From Farms to Factories: Anthropogenic pollution in heavy metals as an indicator of "industrialized production" of copper in ancient Western Asia

Detailed Description

Context

Over the last decade significant progress has been made in understanding the development and spread of early copper technology in ancient Western Asia. A major centre of this research has been in the Faynan region of southern Jordan, the oldest and largest industrial landscape of the ancient world. At Faynan a number of researchers have been actively investigating the technological development of metallurgy and the implications of these developments upon social evolution during later prehistory. The technological investigation into early mining and smelting was begun by Hauptmann, whose Early Metallurgy Project (1985-1993) formed the basis for subsequent investigations (Hauptmann 2000, 2007). The archaeological investigations of early metallurgical production sites was pioneered by the applicant first as the focus of a PhD thesis (1989-1993) (Adams 1999) and later expanded by the applicant as a collaborative project (1997-2002) (Levy and Adams *et al.* 2001).

To date these archaeological investigations have resulted in a small-scale survey focused upon the Wadi Fidan drainage and extensive excavation of two major and highly visible sites in the same wadi. The first site dates to the developmental phase of metallurgy in the mid-fourth millennium BC (3600-3300 BC), and the second is a large production centre dating to the mid-third millennium BC (2600-2300 BC). The cumulative result of these investigations has been the development of a sequence for the evolution of early metallurgy spanning this period, which suggests a change from small-scale, village-level production (Adams and Genz 1995; Adams 1999), to highly-developed, large-scale, intensive production by the end of this period (Adams 1999, 2002; Levy and Adams *et al.* 2002). Intensive 'industrialized' production emerges at the beginning of the third millennium BC (c. 2900 BC), at a time when other social changes were occurring in the Levant. Previous scholarship has noted a significant increase in the appearance of copper products at this time throughout the eastern Mediterranean, but recent work at Faynan in Jordan provides the first evidence of these processes from the perspective of the copper production sites (Adams 1999, 2002, 2003). At Faynan, the details from the excavations at these two sites have provided answers to many technical questions regarding copper production including the *chaine opérateur* and the social use of space within these sites, but they still remain isolated sites within the wider region. The relationship of these sites to other local copper production centers and the overall scale and intensity of metal production remains poorly understood.

Despite the quality of the archaeological evidence from the limited excavations at Faynan to date, significant underlying questions remain about the organization, scale and intensity of production of copper during the third millennium BC. The overall scale of these activities is hinted at by the preliminary results of the ancient mining surveys undertaken by Hauptmann (2000, 2007) which revealed extensive mining in the Faynan region during the third millennium BC. There is also evidence of slag deposits throughout the landscape in various locations, at several of the dedicated primary smelting sites that have been investigated at Khirbat Faynan and elsewhere in the region (Hauptmann 2000, 2007). To date, however, we lack a robust quantitative analysis of data which will allow us to determine the overall scale and distribution of production activities during the third millennium BC.

The best preserved prehistoric landscape in the Faynan region lies to the southwest of the Wadi Fidan, in the region of Barqa, an area of approximately 60 square kilometers, along the edge of the Arabah rift valley. During the early 1990s Hauptmann's 'Early Metallurgy Project' conducted limited excavations in the Barqa region at the site of Barqa al-Hatiye (another highly visible site). Exposure there of a well preserved building radiocarbon dated to the earliest phase of intensification of copper production (2900-2700 BC) suggests that the Barqa region will provide further evidence of this transitional phase of copper production (Fritz 1994a, 1994b; Adams 1999, 2003). The results of a very limited and undocumented reconnaissance revealed that the surrounding landscape was densely populated during the third millennium BC and contained numerous structures and features with archaeological finds similar to those found at the third millennium BC site at Khirbat Hamra Ifdan, the largest and best preserved copper production centre in the Old World (Levy and Adams *et al.* 2002). This reconnaissance suggests that numerous metal processing activities took place in the Barqa region at this time, as evidenced by visible building remains, slags, copper production waste and extensive remains of ceramic casting moulds.

The Barqa region is therefore a key zone for the understanding of copper production at Faynan, and investigation of the variety and distribution of the many sites here likely holds the answer to understanding the context of the intensification of copper production during the third millennium BC.

Theoretical Overview

There has been considerable attention to processes surrounding the development of social complexity in early civilizations in Western Asia and equally there has been significant emphasis upon trying to understand the development of 'specialized production' of various types of materials (ceramics, flint, metals, textiles) in the contexts of these early complex societies. In Old World archaeometallurgy however, the vast amount of effort until quite recently has been focused upon looking at the origins of metallurgy in the earliest phase of metal production during the sixth through fourth millennia BC, with very little attempt to understand the adoption of metals in society and the major technological and social innovations which occurred in order to make the use of metals central to human societies. There has also been an overemphasis upon looking at the adoption and spread of metals in society from the consumption end of the metallurgical cycle, largely through metal objects derived from 'elite' burials.

The recent research at Faynan described above has begun to redress this imbalance, with research efforts focused upon the technological advances and intensification of copper production during the third millennium BC — a pivotal time in the advancement of both complexity in the region and in the adoption and spread of metallurgy. A great deal has been learned from surveys of mines, analysis of ancient smelting furnaces and associated ores and slags and from limited excavations of large visible sites related to copper production. We have been able to 'fingerprint' the ores of the region through isotopic analysis and have begun to trace both copper ores and metal throughout the region and to understand the complex trading networks which developed to distribute these metals (Hauptmann 2000, 2007; Adams 2006). On the basis of this evidence it has been possible for the first time to develop a model for this phase of expansion of copper production, from the copper production zone, and to delineate specific changes in social processes and technologies that accompanied this expansion in the use of metals (Adams 1999, 2002). However, our model building is at best only preliminary, since most evidence to date has come from a limited number of large sites: These isolated excavations provide only a snapshot of events and processes without enough contextual evidence to prove that they are representative of copper production sites and activities across the Faynan landscape during the third millennium BC.

The evidence to date from excavated sites suggests that copper producing activities which had remained small-scale/low intensity operations throughout the fourth millennium BC suddenly and very rapidly changed during the early third millennium BC to large scale/high-intensity operations conducted by specialists. One possible reason for these changes and the resulting re-organization of production activities and scales of production may have been the increasing consumption of copper by emerging elites. Possible models for production range from some form of a hierarchical organization of production such as attached specialization (Costin 1991; Adams 1999, 2002) at one end of the spectrum to a heterarchical organization at the other (Crumley *et al.* 1995). To date, without the evidence that is available from the less visible sites in the region the data is insufficient to fully support either of these models. In order to build up an accurate picture of these social and technological changes it is important to have a broad sample of data from production, habitation and other types of sites. The ability to provide this contextual background relies upon the collection of less visible and less easily accessible evidence in the landscape. Therefore in order to advance our understanding of this phase of metallurgical development it is imperative to be able to understand the distribution of and relationship between all types and sizes of sites related to production and related activities across the landscape.

Faynan is of course not the only copper resource zone in Western Asia, but none of the other regions currently have similar third millennium BC production sites which can answer the types of questions asked here pertaining to the large-scale industrialization of copper production.

The copper resource zones in eastern Turkey have provided very interesting and useful information in regard to the earliest developmental sequences of copper metallurgy in Anatolia. Yener's work at Göltepe and Kestel demonstrate the early phases of copper metallurgy in the Keban region and also the possible development of metal alloying (Yener 2000, and references therein). The equally important work of Palmieri and others (1996) at Arslantepe in eastern Turkey have yielded material very similar, although earlier and less extensive than the large copper production sites at Faynan. Equally important, although as yet poorly investigated are a number of important copper resource zones in Iran in both the Fars and Kerban regions. Renewed interest in these regions, and the work of Fazeli in particular on fourth millennium BC metallurgy (Matthews and Fazeli 2004) and the German Archaeological Institute's work at Arisman (Chegini 2000, 2004; Helwing 2005) will in time provide exciting results. Previous work in Oman by Weisgerber on mining and smelting sites from the late third and second millennia BC, although of great importance in particular for understanding the development of copper metallurgy in Mesopotamia, is still largely unpublished. In the Levant, the Timna region was extensively explored by Rothenberg (1962, 1988, 1990) and provided a number of key sites of varying periods, but third millennium production sites are few in number and small in scale. A number of important copper production sites in the Negev have also produced important data for the earliest phase of copper metallurgy during the fourth millennium BC, but these pre-date the important transition to industrialized production seen at Faynan (Golden 1998; Shugar 2001). Of all of these regions only Faynan has both a significant preservation of sites and evidence of the industrialization of copper production over an extensive landscape during the third millennium BC.

The research proposed here will help us to confirm the changes in scale as evidenced from the environmental pollution data. The ancillary evidence from the mines, smelters and production sites at Faynan investigated to date suggests a rapid transition from small-scale, village-level production (Adams 1999), to highly-developed, large-scale, intensive production at the beginning of the third millennium BC (Adams 1999, 2002; Levy and Adams *et al.* 2002). This is of great importance since this transition occurs at a time when other social changes were occurring in the Levant and elsewhere, as societies in Egypt and the Near East are becoming increasingly more complex and more reliant upon specialized production of goods. The changes which we perceive in copper production at Faynan are mirrored in other technologies, in other places, (McCorriston 1997) where we also see evidence of increased specialization and mass-production within early complex societies.

Some of the most important question asked by anthropologists concerning the rise of social complexity in the region during the third millennium BC concerns the organization, production, trade and consumption of specialized products (Wright and Johnson 1975). These are often seen as significant components of elite strategies for gaining and maintaining economic and political power and the implementation and formalization of inequality both in terms of wealth and gender (Zagarell 1986; Pollock 1992). Algaze's idea of the "Uruk Expansion" in Mesopotamia at the end of the fourth millennium (1989, 2001a, 2001b) is founded on the idea of the acquisition of remote and scarce materials and products by emerging elites. Our research adds to this anthropological discussion by focusing upon one of the key specialized products at this time by ascertaining the scale and intensity of metal production. While we are beginning to understand the trade and consumption end of the copper cycle from the archaeological record, we do not yet have an accurate picture of what is occurring from the centers of production of these goods. Understanding the development of scale and intensity is but the first step to answering the broader questions of how and why this increase may be taking place. The ability to provide this contextual background relies upon the collection of less visible and less easily accessible evidence in the landscape, such as that which this research will provide.

This research will not answer the question of 'why' these developments occur—an essentially social question—but will provide the data which will allow us to gain a greater understanding of the social contexts of production, as well as the expansion and dynamics of the transition to large-scale production.

One of the pioneering contributions of this research will be the collection and use of environmental pollution data on a sufficiently large-scale to allow for a quantitative analysis of the expansion of industrial activities through time, and the ability to discuss these changes in scale and intensity within the contexts of competing models of social development, production and trade that are currently advanced for early complex societies in ancient Western Asia.

Objectives

The Barqa Landscape Survey (BLS) has been designed to fill this gap in our knowledge through a three year research program which will investigate the archaeological and environmental evidence for intensive copper production during the third millennium BC.

To date these investigations have concentrated upon mining and smelting sites (Hauptmann 2000, 2007) and upon limited evidence from only a few large and *highly visible sites* (Adams 1999, 2000, 2002, 2003; Levy and Adams *et al.* 2002). This proposal seeks to expand our understanding of the scale and intensity of copper production by documenting the environmental impact of copper production in the wider region from a variety of natural and archaeological contexts (cf. Grattan *et al.* 2003a, 2004, 2005, 2007) Our intention is to move the common research paradigm away from hypotheses which focus on site-based problems and solutions and instead encourage hypotheses which explore critical aspects of human development which can be enlightened by a landscape based approach (Wilkinson 2003).

Theoretical models for the intensification and changes in technology of copper production suggest that the processes which are observable in the larger production sites should be discernible in the wider landscape, with a number of production centers of similar (or differing) types (Adams 1999, 2002). The Barqa Landscape Survey seeks to test this model of intensification of production through an analysis of the less archaeologically visible production sites in the region, and to identify the nature and distribution of these sites in the landscape.

In order to arrive at a quantitative means of assessing the scale and intensity of copper production, it is essential to use a method which can provide numerous and demonstrable results of copper smelting and production activities. Archaeological survey and excavation alone is not enough to do this in a cost-effective way over a large area. We propose therefore to undertake an assessment of environmental pollution in areas which we can determine to be of the correct chronological time frame. The degree of pollution as determined by sampling across the region can be used to establish the scale and intensity of copper production. The Barqa region was chosen because it has archaeological deposits which date to the period of interest and is free of later occupation.

Using a combination of archaeological survey, space borne multi-spectral analysis, sampling excavations and geochemical mapping we propose to examine this early industrialization from the production residues and palaeoecological materials preserved across and within the ancient landscape. The geochemical analysis of dated contexts will inform us about the ore bodies being exploited at different periods, the efficiency of the smelting process and the impact of these activities on the environment. These chemical fingerprints will enable us to identify the magnitude and intensity of these activities at different periods and the organization of the landscape in support of them.

Similar research has already been successfully undertaken in the eastern Faynan basin (adjacent to the Barqa region), in order to explore and document the impact of Imperial Roman mining and smelting activities (Grattan *et al.* 2003b; Hunt *et al.* 2004; McClaren *et al.* 2004; Pyatt and Grattan 2002a, 2002b, 2005; Pyatt *et al.* 2000). This prior research has allowed us to develop the key techniques and methods which can be employed in looking at the prehistoric landscape in similar detail, and with equal success.

The copper ores of the Faynan region are infused with lead — which is unusual — and as a result pollution and health problem stem from the release of lead and other associated suites of very dangerous metals (beryllium, cadmium, chromium, arsenic, nickel, mercury) whilst smelting copper. The Faynan evidence indicates that these metals accumulate and stay in biological systems causing substantial health problems. To date, geochemical analysis of Holocene sequences in this region suggest a model of increasing environmental degradation from the third millennium BC onwards. Through extensive sampling of a variety of sites and geographic locations identified through the survey and excavations, this project seeks to identify correlations between areas of maximum pollution intensity, metal extraction and smelting, and settlement and industrial patterns. This evidence is important to understand the patterns of human activity, industry and natural processes in this region over the span of the third millennium BC, and are also equally important to understand continuing problems of environmental pollution up to the present time (Grattan 2003; Grattan *et al*. 2003a, 2005; Pyatt and Grattan 2005).

Methodology

Preliminary analysis of the Barqa research area prior to fieldwork will be undertaken by Grattan using Hyperion hyperspectral imagery which will allow us to preliminarily identify mining sites, ore processing locations, waste tips, agricultural sediments, settlement sites and pollution intensities across the broader landscape. In conjunction with this he will use JERS(1) radar images of the Barqa region which will allow us to identify old water channels and other fossil geographical features. Using this remotely sensed imagery we can predict areas of copper production across the wider landscape.

During the first season of field work in year one, Anderson will set up the survey grid of the Barqa region and tie it in with established benchmarks. We will then refine the GIS mapping prior to undertaking a 100% coverage pedestrian survey of the region to map surface archaeological sites and features, collecting and recording archaeological data in the landscape.

The use of an established survey grid using a Total Station along with Geographic Information System software will allow the survey to spatially map the full range of sites and metallurgical installations in the Barqa region which will help in reconstructing the dynamics of ancient copper production within a broader regional context than has yet been possible. The aim will be for 100 percent coverage of the research zone with pedestrian teams systematically covering the landscape and plotting archaeological sites which the survey team will map and enter into the Geographic Information System. We will also produce a digital elevation model of the geographic region into which the archaeological data can be integrated through the use of Geographical Information System software, enabling all collected archaeological data from the survey to be related to existing data sets from prior research projects (see *8. Response to Previous Critiques*, below).

The field survey will depend upon use of a Total Station survey instrument. Working from a network of permanent benchmarks, both primary and secondary network stations will be established in advance of the pedestrian surveyors. This survey network will be used to establish line-of-sight measurement of archaeological sites through collecting discrete archaeological points for each site or find spot which will be stored electronically. From each station, the perimeter of each archaeological site within the line-of-sight will be recorded, followed by the various archaeological features that comprise the site (eg. walls, cairns, tombs, *etc*.). When everything within the line-of-sight of the Total Station had been surveyed, the Total Station will be moved to the next benchmark, and the process repeated, until all the sites identified by the pedestrian crews in the area have been surveyed. The survey team therefore follows the progress of the pedestrian survey teams, mapping the extent and nature of each archaeological site discovered.

During the pedestrian survey the survey groups will be recording observations about each site on a standardized form, recording specific archaeological and geographical features, along with information about the collections of artifacts from each site. Collections of specific categories of artifacts, including ceramics, chipped stone and a wide range of other metallurgically related artifacts will be facilitated through the use of a handbook for surveyors that will help them to identify categories of materials, so that uniformity of identification can be maintained.

The final part of the field survey will involve entering the survey data into the Geographic Information System. With the use of 'automap' features in surveying Computer Assisted Drawing (CAD) programs, these collected points will then be joined automatically into 'polygons', or, as in the case of artefacts, collected as individual points. Both sets of data will then enter the Geographic Information System as discrete shape files, allowing artifacts to be queried according to spatial context and *vice versa*.

The observations based on data from the survey will form the basis for the excavations and sampling which will be undertaken in year two of the project. Initial observations within the Barqa research zone already suggest a wide variety of different types of sites and features related to copper production activities throughout the region. The quality of the survey data collected in the Geographic Information System will allow us to return to these sites to undertake sampling excavations.

During a subsequent period of field work in year two we will return to conduct extensive sampling of target sites using 1x1 m test-pits. In the four week period we expect to be able to excavate 90 test pits and collect both archaeological and environmental data. Test pits are preferable to coring of sediments in order to allow for a better understanding of the stratigraphic context of samples being analyzed. Due to the arid conditions in the region and general lack of vegetation cover, remote-sensing, pedestrian survey and grid set up for systematic sampling is relatively straightforward.

Geochemical sampling will be undertaken using a hand-held XRF-analyzer, supplied by the University of Wales. This will be the first time any archaeological excavation has used this technology and will provide us with immediate insight into the metal content and potential significance of each archaeological horizon as we excavate the test pits and will avoid the time and expense of collection of samples in the field and lengthy geochemical analyses in the lab. The XRF instrument will also be used to calibrate the hyperspectral data already acquired by the Hyperion satellite. Archaeological artifacts, palaeobotanical, faunal and radiometric samples will also be collected from each test where possible.

Our proposed sampling strategy is analyze samples of sediments and residues from each test pit: 30 test pits will be excavated from predetermined sites identified with remote sensing, 30 test pits will be selected using a stratified unaligned systematic sampling procedure and 30 test pits will be selected from sites located by the pedestrian archaeological survey undertaken in year one. Our dating of samples using cultural material will be supplemented where necessary by radiometric dates.

We expect to be able to ascertain the relative chronology within each test-pit using established chronological indicators (i.e. ceramics and flint tools), and to determine the types of activities taking place at each site, through the artifactual, metallurgical and environmental and subsistence data (botanical and faunal) collected. However, there will likely be a percentage of important environmental samples which cannot be dated directly using cultural materials, and to determine the dating of these samples we propose to use AMS radiocarbon dating. A wide range of site types are already known from previous work in the Faynan district, including habitation sites (ranging in size from individual isolated 'farmsteads' to small villages composed of clusters of houses); primary smelting sites (distinguishable from large volumes of primary copper slags); a wide range of sites which exhibit evidence of secondary copper production activities (crushing, sorting, melting and casting activities); and a number of small cemeteries with a variety of graves types. Each of these types of sites can be distinguished on the basis of the archaeological and artifactual assemblages and we will investigate a broad range of these throughout the excavation phase of the project.

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