One man's waste is another man's obsession: a theoretical framework for the study of ferrous slags

Allan B Daoust

ABSTRACT: Since archaeometallurgy essentially originated from the unplanned union of two widely disparate fields of study, this new sub-field of archaeology was left without a clearly defined framework or research agenda beyond the study of past metallurgy and its associated remains. While the virgin territory that this field encompassed allowed for tremendous progress to be made, the lack of a specific theoretical framework resulted in this progress being skewed towards a predominantly technological focus. This paper attempts to establish a clear theoretical framework within which the current parameters of archaeometallurgical research may be expanded, to be more in line with archaeology as a whole. Such a model shall demonstrate the role of archaeometallurgical remains, such as ferrous smithing and smelting slags, within a broader techno-industrial and socio-cultural context, while elucidating the various relationships that exist between technological processes and their products.

Introduction

Archaeometallurgy was, and very much continues to be, a highly technical, scientifically-dominated sub-field of archaeology, which often renders its research output beyond the reach of other archaeologists. While a number of studies have placed metallurgical industries within a wider socio-cultural context by exploring their mythico-religious connections (Blakely 2006), their relationship with the role of kingship and power (Maret 1985), or the symbolic reflection of socio-cultural ideals within metal technologies (Hosler 1994), many studies remain detached from the cultural environment of these technologies. Archaeometallurgical publications are typically rife with tables of chemical compositions resulting from instrumental analyses and sample micrographs, which frequently occupy the bulk of the research narratives. In many cases, the implicit focus of this research has been the creation of a database of past metals technologies, prompted by the ever-present belief that 'more analytical data are needed' (Bayley 1998, 168); but the current problem with archaeometallurgy lies not with the quantity, or even the quality, of the available data, but rather with the focus of these data and their role within interpretation. For archaeometallurgists 'have rarely ventured any opinion on the social context of early metallurgy, preferring to stick closely to technical interpretation' (Killick 2001, 486), resulting in the production of highly technical metallurgical works that are often inaccessible to other archaeologists.

This problem is especially prevalent within the archaeometallurgy of iron technologies, with which the present work is specifically concerned. Although some works have incorporated the archaeometallurgy of iron into a wider archaeological and socio-cultural narrative (Humphris *et al* 2009; Iles and Martinón-Torres 2009; Reid and MacLean 1995), many remain focussed on metallurgical concerns alone. Since the early archaeometallurgists were largely trained in modern metallurgy they 'tried to adapt techniques used in the analysis of blast furnace slags to the interpretation of prehistoric slags' (Killick 2001, 488), leading to the adoption of a highly scientific, metallurgically-driven methodological approach to past technologies, 'starting with morphology and ending with chemical analysis' (Espelund 1997, 8).

Thus, many of the early studies into the archaeometallurgy of iron were dominated by the physico-chemical analysis of past metallurgical materials (Hedges and Salter 1979; Morton and Wingrove 1969 and 1972; Tylecote *et al* 1971). This trend has subsequently continued into the present (Allen 1988; Buchwald and Wivel 1998; Coustures *et al* 2003; Paynter 2006). These studies have all made significant contributions to our understanding of past ferrous technologies, but their influence within the broader study of archaeology has been quite limited.

This technical understanding provides a solid foundation upon which further studies may be built, but without integration into the broader archaeological narrative it also has the potential to isolate ferrous archaeometallurgy from archaeology and the social sciences. Such technological isolationism has infiltrated the conceptual framework within which some archaeometallurgists operate, leading to false suggestions such as that 'many types of sites are "monocultures", not influenced by activities other than ironmaking' (Espelund 1997, 8), which only emphasise the extent of the disconnection between archaeometallurgy and one of its parent fields. Technology does not occur within a vacuum, and it can only be understood within a broader socio-cultural framework, a concept which forms the basis for archaeological and anthropological studies of technology. As Killick (2001, 490) points out, '[e]xtractive metallurgy is human behaviour', and this consideration must inform the design and execution of archaeometallurgical research projects.

The question, it seems, ultimately comes down to one of purpose. Is the purpose of archaeometallurgy simply to understand the metallurgical principles and science behind past metals technologies, or is it to inform and contribute to a broader understanding of the cultures and societies that engaged in metalworking through an examination of the remains of these technologies? Put another way, are we engaged in the study of archaeo*metallurgy* or *archaeo*metallurgy, or perhaps some combination of the two? If the aim of this field is to examine the various facets of the relationship between metals, metalworking, and societies, then archaeometallurgy needs to review and restructure its approach to the study of its materials. The best way to achieve this end is to adopt an underlying theoretical framework, especially one that will be comparable to, and understood by, other fields of archaeological research, in order to guide future research and facilitate both its dissemination and use amongst a broader audience.

A theoretical framework

Although slags may be viewed simply as a waste by-product of high-temperature metallurgical processes, they occupy an unrivalled position within archaeometallurgical research since they serve as the most informative, and quite often the only, witness to the execution of past metallurgical activities (Bachmann 1982; White 1980). The study of this material has been central to archaeometallurgy from its formative stage through to the present. The capacity of this archaeological material to inform understanding of past modes of metal production, as well as their place within socio-cultural networks, is significantly impaired by the lack of an established or consistent theoretical framework to guide research and the dissemination of its results. Much of the focus within slag analysis and research has been on understanding the processes and mechanisms by which they were formed, often removed from any wider context (Bachmann 1982; Kresten and Serning 1983; Kresten *et al* 1998; Kresten *et al* 2000; Kronz 2000; Kronz 2003; Morton and Wingrove 1969; Morton and Wingrove 1972; Tylecote *et al* 1971; Tholander and Blomgren 1985; Rose *et al* 1990; Thomas and Young 1999a; Thomas and Young 1999b; Wynne and Tylecote 1958). Yet slags have been poetically described as 'anthropic rocks' (Ploquin *et al* 1996), referring to the socio-cultural context that has been written upon the very origins of this material. What is needed then is an appropriate model to bridge the divide between metallurgy and archaeology; one based upon current theoretical approaches to ancient technology within archaeology but modified for a metallurgical context.

On a simplified level, metallurgical activities are no different from any other productive industry or technological system, and thus may be viewed as such within a theoretical framework. Yet metallurgical activities, such as iron production, differ from other technological systems in one key aspect. As the waste product of a technological process, slags occupy a position that is significantly different from the waste materials of other industries studied by archaeologists. While a variety of theoretical models have been developed and applied over the past half century for the study of ancient technologies, their primary focus has been on industries such as lithics (Sellet 1993) and ceramics (Sillar and Tite 2000). The model proposed here, however, has been developed specifically for the position that ferrous slags hold, as witnesses to the technological procedures that were followed and the choices that were made by the human agents involved in the production of iron.

In many respects the following model represents a variation on the principles behind the *chaîne opératoire* approach to technology, utilised. within archaeology, ‘to detail with extraordinary precision productive sequence(s) and decision-making strategies of raw material transformations’ (Dobres 1999, 124). This model allows archaeologists to explore the various processes involved in the production of artefacts, to situate these technologies within a socio-cultural context, and to study the cultural choices that were made within a given system of artefact production. By outlining the complete process by which raw materials were transformed into finished artefacts, *chaîne opératoire* allows the full complexity of a given technology to be studied, together with the artefacts it produced.

Many of these principles are already implicit within archaeometallurgical research (Bayley *et al* 2008), and so the following model is intended to bring these concepts to the fore in a manner that is familiar to archaeologists in general. Thus, the simplified model proposed here may be considered an inverted *chaîne opératoire,* which is based around the position of slags within metallurgical processes and the relationships that they have with other aspects of these technological systems. This model is intended to serve as a framework by which the metallurgical data that slags provide may be converted into archaeological information in a format that is familiar to a variety of archaeologists

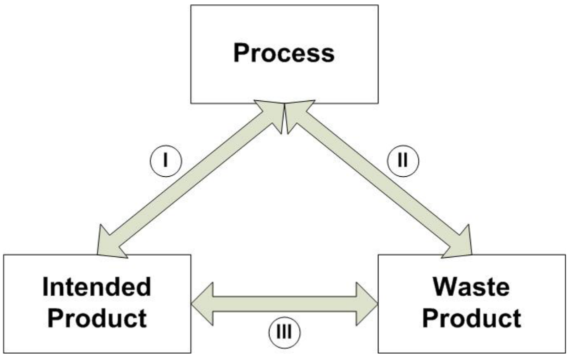

Figure 1: Industrial association diagram.

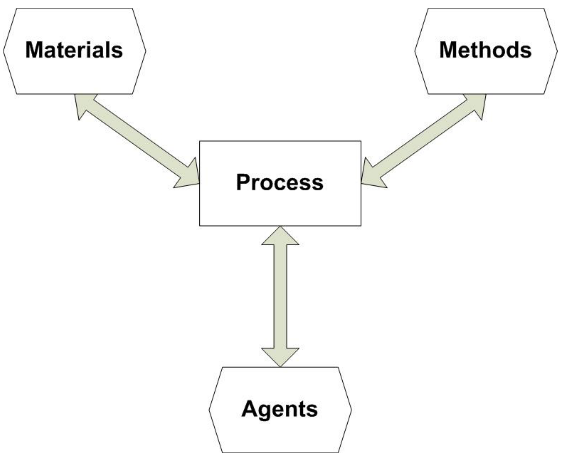

Figure 2: Industrial process diagram.

Past metallurgical processes may be envisaged as three separate yet closely interconnected components: the Process, the Intended Product, and the Waste Product. These components and the interconnections between them may be represented as a simplified chart (Fig 1).

The Process

In many respects the Process is the most important element of this system from the perspective of archaeometallurgical research, with its history of investigating process and using that data to classify metallurgical industries (Gordon 1997; Killick and Gordon 1987; Morton and Wingrove 1969;1972). However, many such studies approach these metallurgical Processes as though they constitute a singular or coherent phenomenon that may be understood through a scientific or analytical positing of variations on the question of ‘how’. Yet when reduced to its base level of theoretical simplification, as suggested here, the Process cannot be considered as a singular, monolithic subject, but rather emerges as a conceptual category. In this model, the Process becomes an entity formed from the contributions of three component classes, which may be labeled as Materials, Methods, and Agents (Fig 2).

In order to address the various metallurgical Processes properly within a research framework, each individual constituent must be approached from a separate perspective. The Materials are the physical components necessary for the execution of a specific Process, and these often leave remains which may then be recovered from archaeological contexts. Yet this is not the case for the Methods, which are the means by which the physical components are employed and the Process is executed. Such actions rarely leave any direct or specific evidence, leading some to pursue experimental reconstructions or ethnographic analogy. The final component of the Process system is also often the most overlooked in empirical archaeometallurgical studies, since it may not be understood from a scientific or technological perspective. The Process cannot be executed independently, and thus requires an Agent to select the appropriate Materials and perform the necessary Methods, providing a distinct human connection to the Process.

The Intended Product

The execution of any industrial activity is the result of a deliberate choice on the part of either an individual or group and such a decision is made with a specific aim or objective in mind, the physical manifestation of which is the Intended Product. Every artefact that was deliberately produced or modified through human agency stands as the Intended Product of some Process, and thus this category of materials is of great importance to archaeologists. The form and function of the Intended Product represents the final outcome of a series of choices concerning the nature and execution of the Process, and provides specific insight into the parameters of the Process, while providing archaeologists with both the socio-cultural and temporal identity of its manufacturers. This category, however, consists not only of completed artefacts but also of processed raw materials, and thus the Intended Product of one Process may constitute one of the Materials of a further Process. For example, iron bar stock may serve as the Intended Product of a smelting Process; this then becomes one of the Materials employed within the smithing Process in order to produce a further Intended Product in the form of a ferrous artefact.

The Waste Product

While the Intended Product is the deliberately-produced material impetus for the Process, it is not the only material product that results from the execution of such activities. Thus, the transformation or modification of the Materials employed within the Process invariably results in the production of various unintended waste by-products, referred to here as the Waste Product. Yet far from being merely an undesirable by-product of the production of a desired material or artefact, the Waste Product is an essential component of this system and its presence is necessary for the successful completion of the Process cycle. Since these materials were typically regarded as simple industrial refuse, the Waste Products generally survive within the archaeological record as a testament to the presence of some industrial process, unlike the Intended Product, which was often a commodity of some value and may be traded a great distance from where it was produced. As such, this category of materials is of prime importance for archaeologists, for the presence of certain Waste Products provides a marker for the execution of specific Processes nearby.

Relationships

The system of industrial activity expressed within this model provides a distinct context for each of its constituent elements, resulting in the presence of several key relationships amongst these constituents (Fig 1). Close relationships exist between the Process and the Intended Product (I), the Process and the Waste Product (II), and both the Intended and Waste Products (III). Since this is a closed yet interconnected system, decisions made concerning one element shall ultimately affect the nature of the others. In order to produce a specific Intended Product, a particular set of methods and materials would be selected for the appropriate Process, in turn resulting in morphological and physico-chemical variations within the resultant Waste Product. Current understanding of past metallurgical Processes is made possible through the presence of the Process-Waste Product relationship, and thus the exploitation of this specific relationship is currently recommended as part of the stated best practice for archaeometallurgy (Bayley *et al* 2008, 10–11).

Initial systematic analyses of ferrous smelting slags demonstrated that their relationship with the Process was quantifiable at some level (Morton and Wingrove 1969; 1972). As a direct archaeological link to past smelting activities, slags have been analysed and studied primarily to classify and categorise the different Processes employed throughout history (Buchwald and Wivel 1998; Buchwald 2003; Tholander and Blomgren 1985; White 1980). The Process-Waste Product relationship has also led archaeometallurgists to explore the extent to which regional variations are manifest within the composition of ferrous slags, forming the basis of provenancing studies (Buchwald and Wivel 1998; Buchwald 2001; Hjärthner-Holdar and Kresten 1996; Paynter 2006). These studies, however, have only focused on the relationships with the Process Methods and Materials, limiting their potential to inform the broader picture.

The application of such relationships within archaeometallurgy has not only been limited to the pursuit of a relatively narrow range of research questions, but it has also been limited to a specific group of archaeological materials. While this approach has been consistently utilised to provide insight into the smelting Process through the analysis and study of archaeological production slags, blacksmithing residues have not been equally regarded as viable sources of such archaeometallurgical data (McDonnell 1991), though recently that view has begun to change (Bayley *et al* 2008, 28–9; Young 2011). Yet the activities involved in the forging of ferrous artefacts involve a similar system to that of smelting activities, consisting of a Process which results in the production of both Intended, and Waste, Products. With such a model employed as an underlying premise, a pilot study was conducted that indicated that a similarly quantifiable relationship exists between the various components of the blacksmithing Process (Daoust 2007). Thus, when consciously applied as part of the research design, such a model has the potential to expand the conventional boundaries of archaeometallurgy.

Since conventional archaeometallurgy has generally only considered such aspects in isolation, separated from the context of the wider system, such studies have only had limited impact outside the sub-field. The Process-Waste Product relationship may be utilised to pursue cultural and anthropological questions associated with past metal production. Metallurgy is a technological expression that operates within a particular socio-cultural framework, the parameters of which are imprinted upon the human Agents behind the execution of these Processes. The socio-cultural context in which these Agents operate informs the decisions made regarding the Methods and Materials of the Process, decisions which ultimately determine the form and composition of the Waste Product. While several studies have explored the nature of these relationships, they have generally been restricted to African materials (Barndon 2004; Haaland 1985; Rehren *et al* 2007). Nonetheless, such studies have demonstrated the potential for archaeological slags to reflect the socio-cultural systems in which they were formed, when they are considered in the context of the human Agents responsible for their production.

Concluding remarks

With similar problems and possibilities defining their current status, the study of past ferrous slags is, in many respects, a microcosm for archaeometallurgy as a whole. The influence of modern metallurgy on the first generation of archaeometallurgists established a general research agenda which isolated the study of archaeological slags from all but their association with the mechanisms by which metallurgical Processes were successfully executed. Having been passed through the filter of modern metallurgical science, any wider research potential held by this material has become lost in the pursuit of the technology itself. Many researchers can no longer see the slag for all the fayalite.

These slags are not merely waste by-products or an unwanted necessity in the production of valuable commodities; they are cultural relics, markers of the technological achievements of past societies. Archaeometallurgists need to look beyond the paradigm of modern metallurgy and consider these archaeological slags as both metallurgical and cultural artefacts by adopting an approach that will 'reflect the goals of the study of archaeological materials in general' (Ehrenreich 1991, 55). The simplified model that has been discussed here is only one possible means by which this end may be achieved, although the majority of its principles are in line with the current thrust of archaeometallurgical research. It is hoped, however, that the explicit adoption of such an approach within future studies will help to put the archaeology back in archaeometallurgy and thus allow the results of archaeometallurgical research to reach a wider archaeological audience.

Acknowledgements

The author would like to express his indebtedness to his mentor and colleague, Dr Gerry McDonnell, who formed the inspiration for this work. He would also like to express his deepest gratitude to Dr Sally Katary, whose infinite generosity and kindness provided him with an opportunity to present this work to a wider audience. Your gifts of inspiration will never be forgotten.

References

Allen J R L 1988, 'Chemical compositional patterns in Romano-British bloomery slags from the wetlands of the Severn estuary', *Historical Metallurgy* 22(2), 81–86.

Bachmann H G 1982, *The identification of slags from archaeological sites* (London).

Barndon R 2004, *An ethnoarchaeoarchaeological study of iron-smelting practices among the Pangwa and Fipa in Tanzania* (Oxford: Cambridge Monographs in African Archaeology 61).

Bayley J 1998, 'Metals and metalworking in the first millennium AD', in J Bayley (ed), *Science in archaeology: an agenda for the future* (London), 161–168.

Bayley J, Crossley D, and Ponting M (eds) 2008, *Metals and metalworking: a research framework for archaeometallurgy* (London: Historical Metallurgy Society Occasional Publication No. 6).

Blakely S 2006, *Myth, ritual and metallurgy in ancient Greece and recent Africa* (Cambridge).

Buchwald V F 2001, *Ancient iron and slags in Greenland* (Copenhagen: Meddelelser om Grønland, Man and Society 26).

Buchwald V F 2003, 'Bloomery iron, Osmond iron, fined iron and puddled iron', in L C Nørbach (ed), *Prehistoric and medieval direct iron smelting in Scandinavia and Europe: aspects of technology and society. Proceedings of the Sandbjerg conference, 16th to 20th September 1999* (Aarhus), 171–175.

Buchwald V F and Wivel H 1998, 'Slag analysis as a method for the characterization and provenancing of ancient iron objects', *Materials Characterization* 40, 73–96.

Coustures M P D, Béziat F, Tollon C, Domergue L,and Rebiscoul A 2003, 'The use of trace element analysis of entrapped slag inclusions to establish ore – bar iron links: examples from two Gallo-Roman iron-making sites in France (Les Martys, Montagne Noire, and Les Ferrys, Loiret)', *Archaeometry* 45(4), 599–613.

Daoust A B 2007, The nature and composition of blacksmithing residues and their relation to weld-line slag inclusions, unpublished MSc dissertation, University of Bradford.

Dobres M-A 1999, 'Technology's links and chaînes: the processual unfolding of technique and technician', in M-A Dobres and C R Hoffman (eds), *The social dynamics of technology: practice, politics, and world views* (Washington), 124–46.

Ehrenreich R M 1991, 'Archaeometallurgy and archaeology: widening the scope', in P D Glumac (ed) *Recent trends in archaeometallurgical research* (Philadelphia: MASCA Research Papers in Archaeology 8), 55–61.

Espelund A 1997, 'An attempt to define archaeo-metallurgy', in L C Nørbach (ed) *Early iron production: archaeology, technology* *and experiments* (Lejre: Historical-Archaeological Experimental Centre Technical Report 3), 7–13.

Gordon R B 1997, 'Process deduced from ironmaking wastes and artefacts', *Journal of Archaeological Science* 24, 9–18.

Haaland R 1985, 'Iron production, its socio-cultural context and ecological implications', in R Haaland and P Shinnie (eds), *African iron working, ancient and traditional* (Oslo), 50–72.

Hedges R E M and Salter C J 1979, 'Source determination of iron currency bars through analysis of the slag inclusions', *Archaeometry* 21(2), 161–175.

Hjärthner-Holdar E and Kresten P 1996, 'Continuity and change during 2000 years of iron making', in G Magnusson (ed), *The importance of ironmaking: technical innovation and social change. Vol II* (Stockholm), 29–46.

Hosler D 1994, *The sounds and colors of power: the sacred metallurgical technology of ancient west Mexico* (Cambridge, MA).

Humphris J, Martinón-Torres M, Rehren T and Reid A 2009, 'Variability in single smelting episodes – a pilot study using iron slag from Uganda', *Journal of Archaeological Science* 36, 359–69.

Iles L and Martinón-Torres M 2009, 'Pastoralist iron production on the Laikipia Plateau, Kenya: wider implications for archaeometallurgical studies', *Journal of Archaeological Science* 36, 2314–26.

Killick D and Gordon R B, 1987 'Microstructures of puddling slags from Fontley, England and Roxbury, Connecticut, USA', *Historical Metallurgy* 21(1), 28–36.

Killick D 2001, 'Science, speculation and the origins of extractive metallurgy', in D R Brothwell and A M Pollard (eds), *Handbook of Archaeological Sciences* (Chichester), 483–492.

Kresten P and Serning I 1983, *The calculation of normative constituents from the chemical analyses of ancient slags* (Stockholm).

Kresten P, Grandin L and Hjärthner-Holdar E 2000, 'Mineralogy of archaeometallurgic slags', in D Rammlmair, J Mederer, T Oberthür, R B Heimann and H Pentinghaus (eds), *Applied mineralogy in research, economy, technology, ecology and culture. Vol 2* (Rotterdam), 1001–4.

Kresten P, Hjärthner-Holdar E and Larsson L 1998, 'Geochemistry in archaeometallurgy', in *Proceedings: the fourth international conference on the beginning of the use of metals and alloys (BUMA-IV). May 25-27, 1998, Kunibiki esse, Matsue, Shimane, Japan* (Sendai), 139–144.

Kronz A 2000, 'Self-mixing melt compositions in fayalitic slags – a key to understanding early metal production?', in D Rammlmair, J Mederer, T Oberthür, R B Heimann and H Pentinghaus (eds), *Applied mineralogy in research, economy, technology, ecology and culture. Vol 2* (Rotterdam), 1005–8.

Kronz A 2003, 'Ancient iron production compared to medieval techniques in Germany: fayalitic slag and elemental mass balances', in *Archaeometallurgy in Europe 2003* (Milan), 555–564.

Maret P 1985, 'The smith's myth and the origin of leadership in central Africa', in R Haaland and P Shinnie (eds), *African Iron working, Ancient and Traditional* (Oslo), 73–87.

McDonnell G 1991 'A model for the formation of smithing slags', *Materialy Archeologiczne* 26, 23–26.

Morton G R and Wingrove J 1969, 'Constitution of bloomery slags. Part 1: Roman', *Journal of the Iron and Steel Institute* 207, 1556–1564.

Morton G R and Wingrove J 1972, 'Constitution of bloomery slags. Part 2: Medieval', *Journal of the Iron and Steel Institute* 210, 478–488.

Paynter S 2006, 'Regional variations in bloomery smelting slag of the Iron Age and Romano-British periods', *Archaeometry* 48(2), 271–292.

Ploquin A, Mahe C and Leroy M 1996, 'Reconstruction of ironmaking procedure: a progress report about petrographical studies of slaggy wastes from archaeo-ironmaking sites' in G Magnusson (ed), *The importance of ironmaking: technical innovation and social change. Vol 2* (Stockholm), 105–119.

Rehren T, Charlton M, Chirikure S, Humphris J, Ige A, Veldhuijzen H A 2007, 'Decisions set in slag: the human factor in African iron smelting', in S La Niece, D Hook and P Craddock (eds) *Metals and mines: studies in archaeometallurgy* (London), 211–18.

Reid A and MacLean R 1995, 'Symbolism and the social contexts of iron production in Karagwe', *World Archaeology* 27(1), 144–61.

Rose D, Endlicher G and Mucke A 1990, 'The occurrence of 'iscorite' in medieval iron slags', *Historical Metallurgy* 24(1), 27–32.

Sellet F 1993, 'Chaine operatoire: The concept and its applications', *Lithic Technology* 18 (1 and 2), 106–12.

Sillar B and Tite M S 2000, 'The challenge of 'technological choices' for materials science approaches in archaeology', *Archaeometry* 42(1), 2–20.

Tholander E and Blomgren S 1985, 'On the classification of ancient slags by microstructure examination', in T Edgren and H Jungner (eds), *Proceedings of the third Nordic conference on the application of scientific methods in archaeology* (Helsinki: ISKOS 5), 415–425.

Thomas G R and Young T P 1999a, 'A graphical method to determine furnace efficiency and lining contribution to Romano-British bloomery iron making slags (Bristol Channel orefield, UK)', in S M M Young, A M Pollard, P Budd and R A Ixer (eds), *Metals in Antiquity* (Oxford), 223–226.

Thomas G R and T P Young 1999b, 'The determination of bloomery furnace mass balance and efficiency', in A M Pollard (ed), *Geoarchaeology: Exploration, Environments, Resources* (London: Geological Society Special Publications 165), 155–164.

Tylecote R F, Austen J N and Wraith A E 1971, 'The mechanism of the bloomery process in shaft furnaces', *Journal of the Iron and Steel Institute* 209, 342–363.

White J R 1980, 'Historic blast furnace slags: archaeological and metallurgical analysis', *Historical Metallurgy* 14(2), 55–64.

Wynne E J and Tylecote R F 1958, 'An experimental investigation into primitive iron-smelting techniques', *Journal of the Iron and Steel Institute* 190(3), 339–348.

Young T 2011, 'Some preliminary observations on hammerscale and its implications for understanding welding', *Historical Metallurgy* 45(1), 26–41.

The author

Allan B Daoust completed his MSc under Dr Gerry McDonnell at the University of Bradford. He is currently teaching within the Department of Ancient Studies, Thorneloe University at Laurentian in Sudbury, Ontario. His research interests include the relationship between technology and culture, the metallurgical industries of the Roman Empire and the nature of metallurgical craft specialisation.

Address: Thorneloe University at Laurentian, Ramsey Lake Road, Sudbury, Ontario, P3E 2C6, Canada.

Email: ax_daoust@laurentian.ca