Matsui 2001). They also have shallow, broad pits dug out near the short sides of the furnace for the slag to flow out into and cool (Matsui 2001).

The smelting furnace found at the Kashiwara M site in Fukuoka Prefecture is notably different to the Kibi furnaces. It was built on a slope, free standing with a nearly rectangular base. The shorter side faced uphill, and air was supplied from this area via tuyere(s), and slag was drained on the downhill side (Murakami 2007). The furnaces that appear later in the Tango and Omi regions are rectangular box-type furnaces (Nojima 2012).

Tosa Masahiko (1981) and Anazawa Yoshitaka (1984) conducted early research on the distribution, classification, and chronology of smelting furnace designs in the Japanese archipelago, and Hanada Katsuhiko (2002) built on their work to further classify furnace designs based on the heated part of the substructure as well as their moisture prevention structures. His Type A was a rectangular furnace, which was located around the Kinai region, including in Tango and Omi, and was under strong influence from the central government. Type B, a round-cornered square furnace, was often found in large-scale workshops in the Bitchu region, where multiple smelting furnaces were operated in succession (Hanada 2002). Increasingly detailed classification of furnace structures based on their underground components has continued, but there are limits to what can be learned about the character of the metal produced (Nojima 2012).

That said, Omichi Kazuto's (1994) work on the chronology of furnace types in the Omi region, based on reconstructing furnace bottom shapes from masses of slag and metal remaining inside, brought attention to these so-called furnace-bottom-lumps as an artifact type. Kakuta

Noriyuki's (1999) research on furnace-bottom-lumps suggests that small lumps of hypoeutectoid steel may have been extracted from them. This model of production based on small lumps of low-carbon product became the prevailing theory, and Matsui Kazuyuki's (1987) work at the To-no-Maruyama site in Hiroshima Prefecture suggesting cast iron production there has not been as influential (Nojima 2012). However, later work by Murakami Yasuyuki, Manabe Seiji, and others at the Okuraike Minami Site in Okayama Prefecture, the Imasayayama Site in Shimane Prefecture, and the To-no-Maruyama Site in Hiroshima Prefecture suggests that the furnace bottom masses were not themselves direct smelting products, but rather byproducts leftover after cast iron was discharged from the furnace (Murakami 2006).

The production of cast iron is assumed based on the morphological features of the furnace-bottom-lumps and the furnace itself: If the upper structures of the furnace have not been destroyed (to remove bloomery products) and the surface of the remaining slag in the bottom shows high fluidity with no small lumps of iron attached to it, it is understood that liquid cast iron flowed out of the furnace. Based on its furnace-bottom-lump, Furnace 1 at Okuraike Minami is reconstructed as a tall freestanding furnace with a base plan between circular and a rounded square, with a wide reduction zone for carbon absorption (Murakami 2007). This kind of research leads Manabe (2009) to suggest that during the Late Kofun Period, smelting in the Japanese archipelago was primarily bloomery smelting, but in the succeeding Asuka Period, iron production transitioned to the production of liquid cast iron. However, cast iron smelting experiments have produced very little slag (Furuse 2000a), so it must be assumed from the large amounts of slag present at specialized ironworking sites in the Kinai region that bloomery products were the main raw material at these sites (Nojima 2012).

Mineralogical and chemical research into slags has also contributed to the current understanding of when smelting was introduced, since the discovery of smelting slags is a good indicator that smelting was conducted nearby, even if the exact site and smelting apparatus are never uncovered. Osawa Masami conducted chemical and mineralogical analyses of slags that were interred in *kofun* as grave goods and found that slags from tombs dating to before the mid-6th century were forge slags, not smelting slags, but that smelting slags began to be interred in *kofun* after that point (1983). This seminal research formed the basis for the mainstream theory that smelting began in the archipelago in the mid- to late 6th century. However, Osawa also concluded that slags excavated from a ritual feature at the Junzaki site in Fukuoka Prefecture were smelting slags derived from smelting iron sands (1986). Based on those analytical results and the site date, Osawa suggested that smelting likely began in the latter half of the 5th century, but on a small scale. He also indicates that early smelters in the archipelago used both stone and sands ores for smelting (Osawa 2003: 284).

Dedicated and creative research efforts, especially since the 1980s, have done much to illuminate the timing and technological characteristics of early iron smelting in the Japanese archipelago. At present, this research strongly indicates that smelting was uncommon prior to the middle of the 6th century, and when it was firmly established, there was considerable variation in the smelting furnace design. Beyond that, uncertainty remains surrounding the products (bloomery or cast iron), and ore types and sources are unknown for most early smelting sites. Further research on smelting technology, forging/smithing technology, their relationships to social, technological, economic, and political developments in the archipelago as well as the Korean peninsula and Chinese mainland is necessary to bridge the seeming contradictions.

Given the timing of these developments in the archipelago, smelting activities can be considered external to the *chaînes opératoires* of ironworking at Ogata. Since the iron raw

material there was smelted somewhere beyond Ogata, and the technical procedures were not controlled by local ironworkers, the environmental effects of those activities, and any management associated with them are beyond the scope of this project. That said, since smelting is a fuel intensive activity, if the ironworkers at Ogata had access to smelting technology but opted to work only iron smelted elsewhere, that choice would constitute a significant aspect of this study. At present though, that possibility appears precluded by the dates of smelting furnace features across the archipelago.

Refining and Forging Technologies

As discussed in Chapter 3, refining is a polyvalent term that can refer to the removal of slag inclusions and other impurities, or to the decarburization of cast iron to forgeable iron or steel. These are very different processes, and detecting them archaeologically, especially in the first meaning, as distinct from the production of iron implements is challenging. This is because removing slag from bloomery products generally entails heating and then hammering them to force out the liquid slag, which depending on the scale of operations, can be very similar to producing iron implements by heating them and hammering them to shape. In early modern Japan, both bloomery and cast iron were produced to supply crafters (Suzuki 2008), and there was an established division of labor between smelting, large-scale ironworking (大鍛冶), wherein cast iron was refined (decarburized), and small-scale forging (小鍛冶), wherein pre-refined iron (either bloomery products or decarburized cast iron) was forged into implements (Suzuki 2008, Nagata and Watanabe 2014).

Scholars acknowledge that the division of labor may have been very different in the Kofun Period (Nojima 2012), and in the period prior to smelting in the archipelago it would have depended on what kind of raw material was available via import from overseas. Even so, this known historical division of labor has cast a long shadow over research into ironworking in earlier periods; much research has gone into identifying “refining” sites, features, and wastes. Since with few indisputable exceptions, forge refining and forging iron implements are archaeologically indistinguishable, this project eschews the classification of archaeological features according to presumed roles in either refining or forging. While the refining (in either sense) of iron raw material may have been an important activity at Ogata, it must be distinguished via scientific analyses of waste slags.

Forge Slag

As mentioned above, Osawa Masami’s (1983) seminal analyses of slags strongly colored subsequent discussions of when smelting began in the archipelago. His same 1983 paper also provided the blueprint for chemical and mineralogical analyses of slags in Japan more generally. Osawa noted that the wastes from smelting, refining, and ironware manufacture had different characteristics with respect to total iron content and other slag-forming constituents. Smelting slags contain the least total iron, and the total iron content of refining and ironware manufacture successively increased. At the same time, the other slag-forming constituents decreased successively as iron moved through the manufacture process from smelting through refining to ironware manufacture. Because the slag entrapped in freshly smelted iron is in fact smelting slag, after it is removed in the refining process, little remains to enter the smithing slag. When the iron is reheated for either refining or ironware production, the iron oxides that form on its surface enter the slag as it forms. So the quantity of non-ferrous slag-forming constituents present

decreases as the iron becomes freer of slag inclusions, and the proportion of iron naturally increases, eventually becoming the majority constituent of forge slags (Osawa 1983 120-122).

According to Osawa, smelting slag contains many more mineral forms than refining or smithing slags due to the wider variety of constituents present, and refining slags and smithing slags generally have no significant difference in mineral composition, with both essentially formed of wustite and fayalite (1983 111-113, 120). Both have been found in Kofun Period contexts (Manabe 2003). Slags containing about 50% total iron are classed as refining slags, while those with total iron content in the 53% to 63% range are classed as smithing/forging slags (Osawa 1983).

In morphological studies of archaeological slags, they are often classified according to the schema developed for the Heian Period Kanayama site in Tochigi Prefecture (Tsuno et al 1993), and some scholars have used the shapes of slags to reconstruct the shapes of forging furnaces (Manabe 2000, Furuse 2002). Forging/refining slags of the Early and Middle Kofun Period are constrained by the small size of the smithing furnaces, and none larger than 1kg have been reported (Manabe 2003a 277). Additionally, there are many examples from this period with a thick layer of the forge floor adhering to the slag, and examples where the tuyere tip has become stuck to the slag as well (Manabe 2003a). In fact, from these stuck-on tuyere tips, it is known that in some cases two tuyeres were used simultaneously (Manabe 2003a).

The recognition of chemical differences between so-called refining slag and smithing slag has led to attempts to distinguish between them based on external morphology, but this is difficult in most cases (Manabe 2003a). A deeper slag, that is to say one with a greater distance between its bottom and the tuyere tip, which was presumably quite close to the top of the slag, is said to be more likely a refining slag than a shallower slag (Manabe 2003a). Similarly, a concave shape to the top surface of the slag is thought to result from where unrefined lumps of iron rested atop the slag in the furnace, and accordingly, slags with concave top surfaces are understood as more likely to be refining slags than those without concave upper surfaces, which result when the iron material does not come in contact with the slag, as during smithing (Manabe 2003a). In contrast, smithing slags are said to be denser due to containing fewer impurities, and charcoal impressions are common (Manabe 2003a). Additionally, during smithing operations, hammer scale may become stuck to the outside surface or embedded within the slag forming in the furnace (Manabe 2003a 277).

In the Late Kofun Period and into the Asuka Period, slags weighing over one kilogram begin to be found (Manabe 2003a 277). These are larger than slags from previous periods in horizontal spread, depth, or both (Manabe 2003 277). Additionally, fewer examples have layers of soil from the furnace floor adhering to them (Manabe 2003a 277). This is thought to be the result of improved air supply technologies, enabling larger forge furnaces in which the hottest zone where the slag forms is in the middle, away from the edges (Manabe 2003a 277).

In contrast to previous periods, the excavation contexts for forge slags from the Late Kofun Period onward includes sites in northern Kyushu and the Chugoku region where smelting slags are also found (Manabe 2003a 277). These smelting slags are not the kind that flowed out of the smelting furnace during operation, but rather the furnace-bottom-lumps that remained afterward. This indicates that iron lumps from smelting were brought to these forging sites to have the slag removed (Manabe 2003b).

Lightweight materials such as tuyere tips, clay lining the forge furnace, or clay slip/flux used during forging can also become molten during ironworking and solidify afterward. This results in a glassy slag that is sometimes distinguished from iron slag (Furuse 2002). These

glassy slags are not found in Yayoi Period contexts, but are common at Kofun Period ironworking sites (Manabe 2003a 278). Their appearance is likely connected to higher operating temperatures associated with the introduction of air flow into the hearth through clay nozzles called tuyeres, and forge welding using fluxes (Manabe 2003a 278). When glassy slag forms from the clay lining of the forge in small forges from the Early and Middle Kofun Period, it can preserve the shape of the forge furnace pit, and in this case, the slag is called “furnace wall.” Such slags have been unearthed from the Okizuka site in Chiba Prefecture in Early Kofun Period, as well as the Shingaku site in Tochigi Prefecture and the Mori site in Osaka Prefecture, among others in the Middle Kofun Period (Manabe 2003a 278). The actual fire pits of the furnaces at these sites were similar in size, even though their larger forge hearth structures, including underground structures, varied in size (Manabe 2003a 278).

Both scientific and simple morphological studies of forge slags have extensively contributed to reconstructions of ironworking activities in the Kofun Period. These considerations as well as novel analyses are instrumental to developing ironworking *chaînes opératoires* at Ogata.

Workshop Structures

Kofun Period ironworking workshop structures have a direct lineage from those of the Yayoi Period (Murakami 2007, 2012). They take the form of structures similar to the semi-subterranean pit dwellings of the period, and can generally be called “pit-type” workshops (Murakami 2007). With that said, the Hakata Site Group in Fukuoka Prefecture, which is the most significant ironworking site of the Early Kofun Period, may have had aboveground workshop structures. Forge slag, hammerscale, globular slags, unfinished iron implements, and numerous tuyere tips were found, indicating large-scale operations. Notably, some of the forge slags are as large as those from the Late Kofun Period, and their morphology suggests large and deep furnaces were in use. Despite this, no forge furnace features have been found, even though other pit dwellings as well as other kinds of pits have been. This leads researchers to speculate that aboveground structures that left no trace in the archaeological record formed the basis for ironworking activities there (Murakami 2012 145). These might be called “non-pit type workshops.” By the end of the Early Kofun Period (late 3rd through 4th centuries), pit-type workshops are found as far as the western part of the Setouchi region, but an example of a non-pit type workshop is also known from the Matsuki-Hirota site in Ehime Prefecture from the end of the Early Kofun Period (Murakami 2012).

In the mid-5th century, pit-type workshops spread throughout the archipelago from the Tohoku region to southern Kyushu. As pit-type workshops spread, a variation on their architecture appeared: small workshops with the main pillars located outside the pit instead of inside the pit, where they are located in pit dwellings. These appear in Kyushu in the first half of the 5th century at the Ogitsuru site in Oita Prefecture, and by the latter half of the 5th century in the Kanto region, as seen as the Nishiura site in Tochigi Prefecture (Murakami 2012). Based on excavation data from the Kanto region, Uchiyama Toshiyuki classifies these as Nakata-type workshops, which were dedicated workshop structures, in contrast to Morito-type workshops, which were combined workshops and dwellings (1998).

There is no detectable difference between the work done in each kind of workshop, so the development of specialized workshop facilities alongside combined residences and workshops during this period is better understood as the result of changes to social structure and craft

organization rather than the introduction of new ironworking technologies from overseas (Murakami 2012 145).

There were also transformations to non-pit type workshops after the Early Kofun Period. In the Chugoku region, they start to appear on terraces built on hills or slopes, such as at the 5th century Onari site in Hiroshima Prefecture, and at the Sakigaya site, also in Hiroshima Prefecture during the 6th century (Murakami 2012 145). Similar trends can also be seen from the 6th century on in the San'in and northern Kinki regions (Murakami 2012 145). Non-pit type workshops with numerous forge hearths appear, including at Mori and Ogata in Osaka Prefecture, and the late 6th century Kashiwara Site Group M in Fukuoka Prefecture, where fifteen closely packed furnaces were found, offers an important example outside the Kinki region (Matsui 2001). At Ogata, a currently unique type of aboveground workshop was unearthed with a ditch surrounding it (Kitano 1988). Since forge slag and scale were recovered, but no furnace features, this workshop probably had a raised earth platform and walls (Murakami 2012 146). It is unclear whether the forms of these later non-pit type workshops can be traced back to those from the Hakata Site Group, but in the period after smelting begins to spread through the archipelago they can be seen as representative of a division of labor between smelting operations and other ironworking activities (Murakami 2012). This research demonstrates some of the diversity of ironworking facilities, and by extension technologies in the Kofun Period, and highlights the differences between Ogata and other Kofun Period ironworking sites even within the Kinki region.

Hearth Features

Forging hearth/furnace features have been excavated from numerous Yayoi and Kofun Period sites across the Japanese archipelago, as well as on the Korean Peninsula. Several researchers have created classification systems to highlight different aspects of their development, with different geographic and temporal ranges, including Osawa Masami (1984), Hanada Katsuhiro (1989, 2002), and Anma (1995), but Murakami Yasuyuki's (2007) schema is simultaneously the most detailed and most universal, as well as focused on Kofun Period developments. Murakami has worked to classify hearths into six classes in order to clarify the relationships between Kofun Period forging hearth features, and those of the Yayoi Period of the Three Kingdoms Period on the Korean Peninsula (2007). Though Murakami's purpose was to track the development and spread of ironworking traditions, the observable differences between different classes of hearth also bear on the techniques and choices available to the ironworkers themselves. Accordingly, reconstructing Kofun Period ironworking practices and fuel use requires an understanding of hearth forms as an element of a *chaîne opératoire*. Murakami's schema and observations are as follows.

Class A: The hearth is a depression in the floor of the workshop with a diameter clearly larger than its depth. Type A is further subdivided into subtypes 1 and 2 to denote the shape of the hearth's plan, circular or square with rounded corners, or elliptical or rectangular with rounded corners, respectively. Another subdivision is applied to denote the presence (a) or absence (b) of clay applied to line the inside of the hearth.

Class B: The hearth is made directly on the ground or the floor of a dwelling, or it consists of clay spread on the floor. In either case, there is no depression dug into the surface.

Class C: The hearth is made by digging out the area surrounding the hearth, then backfilling it and constructing the hearth in the backfill, giving it an underground structure.

Class D: A furnace wall is built on the floor of the workshop with a shallow moisture-proof structure underneath the hearth, and the bottom of the hearth is nearly the same level as the floor.

Class E: The floor of the workshop is raised to make the bottom of the hearth, and a shallow moisture-proof structure is installed underground. Class E is subdivided into Class E1, in which the walls are high, and Class E2, which has low embankment-like structure.

Class F: These furnaces consist of a deep clay pit covered with a clay roof through which an L-shaped tuyere with a large diameter supplies air, and there is an opening in the roof to supply fuel and iron raw material.

Forging hearths of Class A and Class B in the Kofun Period have Yayoi Period precedents. Class A hearths are the main type found in the pit-type workshop structures of the period. Kofun Period examples of Class B are only known from the Early Kofun Period at the Hirata II site in Shimane Prefecture, but more examples may be found as excavators come to recognize these hearth features as such. Based on their structure and shallowness, it seems as though little slag could be produced in these hearths, though slag has been found with examples of Class A hearths. It is thought that the placement of the tuyere tip and the piling of charcoal fuel required care in these hearths. It appears that in the Tohoku region, based on the placement of the tuyere tip, either forging or refining could be conducted using these hearths (Furuse 2005), but considering the size of the hearths and the amount of slag recovered, the amount that could be produced was limited (Murakami 2012: 148).

Class C hearths are deeper than Class A or B hearths, and so large slags could form in them. Due to their depth, it is thought that these were used for refining, and hammer scale and globular slag is rarely recovered from these features. This type is unknown from the Korean Peninsula and developed in the Japanese archipelago for refining slaggy raw material, reaching its final form in the 6th century (Murakami 2012: 148).

The aboveground Class D and E forging hearths with walls are known from the Korean Peninsula by the early Three Kingdoms Period (4th through 7th centuries). Based on excavations at the Karakami site in Nagasaki Prefecture, these aboveground forging hearths may date back to the late Middle Yayoi Period (Miyamoto, ed. 2011), but disappear again until the 6th century, when the only clear Kofun Period example is found in the non-pit type workshop of the Ogata site in Osaka Prefecture. However, it is likely that more examples existed, particularly at the non-pit type workshop sites in northern Kyushu and the Kinki region where the actual type of forging hearth cannot be directly confirmed, but hammer scale and burn soil originating from the collapsed and weathered walls of the hearth are found (Murakami 2012: 148).

The function of these two hearth types remains a question, at least in part due to the fragmentary nature of the remains. At Ogata, an anvil stone was unearthed nearby, suggesting smithing work rather than refining. Accordingly, while the height of the hearth walls is unknown, they may have had openings in the side for inserting and removing raw materials, as well as the air supply. On the other hand, the example detected in the embedded pillar building at the Godseong-dong site had no side openings, and fuel and metal were inserted through the top, and is thought to have used airflow to melt or refine metal rather than for forging (Murakami 2012: 143-144). These types of hearths are seen as having a peninsular origin. (Murakami 2012: 148).

Type F features are actually unknown from the Japanese archipelago (Murakami 2007: 147). While multiple examples are known from the Korean Peninsula, the first and best known is from the Godseong-dong site in Gyeongju (Kim 2006). This furnace type resembles those used from the Early Han Period in China onward as part of a decarburization process for cast iron translated variously as the roasting, converting, fining, or puddling (Wagner 2008: 16).

To summarize, forge hearths from the Kofun Period are highly variable in their form and potential functions. They reflect both local development from Yayoi Period traditions as well as clear influences from peninsular technologies. The multiple traditions of Kofun Period forging technology pose a challenge for generalized narratives of the period, but it is clear from forge hearth remains around the archipelago that increasingly sophisticated technologies became available over time.

Charcoal Production Features

Ironworking in the Kofun Period was fueled by charcoal, but dedicated charcoal kilns do not appear in the archaeological record until the late 6th century in Kibi (modern Okayama Prefecture and the eastern part of Hiroshima Prefecture) where they appear near smelting furnaces (Nojima 2012 98-99). Charcoal kilns were also built in close proximity to early smelting furnaces in Chikuzen, Tango, Omi, and other regions, and from the 7th to 8th centuries, they spread to eastern Japan (Omichi 1995). The strong association of these kilns with smelting sites suggests that the charcoal kiln technology was introduced alongside smelting itself. Called “charcoal kilns with side openings,” these were dug out horizontally on a hill slope, with a fire (fuel) opening on one side, a smoke exhaust hole on the other, and a side entrance connected to the kiln body on the valley side (Nojima 2012 98-99). Some scholars (Uwagaki 2001, Anma 2007) assume this kiln design was for the production of high temperature so-called “white charcoal,” but this claim requires rigorous testing.

Charcoal kilns of similar design have been found on the Korean peninsula as well, at Gedan-ri, Ulsan, Gyeongsangnam-do, and at iron implement production sites such as Qiang-ri in Hwaseong, Gyeonggi-do (Nojima 2012 98-99). This suggests a peninsular origin for the smelting technology that the side-opening kilns accompany at early smelting sites in the Kibi region (Nojima 2012 98-99).

Charcoal was certainly used for ironworking prior to the introduction of smelting technology, even if it was not produced in side-opening kilns. The specific technologies and scale of charcoal production in the earlier parts of the Kofun Period remain unclear, but charcoal is not difficult to produce on a small scale. However, it may be difficult to detect and analyze archaeologically. Some features at the Ogata and Ogata Minami sites in Osaka Prefecture may represent charcoal production activities for ironworking use, but these identifications are uncertain, and may in fact be large ironworking furnaces (Hanada and Sakaguchi 2012 102-104).

Bellows and Tuyeres

Even though tuyeres for bronze casting are known from the Yayoi Period, no confirmed ironworking tuyeres are known in the Japanese archipelago that predate the Kofun Period (Manabe 2003: 279). Tuyeres feed air into furnaces and hearths from a pipe connected to a bellows, and their rapid appearance in the Early Kofun Period signals the introduction of a new and powerful technology. Specifically, with a forced air supply, much higher temperatures could be reached, enabling new smithing techniques such as forge welding. Like much of ironworking technology in the Kofun Period, tuyeres display considerable variation both temporally and geographically.

Bellows are more enigmatic as none have been preserved in the archaeological record. Even so, some aspects of their form and use can be inferred archaeologically from tuyeres, and historically from early Japanese texts, which admittedly postdate the Kofun Period. *Nihon Shoki* indicates that bellows were made from entire deer skins (Hanada and Sakaguchi 2012: 104), and

Engi Shiki indicates that bellows were made from animal skins even into the Heian Period (Manabe 2003: 279). There is no indication that the Chinese-style double action box bellows famously used by historic Japanese smiths had been introduced by the end of this period. Certain forms of Kofun Period tuyere seem designed to accept air flow from multiple bellows, and placing them in the wider context of the chronology of tuyeres can elucidate the development of air supply technology for ironworking in the Japanese archipelago.

Kofun Period tuyeres are made of fired clay, either specifically made for the task, or in the form of repurposed hollow legs from pedestaled pottery. The earliest example of a repurposed pottery pedestal tuyere is from the beginning of the Early Kofun period at the Kaedo site in Shiga Prefecture, and examples from the 4th century have been found in the Kanto region, while examples from the 5th century onward have been found in the Tohoku and southern Kyushu regions. In the Tohoku and southern Kyushu regions, examples survive until the 6th century (Murakami 2012: 149-150). In some regions, these repurposed pottery tuyeres exist alongside purpose-made tuyeres, and in other regions, in other regions, tuyeres of repurposed pottery are never found. In general, it can be said that their prevalence decreases over time and with proximity to the Kinki region. While examples are known in Kyushu, they are more common in the eastern part of the archipelago.

In areas where only dedicated tuyeres were used, they nevertheless can display some variation in size and clay material. Murakami Yasuyuki suggests that these variations reflect differences in forging operations, in particular between refining or smithing, or high or low temperature smithing (2012: 150). Additional research is necessary to verify this, but two distinct clay sources are noted in the tuyeres from the Ogata site in Osaka Prefecture: a local clay containing quartz and feldspar grains, and a clay from the western base of the Ikoma mountain range containing mica and amphibole (Hanada and Sakaguchi 2012: 104).

Dedicated tuyeres of the Early Kofun period display significant variation. Tuyeres unearthed at the Hakata site group and sporadically from sites in the San'in and Kinki regions have a cross section like a capital letter D turned on its side (Murakami 2007). This flat underside suggests that it was installed on a flat portion of the furnace (Murakami 2012: 149). As evidenced by the tuyeres excavated from the Matsuki-Hirota site, this shape disappears by the end of the Early Kofun Period (Murakami 2012). Other single-purpose tuyeres take the form of cones with the tips cut off (frustum). Murakami Yasuyuki has pointed out that further research is required examining connections between these types of tuyeres in the Japanese archipelago, and the much greater variety known from the Korean peninsula (Murakami 2012).

Given the importance of air flow for temperature and fuel management in a hearth during forging operations, understanding tuyere forms and how they changed over time is a key part of understanding changes to forging technology more broadly over time, and in particular with respect to fuel use. Murakami Einosuke (1970) divides frustum-shaped tuyeres into five classes, and notes that class II and class IV flare at the base internally to accommodate the air pipes from multiple bellows, while the other classes have bases shaped to accept one pipe. In terms of air supply technology, two simple bellows can be worked in alternation to provide a smooth supply of air, with one taking in air while the other pushes air out. The concurrent use of tuyeres that accept only one pipe alongside those that accept multiple pipes has been taken as evidence that whatever form of bellows was attached to the single-pipe tuyeres, it, too, could provide a smooth air flow (Nojima 2012).

Manabe Seiji has built on this research and subdivided Murakami's classes I and II to delineate diachronic changes to their form during the Kofun period and elucidate their

relationship to class III (Manabe 2003a: 279-280). His class Ia is the most common in the Early Kofun period, and like classes Ib and Ic, was made by wrapping clay around a rod to form the frustum, then carving out the base to make the attachment point for the bellows pipe. In the Middle Kofun Period, the thick walled class Ia gives way to the thinner-walled, narrower, and longer class Ib. Type IIa, which is a large hand formed tuyere without a specific pipe attachment point appears by the start of the Middle Kofun Period, and then is replaced by the notably shorter and thinner walled class IIb, which rapidly spreads as far as the Kanto region (Manabe 2003a: 280).

By the Late Kofun Period, tuyeres made of repurposed pottery pedestals disappear. In the Kinki region, the gracile class Ib becomes longer, transforming into class Ic. At the same time class III, which is a thick walled, long, nearly cylindrical tuyere with a single-pipe attachment point appears to replace class IIb. Its development appears to have been influenced by class Ib tuyeres. Both class Ic and class III are known from the Ogata and Tanabe sites in Osaka Prefecture. Class III continues to see use through the Nara and Heian Periods, with examples as long as 30cm known. Interestingly, in the Chugoku region, where forge sites are often near smelting sites, thick walled tuyeres of class IIa and III are common, but examples of tuyeres in good condition are surprisingly rare in this region (Manabe 2003a: 280).

Considering Ogata's position in the political core of the archipelago and its inferred importance, it is hardly surprising that the tuyeres found there were purpose-made, but the appearance of multiple kinds does suggest the presence of multiple technological traditions for forge operations. This body of research helps position those traditions and contextualize the activities and their implications for fuel use.

Ironworking Tools

Archaeologically attested ironworking tools from the Kofun Period include hammers, anvils, tongs, and chisels, and grinding stones. Additionally, smiths' models of iron implements are known from the Asuka Period (Manabe 2003a), and may be reasonably assumed to have existed in the Kofun Period, especially in light of the "patterns" inferred from the highly standardized iron armor of the Middle Kofun Period (Yoshimura 2014). This is hardly an exhaustive catalog of tools used by historic smiths, and so it is not unreasonable to think that Kofun Period smiths may have had many additional types of tools as well, such as files, spatulas, brushes, quenching tanks, and the like, however, they are not archaeologically attested, or in cases where they are, they cannot be conclusively linked to ironworking activities.

Unlike other artifacts related to ironworking, smithing tools are more commonly unearthed from grave contexts of the Middle and Late Kofun Period than from workshop sites. In form, they are very similar to tools used by historic and modern smiths, and show considerable variety. At least some of this variety can be related to the type of work they were used for: as with modern smiths, longer tongs and heavier hammers were presumably for large working stock and the early stages of making an object, and shorter tongs and lighter hammers for smaller stock and the later stages of making an object (Yoshikawa 1991).

Prior to the Early Kofun Period, ironworking technology seems to have been quite limited in the Japanese archipelago, and essentially the only archaeologically verified smithing tools made of iron are chisels. However, experimental archaeology has demonstrated the possibility of using stones as anvils and hammers, and bamboo in place of tongs for smithing (Murakami 1998). That said, an iron hammer was unearthed at the Haru-no-Tsuji site in Nagasaki Prefecture, which was occupied in the Late Yayoi and Early Kofun Periods (Nagasaki

Ken Kyouiku Iinkai 2000), but no tongs were found, and it would be premature to assume that they were used in blacksmithing at this point (Manabe 2003a).

The oldest definite ironworking tools are from Ike-no-Ue Tomb No. 6 in Fukuoka Prefecture, which dates to the early Middle Kofun Period (Hashiguchi et al 1979). After this, blacksmithing tools are found in *kofun* mounded tombs across the archipelago. The Late Kofun Period Asamachi Yama-no-Kuchi Tomb No. 5, also in Fukuoka Prefecture, contained both tongs and hammers, including tongs 47.2cm long with 14.9cm long “mouth,” suitable for working large iron stock. Large and small hammer heads, 21.4cm, 11.6cm and 9.7cm long were also found. Whether these hammers were used in successive stages of ironworking, or in different roles such as striker and director, while working together with multiple smiths, is unknown (Manabe 2003a).

Large tongs and hammers are also known from Ipponmatsu Kofun in Okayama Prefecture and Horinowo Kofun No. 2 in Nara Prefecture, which Manabe Seiji suggests may indicate their use in making large items such as swords (Manabe 2003: 279). Smaller hammers and tongs are known from Hiroishi Minami Kofun No. A-4 and Ishi-ga-Moto Kofun No. 12 in Fukuoka, as well as the mid-5th century Gojo Nekozuka Kofun in Nara Prefecture, where an anvil was also interred. These smaller tools were perhaps suitable for making smaller items or used in the later stages of making larger ones, and still smaller tools are known from Shinbara-Nuyama Kofun in Fukuoka Prefecture, the hammer from which is only 10cm, and Teraguchi Oshimi Kofun No. H-16 in Nara Prefecture (Manabe 2003a).

Tools that may be for more specialized elements of ironworking are known from the mid- to late 5th century Zuian Kofun in Okayama Prefecture, where a hammer with a very narrow head and a small specialized anvil called a “*narashi*” were found along with tongs, a chisel, and possibly a file (Manabe 2003a, Chiga and Murakami 2003: 15). These smaller tools were likely suited for the final stages of forging (Furuse 2000b).

Interestingly, of the archaeologically excavated tongs that have been examined metallographically, most were found to have low carbon content, which would make them easy to produce and easy to repair if they become deformed during smithing work (Manabe 2003a: 279).

Like at most other workshop sites, excavations at Ogata have yielded no clear ironworking tools besides grinding stones. Even so, finds from contemporary and near-contemporary mortuary contexts provide a glimpse of the kinds of tools, and therefore other aspects of ironworking *chaînes opératoires* likely in use at Ogata.

Iron Raw Material for Forging

As smelting technology was at the very least rare in the archipelago until the Late Kofun Period, raw material for ironworking had to be sourced from overseas. While this chapter focuses on Kofun Period technology, a discussion of Yayoi Period raw material for ironworking helps to illuminate both changes in Kofun Period technology and long-term continuities in sourcing. Over the course of the Yayoi and Kofun Periods, the types of iron raw material used can generally be divided into three categories: discarded or recycled iron objects, specifically prepared stock such as bars, plates, or ingots, and unrefined raw iron lumps (Manabe 2003a: 275).

Most of the ironworking raw material in the Yayoi Period came in the form of cast iron axe heads made in the area from the Liaodong peninsula in what is now China, to the northwest part of the Korean peninsula (Murakami 1988). Metallographic investigation has shown that these axe heads, though of cast iron, had been decarburized to soften them, which enabled one of

the hallmarks of Yayoi Period ironworking, which is the reshaping of these axe heads and fragments thereof without heating them by using grinding stones (Osawa 2000, Nojima 1992, Murakami 1992, 1994). The earliest examples of this kind of Yayoi Period ironworking of imported iron objects are found most commonly in northern Kyushu, which functioned as the gateway to the continent (Murakami 1998b). From the late Middle Yayoi Period, there are examples of plate-shaped cast axes reworked into smaller axes, swords with re-ground tips, and plate-shaped axes that were fashioned out of old swords (Manabe 2003a: 275).

From the late Middle Yayoi Period (4th century BCE through 1st century AD), finds of pieces of iron rods and plates thought to be iron stock for smithing increase (Manabe 2003a: 276). These, too are concentrated in northern Kyushu, and have the same distribution as the aforementioned cast iron axe heads (Manabe 2003a: 276). Metallurgical investigations have revealed that these are varied in their origin, and include cast iron decarburized by multiple processes, including “roasting” as well as “wrought” iron (Osawa 2000). Additionally, triangular and rectangular scraps of iron have been excavated from around the simple forging hearths that increase in this period, and they are interpreted as bits of stock that were cut off during production of iron objects (Murakami 1998). The presence of these scraps is also taken as evidence that they could not be recycled using the technology of the period (Manabe 2003a: 276).

Reports of so-called “iron lump artifacts,” which are thought to result in iron raw material through melting or refining processes, are exceedingly rare in the Yayoi Period. However, the few objects of this type that were subjected to scientific analysis turned out to be pieces of rod-shaped iron stock, so discussion of iron lump artifacts from this period is constrained by the fact that there are no confirmed examples until the Kofun Period. (Manabe 2003a: 276). It is thought that the technology to turn such raw iron into iron stock for forging use appeared during the Yayoi Period.

With the low operating temperatures of Yayoi Period forges, it was not technically possible to recycle worn out iron implements into new forging stock, but beginning in the Early Kofun Period, it is thought that higher operating temperatures in forges enabled recycling disused iron objects into new stock leaving no trace of their previous form. In the Early and Middle Kofun Period, finds of discarded iron objects decrease, but this does not indicate that disused iron was not in circulation. Rather, it appears to have been carefully collected for recycling (Manabe 2003a: 275). Finds of discarded iron objects at the Kuboki Yakushi site in Okayama Prefecture seem to bear this out (Shimazaki 1993).

Several kinds of specific types of recycled iron are known from the Kofun Period. The first is cast iron axe heads from the Korean Peninsula (Murakami 1988). Unlike the imported cast iron axes seen in the Yayoi Period, these were not decarburized and so it is thought that they were processed into new stock using heat, though the details of that process are unclear (Osawa 1999). These are known from the Nagase Takahama site in Tottori Prefecture, the Nango site group in Nara Prefecture, and the Mori site in Osaka Prefecture, among others (Manabe 2003a: 275).

Virgin iron raw material generally does not contain copper, so finds of ironworking artifacts bearing copper is taken as evidence for recycling iron objects that were plated with copper and then gilded, such as high status horse tack, swords, and armor (Manabe 2003a: 275). Excavations at the Ueza-Yabashi site in Chiba Prefecture unearthed an iron lump with a blue-green hue suggesting copper content, a copper clad iron sword fitting, and a knife-shaped artifact with grains of copper inside (Manabe 2003a: 275). In Osaka Prefecture, an iron lump containing copper as well as a fragment of a copper-plated iron object were found at the Middle Kofun

Period Mori site, and Late Kofun Period strata below Osaka Castle yielded a piece of an iron sickle that contained copper (Manabe 2003a: 275).

Other clear evidence of iron recycling comes from iron objects that appear to have been marked as disused either by traces of cutting on the iron, or through bending the object. These traces were found on pieces of iron sickles, nails, and arrowheads at the aforementioned Kuboki Yakushi site in Okayama Prefecture. A piece of an unknown iron object that was cut by a chisel was also unearthed (Manabe 2003a: 275).

Finds of iron scraps from around forging hearths also dramatically decrease in the Early and Middle Kofun Period, and this is typically attributed to the aforementioned recycling (Manabe 2003: 276). Once smelting technology became widespread in the Late Kofun Period, iron raw materials became more readily available, diminishing the need for recycling old iron, and accordingly, archaeological finds of disused iron objects and cut scraps of stock increase again beginning in this period (Manabe 2003a: 275-276).

Some scholars believe that in the Early Kofun Period, so-called *tanzaku*-shaped axe heads, which were related to the plate-shaped axe heads of the Yayoi Period were used as forging stock, and from the Middle Kofun Period, so-called *tettei* ingots held this role (Kadoma 1992, Azuma 1999). However, in the case of *tettei*, there is no scholarly consensus. Rather than as raw material for forging, Mori Koichi (1998) saw *tettei* as having currency-like characteristics, and based on finds from ritual sites, Murakami Yasuyuki has argued that they strongly bear the characteristics of prestige items (1998). Elsewhere, Murakami has argued that interpretations of *tettei* as raw material for forging operations is self-contradictory (2012: 151). His reasoning is that the presence and character of Kofun Period slags indicates that the raw materials required refining to remove that slag, and since analysis of *tettei* show them to be mostly free of slag, their function cannot have been as a raw material for ironworking. Further, he argues that using thin *tettei* to make larger rod or plate stock is the height of uneconomic usage, and that their shape makes them completely unsuitable for forging into objects like axes and swords (2012: 151). He does acknowledge that they may be suitable for making non-utilitarian items like ritual miniatures, though (2007). In the absence of flux additions in forge welding, the entrapped slag in raw material can act as a flux to aid in joining multiple pieces of metal (2012: 151). The implication is that the mostly clean *tettei* would be difficult to forge weld together into a new billet without flux, further militating against a role for them as iron stock for forging. However, recent analyses of *tettei* from Uwanabe Yamato Kofun No. 6 in Nara Prefecture diminish his argument. It is evident that at least some *tettei* were made from even smaller pieces of iron welded together, and somewhat poorly welded at that (Kunaicho Shoryou-bu Ryoubo-Ka 2017). This indicates that regardless of suitability in terms of shape or size, small iron pieces were in fact combined to make larger ones. Beyond that, the use of fluxes and clay slip to prevent oxidization while forging are hypothesized for the Kofun Period (Osawa 2003), and can indeed contribute to forge slag formation, which may obfuscate the cleanliness of whatever iron stock was used.

All that said, *tettei* are not the only candidate for forging stock in this period. A four millimeter thick iron rod was excavated from the Middle Kofun Period Shingaku site in Tochigi Prefecture, and neutron activation analysis suggests that it originated from the Korean Peninsula (Hirai 1998). Additionally, bar stock made from pieces of discarded iron welded together have been reported from the Early Kofun Period site of Okizuka in Chiba Prefecture, as well as the Late Kofun Period site of Kuboki Yakushi in Okayama Prefecture (Manabe 2003a: 276).

While the absence of smelting technology prior to the Late Kofun Period indicates that imported iron was used in ironworking, little is known about the character of that iron, either metallurgically or morphologically. Nevertheless, Murakami Yasuyuki points out that the presence of refining slags indicates that at least some of the iron entering the archipelago was unrefined, but also points to the 40cm square bars of iron from Hwangnam Daechong in Gyeongju City and the iron stock excavated from the Okjeon Tomb M3 in Hapcheon-gun, Gyeongsangnam-do in South Korea as likely candidates for the type of material used in the Kofun Period (Murakami 2012: 151).

Based on finds from the Heian Period Kinzan site in Tochigi Prefecture, iron lump artifacts have come to be classified according to the presence or absence of forging marks and slag on their surface (Tsuno et al 1993), and these classifications are frequently implemented for Kofun Period sites as well. Generally, they can be divided into smelting iron lump artifacts and forged iron lump artifacts (Taguchi and Anazawa 1994). There are artifacts that may be examples of smelting iron lump artifacts with high carbon content known from Early and Middle Kofun Period contexts. Their carbon content is high enough to necessitate a refining (decarburization) process before they can be forged (Manabe 2003a: 276). As they predate evidence for smelting in the archipelago, an overseas origin seems likely (Nojima 1997). Neutron activation analyses of some of these artifacts also indicate an overseas origin (Hirai 1996, 1998).

As discussed above, from the Late Kofun Period onward when smelting technology spreads through the archipelago, furnace bottom masses containing iron and slag mixed up together begin to appear. It is thought that this early smelting technology was immature and resulted in small iron lump artifacts as products (Manabe 2002). Smelting iron lump artifacts derived from furnace bottom masses and ones bearing signs of rapid cooling after extraction from furnaces have been recovered from forge sites near smelting sites (Manabe 2003a: 276). It seems that iron lump artifacts that contained incompletely reduced iron sand or iron ore were separated and discarded on site (Manabe 2003b). Forged iron lump artifacts can be further divided into refining iron lump artifacts and forging iron lump artifacts based on their surface smoothness and the kind of slag (refining or forging) adhering to them (Manabe 2003a: 276).

The qualities of iron raw material have a large impact on the characteristics of the items that can be produced as well as the efficiency with which they can be made and the processes used to do so. At present, an exhaustive and conclusive accounting of what kinds of iron raw materials were available to ironworkers in the Kofun Period is unclear and unlikely to be resolved in the near future. It seems safest to assume that materials may have arrived in varying shapes and varying states of refinement. At Ogata, the shapes of imported iron stock are difficult to estimate, but the degree of refinement may be inferred in part through the chemical analysis of forge slags.

Iron Implements

In a sense, research on Kofun Period ironworking technology began with research on the iron objects themselves. Basic typological studies of many Kofun Period iron burial goods were completed by the mid-20th century, and revealed changes not only in the objects' functional characteristics, but also the appearance of new technical capabilities to achieve them, such as the use of rivets in armor-making and the socket groove of U-shaped hoe blades. These epochal technological changes in the Middle Kofun Period had outsized effects on the trajectory of Kofun Period society (Tsude 1967), and are generally attributed to introduction via the Korean

Peninsula (Murakami 2012). These major introductions of new techniques are not the only changes to ironworking technology that affected how objects were made, they are merely the most obvious. Other changes are not generally visible externally.

Instead, metallographic examination of artifacts' interior material is necessary to clarify many aspects of their manufacture, like their heat treatment, welding techniques, and characteristics of the raw material. Unfortunately, the severe corrosion of artifacts in Japanese archaeological contexts as well as bureaucratic resistance to invasive analyses have limited the scope and results of such investigations in Japan. Nevertheless, some analyses have been done, particularly by Osawa Masami, and they offer some insights into the manufacture of iron items circulating in the Kofun Period, particularly swords. These insights are somewhat muted by the question of whether these generally high-status objects were made in the archipelago, or if they were manufactured on the Korean peninsula or in the Chinese mainland.

Setting that aside to assume that sword blades were in fact made in the archipelago, their analysis offers windows to some generalizable aspects of forging beyond what may be revealed about the source of raw materials. In particular, these include forge welding to combine small pieces of metal into larger ones or to combine the properties of different alloys in one object, the carbon content of available raw materials, and heat treatment methods (Osawa 2003).

Iron swords of the Yayoi Period were made from variety of raw materials and with a variety of forging techniques. Upon metallographic examination, the short sword and spiral pattern swords from the Late Yayoi Period Netsuka site in Nagano Prefecture, as well as the ring-pommel long sword from the Late Yayoi to Early Kofun Period Kamimachi Mukaibaru site in Fukuoka Prefecture proved to be made of single pieces of metal stock rather than multiple pieces welded together. Based on their slag inclusions, the Kamimachi Mukaibaru sword and short sword from the Netsuka site seem to be made of so-called roasted (fined) steel, while the spiral patterned sword was made from lump "wrought" iron. In contrast, the sword from the Late Yayoi Period Miyauchi No. 1 site in Tottori Prefecture was made of a higher carbon (0.5-0.8%) steel edge welded to a core of lower carbon (0.2%) steel. Both pieces were of roasted steel (Osawa 2003: 283). Given the previously discussed comparative lack of sophisticated smithing technology in the Yayoi Period, it is reasonable to assume these were all manufactured outside of the archipelago, but the representation of multiple kinds of raw material as well as forging techniques suggests the presence of multiple potential sources for later forging traditions.

In the case of particularly skilled smithing, there may be no obvious weld lines inside an object left from when multiple pieces of raw material were combined, but the sword from the Kuboki Yakushi site from the middle of the Late Kofun Period in Okayama Prefecture has coarse weld lines joining its layers of "wrought" iron, suggesting a low level of welding skill. Osawa takes this low skill to indicate that the sword was made locally (Osawa 2003: 283). The welding joins in the sword from late Early Kofun Period Hirui Otsuka Kofun in Gifu Prefecture are also prominent. That sword was also made of "wrought" iron.

Swords made from multiple pieces of raw material welded together can be assembled in numerous ways, but it may be easiest to make a distinction between "vertical" and "horizontal" piling patterns. Intuitively, a sword made with vertical piling patterns has weld lines that run vertically when the cross section is viewed such that the back and edge of the sword are aligned vertically, and horizontal piling patterns have horizontal weld lines when the cross section is viewed from that same orientation. Swords of both constructions are known from the Kofun Period, though the only example of horizontal piling known is the sword from Gamo Teranaka Kofun in Fukuoka Prefecture from the early Middle Kofun Period (Osawa 2003).

Constructing a sword of multiple pieces of metal with varying carbon content to combine their properties in a single object is a common technique, but its success depends on the actual carbon content of the alloys used and where in the swords' construction they are located. In many cases, corrosion has destroyed the edges and outermost portions of blades, which is precisely where higher carbon alloys would be most useful, so the prevalence of skilled combinations of different alloys is difficult to judge archaeologically. Even so, the trend of placing lower carbon alloys in the middle or back of swords and higher carbon alloys along the edge and sides does seem probable from analyses (Osawa 2003). Kofun Period swords from Hirui Otsuka Kofun, Gamo Teranaka Kofun, and the Kuboki Yakushi site all have core metal with carbon content of 0.1% or lower, which will not transform to martensite when quenched (Osawa 2003: 283). A slightly contrasting example from Tokunaga Tomb No. H-26 has a core made of “roasted” steel that varies in carbon content between 0.2% and 0.6% (Osawa 2003: 283), which may have transformed to martensite in some places if quenched. A sword said to have been unearthed in Kashiba City, Nara Prefecture (伝今泉出土銀装大刀) is well preserved enough to reveal that its core steel has a carbon content of 0.15%, and its outer steel is of 0.7% (Osawa 2003: 283). That sword dates to the Asuka Period, and is made of “roasted” steel, but may suggest the skills and knowledge present in earlier periods. On the whole, evidence for the use of high carbon steels in Kofun Period ironworking is limited and circumstantial, but it cannot be ruled out.

As discussed in Chapter 3, heat treatment is the most significant factor in the properties exhibited by a steel object. Heat treatments to transform pearlite to martensite are only effective on alloys of sufficient carbon content, but as seen above, there is little evidence for the use of medium or high carbon steels in Kofun Period ironworking. Accordingly, evidence for quenching and tempering is similarly limited. The aforementioned Asuka Period sword from Kashiba City does show a martensitic structure in the tip thought to be the result of quenching in water (Osawa 2003: 284). Tawara Kuniichi's early study of ten straight swords from the “ancient” period, broadly defined, found that three of them were heat treated in a three-step process involving quenching and tempering the entire sword, and then applying a second quench to the edge. Two swords were fully quenched, and five swords had not been quenched at all (Shiomi 1982). This suggests that even beyond the Kofun Period, many swords were not quenched at all, but these results should not be taken as dispositive because corrosion or repeated polishing may have removed the outermost layers of steel, which may be an especially important factor in light of the depth of quenching likely with these low-alloy steels (Siebert et al 1977).

Because the analyses with the greatest potential to illuminate the technical processes and skills in Kofun Period ironworking are so rarely conducted, many of their aspects remain poorly understood and for better or worse, open to speculation. Improvements to slag analysis (Serneels and Perret 2003) and increased application of noninvasive analyses such as CT scanning (Murakami 2003, 2006, Stelzner et al 2016) and neutron diffraction (Fedrigo et al 2015, Grazzi et al 2012, Postma et al 2010) may in part mitigate this in the future, but even these advanced technologies cannot reveal many aspects of artifacts' metallurgical microstructures.

No intact iron implements from the Kofun Period have been unearthed at Ogata, so investigation of what forging techniques were used can only be inferred from other evidence. However, prior research on iron artifacts suggests the range of skills and techniques that can be reasonably inferred as possible.

Conclusions

As discussed in Chapter 3, though iron as a material presents some constraints for its production and working, there is considerable latitude for variation in execution in nearly every aspect of ironworking. Indeed this overview of research on several elements of ironworking in the Kofun Period shows that differing technological traditions existed both synchronically and diachronically within the archipelago. This technological diversity serves not only to contextualize the developments at Ogata but also to clarify them. Where evidence is absent from Ogata, techniques and materials known from other sites can be used to estimate a range of plausible choices. In addition to the milieu of ironworking technologies in the archipelago and the Korean Peninsula, the technologies in use at Ogata were also tied to the landscape where they occurred. Characterizing the physical elements of that forest landscape is the subject of Chapter 5.

Chapter 5: Paleogeography and Climate of the Osaka Plain and Ogata

Introduction

The landscape of the Osaka Plain was constituted through the accumulated consequences, both intended and otherwise, of the historical activities of the people who lived on and around it, as well as through processes beyond premodern human influence. That is to say, the Osaka Plain did not serve as a background for the activities of the people who lived on and around it; but in a way it does form part of the background for this study. Determining where ironworking fits into the history of this landscape necessitates a clear understanding of the overall trajectory of its development, including the probable contributions of past non-anthropogenic and non-metallurgical anthropogenic activities on and around the plain. Those narratives are hardly straightforward, so this chapter serves to introduce the landscape through its physical geography, climate, and vegetation dynamics as glimpsed through several lines of evidence. Additionally, an examination of the pollen records from several archaeological sites near Ogata will provide a closer look at its local landscape.

Geography of the Osaka Plain

The Osaka Plain is an alluvial plain centered in the modern prefecture of Osaka, itself located on the island of Honshu in the Kinki or Kansai region of western Japan. On the west, it is bordered by the eastern end of the Seto Inland Sea, which forms Osaka Bay, and the plain is enclosed by the Rokko and Hokusetsu mountain ranges to the north, the Ikoma and Kongo ranges to the east, and the Izumi range to the south. These ranges are low, with only a handful of peaks reaching above 700m elevation, and the highest point formed by Mount Kongo, which extends to 1125m. The Ikoma range is particularly low, with its highest peak, Mount Ikoma only reaching 642m, and most mountains have an elevation under 400m.

Many rivers drain to the sea via the Osaka Plain, but the main two are the Yodo River and the Yamato River. The Yodo River flows into the plain from the northeast between the Hokusetsu and Ikoma mountain ranges, and is primarily fed by Lake Biwa as well as the confluence with the Katsura and Kizu rivers. The Yamato River flows from its headwaters in eastern Nara Prefecture onto the Osaka Plain from the east between the Ikoma Mountains to its north and the Kongo Mountains to its south. While the plain has been the site of considerable hydraulic engineering since the Kofun Period (Pearson 2016), the rerouting of the Yamato River within the bounds of the Osaka Plain from its former northerly course to its current westerly course in 1704 CE is particularly relevant to protohistoric archaeology for understanding riverine transportation routes prior to this event.

The low, narrow Uemachi Plateau extends some 12km on the western side of the plain, stretching north from about Sumiyoshi Shrine in the south with the current Osaka Castle perched on its northern tip. This plateau slopes gently to the east, but steeply toward Osaka Bay in the west. This is in part due to the active fault on its western edge and uplifting due to earthquakes (Toyama 2013). Other faults lie on the western edge of the Ikoma Mountains and just north of the Hokusetsu Mountains at the southern end of the plain, and archaeological excavations have revealed traces of Kofun-period earthquakes at four sites (Toyama 2013). While these earthquakes left significant traces, it is unclear precisely when they occurred or how much they changed the landscape.

Owing to both natural and anthropogenic factors, the Osaka Plain has changed dramatically over the course of the late Holocene. The most dramatic changes have been

topographical, and have been caused by changes in sea level and the alluvial regime of the Yodo River. At their peak, high sea levels resulting from the Holocene glacial retreat inundated much of the Osaka Plain, especially the subunit known as the Kawachi Plain, which includes the Yamato River basin and stretches north to the south bank of the Yodo River, forming what is known as Kawachi Bay, separated from Osaka Bay by the Uemachi Plateau, which formed a peninsula between the two (Takahashi and Toyama 2000).

Kawachi Bay persisted until about 3000 cal BP (Pearson 2016), but by then, sedimentation from the Yamato River had built up a delta, and deposition from the Yodo River built up its banks and sandbars, shifting the bay to a freshwater Kawachi Lagoon by the late Jomon Period (Toyama 2013). From the Yayoi Period onward, a large quantity of sediment was supplied by possibly anthropogenic changes to the topography of the upper reaches of these rivers (Umitsu 2012, Izeki 1983), and by 1800 cal BP, Kawachi Lagoon had shrank to Kawachi Lake, which itself disappeared into the Yodo River by about 1600 cal BP (Toyama 2013, Pearson 2016, Kajiya and Ichihara 1986).

Climate of the Osaka Plain

Osaka Prefecture is located in the northeastern part of Japan's warm temperate zone, with an average annual air temperature during the common reference period of 1961-1990 of 16.2 degrees Celsius, and average summer temperature (June through August) during that same period of 26.1 degrees Celsius (Japan Meteorological Agency). Like most of Japan, Osaka Prefecture averages over 1300mm of precipitation per year, much of it in the summer months due to the East Asian Monsoon (Japan Meteorological Agency). The warmer months also bring typhoons to the Japanese archipelago, and between 1961 and 1990, typhoons tracked directly over the Osaka Plain every two to three years, and tracked nearby through Hyogo or Wakayama Prefectures about every one to two years (Japan Meteorological Agency). While these figures stand as reasonable references, they cannot be taken at face value as representative of climatic conditions during the Kofun Period.

The conventional view (Sakaguchi 1983, Kanehara 1997), based on an increase of *Strobilus* pine pollen detected in the Ozegahara marshland straddling Fukushima, Gunma, and Niigata Prefectures, holds that the Kofun Period was a cold period with an intensity that "exceeded that of the Little Ice Age" (Sakaguchi 1983: 19). Beyond that, evidence from the Ikegaya archaeological site in Shizuoka Prefecture has been taken to indicate that the Early Kofun Period was comparatively dry, but conditions became wetter during the Middle and Late Kofun Period (Kanehara 1997). Because of the low sedimentation rate during the Kofun Period as well as the possibility of anthropogenic changes to vegetation patterns (Nakatsuka et al 2020, Kanehara 2012), approximations of climate change based on pollen records should not be taken as authoritative, and other lines of evidence complicate the picture.

In recent years increasingly precise paleoclimate reconstructions have become available at a variety of scales, and these can aid in understanding the development of landscapes on the Osaka Plain during the first millennium CE. While global temperature reconstructions are of interest in understanding anthropogenic global climate change and climate forecasting, they are less useful for archaeologists, as climate change in the past was not uniform across the planet, but rather showed significant regional differences (PAGES 2k Network 2013). In fact, researchers from Past Global Changes found that over the last two millennia prior to the industrial era, warm and cold periods, such as the so-called "Little Ice Age," and "Medieval Climate Anomaly" were not spatiotemporally consistent around the world (Neukom et al 2019).

Accordingly, climate records used in archaeology should be as local as possible to the sites under investigation. Unfortunately, there are currently no published high-resolution climate proxies for the first millennium CE Osaka Plain, however, there are records from other parts of the Japanese archipelago and the surrounding region.

Kawahata et al (2009) found that summer sea surface temperatures reconstructed from high-resolution C37 alkenone records from a core in Mutsu Bay at the northern end of Honshu were warm between 2300 and 1400 cal BP, with a mean temperature of 23.5 degrees Celsius, but cooled to about 22.5 degrees Celsius by 900 cal BP. This is warmer than the present summer sea surface temperature there of about 22 degrees Celsius (Kawahata et al 2009: 968). Mutsu Bay's temperature is primarily influenced by the Tsugaru Warm Current, itself branched off of the Tsushima Warm Current flowing north through the Sea of Japan close to the western shores of the Japanese archipelago. Osaka Bay, on the eastern side of Honshu, is more closely aligned with the Kuroshio Current, which flows north along the Pacific Ocean side of the archipelago.

Kawahata and another team (2017) conducted separate study of past summer sea surface temperature based on C37 alkenones in Hiroshima Bay. Hiroshima Bay is only about 170 miles slightly southwest of Osaka Bay, instead of about 540 to the northeast, like Mutsu Bay, and like Osaka Bay, is along the Seto Inland Sea on the Pacific Ocean side of Japan, influenced by the Kuroshio Current. This makes it a potentially superior proxy for Osaka Bay, but the differences nevertheless require caution. Results from this study had a much higher chronological resolution and showed the following trends across the first millennium CE: From a high of 23.7 degrees Celsius in 243 BCE, summer sea surface temperatures declined to 22.9 degrees Celsius by 125 BCE before rising again to 23.7 degrees Celsius by 212 CE. Temperatures remained warm for almost three centuries, peaking at 23.9 degrees Celsius in 505 CE before rapidly dropping to 23.1 degrees Celsius in 561 CE. The temperatures remained cool at least until 617 CE, but rapidly rebounded by 673 CE and warmed to 24.0 degrees Celsius in 707 CE, remaining warm until a cooling trend that began in 820 CE and reaches the twentieth century average of 23.6 degrees Celsius in 943 CE and despite rapid fluctuations continued cooling into the second millennium CE.

The researchers point out that the rapid cooling in the 6th century correlates with a volcanic eruption that triggered extreme cold weather in China. This dip in summer sea surface temperature is probably the result of two volcanic eruptions, the first in 535 or 536 CE in the northern hemisphere, and the second in 539 or 540 CE in the tropics. While there are no annually resolved temperature reconstructions for this time period in Japan, in Europe, the first eruption dropped summer atmospheric temperatures between 1.6 and 2.5 degrees Celsius relative to the previous thirty years, and the second dropped temperatures by 1.4-2.7 degrees Celsius, making the decade from 536 to 545 AD the coldest in Europe in a millennium (Sigl et al 2015).

Kawahata et al (2017) point out that sea surface temperature and atmospheric temperature are strongly correlated, and estimate atmospheric temperatures at Hiroshima Bay to be 1.6 degrees Celsius higher than the sea surface temperature. Taken at face value, this would suggest that the drop in temperature due to volcanic eruptions in 535-536 and 539-540 CE were much less severe in the Japanese archipelago than they were in Europe, but there are two reasons to doubt this. First, Chinese chronicles record extreme cold even in summer in 537 CE, suggesting a precipitous drop in temperature in East Asia, even in the summer. Second, given the thermal mass of the ocean compared to the atmosphere, the sea surface temperature is unlikely to drop as significantly as the atmosphere in the event of sudden cooling. Accordingly, while Kawahata et al's research provides a relatively high-resolution record of sea surface temperature for the

western Japanese archipelago, the late 6th century was probably much colder than this record suggests, at least at first.

Nakatsuka Takeshi has led efforts to investigate past climate in Japan based on another data source, the oxygen isotope ratios of tree rings. This work gives high resolution (annual) reconstructions of not just summer temperatures, but also summer precipitation, giving a more detailed reconstruction of climatic conditions than summer temperature alone (Nakatsuka et al 2020). These data, too, however, do not come from the Osaka Plain directly, but comprise a synthesis of data from 67 samples spanning from Nara Prefecture in the west to Nagano Prefecture in the east, with most samples coming from the eastern parts of that range. Nevertheless, the researchers show that their methods produce data that are significantly positively correlated with summer temperature and negatively correlated with precipitation across a much wider area, including Osaka Prefecture. However, although the correlations are statistically significant, the correlations themselves are quite weak ($0.3 < R < 0.4$ for summer temperature, $-0.5 > R > -0.6$ for summer precipitation), significantly limiting their value in the interpretation of archaeological remains.

In contrast with the alkenone summer sea surface temperature reconstructions, which suggest that the fifth and sixth centuries CE were slightly warmer than the late 20th century, the tree ring oxygen isotope ratios suggest that conditions throughout the Kofun Period were slightly cooler and wetter than late 20th century, more closely aligning with the conventional view, though considerably warmer than the Medieval and Early Modern Periods. Nakatsuka et al's (2020) data also show an overall cooling trend from 535-550CE, but compared to the sixth century overall, the trend is not out of line with the amplitude and periodicity of climatic variation, and neither is the variation year-to-year during this period more extreme than the rest of the century. That is, the data do not seem to show clear influence from a volcanic eruption in 535-536 CE or 539-540 CE as seen in the sea surface temperature reconstructions.

Looking at climatic variability specifically, the late third through late fifth centuries (roughly corresponding to the Early and Middle Kofun Period) show relatively consistent conditions, the sixth century (roughly the Late Kofun Period) shows greater amplitude swings in a cyclical period of about twenty to twenty-five years. Nakatsuka (2012, 2015) links this change periodicity to the outbreak of war and new policies for regional control in support of an argument that changes in the cycles of climatic variability, specifically multi-decadal cycles, are more relevant to understanding environmental hardships than simple warm or cold conditions due to limits in human knowledge transmission. Regardless of any hypothesized connections to political developments, these variations are unlikely to have significantly changed the pace of forest stand regeneration periods.

C37 alkenone data from sea cores and tree ring oxygen isotope data disagree on atmospheric temperatures compared to the present, but the balance of evidence suggests that temperature and precipitation during much of the Kofun Period were not so different from the mid-twentieth century.

The frequency of typhoon strikes to the Japanese archipelago is heavily influenced by the conditions of the El Niño-Southern Oscillation (ENSO) (Elsner and Liu 2003). One effect of El Niño events is that the path of tropical cyclones shifts toward the Japanese archipelago and away from southern China (Elsner and Liu 2003). Accordingly, understanding the frequency of typhoon strikes near the Osaka Plain begins with the record of ENSO events.

In their study of millennial-scale ENSO variability Moy et al (2002) examined sediments from 12,000 cal BP to the present from Laguna Pallcacocha in southern Ecuador and were able

to document periods of moderate to strong El Niño events across that entire period. They found that from 7000 cal BP, ENSO events increased in frequency in a series of pulses, and that event frequency peaked around 1200 cal BP before beginning to decrease toward the present. In the first millennium AD, they found large peaks in moderate to strong ENSO event frequency between 1700 and 1600 cal BP and again between 1400 and 1300 cal BP, and a lull between these peaks with very few recorded events, more comparable to 19th and 20th century conditions. Based on these results, we would expect many typhoons at the start of the Early Kofun Period, a time of few typhoons that lasted from the late 4th century until the late 6th century, after which typhoon activity became far more frequent.

Woodruff et al's (2009) analyses of grain size, stratigraphic breaks, and strontium concentrations across cores taken from two lakes on Kamikoshiki island off the southwest coast of Kyushu show a period of low typhoon activity from 2200 to 1200 BP, covering the entire Kofun Period. Typhoon activity in this period was comparable to present conditions. However, in 2015, Woodruff and other researchers presented a more finely resolved record of overwash into the coastal lagoon Lake Daija on nearby Amakusa island (Woodruff et al 2015). This newer research contradicts elements of the Kamikoshiki record, revealing overwash events (evidence of typhoon strikes) more common than in the present from AD 250 through 1600. Not only do they find greater typhoon activity during this period, the record shows pulses of activity that align with Moy et al's (2002) pulses in ENSO frequency, with peaks in about AD 400 and 600, and a trough in about AD 500.

At Lake Suigetsu in Fukui Prefecture, Suzuki et al's (2021) study of extreme flood events (>571mm rainfall) recorded in lake sediments evaluates both the frequency and intensity of flooding from about 8000 BP to present, which is presumed to be caused by typhoon strikes. They find evidence for three extreme events in the third century, two in the fourth century, and one in each following century until the tenth, which had three. This pattern seems to match expectations based on the first of Moy et al's (2020) Kofun Period ENSO event frequency pulse, but not the second pulse. It is also important to note that while the frequency of recorded extreme flooding events for most of the Kofun Period, including the fifth and sixth centuries, is similar to twentieth century frequency (Suzuki et al 2016, Suzuki et al 2021), the intensity of recorded events is significantly greater than those of the recent past. Unfortunately, this data does not speak to the frequency or intensity of less extreme events, but it is reasonable to infer at least an event frequency similar to the twentieth century for at least the fifth and sixth centuries.

Overall, the theoretical and empirical evidence for ancient typhoon strikes to the Japanese archipelago agree quite well, indicating typhoon activity well in excess of the twentieth century for the Early Kofun Period, and decreased activity not unlike the twentieth century for the Middle and early Late Kofun Period before another period of intense typhoon activity. With this agreement, it seems reasonable to infer that typhoons probably struck the Osaka Plain (or nearby) in the fifth and sixth centuries with similar frequency to the twentieth century, with the caveats that the beginning and end of that period may have witnessed more typhoons, and that the rare extreme events may have been even more extreme than those of the recent past.

Forest Dynamics on the Osaka Plain

As one of Japan's major population centers, the Osaka Plain is heavily developed and highly urbanized. As a consequence, few areas retain managed or wild non-agricultural vegetation cover. Even so, forestry and ecological studies have much to say about the kinds of forest that covered this landscape in the past, and understanding some of the ecological dynamics

of these forests and their constituent species. Understanding these dynamics is in turn vital for understanding past vegetation dynamics, which are only visible through the distorted lens of pollen records.

Today, the zonal climax vegetation below 700m elevation in the Kinki region is lucidophyllous forest, sometimes called “laurel forest” or “shiny-leaved” forest, dominated by evergreen broadleaved trees (Hayashi 1990) such as *Castanopsis* and *Quercus* subgen. *Cyclobalanopsis*. However, varying edaphic conditions as well as disturbance leads to colonization of the laurel forest zone by plant genera not found among the 128 catalogued for climax lucidophyllous forest by Hattori et al (2004). In particular warm temperate deciduous forest composed largely of deciduous oaks, *Castanea*, and *Carpinus* emerges as secondary forest in the lucidophyllous forest zone in Japan (Fujiwara and Harada 2015). Other non-lucidophyllous trees, particularly conifers like *Pinus*, *Tsuga*, *Cryptomeria*, *Sciadopitys*, and *Chamaecyparis* colonize ridges and areas with rocky or poor soils (Hattori et al 1995, Tanaka and Matsui 2007-). Non-lucidophyllous taxa like *Alnus*, *Celtis*, *Ulmus*, *Zelkova*, and *Aphananthe* also emerge in river floodplains (Hattori et al 1995). These species are not likely to have been found evenly mixed throughout the forest, since mature natural forests are typically patchy mosaics (Shugart 1983 (cited in Hirabuki 1991)).

Due to the high precipitation, naturally occurring wildfires are rare in the Japanese archipelago, but other natural disturbances, such as typhoons, landslides, and gaps formed by single tree falls, have important effects. Additionally, human activities such as clearing land for agriculture, and harvesting trees either through clear cutting or selective logging have similar effects. Absent human activity, the main sources of disturbance in these forests are typhoons. Based on records between 1961 and 1990, typhoons strike Osaka Prefecture on average every 2.50 years (Japan Meteorological Agency). Naka’s (1982) work on similarly composed evergreen oak forest in neighboring Nara Prefecture’s Kasugayama Forest Reserve found that typhoon strikes cause an average canopy gap of 365 square meters per hectare, and applying that number to Osaka forests yields an average annual canopy opening of 146 square meters per hectare, or 1.46%. This in turn means that the mean undisturbed residence time for any point in the forest, approximately equivalent to the average lifespan of canopy trees in the forest, is 68.49 years. This is similar to the age (70 years) Naka and Yoneda (1984) estimated for the regeneration of gaps by large fully grown trees in Kasugayama Forest Reserve.

When typhoons strikes were more frequent than in the twentieth century, the undisturbed residence time for the forested areas of the Osaka Plain would likely be shorter than the time required for full canopy gap regeneration by large trees, suggesting that the forest may have been composed of smaller, younger trees that would be expected today. This does not mean that the forest would be any more open at ground level, as Sato (2004) found that tree volume and density of trees at least 18 cm in diameter at breast height recovered within eight years of a major typhoon disturbance in a *Castanopsis cuspidata* stand in Kumamoto Prefecture. Indeed Naka suggests that regardless of forest type, gap levels tend to remain between 10% and 20% of the forest area (1982), and Yamamoto found a similar range for warm temperate evergreen broadleaf forest in Kyushu, which has an even higher typhoon frequency than Osaka (1992, 1998).

Even though the average gap formation due to typhoons was estimated at 365 square meters per hectare (Naka 1982), most individual gaps are much smaller. Yamamoto (1992) found that most gaps consisted of a single treefall, and the mean gap size in primary evergreen broadleaf forest on Tsushima was just 80.3 square meters, and more than 40% of gaps were under 40 square meters.

These canopy gaps regenerate through growth by plants relying on one or more reproductive strategies. These can be broadly divided into resprouting, advanced regeneration (regeneration from seedling and sapling banks), and germination from seed banks. Many evergreen broadleaf species, like *Q. salicina*, *Symplocos glauca*, *C. cuspidata*, and *Persea thunbergii*, are strongly capable of regeneration through resprouting (Bellingham et al 1996, Yamamoto 1992, 1996). However, resprouting ability declines with individual tree age (Shibata et al 2014), and Bellingham et al (1996) found that typhoons are more likely to kill larger trees than smaller ones. Together these findings suggest gaps formed by the death of particularly large trees provide opportunities for different taxa to reach the canopy. Even so, secondary deciduous forest taxa often struggle to become established in small gaps because evergreen broadleaf taxa tend to recruit from seedling and sapling banks rather than seed banks as most deciduous taxa do (Naka and Yoda 1984, Yamagawa and Ito 2006). Some deciduous species, like *Acer rucinerve* and *Carpinus laxiflora* can successfully form even-aged stands within former gaps in evergreen broadleaf forests, but many so-called pioneer species depend on large disturbances creating large gaps (Naka and Yoda 1984, Yamagawa and Ito 2006).

This suggests that while more frequent typhoons in the past may have resulted in an overall younger forest, they likely did not impact the composition of the forest. These principles can be extended to small anthropogenic gaps caused by selective logging, and empirical research on subtropical lucidophyllous forest in Okinawa indicates that forests regenerating in selectively logged stands are highly similar to the mature forest (Wu et al 2013).

Instead, for secondary warm temperate deciduous forest to successfully colonize the Osaka Plain, disturbance would have to be intense over a relatively large area. Candidates for this kind of disturbance are particularly catastrophic typhoons, landslides, anthropogenic clear cutting (logging), or anthropogenic burning. Traces of earthquakes in the Kofun and Yayoi Periods have been found at several sites in Osaka Prefecture, mostly on the eastern side of the Osaka Plain (Toyama 2013: 68). A Yayoi Period landslide was detected at Shiki, and Kofun Period landslides were detected at Kohoji, Shiki, and Shin'ike (Toyama 2013: 68). Soil liquefaction was detected in both periods at additional sites, but in contrast to landslides, deleterious effects of soil liquefaction are not immediate or necessarily as fatal as landslides (Morgenroth and Armstrong 2012). In any case, while the extent and even frequency of forest disturbance from these earthquakes are difficult to gauge, their comparative rare detection in the archaeological record suggests that they were not a major factor in the disturbance dynamics of forests on the Osaka Plain. In light of the preceding discussion of typhoon frequency, particularly catastrophic typhoons were presumably similarly rare in the Kofun Period, providing limited opportunities for colonization by deciduous secondary forest.

The extent of past large-scale anthropogenic disturbances like clear cutting and burning can only be assessed with an understanding of the likely effects of these activities. They fall on a spectrum of least to most likely to replace evergreen broadleaf forest with secondary forest. Clear cutting involves removing all canopy trees in an area, and may or may not include removing the understory, consisting of shrubs, small tree taxa, and suppressed saplings of canopy trees. The different long term effects of these understory treatments are not understood with great certainty, but in the short term, it appears that not only does leaving the understory intact accelerate recovery (Yamagawa et al 2008), it may actually lead to increased recruitment of bird-dispersed taxa, as the remaining vegetation provides attractive perches (Yarranton and Morrison 1974, McDonnell and Stiles 1983).

In contrast, removing the understory removes not only a source of advanced regeneration in the suppressed saplings, but also the increase in bird-dispersed seeds. Even so, reduced competition from existing saplings may give these exogenous taxa a better chance of long-term survival and converting the area to secondary forest. Admittedly, this requires empirical validation, but Yamagawa and Ito (2006) found that pioneer seedlings greatly outnumber those arising from advanced regeneration in a clear cut research plot with understory removed, and it does seem clear that clear cutting the understory along with canopy trees will increase the overall recovery time, especially considering the numbers of seedlings required for growth to outpace deer predation (Shimoda et al 1994).

Kohyama and Aiba (1997) showed that in Yakushima, secondary forest trees (which overlap with local primary forest trees and are different from the *Quercus serrata* secondary forest found in the Kinki region) grow fast enough to recover to primary forest-levels of biomass just fifty years after clear cutting, which closely matched the mean residence time in their research plots. On the Osaka Plain, which is cooler, receives less precipitation, but is struck by fewer typhoons, recovery may well take somewhat longer. Even so, biomass recovery time probably does not exceed the aforementioned mean residence time, which itself closely matches the time for large fully grown trees to regenerate in small gaps.

Finally, using fire to clear land is probably the biggest impediment to regeneration of evergreen broadleaf taxa as opposed to secondary forest composed of warm temperate deciduous taxa. This is because fire can inflict greater damage to stumps that would otherwise resprout, kill off suppressed saplings and seedlings, as well as impact dormant seeds in the seed bank. Evergreen broadleaf regeneration from these sources is further degraded due to the very reasons that fire rather than mechanical means might be employed to remove vegetation: the goal of clearance is to use the land itself, perhaps for plant cultivation or pasture, rather than to gather forest resources. Ongoing maintenance of the land for agricultural or other purposes suppresses regeneration of forest cover by any means until after the land is abandoned. Few viable seeds likely remain in the seed bank, and depending on how the land was used, the soil may be impoverished. Accordingly, evergreen broadleaf forest regeneration from abandoned land is less likely than colonization by warm temperate deciduous secondary forest taxa and other taxa that can thrive on impoverished soil, like *Pinus densiflora*.

Tied to regeneration rates are forests' rates of biomass production, which can also suggest "sustainable" levels of forest resource exploitation. Estimates of biomass production for Japanese forests in the evergreen broadleaf zones differ significantly based on methodology, forest composition and timing of studies with respect to typhoon disturbances. Kimura Makoto estimated the yearly aboveground biomass production of an old-growth lucidophyllous forest in southern part of the Osumi Peninsula in Kagoshima Prefecture, Kyushu to be 21.6 tons/ha (1960). Enoki et al's work in Fukuoka Prefecture, northern Kyushu gave comparable results in a yearly increment of 16.8 tons/ha of aboveground biomass (2011). These numbers suggest a range that may be slightly too high for the somewhat cooler and drier Osaka Plain, however, they can nevertheless serve as an upper bound for estimating yearly aboveground biomass production.

Much aboveground biomass produced by a forest is shed to the floor through litterfall ranging in size from individual leaves to entire trees. Understanding the amount of wood available for conversion to fuel without intentionally felling trees is important to understanding potential impacts of ironworking and other pyrotechnologies. Many researchers have examined litterfall rates, but fewer have specifically examined coarse woody debris (CWD) specifically for Japan's lucidophyllous forests. Sato Tamotsu (2010) estimated CWD inputs at two sites in

southern Kyushu by measuring tree mortality. At Aya, in Miyazaki Prefecture, 2.30 tons/ha/year, and at Okuchi, in Kagoshima Prefecture, 4.01 tons/ha/year were measured (Sato 2010). This research methodology only counted stems over 10cm in diameter, and so undercounted the amount of usable fuel wood dropped in these plots by excluding branches of any size dropped from trees without tree death.

More studies, examining finer litterfall, which while potentially useful as compost for agriculture, is unlikely to be burned in home fires, used in firing pottery, or converted to charcoal fuel for ironworking, help narrow the estimates for sustainable fuel harvest. These studies typically exclude woody material greater than two centimeters in diameter, and so do not fill the aforementioned gap in data on branch falls. Satoo (1983) estimated the average yearly litterfall for Japanese lucidophyllous forests to be 6.3 tons/ha/year. The results of later studies largely agree with these results. In a 2004 study, Sato found the litter production of a *Castanopsis cuspidata* coppice forest in Kumamoto Prefecture, southern Kyushu, to be 6.00 tons/ha/year, and Sato et al (2010) found litterfall production at Aya to be 6.32 tons/ha/year. Like other measurements of Japanese evergreen broadleaf forest productivity, these studies were conducted at sites that are warmer and wetter than the Osaka Plain, as well as more frequently struck by typhoons, which is a significant factor in both fine litter and CWD production (Sato 2004, 2010, Sato et al 2010).

Accordingly, these should be taken as upper limits for estimates of yearly plant necromass production in forests on the Osaka Plain. With this in mind, it nevertheless seems that under conditions similar to the twentieth century, evergreen broadleaf forests on the Osaka Plain might produce up to 16.8 tons of biomass per hectare per year, and shed about half of that to the forest floor, over two tons of which could be used as fuel. The remaining 8.4 tons could be harvested through selective logging without altering the taxonomic makeup of the forest or reducing overall plant biomass in the forest. Harvesting wood through clear cutting or clearing land with fire are expected to have significant effects on forest composition once the land is abandoned or otherwise allowed to regenerate to forest.

Late Holocene Vegetation Changes Near Ogata

As mentioned above, the climax vegetation of the Osaka Plain under modern climatic conditions, and those generally prevailing during the first millennium CE, is warm-temperate evergreen broadleaved forest, often called laurel forest or lucidophyllous forest. Of course, the specific history of the plain and human activities there mean that the vegetation of the plain is not in a climax state, nor has it been over the course of the late Holocene. Indeed, the broad contours of late Holocene vegetation change in the Japanese archipelago are well understood from pollen records.

That said, pollen records are not straightforward to interpret, especially in the depositional settings of archaeological sites. As Faegri and Iverson point out, pollen diagrams often contain a great deal of statistical noise (1989: 153). Compounding difficulties is the question of the pollen source area, which has troubled palynologists for over a century (Davis 2000). Utilizing empirical studies of the relative pollen production of various taxa as well as how quickly their pollen falls to the ground, researchers like Prentice (1985), and especially Sugita (1993, 1994, 2007a, 2007b) have made great strides toward the quantitative reconstruction of “pseudolandscapes” (Edwards et al 2015) at both regional and local scales through mathematical modeling and simulation. Though much pollen is deposited through waterborne transport (Traverse 2007), these sophisticated simulations rely on modeling pollen rain composition as it

falls on lakes or bogs of various sizes, and more recently coastal lagoons (Azuara et al 2019) from which pollen cores are typically retrieved.

Despite these advances and the powerful analyses they have enabled for both paleoecology and archaeology (Li et al 2020, Bunting and Farrell 2018, Richer and Gearey 2018), several obstacles remain preventing their application to archaeological pollen data on the Osaka Plain. First and most simply, while measurements of relative pollen production are becoming more available for northern hemisphere taxa in general (Wieczorek and Herschuh 2020), these data are absent for many important taxa in Japanese lucidophyllous forests, and the same can be said for pollen falling rates. This issue will likely be remedied in the coming years and decades as research continues, but the larger problem is due to the nature of archaeological sites, excavation, and the assumptions of the models. Models assume that vegetation extends very closely to the edge of the body of water where the samples are collected, and that the pollen is well mixed in the water at the time of deposition, and that the size of the body of water is known. These assumptions are unlikely to be verifiable or reasonably assumed to hold true at archaeological sites on the Osaka Plain, where excavation, while “complete,” extends to the boundaries of the land under development, not the “site” itself, however defined. That is to say that even when samples are taken from a formerly inundated area, such as an ancient paddy field, the full size of that paddy is rarely known, nor is it often known how much land had been cleared around the paddy field and/or associated settlement. Furthermore, the agricultural processes of paddy rice agriculture make for taphonomic conditions very unlike the well mixed, mostly undisturbed pollen deposition of lakes and bogs. Finally, the issue of waterborne pollen is especially relevant to irrigated fields. The moats of kofun mounded tombs may provide slightly better conditions for deposition, but the assumptions required for quantitative modeling are nevertheless unmet.

Even so, quantitative modeling offers some insights into understanding the source area for pollen assemblages. Though the trees nearest the water’s edge contribute far more pollen than more distant ones, their effect on abundance in pollen samples is decreased compared to regional vegetation because the ratio of a body of water’s perimeter to its surface area decreases as the surface area increases; in short, pollen samples from small bodies of water reflect very local vegetation, whereas samples from lakes with diameters measured in kilometers reflect the regional vegetation much more evenly (Davis 2000). Pollen data from archaeological sites on the Osaka Plain is best reconstructed qualitatively in terms of trends with these principles in mind, rather than quantitatively.

Traditionally, a sudden increase in *Pinus* pollen is seen as evidence for human disturbance in the form of land clearance for agriculture (Tsukada 1963). This deforestation is evident in northern Kyushu around 2000 BP (Hatanaka et al., 1998), spreading to the Kinki region by 1500 BP (Takahara 1998). That said, the timing of major shifts to pine forest varies spatially within these large regions. Indeed, at various sites within the Kinki region, palynological studies have produced dates of 2040 BP (Lake Mikata, Yasuda 1984), 1000 BP (Hira mountains, Takahara et al 1989), and 900-700BP (Chojidani and Daraike moors, Yamaguchi et al 1989), along with possible human impacts as early as 2500 BP in the Tamba highlands of Kyoto Prefecture (Sasaki and Takahara 2012).

However, a rise in *Pinus* pollen is neither a necessary nor sufficient condition for detecting human disturbance on the Osaka Plain. First, pollen analyses generally cannot distinguish between *Pinus densiflora* (Japanese red pine), and *P. thunbergii* (Japanese black pine). While the former does naturally inhabit ridges and produce large amounts of pollen that

can thus spread a long distance, it is strongly associated with post-disturbance regeneration, however, the latter is not, and because it colonizes sandy shores it has been present along the coast since about 4000 BP (Tsukada 1986: 46). In short, levels of *Pinus* pollen associated with human disturbance may be expected from samples on the Osaka Plain, and can reasonably be attributed to a combination of statistical noise and edaphic climax vegetation. Second, as discussed above, *Pinus densiflora* is not the only tree associated with secondary forest after human disturbance. Warm temperate deciduous forest trees or other non-lucidophyllous taxa may be stronger indicators of human disturbance than pine when interpreting pollen records.

The intraregional differences in *Pinus* appearance also suggest a problem that Kanehara (2012) has pointed out: while these studies are likely to accurately describe the vegetation very near the study site, for reasons discussed above, they do not necessarily reflect the vegetation of the wider region. This is especially salient on the Osaka Plain in the late Holocene, when land-use and settlement patterns were rapidly changing not only due to the introduction of paddy rice farming, but also because of the shifting topography into the late Kofun Period and significant flooding in the Yayoi Period (Pearson 2016). Beyond this, the Kofun Period in particular was a time of low sedimentation rates, even on the alluvial Kawachi Plain (Kanehara 2012), and so both obtaining and properly dating samples from this time are challenging. With these caveats and limitations in mind, I will next discuss the pollen records from several sites on the Osaka Plain in order to clarify the trajectory of vegetation change near Ogata during the Kofun Period.

Konda Gobyoyama Kofun

Unfortunately, no pollen samples have been collected from Ogata, making hyper-local reconstruction of its vegetation history impossible. However, since the late 1970s, pollen samples have been analyzed from many sites in Osaka Prefecture, and an examination of some of the nearest sites to Ogata may help elucidate the local patterns of vegetation change. Unfortunately, none are a direct proxy for Ogata itself because while Ogata is at the base of the mountains, all other known sites in the area where paleoenvironmental analyses have been performed are further toward the center of the plain, offering only the narrowest glimpses of the mountain flora, which would provide the fuel for forging operations at Ogata. Even so, taken as a group, these sites offer the best available look at nearby vegetation change over the course of the Kofun Period.

Based primarily, though not exclusively, on samples collected to the west of Konda Gobyoyama Kofun in Habikino City, about 4.25 km to the southwest of Ogata, Yasuda (1978) reconstructs a vegetation history for the Kawachi Plain for the last 13,000 years. While climatic shifts are most likely responsible for most of the vegetation changes during this time, from the Yayoi Period onward, Yasuda duly considers the role of human activities in shaping the vegetation of the plain.

Two pollen zones identified in this study are relevant to this question: RIIIa (3000-1600 BP) and RIIIb (1600 BP-present). RIIIa shows a significant decrease in absolute pollen fraction of both arboreal and nonarboreal pollen. In terms of composition, there is a major shift away from the *Castanopsis* (chinquapin) and *Quercus* subg. *Cyclobalanopsis* (evergreen oak) that dominated in the laurel forest that had developed by 6500 BP. Minor genera such as *Alnus*, *Myrica*, *Juglans*, and *Podocarpus* actually disappear shortly before the start of RIIIa, but their absence is nevertheless noticeable.

In their place, *Pinus* (pine) and especially the warm temperate deciduous taxa that prefer river floodplains, *Celtis* (hackberry) and *Aphananthe* (muku) dominate the assemblage. *Ulmus*-

Zelkova, other warm temperate deciduous taxa that share that edaphic preference also increase, but remain a minor constituent of the pollen assemblage. *Cryptomeria*, which while not a deciduous taxon nevertheless thrives in moist conditions, also notably increases. *Abies*, *Carpinus*, and *Fagus*, which are also constituent taxa of warm temperate deciduous forest also notably increase, though their overall proportions of pollen are minor within the assemblage. *Quercus* subg. *Lepidobalanus* remains a very minor constituent and continues to proportionally decrease. Poaceae pollen larger than 40 microns, associated with cultivated plants, significantly increases at the start of RIIIa, after a period of decline from similarly high levels in the middle of pollen zone RIIb'', though small Poaceae remain a large constituent of the assemblage after drastically increasing at the very end of the preceding RIIb'' pollen zone. Noting that *Celtis* and *Aphananthe* are strongly associated with secondary succession, Yasuda hypothesizes that their increase is related to human deforestation of *Castanopsis* and *Quercus* subg. *Cyclobalanopsis*, though he is careful to note that climate may also have played a role (Yasuda 1978).

RIIIb is characterized by the continued low absolute pollen deposition, and the overwhelming dominance of *Pinus* in the arboreal pollen assemblage, with the rapid reduction of *Celtis*, *Aphananthe*, *Quercus* subg. *Cyclobalanopsis* and other trees except *Cryptomeria*, which increases slightly (Yasuda 1978). Large Poaceae pollen remains at similar levels to RIIIa, but small Poaceae pollen decreases significantly. Yasuda attributes this shift to further development of paddy agriculture, and eventually a clearing of the evergreen broad-leaved taxa from hillsides for fuel in producing Sue ware. While Sue ware production was at least a local driver of deforestation (Nishida 1976, 1978), Yasuda's sample location suggests other causes.

Based on his observations, Yasuda conceptualizes the following sequence of anthropogenic disturbance and deforestation: introduction of paddy rice agriculture, destruction of evergreen broad leaved forests around the valley bottom lowlands at the foot of hills, expansion of *Celtis* and *Aphananthe* forests, development of rice agriculture and development of valley rice paddies, destruction and disappearance of *Celtis* and *Aphananthe* forests, expansion of productive capacity in the Kofun period, destruction of evergreen broad leaved forests in hills and mountains, and finally, formation of red pine forests (Yasuda 1978: 226).

Yasuda's dates are based on sedimentation rates estimated between radiocarbon dates in the lower strata of the site (1978: 214). Akiyama (2006) gives 950 BC as the start of the Initial Yayoi Period in the Osaka region, which is about a century later than Yasuda's RIIIa. Yasuda gives no information on what radiocarbon methodology was used or what laboratory performed the dating, but does provide date ranges in excess of 100 years either way for every date (though he does not state how these were derived), which makes his date for the introduction of paddy rice agriculture seem more reasonable, but it nevertheless seems quite early for the level of land clearance he postulates. I am inclined to the notion that Yasuda's dates are erroneous, but that his general narrative for the local area is correct.

While this study may not actually represent the entire Kawachi Plain, Konda Gobyoyama Kofun is less than 4km southwest of Ogata, and offers a valuable glimpse of Kofun Period vegetation changes in the eastern Osaka Plain. However, the applicability of these results is further tempered by the site's location. That is to say that the area was undoubtedly cleared of vegetation for the construction of the tomb, which is thought to date to the early 5th century. Not only was this land for Konda Gobyoyama Kofun itself cleared, it is part of the much larger Furuichi Kofun Group and very near the Konda Hakucho Site, itself a workshop for the production of Haniwa funerary ceramics from the late 5th and 6th centuries that undoubtedly consumed large quantities of fuel wood. In short, Yasuda's study is probably not indicative of

conditions across the Kawachi Plain, specifically, overestimating the abruptness of deforestation and conversion to secondary forest, even at a site like Ogata, which also had a large need for fuel. Nevertheless, the pattern that Yasuda identifies for the succession of vegetation beginning with the introduction of paddy rice agriculture amply demonstrates that anthropogenic disturbances may appear long before a rapid increase in *Pinus* pollen, and provides a template for comparison with other sites. These changes, though perhaps too subtle to register as a shift in biome (Gotanda et al 2002, Gotanda and Yasuda 2008), are nevertheless significant to the reconstruction of past forest management practices.

Nishi Oi

Approximately 2.2km north of Yasuda's sampling location and 2.5km southwest of Ogata, at the northern edge of the Furuichi Kofun Group along the present south bank of the Yamato River in Fujiidera City lies the Nishi Oi site. Occasional excavations since 1979 have yielded material from the Paleolithic through the Early Modern Period (Seki 2007), but the strata associated with the Yayoi and Kofun Periods are of greatest interest here. The site appears to have flourished during the Early and Middle Kofun Periods, especially in the second half of the fifth century, when construction of the giant kofun of Furuichi Kofun Group were constructed (Seki 2007: 40-42). Excavations at Nishi Oi have revealed over 5000 pits dating to the latter half of the Yayoi Period and Kofun Period, many of which are interpreted as graves, and ditches understood to be part of an irrigation system that was abandoned before the site's peak have been unearthed. Though excavations to date have not uncovered living areas, a settlement to match the production and possible mortuary features is suspected to lie just to the west of currently excavated areas (Seki 2007). The site rapidly declined in the Late Kofun Period, which draws further attention to its relationship to Furuichi Kofun Group.

While the paleoenvironment of the site during the Kamakura period was investigated in the early 1980s (Yasuda 1983), additional excavation in the 1990s led to new analyses with the goal of understanding the environment prior to the Heian Period. Pollen, diatom, and phytolith analyses were conducted on samples taken during excavation (Watanabe 1995).

Based on the results of pollen and diatom analysis as well as field observations, investigators believe the sample collection area was the site of an oxbow lake that formed prior to 4000 BP. Over the course of the Yayoi Period and into the Kofun Period, the lake filled in, forming a wetland, which, based on the recovery of large *Poacea* pollen, was probably used for rice cultivation which was firmly established at the site by 1600 BP (Watanabe 1995).

In terms of the local vegetation, unfortunately neither the total arboreal, non-arboreal, and spore counts, nor their ratios are reported, but the breakdown of the taxa is nevertheless illuminating. Across the eight samples spanning the Yayoi Period through the early eighth century, there are few identifiable trends. *Pinus* demonstrates a distinct rise beginning the Middle Kofun Period beginning with a sudden increase to about 6% of the arboreal pollen assemblage, and reaches about 10% by the early eighth century. This increase coincides with the tail end of a decline in deciduous oak that began in the Yayoi Period when it filled about 20% of the arboreal pollen assemblage.

Beyond these trends, the pollen samples are generally consistent with respect to their arboreal components. Evergreen oak remains near 50% of the assemblage, and taxa corresponding to evergreen broadleaf forest, such as *Castanopsis/Pasania*, *Podocarpus*, *Myrica*, and *Abies*, warm temperate deciduous forest taxa like *Carpinus*, *Fagus*, and *Celtis/Aphananthe*, as well as taxa associated with specific edaphic conditions like *Cryptomeria*, *Sciadopitys*,

Cupressaceae, *Ulmus*, *Zelkova*, *Alnus*, and *Betula* persist at low but consistent levels from the Yayoi Period all the way through the eighth century with the rise of *Pinus* pollen and decline of deciduous oak.

In terms of herbaceous pollen, *Artemisia* and small Poaceae are present at low levels in all samples, suggestive of at least some open and dry areas nearby. Large Poaceae suggestive of cultivated plants dramatically increases in the Yayoi Period and even more dramatically increases in the Middle Kofun Period to 69% of the herbaceous pollen assemblage, and rising even higher by the eighth century. *Cyperus* decreases in the Yayoi Period, but recovers in the Middle Kofun Period when another aquatic taxon, *Sagittaria*, appears. This pattern likely follows the trajectory of wet rice agriculture at the site.

The phytolith samples are fewer in number and have less chronological resolution, but corroborate the pollen analyses. Nearly no arboreal taxa were identified in samples dating to the Yayoi or Kofun Periods, which mostly consisted of rice and *Sasa*-type phytoliths, with a small proportion of *Miscanthus*. Like the pollen analyses, these findings suggest a wetland and paddy environment with some dry areas and trees cleared to some distance away.

The pollen and diatom analyst, Watanabe Masami, interprets the local landscape as consisting of laurel forest on the local hills and temperate conifer pollen generally blowing in from the Kongo-Katsuragi mountains (Watanabe 1995: 157). Watanabe notes that the gradual decrease in evergreen oak from the Middle Kofun Period onward accompanied by an increase in temperate forest taxa might be attributed to a cooling trend in the climate, but that the increase in *Pinus* alongside the temperate taxa suggests that these species colonizing newly cleared land is another contributing factor (Watanabe 1995: 157).

There are a few reasons to revise this interpretation. The first is simply that contrary to prior research, the Middle Kofun Period does not appear to be especially cold. Second, the Ikoma Mountain range is a closer source of pollen than the Kongo-Katsuragi range, but sites like Ogata-gun Jori and Higashi Yuge, discussed below, which are much closer to the Ikoma Mountains than Nishi Oi, have different conifer pollen assemblages. For that matter, so does Yasuda's sampling site near Konda Gobyoyama Kofun. This suggests that these pollen assemblages are much more reflective of conditions very near the sampling site than across the broader landscape. Third, evergreen oak does not begin to decrease appreciably until the Late Kofun Period, and the taxa that increase (in most cases minimally) are all conifers, which in addition to producing large amounts of pollen leading to overrepresentation in the pollen record, tend to thrive in poor soils with moisture conditions too wet or dry for many other taxa (Tanaka and Matsui 2007). Although the lack of reported absolute pollen numbers makes interpretation difficult, these factors suggest that the rise in *Pinus*, and to a lesser extent other conifers, in the Nishi Oi pollen record are the results of land use changes rather than climate change.

The decline of deciduous oak presents another problem, namely its presence in the first place. Deciduous oak is present in large quantities even in the earliest samples dating to about 4600 BP, and fluctuates before reaching a final peak about 3000 BP, thereafter permanently declining. In the lucidophyllous forest zone, deciduous oak and its concomitant warm temperate deciduous taxa are associated with secondary regeneration after significant human disturbance, however, such disturbance so long ago does seem unlikely compared to prior colder periods leaving a legacy of mixed forest by the start of the Yayoi Period. Even so, the decline in deciduous oak does seem to be correlated with human activity, though non-rice crops have not been established at the site, and the cultivation of rice at the site is not entrenched until the Kofun Period, only dominating the herbaceous pollen assemblage from the Middle Kofun Period

onward. While rice agriculture may have increased in scope over time at the site, it was largely at the expense of deciduous oak stands. At Nishi Oi, the Middle Kofun Period was the period of greatest activity, but it also came with changes to the irrigation system (Seki 2007), potentially allowing some spaces to begin regenerate with arboreal cover, including conifers. The degree to which this specific interpretation is true is less important than the impression of the landscape that the records leaves: During the Kofun Period, the immediate vicinity of the sample location at Nishi Oi was a wetland or paddy used for rice agriculture, but dry open space was also present. Some small distance away, the forest was mixed, with many taxa available for exploitation. Evergreen oak was dominant, and other lucidophyllous taxa accompanied it, however, secondary warm temperate deciduous taxa like deciduous oak were common, as well as taxa that preferentially live in river floodplains and poor soils. While this would seem to provide a wealth of forest resources, they did not likely extend to the ironworkers at Ogata, who were located on the other side of the Yamato River.

Ogata-gun Jori

Just 1.0 km northwest of Ogata itself in Kashiwara, Ogata-gun Jori is the closest site where paleoenvironmental analyses have been performed (Kurosu and Fukusa 2015). The site of this excavation is located near the transition point from the Ikoma Mountain fan to the alluvial lowland. Deposits are heavily mixed, and chronological control over the pollen and phytolith samples is poor. Samples were taken at two locations, from the south wall of the excavation, and from a trench dug across the middle of the excavation area. Dates for samples in and above Layer 8, however broad, should be taken with caution. Additionally, the analysts report that the pollen counts for the lowest layers were poor, preventing statistical analyses (Kurosu and Fukusa 2015: 58).

Based on the recovered pollen remains, the excavators identify two pollen zones, one stretching from the Final Jomon Period through the Nara Period (Zone II, Layers 9 through 7), and another from the Heian Period onward (Zone I, Layers 6 through 3). Zone II is subdivided into subzones a through d, and the basis for these subdivisions is the low absolute pollen counts in the lowest layers, as well as differences in assemblages between the samples taken at the two points, which fit between each other stratigraphically (Kurosu and Fukusa 2015). This is to say that the vegetation recorded at Ogata-gun Jori is fairly consistent between the Final Jomon and the Nara Periods, with few trends not best explained by the slight differences in sampling location and statistical noise in small samples. Consistent trends appear to be the gradual reduction in *Cyclobalanopsis* pollen and gradual increase in *Diploxylon* pine pollen, as well as a large increase in absolute pollen count between the Lower Layer 8 and Middle Layer 8.

Aside from these trends, the assemblages are characterized by a high percentage of herbaceous pollen and spores as compared to arboreal pollen. Herbaceous pollen included Poaceae both larger than 40 microns (associated with cultivated plants) and smaller than 40 microns, as well as wetland taxa and sun-loving dry land taxa suggesting an open area. Conifer pollen exceeds broadleaf pollen in all subzones of Zone II, but conifers produce large amounts of pollen, so this is not necessarily indicative of conifer dominance. The excavators posit that the open areas extended to the foot of the Ikoma Mountains, above which, taxa were largely separated according to elevation and edaphic conditions, with *Cyclobalanopsis* at lower elevations and more conifers at higher elevations, but acknowledge that *Sciadopitys* (Japanese umbrella pine) and *Tsuga* mixed at lower elevations during some periods (Kurosu and Fukusa 2015: 62). While it is impossible to assess the extent of the open area at and around the site

without further work, the distance between the sampling location and the foot of the mountains is less than 600 meters, it is plausible that the forest was largely cleared to that distance.

However, phytolith analyses suggest that it was not completely deforested near the sampling locations. Lauraceae (laurel family) phytoliths were found in all samples from both sampling locations, and *Castanopsis* phytoliths were in Upper Layer 8 and Layer 7 of the trench samples, albeit as a very small proportion compared to herbaceous taxa (Kurosu and Fukusa 2015: 66). This is strongly indicative that evergreen broadleaved forest elements were in close proximity for at least some of the time between the Final Jomon and Nara Periods. Additionally, the excavators report comparatively large quantities of charred material in Layers 9 through Middle Layer 8, which they understand to be suggestive of soil formation (Kurosu and Fukusa 2015: 62), but it also suggests that the land was cleared with fire, and that it was probably maintained using fire for several centuries.

Due to the large time span of features and artifacts unearthed from Layer 8, lack of radiocarbon dating, and somewhat unclear reporting on sampling locations, drawing conclusions about how the vegetation on the landscape changed during the Kofun Period is difficult. However, aside from a gradual rise in *Pinus* pollen and gradual decrease in evergreen oak pollen, there is little to suggest change. Even if the sediments are even more mixed than the excavators indicate, they represent a landscape that on average over several centuries was mostly an open agricultural one with limited arboreal cover. This much is clear because while the Layer 9 sample from the south wall is stratigraphically ambiguous in the report, the Layer 9 sample from the trench sampling location is not. Only Final Jomon material is reported from Layer 9, so the dating of that sample is comparatively secure. This may seem early for an agricultural landscape, but both phytolith and pollen finds indicate the likelihood of plant cultivation, including rice at this site (Kurosu and Fukusa 2015), and it is not entirely unexpected for Final Jomon settlements in Osaka Prefecture (Pearson 2016: 16-17).

Based on the preponderance of evidence, it seems that beginning no later than the Final Jomon, and lasting through the Nara Period, the local area around Ogata-gun Jori was cleared for cultivation of both rice and vegetables using fire, and may have been part of a swidden agriculture regime. The landscape was not completely devoid of trees, but they were likely maintained at a low density out to the foot of the Ikoma Mountains. The trees themselves were by and large expected constituents of evergreen broadleaf forests, with some conifers concentrated in areas of their edaphic preferences. Probably because the land was maintained in a mostly cleared state, there is no evidence for colonization by temperate deciduous forest elements or domination by *Pinus*. The area was not likely a good source of wood for fuel or charcoal, but wood harvested from this area would likely conform to the taxa outlined above.

Higashi Yuge

At a spot 1.20km northwest of Ogata-gun Jori and 2.46km north-northwest of Ogata, pollen sampling was also conducted as part of the thirteenth excavation at the archaeological site of Higashi Yuge, which as designated, is an area just over one square kilometer in the southeastern part of Yao City. Geographically, the site is located on alluvial land between the Nagase River and the Tamakushi River, which run from southeast to northwest through the center of the Kawachi Plain. Five samples were taken from the north and south walls of the 6.7m by 6.5m excavation, providing a glimpse of local vegetation in the Early Kofun Period (Tsujimoto and Saito 2005), but the character of this area of the site during the Kofun Period is

not very clear, as there were no features uncovered, except for what seems to be a natural river channel (Okada 2005).

The three samples taken from layers prior to the Early Kofun Period were poorly preserved, likely due to weathering due to aerobic conditioning (Nakamura 1967). Though the depositional environment is understood to have been a wetland associated with meandering river channel, later changes to the conditions prevented the long-term preservation of arboreal pollen in these layers, leaving only taxa with pollen or spores that strongly resist decomposition (Tsujimoto and Saito 2005). Samples from two layers deposited above a channel fill containing Shonai and Furu-type pottery contain much more arboreal pollen and are understood to represent the Early Kofun Period.

The ratio of arboreal pollen to non-arboreal pollen to pteridophyte spores in these layers was very similar, with over 50% of each sample composed of arboreal pollen. This suggests a more forested, albeit still fairly open landscape than at Ogata-gun Jori, or perhaps one with closer forest. Since the sample location is about 1.2km from the foot of the mountains, or twice as far as Ogata-gun Jori, either interpretation suggests a greater presence of trees compared to Ogata-gun Jori to the southeast.

In terms of composition, there was also little difference between the arboreal pollen assemblages of the two samples, except in terms of species richness. The lower layer contained 27 arboreal taxa compared to 17 in the upper layer, however, many of the additional taxa in the lower layer are represented by a single pollen grain, and so some of this apparent decreased diversity may be an artifact of the smaller sample size recovered from the upper layer. Nevertheless, in both samples, evergreen oak (*Quercus* subsect *Cyclobalanopsis*) was the most abundant taxon, and this was followed by conifers as a whole (primarily *Cryptomeria*, *Tsuga*, *Abies*, and *Pinus*). This is similar to Ogata-gun Jori, except for the complete lack of *Sciadopitys*. In addition to *Pinus*, several other taxa associated with secondary forest, particularly *Quercus* subg. *Lepidobalanus*, *Carpinus/Ostrya*, *Castanea*, *Ulmus/Zelkova*, and *Celtis/Aphananthe* were detected in notably higher proportion than at Ogata-gun Jori.

Among the nonarboreal taxa, Poaceae is by far the most abundant, however, the analysts did not differentiate between large and small pollen, so the presence of cultivated plants is unknown. *Artemisia*, *Plantago*, and Moraceae, which are closely associated with human settlements, are also abundant (Tsujimoto and Saito 2005). Based on the presence of these taxa, the analysts suggest that grassland existed nearby (Tsujimoto and Saito 2005), which accords with the level of openness suggested by the arboreal pollen proportion.

The presence of *Pinus*, temperate deciduous forest taxa, and herbaceous taxa indicates that the area in the vicinity of the site was subject to disturbance. At least part of the area was subject to relatively recent disturbance at the time of deposition, but the presence of secondary forest elements and *Pinus* pollen demonstrates that some disturbed areas had been allowed to regenerate as well. The lack of chronological resolution prevents any detailed understanding of long-term trends at the site, however, the increase in evergreen oak pollen between the two samples suggests that the regeneration of the lucidophyllous forest may have proceeded alongside colonization by secondary forest taxa.

Based on this evidence, it does seem that beyond Ogata-gun Jori, the area northeast of Ogata was more heavily forested than the areas closer to the site itself. By the Kofun Period, this northeast area in general does seem to have been under active management for agricultural purposes for centuries, though perhaps due to changes in population distribution or simply the fallow period of a slash and burn regime, at least some areas were allowed to regenerate as

forest. Nevertheless, unless other areas were more completely depleted, it seems unlikely that the area around Higashi Yuge would supply fuel wood to Ogata simply because of the other sites around it, like Ogata-gun Jori to the southeast and Tanaka to the northwest that would likely also need access to forest resources.

Tai Naka

The Tai Naka site was a major Yayoi Period settlement discovered in 1970 during sewer line construction at the Ground Self Defense Force base in Yao City and extends onto what is now Yao Airport, about 2.6km west-northwest of the Ogata site and 1.9km north of Nishi Oi. The site was subject to considerable environmental change from the Yayoi through the Kofun Period due to its location on a river floodplain with some minor topographic variation allowing for changes in land use as the river course and flooding dictated (Suzuki and Fujine 1997, Watanabe 1997). Specifically, the site was dry for much of the Yayoi Period and rice cultivation took place at the nearby Shiki site, but in the Early Kofun Period, Shiki became less tenable for cultivation, and parts of Tai Naka became a wetland environment and were no longer occupied, though other areas were still in use even in the Middle and Late Kofun Periods (Tsujimoto and Tanaka 1997). In the 1990s, excavations on both the Ground Self Defense Force base and on the airport land included pollen, diatom, and phytolith analyses for paleoenvironmental reconstruction, which are summarized and interpreted here.

Samples were taken from several parts of the site (Tsujimoto and Tanaka 1997, Suzuki and Fujine 1997, Watanabe 1996, Watanabe 1997), which when taken together demonstrate the highly local character of archaeological paleoenvironmental analyses as well as wider trends in the area. Tsujimoto and Tanaka's analyses of flood deposits from a buried pit have a gap between the Middle Yayoi Period and the Kofun Period. With the poor absolute dating of these samples, identifying vegetation contemporary with the height of forging activities at Ogata is essentially impossible, however, some clues about land use and disturbance can still be gleaned. During the Yayoi Period this area of site and surrounding area was significantly deforested, as indicated by the large proportion of grass and shrub pollen compared to arboreal pollen and spores. Across this period, evergreen oak provided the largest input to the arboreal pollen assemblage, but conifers *Cryptomeria*, *Pinus*, *Tsuga*, and *Abies* were also present in significant proportion. The presence of *Pinus* is particularly noticeable at this early date, suggesting that consistent disturbance was already ongoing in the Yayoi Period. Other broadleaf taxa are not well represented, except for a small proportion of *Celtis/Aphananthe*, and deciduous oak.

With the topographical change in the Kofun Period, the proportion of grasses and shrubs rapidly fell, with the difference made up by pteridophytes. The relative proportion of arboreal pollen was roughly the same as before, but the proportion of evergreen oak declined precipitously, and while the conifer taxa increased in general, *Pinus* increased the most dramatically. Later samples show a shift to decreased pteridophytes and arboreal and non-arboreal pollen levels higher than seen in the Yayoi Period. These samples show a recovery in evergreen oak, and very gradual declines in *Pinus* (though it remains well above Yayoi Period levels), *Cryptomeria*, and *Tsuga*. Taken together, these data suggest that the shift to marshland led to decreased disturbance levels, allowing pteridophytes to quickly establish in former grassland, as well as pine to become established as reforestation proceeded. Later reforestation came mainly from evergreen oak in the wake of the pines, which were unable to increase due to the lack of untended bare land. That the laurel forest species were able to recover instead of giving way to a pine forest suggests that the anthropogenic pressure on forest resources was not

overwhelming, even in lowland areas of the Kawachi Plain. Other broadleaf taxa continue to be poorly represented in these samples, except for deciduous oak and *Celtis/Aphananthe*, which show a similar, if muted, trend to evergreen oak. Significant pressure on forest resources, seen in the rapid increase in *Pinus* and rapid decrease in evergreen oak only appears in the latest sample from the 1995 plot, but its absolute date is unfortunately unknown, and may significantly postdate the Kofun Period.

Tsujimoto and Tanaka (1997) note that the pollen assemblage of this site has a higher proportion of fern spores and conifer pollen than other sites in the vicinity and that since these pollen fossils are more resistant to weathering than other pollen fossils, they are often found in poorly preserved sediments. Considering the fact that the sediments treated in this study are flood deposits with a high sedimentation rate, they reason that these weathering-resistant fossils accumulated from a wide area, suggesting the fossil pollen assemblage in this study reflects the wider landscape (Tsujimoto and Tanaka 1997). This makes intuitive sense; most of this pollen was probably deposited via water transport rather than from pollen rain, and therefore reflects the pollen content deposited in the river, potentially at great as well as short distances from the site. This also helps explain the presence of conifers that prefer different edaphic conditions. In this context, the standard caveat of the high pollen production rates of conifers compared to angiosperms is especially applicable. With that all in mind, it seems as though the regional vegetation through both the Yayoi and Kofun Periods was, broadly speaking, lucidophyllous forest with small patches of secondary warm temperate deciduous forest and conifers exploiting their edaphic preferences. At the same time, these samples do not reflect only the wider vegetation, but have also been significantly impacted by local conditions, which are better isolated in other samples.

Suzuki and Fujine (1997) analyzed samples from three locations in a different area of the site than Tsujimoto and Tanaka. Their results show some variation between the three sampling locations, but overall paint a similar picture to each other; one that differs from Tsujimoto and Tanaka's sample location. While Suzuki and Fujine find that the immediate area of the site was host to dry land herbaceous vegetation like *Miscanthus*, *Artemisia*, and *Sasa*, lower elevations at the site became a wetland during the Early Kofun Period. This was thereafter used for paddy agriculture and the proportion of arboreal pollen decreased, whereas Tsujimoto and Tanaka's study area was seemingly abandoned. The arboreal pollen assemblages from the Early and Middle Yayoi Periods through the start of the Heian Period vary in composition between Suzuki and Fujine's three sample locations as well as over time, but allowing for the "noise" inherent to pollen samples, they nevertheless show a different trajectory from Tsujimoto and Tanaka's flood sediments. Most notably, *Pinus*, while present from the Early Kofun Period, remains at a low level until it increases significantly in the Heian Period or later. Instead, they have significant levels of Taxaceae/Cupressaceae conifers, presumably *Taxus*, *Cephalotaxus*, and *Chamaecyparis*, which appear only in low levels in Tsujimoto and Tanaka's samples. As in their samples, though, *Cryptomeria* is well represented in most layers.

The broadleaf taxa also display broadly similar trends to Tsujimoto and Tanaka's samples; secondary warm temperate deciduous forest taxa like deciduous oak retain a small presence in the assemblage over time, but pollen from lucidophyllous taxa such as evergreen oak and *Castanopsis/Lithocarpus* are much more common. That said, Suzuki and Fujine note the impacts on evergreen oak in particular when agricultural activities increase, as well as note that the levels of disturbance were not so high as to prevent the regeneration of taxonomically similar

forest until the rise of *Pinus* and deciduous oak in the Heian Period (1997), though even then lucidophyllous taxa remain dominant.

Watanabe Masami (1996, 1997) completed analyses at two additional areas of Tai Naka. At the first (1996), chronological precision was poor across the eight samples between the Early Yayoi Period and the Nara Period. However, there are few trends that can be detected across that entire time in this location. While Watanabe does not report the ratio of arboreal to herbaceous pollen and spores, the dominant presence of Poaceae larger than 40 microns suggests that this area, too, was largely open for agricultural purposes for the entire first millennium AD. Within the arboreal pollen assemblages, evergreen oak dominates, with deciduous oak retaining a minor presence, along very small amounts of other lucidophyllous, warm temperate deciduous, and edaphically climactic broadleaf taxa. *Cryptomeria* pollen is second most common after evergreen oak, but as a conifer, this is not necessarily indicative of its relative proportion in the forest. Other conifers, including *Pinus*, have pollen proportions similar to deciduous oak, never reaching 10% of the assemblage. Major change does come in the historic periods, but through the Kofun Period, this location shares the same overall trend as Tsujimoto and Tanaka's as well as Suzuki and Fujine's in that despite differences in the conifer components of the assemblage, the forest seems to be predominantly evergreen broadleaf in composition, with some patches of warm temperate deciduous secondary forest represented by deciduous oak.

Watanabe's second set of analyses (1997) cover a larger area of the site, and generally show a similar landscape to other Tai Naka analyses over time. That is to say, based on the large and small Poaceae pollen content as well as other herbaceous pollen, over the course of the Yayoi and Kofun Periods, the area seems to have been utilized for rice agriculture (though it may have been dry field rather than paddy), and arboreal elements come from some small distance away. The arboreal pollen assemblages show a distinct pattern that indicates that while the immediate area is clear, the bulk of pollen at archaeological sites on the Osaka Plain is probably very local. Specifically, even though the sampling locations are less than 500 meters away from each other at most, in the Kofun Period there is a notable difference in conifer pollen composition on a latitudinal cline in this area of the site. All sample locations show the presence of several conifer taxa (*Abies*, *Pinus*, *Tsuga*, *Sciadopitys*, *Cryptomeria*, other Cupressaceae), but the three northernmost samples show similar or greater levels of *Pinus* pollen to evergreen oak pollen, as well as comparatively high levels of *Tsuga*, while the southern samples show low levels of *Pinus* and *Tsuga*, and higher levels of *Cryptomeria* than the northern ones. Watanabe hypothesizes that this is due to *Pinus* growing on the abandoned land when the habitation area of the site moved after the end of the Jomon Period (1997). This stands in opposition to analysts' common assertion that conifer pollen in Kofun Period pollen samples from the Osaka Plain must have originated a great distance away from the sides of the mountains that enclose the plain.

Beyond conifer content, the samples show that as elsewhere, evergreen oak is present in high quantities (though in some samples conifers contribute more, but as Watanabe notes this should not be taken as indicative of a forest dominated by conifers), but it does decrease slightly beginning in the Kofun Period (1997). Other lucidophyllous taxa are present in low quantities, as well as deciduous oak and broadleaf taxa associated with river plains.

The differences between pollen samples taken at different locations around Tai Naka reveal not only the local sensitivity of these analyses, but also the patchy mosaic structure of forest vegetation on the Osaka Plain during the first millennium AD. Stands of *Pinus*, *Tsuga*, and *Cryptomeria*, and warm temperate deciduous taxa were interspersed in a matrix of lucidophyllous forest within a few hundred meters of the open areas of Tai Naka, and differences

between Tai Naka and samples from other sites near Ogata largely conform to this image, albeit with some variation in stand composition, for example *Celtis/Aphananthe* near Konda Gobyoyama Kofun. It seems that despite some decline in evergreen oak in some places during the Kofun Period, the large-scale disturbances and land use changes leading to dominance by *Pinus* and other secondary forest taxa did not overwhelm the lucidophyllous forest taxa on the Osaka Plain until the historic period. The levels of disturbance did allow for limited colonization by warm temperate deciduous forest taxa, and varying edaphic conditions such as rocky or sandy ridges, riversides, and areas with poor soil provided opportunities for other taxa as well. Given that pollen analyses from sites as near to each other as to Ogata all show local permutations on the aforementioned generalized vegetation, there is no paleoenvironmental evidence suggesting Ogata should conform specifically to any one of them, nor to expect any significant departure from that generalization. Without data to the contrary, it is most reasonable to assume that should they so desire, residents and workers at Ogata were able to access wood from a wide variety of lucidophyllous, warm temperate, or eurythermal tree taxa.

The Archaeology of Wood Use on the Osaka Plain

This apparent wide availability of wood types does not preclude cultural constraints or preferences on the use of these woods, and so warrants a brief exploration of archaeological research on wood use preferences and management on the Osaka Plain during the Kofun Period. The analysis of excavated wooden artifacts forms the basis for much of the work in this area. Ito and Yamada (2012) compiled data on all the artifacts for which wood taxon identification had been conducted in Japan, and devoted a chapter to the trends they uncovered in Osaka and Wakayama Prefectures.

Though the number and types of wooden artifacts for which wood taxon identification has been conducted is high and extends from the Jomon Period through the Early Modern Period, it represents only a fraction of the material that has been excavated over the long history of archaeology in the region. Ito and Yamada are careful to acknowledge this incompleteness and hedge their conclusions, but it is the preservation bias in the dataset that invites closer scrutiny of wood use trends. The clearest chronological trend is the dramatic shift toward the use of conifers/softwoods, especially from the Middle Kofun Period onward (Ito and Yamada 2012), and this trend is likely real, but it is amplified by the nature of Kofun Period archaeology.

That is to say, much of what is known about the Kofun Period is based on artifacts unearthed from mortuary contexts, which biases the record in certain ways. Firstly, artifacts recovered from tombs may be thought to have at least a degree of ritual significance, even when they are also utilitarian in form. It is difficult to discern whether these objects were ever intended for use beyond their roles as grave goods, but since the woods most prominently associated with ritual use (*Chamaecyparis*, *Cryptomeria*, and *Sciadopitys*) happen to be conifers, it should come as little surprise that an assemblage of wooden artifacts predominantly unearthed from mortuary contexts would be more weighted toward conifers than earlier assemblages derived from more diverse archaeological contexts.

This mortuary bias dovetails with the other identifiable source of the trend toward conifer usage from the Middle Kofun Period onward: technological change. Joinery and *magemono* bent wood techniques were added to the woodworking repertoire in the Kofun Period, and artifacts made with these techniques rapidly rose in popularity (Ito and Yamada 2012). In contrast with the carved containers and furniture of previous periods, the new styles required the preparation of boards to be fitted together. Prior to the introduction of the rip saw in the medieval period,

planks were made by splitting logs with mallets and wedges (Higami 2016). Hardwoods (broadleaved taxa) and softwoods (conifers) were generally processed into boards using different techniques (Higami 2016), and in addition to being easier to work in general, softwoods could be processed more efficiently with respect to the number of boards produced per log than hardwoods. Accordingly, as plank-built objects and architecture proliferated, the proportion of conifer wood increased as well. Although conifers *Sciadopitys* and *Chamaecyparis* have been used for coffins since at least the Early Yayoi Period (Ito and Yamada 2012), this is particularly significant in the Late Kofun Period, when a larger proportion of the population had access to elite burial customs, and conifers *Pinus* and *Cryptomeria* also came into use for plank-built coffins.

All this gives the impression that conifers were either preferred or much more available from the Middle Kofun Period onward. The latter statement does not appear to be true based on the pollen evidence, and the former is largely, though not completely, an illusion based in preservation bias. Hardwoods continued to be preferred in applications requiring strength and toughness, and *Quercus* subgen *Cyclobalanopsis* remained the overwhelmingly popular choice on the Osaka Plain for many agricultural implements from the Early Yayoi Period onward (Ito and Yamada 2012). Other implements do not exhibit such strong preferences, but it is nevertheless clear that Yayoi and Kofun Period people on the Osaka Plain gave consideration to what wood was most appropriate in what applications.

Higami (2016) goes further in his analyses to understand the relationships people had with the forest resources of their landscapes. Through a close examination of the distances between settlements, the age of wood at harvesting, the level of lumber processing, and the styles of agricultural and ritual implements, he argues that in the Yayoi and Kofun Periods, people across the Japanese archipelago were treating at least some forested lands as managed resources in a multi-decadal rotation, and maintained areas as “*satoyama*” managed forests for local usage (Higami 2016: 16-20). Eventually though, demand for lumber outstripped available resources in some areas, particularly in the lowlands of alluvial plains. Systems were developed not only for the procurement and transport of lumber from settlements near more forested areas, such as the western foot of the Ikoma Mountains, but also for the movement of lumber to areas lacking extensive forests (that nevertheless maintained *satoyama*) (Higami 2016: 253-257). Additionally, he asserts the development of full time specialist woodworkers from the Late Yayoi Period in some regions (Higami 2016: 255). Together, these elements of managed exploitation, long distance lumber and wood product procurement and transport, and craft specialization indicate to Higami the existence of systems of forestry, broadly speaking, in place by the Kofun Period (2016: 257).

Oba Shigenobu’s (2017) examination of wood used for construction on the Osaka Plain between the Middle Yayoi Period and the Nara Period reaches similar conclusions, laying out three stages of wood acquisition range expansion: Between the Middle Yayoi Period and Early Kofun Period, small diameter timbers were sourced locally, and where necessary, other materials and semi-finished products were sourced from nearby settlements bordering forests. Then, in the second half of the Middle Kofun Period, when settlements move from alluvial lowlands to alluvial fans, and regional groups formed with territories encompassing multiple environmental settings, these groups sourced materials within their own territories, and by the historic period, long distance distribution of large-diameter softwood lumber was widespread.

Higami and Oba’s conclusions do not contradict the paleoenvironmental evidence for forest composition in the southeastern part of the Kawachi Plain near Ogata, and fit well with the

consistent low levels of warm temperate deciduous forest pollen from sites in the area from the Yayoi Period through the early historic periods. An image emerges of relatively sustainably managed forest landscapes and appropriate uses for various tree taxa well delineated. Even so, as changes to social structure that Oba alluded to developed, village-level self-sufficiency decreased, with some areas seemingly exploiting the forest beyond its capacity to regenerate with the same taxonomic composition.

The Suemura Kilns site in the Senboku Hills of southern Osaka Prefecture was one such place. Here, the steep slopes of hills and terrace cliffs were used to build climbing kilns for the production of Sue ware that lasted from the first half of the fifth century through the ninth century. Pottery was produced in large quantities and distributed across the archipelago, requiring massive amounts of both clay and fuel. This had significant effects on the local landscape: over time, the distribution of kilns at Suemura moved from the terraces to the inland hills (Toyama 2013), presumably following the available resources. Based on the analysis of charcoal fragments from the remains of Sue ware kilns, Nishida Masaki (1976) found that broadleaf trees such as evergreen oak accounted for most of the fuel through the 5th century, but from the 6th century onward, *Pinus* gradually increased, and by the latter half of the 7th century, most of the fuel was *Pinus*.

Ironworking is a similarly fuel intensive technology, and Ogata's heyday coincides with Oba's second stage of wood resource supply systems, in which material was supplied from within a regional group's territory. With their location near the foot of the Ikoma Mountains and the apparent richness of forest resources at nearby sites, like Suemura's potters, Ogata's ironworkers may not have needed to carefully manage their local resources to meet their needs and obligations in the short to medium term. On the other hand, given the prevailing sensibilities about proper use of different woods, they may have carefully chosen the fuel for their work, or otherwise adapted their technological practices to manage their local forest resources.

Discussion and Conclusions

Evidence of the climate and local vegetation near Ogata during the Kofun Period is varied and sometimes contradictory, however, when weighed together, a fairly coherent picture emerges. Temperatures during the third through fifth centuries were probably about as warm as the twentieth century, before cooling rapidly and significantly in the sixth century, and then warming again in the seventh century. Precipitation in the Japanese archipelago tends to trend inversely with temperature, so while the sixth century was probably wetter than the twentieth century, precipitation in the rest of the Kofun Period was likely similar to twentieth century levels. With the exceptions of the Early and Final Kofun Periods, typhoon intensity and strike frequency was also probably similar to the twentieth century.

These similarities with twentieth century climate are fortuitous for understanding vegetation dynamics in the Kofun Period, since most relevant forestry research in Japan was conducted in the twentieth century. In the Kofun Period as today, the climax vegetation on the Osaka Plain is lucidophyllous forest. In times most like the present, the average age of trees would be about 68.49 years, or somewhat less in times of greater typhoon intensity. Aside from human activities, typhoons are the largest source of disturbance in these forests, but the level of disturbance produced by typhoons is generally not sufficient to permit lasting colonization of the disturbed areas by taxa of other biomes, particularly deciduous secondary forest.

Human activities and local edaphic conditions generally account for the appearance of secondary deciduous forest or conifers in areas with lucidophyllous forest climax vegetation.

Human activities need to be sustained to permit these other taxa to colonize an area, as lucidophyllous forests regenerate quickly. It is this fast growth that makes them rich resources for local populations. With the caveat that all estimates are inherently inaccurate, the laurel forests of the Osaka Plain may have produced as much as 16.8 tons of aboveground biomass per hectare per year during the Kofun Period. Of that biomass, about two tons could be coarse woody debris shed by the trees to the forest floor. This is easily collected for fuel wood. Another 8.4 tons per hectare could potentially be harvested through selective logging of live trees each year without reducing the overall biomass of the forest.

These figures along with some other conservative estimates provide a basis for estimating potential charcoal fuel use at Ogata. While all of the two tons of CWD per hectare could be converted to charcoal, the same is not true of the live biomass. A perhaps optimistic estimate that 80% of aboveground biomass is woody enough to be worthwhile means that 6.72 tons of wood per hectare could be sustainably consumed for charcoal production each year. Adopting a low-end estimate of 8% for the charcoal production yield gives 0.16 tons of charcoal from the CWD, and 0.5376 tons of charcoal from sustainably harvested trees per hectare per year. Naka (1982) found a mean aboveground biomass of 168 tons per hectare, and adopting that measure gives an estimate of 10.752 tons of charcoal per hectare if forest is clear cut, on top of the CWD mass.

How much charcoal is used in forging operations depends on several factors including the size and shape of the hearth and the particular forging activities undertaken. Even so, a consumption rate of two kilograms of charcoal per hour of forge operations is probably a slightly high but not unreasonable estimate. That means that a forge operated for four hours per day every day will require 2.920 tons of charcoal over the course of a year. This means that a clear cut hectare can support 3.737 hearths for one year. If fuel is only taken from CWD, then 18.25 hectares of forest are required to support one hearth for one year. If charcoal is produced from both CWD and sustainably harvested live wood, then 4.186 hectares are required to support one hearth for a year.

Just how much and what kind of forest resources were available to the ironworkers of Ogata is difficult to know with much certainty. No pollen sampling or other paleovegetation analyses have been performed at Ogata itself, and as will be explored later, the extent of occupation at and around Ogata itself is unknown. The best clues to the local vegetation during the Kofun Period come from several sites less than five kilometers from Ogata where analyses have been conducted. Much of the area seems to have been open and settled agricultural land, or possibly cleared in connection with kofun mounded tomb construction. Even so, the forest was never far from these sites, and the mosaic of forest patches around and presumably between these sites, as well as on the slopes of the Ikoma mountain range was largely lucidophyllous, though there were also stands of conifers and enough warm temperate deciduous taxa to indicate prolonged disturbance in the area. It appears that the people of Ogata could access a wide variety of taxa relatively close to the site. Of course, they had to share these resources with neighbors, leaving them with a potential exclusive catchment area rather smaller than the distance between these known sites. Neither the geographic nor temporal resolution of existing research permits very close examination of the vegetation trends, but since lucidophyllous as well as warm temperate deciduous and conifer taxa continued to coexist throughout the Kofun Period and into the succeeding Nara Period, it seems safe to say that ironworking and other fuel-intensive activities were conducted within or near the limits of sustainable harvesting at least into the early historic period.

Seemingly sustainable management of the forest landscape making is undoubtedly tied not only to local ironworking and other pyrotechnological activities but also to preferential use of certain taxa for certain purposes. Considering these preferences for the uses of different woods, ironworkers at Ogata may have carefully selected their fuel stocks or otherwise adapted their ironworking to accommodate limited availability of certain woods, especially since during the Middle and Late Kofun Period forest resource exploitation in some other areas was outstripping the regenerative capacity of the forests, and longer-distance trade in wood products and resources emerged.

Chapter 6: The Ogata Site in Context: Evidence of Large-Scale Ironworking and Its Implications

Introduction

This chapter serves to introduce the Ogata site in its local context and the major excavations conducted there. Finds and features related to ironworking including hearths and workshop structures, tuyeres, and tools are introduced in detail and holistically interpreted alongside evidence for other activities to illustrate ironworking activities and technology on the human scale and their diachronic changes at the site based on pottery typochronology. Large quantities of smithing slags have been unearthed at Ogata, but here they are primarily introduced as evidence for smithing activities, rather than analyzed in detail. Closer macroscopic analyses of slags as well as insights gleaned from scientific analyses will be presented and integrated in the following chapters.

The Ogata Archaeological Site and its Major Excavations

The Ogata site bears the name of an old administrative division dating back to at least the tenth century in what is now the northeast part of Kashiwara City, on the eastern side of Osaka Prefecture on the gentle slope of a fan descending westward from Mt. Takao in the Ikoma Mountains, to the east of the former northerly course of the Yamato River, near the valley where the river flows in from Nara Prefecture. As designated, the site comprises a roughly rectangular area of approximately 0.25 square kilometers, of which only a tiny fraction has been excavated prior to various construction projects. It is very unlikely that this designated area corresponds with any ancient borders, and Ogata is just one of a series of contiguous site designations of similar size running north-south along the foothills of the mountains. To the north of Ogata is the Hirano site, and to the south extending to the northward bend in the Yamato River are Ogata Minami, Taiheiji, Ando, and Takaida (Fujii 2016).

Some 80 excavations have been opened at Ogata, but the vast majority of them were very small tests prior to construction. Larger scale excavations conducted by Kashiwara City in 1982 (excavation number 82-9), 1984 (excavation number 84-1), and 1985 (excavation number 85-2), as well as by Osaka Prefecture in 2012 (excavation number 12024) and 2013 (excavation number 13001) provide almost all of what is known about the large-scale ironworking conducted there during the Kofun and early historic period. Of these large excavations, all but excavation 85-2, which preceded the construction of a new gymnasium at Katashimo Elementary School (柏原市立堅下小学校), were long narrow excavations within the footprint of current roads. Excavation 82-9 was on the road leading from old National Route 170 toward Nudhiko Nudhime Shrine (鐸比古鐸比賣神社), excavation 84-1 on the road in front of Katashimo Elementary School leading toward the Tenrikyo Oogata Grand Church (天理教大縣大教会), and the prefectural excavations on old National Route 170 north of the elementary school.

Site Overview

In the early historic period, this area was known for the six temples aligned north to south along the Higashi Koya Road, itself parallel to the Yamato River and running through these sites. The ruins of two of these temples are located at Ogata, Miyake-ji (三宅寺) at Hirano Haiji, and Osato-dera (大里寺) at Ogata Haiji. Beyond these temples, several shrines are mentioned in the area in the tenth century *Engi Shiki*, but archaeological remains point to human activities here long prior to even the protohistoric Kofun Period ironworking, for which the site is best known.

No Paleolithic remains or artifacts have yet been found at Ogata, but fragmentary remains of Jomon activities are known from around the site. Several types of pottery and stone tools from the Initial Jomon to the Final Jomon have been found, including stone “swords” and stone axes (Miyano et al 2016). Additionally, charcoal-rich soil layers of uncertain (within the Jomon Period) date suggest that Jomon people may have lived on the site, however, due to the fragmentary nature of both excavation and unearthened remains, the character of the site in the Jomon Period is poorly understood (Miyano et al 2016).

The succeeding Yayoi Period saw at least some occupation of the Ogata site, but there were also notable Late Yayoi Period lowland settlements across the Yamato River at the Funahashi and Hongo sites, as well as an upland settlement atop Mt. Takao at the Takaosan Sancho site (Fujii 2016). Unfortunately much as Jomon Period occupation of the site is not well understood, only a little more can be said about Yayoi Period occupation; its continuity with either the preceding Jomon or succeeding Kofun Period occupations is especially unclear.

Pottery from the Early, Middle, and Late Yayoi Period has been found at various locations around Ogata, as well as sanukite and animal remains (Fujii 2016). Beyond that, a pit house from the first half of the Middle Yayoi Period, pits from the end of the Middle Yayoi Period, a pit house and a pit from the first half of the Late Yayoi Period, and a pit house, pits, and a ditch from the latter half of the Late Yayoi Period have all been found over the course of several excavations at various locations around the Ogata site (Fujii 2016, Miyano et al 2016). The precise locations and durations of Yayoi Period occupations at Ogata remain unclear.

The Kofun Period witnessed significant developments not only at Ogata, but also across the wider area. Several kofun groups are found nearby, including the Matsuokayama Kofun Group just south of the Yamato River from the Early Kofun Period, and Tamateyama Kofun Group nearby, which was active in the Early Kofun Period through the start of the fifth century (Middle Kofun Period). Other nearby Middle Kofun Period tombs are found in the Andoyama Kofun Group, and of course the slightly more distant Furuichi Kofun Group. The Late Kofun Period saw over 1200 tombs built in the Hiraoyama Kofun Group (Miyano et al 2016), as well as the construction the Takaida, Anpukuji, and Tamateyama corridor tomb clusters (*yokoanagun*).

Most of the remains recovered from Ogata are from the 6th century onward, but there are some features clearly dating to the Early and Middle Kofun Periods as well, even if they do not firmly establish the existence of a settlement. From the sixth century on in particular, in addition to the ironworking features and artifacts discussed below, there is considerable evidence for other activities at the site. Specifically, many horse bones and teeth have been found, often in association with ironworking remains, which Maruyama (2016) suggests may have been ritually slaughtered as part of the abandonment of ironworking hearths. The presence of salt-making pottery does point to a potential larger presence for horses, and the bones of cattle and wild boar, as well as worked deer antler have also been found (Kitano 1985, Maruyama 2016). Combined with the presence of at least one well and Korean-style pottery (韓式土器), it does seem that Ogata was probably not only a workshop site. Even though Ogata was probably a settlement, its extent in any given phase is unknown, and it is important to note that while this study focuses on remains found at Ogata, Ogata Minami, where glass bead casting remains have been found in addition to ironworking remains, may have been part of the same workshop settlement (Ishida 1995). The presence of Korean-style pottery at Ogata, the “high tech” character of the craft and animal husbandry activities at the site, and burial goods found in Hiraoyama Kofun Group with ties to peninsular cultures, there is considerable evidence to suggest a significant presence of peninsular immigrants and/or their descendants at Ogata in this period.

The seventh century appears to have been an inflection point at Ogata and the surrounding area. The north-south road through the site seems to have been constructed around the start of the century (Yamane 2018), and the “Six Temples of Kawachi,” two of which fall within Ogata’s perimeter, were also probably built in the middle of that century. Though the size of the settlement at Ogata is still unclear, new structures appear on the west side of the road during this time, as well as on the sloping foothills to the east, which seems to be less hospitable (Yamane 2018). Similar shifts are visible at Ogata Minami and Taiheiji, and are probably related to the road and temple construction (Yamane 2018). Ironworking seems to have been a significant activity at Ogata into the seventh century, though the locus of metalworking in the area shifted from Ogata to Tanabe, located to the south on the other side of the Yamato River, some time in that century (Yamane 2018). At least some ironworking did continue at Ogata even into the eighth century (Miyano et al 2016).

In the late eighth century, the Court offered compensation to residents of Ogata and two other districts who would be displaced by the ultimately short-lived Yuge-no-Miya detached palace, thought to have been located about one kilometer northeast of the Ogata site (Fujii 2016). In the Heian Period, the road was known as the Nankai Road, before becoming the Higashi Koya Road pilgrimage route toward Mt. Koya (Yamane 2018, Fujii 2016). While archaeological materials from the Medieval Period have also been found here, ironworking at Ogata seems to have long since ceased. Today, the road is an old segment of National Route 170 that has nevertheless retained its designation in spite of the new parallel segment nearby bearing the same designation. Due to the potential for confusion, it is often referred to as the “former” (旧) road or by its historic designation as the Higashi Koya Road.

Ironworking Remains Uncovered in Excavation 82-9

Sewer improvements in 1982 led to excavation 82-9 on a roughly 2m by 75m stretch of the road leading from old National Route 170 (Higashi Koya Road) toward Nudohiko Nudohime Shrine. This excavation uncovered the remains of five forging hearths, ash and charcoal beds, a pit, a ditch, and an embedded pillar building from the Kofun Period. Forge slags, tuyere tips, and sharpening/polishing stones comprised the artifacts related to ironworking, and large amounts of Sue and Haji ware pottery was also unearthed (Hanada 1984). Precise records of archaeological associations have not survived, but the following observations about the characteristics and chronology of these remains can be made: Forge hearths 1, 2, and 3 are examples of Murakami’s (2007) Class D or E. None of their aboveground structures were preserved, however, their underground structures have several features in common. First, while there is slight variation in size and shape, all have a fairly large round or sub-rectangular base layer ranging from a 70cm diameter circle to a sub-rectangle 120cm by 70cm. Inside this area, all have a smaller circular or sub-rectangular area of 50cm diameter or 60cm by 60cm. All are built into an area paved with cobbles about 20cm deep, and while hearth 2 overlaps with the smaller hearth 3 to establish a relative date, their chronological relationship to the larger sub-rectangular hearth 1 is unclear. There are beds of charcoal around these hearths that are thought to be their ash dumps (Hanada 1984). A fairly complete tuyere tip was found with hearth 3, but given the destruction of the aboveground features, it is difficult to associate it with the hearth’s use. Several forge slags were also found in the hearths and paved area, including four arranged around the rim of hearth 3.

As for these hearths’ dates, no radiocarbon dating was conducted, but despite some inconsistencies in reporting, pottery typochronology allows for some estimates. Hearth 1 was associated with MT-85 Sue ware, which is dated to the mid- to late sixth century, prior to TK43,

which is dated to 588 CE (Chikatsuasuka Museum 2006). Hearth 3 has no associated Sue ware, but TK10 Sue ware, which is slightly earlier or contemporaneous with MT85, was unearthed in association with hearth 2, putting it, too, in the mid- to late sixth century. Sue ware found with the paving stones is contemporaneous, putting all three of the Class C hearths in the mid- to late sixth century (Chikatsuasuka Museum 2006).

Technologically, these hearths are interesting for both their rather large size and their extant substructures. Even though their aboveground structures were probably only as large or smaller than their inner base area, they would be useful for forging comparatively large items. That said, a larger forge requires more fuel. The extant substructures are very interesting because all three have multiple layers of clay improved with refractory features. Hearth 1 is comprised of two layers of black clay mixed with charcoal. Hearth 2 is comprised of four layers, in descending order composed of clay, soil mixed with charcoal, soil mixed with charcoal and slag, and clay with temper. Hearth 3 is comprised of two layers, the upper of soil mixed with slag, and the lower soil mixed with charcoal (Hanada 1984). These layers would insulate the hearths from the ground during operation, helping to retain heat in the forge while the bellows was not in use and the metal was being worked at an anvil. This is a potentially fuel-saving technological feature.

The other two hearths are incompletely known as they extend outside the narrow excavation area, but both seem to be of Murakami's (2007) Class A. They seem to be sub-rectangular in outline and slightly smaller than the Class D or E hearths, possibly in the range of 40-50cm on a side. Both have two layers insulating the forge from the ground. Hearth 4's upper layer is soil mixed with slag and charcoal, and its lower layer is soil mixed with charcoal. The composition of hearth 5's insulating layers is reversed from hearth 4 (Hanada 1984). Despite the different technological lineages of Class A and Class D or E forge hearths, at Ogata they closely share this technical feature. Hearth 4 is of additional interest because it appears to have been inside an embedded pillar building. It was also accompanied by three stones embedded in the ground between the hearth and the wall. They are assumed to have been part of the forge facilities, but their function is unclear (Hanada 1984). In any case, an indoor hearth, or at least one partially enclosed and shaded offers a distinct benefit to the ironworker: it is much easier to judge the temperature of the hot metal when it is in the dark. Why this small forge warranted a significant workshop structure is unclear. No artifacts were found in association that could clarify the date of either the forge or the structure. Unlike hearth 4, but like hearths 1-3, hearth 5 has a charcoal bed associated with it assumed to be the forge's ash dump. The excavation report (Hanada 1984) says that pottery was found dating the hearth to the second half of the sixth century, but that could not be verified based on either the report or other records.

Beyond the hearth structures, the tuyeres uncovered in excavation 82-9 provide evidence for the development of ironworking technology at Ogata. More than 50 were reportedly unearthed, with that number jumping to 386 if small fragments are counted (Hanada 1984). Even so, only twelve are reported in detail. Of those twelve, two are of Manabe's (2003) Class II, which were used only in the Middle Kofun Period. Of the remaining ten Class I tuyeres, nine appear to be of Class Ic, which appeared in the Late Kofun Period, though their state of preservation makes assignment challenging. The other Class I tuyere is shorter and more complete than the rest, and appears to be Class Ia or possibly Ib, pointing, like the Class II tuyeres, to earlier ironworking activities than the hearth features and associated artifacts indicate.

Most of the artifacts uncovered in this excavation are either not associated with any particular feature, or were found in the pit or ditch away from the hearth features. This is true for the tuyere tips as well. One of the reported tuyere tips was associated with the paved area, and

another with hearth 3, though they may not have been used with the hearths in that area. Even so, both are most likely of Class Ic, which is in line with the pottery dates for those features. Most of these were found in the ditch, which had the same assemblage of pottery types as the paved hearth area and features. The Class II tuyeres were not reported to be in association with any features (Hanada 1984).

On a technological level, the Class I tuyeres are very uniform in their inner diameter, ranging from 2.5cm to 3.1cm, but the Class II tuyeres differ from each other, with one narrowing to 2.5cm in diameter like the Class I tuyeres, but the other ending up at a narrower 1.8cm diameter (Hanada 1984), though the entire effect this would have on forge operations is unclear, especially since the bellows mechanism is unknown, a narrower opening would lead to a smaller high temperature area and place constraints on the size of objects that can be easily worked in a pit forge. On the other hand, assuming identical bellows operation, wider openings would lead to a large, though potentially slightly cooler high temperature zone (Okuno and Manabe 2000b). However, at a certain level of air flow rate and control, the difference in maximum achievable temperature would be moot.

Clay tuyeres can have zones of differing colors corresponding to differing exposure to heat across the length of the tube. The tip is exposed to the most heat and can become vitreous and even slaggy when exposed to metal in the hearth. This tip slowly melts away over the tuyere's use life (Okuno and Manabe 2000b). Immediately behind the point where the tuyere is embedded in the wall of the hearth may eventually become partially vitrified from the heat as well, but without contact with iron oxides, it will not become slaggy. This vitrified zone is quite narrow when it is present, but behind it is a band of blue-gray on the external surface, indicating firing in a reducing atmosphere beyond the original firing of the tuyere in manufacture. Beyond the blue-gray band is a white band, followed by the largest area, which is the original yellow-gray color of the tuyere before it was used in the hearth.

Hanada, the excavator, notes that the zone between the tip and the original color of the Class I tuyeres varies between 2.5cm and 3.5cm, and interprets it as the width of the hearth wall (1984). In contrast, although their very tips are both missing, the Class II tuyeres seem to have been exposed to heat evenly (Hanada 1984), and possibly to a lesser degree than the Class I tuyeres. Hanada ascribes this to a significantly different forge hearth structure, and possibly lower operating temperature since both types of tuyere were made of the same clay, which seems to have been sourced from the western foot of the Ikoma Mountains (Hanada 1984).

Okuno and Manabe's (2000b) interpretation of these color zones is more plausible. They do not tie the width of the zones to the width of the hearth wall, but rather to the length of time the tuyere was in use. Experimental archaeology will be necessary to quantitatively assess zone widths, but a qualitative difference between the Class I and Class II tuyeres does suggest that the Class II tuyeres may have been used in lower temperature operations than the Class I tuyeres.

These temperature zones differences also reveal that some tuyeres were inserted horizontally, but others were inserted at an angle into the hearth. While this could not be determined for all tuyeres, among the ones that the angle was apparent, roughly half were horizontal tuyeres and half were angled tuyeres (Hanada 1984). This difference is only observable among the Class I tuyeres, but may indicate a separation of tasks based on the use of one or the other setup: airflow onto hot steel or cast iron will cause decarburization, so building hearths with different air flow directions points to intentional management of the atmospheric conditions inside the forge hearth. On the other hand, the differences may be related to the depth of the hearths they were installed in, which may or may not have been idiosyncratic or related to

the overall width of the hearths. Without more and better-preserved hearths, this is difficult to assess, and Okuno and Manabe (2000b) note that rotating the tuyere at any point could erase traces of the initial angle.

In summary, most of the available evidence for ironworking unearthed in excavation 82-9 points to activities mainly in the mid- to late sixth century. That said, the presence of earlier types of tuyere tips, as well as a single large Sue ware pot from the mid fifth century (TK208) found amongst mid- to late sixth century Sue ware (Hanada 1984), indicate the possibility of an earlier occupation and ironworking in the immediate area. Ironworking was conducted with a basis in at least two technological traditions as indicated by both the tuyeres and the hearth structures. Whether they were concurrent or if the Class D or E hearths and Class I tuyeres postdate the Class A hearths and Class II tuyeres is unfortunately unclear. In any case, ironworkers in both traditions insulated their hearths from the earth using refractory materials, which in the case of the Class A hearths, also may have served to limit oxidation through ensuring a reducing atmosphere in the forge hearth. Unfortunately, the state of preservation of the Class D or E hearths prevents their evaluation in this respect. Smiths may have altered the angle of the tuyere to suit their specific purpose, be it to fit a particular hearth or to engage in different tasks. In either case, this is indicative of knowledgeable management of the hearth's atmosphere. As for fuel use, the size of the hearths, especially the Class D or E hearths, suggests that a comparatively large quantity of charcoal was used in operations. However, the use of insulating substructures may have somewhat reduced that need. Scientific analyses of slags and other artifacts were not conducted at the time of excavation, but the results of later analyses will be discussed elsewhere. Finally, numerous sharpening/polishing stones were found in this excavation, and while they have little bearing on fuel use practices, it is worth noting that both rough and fine stones were found (Hanada 1984).

Ironworking Remains Uncovered in Excavation 84-1

Like excavation 82-9, this was a long, narrow excavation for sewer improvements. Unlike that excavation, only one pyrotechnological feature was uncovered in 84-1, but a large number of tuyere tips and sharpening/polishing stones were found, along with over 150kg of slag (Kitano 1985). Only layers B and C contained ironworking materials. While there is some overlap between the dates for pottery found in these layers, they are understood as follows: Layer B was deposited over a comparatively short period, and in mainly contained pottery from the sixth century through the early seventh century (TK10-TK209 in the area near the pyrotechnological feature). Layer C contained more ironworking materials, and pottery mainly from the mid fifth century through the sixth century (TK208-MT15 in the area near the ironworking feature) (Kitano 1985).

The pyrotechnological feature was found in Layer C, and while it was reported as an ironworking hearth, it is very unusual in multiple respects. It is shaped like a square with rounded corners in plan, and is about 90cm on a side and lined with about 3cm of fired clay (the same clay from the western foot of the Ikoma Mountains used to make tuyere tips) (Kitano 1985). It is quite deep at about 25cm, and contained five layers, the top two of which were somewhat smaller than the overall footprint of the feature. The top layer was mainly slag, followed by brownish yellow clay containing sand and a small amount of fired clay, a gray-blue clay, a sandy gray-blue clay containing some charcoal, and a layer of charcoal on the bottom (Kitano 1985). While the north, east, and west walls of the pit were steep, between 67.5 and 79.5 degrees, the south wall was shallow, only 25.0 degrees, and it faced a ditch. This is thought to be where fuel

was inserted and/or extracted from the feature, and a large layer of charcoal and ash was found in the fill of the ditch, extending six meters west of the feature, and five meters east of it. More charcoal was found in the fill around the feature, decreasing in density with distance from it. If this was an ironworking furnace, no traces remain of either its walls or the hearth bottom (Kitano 1985). Several tuyere tips were found around it, nearly all of which fall into Manabe's Class II (Kitano 1985).

If this feature is an ironworking hearth, there is an argument to be made that it is Murakami's Class A with a layer of clay spread in its bottom (Yamane 2018, using a different classification system). However, if its fill is interpreted as an insulating substructure, atop which the actual hearth structure was built, it could be called a Class D or E hearth, and it is similar in size to the Class D or E hearths unearthed in excavation 82-9. That said, there are several factors suggesting it is not an ironworking hearth at all. First, if this is a Class A hearth, it is quite large for one, far larger than necessary to heat even the largest iron objects of the period, and furthermore we might expect to find some traces of slag adhering to the bottom clay surface. Instead, the lowest layer contained only charred materials. If this is a Class D or E hearth, in contrast with the hearths found in excavation 82-9, its fill layers contain mostly unfired clay, which is one of the substances a refractory substructure should be insulating the hearth from. The sloping "fueling opening" poses issues for any classification as an ironworking hearth as well. It would appear that ironworkers using this feature as a hearth would need to perform their work from within the ditch, which in addition to being a physically awkward workspace, is also the waste dump. These aspects of this feature strongly indicate that it was not actually used for ironworking directly.

Instead, the bottom layer of charcoal seems to be the remains of fuel burned or pyrolyzed in the feature, and the layers above, which did contain pottery sherds, slag, and other artifacts, are simply fill from after the feature was abandoned. As for its actual function, there is no dispositive evidence, but some suppositions are still possible. The shape of the feature's south wall, its location with respect to the ditch, and the spread of charcoal and ash in the ditch around the feature together suggest that when whatever process the feature was used for was completed, the waste materials were raked into the ditch to prepare the feature for use again. As for its actual purpose, several possibilities seem plausible. The first is that it is an early charcoal kiln of sorts. The original excavator, Kitano Shigeru, has expressed doubts over the original interpretation of the feature, and has said that a charcoal kiln is a viable possibility (Kitano personal communication). Another is that it was used to fire the clay tuyere tips used for ironworking. Both tuyere-making and charcoal-making would need to be conducted regularly at the site, but other interpretations are certainly possible, including salt-making, as many flat-bottomed (and round bottomed) salt-making vessels were recovered, including from the aforementioned ditch.

Enough tuyere tip sherds were unearthed in this excavation to fill several storage containers, including twelve complete enough to illustrate (Kitano 1985). Of these twelve, eight are of Manabe's Class II. Further classification of these artifacts is somewhat uncertain, but five appear to be Class IIb, one of Class IIa, and the remaining two somewhat transitional. All four of the other tuyere tips are of Manabe's Class Ic. Precise records of associations and contexts for excavation 84-1 are the best of the Kashiwara City excavations in the 1980s, but that does not extend to these tuyere tips. Even so, Kitano reports (using a different classification system) that the Class II tuyeres were found with pottery of the fifth century, while the Class I tuyere tips were found with pottery from the sixth and seventh centuries (Kitano 1985). This is in line with expectations from Manabe's classification schema, but the presence of Class IIa or transitional

forms suggests the possibility of ironworking in the early part of the Middle Kofun Period, or even slightly earlier. Unlike the Class II tuyere tips found in excavation 82-9, these tuyeres do have uneven heating with slaggy tips, suggesting usage more like Class I tuyeres. Unfortunately, their angles of insertion could not be determined.

Other notable finds from this excavation are the 38 sharpening/polishing stones, the large quantity of multiple forms of salt-making pottery, and the animal remains, including worked antler (Kitano 1985). Finally, while sector D of the site yielded no slag or other ironworking remains, Sue ware bowl and lid dating to a very phase of Sue production (TK73 phase) in the first quarter of the fifth century was found (Kitano 1985) pointing to a certain degree of continuity in occupation from before the bulk of the pottery finds.

Excavation 84-1 provides significant evidence not only of ironworking in earlier phases than found in excavation 82-9, but also evidence for other crafts, including salt-making. Additionally, unlike other excavations from the 1980s, some records of archaeological contexts and their contents from 84-1 have survived to the present, enabling much finer analysis. For this reason all of the original analyses for this project are conducted on materials from this excavation, and will be explored in detail below.

Ironworking Remains Uncovered in Excavation 85-2

In 1985, another excavation was conducted ahead of the construction of a new gymnasium for Katashimo Elementary School just north of the western end of the 84-1 excavation. Unlike previous excavations, this one was not confined to narrow trenches, but was roughly rectangular, about 40m east to west, and 22m north to south. This areal excavation uncovered three layers of occupation. The earliest phase contains remains from the Middle Yayoi through the Middle Kofun Periods. The second phase contains remains from the Late Kofun Period, and the latest phase contains remains from the Nara Period and later. This final phase did not include any artifacts or features related to ironworking except for 22g of slag in the upper layer of a ditch, the lower layer of which contains significant amounts of slag and other artifacts related to ironworking. This phase seems to be connected to the Osato-dera temple complex (Kitano 1988).

Unfortunately, like other excavations in this era, precise analyses are not possible because the original excavation records have not survived to the present. However, the Middle Yayoi through Middle Kofun phase and especially the Late Kofun Period phase provide additional information about ironworking at Ogata. The earliest phase had comparatively few features and artifacts. A Yayoi Period dwelling, a rectangular pit thought to be part of a later pit dwelling, and three ditches were uncovered. Ditch 5 is of particular interest, since slag was recovered along with Haji ware dating to the Furu stylistic period (first half of Kofun Period) (Kitano 1988). The pit dwelling is thought to be roughly contemporaneous with ditch 5 (though ditch 5 did contain a small number of small Yayoi pottery sherds), and contained Korean-style pottery as well as Haji ware, and a large kiln-fired pot belonging to a Korean Peninsular style understood to be a precursor to Sue ware (陶質土器). Finally, the dwelling also contained a sharpening/polishing stone and an iron object (Kitano 1988). Unfortunately the iron object is not reported in any detail. Regardless, the slag in association with these pottery styles suggests some amount of ironworking at Ogata even in the first half of the Middle Kofun Period.

The Late Kofun Period phase included many more ironworking artifacts and features, including four forging hearths. Hearth 1 is a shallow, elliptical Class A hearth about 35cm by 23cm in plan, and 3cm deep. No above ground structures were preserved, and aside from

charcoal and several pieces of slag under 10cm in size, no artifacts were recovered. Accordingly, dating is difficult, but the excavator, Kitano Shigeru (1988) suggests that based on the local stratigraphy it dates to the end of the seventh century or early eighth century.

Hearth 2 was uncovered one meter south of hearth 1 (Kitano 1988). Its shape and dimensions, 32cm by 20cm by 3cm, are similar to hearth 1, but with its long axis running east-west instead of north-south. It was a Class A hearth lined with fired clay, missing any aboveground structure. Its fill likewise contained slag and charcoal. This hearth contained a particularly large elliptical slag, measuring 18cm by 15cm by 3cm, which had many pieces of charcoal embedded in it. A tuyere tip was found nearby, but it is not clear where, if anywhere, it was attached to this hearth. In the absence of datable pottery, Kitano suggests it was approximately contemporaneous with hearth 1, around the end of the seventh century or early eighth century (Kitano 1988).

Hearth 3 is the best-preserved ironworking workshop space anywhere at Ogata. In addition to the hearth feature, an anvil structure was found in situ, and the area is surrounded by a ditch with a gap facing east, making a planar shape like a balloon. Outside the ditch, the area is surrounded by small postholes, suggestive of some kind of roof structure (Kitano 1988). The hearth itself has a planar form of a rectangle with rounded corners and is about 40cm by 55cm, with its long axis oriented north-south. While there are some remains aboveground, they do not seem to have formed the actual hearth surface themselves. Accordingly, this is most likely a Class E hearth. The assumed aboveground structure would provide some insulation from the ground in and of itself, but hearth 3 does have a complex underground structure as well. The remains of the aboveground structure are comprised of a layer of yellow-brown clayey soil and a 20cm by 20cm rock over a body of grey-brown clayey soil. This rests atop a thin layer of charcoal that is very nearly at ground level, itself covering another layer of grey-grown clayey soil over a lens of fired clay. Kitano notes that this fired clay was not fired enough to indicate that it was actually an ironworking hearth surface (1988). Beneath this is a thick layer of dark blue-gray clayey soil that fills the bottom of the basin dug into the substrate.

The anvil structure was located about 1.4m to the north of the hearth feature and measured 85cm in the east-west direction, 55cm in the north-south direction, and was 20cm tall. Three stones between 10 and 30cm were embedded in the feature, and formed a top layer with a lot of hard, coagulated slag holding it together. Intermingled with the stones and slag was a mass of soil containing gravel, beneath which was a layer of soil containing sand. This rested on a bed of blue-grey sandy soil that had been worked like wall clay, and this sat atop the substrate (Kitano 1988).

The ditch has a total length of about 20m, and varies in width between 25cm and 155cm (Kitano 1988). The ditch is trapezoidal in cross section, with a flat bottom and a depth varying between 25cm and 35cm. About 39kg of slag was recovered from the ditch, along with some sharpening/polishing stones, and 180 tuyere tips, of which more than 35 were nearly complete. The slag and tuyere tips were recovered from all areas of the ditch. In addition to these ironworking remains, animal bones, Haji ware and Sue ware were also recovered. The postholes for the possible roof structure were absent from the west side, in alignment with the side of the ditch with the gap. The postholes are about 10cm in diameter, shallow, and follow the contours of the ditch rather than forming a rectilinear plan (Kitano 1988). These features are more suggestive of a lightweight structure or possibly a tent than a longstanding building. Kitano ascribes this assemblage of features to the end of the sixth century or start of the seventh (1988). The Sue ware unearthed from the ditch ranges between TK10 and TK217, supporting this date.

Northwest of hearth 3, hearth 4 was also found with an anvil setup, but lacked the surrounding ditch and postholes. The hearth feature was slightly smaller, measuring 44cm in the north-south direction and 32cm in the east-west direction, but was also roughly shaped like a rectangle with rounded corners. Aboveground structures are completely missing, but it appears to be a Class E hearth. A basin excavated from the substrate contained three identifiable layers: the bottom layer and the middle layer together are about 10 to 20cm thick and made of the same clayey soil, but about half of that thickness, comprising the middle layer has been fired in an oxidizing atmosphere, turning it red. The uppermost layer, which measures only 22cm north-south by 27cm east-west, is composed of a thinner layer of fired clay turned greyish blue under reducing conditions. This surface is thought to have been the actual working surface of the hearth (Kitano 1988).

The anvil setup was located about 1m north of the hearth feature, and differed significantly from the anvil setup at hearth 3. Hearth 4's anvil is simply a 30cm by 50cm by 10cm thick flat rock embedded in the substrate with its upper surface only slightly above the surface (Kitano 1988). The soil immediately to the south of the anvil and stretching toward the hearth contained a very large quantity of slag (Kitano 1988), though no information about the precise amount or the size of slag pieces is available. No pottery was found directly associated with this feature, so a typochronological date is not available, but a large quantity of ironworking remains were found in ditch 4 immediately in front of hearth 4, and the Kitano believes that both ditch 1 and 4 were filled concurrently with the use of hearth 3 and 4, though he speculates that hearth 4 may be slightly later than hearth 3 (1988).

Ditch 1 runs east-west south of the hearth 3 assemblage of features, and while its upper layer dates to the third phase of the site, the ditch predates this, and its lower layer of fill is seen as concurrent with hearth 3's period of activity, the late sixth century and early seventh century (Kitano 1988). While the ditch is only partially inside the excavation area, it is assumed to be about 5m wide. Sue ware, Haji ware, salt-making pottery, animal bones, wooden artifacts, peach pits, slag, and tuyere tips were all unearthed from the lower layer of this ditch (Kitano 1988). Sue ware unearthed from the lower layer falls typochronologically between TK43 and TK217 in agreement with Kitano's assessment.

Ditch 4 ran north-south just west of hearth 4. Like ditch 1, only one bank of the ditch fell within the excavation area (Kitano 1988). Kitano estimates that it was at least seven meters wide (1988). Sue ware, Haji ware, animal bones, slag, and tuyere tips were recovered from the ditch, which is composed of two layers. Slag and tuyere tips were recovered mostly from the area closest to hearth 4, and were unearthed from both layers (Kitano 1988). Kitano estimates that the upper layer dates to the early seventh century, and the lower layer dates to the second half of the sixth century (1988). The Sue ware recovered from the ditch falls typochronologically between TK10 and TK217, in agreement with Kitano.

430 tuyere tips were unearthed in excavation 85-2, mostly from the ditch surrounding hearth 3 or not associated with any particular feature. Of these, only twelve of the 180 tuyere tips recovered from around hearth 3 are reported in detail (Kitano 1988). Although most are missing parts of one or both ends, they all appear to fall into Class Ic or Class III, which is expected based on the pottery assemblage from the ditch. The missing ends of the tuyere tips makes it difficult to generalize about their internal and external diameters, but based on extant remains, they varied between 2.0 and 2.8cm at the tip, and between 2.1 and 3.3cm at the outside end (Kitano 1988). This is considerably more variation than seen in the tuyeres excavated during 82-9, but does not appear to correlate with the class of the tuyere. Unfortunately, the depositional

processes and taphonomy both of these artifacts and the pottery assemblage is unknown, but in light of the typochronological breadth of the assemblage, these tuyere tips may have been deposited over several decades of ironworking, and that may explain some of the variation, though there is no way to verify this with extant records.

Another difference compared to the 82-9 tuyeres is the width of the heat color zones. heat color zones width could be determined for nine of the twelve tuyere tips, which varied between 1.4 and 2.5cm, with six falling in the range between 1.6 and 1.8cm (Kitano 1988). This is much thinner than observed on the 82-9 tuyere tips, suggesting they were not used as long, or at lower temperatures (Okuno and Manabe 2000b). Finally, two of the tuyere tips were marked with lines inscribed with a spatula. This is also rarely seen on Sue ware, and is thought to relate to demarcating units of production or particular makers. To find them on tuyere tips suggests that they were not made ad hoc as the need arose, but systematically. On the other hand, the comparison to Sue ware may be unfounded and the markings could be anything. Lastly, one of the tuyere tips (without a spatula mark) is marked with vermillion (Kitano 1988). The composition of the colorant has not been determined, but it appears that at least sometimes, tuyeres held special significance. Like those unearthed elsewhere at Ogata, tuyere tips from excavation 85-2 were made of local clay from the western foot of the Ikoma Mountains. Finally, only eight sharpening/polishing stones were recovered during this excavation, notably fewer than found in previous excavations.

Excavation 85-2 provided the most detailed look at ironworking features at Ogata, as well as several points of comparison to earlier finds. Interestingly, the more sophisticated Class D and E hearth features predate the simple Class A hearths. Chronologically, this excavation established some continuity from the Middle Yayoi Period through the early historic period and beyond the heyday of ironworking at Ogata. The evidence for ironworking prior to the late sixth century is scant at this location, even if there is evidence for Middle Kofun Period contact with, and perhaps presence of communities of migrants and their descendants closely associated with the arrival of new technologies.

Ironworking technology in use at this location seems to differ from that encountered in excavation 82-9, at least somewhat. While the later Class A hearths 1 and 2 are similar to others at Ogata, the Class D and E hearths are notably smaller in scale than those found in excavation 82-9, and they have less complex insulating substructures, making less use of charcoal and no use of slag in their construction. Part of the internal makeup of an aboveground hearth was also revealed in this excavation, however, given the differences in underground structures, it may not be possible to extrapolate hearth 3's construction to the hearths from 82-9.

Though it is unclear if it relates to the smaller overall scale of hearths in 85-2, evidence from tuyeres indicates that work times were shorter or temperatures were lower than those from 82-9. It is unclear what might drive that change, but it could relate to the types of objects being produced. Variation in the internal diameter of tuyere tips may simply be a consequence of a long period of occupation, but without better information about bellows technologies, it is difficult to speculate on what effects it might have on the operations of the forge hearth. The use of both Class I and Class III (or possibly transitional toward Class III) tuyeres is also interesting, and may be related to the ongoing parallel continuation of different forge construction traditions (Class A vs Class D/E), but this, too, cannot be clarified without better chronological resolution. Similarly, architectural forms used for workshop spaces are very different between hearths found in 82-9 and 85-2, but the hearths that were enclosed as opposed to exposed also differ, widening the range of plausible interpretations of parallel ironworking traditions.

While there does seem to be some chronological space between hearths 1 and 2 on one hand and 3 and 4 on the other, in combination with the hearth evidence from 82-9, the apparent parallel existence of forging hearth technologies raises the question of possible divisions of labor depending on what kinds of objects were made, or what stage of processing was conducted. The presence of anvil structures with both hearths 3 and 4 supports this, even though hearths 3 and 4 can broadly be classed together in contrast with hearths 1 and 2. The presence of a division of labor scheme is evident in the differences between the two anvil setups. Hearth 3's anvil is raised off the ground, allowing work by a seated (possibly on a stool) head smith and one or more striking assistants, which is particularly useful for forging larger pieces of metal or harder alloys with significant carbon content, but would make many steps of forging processes progress faster almost regardless of the size or carbon content of the metal. In contrast, hearth 4's anvil barely protrudes above the ground. Striking assistants would need to be seated, robbing them of body mechanics for the hard strikes they are present to provide. In short, there were some forging activities performed at Ogata that did not require striking assistants, and presumably were performed frequently enough to build a dedicated hearth for such activities. The large amount of slag encrusted on the anvil setup at hearth 3 and in the ground between hearth 4 and its anvil setup suggests the use of particularly slaggy raw materials or particularly long service lives for these hearths. Both interpretations are plausible, and without better chronological resolution cannot be distinguished, but if particularly slaggy materials were used even in fine, detailed work where strikers were not useful, it may be that the necessary quality of the product was not high enough to justify using more fuel to refine the metal.

A final point to make about the division of labor at Ogata as seen through excavation 85-2 is that the recovery of sharpening/polishing stones from around hearth 3 does not imply that the final stages of ironworking were necessarily carried out nearby, as the ditch served as a disposal area for objects unrelated to the ironworking at the hearth in addition to the tuyere tips and slag. Even so, based on the results of excavation 85-2, it appears that ironworking technologies were diverse and rapidly changing through the sixth and into the seventh century at Ogata.

Ironworking Remains Uncovered during Prefectural Excavations, 2012-2013

Prior to the installation of sidewalks and the widening of part of Old National Road 170 between Katashimo Elementary School in the south and Hirano Intersection in the north, the Osaka Prefectural Board of Education undertook several test excavations in 2010 and 2011 to determine the extent of excavation necessary, and conducted full-scale excavations in 2012 and 2013. In 2012, they opened four trenches along the west side of old National Road 170 between the elementary school to the south and Hirano Dai San Chibikko Rojin Ikoi no Hiroba Park (平野大3ちびっこ老人憩いの広場) to the north, separated from each other by intersections in the road. The 2013 excavations consisted of three contiguous trenches along the east side of Old National Road 170 between the park and Kashiwara Police Station Hirano Police Box (柏原警察署平野交番) to the north. In total these narrow trenches covered about 660 square meters.

These excavations uncovered ironworking artifacts and several features thought to be related to ironworking activities dating to the late sixth century and the mid-eighth century, and potentially the ninth century, with a gap through most of the seventh century. Sixth century features were clustered in the northern sections of the excavation (2013), and the eighth century features were found in the southern trenches (2012). Many of these features are less conclusively ironworking features than those uncovered in previous excavations, but they may nevertheless offer some hints to characterize ironworking at Ogata over time.

Probably earliest of the sixth century features is hearth 59 and the complex of related features surrounding it (Iwase 2016). Hearth 59 itself consists of a roughly U-shaped raised section of earth measuring about 20cm wide and opening north. Its opening on the north side is about 1.2m, and it is about 1.5m wide at the south end, with a total north-south length of about 2.0m. The interior space had a layer of broken hearth wall, iron slag, and charcoal. The fill also contained Sue ware and Haji ware, and slag. Around the outside of the U-shaped hearth wall was a narrow ditch 10 to 20cm wide and 10cm deep, and ditch 60, thought to be a waste ditch for hearth 59 extended directly out of the north side of hearth 59. It was between 60 and 80cm wide and 20cm deep. Its fill contained Sue ware, Haji ware, tuyere tips, sharpening/polishing stones, and a clay spindle whorl. Outside of the U-shaped ditch, the ground surface was filled with small stones and tamped down hard (Iwase 2016). Sue ware in the fill of hearth 59 dates to the late 6th century prior to 588, (MT85/ Type II stage 3 in the Nakamura chronology) and that found in ditch 60 dates to the late 6th century around 588 (TK43/ Type II stage 4 in the Nakamura chronology).

While the shape of this feature immediately recalls hearth 3 from excavation 85-2 with its outer ditch, hearth 59 differs significantly, and may not actually be an ironworking feature. First, while the area enclosed by the U-shaped walls contained significant ironworking remains as well as broken pieces of the wall, it did not have an identifiable base of fired earth, and if it were an ironworking hearth, it would have been far larger than necessary for making any of the kinds of iron objects known from the Late Kofun Period. Additionally, at 20cm thick, its walls are thicker than known tuyere tips are long, suggesting an alternate method of supplying air; and yet tuyere tips were recovered from ditch 60, thought to be a waste ditch for hearth 59. If hearth 59 is truly an ironworking hearth, it must have been entirely aboveground, and when disused, almost entirely excavated, leaving a depression inside of what appears to be thick walls with no base layer. It is unlike any other ironworking hearth known, and if it is an ironworking hearth, its state of preservation is such that it is difficult to infer much about its operation.

The other features identified as possible ironworking remains from the sixth century also present difficulties in interpretation. These features were found north of hearth 59 and overlap significantly, complicating the interpretation. Hearth 87 is two parallel irregular ellipsoids of hard fired earth together about 5.2m long in the north-south direction and 2.2 meters wide in the east-west direction, making a roughly trapezoidal shape overall (Iwase 2016). This hard fired earth is reported to be the working floor of the hearth, with the rest of the hearth structure lost. Sue ware and Haji ware sherds were found near the hearth surface, and the Sue ware sherds belong to Nakamura's Type II Stage 4, dating them to around 588. No artifacts related to ironworking were found directly with this feature (Iwase 2016).

Ditches 82 and 86, running parallel to each other in the north-south direction, overlap with the patches of hard fired earth such that the upper surface of the lower layer of both ditches' fill is the so-called hearth bottom (Iwase 2016). The fill from ditch 82 contained Sue ware, Haji ware, tuyere tips, sharpening/polishing stones, and sanukite flaked stone tools. The Sue ware from ditch 82 belongs to Nakamura's Type II Stage 3, dating to the second half of the sixth century, prior to 588. Ditch 86's fill contained only Sue ware, belonging to Nakamura's Type II Stage 4, dating to about 588.

Immediately above and overlapping with ditches 82 and 86, and by extension hearth 87, is a group of pit and ditch features that can be further divided into three subgroups. The southern group consists only of pit 80, which barely overlaps with the end of ditch 82 (Iwase 2016). It is about 25cm deep, and is irregularly shaped, but measuring 3.5m in the east-west direction and

more than 3.2m in the north-south direction. Many artifacts were unearthed from within its fill, including Sue ware, Haji ware, tuyere tips, possible stone anvils, a piece of an unidentifiable iron artifact, horse teeth, iron slag, and several kinds of sanukite flaked tools (Iwase 2016). The Sue ware belongs to Nakamura's Type II Stage 4, dating it to about 588, and the excavator gives a date for the late sixth century for this feature. A late sixth century date for the ironworking residues and artifacts from this feature makes sense stratigraphically, but can only be accepted cautiously given the presence of stone tools centuries earlier, pointing to fill taken from at least one other location at the site. Similarly, though it is not unlikely, these ironworking artifacts cannot be said with certainty to have originated in the immediate vicinity of this pit.

The excavator apparently initially suspected a hearth feature was located on the west side of this pit (Kitano and Manabe 2016: 232), but claims no ironworking hearth was found in the final report (Abe and Iwase 2016: 179). In any case, while no written description or photograph is provided, a circular feature about 60cm in diameter is illustrated in on the west side of pit 80 in one of the feature plan illustrations (Iwase 2016). Based only on this illustration it is impossible to say this was an ironworking hearth, but the size is plausible. However, the stratigraphic illustration shows no evidence of a charcoal layer or other characteristics associated with ironworking hearth features. It also could be the remains of a cooking feature, as even in the Kofun Period these were diverse in form and location within a dwelling (Goda 2013), and pieces of *kamado* cooking equipment have been unearthed elsewhere at Ogata. Even so, because of the large number of ironworking artifacts, the excavator hypothesizes that it may have been an ironworking workshop space before being abandoned and used as a refuse pit (Iwase 2016). Unfortunately, the feature itself provides little information about how ironworking may have been conducted there.

Just north of pit 80 is the middle group of features, comprised of pits 76, 77, 78, and 79 (Iwase 2016). These cover all of hearth 87 and much of ditches 82 and 86, with ditch 82 extending to the south and ditch 86 extending to the north beyond this cluster of features. Based on their overlap and contents, their order of construction appears to be pit 77, 78, 76, and finally 79. Pit 77 is also the northernmost of these features, and is approximately a square with rounded corners in plan, measuring approximately 2.9m in the east-west direction and 2.8m in the north-south direction. No hearth feature was found inside, but tuyere tips, iron slags, and sharpening/polishing stones were recovered, along with Sue ware, Haji ware, horse teeth, a clay bead, sanukite arrowheads, and other sanukite flaked tools (Iwase 2016). The Sue ware unearthed from this feature belongs to Nakamura's Type II Stage 4, dating to about 588. Like pit 80, the number of ironworking remains unearthed from pit 77 suggests to the excavators that it may have been an ironworking workshop space before it was abandoned and reused as a refuse pit (Iwase 2016).

Pit 78 overlaps with pit 77 to the south and despite an irregular shape and being truncated by the edge of the excavation on the west side, seems slightly larger than pit 77 (Iwase 2016). In plan, the pit is approximately a parallelogram with rounded corners, measuring about 4.9m in the north-south direction and at least 2.9m in the east-west direction. Like pit 77, it contained many ironworking artifacts, including tuyere tips, iron slag, and sharpening/polishing stones, as well as a sanukite core, horse teeth, a portable *kamado* stove, and most significantly, two iron arrowheads (Iwase 2016). The Sue ware unearthed from pit 78 belongs to Nakamura's Type II Stage 4, dating to about 588. Like pits 77 and 80, the number of ironworking remains unearthed from pit 78 suggests to the excavators that it may have been an ironworking workshop space before it was abandoned and used as a refuse pit (Iwase 2016).

Pit 76 overlaps pit 77 on its east side, and measures about 1.75m by about 1.2m, and is 40cm deep (Iwase 2016). Pit 79 overlaps pits 76, 77, and 78, and is an ellipsoid about 2.25m by about 1.15m, with only the bottom 1cm remaining of its depth (Iwase 2016). Pit 76 contained only Sue ware and Haji ware, and while its date could not be determined very precisely, the Haji ware is thought to be from the historic period, broadly construed (Iwase 2016). Pit 79 contained some iron slag in addition to Sue and Haji ware. The pottery was very fragmentary, and the most precise date possible is seventh century for the Sue ware. This makes pits 76 and 79 some of the very few seventh century features uncovered during the 2012 and 2013 excavations.

The northern cluster of features consists of pit 73 and ditch 74 (Iwase 2016). Pit 73 is a large square feature over much of ditch 86, and ditch 74 was constructed some time later, cutting into pit 73, in the north-south direction to the east of ditch 86, then making a ninety degree turn to the west, cutting through the fill over ditch 86. Pit is probably not the best term for pit 73, as its interior is not sunken compared to the surrounding area, but is defined by a perimeter of wall clay remaining only at and below the surface, forming a rectangle 3.5m in the north-south direction and 2.5m in the east-west direction. The wall clay is 20 to 30cm thick and reaches a depth of about 10cm. This is thought to be the remains of some kind of building (Iwase 2016). The fill of this structure contained Sue and Haji ware, Yayoi Period pottery, and a single piece of glazed pottery (Iwase 2016). Despite the presence of the glazed pottery, the date and precise context of which is not discussed, nor are any photos provided, the excavators assign pit 73 to the start of the seventh century (Iwase 2016). The Sue ware belongs to Type II Stage 5 in Nakamura's typochronology, for an approximate date of between 588 and 616, if the glazed pottery is taken to be a later intrusion. Ditch 74 is about 35cm wide, and between 10 and 20cm deep. Both Sue and Haji ware were unearthed from its single layer of fill, and the Sue ware belongs to Nakamura's Type II Stage 5, suggesting a date between 588 and 616.

Directly above these three clusters of features was ditch 66, which ran north-south over pit 73, crossed ditch 74, then ran over pits 77 and 78, along with ditches 82 and 86, and finally over pit 80 in the south (Iwase 2016). Ditch 66 actually runs north-south through nearly the entire excavation area, from sector 25-A to 25-C, where it was renamed ditch 45. All of the aforementioned features are located in sector 25-B, but given its length, ditch 66 is best discussed in terms of the finds in each sector. Over its entire length, the ditch varies in width between 60 and 100cm, and between 20 and 30cm in depth. In sector 25-B, no pottery was unearthed from the ditch, only stone tools and an unidentifiable iron object (Iwase 2016). Other ironworking artifacts were also recovered, but due to the thin strata, they were attributed to the underlying features (Iwase 2016). However, in sector 25-A, Sue and Haji ware were found. This Sue ware falls into Nakamura's Type II Stage 5, for an approximate date of 588-616. In sector 25-C, a sherd of Ga ware was unearthed in addition to Sue ware, Haji ware, and sanukite flaked stone tools (Iwase 2016). These remains are fragmentary and difficult to date, but Ga ware is generally from the late Heian Period onward, suggesting a very long use of this ditch, or a later intrusion. Despite reporting the Sue ware from sector 25-A as Type II Stage 5, the excavators date this section of the ditch to the Nara Period for reasons not detailed (Iwase 2016). The reporters provide no date estimate for the segment in sector 25-B, and that in 25-C is assigned to between the Asuka Period and the Heian Period (Iwase 2016).

The overlapping construction and thin stratigraphy have led to limited preservation of the features in this area, as well as some difficulty associating finds with these features. Even so, there is considerable evidence for ironworking in the vicinity. Hearth 87 is dubious as an ironworking feature, but Yamane (2018) suggests that pits 77, 78, and 80 may have been

ironworking workshop spaces built and converted to refuse pits on after the other. In any case, pottery finds from these features suggest a relatively narrow period of activity in the late sixth century, with abandonment and filling, including with materials from elsewhere at the site, by the early seventh century.

The last sixth century feature that may be related to ironworking is depression 204. Unlike the aforementioned features, depression 204 was found during the 2012 excavations to the south of the 2013 work (Iwase 2016). It is truncated by the edge of the excavation area, but is roughly rectangular and measures 3.86m by at least 1.98m, and is about 30cm deep. Sue ware, Haji ware, tuyere tips, iron slag, sharpening/polishing stones, and horse teeth were recovered from this feature. The Sue ware belongs to Type II Stage 3 and Stage 4 of Nakamura's typochronology. This gives an approximate date of the mid- to late sixth century. Depression 204 is not thought to have been used as anything other than a refuse pit, albeit one that received a lot of ironworking residues (Iwase 2016).

Despite the large number of sixth-century features associated with ironworking uncovered in the 2012 and 2013 excavations, they offer little concrete evidence about ironworking practices at that time. It may be that forge hearths in this vicinity were either themselves shallow, or had shallow substructures that were destroyed by later construction. It is at least as likely that forge hearths at this time were completely aboveground and destroyed by later construction. With no way to discern which, if either, of these is true, further information about ironworking practices at Ogata in the sixth century will have to come from the study of artifacts rather than features. However, examining the eighth century features may provide some hints as to larger trends in ironworking at the end of the Kofun Period and into the historic periods.

Pit 224 was large and rectangular, measuring 3.76m in the north-south direction but cut off by the edge of the excavation trench leaving only the easternmost 70cm of width in the east-west direction available to investigators (Iwase 2016). The pit was ringed by a narrow ditch slightly deeper than the rest of the pit, which is thought to be the foundation for walls. Only 10cm of depth remains of the pit, and Haji ware, Sue ware, tuyere tips, and iron slag were recovered from the fill. The Sue ware is fragmentary, and can only be assigned as far as Type IV in Nakamura's typochronology, dating to the eighth century. Based on the contents of the fill, the excavators believe this to be an ironworking workspace (Iwase 2016).

North of pit 224 is pit 56, which is also cut off on the west side by the edge of the trench (Iwase 2016). It, too, is roughly rectangular, measuring 1.85m in the north-south direction and at least 95cm in the east-west direction. It has no traces of wall foundations like pit 224, nor does it have traces of a hearth. Sue ware, Haji ware, tuyere tips, iron slag, and sanukite stone tools were recovered from the fill. The Sue ware sherds belong to Nakamura's Type IV Stage 2, dating them to the mid-eighth century. Based on the contents of the fill, the excavators believe this feature may have been an ironworking workspace as well (Iwase 2016).

To the south are two more features thought to relate to ironworking. Like pits 224 and 56, both are cut off on the west side by the edge of the excavation trench, limiting what is available for interpretation. Hearth 276 is the northerly of the two, and seems to be rectangular or possibly square in plan, measuring 80cm in the north-south direction and 40cm in the east-west direction (Iwase 2016). It is defined by hard fired earth 5 to 10cm thick and 10 to 15cm deep forming the perimeter of the rectangular feature. Little of the area inside this perimeter could be excavated, but the fill contained Haji ware, Jomon pottery, sanukite stone tools, and iron slag. Charcoal was heavily mixed in the fill on the north side in particular. No fired earth bottom was found. Based

on the Haji ware sherds, the excavators date this feature to the mid- to late eighth century (Iwase 2016).

Ironworking feature 213 is about three meters south of hearth 276 and actually consists of pit/hearth 211 and ditches 212 and 256 (Iwase 2016). Feature 211 is sometimes referred to as a pit and sometimes referred to as a hearth by the excavators, and it closely resembles hearth 276. It is also defined by a perimeter of fired earth presumed to be the hearth wall about 10cm thick and 10cm tall, measuring about 80cm in the north-south direction and 40cm in the east-west direction. It similarly lacks a fired earth floor. There were three layers of fill to the base of the hearth wall, and only the uppermost contained significant quantities of charcoal and hearth wall fragments. In addition to this charcoal, Sue ware, Haji ware, salt-making pottery, iron slag, and animal bones were recovered from the feature. The Haji ware dates to the mid- to late eighth century (Iwase 2016).

Unlike hearth 276, this feature has two additional ditches associated with it. Ditch 212 extends directly from the hearth wall east (Iwase 2016). It is 40cm wide and 5cm deep. Haji ware, salt-making pottery, a portable *kamado* stove, iron slag, and animal bones were recovered from this ditch. Ditch 256 runs parallel to ditch 212 about 1.2m north and is 25cm wide with a depth of 10cm. No artifacts are recorded for this ditch, and while it is described as a boundary ditch for this ironworking feature, its extent and relationship to nearby features is somewhat unclear (Iwase 2016).

Like the late sixth century features, these eighth century features provide few details about ironworking practices. Hearth 276 and ironworking feature 213 lack any evidence of fired earth in their bases, consisting only of (presumed) rings of fired earth probably too thick to fit a tuyere in the conventional manner, and are on the edge of the upper limit for a practical forging hearth. Like hearth 59 from the 2013 excavation, ironworking feature 213 has a comparatively wide waste ditch extending directly out of one side of the feature, suggesting a similar purpose, albeit maybe not one related to ironworking, as well as continuity in activities at the site over more than a century. Pit 224's size alone makes it a plausible workspace with an aboveground forge hearth, but the feature itself does not provide evidence that it in fact was such a workspace. Pit 56 is even less clearly an ironworking space. Together, these features suggest, though do not indicate, that by the eighth century, forge hearths were entirely aboveground structures. If these features are not assumed to be related to ironworking, then the unusual forms of ironworking feature 213, hearth 276, and pit 59 suggest a long-term continuity of activity at the site outside of ironworking. These features are not the only evidence for ironworking unearthed in these excavations; numerous artifacts directly related to ironworking were also found in association with these features as well as others around the site.

These artifacts include stones identified as anvils, tuyere tips, sharpening/polishing stones, iron objects, slag, and corroded masses identified as iron raw material. The latter two will be treated later in this chapter, but the others are the focus of this section. Like sanukite stone tools and Yayoi and Jomon Period pottery, ironworking artifacts were unearthed from contexts around the excavation areas removed both spatially and temporally from their initial areas of production and use. Accordingly, details about the excavation contexts of many of these artifacts is minimized to maintain focus on analysis of the artifacts and assemblages.

Excavators refer to stone anvils recovered from several features, including ditch 60 (the waste ditch for hearth 59), pit 62, pit 80, ditch 210, and well 62. Unfortunately, only two stone artifacts that might be plausibly understood to be an ironworking anvil are published in the report. A broken piece of flat andesite weighing 1083.5g, 3.8cm thick, 19.3cm long and about 10.0cm

wide was recovered from ditch 60, and appears as though it may have originally been about twice as large (Miyano 2016). The excavators comment that neither polished surfaces nor traces of percussion are visible, and do not mention any rust staining or slag adhering to it (Miyano 2016). However, the andesite is not local (the Ikoma Mountains are made of granite and gabbro rather than andesite), so it appears to have been specially brought to the site, and the excavators postulate that it was used as an anvil (Miyano 2016). The stone is thinner and probably smaller overall than the anvil identified at hearth 4 in excavation 85-2, but without additional context, it is difficult to make any solid inferences about changes to ironworking practices based on this find.

The other reported possible anvil was recovered from well 62, which had two layers of fill, one dating to the middle of the fifth century, and one dating to the late sixth century (Miyano 2016). Unfortunately, the excavators do not report which layer this anvil stone was recovered from. The stone itself is not explicitly described as an anvil in its description, but it is the only stone that is actually reported from this well that could plausibly be an anvil. It is also made of andesite and is 3.5 to 3.9cm thick. It is approximately square, but broken on three of its sides, which each measure roughly 10cm. The entire surface shows signs of heating, and one of the broken sides has been blackened with fire, which does support the hypothesis that it was used in some pyrotechnical process and potentially in ironworking, but despite its potentially early date, little can be inferred about ironworking without making significant assumptions about this artifact (Miyano 2016). If it were an anvil, it would likely have been raised off the ground level due to its small size, though it may have originally been larger.

In addition to stone anvils, the excavators report stone artifacts that may have been used as hammers for ironworking. These were found in pit 77 and ditches 66 and 68, and all three are made of a hard sandstone (Miyano 2016). The stone from pit 77 is a broken cobble shaped rather like a hammer head. Its remaining length is 7.5cm, and it has fine traces of impact on the striking face. The hammer stones from ditches 66 and 68 are both discoidal in shape. The one from ditch 66 is between 8.3 and 8.5cm in diameter and made from a broken flat cobble 2.3cm thick. Two areas of the rim have been broken off by percussion, and traces of impact are visible in the center of one of its faces. The hammer stone from ditch 68 is smaller than the one from ditch 66, with a diameter between 5.2 and 5.4cm (Miyano 2016). Unlike the hammer stone from ditch 66, this one is broken off on both faces. That may explain why there are no traces of percussion on the face, but like the ditch 66 example, the ditch 68 hammer stone does have chipping on the rim, this time in three places.

The assertion that these artifacts are stone hammers for ironworking should be taken seriously, but also approached cautiously. None of these were recovered from a securely dated context concretely associated with ironworking. All three are made of the same material and two show signs of percussive use, but grinding stones made of the same hard sandstone were also found at the site, including from pit 80 and ditch 66. In fact, the example from ditch 66 is a broken discoid with traces of percussion overlapping with the traces of grinding. As discussed in Chapter 4, metal ironworking tools are known from the Kofun Period, including hammers and anvils, and as Kitano and Manabe note (2016), the iron tongs recovered from a late sixth century tomb in the nearby Hiraoyama Kofun Group can be taken to imply the use of iron tools at this time at Ogata. The comparatively large scale of the site and its ironworking activities suggests a stable supply of iron to make such tools as well.

Even so, it is not impossible to think that it was more important to supply iron objects to their end users than to use the most sophisticated and efficient percussion tools for forging.

Kitano and Manabe go on to mention that stone anvils and hammers are still used for ironworking in some societies (though they do not give any examples), demonstrating the plausibility of similar tools' use at Ogata (2016), albeit without hypothesizing about their forms. Though some ironworking hammer stones from the Yayoi Period are hypothesized to have been simply held in ironworkers' hands for forging, others may have been hafted like axes (Murakami 2007). The hypothesized hammer stones from Ogata are similarly made from cobbles, but in two of the three cases, broken into discoids. These discoids or cylindrical stone striking surfaces might have been affixed to the heads of wooden mallets to provide the desired durability and hardness for forging iron to a cheaper wooden mallet all while retaining the ergonomics and leverage of iron-headed hammers. Though very rare compared to other forms, plausible wooden mallet heads are known from the first half of the sixth century in Osaka Prefecture, and fifth century examples are plausible based on the forms of the aforementioned iron hammers (Nara National Research Institute for Cultural Properties 1993).

While both iron hammers and anvils are known from the Kofun Period, stone anvils are also known from even the early historic period (Murakami 2007). Accordingly, the use of stone anvils is not an unreasonable assertion for Ogata, and neither are the artifacts proposed as such from the 2012 and 2013 excavations. As for the hammer stones, despite the plausibility, the evidence for either very simple handheld hammers or very complex, unprecedented composite hammer heads is not compelling when weighed against the plausibility of iron hammer heads being used, but not preserved, at Ogata.

As for other stone ironworking implements found in the 2012 and 2013 excavations, several sharpening/polishing stones were unearthed from features from all phases. Kitano and Manabe (2016) comment that the number found seems disproportionately few compared to the amount of slag and number of tuyere tips recovered, but it is difficult to translate this to generalizations about ironworking at Ogata. The sharpening/polishing stones themselves are all broken, and small enough to have been used as a hand tool rather than an installation to which objects were brought. Finally, while the excavators do not report such stones, Kitano and Manabe (2016), who worked closely with the excavators to furnish their analysis, mention that many pieces of granite bearing signs of heating or with traces of iron adhering to them were found in the 2013 excavation, which yielded most of the sixth century finds, and hypothesize that they may have been anvil stones or parts of hearth structures. Without further details about these stones, it is impossible to make additional interpretations.

Tuyere tips were unearthed from features in both the late sixth century phase and the eighth century phase (Fujita and Iwase 2016, Iwase and Fujita 2016). However, most were from the late sixth century phase, and those found in other contexts were extremely fragmentary and were not reported in detail. What taphonomic processes led to this phenomenon is unclear from the excavation report. In any case, the tuyere tips that could be reconstructed are generally very similar with just one or two exceptions to their uniformity in their general characteristics. All of the tuyere tips except for number 635, unearthed from pit 78, seem to be of Manabe's class Ib or Ic, and 635 appears to be of type IIb. It is difficult to grasp the original length of the tuyeres and distinguish between class Ib and Ic because nearly all are missing their socket ends, with only 632, 635, 642, and 643 have any part of it represented in their current state.

This pattern of breakage may actually illuminate an aspect of tuyere use at Ogata, especially considered alongside tuyere tip 632. Tuyere tip socket ends flare out wider than the main channel of the clay tube, but the tiny amount of the socket end that is left on 632 actually quickly constricts to a narrower diameter than the rest of the tuyere tip. The excavators postulate

that this is may be due to the presence of clay used to secure the connection between a narrow bellows pipe and the tuyere tip (Iwase and Fujita 2016). That the state of preservation does not allow for a more definitive understanding is unfortunate, but the presence of a hardened clay (fired over the course of use?) seal that cannot be readily distinguished from the body of the tuyere tip itself suggests that the tuyere tips may not have been fired very hard to begin with, and also that a seal as tough as the tuyere itself may have necessitated breaking tuyere to extract the bellows pipe at the end of the tuyere's use life, removing the socket end from most tuyere tips, especially those of class I, which had notably thinner walls in the socket end than the body of the tuyere tip.

The air channel through class I and III tuyeres is nearly cylindrical, in contrast to those of class II. Even so, they taper a little toward the tip, as a result of either a slight taper to the dowel around which they were formed or compression as they were removed wet from the dowel. This makes any measurements of interior diameter based on fragmentary remains subject to variation based on proximity to the tip. Even so, it appears that tuyere tip diameter in these areas of Ogata during the late sixth century was between 2.2 and 2.8cm, with a few outliers in the 3.0 to 3.5cm range. This is very similar to the inner diameters of the tuyere tips found in excavation 85-2.

Previous excavators noted that while some tuyere tips seemed to extend straight into the hearth, some appeared to have been inserted at an angle (Hanada 1984). Okuno and Manabe (2000b) claim that tuyeres were normally set at an angle with respect to the furnace wall (which may be due to angling the tuyere downward, a sloped furnace wall, or both), but that is obscured by occasional rotating and refitting the tuyere tip, or insufficient heat in the hearth to leave an angled firing temperature color gradient of which to measure the angle. Unfortunately, this hypothesis is beyond verification, but the excavators were only able to determine the angle between the hearth wall and the tuyere tip for a single example of among the all those unearthed in the 2012 and 2013 excavations. Based on the angle of the melted and discolored portions and the glassy slag dripping from the tip, they determined that tuyere tip 627 was canted about 10 degrees relative to the hearth wall, which suggests a shallow hearth. Tuyere tip 632 appears to have been mounted at a similar angle, though the excavators are not confident enough to report it as such. No reporting or analysis has been conducted based on the firing temperature color gradient to hypothesize about the thickness of hearth walls or duration of use.

Lastly, tuyere tip 199, unearthed from pit 145 in the 2012 excavation, was marked with spatula markings like some found in excavation 85-2 (Fujita and Iwase 2016). The pit contained a roof tile fragment suggesting an eighth century date, but the pit's fill may be composed of earlier sediments from elsewhere at the site, and the tuyere tip's morphology closely matches ones found in late sixth century contexts, and not the class III morphology expected for later in the early historic periods (Manabe 2003).

Perhaps the most intriguing finds from the 2012 and 2013 excavations are the iron objects themselves. Aside from several "iron lumps" discussed later, five iron artifacts from the Nara Period and earlier during the 2012 and 2013 excavations. All five were found in the 2013 excavations in sectors 25-B and 25-C, and four came from sixth century or earlier contexts (Iwase 2016). Object 608 was unearthed from pit 50 in sector 25-C, which though stone tools, Jomon Period pottery, Yayoi Period pottery, and roof tile fragments were found in addition to Sue ware (ranging from Type I to Type II Stage 4 in Nakamura's typochronology), Haji ware, and tuyere tips, is understood to be a large late sixth century disposal pit. The object itself is a metal fitting from a set of horse tack, and consists of three lobes, each with three small rivet holes, protruding from a circular center. A fourth lobe was originally present, but is now missing.

It is currently about 7.5 by 5.6cm in planar dimensions, but due to severe corrosion, its thickness is unknown. Because it has rivet holes but no rivets, excavators believe it to be unfinished (Iwase 2016).

Just north in sector 25-B object 606 was unearthed from pit 80 (Iwase 2016). This object is 5.3cm long, 0.9cm thick, and 1.4cm wide for most of its length, but quickly tapers to just 0.6cm wide at one end. It has a rectangular cross section, but its intended purpose is unknown. It may have been raw material for forging, or perhaps a chisel (Kitano and Manabe 2016), or something else entirely. It is also unclear if it was an abandoned incomplete object or if it was a broken one intended for recycling. Fortunately, the level of corrosion on this artifact was such that some scientific analysis was possible, which will be explored below.

Objects 604 and 605 are two short-stemmed iron arrowheads with very similar forms unearthed from pit 78 (Iwase 2016). After conservation, 604 has a 6.2cm head with 2.5cm barbs, a 2.5cm neck, and 1.3cm tang. 605 has a 5.5cm head with 1.5cm barbs, a 2.5cm neck, and a 5.0cm tang. Kitano and Manabe (2015: 232) class them both as incomplete forgings, but they also may have been intended for recycling.

Finally, object 607 was unearthed from ditch 66, but may be more closely associated with pit 73 (Kitano and Manabe 2016: 209). Its form is heavily obscured due to corrosion, but it flat, and measures 4.9 by 4.0cm, with a thickness in the center of about 1.1cm (though this was probably less originally), and has thinner projections extending in two directions approximately perpendicular to each other. The excavators suggest that if it either had or were intended to have projections in the remaining two directions, it may have been an unfinished piece of horse tack like object 608 (Iwase 2016).

All of these objects were found in disposal contexts, which provide a different view of ironworking at Ogata than had they been found more closely associated with undisturbed production contexts. The reuse of old iron objects is understood to be an important aspect of Kofun Period ironworking (Murakami 2007), and this complicates interpretation of these finds. The case for object 608 being an abandoned incomplete forging rather than a worn out item brought to Ogata for recycling is strongest, and if the hypothesis that 607 is also an incomplete piece of horse tack is accepted, then its likelihood of being produced at Ogata is similarly high. Objects 604, 605, and 606 are less clearly incomplete forgings, and more open to interpretation of broken or used-up objects collected for recycling, or in the case of 606, even a small piece of abandoned raw material. Accordingly, it is less clear that they were made at Ogata.

The fact that they were discarded at all is suggestive of a secure and abundant supply of iron raw material, obviating the need for careful recycling of every scrap by the time these objects were made or brought to Ogata. While the association with late sixth century pottery does not prove a late sixth century date for the features or their other contents, by that point iron smelting had begun in the archipelago, and Ogata may have been supplied by closer and more reliable sources of raw material than in earlier phases. Without a better understanding of the iron supply in earlier phases, this can only remain a plausible hypothesis. What does seem more certain is that smiths at Ogata were engaged in making horse trappings, and were capable of producing complex forms and using advanced technology like riveting. The production of horse trappings is not surprising given the hypothesized close association of Ogata ironworking with the highest level of political elites, as well as direct evidence for the importance of horses at Ogata in general, as seen in both the long history of salt-making there and the abundance of horse remains unearthed at the site. While it is unclear if arrowheads were made at Ogata (though arrowhead production seems to be within the technical capabilities of smiths there), it

does appear that the site was at least part of a network of circulation of goods that included arrowheads and presumably other iron implements.

Previous excavations at Ogata unearthed large quantities of salt-making pottery, but in the 2012 and 2013 excavations, finds of salt-making pottery were few and limited to two features from the 2012 excavation, hearth (mid- to late eighth century), and pit 145 (date uncertain, but probably historic). These pieces were fragmentary, but they attest to a continuity of activity at Ogata into the eighth century.

Animal remains recovered in the 2012 and 2013 excavations differed in some ways from the assemblages from previous excavations. Most notably, while horse, cow, pig/wild boar, and fish remains were found, deer were not represented at all. While animal remains were found in both the 2012 and 2013, about three quarters were recovered in 2013, and most of them were from horses. These remains largely consisted of teeth, due in some part to the acidic soil destroying most bone, but the analyst, Maruyama Masashi (2016), hypothesizes other reasons as well. In particular, Maruyama (2016) notes their association with ironworking. Not only were horse teeth found in the possible ironworking features unearthed in the 2013 excavation, at least one tooth was found stuck to ironworking slag, but with no signs of heating, indicating that the slag was already mostly cooled when it was brought together with the horse tooth (Maruyama 2016). Based on this, and the fact that some teeth appear to have been intentionally extracted and broken, he hypothesizes that horse teeth may have been involved in rituals or ceremonies upon the conclusion of forge work (2016).

Another explanation, unexplored in reporting so far, is the possible practice of equine dentistry at the site. Horses can develop problems with their teeth for several reasons, and these problems in turn can lead to feeding and behavioral problems, especially with respect to the use of the bit (Taylor et al 2018). Due to horses' the great value, the diminishment thereof that comes with dental problems, and the comparative difficulty of replacing a horse, equine veterinary care, including dental care, has been practiced for millennia (Taylor et al 2018). Some of the occlusion problems stem from feeding with soft grains rather than abrasive natural forage (Taylor et al 2018), and isotopic analyses of some of the horse teeth found in the 2012 and 2013 indicate that at least some of the horses there were fed at least partially with grains (Gakuhari 2016). Beyond dietary issues, horses' natural dentition and the use of the bit can come into conflict. Some horses have a vestigial first premolar, called a "wolf tooth," that can interfere with the bit or cause other issues, and so were often extracted both in ancient times (Taylor et al 2018) and in modern veterinary practice. In Mongolia, even contemporary bits cause damage to the second (first non-vestigial) premolars (Taylor et al 2018). With these kinds of issues, there is ample reason to potentially extract horses' teeth.

Maruyama (2016) notes that many of the teeth were broken, possibly intentionally, and about half of reported horse teeth could not be identified, and behind the third molar, the second premolar was the second most common identifiable tooth recovered. Specialist examination and analysis is required, but it may be that many of the unidentifiable teeth are wolf teeth, which grow in irregular and unpredictable sizes and shapes. Even pending reanalysis of these remains, and the presence of some horse bones in addition to the teeth, compared to Maruyama's hypothesis of slaughtering horses for their teeth to use in ironworking rituals, equine dentistry seems the more parsimonious explanation for the large number of horse teeth found both associated and dissociated from ironworking remains. As for the horse tooth adhering to slag, to speculate a little, the possible ritual involvement of horse teeth and forging activities may be related to the production of horse trappings, perhaps particularly for horses that had teeth

extracted due to issues with bit acceptance or tooth damage. This would make the appearance of horse teeth in ironworking more a feature of a horse husbandry *chaîne opératoire* than a generalized ironworking *chaîne opératoire* at Ogata.

The 2012 and 2013 excavations at Ogata were the most recent large-scale investigations at the site, and the best reported to date, yielding many new finds and features related to ironworking and other activities. Despite their large overall sizes, like many previous excavations at Ogata, the 2012 and 2013 ones were long and narrow, which by poor luck just happened to bisect many features, particularly in the eighth century phase. Interpretation of some features as relating to ironworking is less grounded in the characteristics of the features as recorded, and more based on prior understanding of the site in general, especially in earlier phases. The large plans (but too small to be an indoor workspace), lack of fired earth bottoms, and perpendicular waste ditches associated with hearth 59 in the sixth century phase and ironworking feature 213 in the eighth century phase are more suggestive of charcoal or salt-making kilns than ironworking features, though they do differ from the pyrotechnical feature from excavation 84-1. There is similar room for skepticism of the interpretations of some stone artifacts as ironworking tools, though stone anvils remain likely.

Despite these issues, the excavations did demonstrate the continued importance of ironworking, salt-making, and horses to the people at Ogata at least through the end of the sixth century. Regarding ironworking in particular, the large quantities of tuyere tips as well as slag from sixth century contexts attest to its significant role at the site, but the features associated with ironworking (particularly pits 77, 78, and 80) provide little positive information about ironworking practices. These features were constructed in relatively quick succession, and two overlap, indicating that they were not in use at the same time, and therefore had relatively short use-lives prior to being converted to waste pits. Though the pits contain some artifacts that long predate their apparent late sixth century dates, the excavators suggest that these features may have been ironworking workshop spaces and their fill comprised mostly of waste from that work. If this is the case, the lack of confirmed hearth features within these structures suggests that ironworking hearths were completely aboveground by the late sixth century. This may simply be an illusion based on the excavation size and location within Ogata, though the conclusion is not contradicted by evidence from earlier excavations. Regardless, based on the limited reporting of slaggy granite from the site, it seems apparent that at least some hearth features were indeed aboveground structures.

Aside from the slags, discussed below, the excavated tuyere tips provide the most insight into ironworking at Ogata in the late sixth century. Nearly all examples unearthed in the 2012 and 2013 excavations clearly fall into Manabe's class Ic, with one example seeming more like class IIb or an intermediate form. Given the issues with older artifacts appearing in later waste pits, the date for this tuyere tip is up for debate, but it does further attest to the dual traditions of ironworking seen in prior excavations, even if by the late sixth century the conical class II tradition was either nearly or completely superseded by the tradition associated with class I tuyere tips. Evidence from other tuyere tips suggests that bellows pipes were strongly affixed to the tuyere tips, and at least some were probably narrower than the tuyere tips' internal channels. The diameter of these channels is consistent with examples unearthed in earlier excavations, suggesting that air delivery mechanisms and quantity did not change much within the ironworking tradition associated with class I tuyere tips.

The 2012 and 2013 excavations also provided new insight into what kinds of objects were produced at Ogata. Though there is room for alternative interpretations, finds of

arrowheads and horse trapping components from late sixth century waste pits implies the production of these items as well as a sufficient supply of iron raw material to allow them to escape recycling, though both these aspects of ironworking may predate the late sixth century.

Summary and Discussion

Excavations in the 1980s and more recently in 2012 and 2013 are the main sources for understanding ironworking at Ogata. Large-scale ironworking sites are very rare in the Kofun Period, and the amount of ironworking residues unearthed even from narrow excavation trenches has raised the site's profile in discussions of early ironworking in the Japanese Archipelago. Along with the slags, tuyeres, and whetstones, several features identified as ironworking hearths or workshops have also been unearthed. The strength of evidence supporting these identifications varies, and the larger "ironworking hearths" unearthed in the 84-1 excavation as well as the 2012 and 2013 excavations merit additional scrutiny.

Hearths of this size might conceivably be used in a Chinese-style "roasting" process for decarburizing cast iron, but the rest of the evidence does not support this function. Such a process would require much larger tuyeres than have been found at Ogata, and while the large feature found in excavation 84-1 does have a floor structure of fire-hardened earth and a layer of charcoal, the others do not, suggesting that they did not reach especially high temperatures, even if they had walls of fire-hardened earth.

Above, I suggested that the large feature found in excavation 84-1 may be related to making tuyere tips, charcoal production, or salt-making, and in light of the salt-making pottery found at the site, this last possibility merits additional consideration as a potential additional pyrotechnology employed at Ogata, as well as in context of the other finds from the site and others in the area. Kitano classified salt-making pottery among the finds from excavation 84-1 into six classes based on form, suggesting that at least some of the salt-making pottery was not made at Ogata. Further, while much of this pottery was made from clay identifiable as from the west side of the Ikoma Mountains (Kitano 1985), some of it was not. Of the classes containing vessels not made of clay from the west side of the Ikoma Mountains, one class was exclusively of a non-local clay, suggesting that at least some of the salt-making pottery was from somewhat further away. Additionally, Kitano was able to determine that some of the salt-making pottery unearthed in excavation 85-2 was of a style from what is now Okayama Prefecture (Kitano 1988), indicating that salt was coming to Ogata from a significant distance.

In spite of this evidence for salt-making pottery entering the site from elsewhere, the question of whether it was also being made at Ogata appears to be open. Excavation 85-1 at Ogata Minami (大県南) just south of Ogata unearthed not only a significant quantity of salt-making pottery made from four different clays, but also a feature that the excavator indicates has a high likelihood of being a salt-making hearth (Kitano 1986). The feature was not well preserved, but was roughly circular to sub-rectangular and about 1m in diameter. The bottom was not plastered, but had been fire-hardened and while it was very flat, it was also very uneven. Many flat rocks and cobbles that had been exposed to fire were unearthed, suggesting it was paved on the bottom. Along with charcoal and salt-making pottery, Haji ware, a single piece of iron slag, and Sue ware (mostly Nakamura's Type II Stage 4, with a few older pieces) were unearthed from this feature. Based on the large amount of salt-making pottery and the form of the hearth, Kitano surmises that this was probably a salt-making hearth.

Nearby, another hearth with even worse preservation seemed similar and also contained charcoal, flat rocks that had been exposed to fire, salt-making pottery, a piece of slag, Haji ware,

and Sue ware, albeit older types (ranging from Nakamura's Type I Stage 3 to Type I Stage 5, suggesting a date to the second half of the fifth century) (Kitano 1986). Kitano declined to speculate on the purpose of this hearth, but it, too, may have been a salt-making hearth, and if so, shows a lengthy continuity of practices between the two. In contrast to these possible salt-making hearths, a third hearth actually closely resembles the feature found in the 84-1 excavation at Ogata in terms of scale and structure (though it is not located adjacent to a ditch), but no artifacts related to ironworking were found (Kitano 1986). Aside from charcoal, only the sherds of a single Sue ware pot belonging to Nakamura's Type I Stage 1 (early fifth century, around 412), seemingly placed purposely over the feature, were recovered (Kitano 1986).

This combination of features suggests that the 84-1 hearth at Ogata was probably not a salt-making hearth, but the presence of other likely salt-making hearths suggests that salt-making nevertheless may have been conducted there across the Middle and Late Kofun Period. Despite the presence of possibly multiple salt-making hearths in the area, salt-making was probably a relatively minor activity at the site, as suggested by the presence of so many styles of salt-making pottery from both relatively nearby and distant areas, as well as the impracticality of transporting brine to Ogata from either the coast or from the Naniwa Lake/Swamp. Ban Yasushi (2012) suggests that salt was exchanged for iron in the Kofun Period at the Nango Site Group (南郷遺跡群) in southern Nara Prefecture. This may have been the case at Ogata as well, though the presence of salt-making pottery from Okayama in a late sixth century context complicates the matter. Okayama was an important region in ironworking at the time, so demand for iron goods from so far away would be perhaps based on some specific qualities of the iron implements produced there, or the reputation of the specific smithy that produced them.

The apparent importance of salt may be more closely related to horse riding than to iron directly. Keeping and breeding horses is closely associated with salt consumption, and the relationship between iron, salt, and horses is not unique to Ogata in the Kinki region. Shitomiya Kita (蒨屋北) in Shijonawate City, is a mostly Middle and Late Kofun Period site located on the western side of the northern end of the Ikoma Mountains in Osaka Prefecture. Excavations there have unearthed a small amount of material related to ironworking, significant quantities of Peninsular-style pottery, more than 82kg of salt-making potsherds, totaling over 1600 vessels, numerous artifacts related to horse riding, as well as hundreds of horse bones (Miyazaki 2012) (MNI for the 5th and 6th centuries is 15 [Abe 2010]). Based on the condition of the recovered salt-making pottery sherds, Miyazaki (2012) posits that the salt-making was conducted nearby, which given Shitomiya Kita's location near the edge of the Naniwa swamp, appears plausible. The quantities of horse remains, artifacts related to equestrian activities and salt-making pottery along with the site's proximity to a salt source point to Shitomiya Kita being a horse breeding center but not necessarily a salt making or ironworking center.

Ogata has much in common with Shitomiya Kita, in terms of activities attested by the archaeological record, but significant differences in the relative quantities of artifacts and features paints a different picture. The amount of salt-making pottery and horse remains at Ogata, especially in the sixth century, is indicative of the importance of the animals to the local community, but does not approach the weight of evidence for horses or salt at Shitomiya Kita. Additionally, as described elsewhere, while the nearest pollen data to Ogata do show some grasses and grains in addition to nearby forest, they are more associated with rice agriculture than pasture grasses. Accordingly, Ogata does not seem like a horse-breeding site, even if horses played an important role there. A large permanent horse presence and extensive salt-making would have been in competition for fuel wood either directly or through clearing forest for

pasture with the extensive ironworking at the site, as well as the glassmaking at Ogata Minami attested by the glass molds unearthed in the 1993-2 and 1993-4 excavations there (Ishida 1995).

While ironworking is the focus of this study and the reason for most of the attention accorded to Ogata in general, any insight into ironworking practices there requires looking at the greater context and other characteristics of the site. Like at Shitomiya Kita, the presence of Peninsular-style pottery as well as portable *kamado* and associated pottery suggests close contact with or even occupation by migrants from the Korean Peninsula or their descendants. These communities are closely linked to the introduction of new technologies from the Korean Peninsula, like new agricultural tool forms, ironworking, and horse riding. Ogata was not just an ironworking site, it was home to a multifaceted community engaged in a variety of production and exchange activities for both local and distant consumption. Furthermore, it was located on an important transit route and near both the huge tombs of the Furuichi Kofun Group and local smaller kofun. This fuller picture must be considered in evaluating the ironworking practices at the site.

Ironworking activities clearly go back to at least the fifth century, and Ogata was occupied long before that. Most of the evidence for ironworking is from the later phases of the site (sixth century onward), but some of the purported ironworking features in particular may have been initially misidentified as such. More certain evidence comes from smithing slags and tuyeres, the scientific analysis of which is the subject of the next chapter. It appears that at least two technological traditions of smithing existed at Ogata in earlier phases, but by the late sixth century, tuyere and hearth morphologies indicate that once divergent technological practices had become more uniform, and in-ground hearths eventually disappear in favor of aboveground installations. Additionally, the presence of seemingly intact iron arrowheads suggests that by this time, iron was supplied regularly and in sufficient quantity to obviate the scrupulous recycling posited for earlier phases of the Kofun Period. Anvils may have been made of stone, but many other tools were probably made of iron. Alongside the changes in technology, the iron products of Ogata may have also changed. Earlier phases contained worked antler indicative of the production of particular styles of sword fittings, but these do not appear in later phases. Whether sword production ended or changes in sword fitting styles is responsible for this phenomenon is unclear, but the latter seems more likely.

Chapter 7: Uncovering and Interpreting Technological Change at Ogata

Introduction

This study seeks to link the activities of ironworkers at Ogata to transformations of the broader landscape in the fifth and sixth century by reconstructing the *chaînes opératoires* of ironworking and extending them out to landscape through examining practices of fuel use and procurement. This undertaking requires understanding the physical landscape and how it changed during the Kofun Period as well as the processes and activities that caused those changes.

Chapter five investigated the climate and natural vegetation dynamics on the Osaka Plain during the Kofun Period. Those investigations determined that the fifth and sixth centuries were climatically similar to the twentieth century in terms of temperature and typhoon strikes, albeit with a cold period in the sixth century and an increase in typhoon frequency and possibly intensity toward the end of that period. While data on the paleovegetation around Ogata is unavailable, close examination of the data from several nearby sites suggests that the landscape was heterogeneously forested with some areas open for agricultural or elite mortuary purposes. Nevertheless, considerable forest remained in the area. The forest itself was composed largely of lucidophyllous taxa, albeit with significant amounts of warm temperate deciduous taxa as well, indicating a degree of ongoing disturbance from human activity. Conifers were also present, but due to their high pollen production, it is difficult to gauge how prevalent they were outside of edaphic conditions unsuitable for lucidophyllous plants.

Furthermore, based on twentieth century studies of lucidophyllous forest regeneration after disturbance, it seems that by conservative estimates for the availability of deadwood and sustainable selective logging of the forest, that charcoal needs for many smithing hearths could easily be sustained by the deadwood from a small patch of forest, and selective logging could provide even more. However, as discussed in chapter six, ironworking was not the only pressure on forest resources. At Ogata and its immediate vicinity, household cooking and heating, local pottery production, glassmaking and potentially salt making required fuel as well. Nearby, haniwa production for the Furuichi Kofun Mounded Tomb Group would require significant wood fuel, and the shifting course of the Yamato River necessitated occasionally opening new plots for agriculture and settlement, altering the amount of forested land in the area available for exploitation at any given time. Beyond these nearby pressures, in the Middle and Late Kofun Periods, lumber and wood products were supplied regionally from more to less forested areas (Oba 2017). It is likely that demand from less forested sites on the Osaka Plain and its periphery was served at least in part from the forest area near Ogata. Despite these pressures, it appears that the forest was relatively stable or only slowly declining at least into the early historic period.

In addition to the transformations of the landscape and vegetation, this project also demands understanding ironworking at Ogata both at the scale of the site and at the scale of smithing individual objects. Chapter four discussed Kofun Period ironworking in general, presenting the range of technology available and its limitations, however, this does not allow the reconstruction of ironworking *chaînes opératoires* at Ogata, it only permits the contextualization within (or beyond) that framework of specific findings at Ogata itself. Chapter six explores the archaeology of the Ogata site and discusses what can be determined about ironworking practices and how they changed over the period of the site's occupation. Based on these archaeological findings, ironworking appears to have continued from the fifth century through the end of the Kofun Period, and potentially through the eighth century, although much of the evidence for this

later period of ironworking is ambiguous and open to alternative interpretations. During the Kofun Period, some aspects of ironworking practices at Ogata remained consistent, while others changed. Anvils were probably always stone at Ogata in the Kofun Period, and other tools for handling and shaping hot metal were probably always iron. On the other hand, there is a move from in-ground hearths to raised hearths, and two parallel traditions, represented by two different tuyere forms, collapse into one tradition over time. After this occurs, variation in tuyeres is only apparent in their size, internal diameter, and potentially in the angle of installation. These differences do not appear to correlate with time period though, and so either reflect aspects of smithing that are idiosyncratic to particular individual smiths, the specific tasks undertaken at particular hearths, or are arbitrary in relation to the *chaînes opératoires* performed at Ogata in general. It appears that the objects made at Ogata changed as well, with concomitant changes to *chaînes opératoires*.

These *chaînes opératoires* contain the details of ironworking at the scale of smithing individual objects. The site-scale changes mentioned above certainly play a role in the ways individual objects were produced, but are hardly sufficient to link those practices with landscape transformation. Further investigation of the *chaînes opératoires* of ironworking at Ogata, and how they changed, requires applying scientific laboratory methods to artifacts.

Methods and Materials

Particularly informative artifacts include excavated charcoal, tuyeres, fragments of hearth walls, forge slags, so-called “iron lump artifacts,” and iron objects themselves. Unfortunately, although iron objects have been unearthed from Ogata, they are completely corroded with no metal remaining from which to reverse engineer their production. Some examples of these artifacts have already been analyzed in connection to excavation work or other research projects. Some charcoal has been identified to various degrees of precision, a few fragments of tuyeres and hearth wall have been analyzed to determine their firing temperatures, “iron lump artifacts” and some forge slags have been examined petrographically/metallographically to partially examine their microstructure, and other forge slags have been tested for their chemical makeup. These analyses have provided insight into ironworking practices, but often the results are not reported with much temporal or contextual information, nor any information on how the artifacts were selected for analysis, which imposes limits on the inferences that can be drawn from them. Furthermore, while the data from these analyses are useful for potentially identifying certain aspects of ironworking technology and practices, it is difficult to link them together to gain a coherent picture of how any given object may have been produced. This is because of the lack of clarity surrounding the range of objects that were made at Ogata, each of which with its own *chaîne opératoire*.

Exactly what kinds of objects were made at Ogata will probably never be definitively known. Even so, additional well-contextualized analyses can help to understand both the range of *chaînes opératoires* and how they changed over time. A key for guiding analysis is the recognition of both the social and physico-chemical formation processes of forge slags. Forge slags are not true slags, strictly speaking, though slag it is a constituent of forge slags. During hot working operations, smelting slag that remained entrapped in the iron raw material melts out and combines with the iron oxide scale that develops on the surface of the iron, ash from expended fuel, vitrified pieces of the tuyere and forge lining, unburnt charcoal, and any flux the smith may be using, such as quartz sand. This waste product is the forge slag, and it must be periodically

removed from the forge and discarded when it grows so large as to become a hindrance to work, or whenever the smith cleans out the forge for other reasons.

The formation of these forge slags is dependent on the nature of the operations going on in the hearth. Different temperatures, qualities of raw material, fuel, and other additives result in different chemical and mineralogical compositions. Moreover, as smiths operate the forge to suit different steps of production, the forge slag builds up heterogeneously according to the conditions and materials in the hearth. Vincent Serneels and Sébastien Perret (2003) recognized that a forge slag thus not only represents a unit of work, but also contains a record of that work. Their research has identified three materials in forging slags associated with different forge operations, and based on the physical arrangement of those materials in slags, have reconstructed the sequences of ironworking that led to their formation (Serneels and Perret 2003). Raphaëlle Soullignac's (2017) ethnoarchaeological and experimental work has supported Serneels and Perret's conclusions and refined their methods.

When a forge slag is cut to reveal its entire cross section for analysis, as opposed to the single small sample typically cut out for analysis in Japan, the presence, arrangement of materials and their relative quantities become visible. The three materials that Serneels and Perret (2003) identified and Soullignac (2017) elaborated upon are named with French acronyms.

SGD, from "*scorie grise dense*" (dense grey slag) is similar to bloomery smelting slag. It is grey or greenish-grey and its composition is 50% to 100% fayalite, with some amount of wüstite also present along with some interstitial glass. SAS, from "*scorie argilo-sableuse*" (sandy-clayey slag) has a wide variation in possible colors: it may be black, brown, green, or even blue. It is typically composed of grains of quartz more or less melted, as well as unmelted rocks and/or ceramics in a matrix of glass, and has many round pores. SFR, from "*scorie ferreuse rouillée*" (iron-rich rusty slag), as the name suggests, contains as much as 90% iron, either in its metallic form or as oxides and oxy-hydroxides formed from metallic iron after burial. It also contains fayalite. SFR often contains inclusions of charcoal as well (Serneels and Perret 2003, Soullignac 2017).

Soullignac (2017) found that when using modern steel or antique forge-refined bloomery iron, in other words, generally pure metal without many slag inclusions, SGD forms during high temperature work (particularly when welding is involved) when the iron oxide forge scale that forms on the hot iron work piece combines with the silicate minerals of the hearth and gives a fayalitic composition to the slag. Serneels and Perret (2003) hypothesize that this is the dominant process of forge slag formation in archaeological contexts. While none of these researchers states as much, the similarity of SGD to bloomery slag suggests that SGD in archaeological forge slags may also come from bloomery slag removed during forge refining.

SFR is also a product of high temperature work, however the quantity of metallic iron results from the loss of metal from the stock into the hearth (Serneels and Perret 2003, Soullignac 2017). As Serneels and Perret (2003) suggest, this may originate from lost particles from poorly compacted bloomery iron. Soullignac (2017) identifies additional ways metallic iron can enter the fayalitic matrix in such quantities. If the iron stock is heated too much, there may be some slight melting on the surface, and this liquid iron can drip or flow into the slag. Additionally, iron oxides in the slag may be reduced to metallic iron through carbon monoxide bubbling up through the molten slag, or from the charcoal itself (Soullignac 2017). As for the kind of forging work that results in SFR, he found that it forms when imperfections requiring additional welds to repair arose during the early stages of forging (2017). In such instances, metal is accidentally lost to the hearth either from the imperfection itself or during the repair process (2017). He also notes

that this is surely not the only way that SFR can form given its frequency in the archaeological record and the low probability that so many forging errors were made (2017).

SAS forms when iron (oxide) is only a small percentage of the slag's composition. Serneels and Perret (2003) attribute this to the use of lots of flux, either in welding or to limit decarburization of steel, however Soulignac (2017) found that it forms from the dirt, clay, or other siliceous materials that make up the hearth or its liner so long as iron does not enter the slag to form fayalite. Regardless of the use of any flux, SAS can form when the iron is heated slowly in a comparatively cool hearth, or quickly enough in a hotter to forestall the loss of significant quantities of scale into the slag (Soulignac 2017). Given the multiple potential origins of each of these component materials, as well as considerations of their spatial distribution within slags potentially owing to multiple periods of partial cooling, there are limits to what is possible to infer from this analysis. Even so, this analytical method, especially in combination with contextual archaeological data allows for far greater detail in understanding the specific processes of ironworking than the small partial petrographic analysis typically conducted in Japan.

Accordingly, this project uses a modification of Soulignac's method to fit the constraints of commercially available sample preparation procedures available in Japan, but the core logic remains. In short, because whole slag cross sections are too large to be commercially prepared as samples, slags were prepared for analysis by sectioning them into several small samples which can be viewed and photographed separately, but analyzed together. SGD, SAS, and SFR are identified visually in images of the slag cross sections, and their relative proportions estimated. The relative proportions of each constituent material permit their classification into a schema devised by Serneels and Perret (2003) and elaborated upon by Soulignac (2017). Details of this classification as well as the interpretation of the spatial configurations of the constituent materials as followed for in this project are available in Soulignac 2017.

In addition to the analysis of forge slag, this project also makes use of charcoal identification from charcoal removed directly from forge slags as well as from the large pyrotechnical feature uncovered in excavation 84-1 that may be a charcoal kiln. Radiocarbon dating of charcoal from slags and the same feature provide additional dates for chronological comparison in addition to the pottery typochronology used to date features and artifacts at Ogata to date.

Material Selection

Because it is the only excavation that yielded both Middle and Late Kofun Period ironworking remains for which comparatively detailed excavation records remain, excavation 84-1 is the source of all the materials analyzed in this project. The unpublished original excavation log book (遺物台帳) is the only source containing the approximate locations of excavation contexts and features by number (R-number), which matches the artifact storage system. Without this crucial information, it is impossible to draw anything but the vaguest conclusions about ironworking at Ogata.

Forge slags were unearthed from almost every context in excavation 84-1, but many contexts were fairly disturbed and contained material clearly from later periods, such as ceramic roof tiles or porcelain. Both Layers B and C contained Kofun Period materials, but only Layer C contained Middle Kofun artifacts in addition to Late Kofun Period artifacts (Kitano 1985), so materials for analysis were drawn from Layer C contexts. The large pyrotechnical feature that

may be a charcoal kiln was also from Layer C and was specifically chosen for investigation because of its potential value in understanding fuel use.

Budgetary constraints limited the number of slags that could be analyzed, so random sampling was unlikely to provide a selection that represented the variation apparent in the assemblage from these contexts. Accordingly, slags were selected for analysis according to several criteria. First, the sample as a whole should contain selections from each context to cover as much area of the excavation as possible. Ideally, each context should be represented in the sample in proportion to its relative share of the total slag assemblage. However, in practice this was neither truly possible nor actually desirable. Even though slags are very tough and durable objects, many of the unearthed slags were actually fragments of slags rather than complete specimens. This means that there is no way to be sure that either the number or mass of slags unearthed from a given context actually reflects quantities of slag deposited in that location. Beyond that, the pyrotechnical feature contained many slags and other artifacts in addition to charcoal, and a representative sample would privilege this distinctive depositional context at the expense of ones that may represent longer periods of deposition and thus better enable a diachronic view of ironworking practices. With that in mind, only three slags were selected from this context.

Slags were also chosen preferentially for completeness, since those missing significant portions of their original mass are no longer very representative of the conditions under which they formed. This has probably led to a bias toward large slags, since it can be very difficult to discern whether a small slag is complete or simply a fragment broken off from a larger slag. Additionally, under the assumption that some charcoal was entrapped in all complete slags, ones with charcoal visible on the surface were preferentially chosen for ease of charcoal sampling for taxon identification and radiocarbon dating. Beyond this, slags were also chosen to create a sample that contained the full range of magnetic susceptibility, strength of response to a handheld metal detector, external morphology, and color. In all twenty slags were selected to form the sample. Since removing artifacts from the country is difficult, these slags were prepared as petrographic specimens for reflected light microscopy and initially examined photographed by Suzuki Mizuho through Nippon Steel Technology Co., Ltd.

In addition to slag analysis, this project involves charcoal identification and radiocarbon dating charcoal extracted from slags. Additionally four fragments of charcoal and a charred peach pit unearthed from the possible kiln feature were selected for radiocarbon dating by Beta Analytic, Inc. Thirteen pieces of charcoal extracted from six of the twenty slags were sent to Paleo Labo Co., Ltd. for identification. Additionally, charcoal fragments extracted from nine of the slags were sent to Beta Analytic, Inc. for radiocarbon dating.

Constructing Chaînes Opératoires

Analyses of these materials are supplemented by the results of prior analyses and will enable a high level of detail in reconstructing ironworking *chaînes opératoires* at Ogata. However, building the *chaînes opératoires* from these analytical results is not a straightforward process. Even with new and detailed additional information concerning specific moments of ironworking, the actual outcomes of those moments will forever be unknown since the final products do not remain. Furthermore, the likely variety of iron objects produced at Ogata in a given phase, each with their own distinct *chaîne opératoire*, and the changes in what objects were produced over time mean that changes in ironworking practices with respect to fuel use and landscape management can be difficult to detect since without knowing exactly what kinds of

things were produced with what *chaîne opératoire*, differences between *chaînes* can just as easily be attributed to different objects being made. For example changes in the *chaîne opératoire* of arrowhead production cannot be identified because no traces of arrowhead production can be distinguished from knife production based on even the most detailed slag analysis for any phase of the site's occupation, much less multiple phases. How do you construct a *chaîne opératoire* at all without knowing what the products were?

Since the 1980s, object biographies have become a staple of anthropological and archaeological research, tracing the ways that individual objects' meanings both shape and are shaped by social shifts from the object's physical process of creation on through its original use and forward through time in different contexts. The best of these studies are based on extremely detailed information about the histories and movements of individual objects as well as their social contexts. This kind of information is exceedingly rare for most excavated objects, especially ones without lively histories in the hands of museums and private collectors. In short, as useful and enlightening as object biography can be, it is unavailable in a practical sense when dealing with disparate and incomplete data. This being the order of the day for most archaeology, researchers have by necessity drawn general conclusions about types of objects based on data from multiple sources. Moving to retain the anthropological themes common to object biographies while thinking archaeologically to draw inferences from multiple objects, Peter Bray (2019) advocates turning to historians' methods to instead produce prosopographies (Stone 1971) of objects. Where prosopography synthesizes data from many historic individuals' lives to generalize about life courses in the past, object prosopography attempts the same for excavated objects. A prosopography of a kind of object is not the same as a *chaîne opératoire* for that kind of object, but the concept of prosopography may be fruitfully applied not just to objects but to *processes* as well. Where multiple fragmentary *chaînes opératoires* of iron objects exist, they can be synthesized to generalize about ironworking in a particular moment, or even diachronically. Absent the actual fruits of Ogata ironworkers' labor, this project instead relies on a prosopography of *chaînes opératoires* reconstructed based on legacy data from scientific analyses of slags, iron lump artifacts, tuyeres, hearth walls, and charcoal as well as new analyses of well contextualized slags and charcoal unearthed at Ogata.

Discussion and Conclusions

Active involvement of ironworkers in the management of the forest landscape around Ogata seems probable considering the established evidence for wood use preferences in the Kofun Period, the existence of regional wood resource supply networks during the Middle and Late Kofun Period, and the apparent relative stability of the vegetation in the area, but it cannot be confirmed without closely examining reconstructed *chaînes opératoires*.

Some elements of these *chaînes* seem to present clear spaces for inferring landscape management, like the amount of forging done at high temperatures and the taxa used for charcoal fuel. Evidence for a reduction in high temperature operations over time would imply taking care to not only avoid iron loss due to scaling, but also to conserve fuel, and would point more strongly to fuel conservation than iron conservation given the increased availability of iron in the Late Kofun Period. Interpreting changes in wood choice for charcoal fuel requires additional work to understand the implications of different choices. A mixture of taxa is more indicative of the use of collected coarse woody debris (CWD) for fuel than of a permissive logging environment because the amount of charcoal produced from a single tree is well in excess of the amount needed to operate a forge for an extended period of time. The presence of taxa known to

be used preferentially in other applications also likely indicates the use of CWD for fuel. The preferential use of specific taxa more likely indicates competition for forest resources and the existence of rules regulating harvesting than it does specific suitability of that taxon for smithing operations. Preferential use probably also indicates a low availability of easily gathered fuel like CWD and a reliance on selective logging to meet the ironworkers' needs. Other potential changes to the *chaînes opératoires* are even more ambiguous and require careful contextualization and potentially additional research to resolve, but change with respect to fuel use is best understood as ironworkers' increasingly active involvement in landscape management.

Since the forest was relatively stable, no observable changes in the character of the *chaînes opératoires* is likely indicative of management practices that were instituted prior to the start of the Middle Kofun Period. It is also possible, although less likely that despite Ogata's position as a large-scale ironworking site, the scale of the work was indeed small enough not to be a major concern in the competition for forest resources.

Chapter 8: Analysis

Introduction

This chapter introduces and explicates the analyses of twenty forge slags selected from five contexts of the 84-1 excavation at Ogata and the possible kiln feature unearthed in the same excavation. Based on these analyses, both general trends and *chaînes opératoires* of ironworking are reconstructed and examined chronologically to understand changes in the interplay between ironworkers' landscape management practices and their work at the forge.

Contexts and Chronology

Slags were selected from four contexts, R-17, R-18, R-27, R-32, and R-38. With the exception of R-18, which is the possible kiln feature and its immediate surroundings, these contexts are best understood not as discrete deposits, but rather as units of arbitrary spatial extent, since their relationship to excavated features is not recorded. However, their temporal extent is limited to Layer C, which contained pottery typochronologically dated to the fifth and sixth centuries AD. The contexts do differ from each other in the phases of Sue ware pottery present, allowing for the construction of a relative chronology.

Using Tanabe's (1981) typochronology, R-17 included pottery from the TK208 through the MT15 type-phases (mid-fifth century through first half of sixth century), though the majority is from the TK23 and TK47 type-phases, which corresponds broadly with the late fifth century. Pottery recovered from R-18 near the possible kiln feature (but not in it) has a narrower range, from MT15 to the following TK10 type-phase, which correspond with the first half of the sixth century through the mid-sixth century. R-27 contained the widest range of Sue ware, from type-phase TK208 through TK43. These type-phases correspond with the mid-fifth century through the last quarter of the sixth century. However, the bulk of the Sue ware from R-27 is from the MT15 and TK10 type-phases. Sue ware unearthed from R-32 is from the TK47 through MT85 type-phases, which correspond with the late fifth century through about 588 AD. Unfortunately, R-38 did not contain any datable Sue ware, and the attempt at radiocarbon dating charcoal extracted from slag R-38-1 failed, limiting the utility of that slag's analysis.

It is not impossible that the slags recovered from these contexts also date to the full range of dates as the Sue ware, but there is of course no way practical to know which slags correspond with which pottery. Accordingly, though the method relies on some untestable assumptions, the relative chronology of the slags is best understood to correspond with the relative chronology of the contexts themselves. Based on the latest type-phase from each context, that chronological order is R-17 first, followed by R-18, R-32, and finally R-27. However, the distribution of pottery across each context's span of type-phases is not even, so there is no reason to think that the dates of the slags in each context would be even, either. It is possible, although unlikely, that all the slags from all the contexts date to the MT15 type-phase. This and similar possibilities temper the strength of diachronic analyses, but the relative order R-17, R-18, R-32, R-27 is nevertheless the best way to grasp the chronology of these contexts.

Notes on Analytical Procedures and Reporting

As detailed in Soullignac (2017), slags are analyzed by cutting a cross section, creating a high resolution image of it, and then locating various materials within that cross section. These materials are color coded in image processing software (in this case Photoshop), and the number of pixels of each color counted to determine their relative quantities in addition to their locations.

Slags are then classified according to the relative quantities of SAS, SGD, and SFR. These quantities are calculated after subtracting the charcoal inclusions and porosity of the slag. The SAS volume is further adjusted by assuming a 30% porosity of the materials that make up SAS. SAS consists of rocks and pebbles, which are coded yellow, as well sandy clay in any stage of melting, which is coded brown. SFR consists of metallic iron, which is coded blue, and iron oxides, which are coded red. SGD consists of dark slag composed predominantly of fayalite with variable amounts of wustite, which is coded white. Charcoal inclusions are coded gray, and pores and other discontinuities are coded black.

In practice, no macroscopic metallic iron was found in any of the cross sections of this study. This is likely due to postdepositional weathering and corrosion of the slags. Traces remain as iron oxides in some places. However, many of these traces are on the interior surfaces of pores, suggesting the possibility that pieces of metal were originally inside the pore, but have corroded away. This may lead to a systematic undercount of SFR. Additionally, the sandy clay found in Ogata's slags is naturally reddish orange, potentially leading to errors concerning the presence of iron oxides originating from the forge iron versus this reddish orange soil. This would potentially lead to an overcount of SAS and undercount of SFR.

In addition to this macro-material analysis, the slags' microstructure was examined for details of their mineral makeup, and in a few cases, EPMA analysis was used to confirm findings from the optical microscopy. The microscopy samples were taken from the opposite half or pieces of slag used for the macro-material analysis. Prior to these analyses, slags were weighed, tested for magnetism with a magnet, and tested for metallic content using a digital wall scanner metal detector made by STS, model number WBS-8652.

Radiocarbon date calibration was performed by Beta Analytic with IntCAL13, and probabilities were calculated with the High Probability Density Range Method. EPMA quantitative analysis was conducted on a JEOL JXA-8230 at an accelerating voltage of 15kV and probe current of 2.00×10^{-8} A.

Slag Analyses

Slag Number: R-17-1

Section Images: Figures 2-3

AMS Radiocarbon Date: N/A

Mass: 95.4g

Magnetic Response: Moderate to strong all over

Slag Class: SGD

SGD: 90%

SFR: 5%

Excavation Context: R-17

Micrographs: Figures 42-43

Typochronological Date (Sue Ware):
TK208-MT15 (mid-5th century through first half of 6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 6%

Section Porosity: 28%

SAS: 4%

Other: Not Detected

Description

Slag R-17-1 is composed overwhelmingly of SGD with small amounts of SAS and SFR. The SFR is primarily located at the bottom of the slag, where metal and scale sank to the bottom of the liquid slag during forge work. The small amount of SAS is located on the top of the slag, where it formed toward the end of forge work due to additions of sand and/or clay from the hearth lining, tuyere, or fluxes. The relatively small amount of SAS may be due to a formerly larger amount becoming incorporated into the hot liquid slag, becoming SGD, but given the

relatively small mass of the slag and its thin profile, it is more likely that the SAS fraction does represent a short comparatively low temperature forming and finishing stage, and the SGD is a result of high temperature work prior to the lower temperature steps, coming from welding multiples pieces of stock together or simply working at a high temperature for ease of hammering and minimizing the number of heats required. Some of the SGD may originate from smelting slag being driven out of the iron stock, but in light of the small size of the slag, it is unlikely that refining was the primary activity while this slag formed. The SGD is composed of fayalite containing considerable amounts of wustite. Iron corrosion product assumed to be goethite is visible under the microscope. This would have formed postdepositionally.

The magnetic and metal detector responses are in line with expectations for a slag that contains few metallic particles as well as iron oxides (namely magnetite) that entered as forge scale and were incompletely incorporated.

Overall, this slag's structure is indicative of a fairly small work piece made mostly at high temperature followed by a short period of lower temperature work.

Slag Number: R-17-2

Section Images: Figures 4-5

AMS Radiocarbon Date: N/A

Mass: 175.2g

Magnetic Response: None

Slag Class: SAS-SGD

SGD: 56%

SFR: <1%

Excavation Context: R-17

Micrographs: Figures 44-45

Typochronological Date (Sue Ware):

TK208-MT15 (mid-5th century through first half of 6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 14%

SAS: 44%

Other: Not Detected

Description

Slag R-17-2 is composed of similar amounts of SAS and SGD. The SAS mostly forms a jacket around the body of SGD. By composition, it is classified as SAS-SGD, but this particular morphology is unknown in either Serneels and Perret (2003) or Soullignac's (2017) characterizations of forge slags. SAS forms during fast or lower temperature forging where there is little input from metal and iron oxides from the iron stock, so at first glance it appears that in this case there was an alternation of tasks. However, this raises other issues. When changing from lower temperature work to higher temperature work, the higher temperatures in the hearth should melt the earlier slag from the lower temperature work which then becomes incorporated into the newly forming high temperature slag, eliminating any stratification. Soullignac (2017) observed this happen even when the hearth was extinguished and work resumed several hours later. However, other archaeological slags do show stratification (Soullignac 2017), and so R-17-2 is not unique. Soullignac (2017) hypothesizes that stratification may occur if the hearth cools sufficiently between tasks, or if the hearth bottom is very soft and the earlier slag can sink into it.

In this case, the bottom layer of SAS appears to be thermally agglomerated material from the bottom of the hearth. The bottommost thin layer of SAS has fired to a light grayish color, whereas the innermost portion of the bottom layer of SAS remains reddish orange. The additional thermal mass of the liquid SGD toward the middle of the slag may have allowed heat to penetrate more deeply, creating a thicker layer of SAS from the hearth lining at that location. Disregarding this lower layer of SAS, R-17-2 is much like R-17-1, except larger and with a larger proportion of SAS on top. Its formation was likely similar: Initial high temperature work,

possibly involving welding, was followed by a stage of lower temperature work to shape the object once the gross changes to the iron stock had been completed. In this case, the lower temperature work was longer than for R-17-1, or the work was completed faster, preventing the SAS on top from melting into the SGD below.

Under microscopic examination, a few tiny particles of metallic iron are visible, but it is not enough to elicit a response from the metal detector. Additionally, examination of the SAS portions confirms that it is mainly composed of quartz, though some forge scale has become trapped in it and there was insufficient heat or time for it to melt. The SGD portion is fayalitic with dendrites of wustite forming throughout. Forge scale has generally been so thoroughly incorporated into the SGD that insufficient magnetite remains to elicit a noticeable magnetic response.

Slag Number: R-17-3

Section Images: Figures 6-7

AMS Radiocarbon Date: N/A

Mass: 139.3g

Magnetic Response: None

Slag Class: SAS

SGD: Not Detected

SFR: Not Detected

Excavation Context: R-17

Micrographs: N/A

Typochronological Date (Sue Ware):

TK208-MT15 (mid-5th century through first half of 6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 15%

SAS: 100%

Other: Not Detected

Description

Slag R-17-3 broke apart when cut for sampling and was revealed to consist entirely of somewhat frangible SAS. The cross section presented is that of the largest single remaining piece. The remainder is substantially identical in appearance. Because it broke into small pieces, no microscopy sample preparation was possible, and therefore no microscopic examination.

Despite this, the presence of charcoal, iron oxide staining (but nothing that could properly be called SFR), and the porous agglomeration of the material in macroscopic examination leave little doubt that this is indeed the product of forge activities. SAS slags such as R-17-3 arise from quick forge operations at relatively low temperatures that limit the amount of scaling on the iron stock as well as the possibility for any scaling to melt into the slag. Limiting the scaling helps to conserve iron, and low temperatures may or may not conserve charcoal. The lack of SGD indicates that the iron being worked was already sufficiently refined, and that no welding or quenching was required to complete this object. This slag was probably formed through the low temperature forging of a single piece of iron stock.

Slag Number: R-17-4
Section Images: Figures 8-9
AMS Radiocarbon Date:
Sample failed dating

Mass: 110.9g

Magnetic Response: Weak, and only in some parts

Slag Class: SGD-B

SGD: 81%

SFR: 1%

Description

Slag R-17-4 is primarily composed of SGD, but has a bead of SAS on top along with a large internal inclusion of the same. The internal SAS is partially incorporated into the SGD, but still distinct. The low magnetism of R-17-4 is typical of SGD-B slags. The arrangement of the SAS to one side is also a representative morphology for SGD-B slags and results from a final step of low temperature working after a session of higher temperature forging to perform the gross shaping of the object.

Microscopic examination also shows the expected fayalite and wustite composition, but also reveals some microscopic bits of partially incorporated forge scale as well as corrosion products (probably goethite).

Slag Number: R-17-5
Section Images: Figures 10-11
AMS Radiocarbon Date: N/A

Mass: 289.1g

Magnetic Response: None

Slag Class: SGD

SGD: 90%

SFR: <1%

Description

R-17-5 is a rather large bowl-shaped forge slag consisting mostly of SGD and about 10% SAS. This ratio leads to a classification as SGD-B, but the location of the SAS complicates that. With the exception of two small rocks embedded in the SGD near the top, nearly all the SAS is located at the bottom of the slag and consists of the clay lining of the hearth that stuck to the slag when it was removed. This slag is better understood as consisting almost entirely of SGD. Since it exhibits no notable magnetic properties and elicits no response from a metal detector, it is reasonable to conclude that the amount of SFR has not been undercounted.

SGD is formed during high temperature work, so this slag is the product of such operations. The SGD-B type slag is well represented in this context, so it seems that smiths were content to work at lower temperatures when they could, during the later stages of smithing. That apparently did not occur as R-17-5 formed, suggesting that either an object was formed entirely at higher temperatures, or the slag is the result of refining activities. If the former possibility

Excavation Context: R-17
Micrographs: Figures 46-47
Typochronological Date (Sue Ware):
TK208-MT15 (mid-5th century through first half of 6th century)
Surface Charcoal ID:
1) Could not be identified
Metal Detector Response: 0%
Section Porosity: 18%
SAS: 18%
Other: Not Detected

Excavation Context: R-17
Micrographs: Figures 48-50
Typochronological Date (Sue Ware):
TK208-MT15 (mid-5th century through first half of 6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 0%
Section Porosity: 18%
SAS: 10%
Other: Not Detected

were true, then more SFR would be expected, so the latter possibility makes the most sense. This slag is probably the result of forge refining slaggy iron raw material. Since SFR is practically absent, it is unlikely that this refining process involved poorly compacted iron bloom that would have flaked iron into the slag. Either the smiths were extremely careful when compacting spongy bloom, or the iron they were refining had already been compacted and shaped into stock that nevertheless was too slaggy for the Ogata smiths' purpose.

Optical microscopy reveals that the bulk of the slag is fayalitic with dendrites of wustite. R-17-5 also has a higher proportion of metallic iron particles that were not incorporated into the melt including some pearlite. Whether the pearlite was a fragment of the iron stock or whether gases from the hearth carburized a particle of pure iron is unclear. Its presence should not be taken as indicative of the presence of steel stock.

Slag Number: R-17-6

Section Images: Figures 12-13

AMS Radiocarbon Date: N/A

Mass: 460.7g

Magnetic Response: Weak, and only in some parts

Slag Class: SAS-SGD

SGD: 68%

SFR: 1%

Description

Slag R-17-6 is large bowl-shaped forge slag that straddles the line between SAS-SDG and SDG-B classification. Like R-17-2, the SAS encloses a central lump of SGD and some of the SAS on the bottom can be attributed to the lining of the hearth. However, the lower SAS layer is much thicker than on unlike R-17-2, and the distribution of thickness is not easily explained by the thermal mass of the SGD. In fact, the SAS is thinnest in the center of the slag.

The mass of the slag is large enough to suggest multiple uses before removal from the hearth, which lends some plausibility to Soulignac's (2017) hypothesis of an especially cold hearth upon restarting work, but it nevertheless seems that the large quantity of melted SGD accumulating atop the lower layer of SAS would completely melt it over the course of the work unless the SGD accumulated very quickly and cooled down very quickly. Microscopic examination does not indicate especially fast cooling, so that seems unlikely. Another possibility is that the first SAS slag to form was in fact very large, and that later high temperature work did in fact melt most of the SAS, but work ended before the SAS was completely incorporated. The presence of tiny amounts of glass and quartz in the middle of the SGD portion of the slag support this hypothesis, though it should be confirmed experimentally. If this hypothesis holds, then it would indicate that the hearth was used to make multiple kinds of objects with different amounts of gross shaping.

In any case, it is clear based on its size that R-17-6 is the result of prolonged work, possibly over multiple sessions. However, the fact that it was allowed to grow this large without being removed while other slags from the same context are considerably smaller suggests that much of the work was probably continuous. Regardless of how many work sessions R-17-6

Excavation Context: R-17

Micrographs: Figures 51-54

Typochronological Date (Sue Ware):

TK208-MT15 (mid-5th century through first half of 6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 13%

SAS: 31%

Other: Not Detected

represents, the work ended with a lower temperature phase after at least some high temperature work, as seen on many other slags.

In addition to the glass and quartz mentioned above, microscopic examination shows corrosion products, fayalite, wustite, and metallic iron as commonly found in Ogata forge slags. However, a tiny amount of metallic copper or bronze was also detected. While examples of iron forge slags that contain copper are known from early historic period sites, they are still rare at Kofun Period sites, and this project is the first to uncover any at Ogata. Copper inclusions are thought to arise when a hearth is used for working both iron and copper or bronze. It is easy to imagine Ogata as a production center for the copper-plated iron goods found in elite burials.

The copper was found in the SGD portion of the slag, and there are a few possibilities for how it got there. Since copper is smelted to a liquid, unlike solid-state smelted iron, it does not contain many if any slag inclusions. Nor does it corrode and scale in the hearth when heated like iron, so forging copper alone should not produce anything like SGD. Copper is typically forged at lower temperatures than iron, so even the presence of pre-existing slag materials within the hearth should not result in SGD when working copper. Flux is not necessary to protect copper while forging, so any buildup of SAS would be due to inadvertently knocking dirt into the hearth along with degradation of the hearth itself. Small bits of copper might nevertheless come loose in the hearth and become incorporated into the SAS there. If the SAS were to later come into prolonged contact with hot liquid SGD from forging iron, it could all be incorporated into the SGD. So, one possibility for the copper in R-17-6 is that the hearth was used to work copper for a prolonged period, building up a relatively frangible SAS with mostly intact grains and a tiny amount of copper. Then, the forge was used to work iron and high temperatures, generating SGD, which incorporated much of the SAS, including the copper.

Another possibility is that one of the aforementioned elite copper-plated iron objects was dismantled and the iron recycled into a new object in the hearth. In such a case, tiny particles of copper from the object to be recycled could have landed in the hearth and become incorporated in the slag. This possibility raises the question of whether elite goods best known from mortuary contexts were actually regularly recycled, as well as the question of iron stock supply. Recycling iron objects is a good way to deal with a limited supply of iron, but once iron smelting began in the Japanese archipelago, the practice of assiduously recycling iron seems to have fallen by the wayside. Furukawa (2007) places the widespread adoption of these kinds of multi-metal objects no later than MT15 type-phase, which significantly predates the TK43 type-phase of Senbiki Kanakurodani site in Okayama Prefecture, earliest known uncontroversial iron smelting site in the Japanese archipelago. From this perspective, it is plausible that the copper found in R-17-6 came from recycling activities rather than newly producing copper-plated goods.

Slag Number: R-17-7
Section Images: Figures 14-15
AMS Radiocarbon Date:
Conventional radiocarbon age:
1580 ±30 BP

Excavation Context: R-17
Micrographs: Figures 55-57
Typochronological Date (Sue Ware):
TK208-MT15 (mid-5th century through first
half of 6th century)

Calibrated age:
95.4% probability: 1540 – 1404 cal BP
38.6% probability: 1464 – 1415 cal BP
21.1% probability: 1506 – 1478 cal BP
8.5% probability: 1524 – 1512 cal BP

Note: One date was obtained by combining
multiple pieces of charcoal to meet sample
size threshold.

Mass: 298.5g

Surface Charcoal ID:

- 1) Probable *Quercus sect. Prinus*
- 2) Probable *Quercus sect. Prinus*
- 3) Probable *Quercus sect. Prinus*
- 4) *Quercus sect. Prinus*
- 5) Probable *Quercus sect. Prinus*

Magnetic Response: Moderate to strong all
over

Slag Class: SGD

SGD: 93%

SFR: <1%

Metal Detector Response: 6%

Section Porosity: 17%

SAS: 7%

Other: Not Detected

Description

R-17-7 is a large forge slag classified as an SGD-type. It contains a very small amount of SAS on top, which at first gives the appearance of an SGD-B type with an especially short low-temperature work period, however, the SAS on top is mostly vitrified rather than the partial melting of most SAS, which indicates a high temperature rather than a low one. Based on its size and location, this SAS glass probably originated from the melting tip of a tuyere during high temperature operations. Like R-17-5, it is probably the result of refining slaggy iron stock, and given the very similar masses of these slags, they probably represent similar amounts of work, which may mean Ogata ironworkers were refining stock of a relatively standardized size.

On the other hand, R-17-7 is much more magnetic than R-17-5 and elicited a small response from the metal detector. Some magnetite was found in microscopic examination, which probably accounts for most of the magnetism. The metal detector indicates that a small amount of metal is still present in the slag, even though SFR was barely detected in the cross section. Most of the SFR originating from forge refining at high temperatures probably corroded to magnetite. This suggests a different set of conditions for the formation and/or the postdepositional transformations for R-17-7 and R-17-5. Aside from magnetite, microscopic examination found the SGD to consist of fayalite and wustite as expected, and probable goethite was also detected.

Several pieces of charcoal were successfully extracted from slag R-17-7, enabling the identification of the charcoal as well as providing a radiocarbon date. All five of the pieces of

charcoal selected for analysis were identified as either *Quercus sect. Prinus*, or probably *Quercus sect. Prinus*. This section of the genus *Quercus* includes the some of the deciduous oaks of the warm temperate deciduous forest that often make up the secondary forest when primary lucidophyllous forest is disturbed. This section does not include the evergreen oak species. As discussed previously, the availability of *Quercus sect. Prinus* in the vicinity of Ogata in the Kofun Period is expected. According to Ito and Yamada's (2012) analysis of wood use trends, *Quercus sect. Prinus* was not especially favored for any particular use during the Middle and Late Kofun Periods on the Osaka Plain, with the possible exception of pounding implements like rice pestles and mallets, which were still more often made from either evergreen oak or *Quercus sect. Cerris*. In short, harvesting this taxon for fuel was unlikely to breach any conventions, regulations, or laws regarding wood use. Whether this fuel was harvested from coarse woody debris (CWD) or other deadwood, or if a live tree was felled is a separate question. *Quercus sect.* is a very hard wood, and as such difficult to fell. If CWD or deadwood were available, it would be far easier to harvest, so that seems more likely.

The radiocarbon date is somewhat less useful, since a relatively flat portion of the radiocarbon calibration curve during the Kofun Period makes for particularly wide probable date ranges. The 95.4% probability range runs from 410 CE to 546 CE, with the single most probable (38.6%) range within that between 486 CE and 535 CE. The pottery typochronology of Sue ware unearthed from R-17 suggests deposition between the mid fifth century and the first half of the sixth century. The charcoal itself should be somewhat older than the deposition due to the time necessary for the tree to grow. The mean age of trees in the lucidophyllous forest was about 68.49 years, which makes it difficult to narrow the date range or draw other conclusions about harvesting from this data.

It is widely thought that hardwood charcoal is preferable for smelting and refining (poorly defined), but softwood charcoal is preferable for smithing iron stock into objects (Shimazu 2015). The presence of hardwood charcoal in this probable smithing slag does not contradict this hypothesis, but the ease of procurement of hardwood as opposed to softwood in the vicinity of Ogata, as well as wood preferences for other purposes during this period mean that this slag cannot be taken as more than circumstantial evidence for the "hardwood charcoal for refining, softwood charcoal for smithing" hypothesis.

Slag Number: R-17-8

Section Images: Figures 16-17

AMS Radiocarbon Date: N/A

Mass: 668.8g

Magnetic Response: Weak, and only in some parts

Slag Class: SAS-SGD

SGD: 62%

SFR: <1%

Description

R-17-8 is the largest forge slag recovered from R-17 and neatly falls into the SAS-SGD type of slag. Given its size, it may be the result of multiple work sessions making small objects, or a long session working on a single larger object. There is a small amount of SAS on the

Excavation Context: R-17

Micrographs: Figures 58-61

Typochronological Date (Sue Ware):

TK208-MT15 (mid-5th century through first half of 6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 9%

SAS: 38%

Other: Not Detected

bottom of the slag, and it is all agglomerated sand and clay from the hearth itself. The majority of the SAS is in a thick layer on top of the mass of SGD. Regardless of how many work sessions it took to accumulate, this thick layer of SAS represents a lot of low temperature work. This suggests that even once the high temperature gross shaping of the object and material preparation was completed, significant low temperature shaping work was still necessary. This in turn implies a few possibilities: first, the object being made may simply have been quite large, or the object was made of a higher carbon alloy that is best forged at a lower temperature. The largest reasonably common iron objects in the Kofun Period were horse trappings and swords, the former of which are large and have complex shapes, and the latter of which may have had high carbon edges welded to low carbon bodies. Production of either at Ogata is plausible given that worked antler, which was used in sword fittings, has been recovered there, and that horse trappings were among the kinds of iron objects that were made with copper plating.

The high temperature work that generated the SGD may have included some forge refining, if bloomery iron were worked directly from bloom material all the way to a finished object instead of being made into intermediate generic iron stock for a multiple of possible uses. However, since there is slag evidence for refining as a standalone activity, such as R-17-5 and possibly R-17-7, directly working bloom into finished objects seems unlikely during this phase. Instead, the SGD is probably the result of welding activities or simply working low carbon iron at a high temperature during the early stages of smithing to reduce the number of times it needs to be heated.

Slag Number: R-18-1

Section Images: Figures 18-19

AMS Radiocarbon Date:

Conventional radiocarbon age:
1550 ±30 BP

Excavation Context: R-18

Micrographs: Figures 62-64

Typochronological Date (Sue Ware):

MT15-TK10 (first half of 6th century through mid-6th century)

Calibrated age:

95.4% probability: 1528 – 1376 cal BP

50.0% probability: 1520 – 1458 cal BP

15.7% probability: 1421 – 1400 cal BP

825% probability: 1438 – 1434 cal BP

Note: One date was obtained by combining multiple pieces of charcoal to meet sample size threshold.

Mass: 224.9g

Magnetic Response: Weak all over

Slag Class: SGD

SGD: 93%

SFR: <1%

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 13%

SAS: 6%

Other: Not Detected

Description

R-18-1 is a large forge slag classified as an SGD-type. Like R-17-5 and R-17-7, it contains a very small amount of SAS, but almost all of it is attributable to the agglomeration of hearth material rather than the character of the work performed. Like R-17-5, it has low magnetism and no metal detector response, so SFR has probably not been undercounted.

Accordingly, similar to R-17-5 and possibly R-17-7, R-18-1 is appears to be the result of refining slaggy iron stock, even though it is slightly smaller than those examples.

As expected, under microscopic examination, R-18-1 is mostly fayalitic with dendrites of wustite. A tiny amount of magnetite was found, as was metallic iron. Tiny particles of metallic copper were found in two locations, and the identity of the metal was confirmed with EPMA analysis. Copper was also found in R-17-6, but the presence of copper in what appears to be a refining slag is harder to explain, since it is unlikely that bloomery iron or lightly refined iron stock would contain any copper. The lack of SAS suggests that no lower temperature work was done, so if R-18-1 is not actually a refining slag, then an object was made entirely at high temperatures. This may be the case, but would be wasteful of both fuel and iron. The lack of SFR also works against this hypothesis. More likely, the object being made was not a finished product, but an intermediate one, such as rough iron stock, as might result from refining work. Copper could appear in the slag if the intermediate product was made from recycled materials that included copper plated objects.

R-18 has the narrowest typochronological date range of any of the contexts examined in this project, apparently spanning the early and mid-sixth century (MT15 and TK10), still predating the earliest known smelting in the Japanese archipelago (TK43), so the pressure to conserve and recycle iron was likely still present when R-18-1 was formed.

The radiocarbon date obtained from R-18-1 unfortunately does little to illuminate either the date of the slag, or aspects of fuel harvesting since the date range is so wide. The 95.4% probability range is from 422 CE to 574 CE, a period of 152 years. The pottery typochronology indicates that R-18 predates the latter part of that date range a little, but the 50% probability range is from 430 CE to 492 CE, which are reasonable dates for a tree harvested or shedding branches in the first half of the sixth century.

Slag Number: R-18-2

Section Images: Figures 20-21

AMS Radiocarbon Date: N/A

Mass: 16.4g

Magnetic Response: Weak, and only in some parts

Slag Class: SAS

SGD: Not Detected

SFR: Not Detected

Description

R-18-2 is a small flat slag consisting entirely of SAS. It is slightly magnetic due to the small amounts of magnetite and metallic iron that has not been incorporated into the melt because of the relatively low temperature. Aside from the magnetite and metallic iron, R-18-2 consists of unidentified rock, quartz, glass, and some orthoclase. This slag was probably formed through the low temperature forging of a single small piece of iron stock.

Excavation Context: R-18

Micrographs: Figure 65

Typochronological Date (Sue Ware):

MT15-TK10 (first half of 6th century through mid-6th century)

Surface Charcoal ID: N/A

Metal Detector Response: 0%

Section Porosity: 6%

SAS: 100%

Other: Not Detected

Slag Number: R-18-3
Section Images: Figures 22-23
AMS Radiocarbon Date: N/A

Mass: 23.0g
Magnetic Response: None
Slag Class: SAS
SGD: Not Detected
SFR: Not Detected

Description

Slag R-18-3 is also a small flat slag consisting entirely of SAS. Accordingly, microscopic examination was not conducted. Based on its shape, staining, and charcoal inclusions visible in cross section, it does appear to be a forge slag. Like R-18-2, it was probably formed through the low temperature forging of a single small piece of iron stock.

Excavation Context: R-18
Micrographs: N/A
Typochronological Date (Sue Ware):
MT15-TK10 (first half of 6th century through mid-6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 0%
Section Porosity: 6%
SAS: 100%
Other: Not Detected

Slag Number: R-27-1
Section Images: Figures 24-25
AMS Radiocarbon Date:
Sample failed dating

Mass: 21.5g
Magnetic Response: Weak, and only in some parts
Slag Class: SAS
SGD: Not Detected
SFR: Not Detected

Description

Like R-18-2 and R-18-3, R-27-1 is a small slag consisting entirely of SAS. Like R-17-3, it broke apart when cutting for sampling, so no microscopic examination was conducted. The cross section presented is that of the largest single remaining piece, and the remainder is substantially identical in appearance. Unlike other small SAS slags, on close inspection of the cross section, R-27-1 appears to be mainly the SAS formed by the heating of the hearth lining that has become detached from a larger slag. As such, it does not provide much information about ironworking. Radiocarbon dating was attempted on charcoal extracted from R-27-1, but after processing, the sample was too small to date.

Excavation Context: R-27
Micrographs: Figure 66
Typochronological Date (Sue Ware):
TK47-TK43 (late 5th century through late 6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 0%
Section Porosity: 22%
SAS: 100%
Other: Not Detected

Slag Number: R-32-1
Section Images: Figures 26-27
AMS Radiocarbon Date: N/A

Mass: 337.7g
Magnetic Response: Moderate, and only in some parts
Slag Class: SGD-SFR?
SGD: 66%
SFR: 9%

Description

Slag R-32-1 is a large basically plano-convex slag. The bulk of the slag is SGD, but there are also significant proportions of both SAS and SFR. Much of the SAS is located along the bottom and is attributable to the agglomeration of hearth materials to the slag, and the rest of it is in the form of large pebbles still relatively intact inside the SGD core of the slag. They seem too large to be part of a flux, and likely entered the slag by accident. Rather than toward the bottom of the slag, where metallic particles are expected to sink as a large slag accumulates, the SFR is in a thin partial layer on top of the slag, where SAS is typically found in an SGD-B slag. The SFR forms a distinct border with the SGD below it, indicating that it formed when the SGD was cool enough that the SFR would neither sink nor be incorporated. The SFR layer is quite porous and many of the pores contain charcoal inclusions. This overall structure suggests that the slag formed as a result of normal high temperature operations followed by fast, hot forging of a small object at the same hearth that was concluded quickly enough to disallow the mixing of the SFR into the SGD.

At the microscopic level, the SGD is fayalitic with variable amounts of wustite. Grains of magnetite and unincorporated scale are occasionally found, particularly in the areas within or bordering SAS. A small amount of pearlite was found within iron corrosion products (probably goethite), and its location suggests that the corrosion was acting on a larger piece of metal that included the pearlite. Accordingly, unlike R-17-5, this pearlite can be understood to have originated with the working stock, indicating the use of some steel in forging, or at least inhomogeneous stock with areas of significant carbon content. Grains of metallic iron are also present. Unidentified stone and glass are also present in the SAS areas.

Toward the bottom of the slag, several small inclusions of metallic copper were also found. Their location there may be due to sinking through the liquid SDG, or it may be that they entered the slag early in the high temperature operations, possibly from the surface of a copper-plated object undergoing recycling. The idiosyncratic structure of this slag and subsequent uncertainty about its formation processes limit the conclusions that can be drawn about the presence of copper. Like the other slags with copper inclusions, this one predates the beginning of iron smelting in Japan, since the typochronological date for R-32 extends from TK47 to MT85, one phase before the TK43 found at Senbiki Kanakurodani.

Excavation Context: R-32
Micrographs: Figures 67-69
Typochronological Date (Sue Ware):
TK47-MT85 (late 5th century through second half of 6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 0%
Section Porosity: 16%
SAS: 24%
Other: Not Detected

Slag Number: R-32-2
Section Images: Figures 28-29
AMS Radiocarbon Date:
Conventional radiocarbon age:
1640 ±30 BP

Excavation Context: R-32
Micrographs: Figure 70
Typochronological Date (Sue Ware):
TK47-MT85 (late 5th century through second
half of 6th century)

Calibrated age:
75.6% probability: 1614 – 1514 cal BP
59.0% probability: 1570 – 1522 cal BP
16.0% probability: 1464 – 1416 cal BP
Mass: 146.4g

Surface Charcoal ID:
1) *Ilex*
2) *Quercus sect. Prinus*
Metal Detector Response: 0%

Magnetic Response: Weak, and only in some
parts

Slag Class: SAS-M? SGD-B?
SGD: 28%
SFR: 10%

Section Porosity: 16%
SAS: 62%
Other: Not Detected

Description

R-32-2 is a medium-sized slag composed mostly of SAS but with a significant portion of SGD, and a full 10% of SFR. Its structure is similar to R-17-6 in that the SAS completely surrounds a core of SGD, but in this case the SAS is of nearly identical thickness on all sides of the slag. R-32-2 is much smaller than R-17-6, so the possible scenario for producing R-32-2 is unlikely. The SAS is melted together to a higher degree here than on most other slags, especially on top and bottom, and forms a distinct boundary with the SGD, indicating distinct formation events. Perhaps Soullignac's (2017) hypothesis about restarting a cold hearth applies here, but without further experimentation it can only be tentatively suggested for R-32-2's origin.

The SFR is unique in this slag in that two large pieces of corroded metal are clearly visible in the cross section. The metal is completely corroded, likely only leaving a shell of corrosion products, so it is not detected by a metal detector, and the slag's magnetic response is weak and only produced by magnetite. Microscopic examination reveals its composition to be as expected: fayalite and wustite alongside rare small grains of metallic iron, magnetite, slivers of forge scale, and glass, quartz, and unidentified stone.

Fortunately, there was enough exposed to conduct both taxon identification and radiocarbon dating. One piece of charcoal was determined to be *Quercus sect. Prinus*, and the other belongs to the genus *Ilex*. *Ilex*, or holly, has several species in Japan and lives in both temperate deciduous forests and lucidophyllous forests. Its wood is notably hard, and it was occasionally used for agricultural and construction tools but it was never a common choice (Ito and Yamada 2012). Much like *Quercus sect. Prinus*, its presence is expected in the area during this period, and its use for non-fuel purposes appears to be limited. Harvesting *Ilex* either through the collection of deadwood or felling was unlikely to be prohibited or restricted, making it a good choice for fuel.

The charcoal sample submitted for radiocarbon dating was not identified, but the 75.6% probability date range is between 336 CE and 436 CE, while the probability of a date between 486 CE and 534 CE is only 16.0%. This means that the wood used for charcoal was somewhat older when it was harvested than seen with R-17-7.

Slag Number: R-32-3
Section Images: Figures 30-31
AMS Radiocarbon Date: N/A

Mass: 265.8g
Magnetic Response: Strong, and only in some places
Slag Class: SGD-B
SGD: 90%
SFR: <1%

Description

Slag R-32-3 is a rather large, typical SGD-B slag consisting of a thin layer of SAS over a thick body of SGD. The magnetic response of R-32-3 is stronger than expected for an SGD-B slag, but the strong magnetic response is localized. While very little SFR was detected, the metal detector response indicates that at least some metal lost in forging remains intact inside the slag. This would also account for the localized strong magnetism. The microstructure of the slag is also typical, with fayalite, wustite, rare grains of metallic iron, and corrosion products all present. R-32-3 was probably formed through a period of high temperature work to perform any welding and gross shaping before a short period of low temperature work to bring the object to a near-finished form.

Excavation Context: R-32
Micrographs: Figures 71-73
Typochronological Date (Sue Ware): TK47-MT85 (late 5th century through second half of 6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 15%
Section Porosity: 26%
SAS: 9%
Other: Not Detected

Slag Number: R-32-4
Section Images: Figures 32-33
AMS Radiocarbon Date: N/A

Mass: 258.0g
Magnetic Response: Moderate all over
Slag Class: SAS-SGD
SGD: 54%
SFR: <1%

Description

Slag R-32-4 is broadly similar to other SAS-SGD slags recovered from excavation 84-1 like R-17-8, R-17-6, and R-17-2, albeit with a very high metal detector response indicating the presence of intact metal despite almost none appearing in the cross section. Remarkably, this slag has pockets of SAS in various sizes interleaved throughout the SGD body. This suggests that despite its relatively large size, the slag formed over a short period of time, as the SAS has not been fully incorporated into the SGD. This slag nevertheless likely formed like the other SAS-SGD slags, only faster.

The microstructure of the slag is typical, with fayalite and wustite alongside some corrosion products. However, remnants of acicular cementite were found within multiple zones of corrosion. This is not surprising considering the metal detector response, but it is remarkable for the rarity of this preservation among these slags. Like the pearlite found in slag R-32-1, this has implications for the stock used by ironworkers at Ogata: it suggests that hypereutectoid steel

Excavation Context: R-32
Micrographs: Figures 74-76
Typochronological Date (Sue Ware): TK47-MT85 (late 5th century through second half of 6th century)
Surface Charcoal ID: N/A
Metal Detector Response: 23%
Section Porosity: 10%
SAS: 46%
Other: Not Detected

was present in some quantity, even if it was just particularly high carbon areas of inhomogeneous stock.

Slag Number: R-32-5

Section Images: Figures 34-35

AMS Radiocarbon Date:

Conventional radiocarbon age:

1710 ±30 BP

Excavation Context: R-32

Micrographs: Figures 77-80

Typochronological Date (Sue Ware):

TK47-MT85 (late 5th century through second half of 6th century)

Calibrated age:

95.4% probability: 1699 – 1552 cal BP

52.7% probability: 1625 – 1564 cal BP

15.5% probability: 1690 – 1670 cal BP

Mass: 631.3g

Magnetic Response: Moderate all over

Slag Class: SGD

SGD: 93%

SFR: <1%

Surface Charcoal ID:

1) Could not be identified

Metal Detector Response: 0%

Section Porosity: 17%

SAS: 6%

Other: <1%

Description

R-32-5 is a very large SGD slag. It broke while cutting for sample preparation, and while the microscope sample-side of the slag was comparatively intact, the side to be used for analysis of the cross section fell apart around a large hollow inside, and could not be easily reconstructed. Therefore the cross section analysis is only of the largest piece of the broken slag, which corresponds to roughly 25% of the original cross sectional area. Even so, an examination of the other pieces confirms that it overwhelmingly consisted of SGD and had only a small amount of SAS on top, and not continuous or concentrated in one place like SGD-B slags. This macrostructure suggests that R-32-5 is the result of forge refining.

The microstructure of the slag consists of glass, probable quartz, and unincorporated scale in the SAS, and hercynite along with the expected fayalite, wustite, and rare grains of metallic iron. Hercynite is indicative of an aluminum-rich environment, and given that it has not been found in other slags from excavation 84-1, the source of the aluminum is probably not the local soil or flux additions, but the original smelting slag present as inclusions in the iron. This bolsters the interpretation of R-32-5 as a refining rather than a smithing slag.

A piece of charcoal extracted from the slag's surface was submitted for identification, but it could not be identified. Even so, the radiocarbon date from another piece of charcoal indicates that the wood used is considerably older than R-32. There is a 95.4% probability that the charcoal dates to between 251 AD and 398 AD, and a 52.7% chance that it dates to between 325 AD and 386 AD.

Slag Number: R-32-6
Section Images: Figures 36-37
AMS Radiocarbon Date:
Conventional radiocarbon age:
1720 ±30 BP

Excavation Context: R-32
Micrographs: Figures 81-84
Typochronological Date (Sue Ware):
TK47-MT85 (late 5th century through second
half of 6th century)

Calibrated age:
95.4.0% probability: 1702 – 1559 cal BP
42.3% probability: 1628 – 1569 cal BP
22.3% probability: 1692 – 1666 cal BP
3.6% probability: 1660 – 1655 cal BP

Note: One date was obtained using the micro-sample AMS method (MSAMS) after combining multiple pieces of charcoal to meet the micro-sample size threshold.

Mass: 453.8g

Surface Charcoal ID:

1) *Quercus sect. Prinus*

Magnetic Response: Weak, and only in some parts

Metal Detector Response: 0%

Slag Class: SGD-B

Section Porosity: 25%

SGD: 83%

SAS: 16%

SFR: <1%

Other: Not Detected

Description

R-32-6 is a very large SGD-B slag with about half of its SAS content the result of the hearth material agglomerating on the bottom of the slag. The rest of the SAS is spread over part of the top of the slag in typical form. It was likely formed through a process of high temperature work followed by low temperature work, or perhaps multiple work sessions that ended in lower temperature forging. Much of the microstructure is typical of SGD with fayalite and wustite, and corrosion products are present near the surfaces of the slag. However, this slag contains many more and considerably larger particles of metal. These particles are round, indicating that they were originally molten droplets of metal from working the stock at very high temperatures. Some of these droplets contain pearlite and cementite, while others are pure ferrite. The steely droplets have carbon contents in the range of 0.3% and 1.5%. These droplets were not found inside corrosion products, but inside the SGD block amidst the fayalite and wustite. Because of this location, it is unclear whether the stock originally contained that much carbon or if the molten metal quickly absorbed carbon from the hearth gases or charcoal.

A single piece of charcoal extracted from R-32-6 was identified as *Quercus sect. Prinus*. Several other pieces were combined to form a micro-sample for radiocarbon dating. The range of 95.4% probability for the date is between 248 CE and 391 CE, with a 42.3% probability of being between 322 CE and 381 CE. Like the other charcoal dates from R-32 slags, this date range indicates that the charcoal came from a very old tree.

Slag Number: R-32-7
Section Images: Figures 38-39
AMS Radiocarbon Date:
Conventional radiocarbon age:
1800 ±30 BP

Excavation Context: R-32
Micrographs: Figures 85-86
Typochronological Date (Sue Ware):
TK47-MT85 (late 5th century through second
half of 6th century)

Calibrated age:
79.0% probability: 1820 – 1690 cal BP
34.7% probability: 1742 – 1698 cal BP
15.5% probability: 1810 – 1754 cal BP

Note: One date was obtained using the micro-sample AMS method (MSAMS).

Mass: 104.6g

Magnetic Response: Moderate all over
Slag Class: SAS-SGD
SGD: 58%
SFR: <1%

Surface Charcoal ID:
1) Could not be identified
2) Could not be identified
3) Could not be identified
Metal Detector Response: 20%
Section Porosity: 19%
SAS: 42%
Other: Not Detected

Description

R-32-7 is a medium-sized plano-convex slag classed as SAS-SGD. Like several other slags, it broke during cutting for microscopy samples, so the cross section analysis is limited to the largest remaining piece. Even so, this piece does appear to be representative of R-32-7 as a whole. As seen on other slags, the SAS is largely surrounding the SGD core of the slag, but like slag R-32-4, the SAS is also interwoven through the SGD. Its formation process was probably very similar: work was completed quickly and the SAS was only partially incorporated into the SGD before the hearth was extinguished and cooled down.

Microscopic examination shows that fayalite and wustite predominate in the SGD area, and corrosion products are visible in some places. Within some of these corrosion products are remnants of acicular cementite. This strengthens the body of evidence for the presence of at least some high carbon alloy at Ogata.

Three pieces of charcoal were submitted for identification, but none could be identified. Enough carbon was obtained from another piece of charcoal for a micro-sample to be radiocarbon dated. The analysis revealed a 79.0% probability that the charcoal dated to between 130 CE and 260 CE. This is a large range, but it is clear that this is the oldest charcoal successfully dated from a slag unearthed at Ogata, and indicates that the tree that supplied the charcoal was over two hundred years old when the wood was harvested.

Slag Number: R-38-1

Section Images: Figures 40-41

AMS Radiocarbon Date:

Sample failed dating

Mass: 54.7g

Magnetic Response: Moderate all over

Slag Class: SAS-SGD

SGD: 58%

SFR: <1%

Excavation Context: R-38

Micrographs: Figure 87

Typochronological Date (Sue Ware): N/A

Surface Charcoal ID: N/A

Metal Detector Response: 5%

Section Porosity: 9%

SAS: 42%

Other: Not Detected

Description

R-38-1 is small SAS-SGD slag. Like R-32-4, the slag both surrounds the SGD core and is seemingly interwoven with it. Due to its small overall size, the bottom layer of SAS is probably the result of the hearth material thermally agglomerating to the bottom of the SGD rather than from forging activities. Even so, the interleaving of SAS and SGD indicates that this was formed quickly. Microscopic examination shows a significant quantity of glass in the SAS, which probably originates from the melting tip of the tuyere rather than from hearth material or additions by the smith. In addition to magnetite, the glass also contains metallic iron, which is more usually found in the SGD block. Scale is also visible in the SAS, but the SGD is unremarkable, consisting of fayalite and wustite. Unfortunately attempts to date charcoal extracted from R-38-1 failed, and in the absence of typochronological dating for R-38, it is difficult to place R-38-1 in chronological context.

A Possible Kiln Feature

In order to investigate the potential kiln feature from context R-18, four fragments of charcoal and one charred peach pit were submitted for radiocarbon dating. The results of these analyses are as shown in table 1. All four charcoal samples returned dates in the range of the fifth through mid-sixth centuries, which when accounting for the age of the trees agrees with the date estimated by pottery typochronology for R-18. Since as a seed, the peach pit was formed over a much shorter period than the multiple years' growth included in most wood charcoal, it should theoretically return a more precise date for the deposit. However, the peach pit dated to approximately a century later, between the mid-sixth and mid-seventh centuries. It may be that the peach pit is truly from the earliest part of that date range, and all the charcoal is actually from the very end of its date range, but this seems very unlikely. It is easier to think that the peach pit is actually an intrusive element in the deposit. Radiocarbon dating cannot confirm that the kiln-like feature of R-18 was actually used as a charcoal kiln for ironworking. However, it is clear that whatever its purpose, this feature involved the production of a large quantity of fuel, either producing it for another purpose, or consuming it to make other products. As such, it is representative of how competing demands for forest resources were resolved at Ogata during the fifth and sixth centuries.

Table 1: Radiocarbon Dating

Sample	Part	Date Ranges
1	Charred Peach Pit	Conventional Age: 1470±30 95.4% Probability (95.4%) 1405-1305 cal BP (545-645 CE) 68.2% Probability (68.2%) 1384-1320 cal BP (566-630 CE)
2	Charred Wood	Conventional Age: 1570±30 95.4% Probability (95.4%) 1526-1386 cal BP (424-564 CE) 68.2% Probability (24.9%) 1515-1485 cal BP (435-465 CE) (22.4%) 1476-1449 cal BP (474-501 CE) (14.2%) 1420-1403 cal BP (530-547 CE) (6.7%) 1443-1434 cal BP (507-516 CE)
3	Charred Wood	Conventional Age: 1580±30 95.4% Probability (95.4%) 1526-1386 cal BP (420-556 CE) 68.2% Probability (28.1%) 1515-1485 cal BP (435-465 CE) (23.6%) 1476-1450 cal BP (474-500 CE) (9.0%) 1420-1410 cal BP (530-540 CE) (7.4%) 1442-1434 cal BP (508-516 CE)
4	Charred Wood	Conventional Age: 1600±30 95.4% Probability (95.4%) 1534-1405 cal BP (416-545 CE) 68.2% Probability (32.0%) 1454-1415 cal BP (496-535 CE) (23.4%) 1501-1472 cal BP (449-478 CE) (12.7%) 1525-1509 cal BP (425-441 CE)
5	Charred Wood	Conventional Age: 1600±30 95.4% Probability (95.4%) 1534-1405 cal BP (416-545 CE) 68.2% Probability (32.0%) 1454-1415 cal BP (496-535 CE) (23.4%) 1501-1472 cal BP (449-478 CE) (12.7%) 1525-1509 cal BP (425-441 CE)

Chaînes Opératoires of Ironworking

The chaîne opératoire is a useful and flexible tool for archaeologists to examine technological processes. This project expands the use of the concept to examine the ties between ironworkers at Ogata during the fifth and sixth centuries AD. In order to do that, the ironworking *chaînes opératoires* must be extended to include practices of fuel procurement on the landscape and examined for change over time. It is tautological, but a useful reminder that the only parts of the *chaînes* that can be analyzed are the portions that about which there is empirical knowledge as well as theoretical. That is to say, that reconstructed *chaînes* are always incomplete, but even an incomplete or abbreviated *chaîne* is a useful analytical tool. The key is to recall that a *chaîne opératoire* is not only the physical activities of making, but the knowledge involved as well. This includes both “know that” -type knowledge and the embodied, habitual, unconscious “know-how” of actually accomplishing a material task. This project is fundamentally concerned with the former in evidence for knowledgeable management of forest resources through technological practices occurring at the forge hearth.

At Ogata, ironworkers were engaged in various ironworking tasks and production, so there were multiple *chaînes opératoires* for ironworking at any given time. This makes it somewhat difficult to pinpoint changes in practice without extensive knowledge of the range of tasks and products undertaken at the site. Unfortunately, those aspects of ironworking at Ogata are not completely understood, complicating the investigation of continuity and change.

Five chronologically overlapping contexts of the Ogata site provide an approximation of a diachronic series. R-17, R-18, R-32, and R-27 were probably deposited in roughly that order, but unfortunately there is no precise temporal information about R-38. The number of slags appropriate for analysis from each context also differs, with R-27 and R-38 notably deficient. Only three slags from R-18 were analyzed, but its comparatively brief period of deposition and inclusion of a pyrotechnical feature make it a valuable source of data bridging R-17 and R-32.

The results of previous analyses can also enrich the interpretation of this project’s data, but despite all the attention Ogata has received as a large-scale ironworking site, the overwhelming majority of analyses concern only the mid-sixth century and later, notably after the beginning of smelting in the archipelago and the concomitant reduction in the value of iron. Even so, Osawa performed chemical analysis of two slags from excavation 84-1 prior to this project. Based on his criteria for classifying slags as “refining” or “forging” slags, he characterized a 90g slag from the Layer C context R-30, which is thought to be from the mid-sixth century, as a refining slag, and drew the same conclusion about a 133.5g slag from the Layer B context R-41, dating to the late sixth century (2003). This does confirm the continuity of forge refining as one of the ironworking practices at Ogata. Beyond this, Shimazu (2015) examined 37 pieces of charcoal from slags unearthed in excavation 84-1, though he does not mention which contexts they came from. He was only able to classify the charcoal as conifer or hardwood rather than any specific taxa, but he found that five pieces were from conifers, 30 were from hardwood taxa, and two were unidentifiable. These results as well as those from this project show that hardwoods were more commonly used, but Shimazu’s data does have a higher proportion of conifer charcoal than seen in this data. It is difficult to draw reliable conclusions without more precise chronological data, but since more slags unearthed in excavation 84-1 were from Layer B than from Layer C, Shimazu’s data may be indicative of a shift toward increasing conifer usage from the mid- to late sixth century onward.

Examining the data gathered for this project reveals additional continuities and changes in ironworking practices at Ogata. Slag types were generally consistent across time; reflecting

refining, recycling, and forging simple objects requiring no high temperature operations as well as ones that required extensive high temperature operations before a later stage of lower temperature forging. Furthermore, the materials used remained consistent: slaggy bloom or iron stock, recycled iron objects, and even some higher carbon stock. Practices surrounding the use of copper are somewhat murky, but also appear to be consistent over time. Slags that consist of SGD seemingly jacketed in SAS are difficult to explain, but their presence is nevertheless consistent over time.

The most notable change in slags is the emergence in R-32 of slags with interleaving SAS and SGD surrounded by SAS. The best explanation for these slags' formation is an increased work pace and/or fast cooling that does not give enough time for SAS to melt into and become incorporated into the SGD. This increase in speed of cooling could be the result of quickly extinguishing the hearth after work, or as simply working harder to complete the work as quickly as possible. Both these options would theoretically lead to a decrease in the fuel used. It seems as though completing a task faster may require higher temperatures to ensure the task is completed in less time, but the slags' morphology demonstrates that it is not the case. Speed could be achieved through the introduction of new tools or the use of (more) assistants to strike the hot iron. The crystal structure of the slags should also show signs of faster cooling, but the crystal habits and grain sizes of both fayalite and wustite vary significantly even within a single slag, and are not a reliable indicator of the overall speed of work.

These new slags appear alongside the same SGD-B and SAS-SGD slags that were present from R-17, so the new fuel-saving practices were not universally employed, but are nevertheless tied to changes on the forest landscape. Fuel taxa choice may have shifted toward conifers from the mid-sixth century onward, but prior to then, changes were subtler. Charcoal fragments identified from slags belong to taxa that were not much used in other contexts, like *Quercus sect. Prinus*. This appears to be consistent over time, however the age of the trees drastically increased in R-32. Chronological precision is difficult in light of the varying typochronological breadth of each context as well as the wide radiocarbon date ranges owing to the calibration curve, however, the trees used for charcoal in R-17 and R-18 were on the order of 50 to 150 years old. Trees in that age range should not be uncommon when the mean age of trees in the forest is just under 70 years.

In R-32, the age of trees used for charcoal is multiple centuries. This indicates that there were still some very old trees living nearby Ogata, suggesting a deep old-growth forest. However, the apparent preferential harvesting of these old, massive trees also implies that other sources were becoming scarce and new resources needed to be found. This may have taken the form of harvesting older trees in the traditional wood gathering area that were previously ignored due to the difficulty of felling them or even out of respect for their age and majesty. Another possibility is that the old trees were on land that was clear-cut for another purpose, such as agricultural development, leaving a temporary surplus of fuel wood. However, if this were the case, then younger trees should also be represented. A third possibility is that trees had to be gathered from up the slope of the Ikoma Mountains. Dealing with this comparatively difficult terrain may have made it worthwhile to seek out particularly large trees to provide a larger supply for a given amount of effort. This does not seem especially likely, since moving logs downhill from the mountains was surely easier (if more dangerous) than transporting them over flat land. A fourth possibility is that these older trees were preferentially killed in extreme weather events like typhoons, making them more available for harvesting. Were that the case, the very old wood should also be common in earlier phases since there was no major change in

typhoon frequency or intensity until the Final Kofun Period. Of these possibilities, the preference for older trees in R-32 is best explained by declining stocks of easily obtainable wood for making charcoal.

The co-occurrence of declining fuel wood availability and the appearance of faster, more fuel-efficient forging may simply be an illusion owed to chronological imprecision, but that is no more likely than the alternative. Two stages at opposite ends of an extended generalized *chaîne opératoire* for ironworking changed in apparent concert, both concerned with fuel availability. Ironworkers undoubtedly understood both their fuel requirements and fuel availability. When fuel procurement strategies had to change and required more effort, they changed their technical practices to be more efficient with respect to fuel. This is a response to changes on the landscape that the ironworkers contributed to, and indicates previous poor management of resources. Instead of altering their forging practices, the ironworkers could have chosen to do less ironworking or to negotiate for a larger share of wood resources with other fuel-using craftspeople like the glassmakers at Ogata Minami, but these were probably not practical options given the proximity to the highest elites in the land and their assumed control over the workshop's activities. Their other alternative was to continue consuming resources at the same rate, further accelerating landscape change, but they instead chose to change the way they worked.

Conclusion

This chapter presented the analysis of twenty forge slags from five contexts from the 84-1 excavation of Ogata spanning the middle of the fifth century through the first half of the sixth century. These analyses revealed aspects of ironworking at Ogata like the kinds of work performed, the kinds of materials used in terms of both fuel and metal stock, and confirmed the presence of copper in some *chaînes opératoires*, either in the production of copper-plated iron objects, or the use of them as material for recycling. Analysis of charcoal from a potential kiln added to the picture of fuel use in ironworking even if the feature cannot be confirmed to be a charcoal kiln for ironworking. The results of the limited number of directly relevant previous analyses of 84-1 ironworking remains are generally in agreement with the new analyses presented here.

These results were used to partially reconstruct generalized *chaînes opératoires* of ironworking that extend into fuel procurement and by extension landscape management. The continuities and changes between the *chaînes opératoires* revealed the probable knowledgeable engagement with landscape management activities through fuel harvesting practices as well as the adoption of faster, more fuel-efficient forging practices over time.

Chapter 9: Conclusion

This study has clarified the relationship between a small group of ironworkers and their forest landscape and built a model for investigating the relationship between craft production and landscape change more broadly. Specifically, it examined the role of fifth and sixth century ironworkers at the Ogata archaeological site in Osaka Prefecture, Japan, in creating and responding to anthropogenic changes to the forest landscape, and the technological choices they made in managing that landscape.

Scholars have long pointed to metallurgical activities as factors in environmental transformations, but these studies have focused on smelting and refining activities, while disregarding smaller scale activities like smithing. Ogata, a large-scale ironworking site of the Middle and Late Kofun Periods located in Kashiwara City, Osaka Prefecture, Japan, has been excavated sporadically since the early 1980s, and the accumulated finds and data offer insight into questions of the reciprocal and knowledgeable influences between ironworkers and their local forest landscape.

This dissertation approached this issue through reconstructing *chaînes opératoires* of ironworking, and extending them to encompass fuel procurement activities on the landscape. The knowledge involved in each step in a *chaîne opératoire* provides a way to investigate not only the choices that actors make, but also the motivation behind them. However, this was only possible with detailed knowledge of the craft as well as the landscape. In addition to the material characteristics and natural processes of the landscape, an appropriate understanding of the general nature of relationships between human activities and landscape transformation. This project adopted the research program of historical ecology as a lens through which to view the empirical evidence of landscape transformation and ironworking activities.

A close examination of available evidence of the landscape of the Osaka Plain near Ogata revealed that the fifth and sixth centuries were climatically similar to the twentieth century in terms of temperature and typhoon strikes, albeit with a cold period in the sixth century and an increase in typhoon frequency and possibly intensity toward the end of that period. Paleovegetation data are unavailable for Ogata and its immediate vicinity, but data from nearby sites indicates the landscape was heterogeneously forested with some areas open for agricultural or elite mortuary purposes. This forest was composed of both lucidophyllous and warm temperate deciduous taxa, ongoing but not overwhelming disturbance from human activities. This forest was productive enough to support the ironworking activities at Ogata, but other pyrotechnical crafts as well as household needs and regional trade in lumber put additional pressure on forest resources.

This project analyzed twenty forge slags from Ogata, representing the period from the middle of the fifth century through the first half of the sixth century. These analyses supported earlier hypotheses about ironworking at Ogata, namely that hardwoods were the preferred fuel, that at least some of the iron stock was actually steel, and that forge refining was carried out there. New results include the confirmation metallic copper in slags, indicating that copper was worked in some capacity at Ogata.

Analysis of slag internal macrostructure and radiocarbon dating of charcoal extracted from slags as well as a possible kiln feature revealed that the age of trees used for charcoal production increased significantly during the period of context R-32's deposition. This demonstrates that there were still some very old trees living nearby Ogata, but also that the need to harvest them arose, most likely due to decreased availability of younger wood from previous

sources. At the same time, a new slag form emerged that suggests an increase in the speed of work or at least faster cooling upon completing work. Either possibility would entail somewhat reduced fuel expenditure compared to prior practices.

These changes both indicate a concern with fuel availability for ironworkers, and reflect their prior insufficient management of forest resources, and a choice to economize with respect to fuel. This was not the only option available to ironworkers; they could have continued to use the same amount of fuel, further accelerating the apparent decrease in fuel availability over time, or negotiated for greater access at the expense of other fuel-users. However, it appears that found that introducing new ironworking techniques was the best way to manage the forest and the competing interests in its resources.

Beyond these results and establishing a *chaîne opératoire* approach as a viable model for investigating human-landscape relationships, this project also revealed several avenues for future research. Mori, the other major Kofun Period ironworking site in Osaka Prefecture, will be an excellent comparative case for Ogata using the same methodology and analytical techniques. At Ogata, additional research is necessary to clarify the role of copper and potentially copper-plated iron artifacts in the production and circulation of iron goods. Finally, this project revealed the need for additional experimental work on slag formation processes. It remains unclear how thick layers of sandy-clayey slag (SAS) can remain after the subsequent deposition of molten liquid slag that freezes to dense gray slag (SGD). Further work exploring the effects of postdepositional corrosion processes on metallic iron inclusions in slag will permit more precise linkage between slag formation processes already revealed through modern experimental and ethnoarchaeological research, and slags unearthed from archaeological contexts.

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Figures

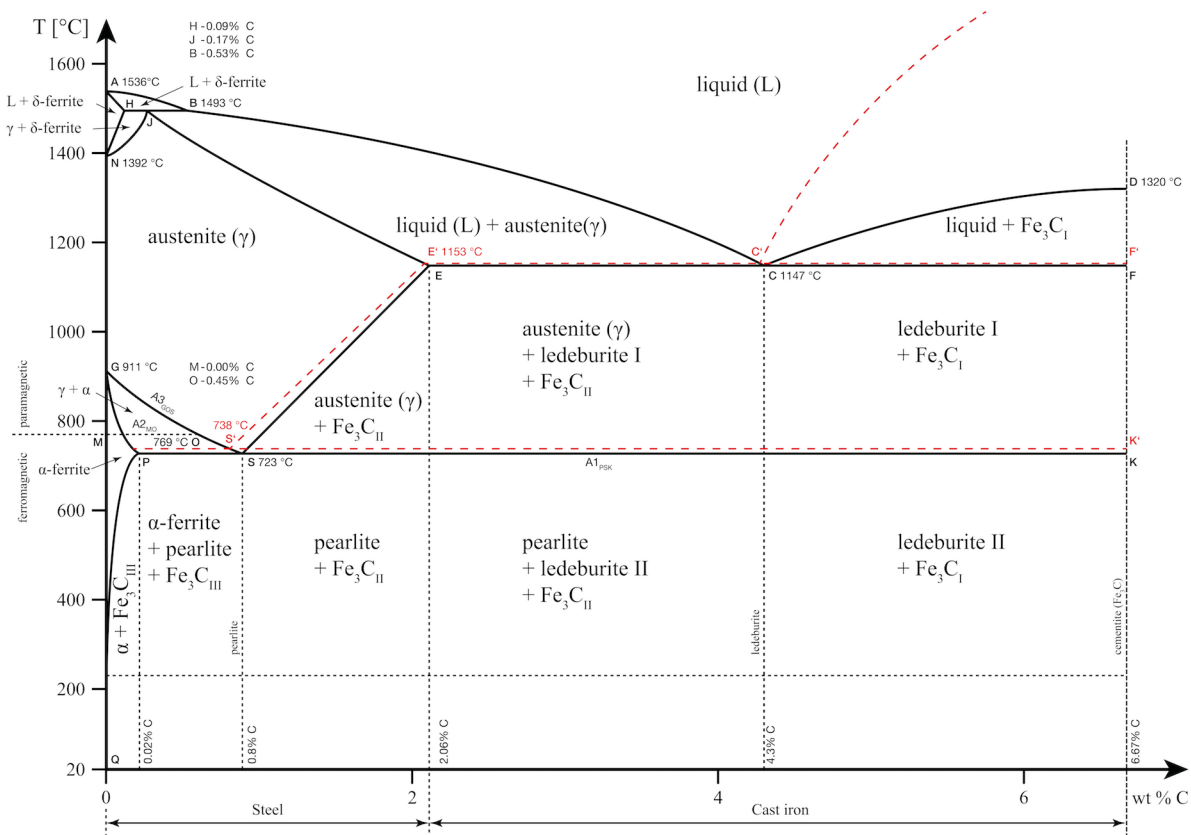


Fig. 1: Iron-Carbon Phase Diagram

Diagram by AG Caesar - Own workLäpple, Volker - Wärmebehandlung des Stahls Grundlagen, Verfahren und Werkstoffe 8. Auflage, Seite 55ff. Weißbach, Wolfgang - Werkstoffkunde Strukturen, Eigenschaften, Prüfung 17. Auflage, Seite 76ff. http://www.chemie.de/lexikon/Eisen-Kohlenstoff-Diagramm.html#Darstellung_der_Phasen_im_Eisen-Kohlenstoff-Diagramm, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=76922696>



Fig. 2: R-17-1 Cross Section

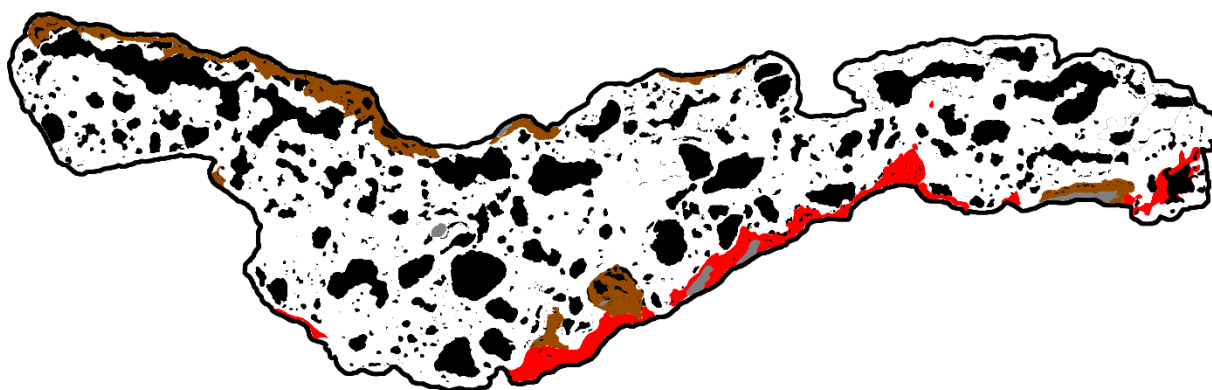


Fig. 3: R-17-1 Material Map

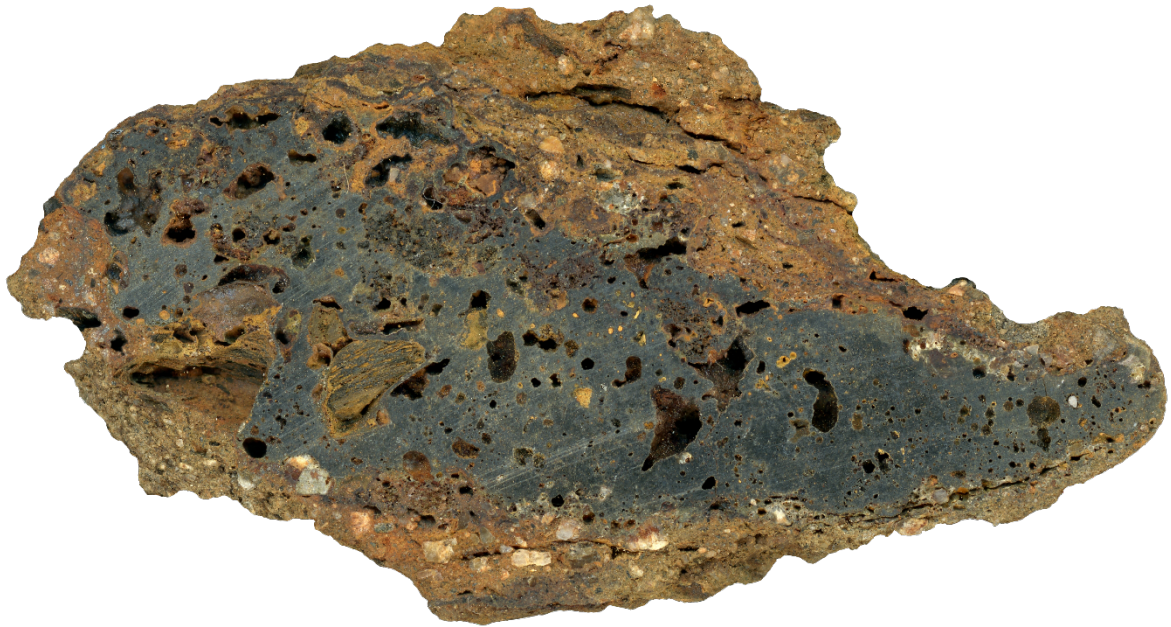


Fig. 4: R-17-2 Cross Section

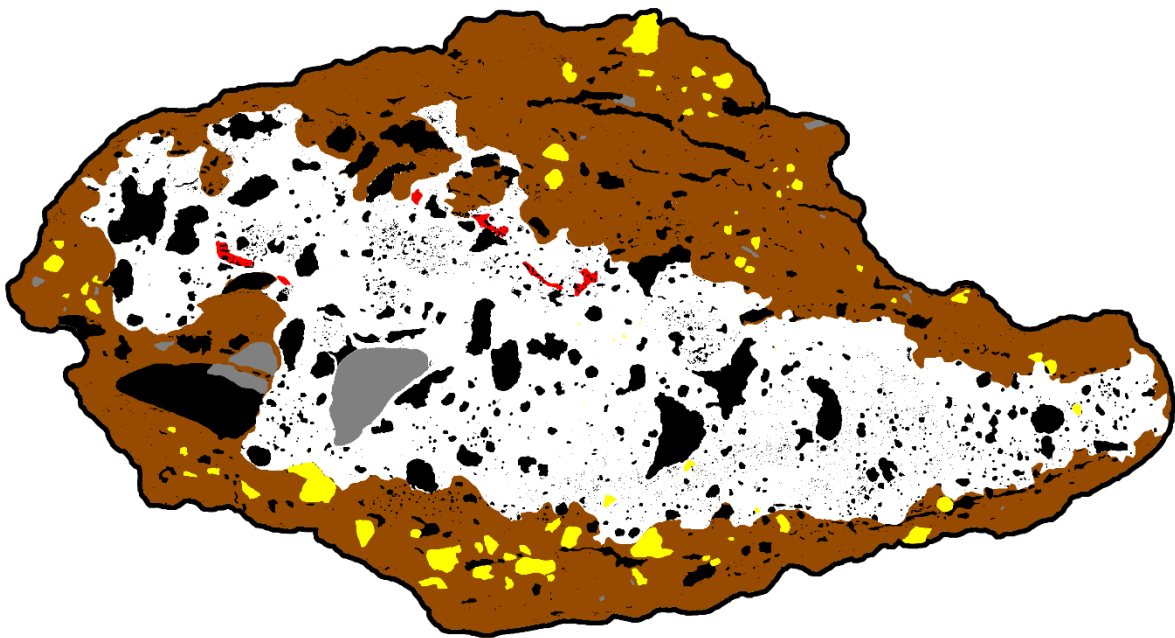


Fig. 5: R-17-2 Material Map



Fig. 6: R-17-3 Cross Section

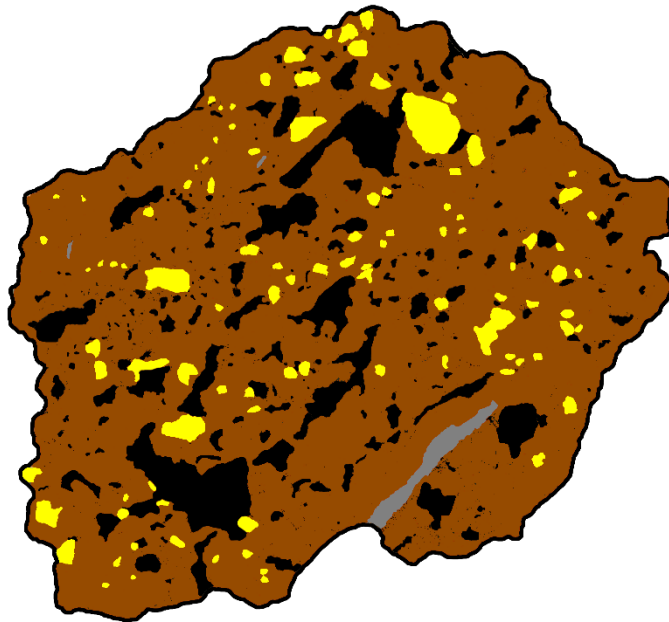


Fig. 7: R-17-3 Material Map

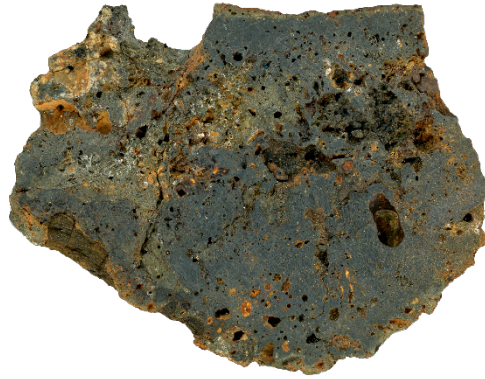


Fig. 8: R-17-4 Cross Section

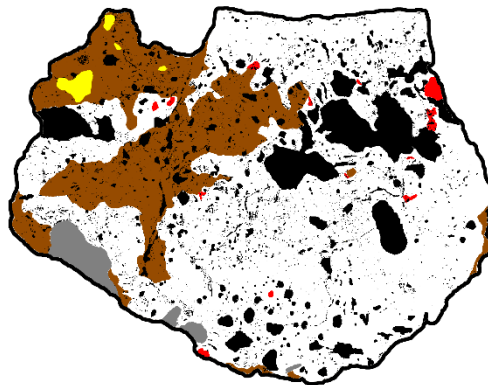


Fig. 9: R-17-4 Material Map



Fig. 10: R-17-5 Cross Section



Fig. 11: R-17-5 Material Map

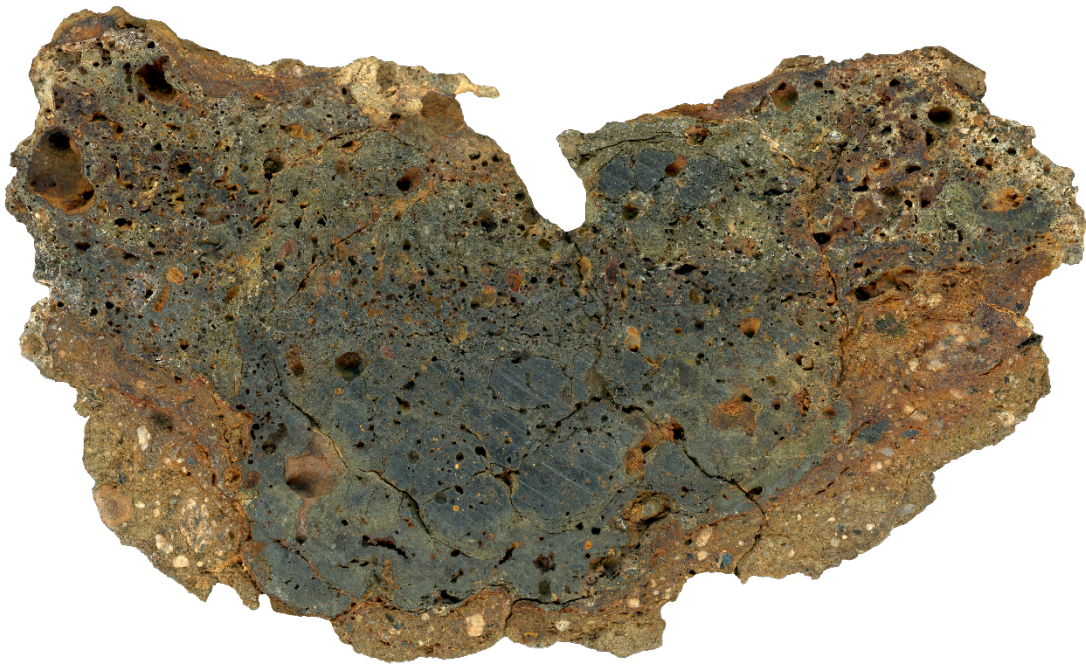


Fig. 12: R-17-6 Cross Section

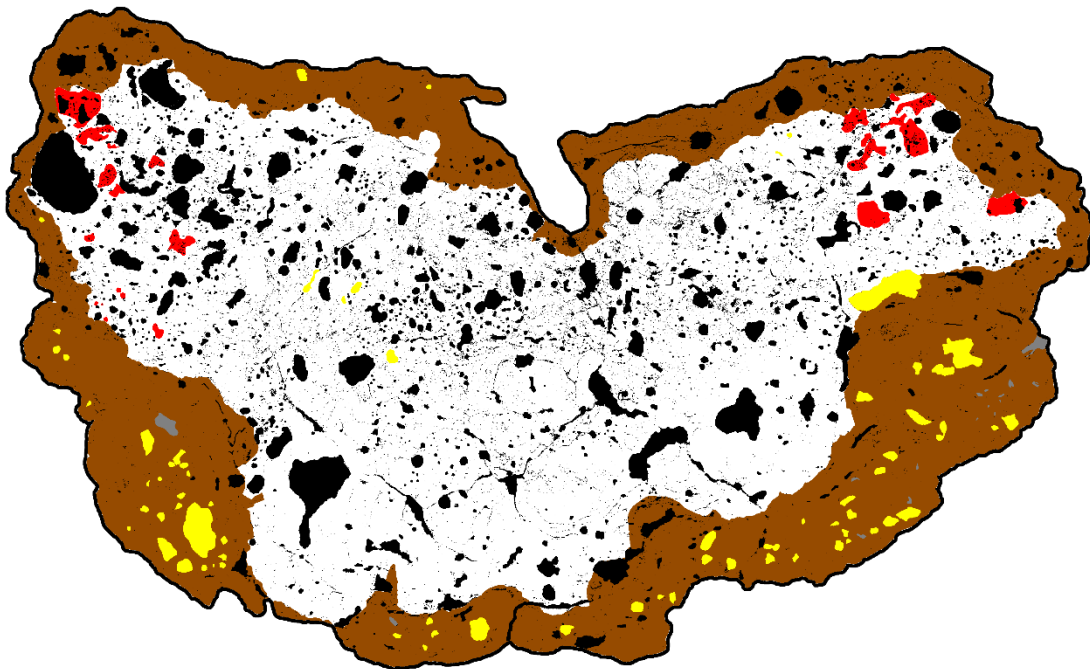


Fig. 13: R-17-6 Material Map

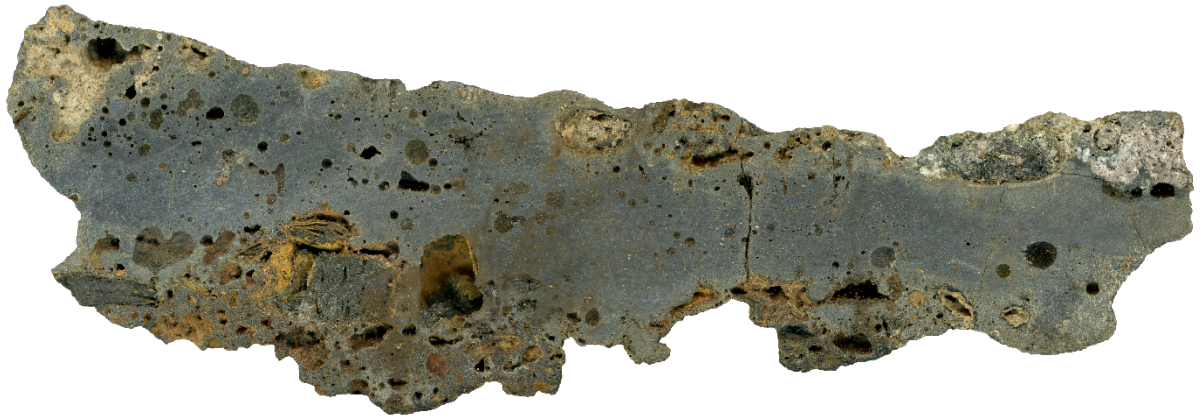


Fig. 14: R-17-7 Cross Section



Fig. 15: R-17-7 Material Map

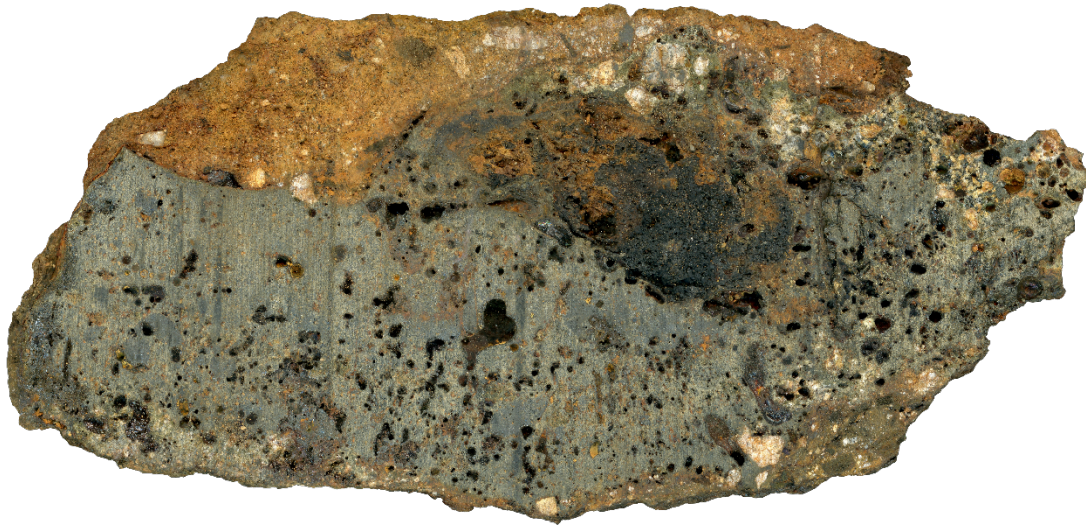


Fig. 16: R-17-8 Cross Section

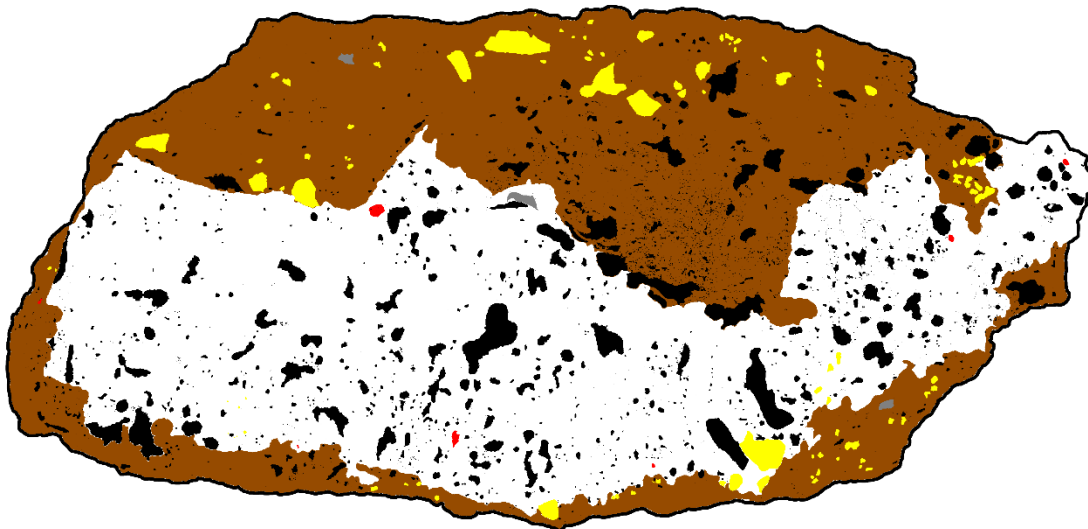


Fig. 17: R-17-8 Material Map

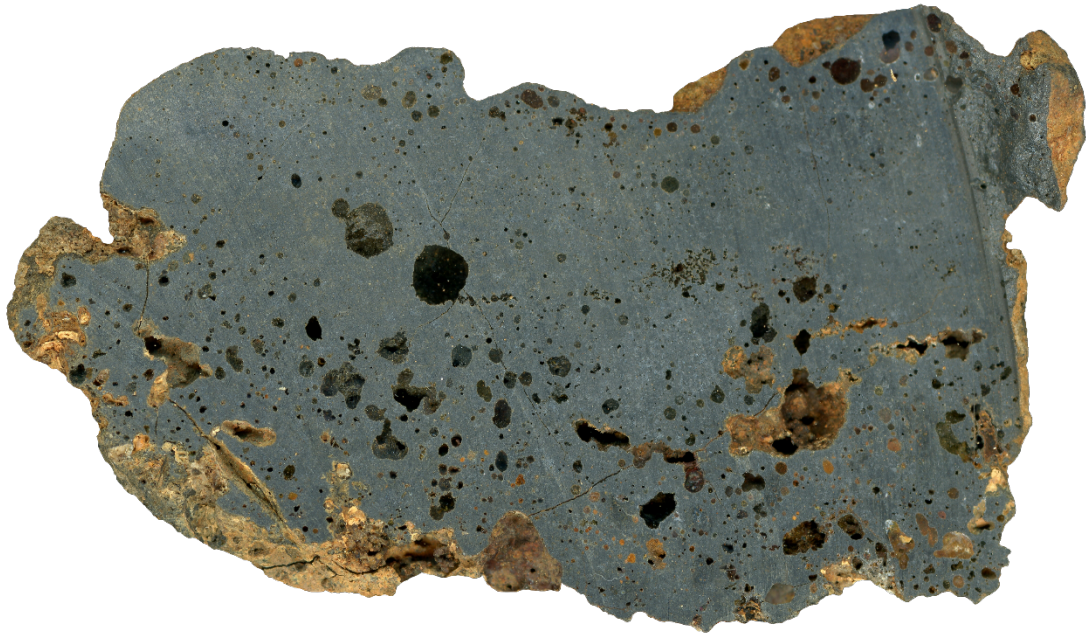


Fig. 18: R-18-1 Cross Section

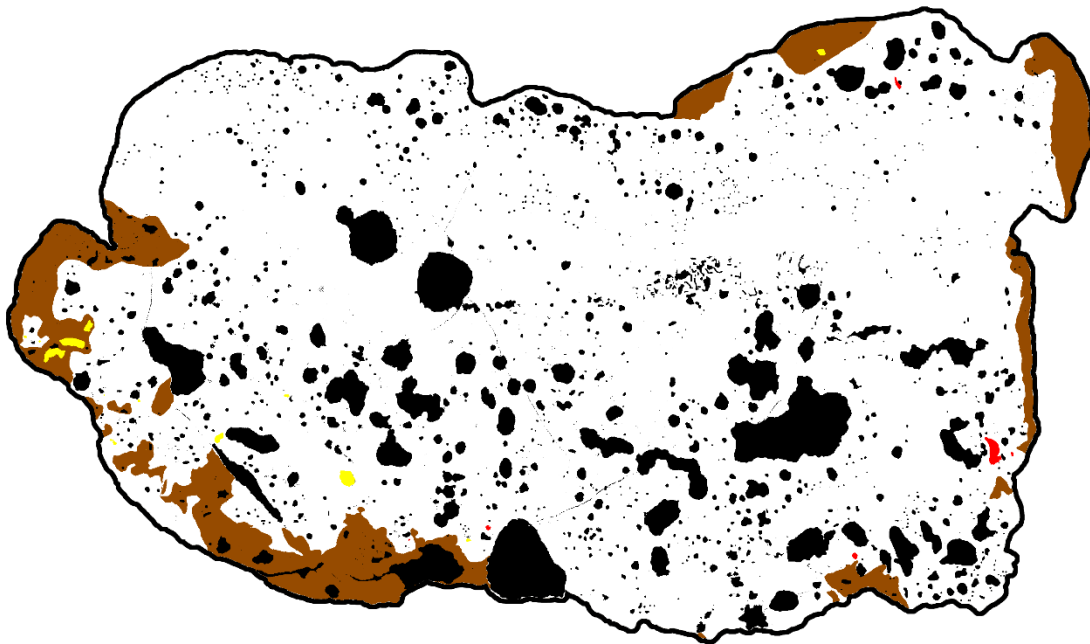


Fig. 19: R-18-1 Material Map



Fig. 20: R-18-2 Cross Section

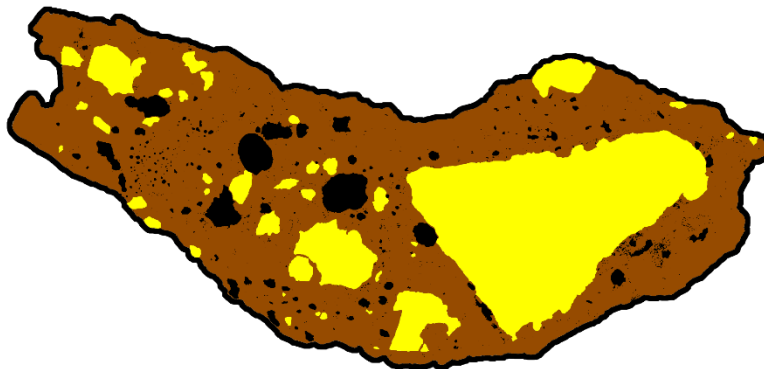


Fig. 21: R-18-2 Material Map



Fig. 22: R-18-3 Cross Section

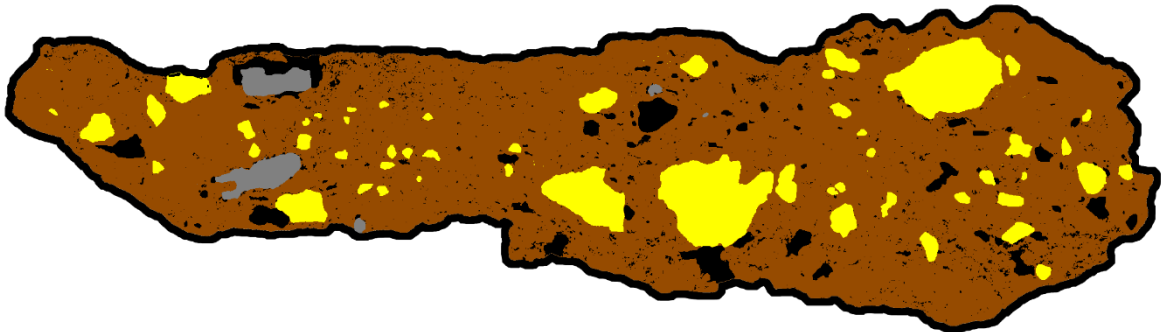


Fig. 23: R-18-3 Material Map



Fig. 24: R-27-1 Cross Section

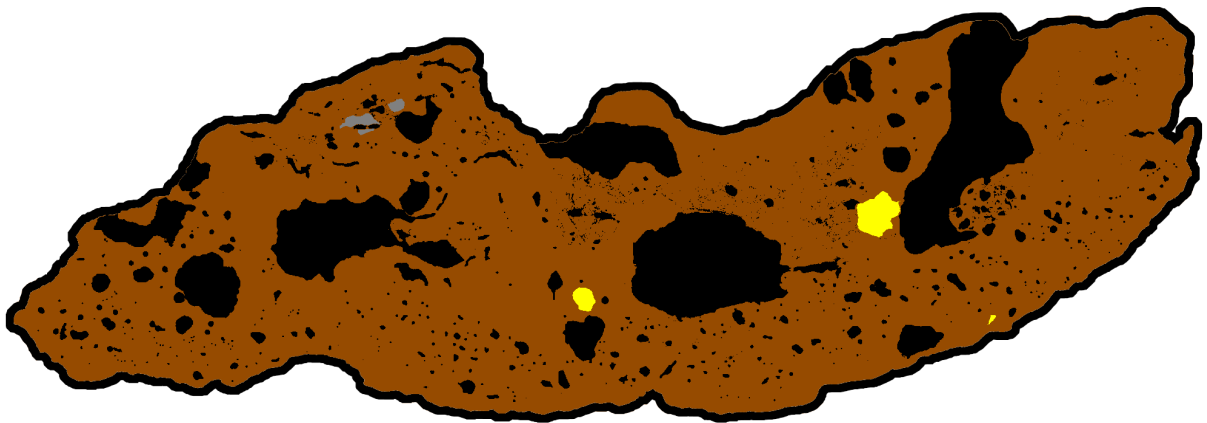


Fig. 25: R-27-1 Material Map

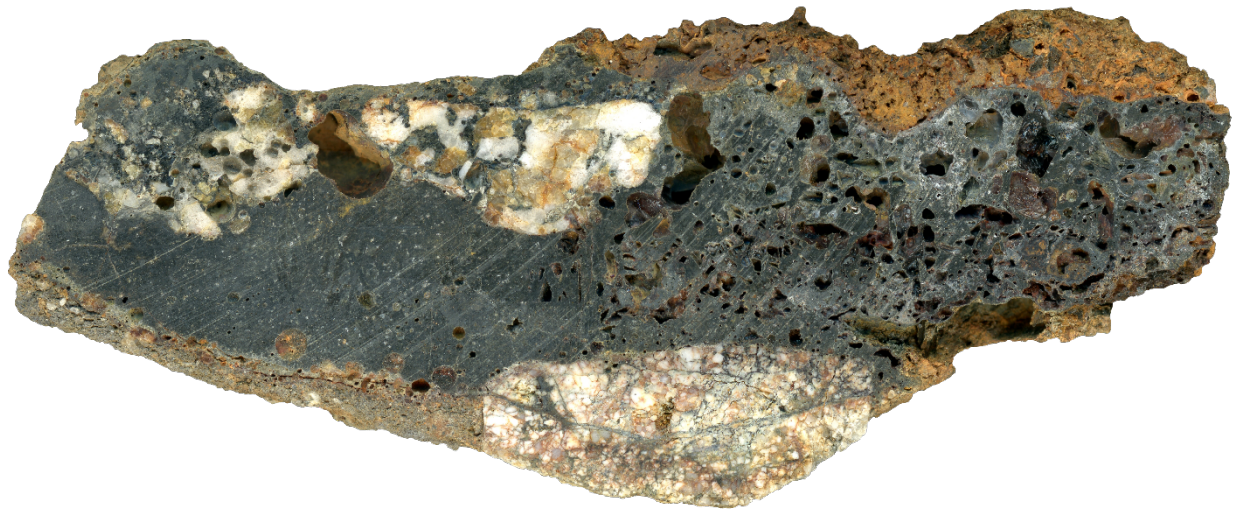


Fig. 26: R-32-1 Cross Section

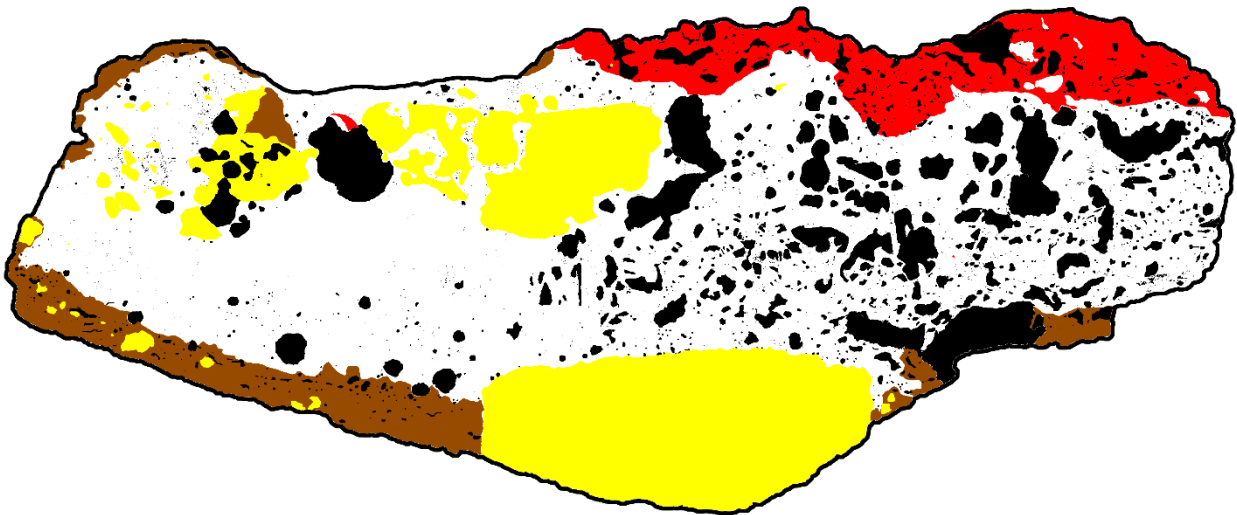


Fig. 27: R-32-1 Material Map



Fig. 28: R-32-2 Cross Section



Fig. 29: R-32-2 Material Map

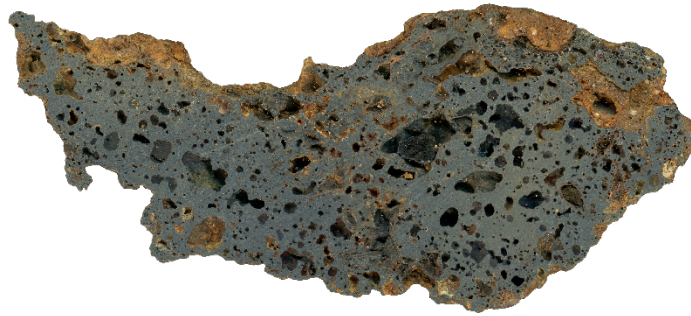


Fig. 30: R-32-3 Cross Section

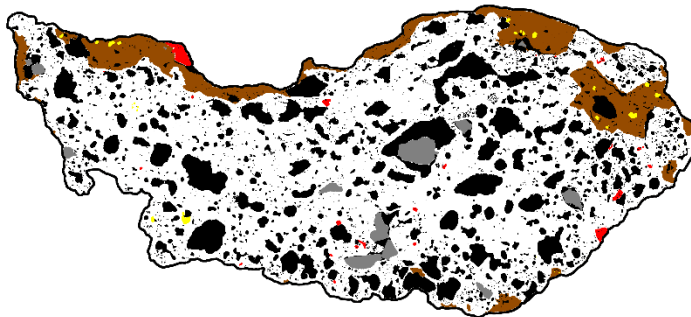


Fig. 31: R-32-3 Material Map



Fig. 32: R-32-4 Cross Section

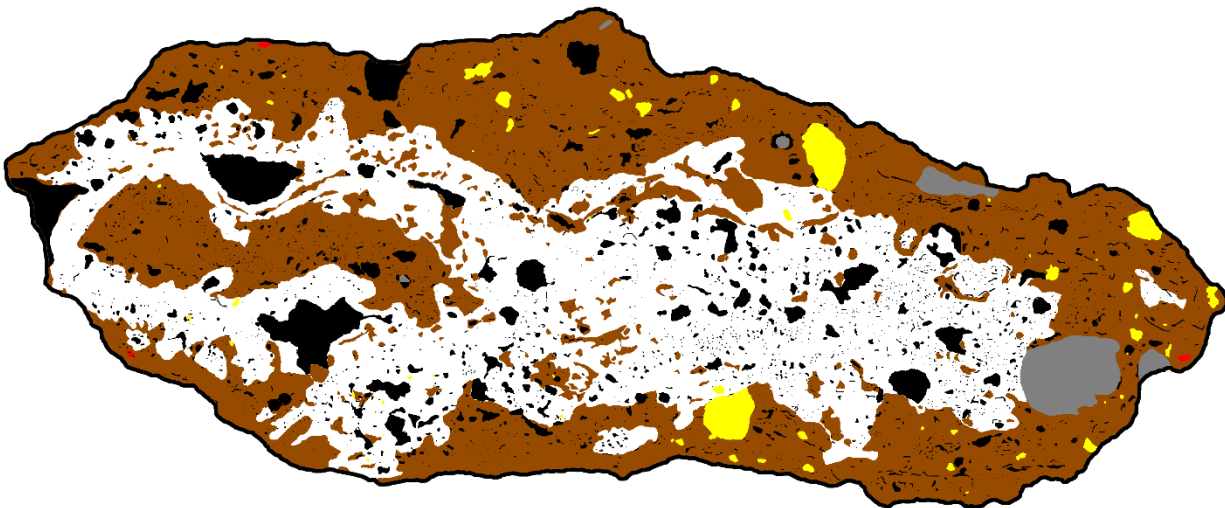


Fig. 33: R-32-4 Material Map

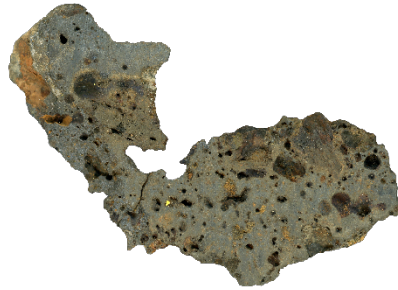


Fig. 34: R-32-5 Cross Section

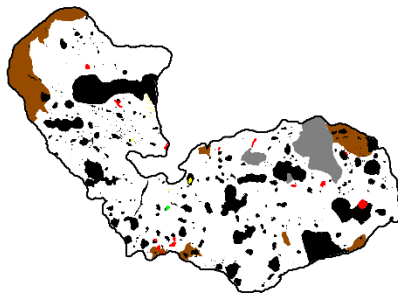


Fig. 35: R-32-5 Material Map



Fig. 36: R-32-6 Cross Section

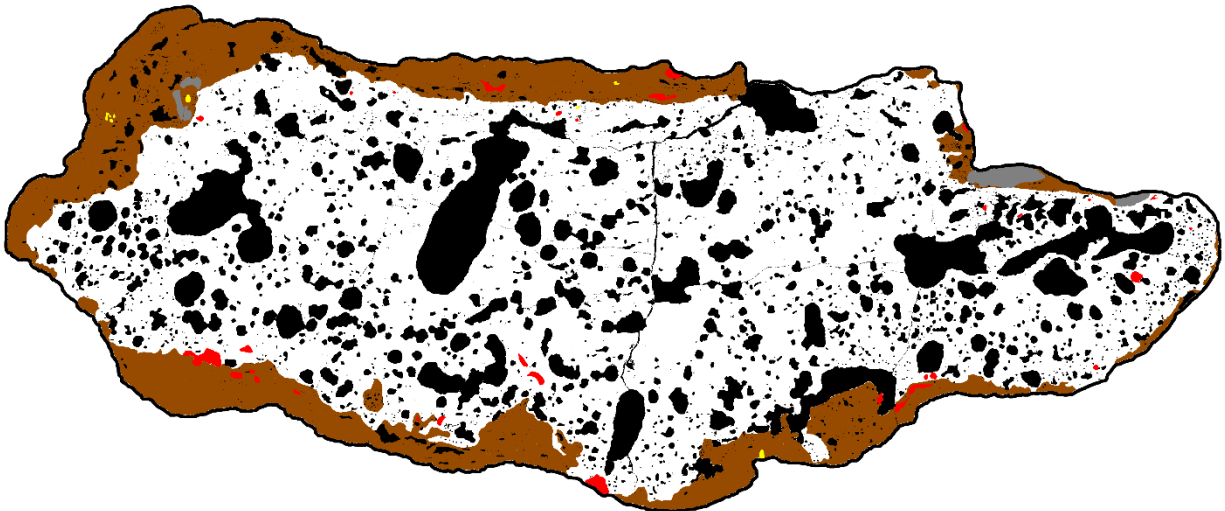


Fig. 37: R-32-6 Material Map



Fig. 36: R-32-7 Cross Section

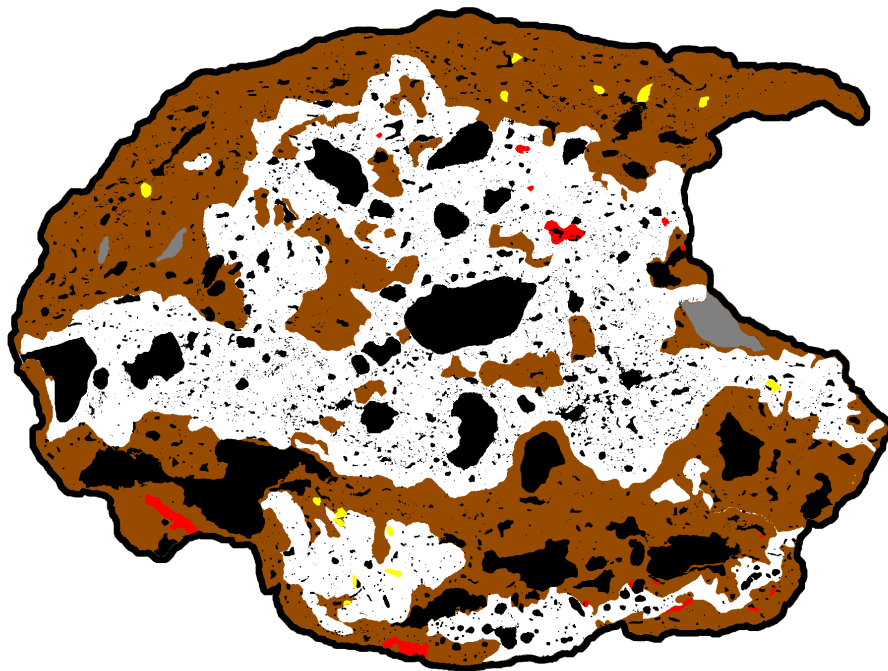


Fig. 39: R-32-7 Material Map

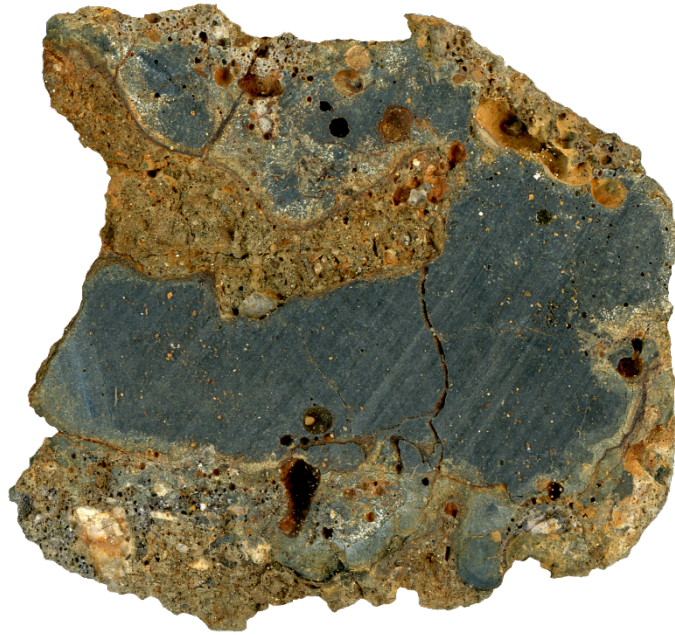


Fig. 40: R-38-1 Cross Section

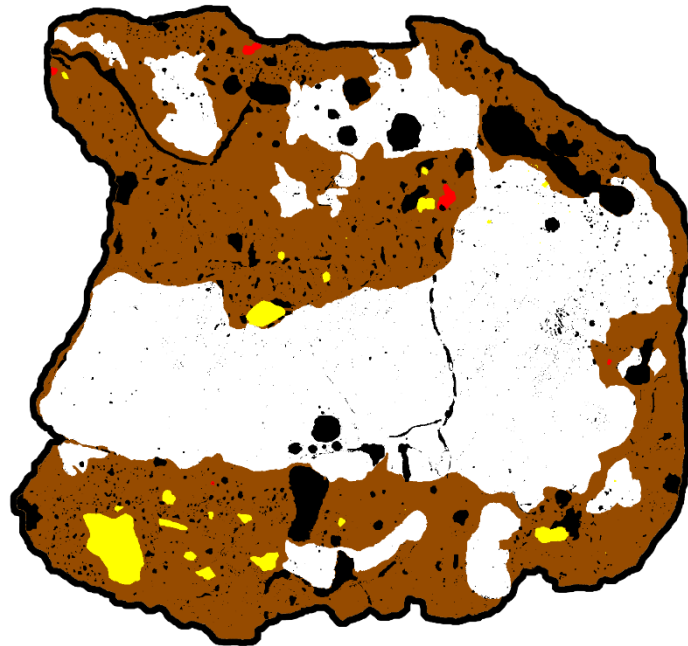


Fig. 41: R-38-1 Material Map

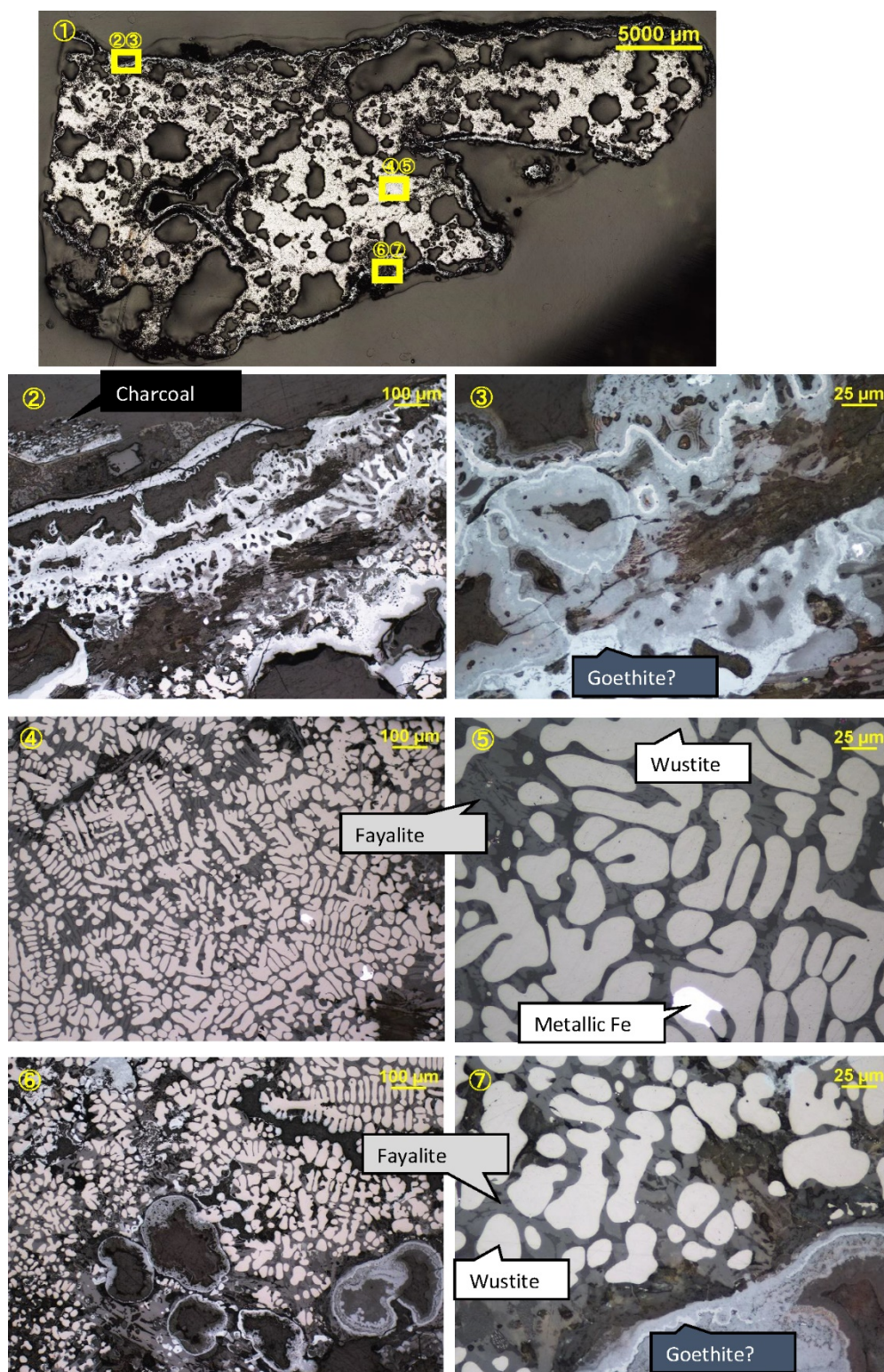


Fig. 42.1-7: R-17-1 Sub-section 1 Micrographs

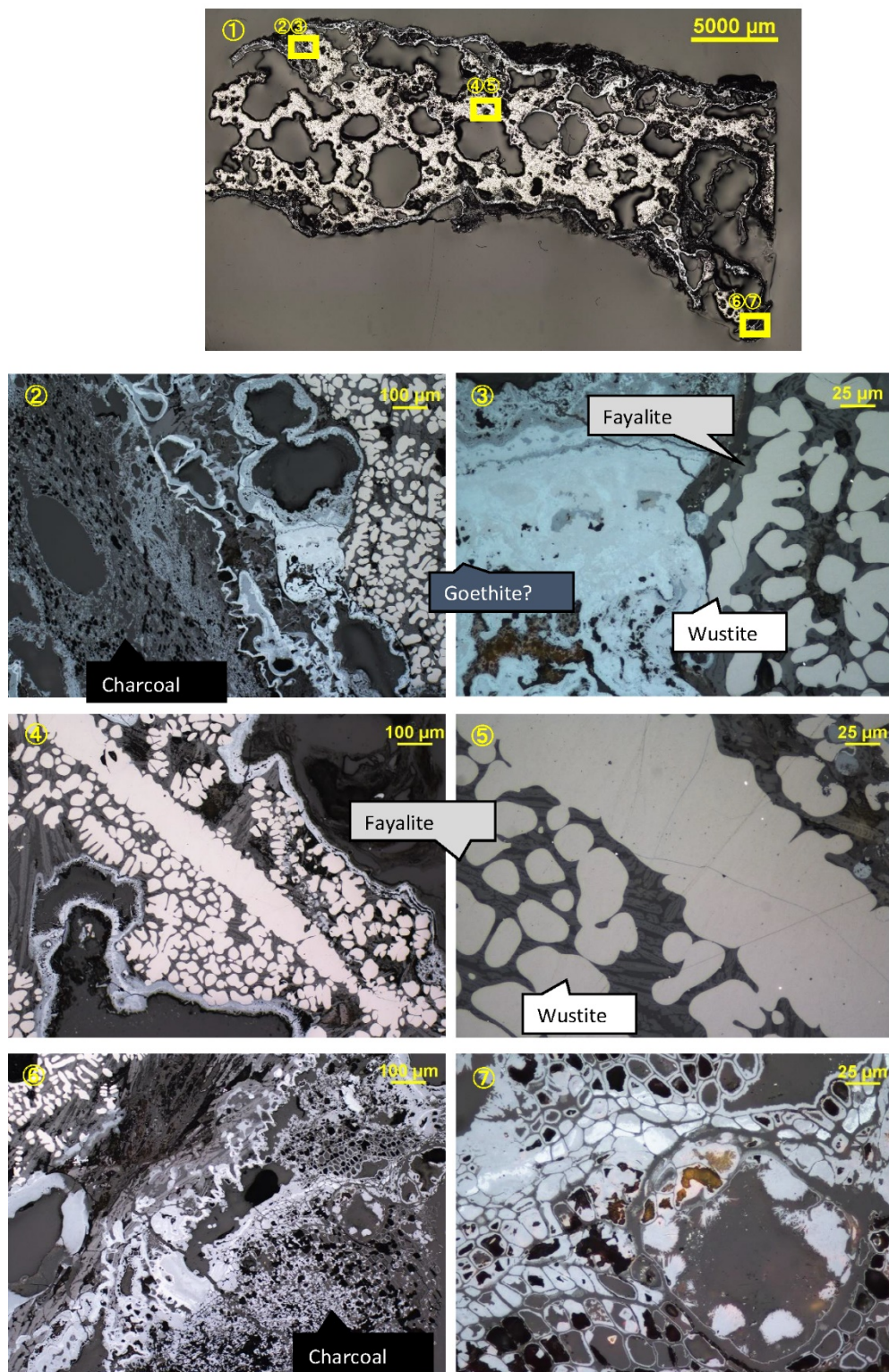


Fig. 43.1-7: R-17-1 Subsection 2 Micrographs

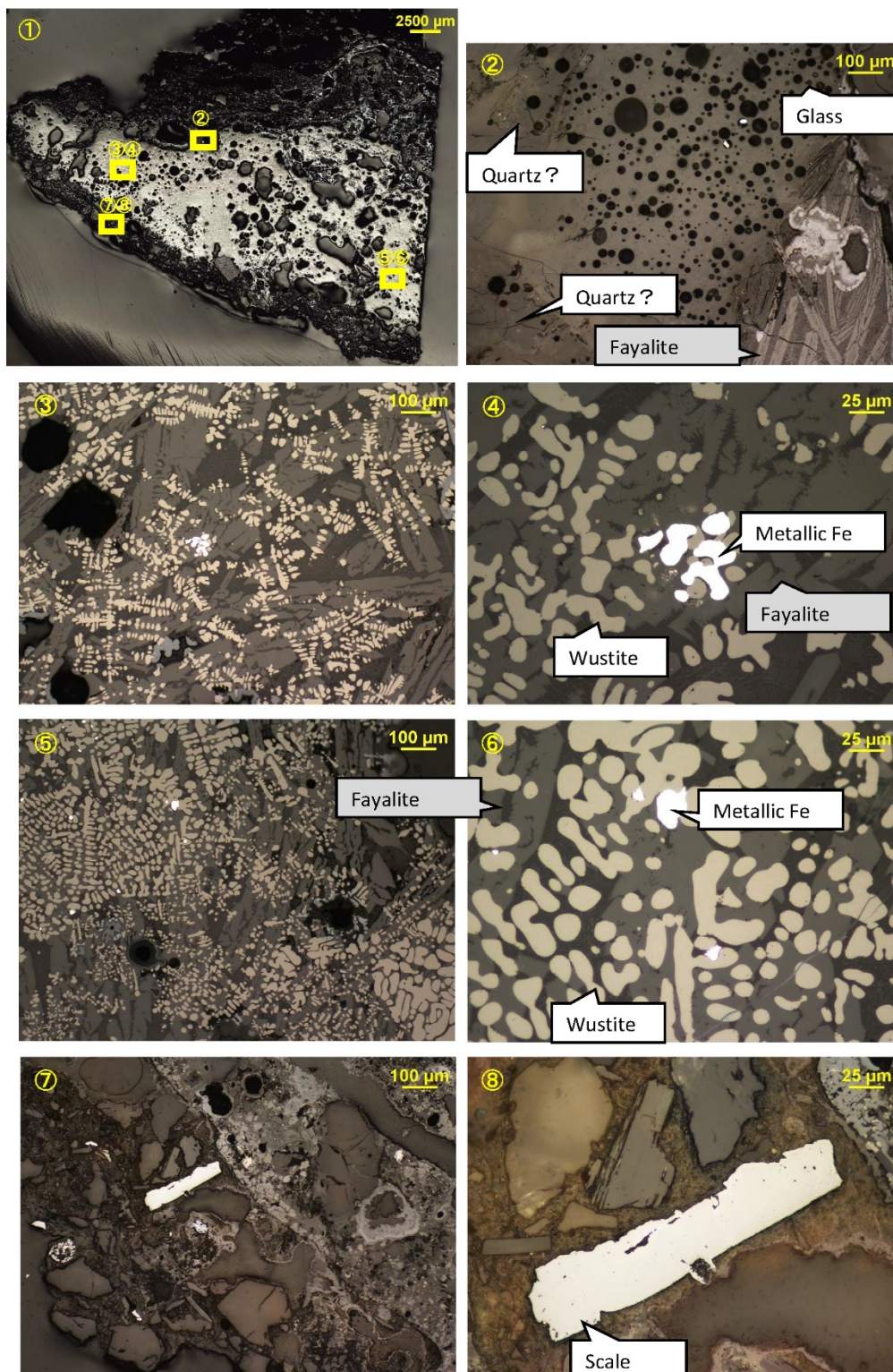


Fig. 44.1-8: R-17-2 Subsection 1 Micrographs

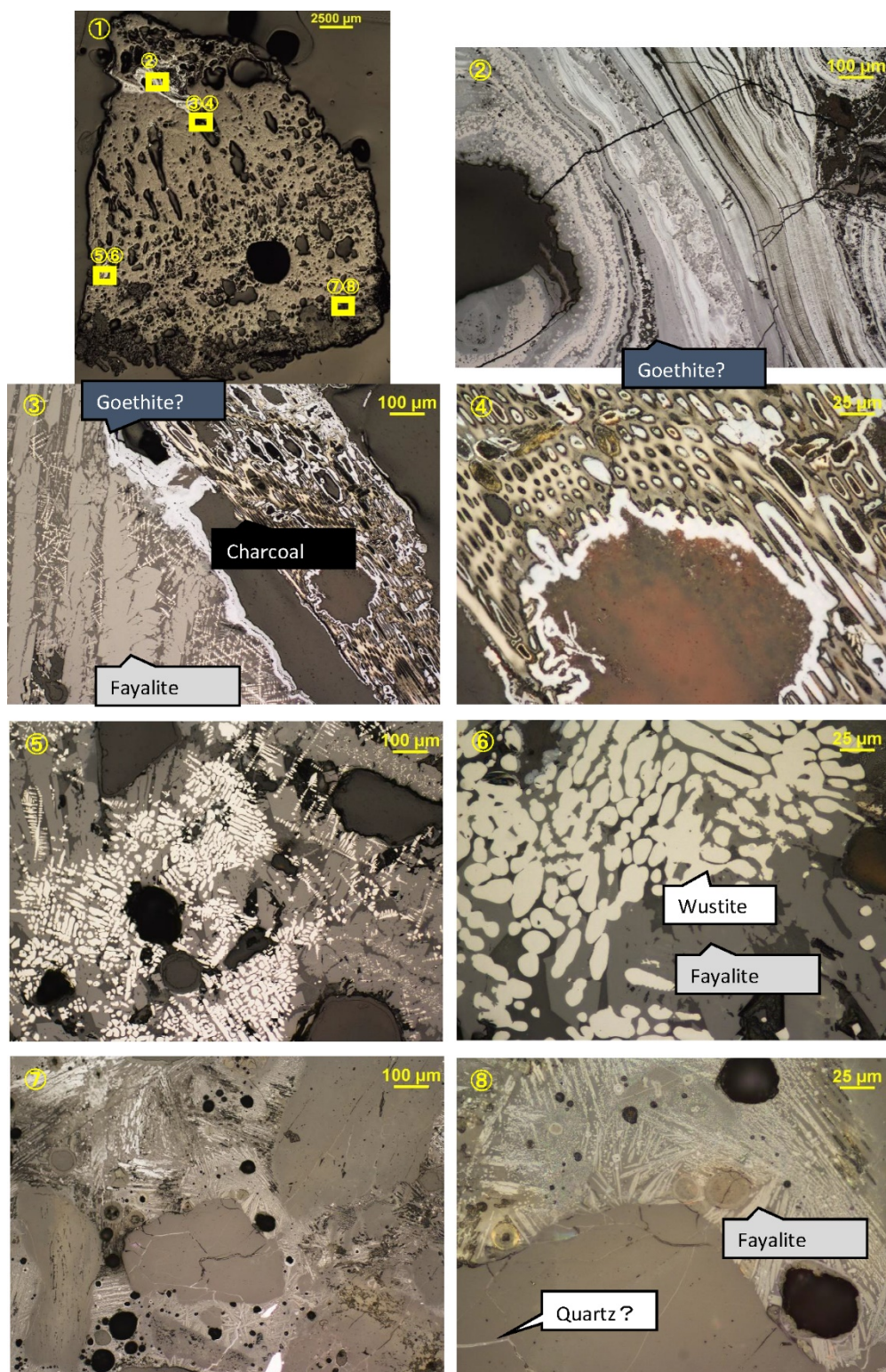


Fig. 45.1-8: R-17-2 Subsection 2 Micrographs

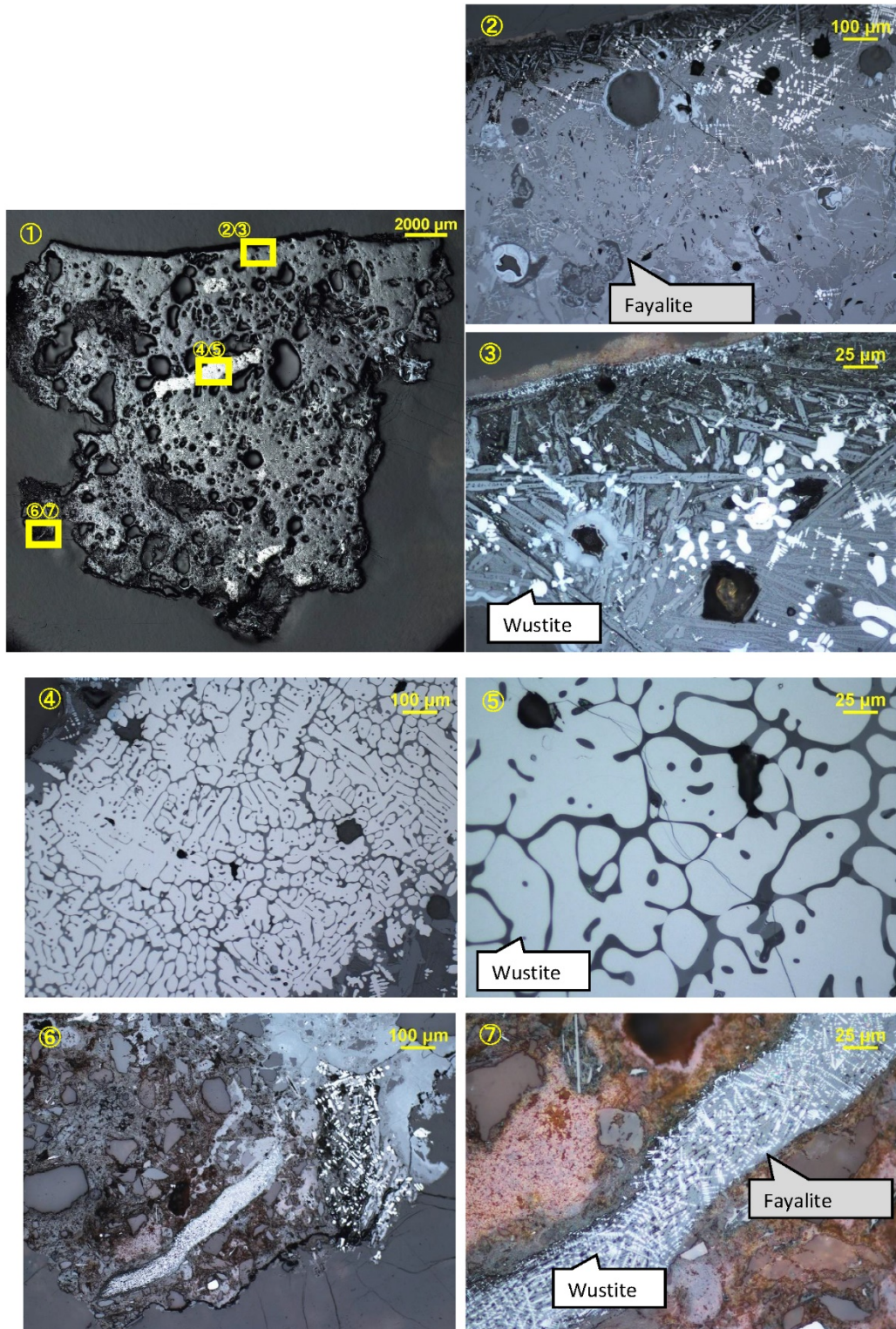


Fig. 46.1-7: R-17-4 Subsection 1 Micrographs

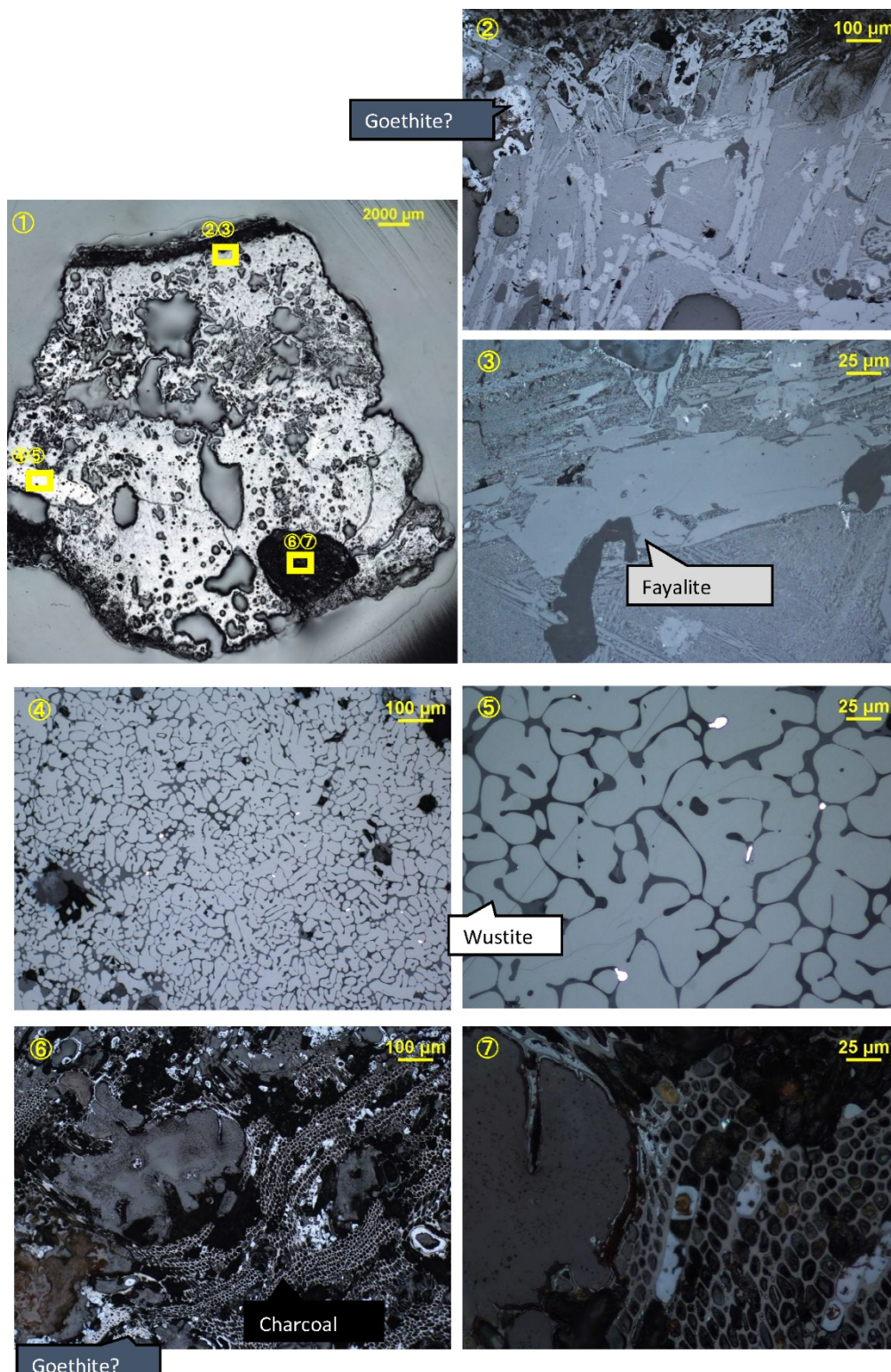


Fig. 47.1-7: R-17-4 Subsection 2 Micrographs

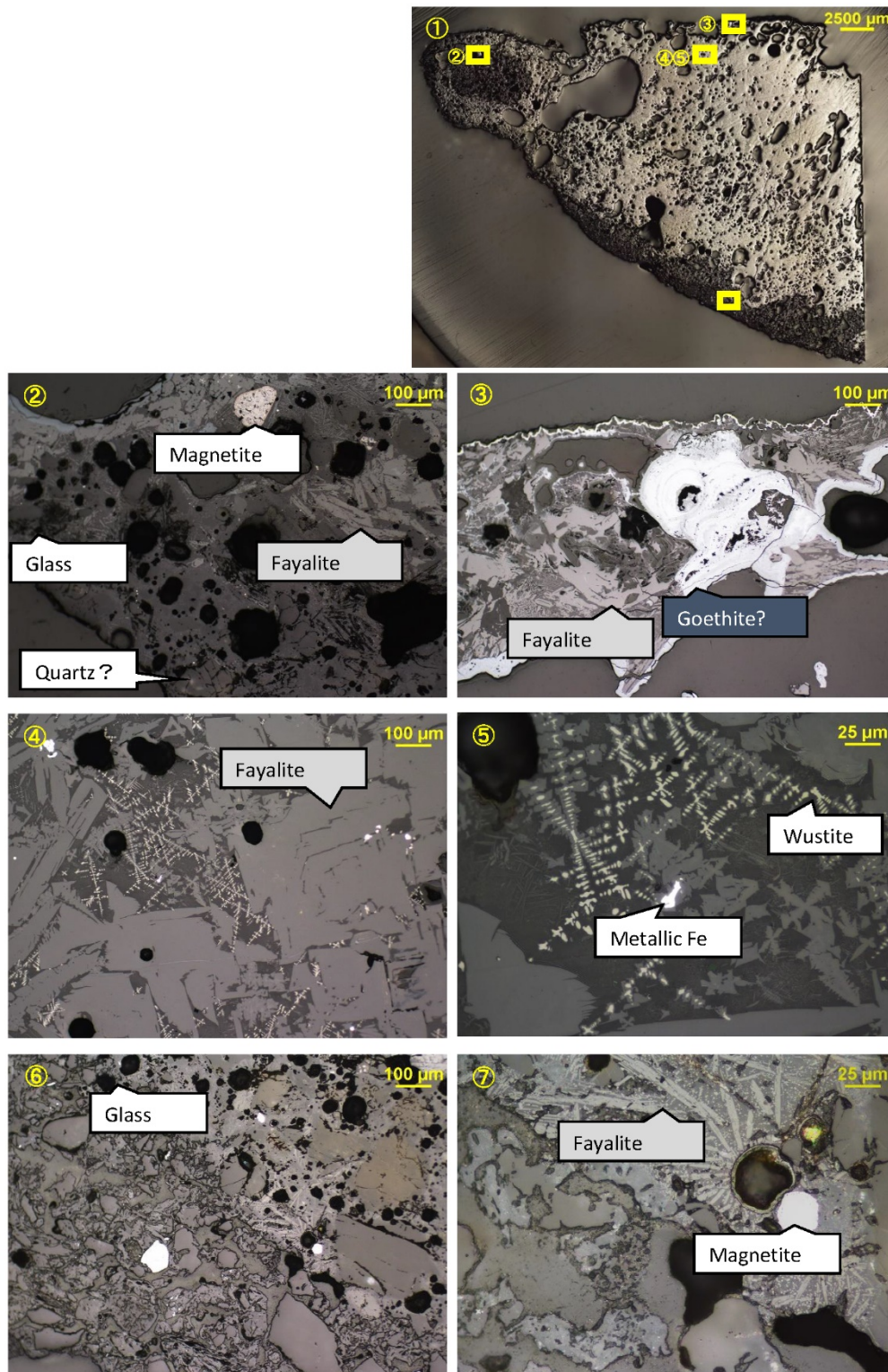


Fig. 48.1-7: R-17-5 Subsection 1 Micrographs

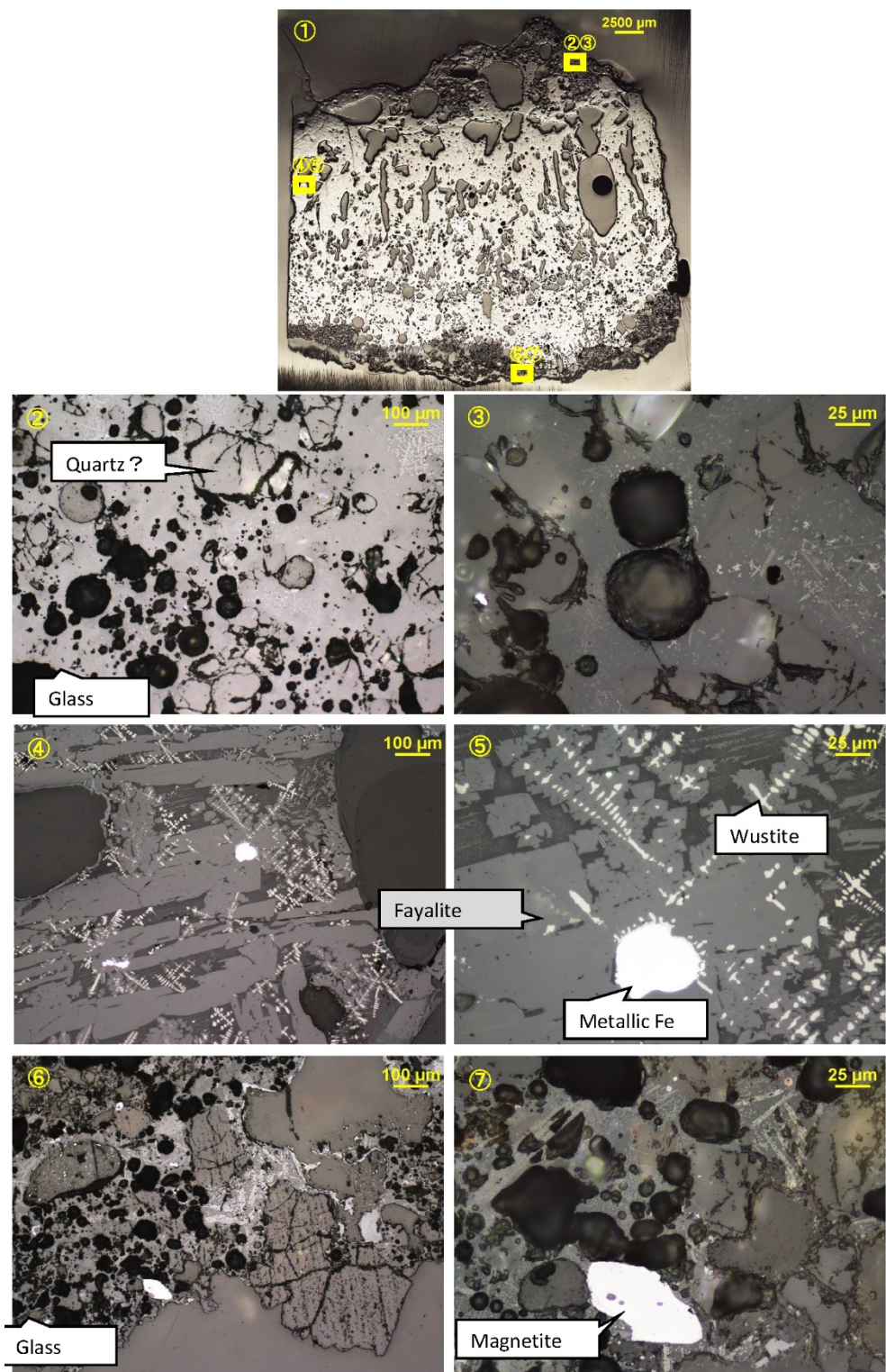


Fig. 49.1-7: R-17-5 Subsection 2 Micrographs

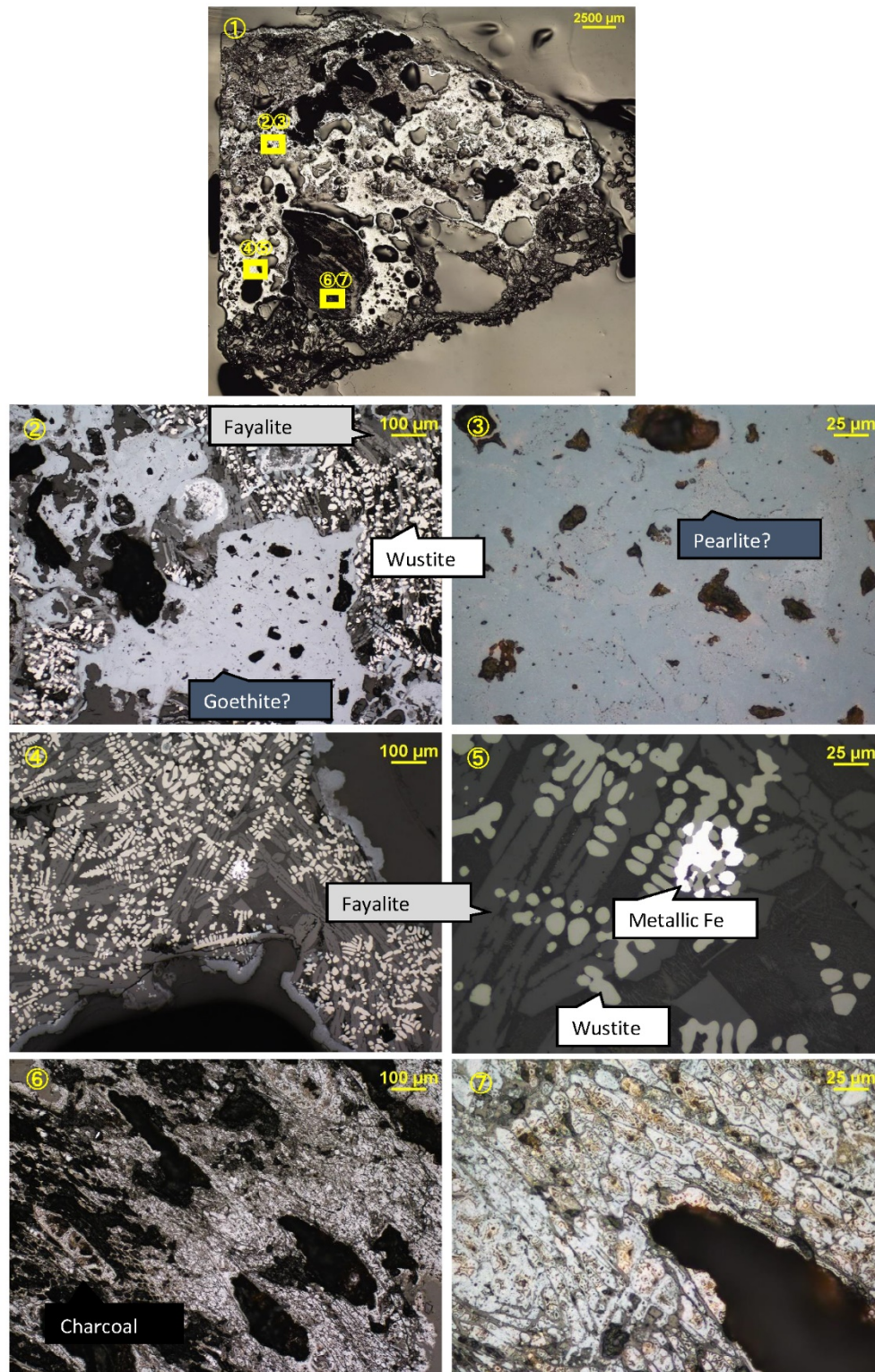


Fig. 50.1-7: R-17-5 Subsection 3 Micrographs

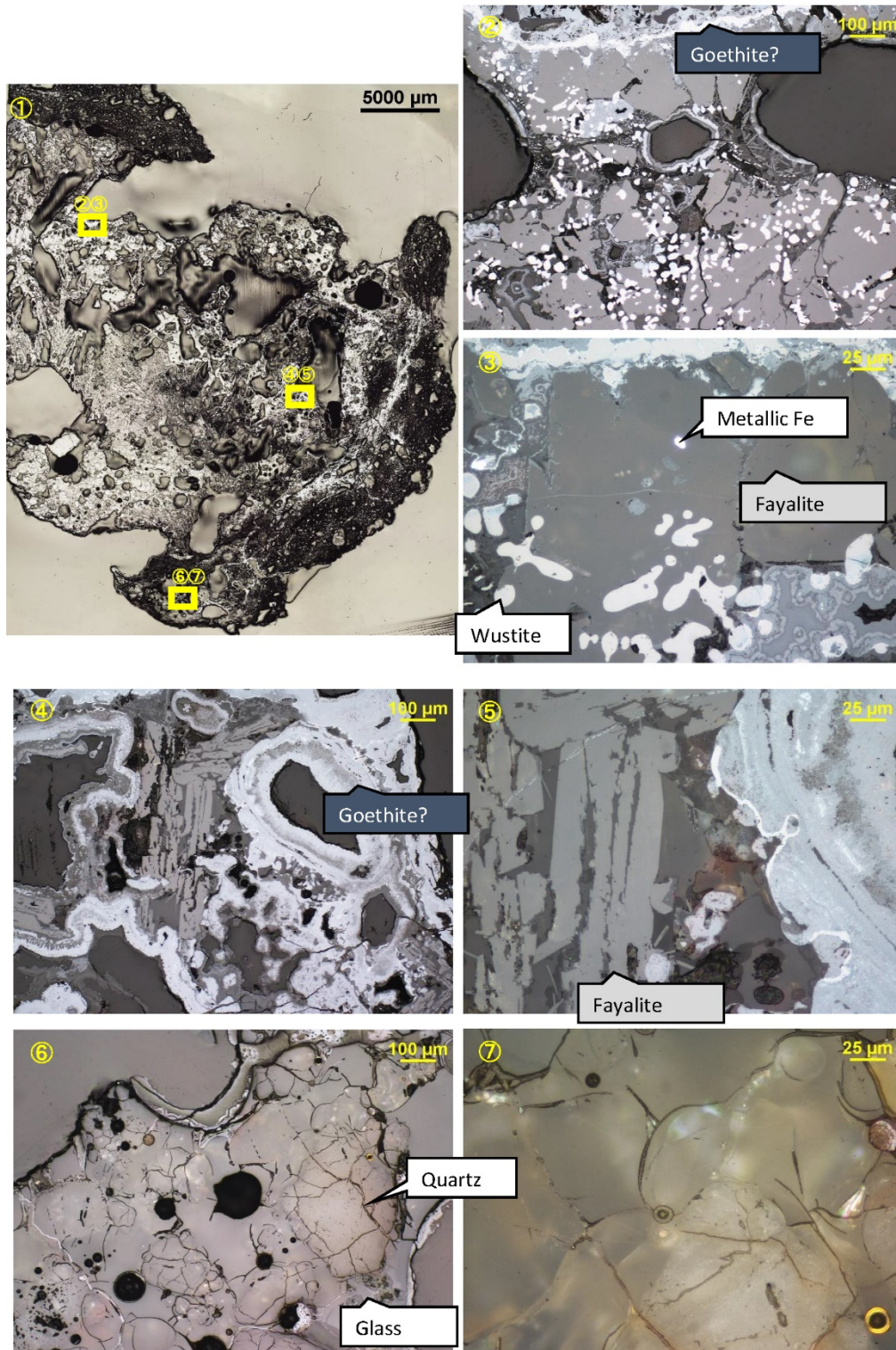


Fig. 51.1-7: R-17-6 Subsection 1 Micrographs

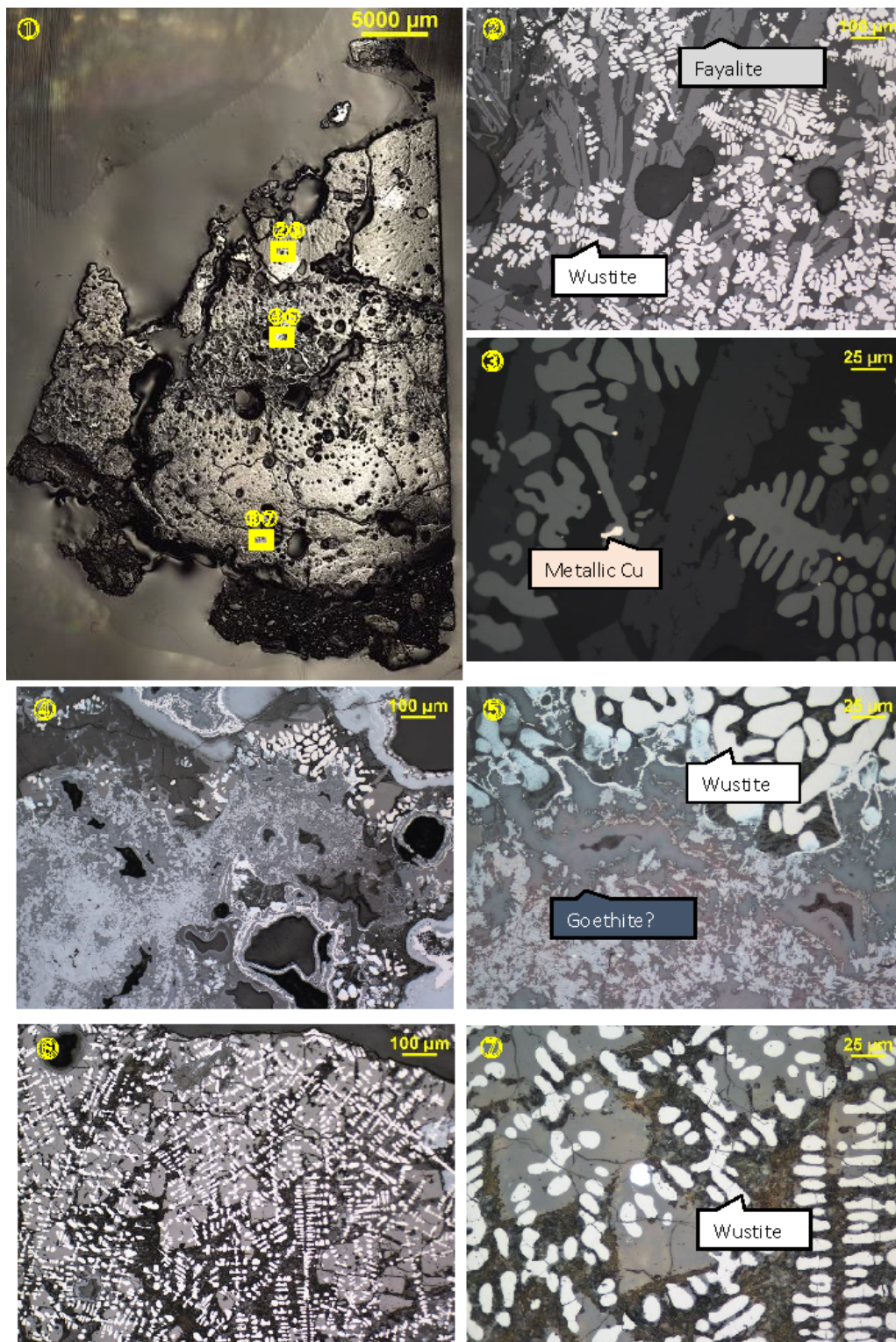


Fig. 52.1-7: R-17-6 Subsection 2 Micrographs

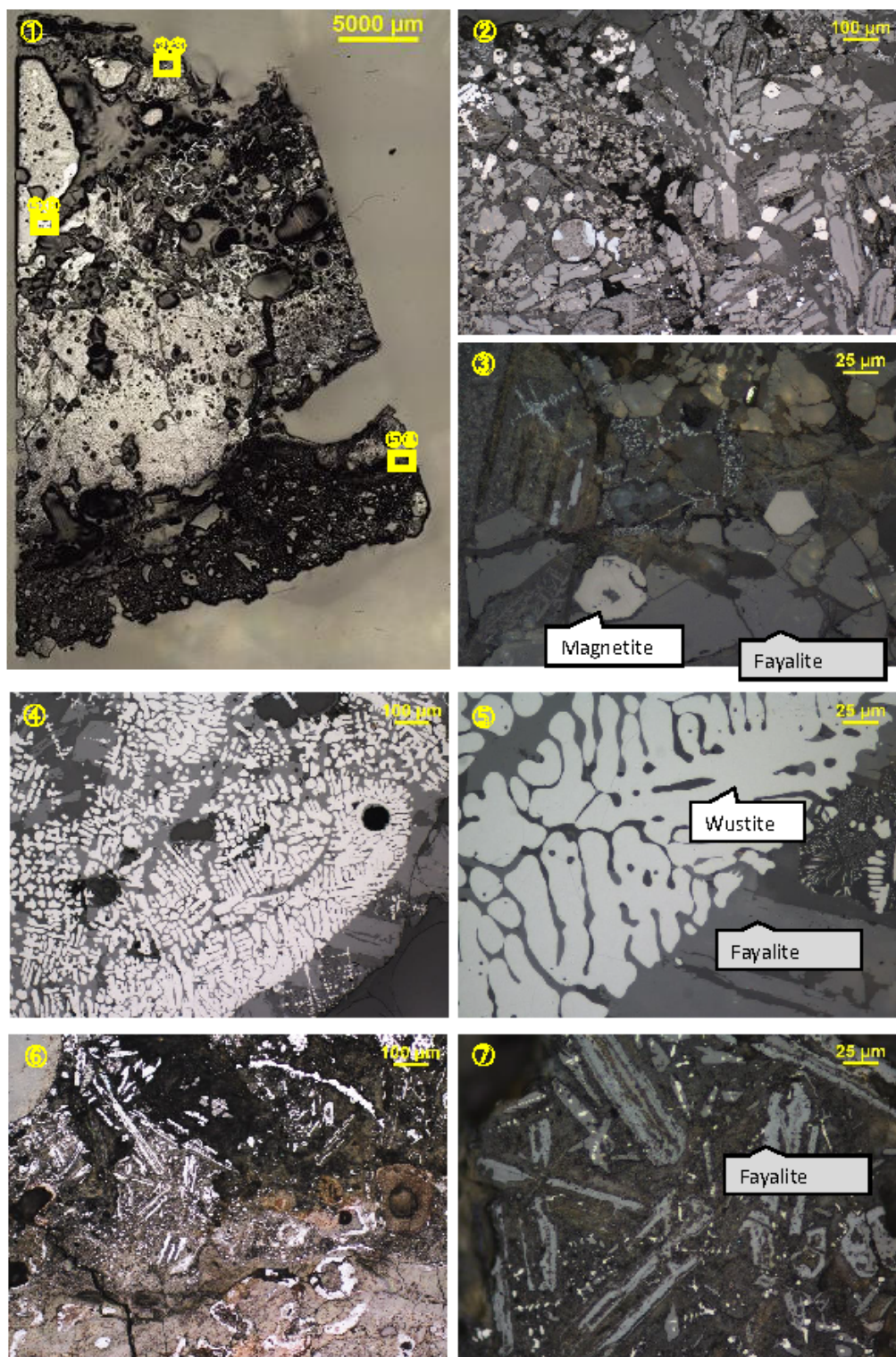


Fig. 53.1-7: R-17-6 Subsection 3 Micrographs

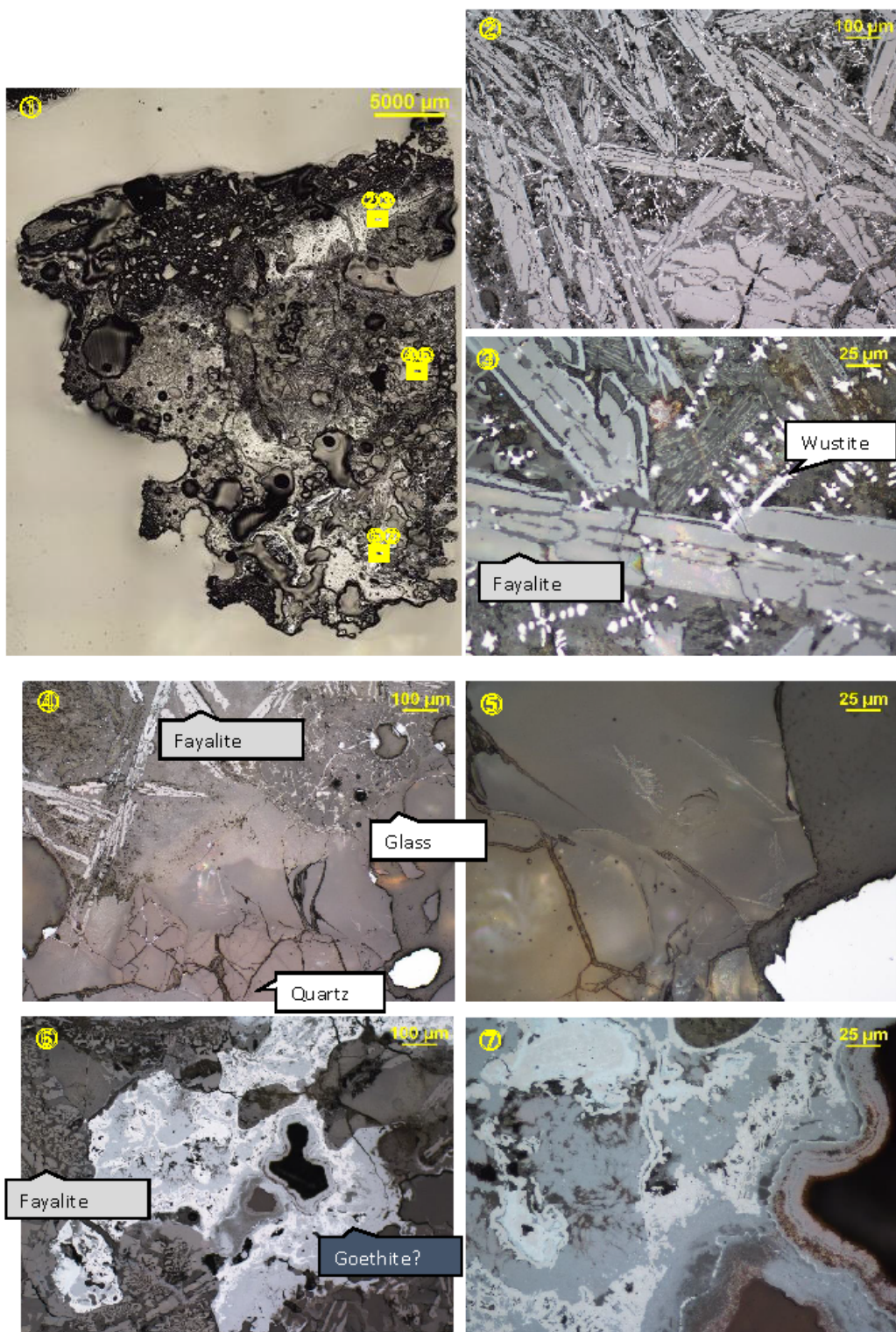


Fig. 54.1-7: R-17-6 Subsection 4 Micrographs

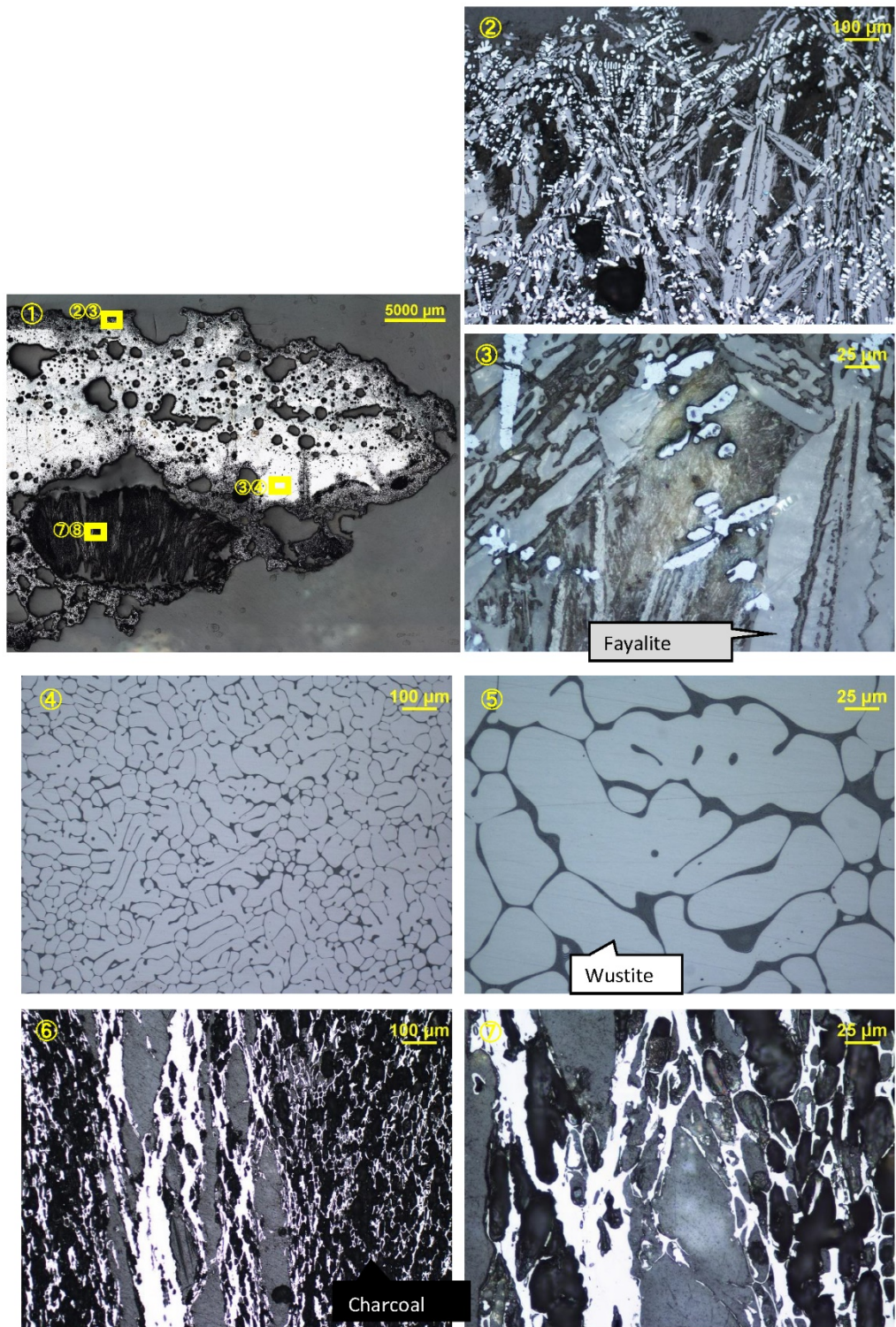


Fig. 55.1-7: R-17-7 Subsection 1 Micrographs

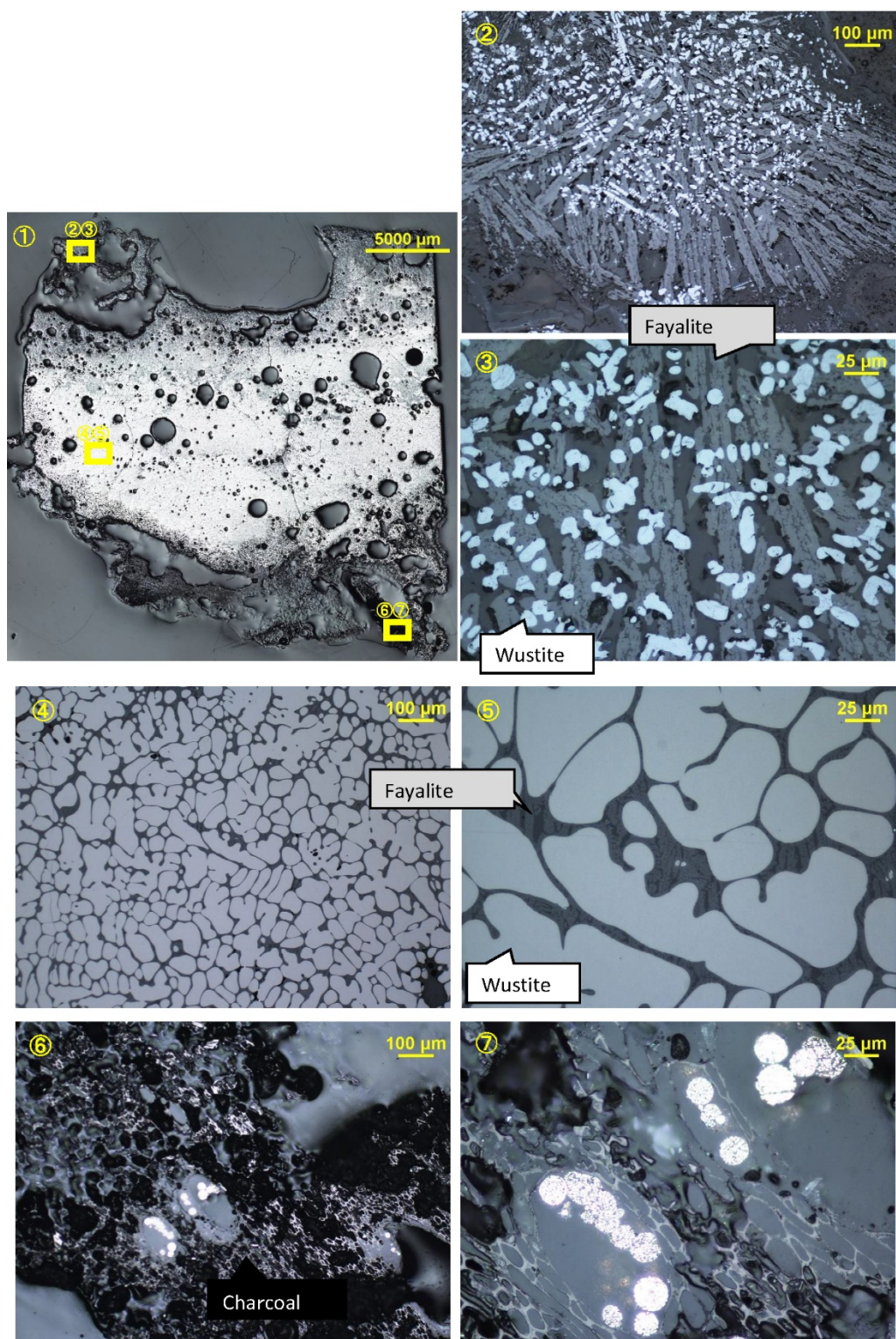


Fig. 56.1-7: R-17-7 Subsection 2 Micrographs

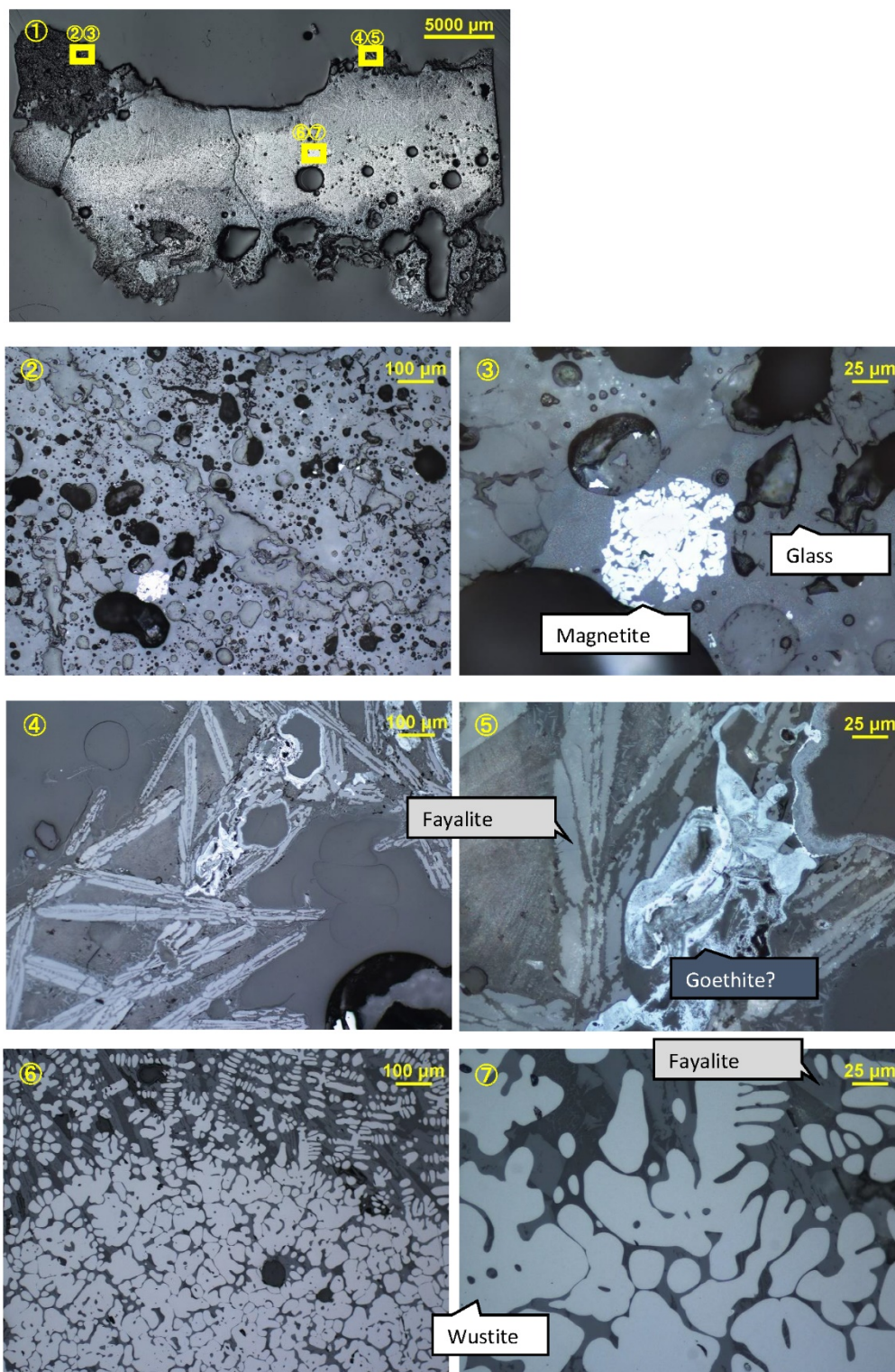


Fig. 57.1-7: R-17-7 Subsection 3 Micrographs

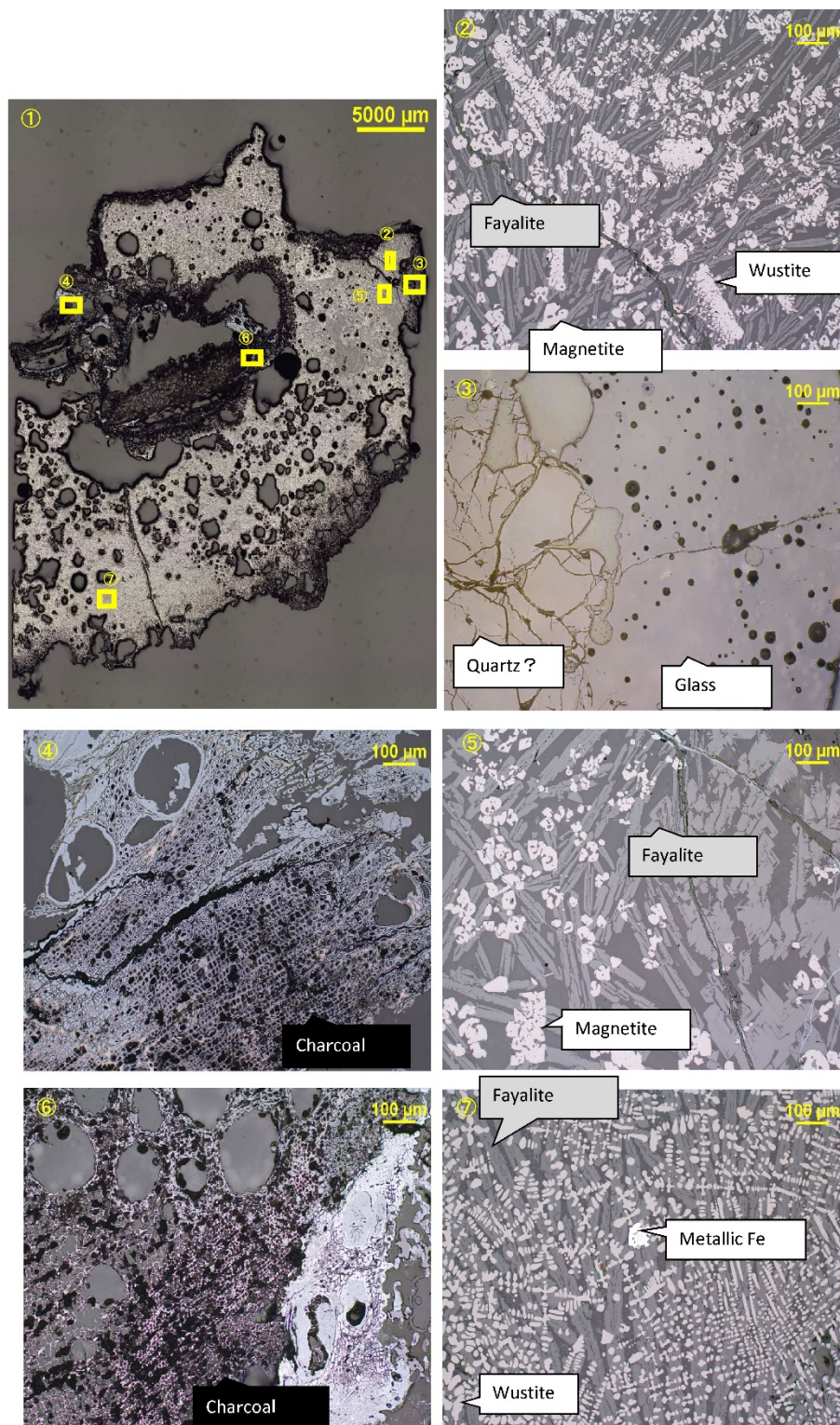


Fig. 58.1-7: R-17-8 Subsection 1 Micrographs

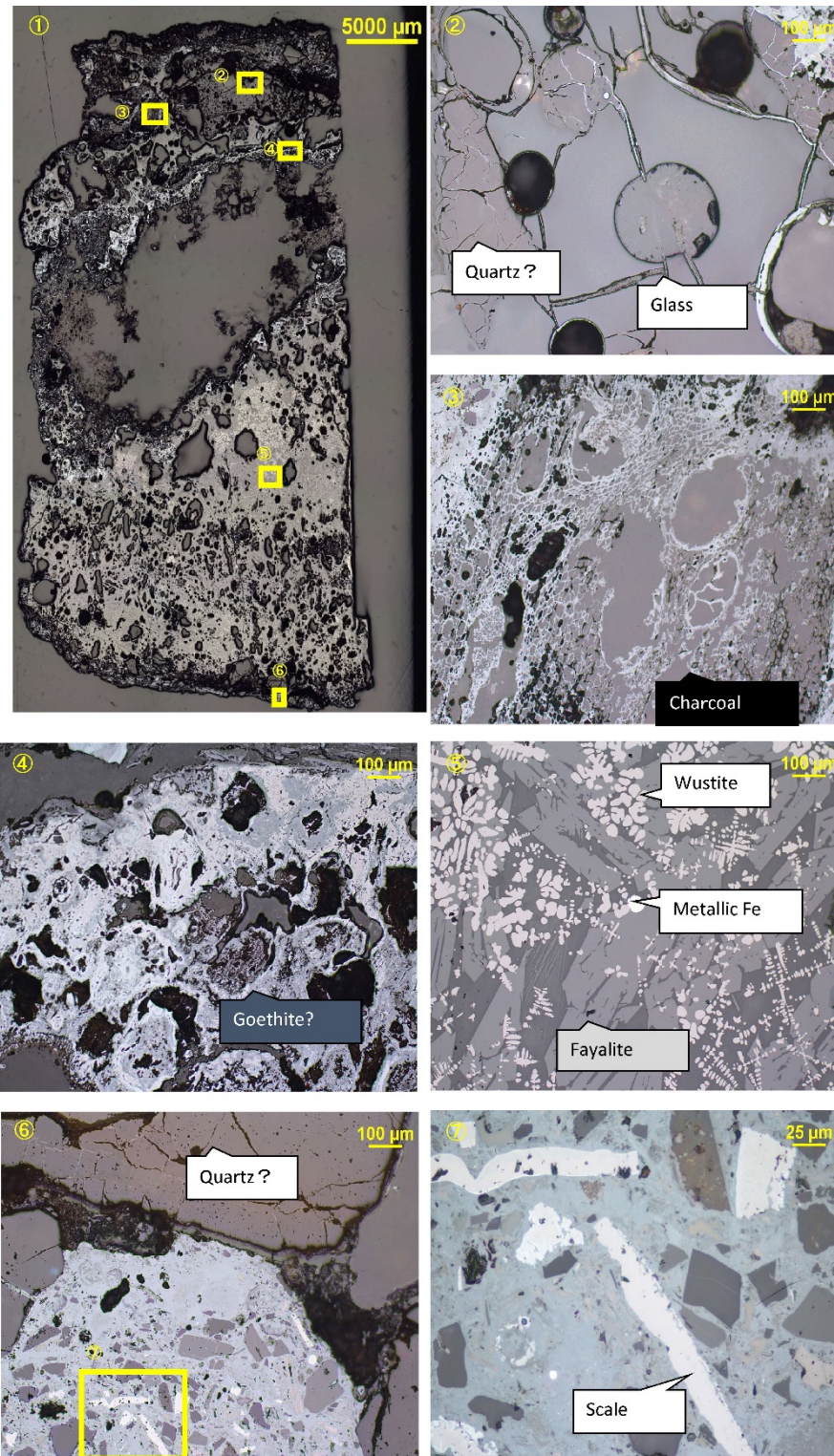


Fig. 59.1-7: R-17-8 Subsection 2 Micrographs

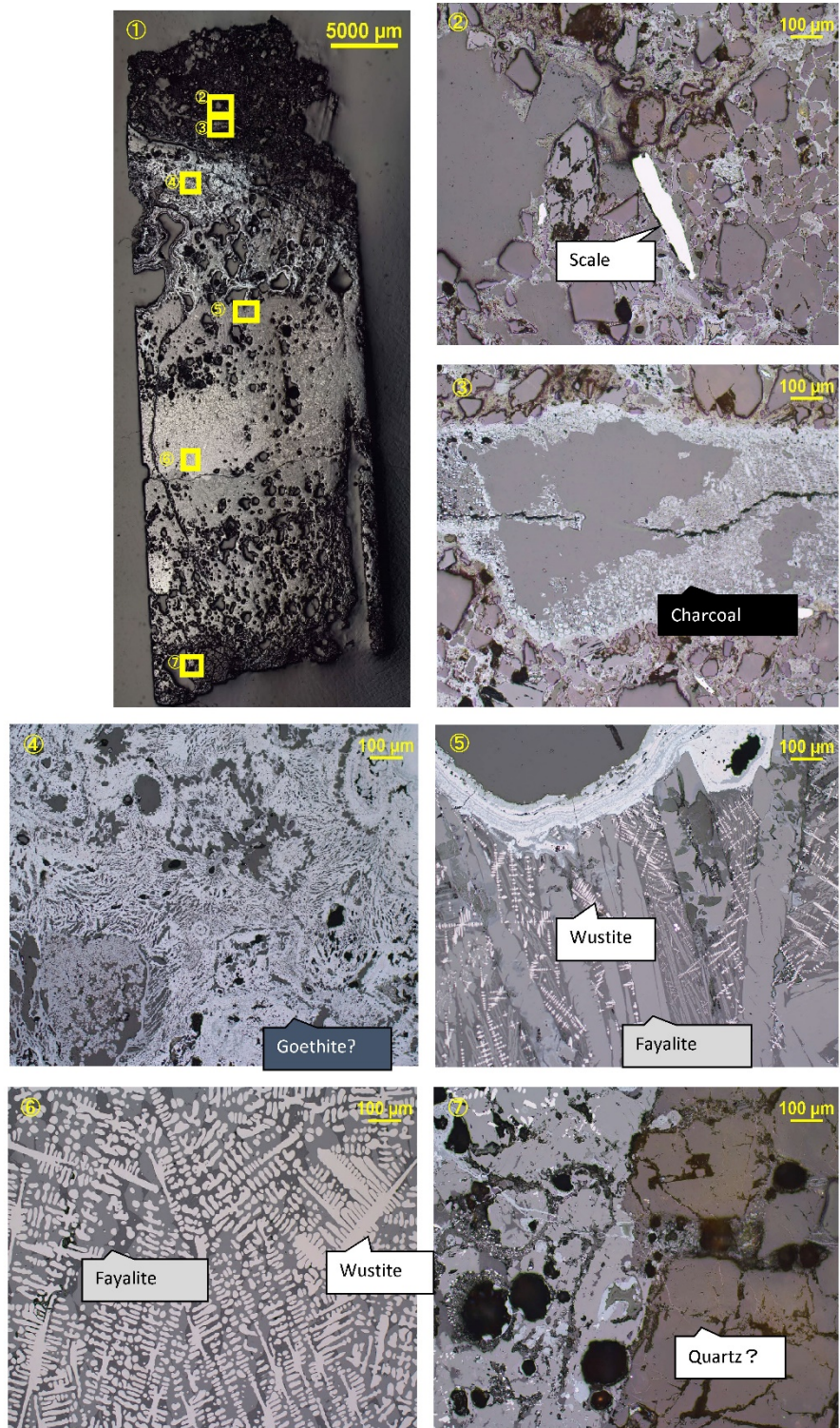


Fig. 60.1-7: R-17-8 Subsection 3 Micrographs

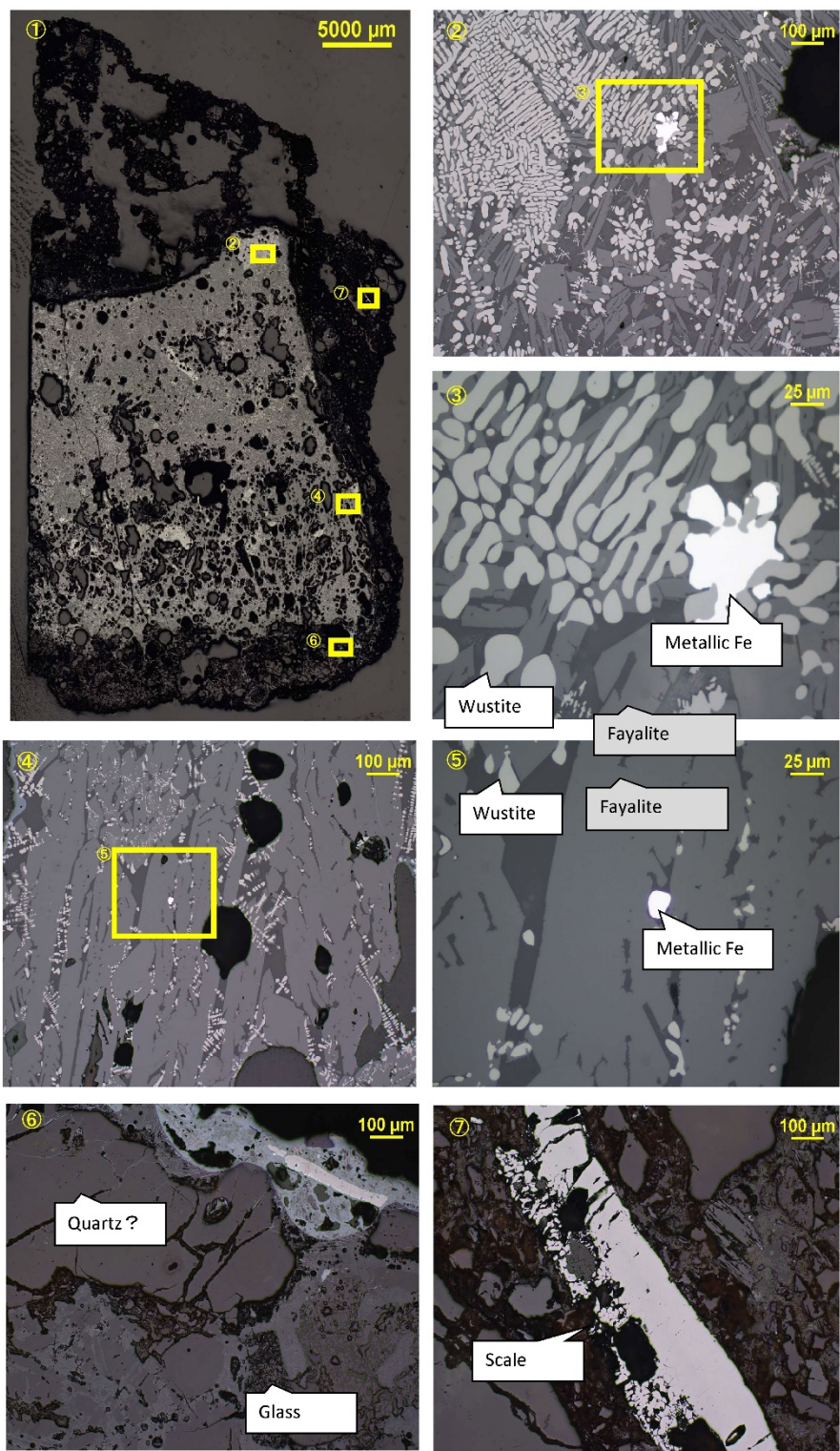


Fig. 61.1-7: R-17-8 Subsection 4 Micrographs

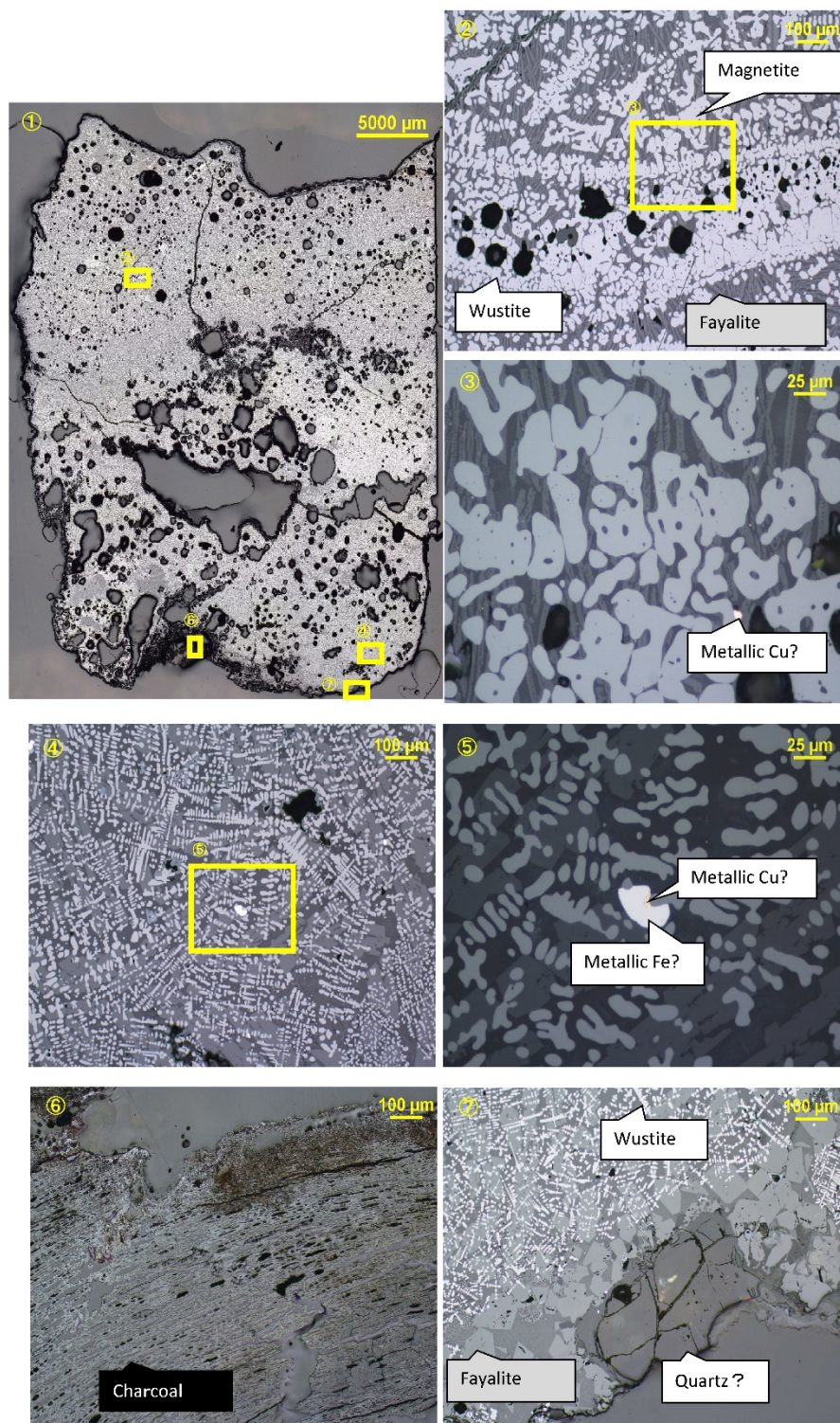


Fig. 62.1-7: R-18-1 Subsection 1 Micrographs

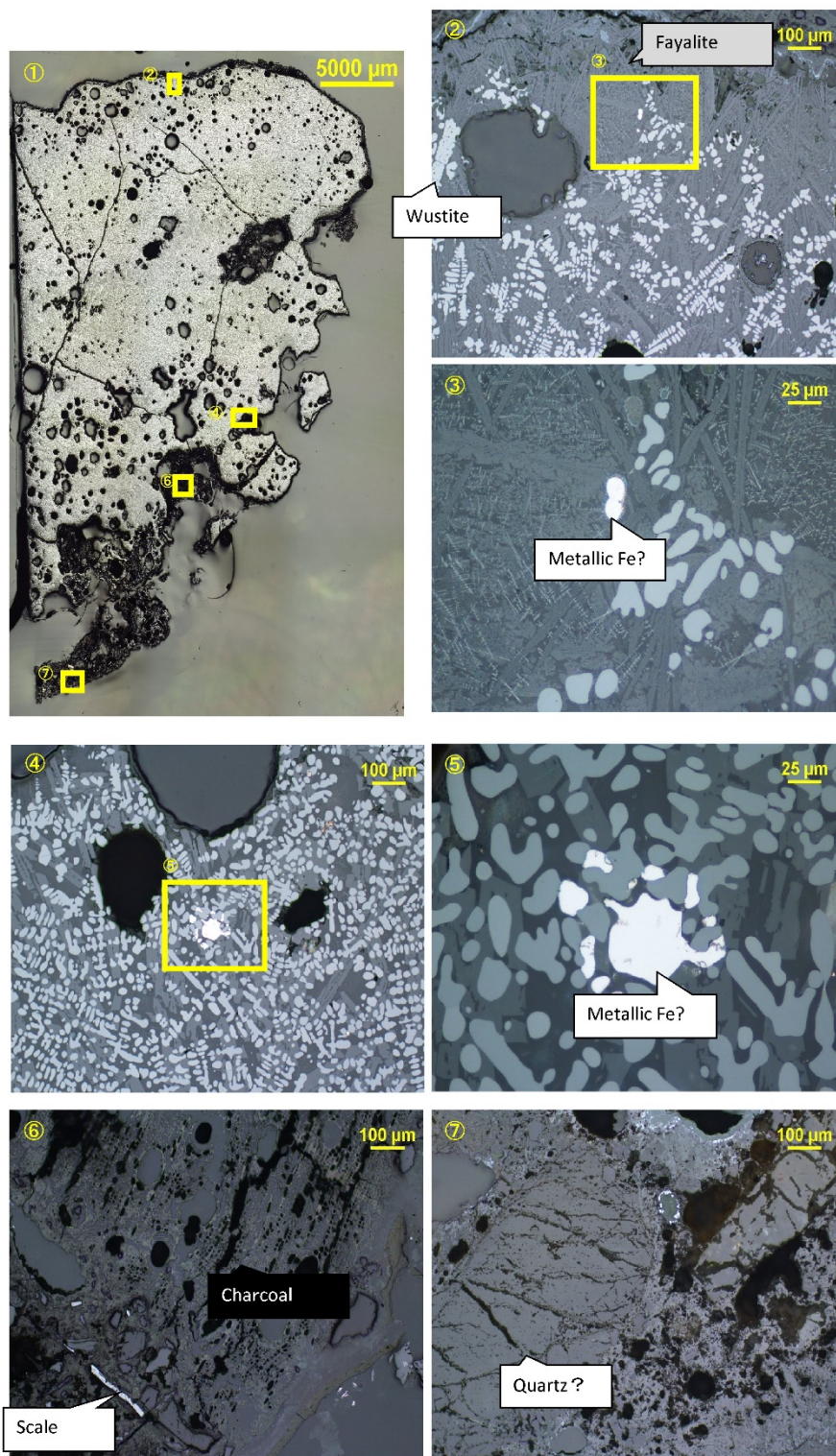


Fig. 63.1-7: R-18-1 Subsection 2 Micrographs

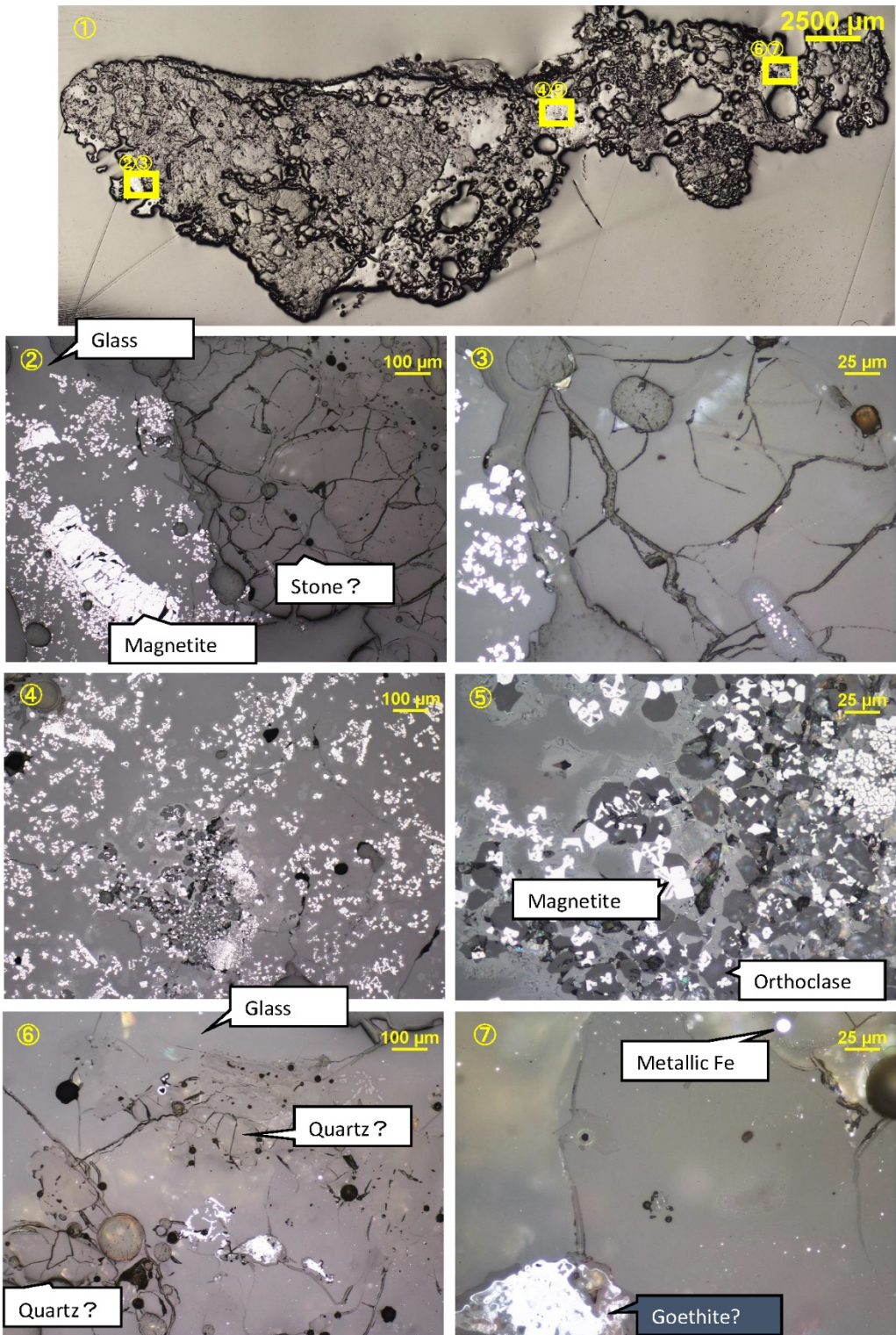


Fig. 65.1-7: R-18-2 Subsection Micrographs

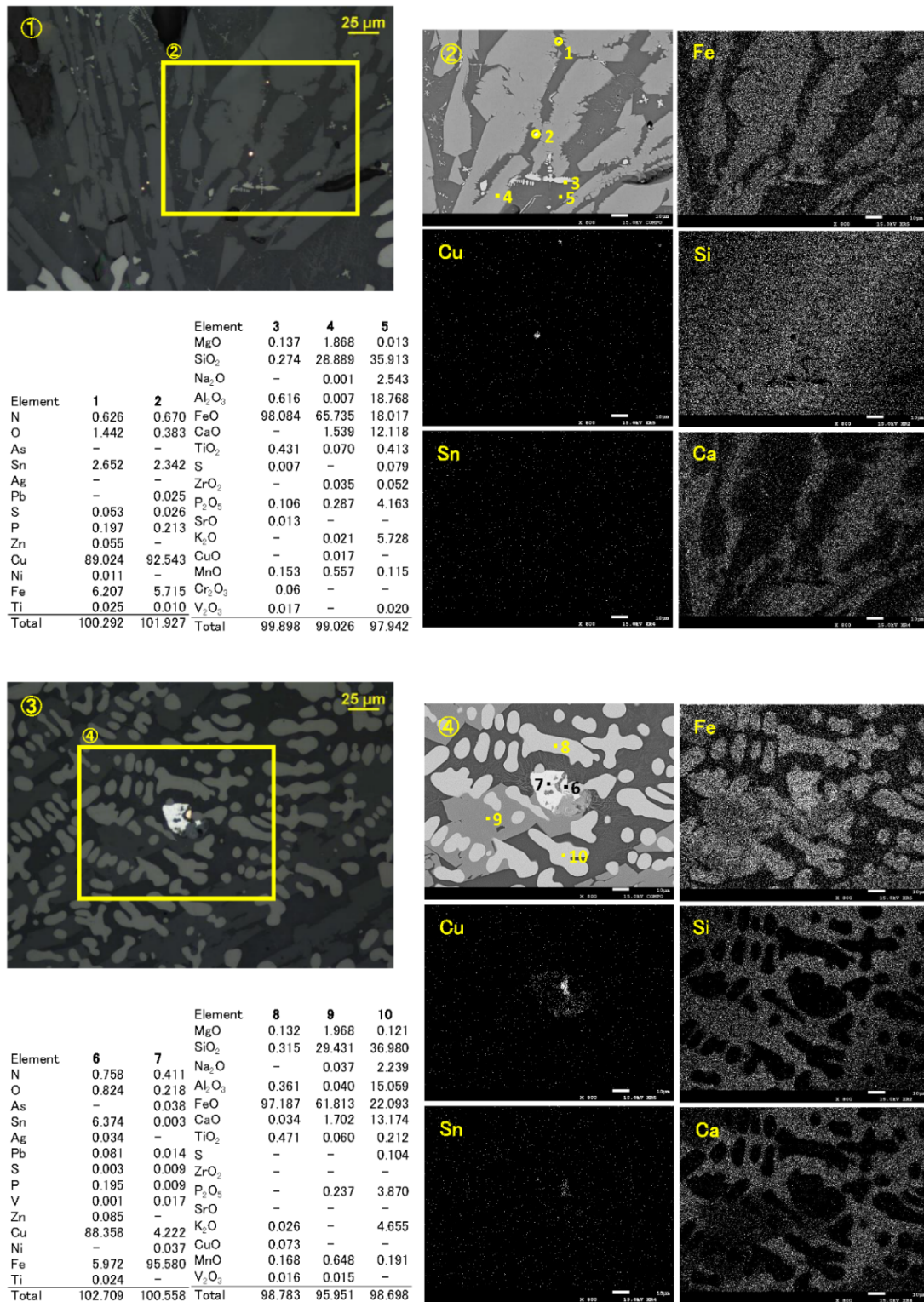


Fig. 64.1-4: R-18-1 EPMA Analysis

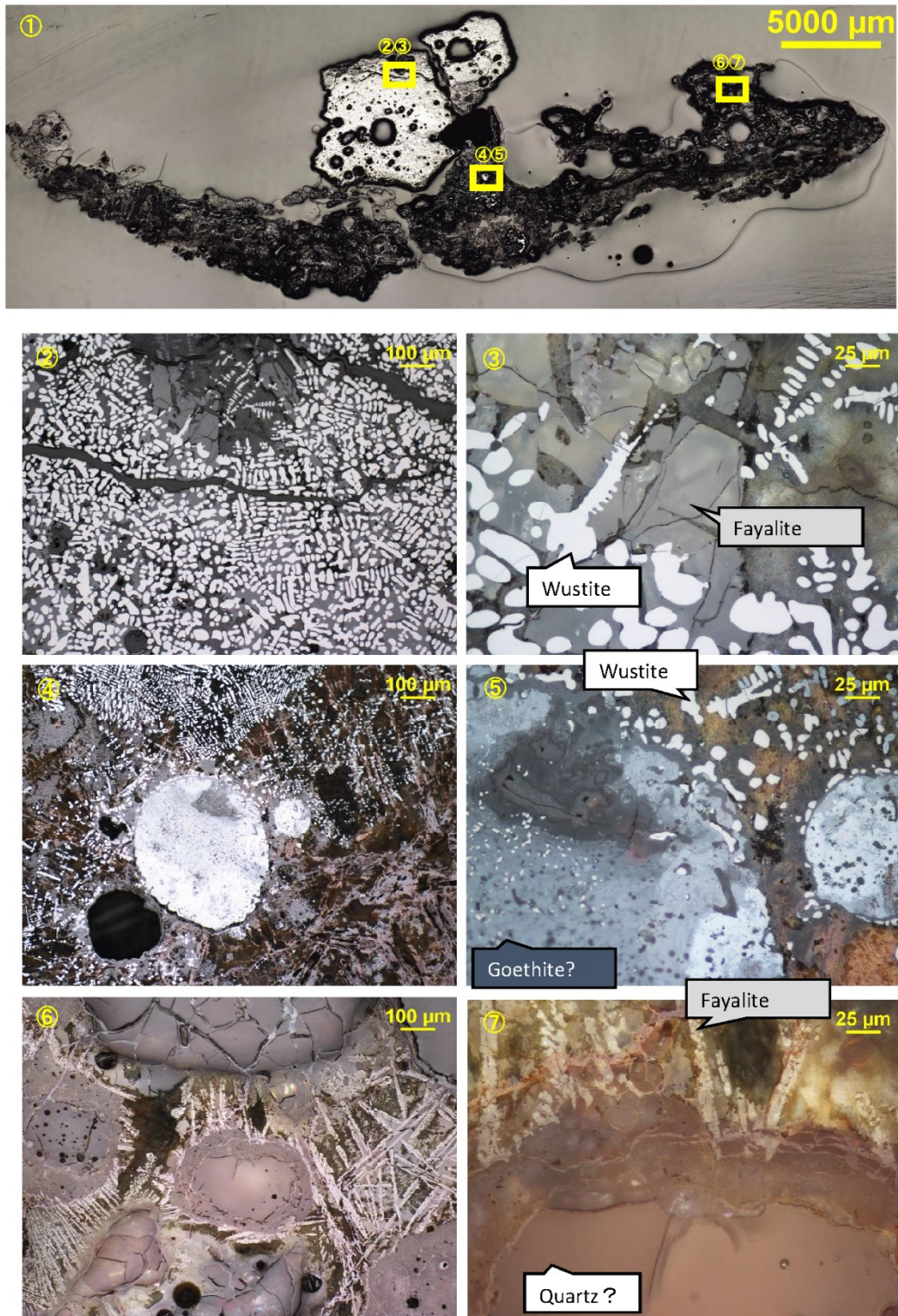


Fig. 66.1-7: R-27-1 Subsection Micrographs

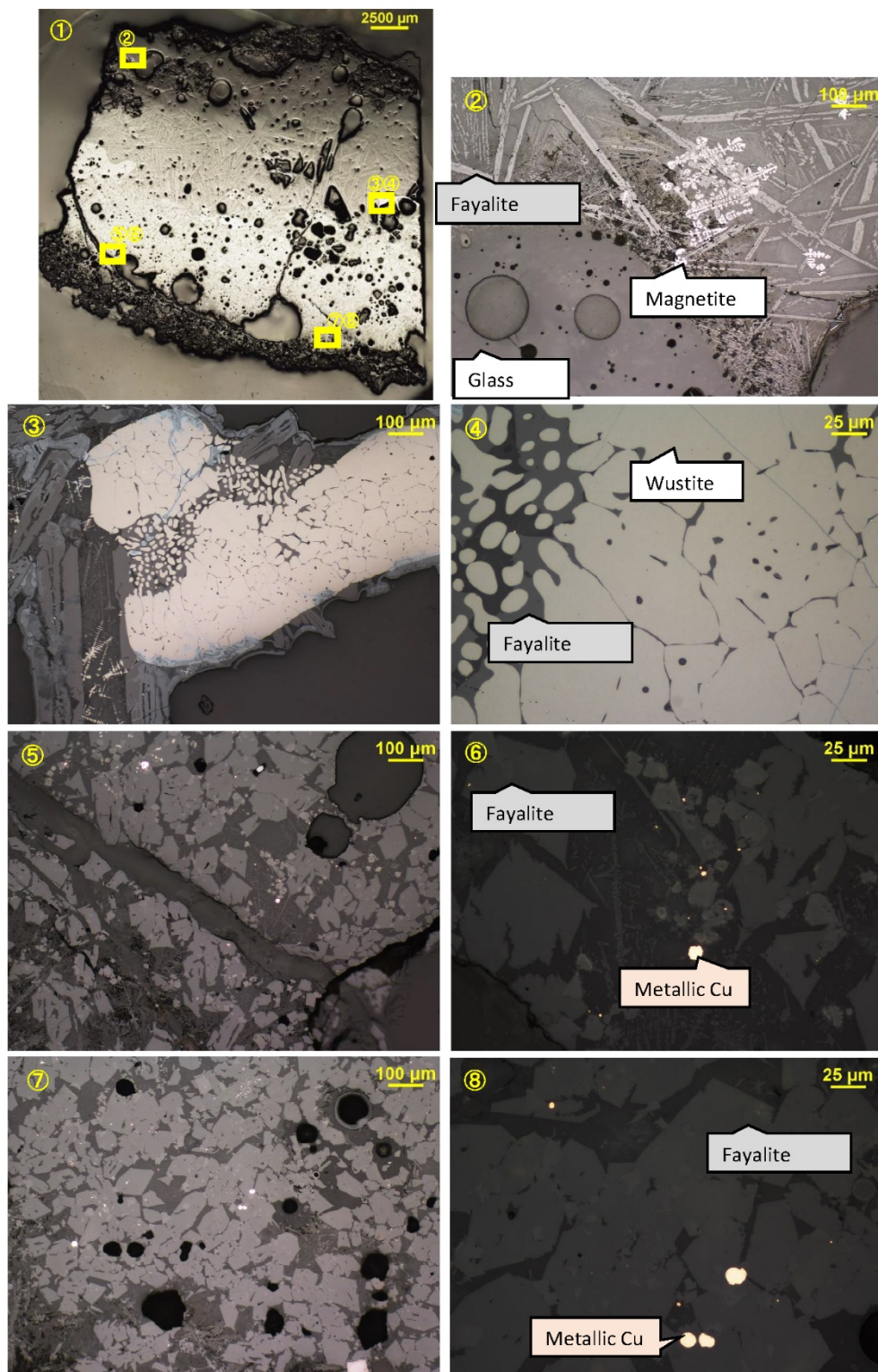


Fig. 67.1-8: R-32-1 Subsection 1 Micrographs

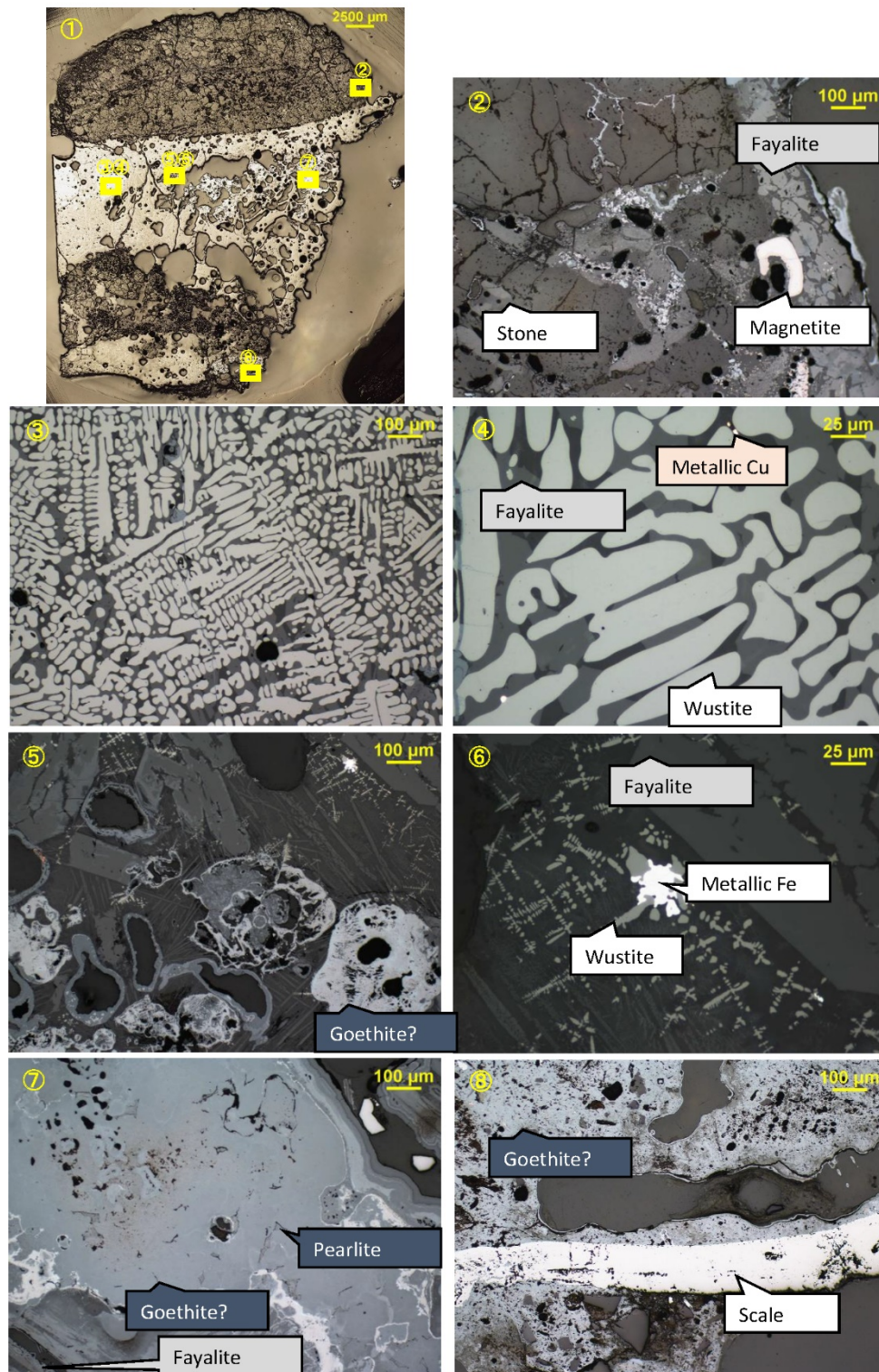


Fig. 68.1-8: R-32-1 Subsection 2 Micrographs

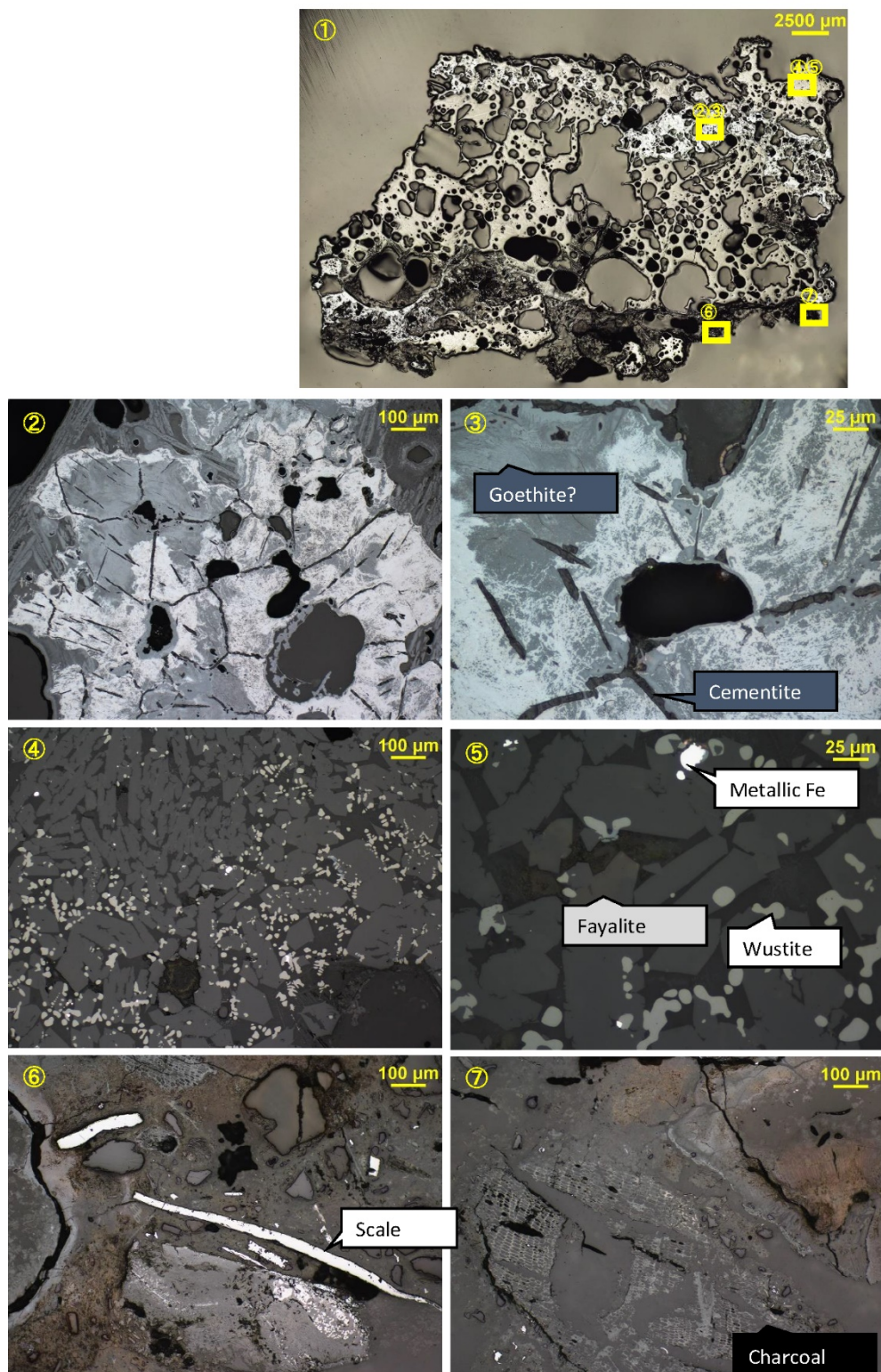


Fig. 69.1-7: R-32-1 Subsection 3 Micrographs

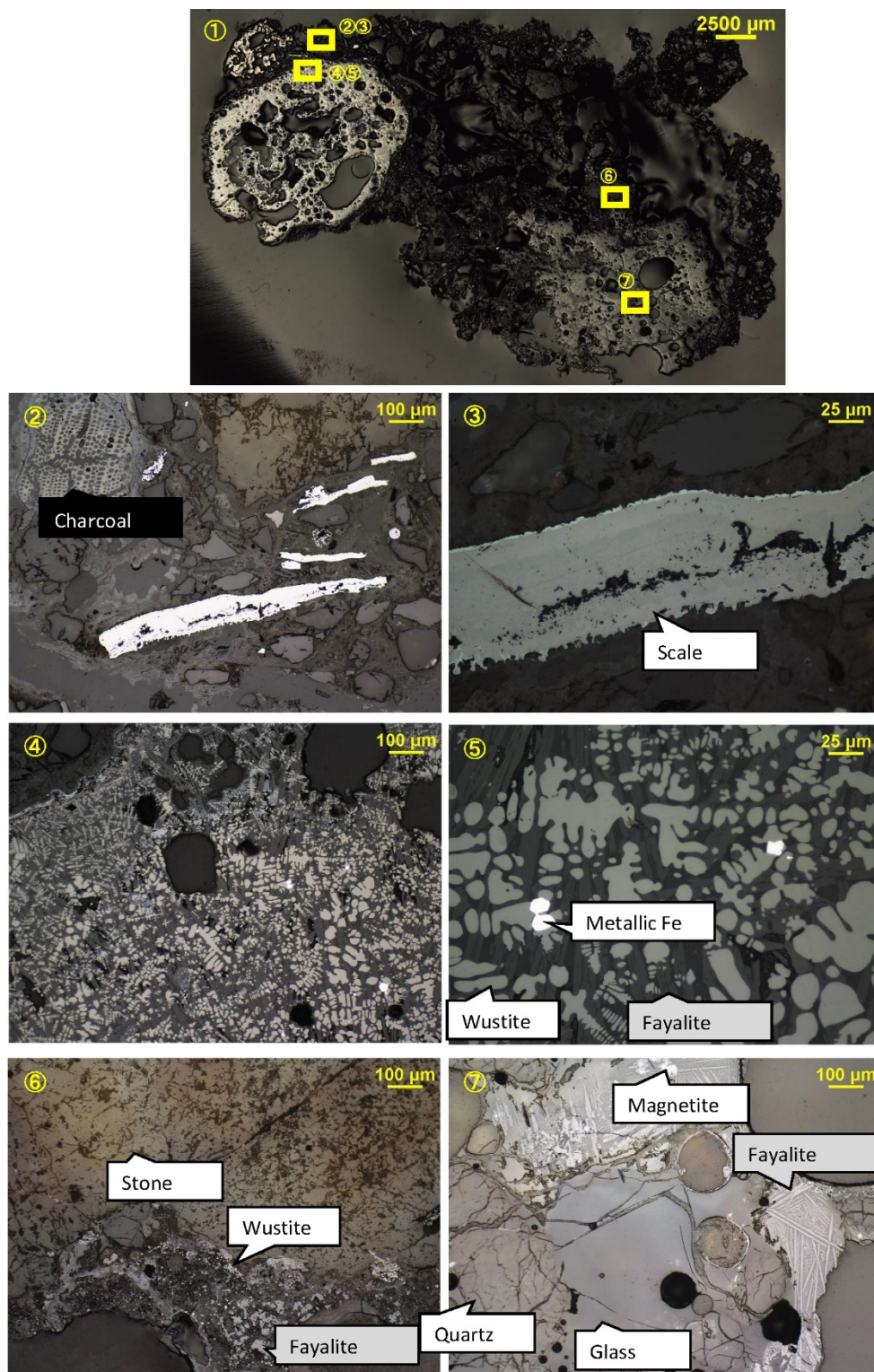


Fig. 70.1-7: R-32-2 Subsection Micrographs

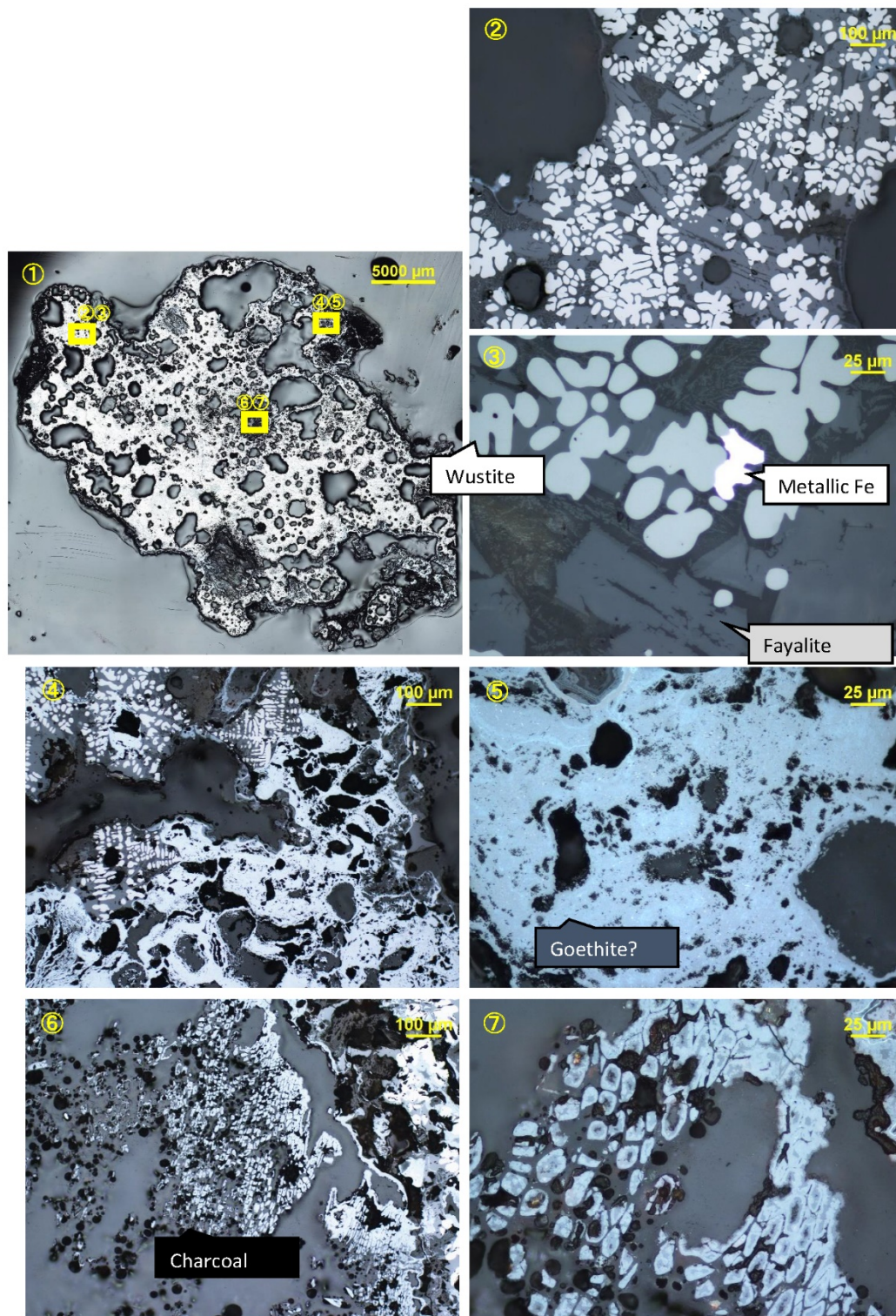


Fig. 71.1-7: R-32-3 Subsection 1 Micrographs

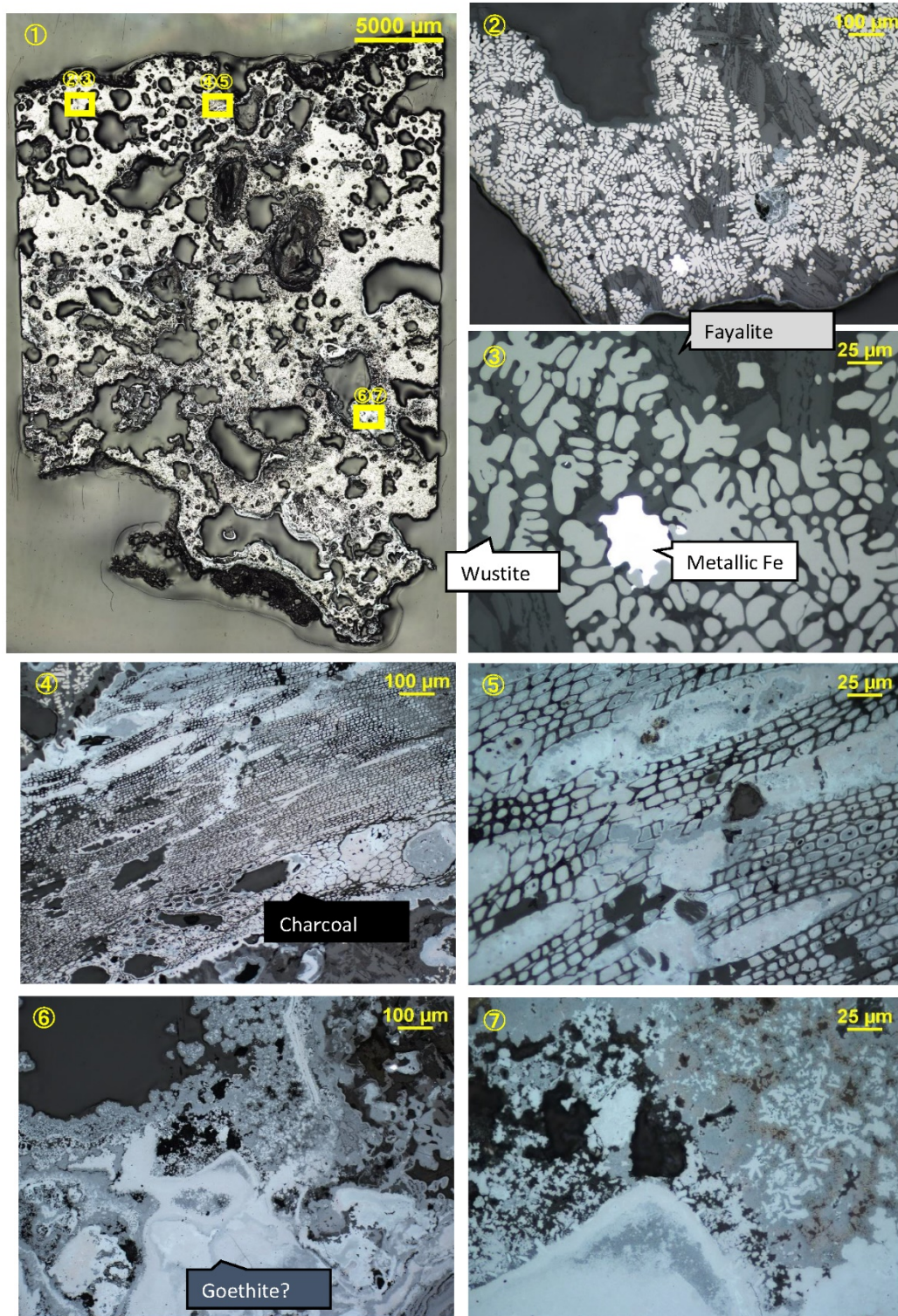


Fig. 72.1-7: R-32-3 Subsection 2 Micrographs

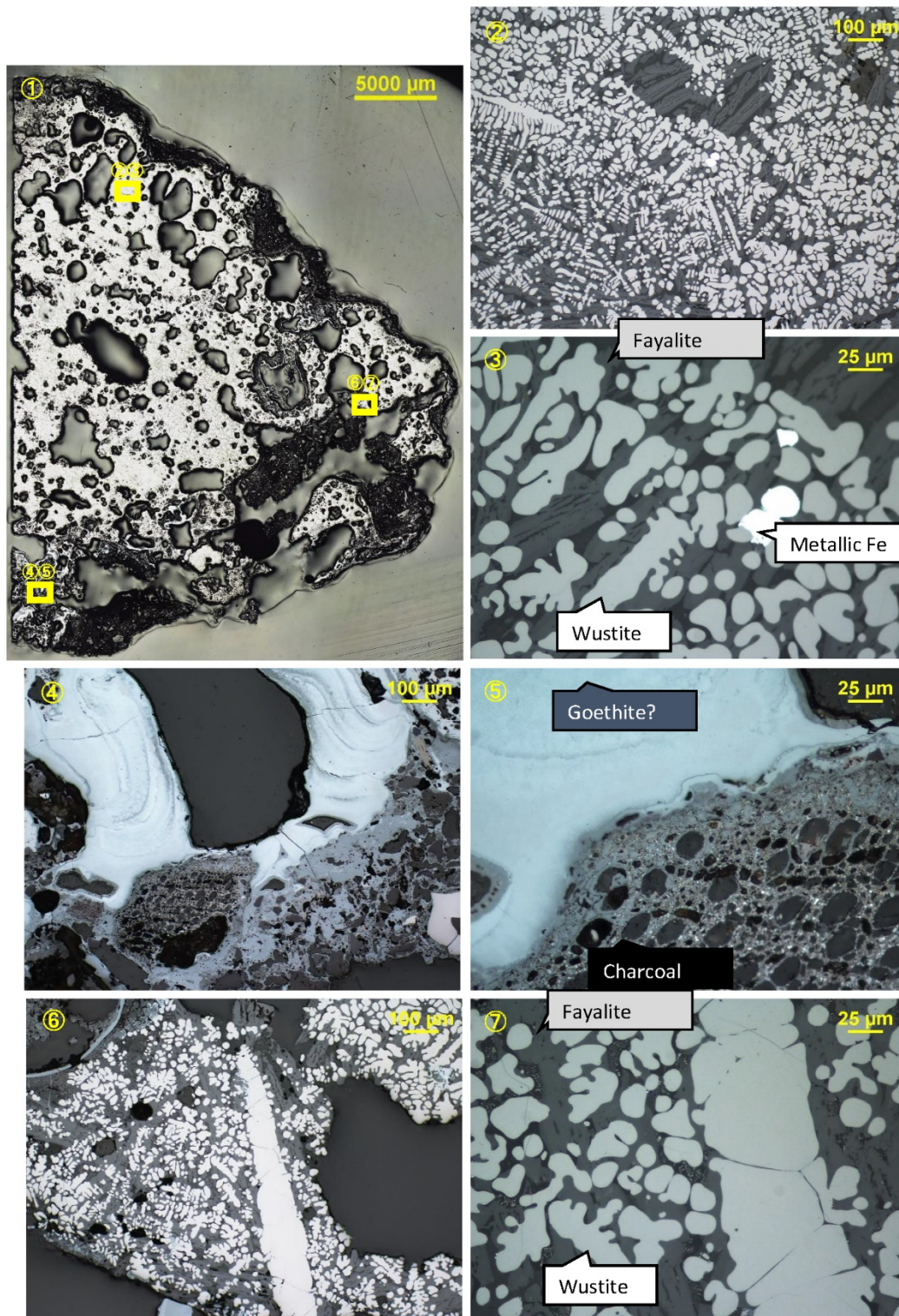


Fig. 73.1-7: R-32-3 Subsection 3 Micrographs

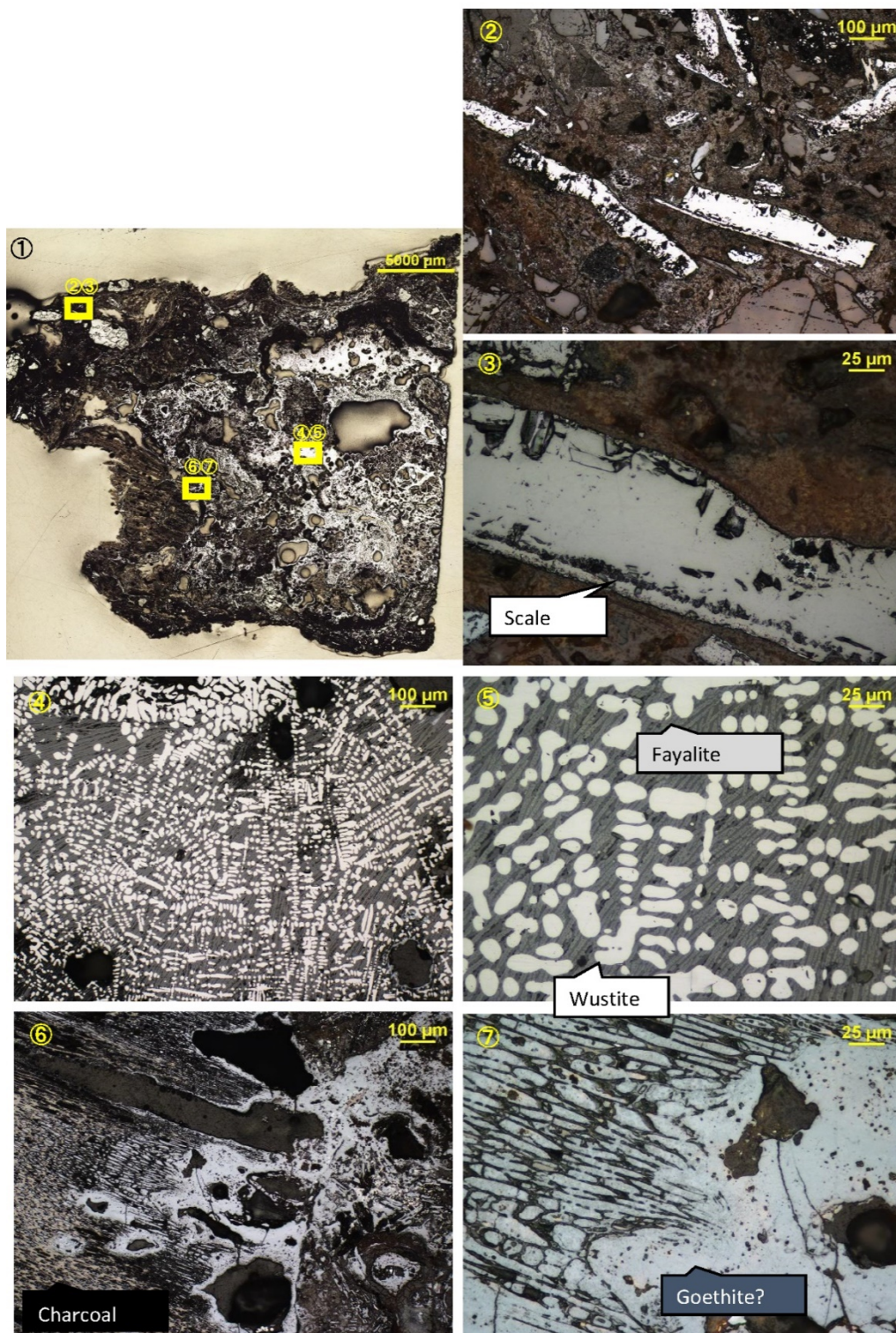


Fig. 74.1-7: R-32-4 Subsection 1 Micrographs

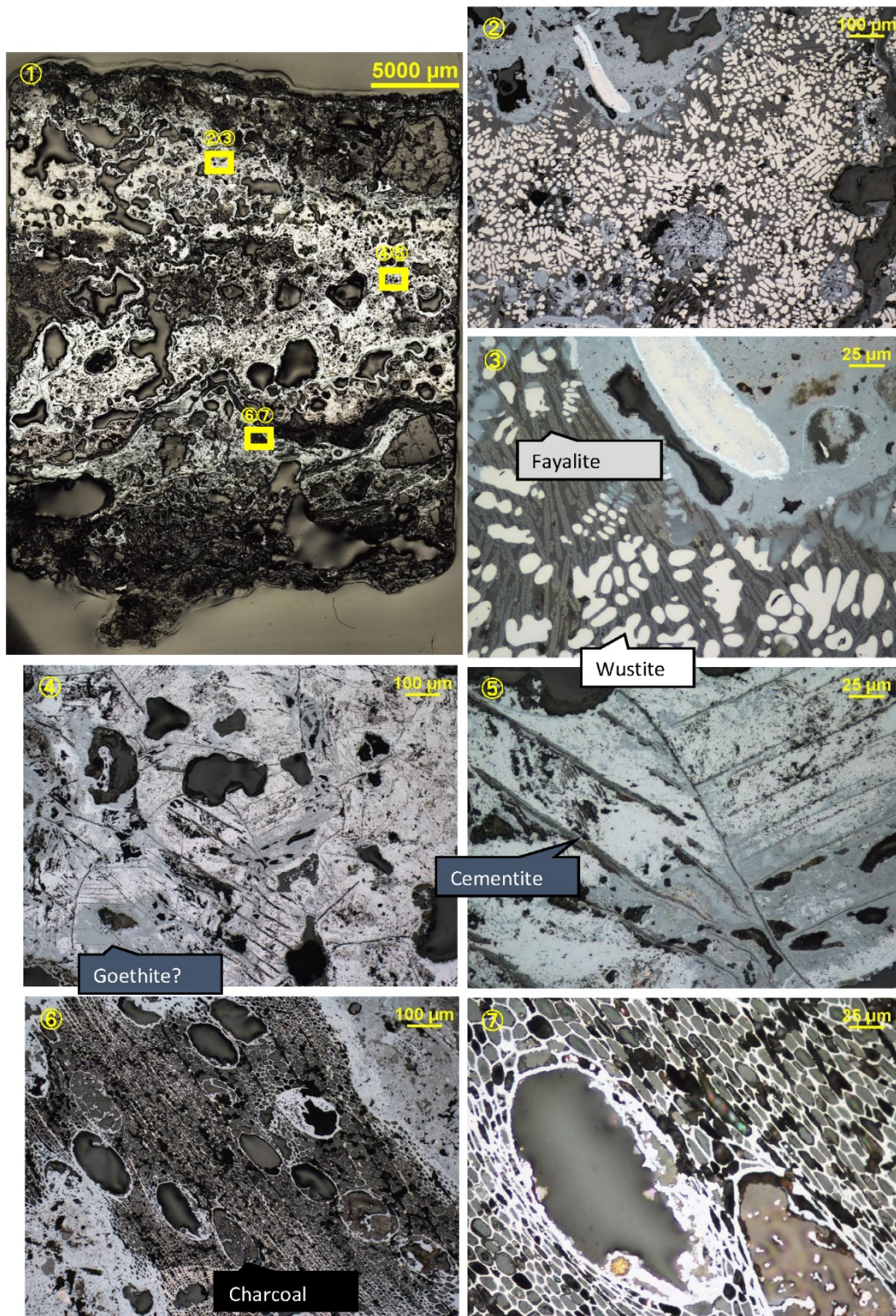


Fig. 75.1-7: R-32-4 Subsection 2 Micrographs

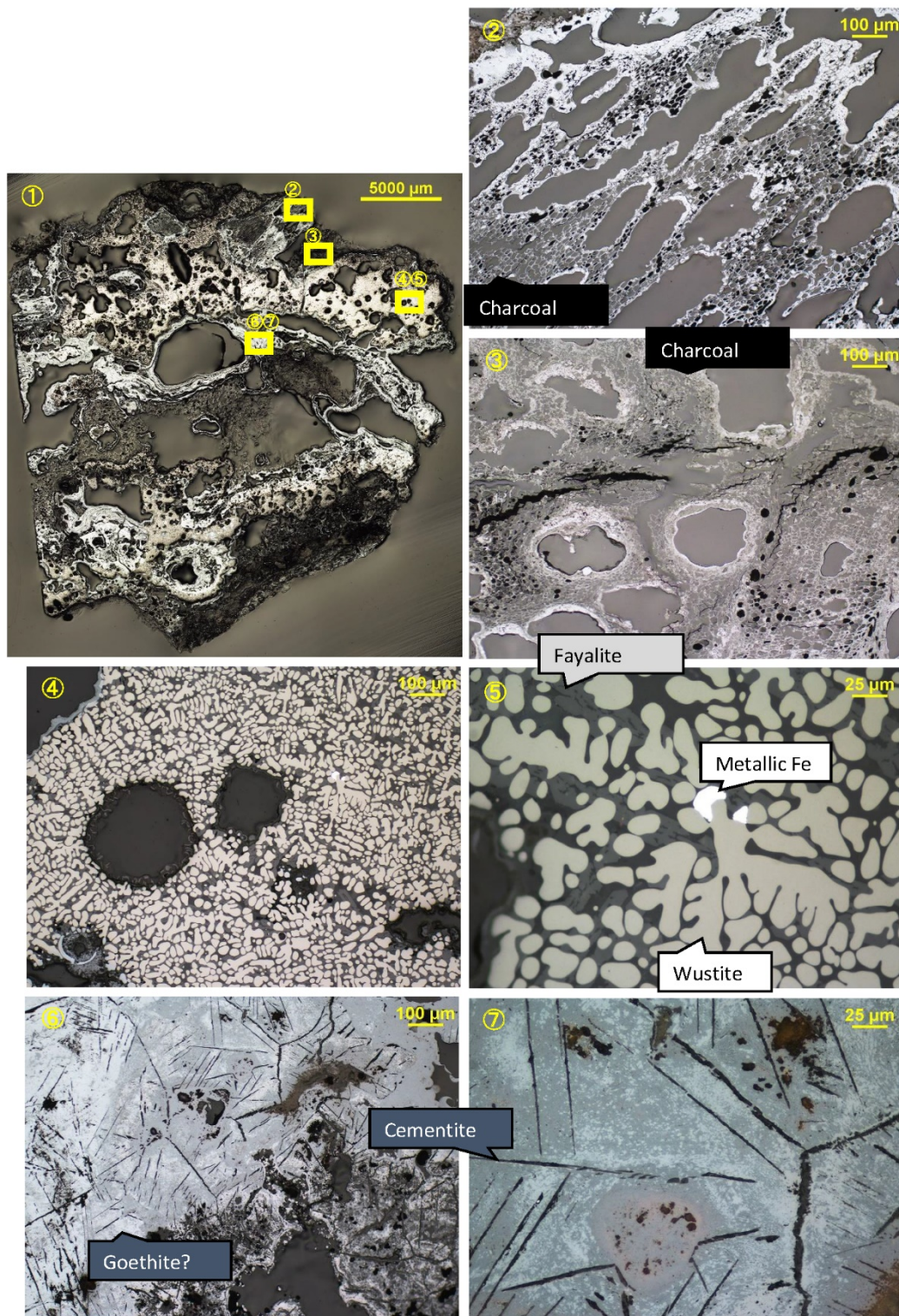


Fig. 76.1-7: R-32-4 Subsection 3 Micrographs

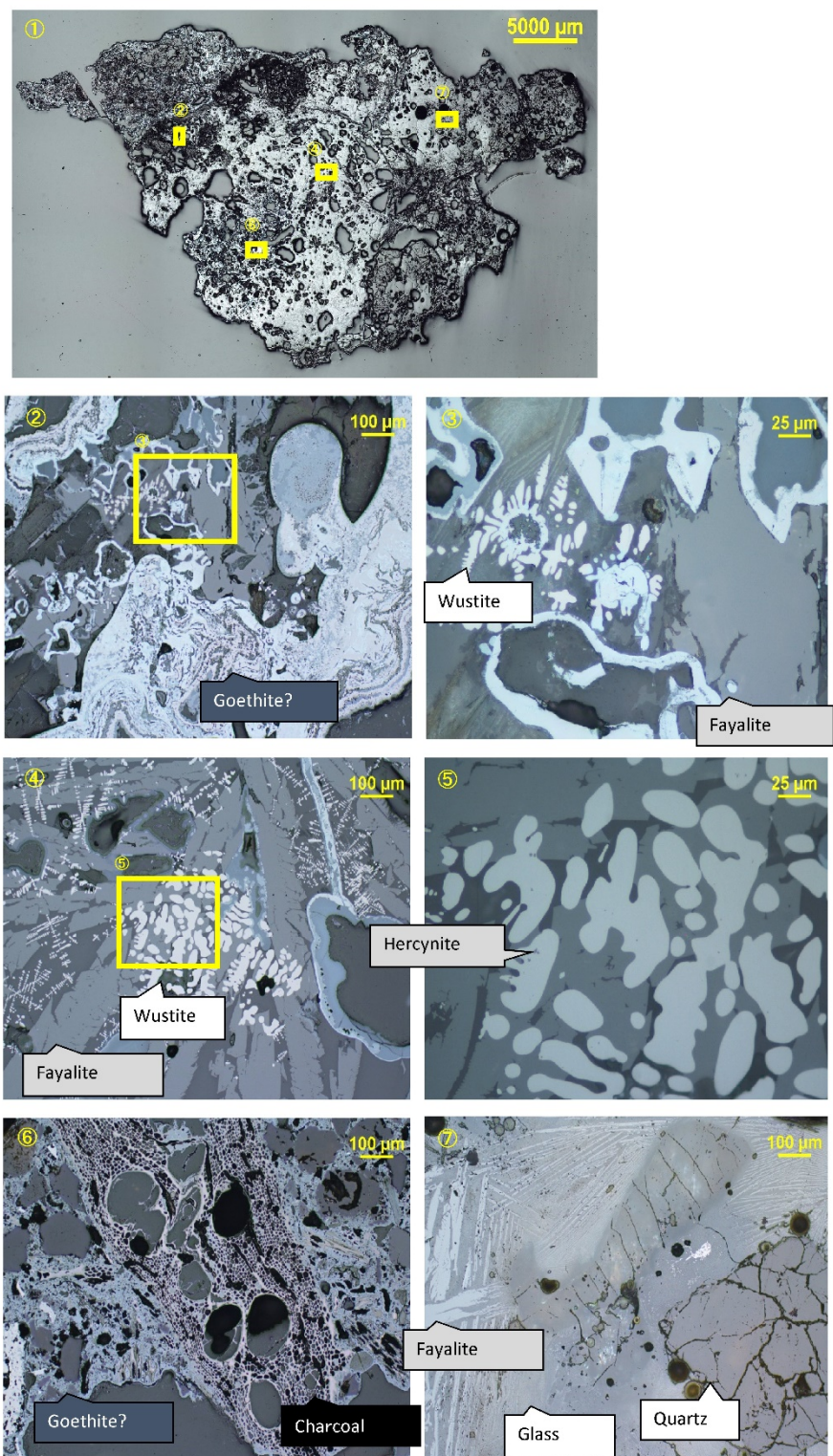


Fig. 77.1-7: R-32-5 Subsection 1 Micrographs

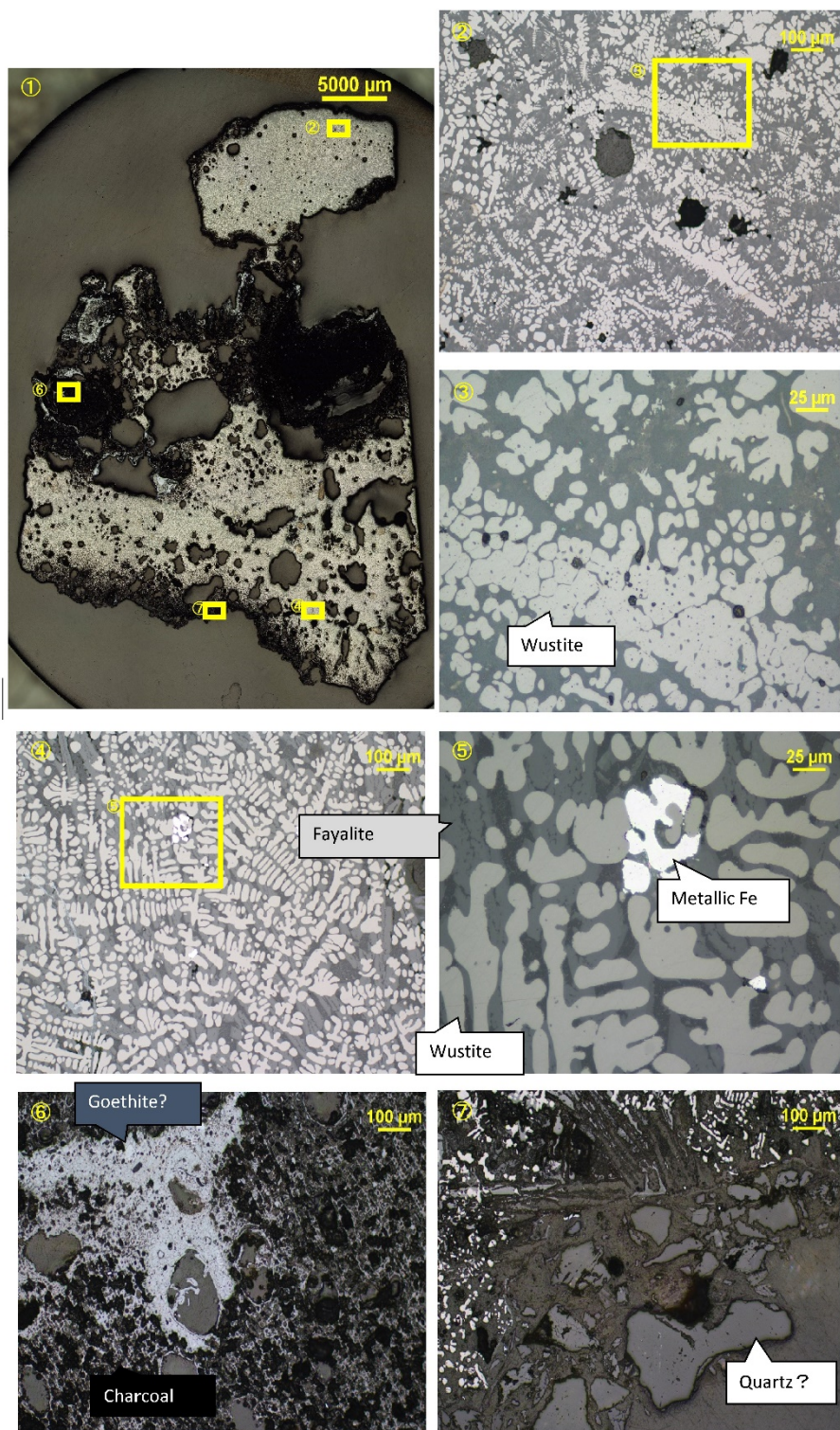


Fig. 78.1-7: R-32-5 Subsection 2 Micrographs

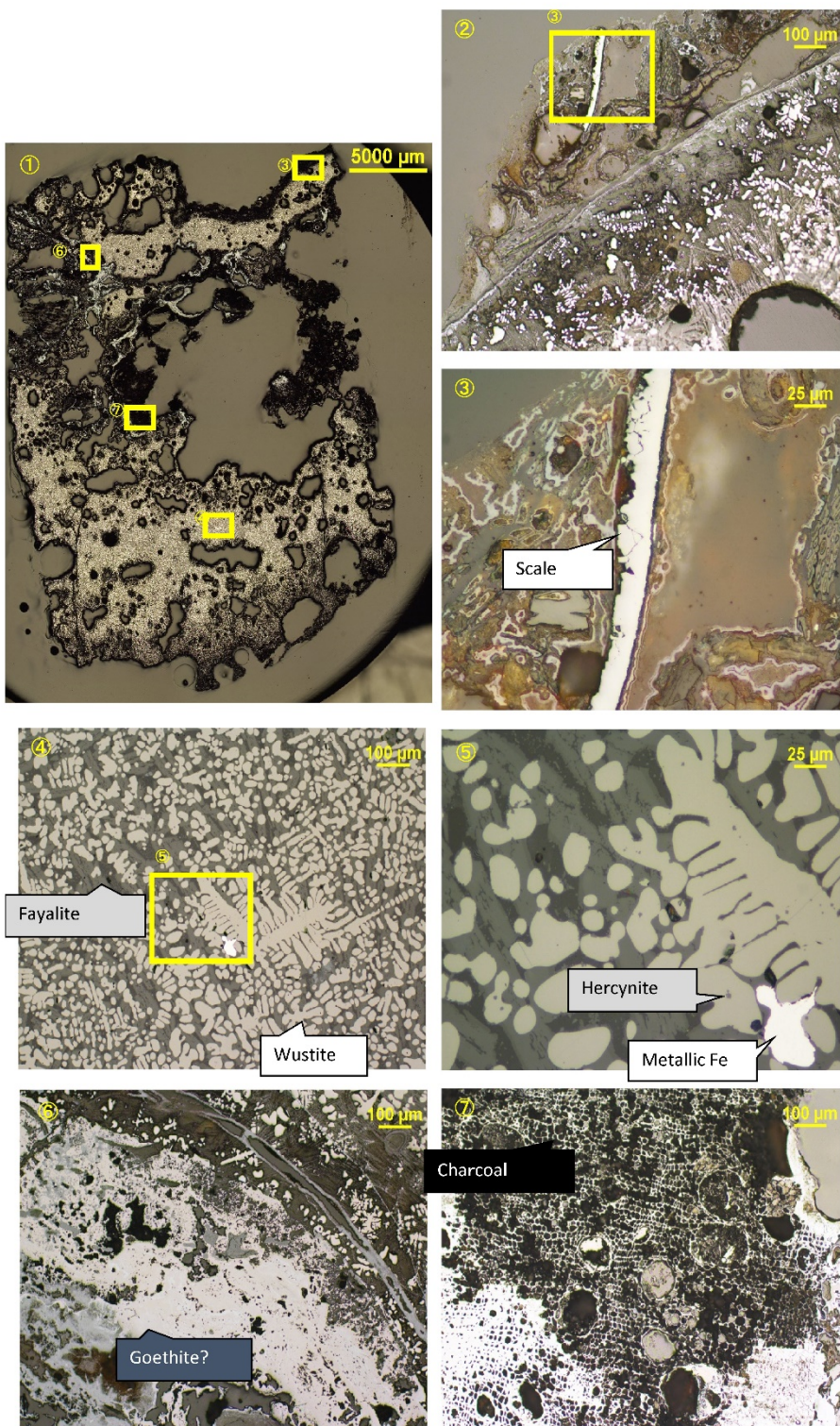


Fig. 79.1-7: R-32-5 Subsection 3 Micrographs

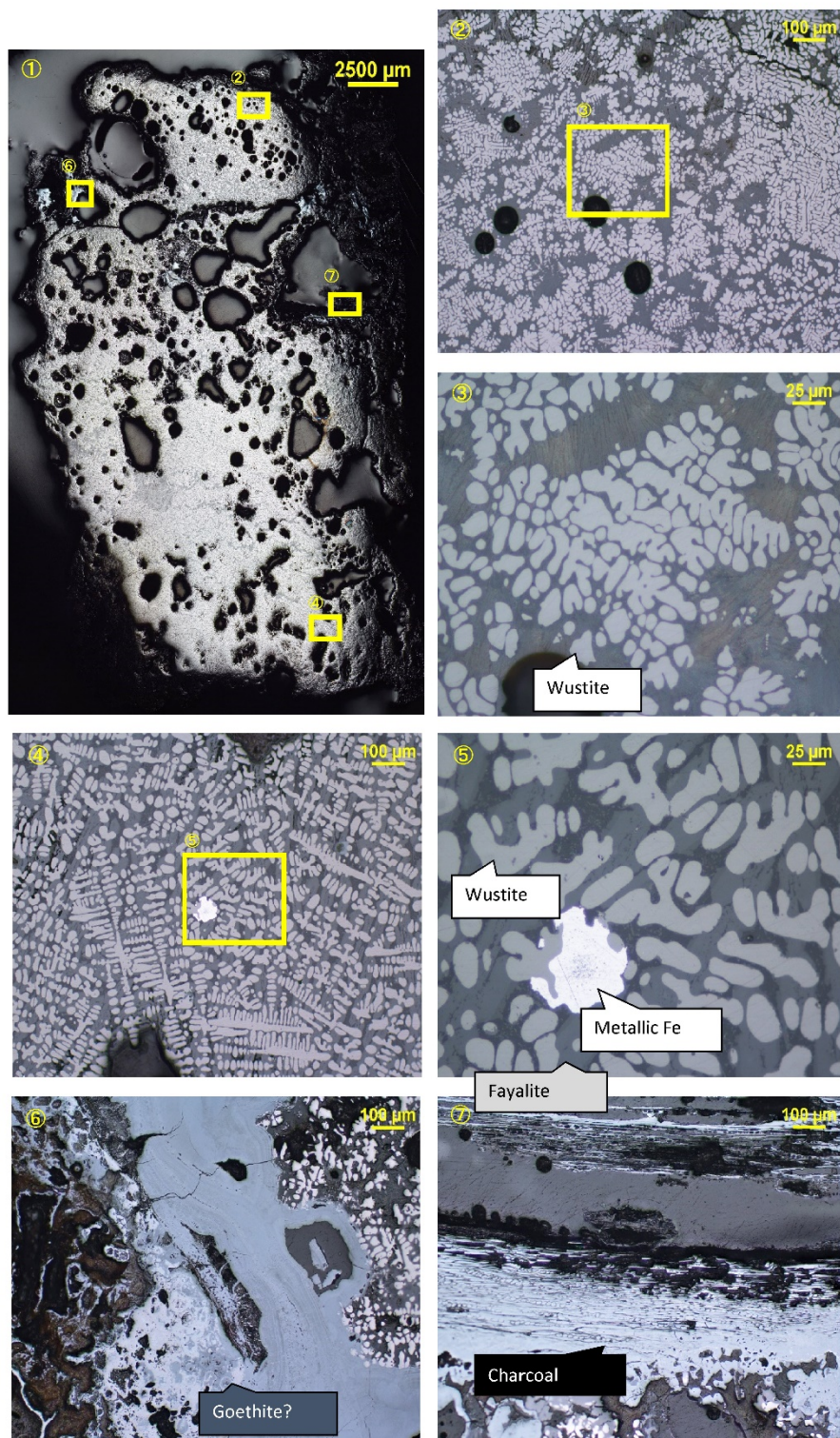


Fig. 80.1-7: R-32-5 Subsection 4 Micrographs

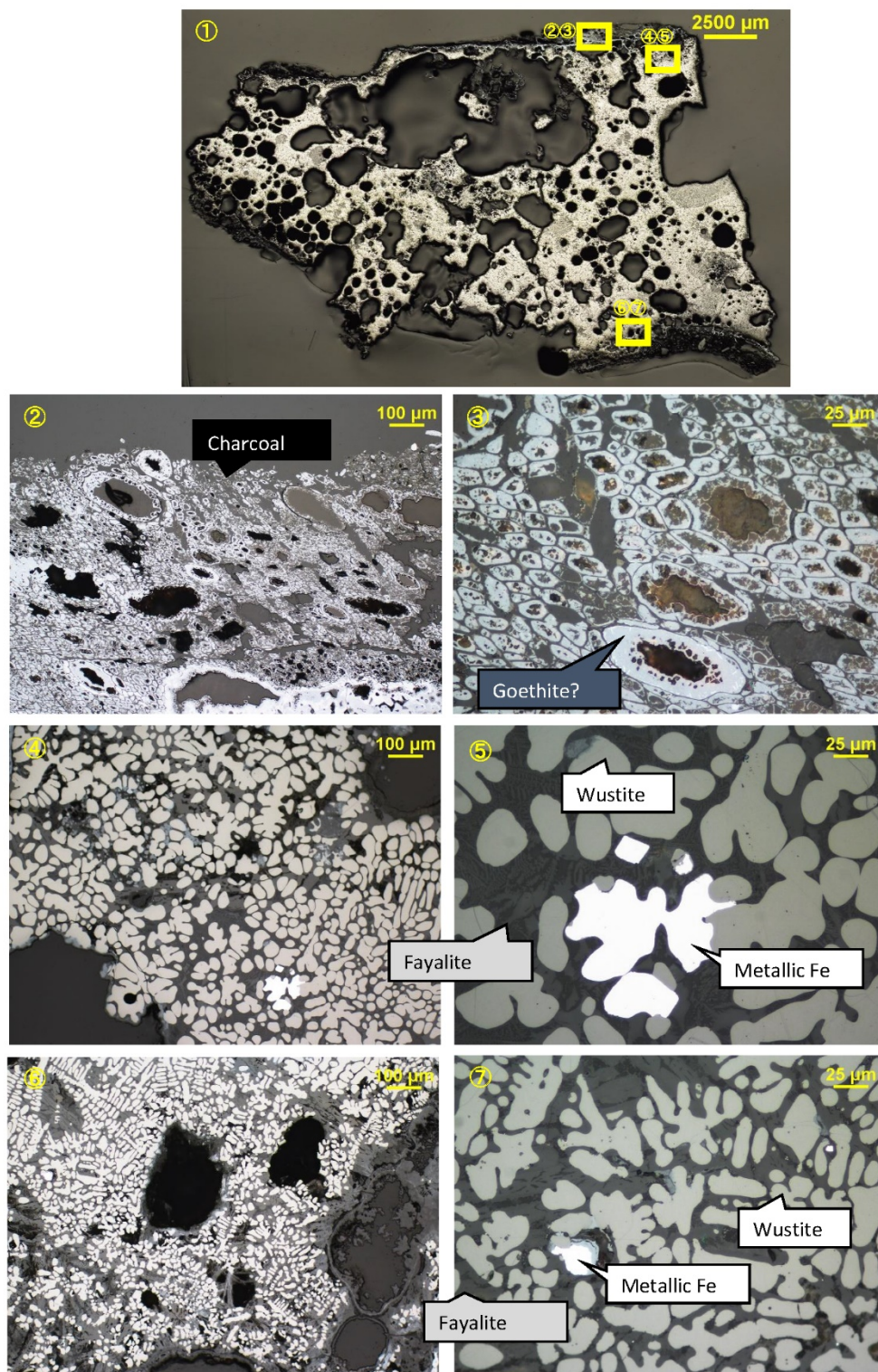


Fig. 81.1-7: R-32-6 Subsection 1 Micrographs

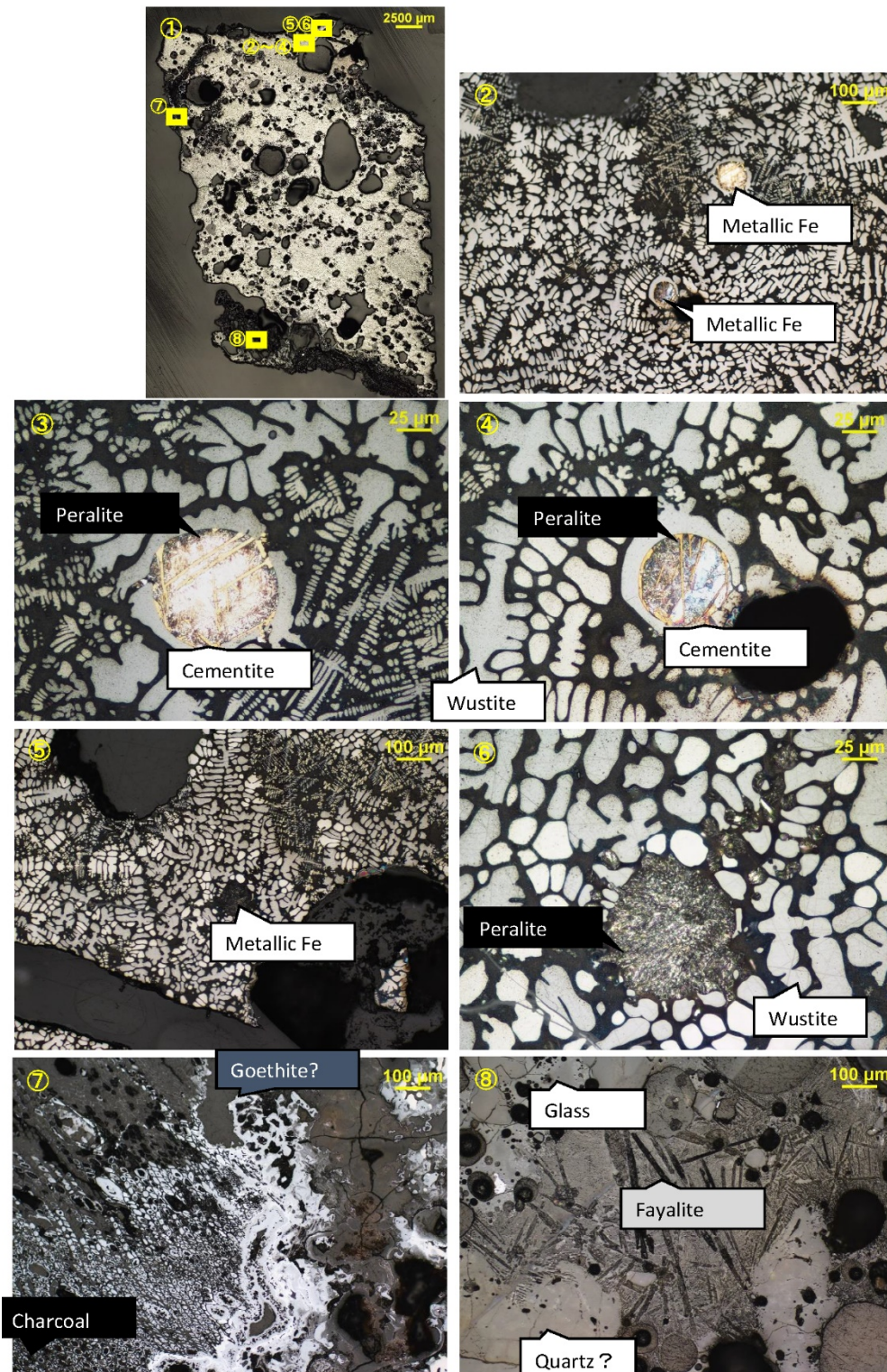


Fig. 82.1-8: R-32-6 Subsection 2 Micrographs

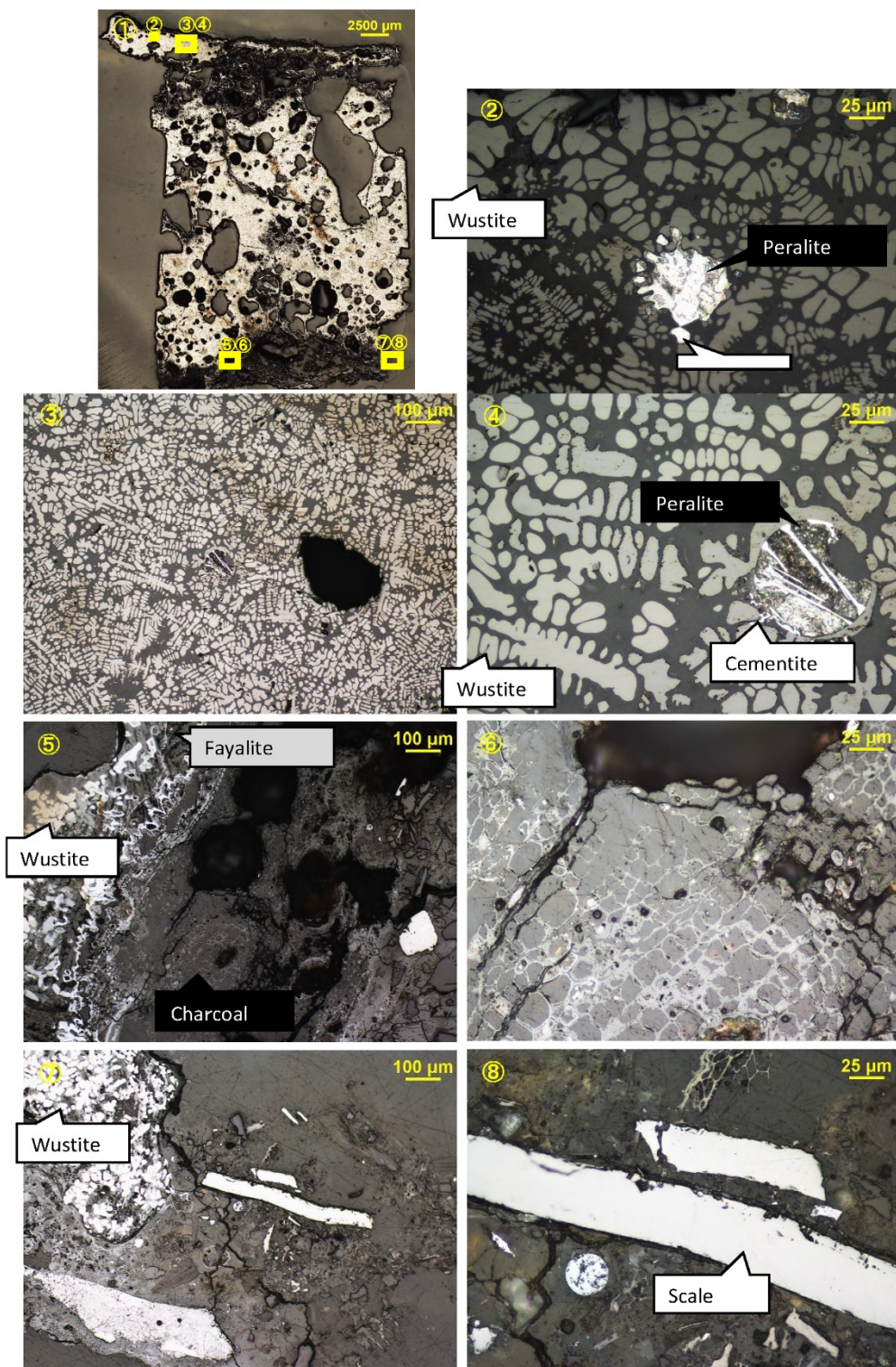


Fig. 83.1-8: R-32-6 Subsection 3 Micrographs

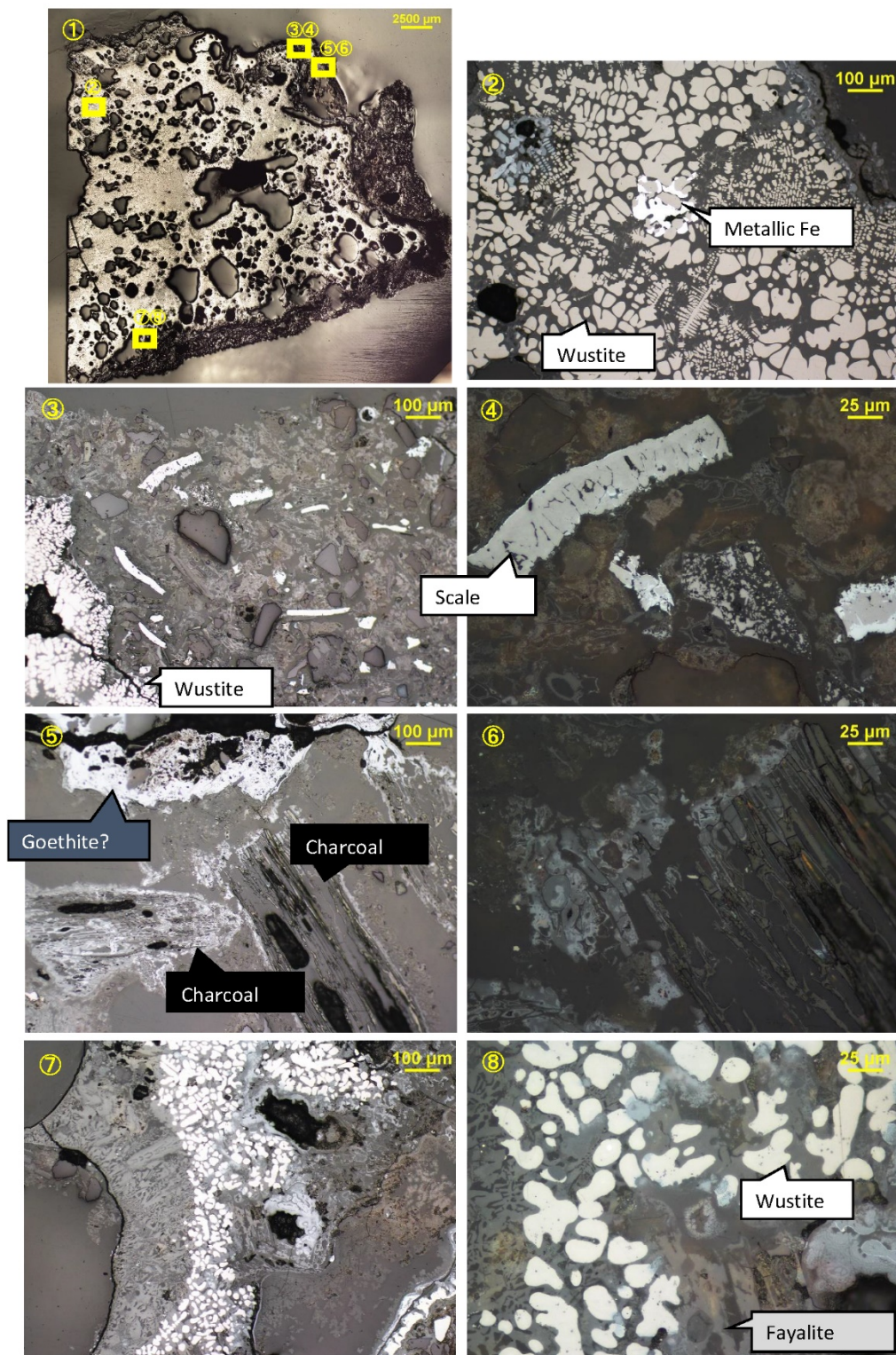


Fig. 84.1-8: R-32-6 Subsection 4 Micrographs

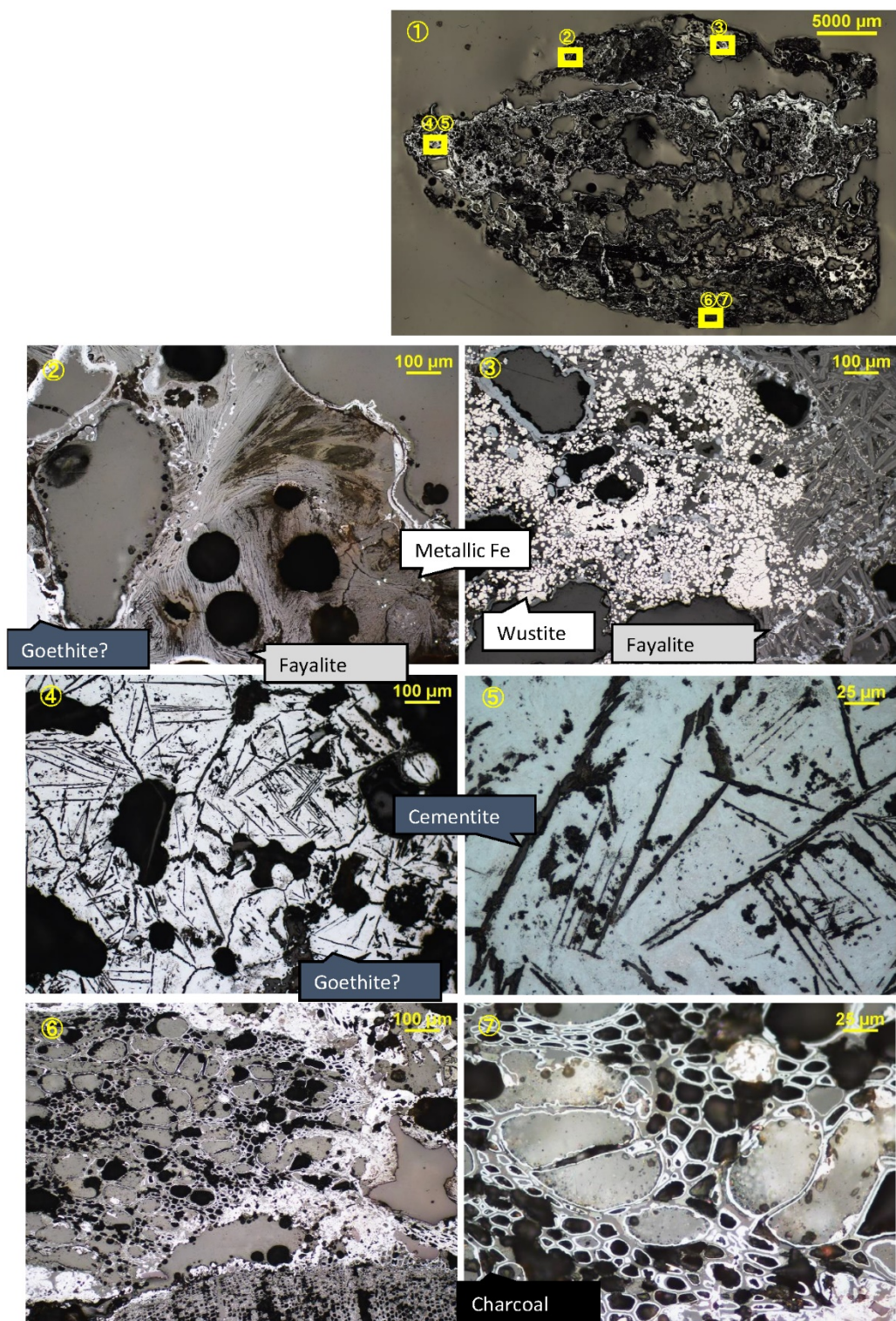


Fig. 85.1-7: R-32-7 Subsection 1 Micrographs

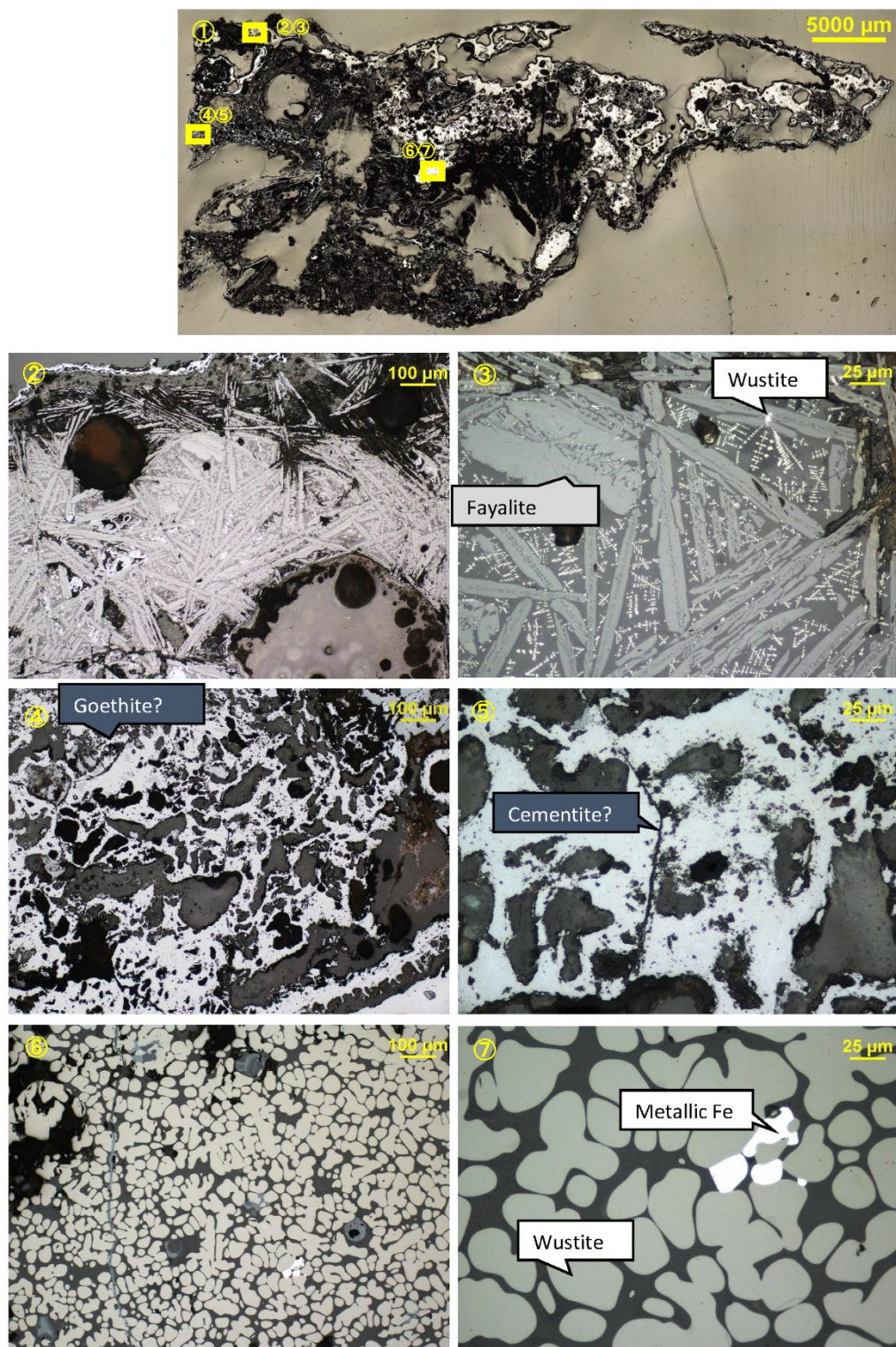


Fig. 86.1-7: R-32-7 Subsection 2 Micrographs

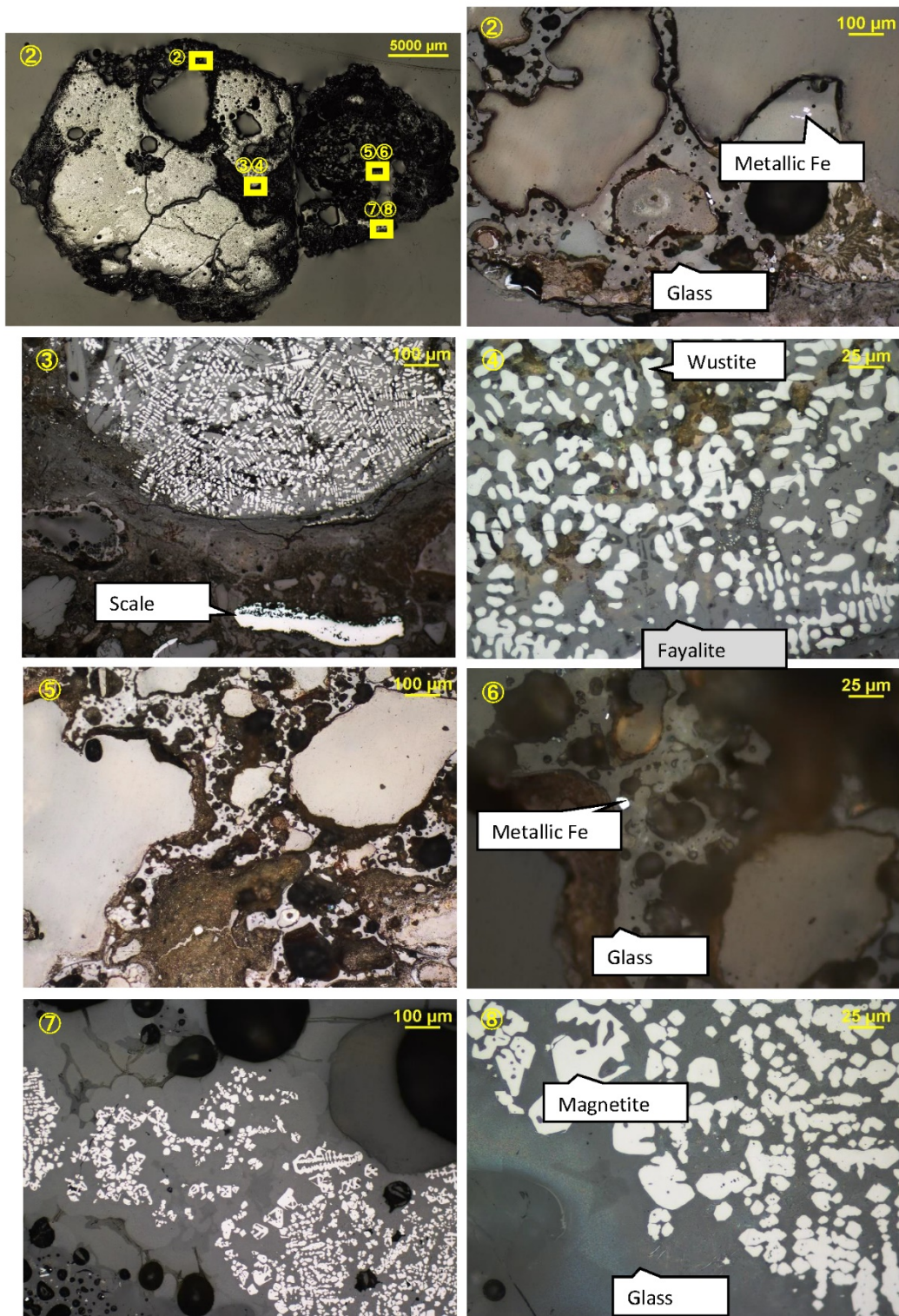


Fig. 87.1-8: R-38-1 Subsection Micrographs