Boom and Bust in Bronze Age Britain

The Great Orme copper mine and European trade

R. Alan Williams

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Front cover: Aerial photograph of the Great Orme mine looking SE towards Llandudno (Great Orme Mines). Back cover: Continental distribution of shield-pattern palstaves.

In memory of my parents,

Gwilym Tegid Williams and Catherine Eirianwen Jones.

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Summary

The Great Orme Bronze Age copper mine is situated on a prominent limestone headland on the north Wales coast high above the popular seaside town of Llandudno. The spectacular mining remains were discovered in 1987 and now form an internationally important archaeological site as one of the largest Bronze Age copper mines in Europe. However, where all the copper went remained a mystery until the research described in this book was undertaken. It was claimed in the 1990s that the mine only produced a low impurity type of copper that was uncommon in the British Bronze Age. These claims marginalised the mine as an unimportant copper source, whose extensive workings were explained away as merely the result of small-scale workings over nearly a thousand years. The results of this new interdisciplinary research, which combined archaeological and geological knowledge with the latest scientific analytical methods, have now radically changed that picture. This new evidence has revealed a copper mine of European importance, which dominated Britain's copper supply for two centuries (*c*. 1600-1400 BC), with some metal reaching mainland Europe stretching from Brittany to the Baltic. This zenith period of large-scale production is very likely to have required a full-time mining community at the mine, possibly supported or controlled by the agriculturally richer area of northeast Wales with its links into wider communication networks. Once the richest parts of the mine had been exhausted, there followed a twilight period of minor production that lasted several centuries. Incredibly, most of the Bronze Age mine workings survived the revival of mining in historic times (AD 1692-1881) because the new areas mined were mostly underneath the ancient workings at a depth that had previously been inaccessible due to the lack of water drainage.

This book is based on the author's doctoral research at the University of Liverpool, Department of Archaeology, Classics and Egyptology. The literature on Bronze Age mining and smelting is reviewed, along with the various scientific approaches to provenancing metals. The author has developed a new interdisciplinary methodology which combines archaeological knowledge with expertise in ore geology, mineralogy, geochemistry and metallurgy. By analysing numerous ore samples from the Bronze Age workings and conducting smelting experiments, the range of Great Orme metal has been characterised or 'fingerprinted' to define a mine-based metal group using two independent analytical techniques (chemical composition and lead isotopes). Confidence in this metal group has been increased by its consistency with the bronze tool fragments excavated in the mine and with copper prills from the nearby Pentrwyn smelting site. Hence, any piece of analysed Bronze Age metalwork can now be checked for consistency with the Great Orme metal group. By combining existing databases of metalwork analyses with typological correlations, the geographical distribution of Great Orme metal across Britain and Europe has been deduced, as well as its chronological distribution. A radically new narrative emerges in which the Great Orme mine had a two-hundred-year 'golden age' of Bronze Age production, which reached across Britain and into Europe. Overall, the evidence from Great Orme metal suggests that Britain had a greater integration into European Bronze Age trade/exchange networks than had been previously suspected, even more so if tin from Cornwall/Devon and possibly gold is also included. This also implies greater organisation and complexity of social interactions between the numerous small farming communities across Britain than previously thought. A summary paper of this study was published in the journal *Antiquity* and was awarded the Ben Cullen Prize in 2020 (Williams and Le Carlier 2019). A general reader wishing to avoid too much technical discussion may prefer to focus on Chapters 1, 2, 3 (second half), 4, 9 and 10.

About the Author

Dr R. Alan Williams completed his PhD on the Great Orme Bronze Age copper mine in 2018 in the Department of Archaeology, Classics and Egyptology at the University of Liverpool, where he is an Honorary Research Fellow. He originally graduated with a BSc (Hons) in Mining Geology from the Royal School of Mines, Imperial College London, and after initially working in metal mining and exploration he had a long research career with the international glass company Pilkington (now NSG). He was head of the Raw Materials and Glass Compositions Department at the company's international research centre and was responsible for sourcing glass-making raw materials in over 20 countries. Since taking early retirement in 2012 he has been applying his expertise in geochemistry, ore geology, mineralogy and pyrotechnology to important archaeological challenges in the field of prehistoric metal mining and smelting. He has written several papers and three books on historic and prehistoric metal mining areas in Britain and Ireland. He also has a long-standing interest in Bronze Age tin since working at Wheal Jane tin mine in Cornwall as a student geologist nearly 50 years ago. He jointly initiated the Leverhulme-funded Bronze Age tin project to determine whether the exceptionally rich tin deposits of Cornwall and Devon powered the major technological and cultural transition from copper to full tin-bronze across Europe and beyond. He is currently a Post-Doctoral Research Associate in the Department of Archaeology at Durham University. He was awarded the Ben Cullen Prize in 2020 by the Antiquity Trust and was elected as a Fellow of the Society of Antiquaries in 2022.

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Chapter 1

Introduction

Setting the scene

The famous Welsh antiquary, Edward Lhuyd, recorded a remarkable discovery made in 1686 in a field at Gloddaeth, three kilometres from the Great Orme headland in north Wales:

> *'there were found...several brass instruments of the shape of axes, but whether they were British or Roman or what use they were designed for, I must leave to be determined by others. There were about fifty of them placed under a great stone placed heads and points, whereof some are yet preserved...They have been found in several other parts of Wales'* (Lhuyd 1698 quoted by Davies 1941: 205)

In 1987, just over three hundred years after this discovery of Bronze Age palstaves, the spectacular surface and underground remains of the Great Orme Bronze Age copper mine were discovered. The mine is situated on a prominent limestone headland above the seaside town of Llandudno on the north Wales coast (Figure1.1) The extraordinary complex of workings is now recognised as one of the largest Bronze Age mines in Europe (O'Brien 2013b: 445; 2015: 146; Timberlake and Marshall 2014: 77; Cunliffe 2012: 204). The other twelve known British Bronze Age mines or trials, all discovered in the last 35 years, are very small by comparison (Timberlake 2009). The radiocarbon dates suggest the Great Orme mine was probably worked for around 800 years (*c.* 1700-900 BC), spanning part of the Early Bronze Age, through the Middle Bronze Age and into the Late Bronze Age. By contrast, all the other known British Bronze Age mines had started earlier and had all closed by around the end of the Early Bronze Age (*c.* 1600 BC) (Timberlake and Marshall 2014: 90).

When the very extensive workings were discovered and dated at the Great Orme mine, it was initially thought that they must have been a major source of Middle Bronze Age copper in Britain (Lewis 1996). However, for this to be true the metal produced from the mine ores must contain the levels of arsenic and nickel impurities that were characteristic of most of the metal artefacts of this period. A series of highly influential papers from 1996 to 2001 claimed the Great Orme ores produced only low impurity metal with no significant levels of arsenic or nickel and so the inevitable conclusion was that the Great Orme mine could not have been a significant Bronze Age metal source (Ixer and Davies 1996; Ixer and Budd 1998; Ixer 2001). The low impurity metal conclusion was based entirely on the absence of any traces of nickel and arsenic minerals in the copper ore samples examined rather than on actual chemical analyses – an issue the current research re-examines. The conclusions from these papers, and subsequent papers that relied upon them, echo through the literature right up to the present day.

> '*the mineralogy of the ores shows that they could only produce trace element poor copper metal.... and that their usefulness in provenancing Bronze Age metalwork based upon distinctive trace element signatures is very limited*' Ixer (2001: 218)

> *'the Great Orme ores contain no arsenic whatsoever'* (Budd 2000: 14)

> '*copper from the Great Orme cannot be identified in the contemporary bronzes...Great Orme ore is characterised by very low nickel contents'* (Craddock 1994: 76)

> 'the *problem with the Great Orme is that...it is incompatible with the bulk of Middle Bronze Age metal'* (Northover 1999: 223)

> *'the copper produced was of high purity making it difficult to follow its circulation ...'* (O'Brien 2015: 150)

However, if these claims were true and the Great Orme metal did not match most Bronze Age metalwork, why was the mine is so large? This was explained by another influential claim, namely that the mine never had a period of large-scale production and was only such an extensive mine site due to small-scale seasonal production over nearly a millennium (Budd and Taylor 1995: 138; Needham 2007a: 281; O'Brien 2015: 270). Confusion in the literature is demonstrated by other scholars expressing the view that the Great Orme mine was probably an important source of Middle Bronze Age metal, but they were unable to explain the conflicting evidence (Rohl and Needham 1998; Lynch *et al.* 2000; Timberlake 2009; Bray 2012). Rohl and Needham's (1998: 111, 181) pioneering lead isotope work on British Bronze Age metal artefacts and ores indicated that Great Orme has isotope data matching some metalwork, but they struggled to explain the often high level of nickel and arsenic in the metalwork which conflicted with the 'prevailing opinion' that there were only low levels of impurities in the ores.

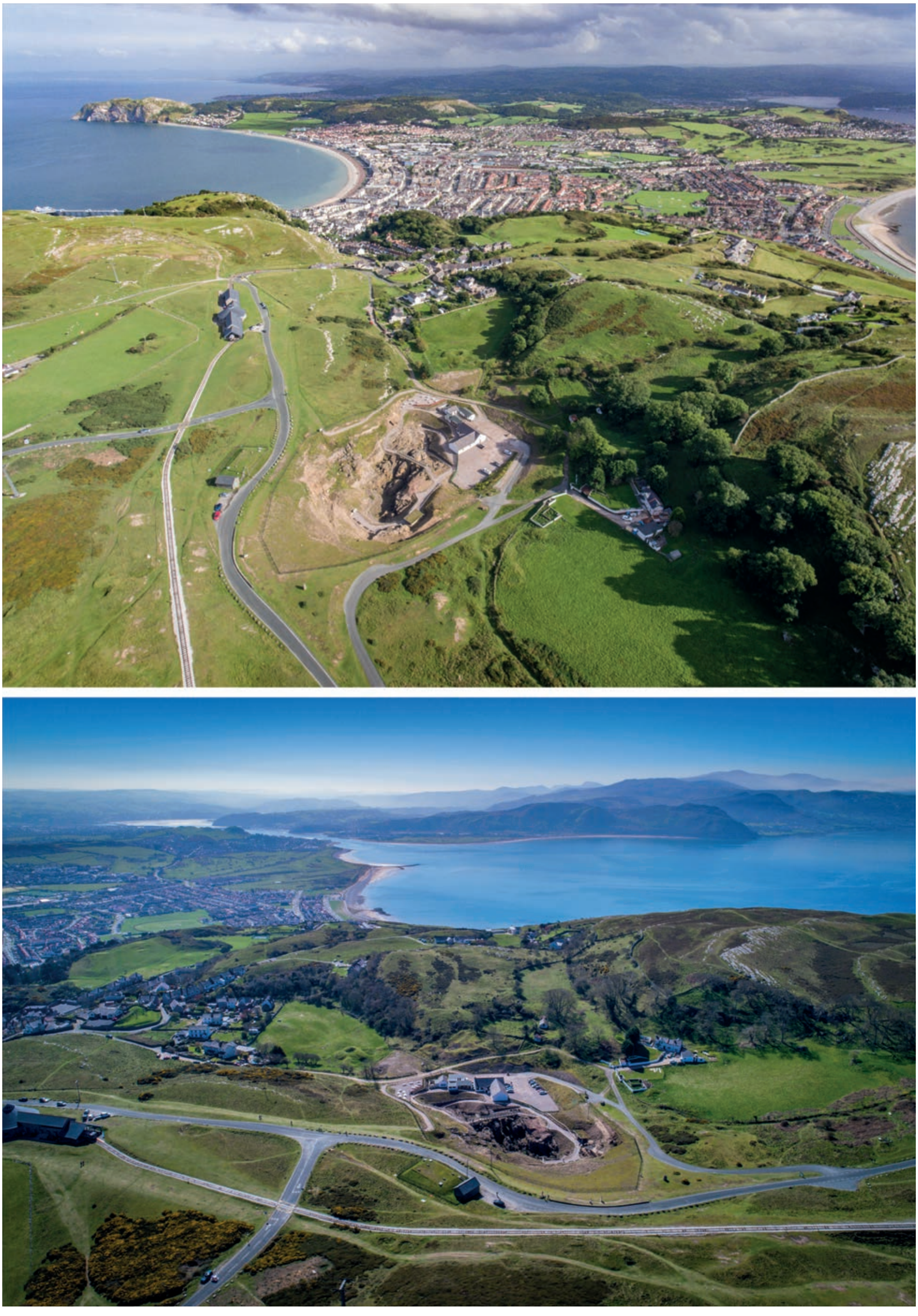

Figure 1.1: General aerial views of the Great Orme mine looking SE (top) and SW (bottom)(Great Orme Mines)

The central challenge of the research project described in this book was to try and resolve the contradictions and confusion in the literature over the enigma of what happened to the Great Orme metal and the true scale of copper production from the mine. The new approach used interdisciplinary knowledge from the author's original degree in Mining Geology from the Royal School of Mines at Imperial College, University of London and his experience of working in metal mines (e.g., Wheal Jane tin mine). Further useful expertise in mineralogy, geochemistry and pyrotechnology was gained by the author during his long career as head of raw materials and glass compositions at the European research centre of an international glass company. While metallurgists have long been very influential in archaeology (archaeometallurgy), mining geologists with their knowledge of ores, have been less prominent. There are strong parallels with the new and expanding field of geometallurgy, a term coined by the modern mining industry to bridge the gap between geosciences and metallurgy as they seek to improve the recovery of metal extracted from ores (Bowell *et al.* 2011). The interdisciplinary research approach adopted in this study can therefore be termed archaeogeometallurgy.

How then can this interdisciplinary knowledge be applied to finding a way of linking the Great Orme ores to Bronze Age metalwork? The answer was to identify distinctive chemical and isotopic 'fingerprints', or defined fields, which can distinguish the copper metal produced at the mine from other potential metal sources. A methodology was developed that involved the new concept of a mine-based metal group. Compositional and isotopic data were obtained from numerous bulk ore samples that were collected systematically throughout the Great Orme Bronze Age mine workings. These two types of ore data were used to define two separate groups or fields (with a compositional component and an isotopic component). For a Bronze Age artefact to be potentially from the Great Orme, it must be consistent with both fields. This new mine-based metal group concept contrasts with the existing artefact-based metal group concept that was established at a time when British Bronze Age mine sites were still unknown and only a few had been discovered in Europe. Artefact-based groups were established by grouping together artefacts with similar chemical analyses (and a later scheme added lead isotope analyses). The actual boundaries of these groups are mostly subjective, although at least one scheme used clusters identified by statistical analysis. While some of these groups have proved useful in indicating major source changes, other groups and their subgroups have been proved less so. Moreover, the groups can be misleading because a single mine source can sometimes produce metal belonging to more than one of these groups (Chapter 5).

The compositional field of the Great Orme mine-based metal group was established in two steps. Before making any adjustment for trace element loses during smelting, the initial compositional field was constructed based on the numerous ore analyses assuming all trace elements were fully transferred into the metal. The adjustments for trace element losses were then made based on the results of smelting experiments comparing the analysis data of the ores with that of the smelted copper metal they produced. This allowed the percentage partitioning of ore trace elements into the metal (rather than the slag) to be calculated and adjustments to be made. The next stage was to test the mine-based metal group for consistency with the two types of associated metals that most likely to be derived from the mine ores. Firstly, the bronze fragments from mining tools found in the mine. Secondly, the copper prills from the Pentrwyn Bronze Age smelting site near the mine. As these two metals were consistent with the defined metal group, then this gave much more confidence that it represented Great Orme metal.

The final stage was to apply the fully established Great Orme mine-based metal group to all artefacts in existing Bronze Age metalwork databases and identify those that are consistent with Great Orme metal. Distribution maps were compiled of artefact types that were newly correlated with Great Orme metal to identify high density areas and possible distribution networks across Britain and into the near Continent. The implications for the mine organisation were then reviewed, including links into wider exchange/trade networks.

Research questions

The project stages summarised above were designed, in conjunction with the other research work described in the following chapters, to answer the important research questions listed below.

- Do geochemical trace/minor element ore analyses support the widespread claim in the literature that the Great Orme mine only produced low impurity copper metal?
- What are the mineralogical and chemical characteristics of the main ores mined and what proportion of the trace/minor elements in the ores transfer into the metal during smelting?
- Can the unusually wide range of (radiogenic) lead isotope results from the Great Orme ores be explained and harnessed to help characterise the metal produced?
- Can the copper metal produced by Great Orme ores be successfully characterised by combining the compositional and isotopic 'signatures', or fields, to define the new concept of a mine-based metal group?

- Is such a mine-based group consistent with the bronze fragments found in the mine and the copper prills from the nearby smelting site at Pentrwyn?
- Can such a mine-based group be used to identify Great Orme metal in existing British Bronze Age metalwork databases? If so, was there a particular period of large-scale production or was it just continuous/sporadic small-scale production as claimed in the literature?
- Can Great Orme metal be linked to the Acton Park metalwork assemblage phase (*c.* 1600/1500-1400 BC) and typologically similar metalwork on mainland Europe?
- Can the distribution of Great Orme metal be established by correlation with particular artefact types, and hence, can possible exchange/trade routes be deduced?
- What are the social and organisational implications that emerge from establishing the temporal and spatial distribution of Great Orme metal?

In order to answer the above questions, the relevant literature was reviewed and an extensive sampling and analytical programme undertaken. The key elements of the work undertaken were:

- Place the Great Orme mine into context by providing an overview of both British/Irish Bronze Age archaeology and British/Irish Bronze Age mines.
- Based on interdisciplinary knowledge, critically review the metal provenancing literature to establish best practice and identify weaknesses.
- Develop a new methodological approach to fully characterise the ores chemically and isotopically in order to create and define the concept of a mine–based metal group.
- Undertake a wide-ranging surface and underground ore-sampling programme in the Bronze Age workings of the Great Orme mine.
- Evaluate a range of analytical techniques to determine the most appropriate methods to tackle the many difficulties associated with ore analyses and confirm key results with more than one method. Provide ore and metal samples for lead isotope analysis.
- Use ore analyses results to establish a compositionally and isotopically defined mine-based metal group, adjusting for losses of trace/minor elements during smelting by using data from controlled smelting experiments. Use new analyses of bronze fragments from the mine and Pentrwyn copper prills to test the new metal group for consistency.
- Search the databases of British Bronze Age artefacts to identify metalwork types that are consistent with the newly established Great Orme mine-based metal group.
- Compile distribution maps with density analysis to assess the possible exchange/trade networks across Britain and into the continent.
- Produce a geologically-based estimate of the likely total Bronze Age output of copper metal from the mine and compare it with past estimates.
- Consider the overall social implications for the mine organisation and control with a review of relevant archaeological sites and finds in the north Wales region.

Book outline

Chapter 1 outlines the background to the project and defines the research questions. **Chapter 2** reviews the development of Bronze Age studies, summarises the chronological divisions and presents an overview of the broader context of the British Bronze Age. **Chapter 3** brings together new geological, mineralogical and geochemical information that can be applied to Bronze Age mining studies. British and Irish Bronze Age mines, plus some European mines, are reviewed in an interdisciplinary light. **Chapter 4** reviews previous research work at the Great Orme mine site, including the dating evidence. The various estimates for copper output from the Great Orme mine are critically examined and a new estimate produced. After a review of the archaeometallurgical context of copper smelting, the Pentrwyn smelting site on the Great Orme is described and research work reviewed. **Chapter 5** critically reviews the development of European metal provenance studies and recycling issues.

Chapter 6 outlines the new mine-based metal group methodology developed for this project and the materials (ores and metals) analysed. The numerous analytical techniques used are briefly described and their relative merits discussed. **Chapter 7** presents the results from the chemical and isotope analyses of ore samples as well as from the copper produced from the smelting experiments to define a mine-based metal group. This group is then tested for consistency with the bronze fragments from the mine and the copper prills from the Pentrwyn smelting site. When this group is applied to the existing metalwork databases it very clearly reveals the temporal distribution of Great Orme metal in the Bronze Age. **Chapter 8** presents the fascinating results of the mineralogical studies and what they reveal about the ores mined at the Great Orme in the Bronze Age, as well as what the Pentrwyn copper slags reveal about the smelting technology used. **Chapter 9** links Great Orme metal to particular types of metalwork and then uses spatial distribution maps to suggest extensive trade/exchange networks. Possible links with the invention of the palstave are explored. Evidence is presented for Great Orme metal having a remarkably widespread distribution in the near Continent, from France to the Baltic. The social and organisational implications required for large-scale copper mining and metal production are reviewed. **Chapter 10** summarises the main conclusions of the study with suggestions for future work. A summary of the research in this book was published in the journal *Antiquity* (Williams and Le Carlier 2019) and earlier papers described 'work in progress' on various topics (Williams 2014; 2015; 2017a; 2017b; 2018a; 2018b; 2019).

A general reader wishing to avoid too much technical discussion may wish to focus on **Chapters 1, 2, 3** (second half), **4, 9** and **10**.