

Indus Tradition Copper and Bronze Metallurgy: A Model from Harappa

By

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Abstract

In this study the copper and copper alloy assemblage from the Harappa Archaeological Research Project (HARP) excavations at the Indus Tradition site of Harappa, Pakistan was analyzed to identify patterns of alloy usage and construct source provenience correlations. The HARP assemblage represents the changing patterns of copper acquisition, use, and discard from the entire chronological sequence, beginning at more than 3300 BCE to around 1700 BCE, spanning the entire period of the prehistoric occupation of the site. The largest component of the sample dates to the height of Indus urbanism, Period 3 at Harappa, dating from 2600-1900 BCE. At almost every excavated site of the Indus Tradition, copper and bronze artifacts have comprised a significant portion of the recovered material assemblage. Throughout the Indus area, copper and copper alloys were used by metalworkers to fashion a variety of objects ranging from prestige goods to basic utilitarian items. Earlier research on copper-bronze metallurgy in the Indus focused on the identification of general patterns and broad characterizations of the metallurgical tradition across the entire Indus area. The current research project applied leading analytical techniques to a comprehensive assemblage of copper and bronze materials from the HARP excavations at the site of Harappa, Pakistan in order to re-evaluate and modify these traditional interpretations to incorporate updated perspectives on the study of ancient metallurgy.

My research has convincingly demonstrated that copper-bronze metallurgy at Harappa was a highly specialized and complex craft industry that included on-site production and importation of finished goods; employed a variety of alloying patterns, recycling and recasting some metal; and procurement of copper materials through a number of overlapping primarily South Asian supply networks. Through a detailed study of the chemical characterization of copper/bronze objects, and the archaeological distribution of metallurgical and pyro-

technological artifacts at Harappa, it is evident that the metal industry at Harappa is unlike contemporaneous industries in neighboring regions, both in terms of initial production and use as well as recycling. Additionally, the analysis has made it possible to define specific interaction networks related to the acquisition of copper ores or metal during the 3rd millennium BCE. Isotopic analyses show that many finished copper and bronze artifacts from Harappa, Mesopotamia, and the Gulf region appear to have been made with copper originating from ore deposits across the Aravalli Range in northwestern India. Compositional analyses have identified the presence of multiple alloying patterns for copper and bronze artifacts at Harappa, pointing towards complex patterns of consumption and use that played a role in social, economic, and political hierarchies during the Indus period. Overall the patterns exhibited in the copper/bronze assemblage at Harappa support a model of relatively unrestricted access to copper and bronze artifacts during the Early Harappan and Harappan Phases. This research has produced a data driven model for all aspects of copper and bronze metallurgy that for the first time allows the Indus Tradition center of Harappa to be directly compared to other Indus Tradition sites and other 3rd millennium BCE copper and bronze using societies.

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Chapter 1: Introduction

Introduction

Copper and bronze metallurgy is an important craft technology of the Indus Tradition. The diverse array of artifacts fashioned in copper and bronze would have been used to display status, signal wealth, accomplish utilitarian tasks, and served as tools in other craft industries. My dissertation is focused on understanding the nature of copper and bronze metallurgy at Harappa for all aspects from raw material procurement, processing, production, and distribution of finished goods. While there are some areas that cannot be addressed without further excavation and survey, this project provides the first comprehensive study of the copper and bronze assemblage from the site of Harappa. Harappa is the only major urban center of the Indus Tradition that has a comprehensive stratigraphic sequence documenting the development of the settlement from its earliest occupation during the Ravi Phase to the end of the Late Harappan Phase (see Table 1.2). As a result, Harappa is an ideal location to investigate the copper and bronze metallurgical traditions for the Indus Tradition.

The copper and bronze metallurgy of the Indus Tradition has been the focus of considerable research since the discovery of sites such as Harappa and Mohenjo-Daro in the 1920's, but more detailed studies have been called for (Kenoyer and Miller 1999; Bhan et al. 2002; Hoffman and Miller 2014). Detailed analysis of raw material processing and procurement, metal production and distribution, and the alloying of copper to produce various types of bronze has not been carried out systematically, although numerous small-scale projects have been undertaken (see Chapter 2 for details). Archaeological survey and excavation data have previously supported a model that Indus cities were not smelting copper raw materials; rather production was based on the processing of semi-finished materials (i.e., ingots) and potentially

the recycling of finished copper/bronze objects (Miller 1994; Kenoyer and Miller 1999). The evidence was interpreted to suggest that copper metal ingots or preforms were imported to Indus sites through long-distance trade networks, however the specific location of these source area remains uncertain (Lahiri 1992; Chakrabarti and Lahiri 1996; Law 2011; Hoffman and Miller 2014). The goal of this project is to begin the process of providing the empirical data and interpretative framework needed to fill in the gaps in the archaeological understanding of copper and bronze metallurgy of the Indus Tradition.

In order to investigate the nature of copper/bronze metallurgy at Harappa a diverse data set derived from a variety of analytical techniques was compiled. For the sake of consistency and simplicity I use the term copper/bronze to refer to objects of copper or various alloys; copper refers to unalloyed copper metal; and bronze refers to a number of copper-based alloys defined in Chapter 2. The term copper mineral(s) is used for the unprocessed raw material and copper raw material is used when referring to semi-processed materials and ingots. The broad focus of the current investigation is the organization of copper trade networks and the use of copper/bronze at the site of Harappa. The construction of a database of lead isotope ratios and compositional signatures obtained through laboratory analyses of archaeological copper/bronze material from Harappa provides the empirical evidence required to identify and interpret the nature of copper/bronze metallurgy at Harappa.

A total of 360 individual copper and bronze artifacts, slag pieces, and copper minerals were selected for sampling. This overall sample set that provided representative coverage of all artifact categories, chronological periods, and spatial locations currently identified at Harappa during the course of the HARP excavations from 1986-2011. A total of 324 were analyzed for their compositional character and 137 were analyzed for their lead isotope signatures. To the best

of my knowledge, this represents not only the largest suite of compositional and isotopic data points for any Indus site, but for any single 3rd millennium site across Eurasia.

In order to address the core research questions, a series of analytical techniques were utilized over the course of the total research program. Portable X-ray fluorescence (PXRF) was used to rapidly scan and characterize the sample assemblage for alloy types. This stage provided a sound foundation for the identification of alloy types by object category as well as the chronological and spatial distribution of those alloying patterns. PXRF analysis was followed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) to both confirm and more precisely determine the alloy types and distribution present in the sample assemblage. ICP-OES was able to discriminate between any of the uncertain designations achieved during the PXRF analysis portion. These two compositional analysis techniques were able to identify a uniquely Indus pattern of alloying during the Integration Era at Harappa. Scanning Electron Microscopy (SEM) and Electron Microprobe Analysis (EMPA) were employed to identify a large slag sample from Harappa as the first conclusive example of copper smelting slag from any Indus urban center. Finally, Lead Isotope Analysis (LIA) was used to identify source provenience linkages between copper/bronze artifacts and copper minerals from Harappa with regional copper deposits. This aspect of the project provides confirmation and extension of patterns first identified by Law (2011; Hoffman and Miller 2014). Additionally, LIA was able to document the existence of previously only theorized copper supply networks at Harappa; establishing strong interaction linkages between the city and copper sources in the Aravalli Range and northwestern Pakistan. An unanticipated outcome of the LIA analyses was the potential identification of a diagnostic “Indus signature” that can be used to identify copper/bronze artifacts manufactured with raw materials from the Aravalli Range.

Archaeological artifacts matching this signature have potentially been identified in copper/bronze assemblages across the Persian Gulf and Mesopotamia. Future research will be required to comprehensively test and substantiate this intriguing new line of evidence for inter-regional copper/bronze interaction networks between large 3rd millennium BCE civilizations.

Using data collected during this research I have been able to shed fresh light on all aspects of copper/bronze metallurgy at Harappa. Lead isotope signatures were utilized to construct correlations between both copper and bronze artifacts. The identification of the exploitation of specific source locales at Harappa provided some of the only empirical documentation of copper source deposit use for the Indus Tradition. The picture of source area use that has emerged from Harappa confirms some previously existing hypotheses while requiring the revision of others. The exploitation of sources in the Aravalli Range in northwestern India confirms the widely held assumption that this area was a crucial component of Indus copper supply (Marshall 1931; Mackay 1938; Vats 1940; Agrawal 1971; Agrawala 1984; Agrawal 2000). However, the isotopic data set also identifies the prevalence of an as of yet unidentified source that is present in the HARP assemblage at comparable levels of source area exploitation to the Aravalli Range sources. Compositional analyses enabled new evidence to be brought to bear on both copper/bronze production and alloying patterns at Harappa. Previously undocumented patterns of alloy usage were identified. Additionally, new evidence for production from both copper minerals through smelting in a furnace and from copper raw materials in crucibles was identified (see Chapter 4 this volume). Finally, the evidence developed during this project was used to establish linkages between all stages of copper and bronze production to create a model for processing, manufacture, usage, and recycling at Harappa during the 3rd millennium BCE that will be presented in the following chapters.

General Chronology and Background

During the late fourth and early third millennium BCE, the Indus Tradition emerged in the region of the alluvial plains and adjacent highlands of northwestern South Asia (Table 1.1 and Figure 1.1). Centered along the Indus and Ghaggar-Hakra river systems, the Indus Tradition expanded to incorporate roughly one million square kilometers (Jansen 2002; Wright 2010; Kenoyer 2015:41) of Pakistan and northwestern India. By 2600 BCE a network of large urban centers, regional towns, and small settlements stretched throughout the region. The Indus Tradition flourished until the early second millennium BCE when, for a variety of factors, there were significant disruptions to Indus interaction and integration networks (see Kenoyer 1998, 2014; Possehl 2002; Wright 2010 for details on the decline of the Indus Tradition). By the latter portion of the second millennium, settlement patterns, economic interactions, and ideological systems throughout the region had all undergone large enough transitions in focus to no longer be considered the coherent combination of socio-political, economic, and ideological networks that defined and supported the Indus Tradition.

There exist many terms for identifying the Indus Tradition. These include but are not limited to Indus Civilization, Harappan Culture, and Harappan Civilization. I have chosen to follow the Indus Tradition framework (see Kenoyer 2015 for details). Throughout the text, I have attempted to use the terminology outlined in the Indus Tradition chronological framework (e.g. Indus Tradition sites or Harappan Phase occupation) when referring to archaeological aspects of the overall cultural phenomenon. I have used “Harappan” or “Indus” when designating people (e.g. Harappan metalworkers or Indus consumers).

Table 1.1: Generalized Chronology for the Indus Tradition

(After Shaffer 1992; Kenoyer 1998; Meadow and Kenoyer 2005; Kenoyer 2014; Kenoyer 2015)

Early Food Producing Era		c. 7000-5500 BCE
Regionalization Era		c. 5500-2600 BCE
	Early Harappan – Ravi Phase (aspect of the Hakra Phase)	3300-2800 BCE
	Early Harappan – Kot Diji Phase	2800-2600 BCE
Integration Era	Harappan Phase	2600-1900 BCE
Localization Era	Late Harappan Phase	1900-1300 BCE

Archaeological excavation and research have revealed the Indus to be an elaborate and complex urban civilization. Indus cities covered hundreds of acres and likely housed tens of thousands of people. Indus traders had contacts with peoples from across Central and West Asia. The expansive nature of not only the Indus Tradition itself, but also its interaction networks supported a complex and diverse material culture. Indus craftspeople worked proficiently in a variety of raw materials and forms (Vidale 2000; Vidale and Miller 2000). The presence of distinctive black on red pottery forms, cubical stone weights, steatite seals and tablets inscribed with the Indus script, beads and jewelry made from a variety of raw materials, terracotta figurines and the use of copper and bronze metal are all diagnostic aspects of Indus material culture (Kenoyer 2015, 2014, 1998; Possehl 2002). All excavated Indus sites, from large cities to smaller settlements (Marshall 1931; Mackay 1938; Vats 1940; Mackay 1943; Rao 1979, 1985; Bisht 1997; Kenoyer 1998; Lal et al. 2003; Shaffer 1982; Agrawal 2000), contain copper metal objects. Aside from clay, there is no other raw material that Indus craftspeople worked into such a diversity of forms and types of artifacts. Evidence from excavations indicates that copper and bronze were used to make tools, such as knives and saws; weapons, such as spears and arrow

points; jewelry, such as beads, rings, and bangles; household materials, such as dishes and other vessels; and items of possible economic control or religious importance, such as scale pans and tablets. Despite the fact that copper was employed to fashion objects that articulate with all aspects of Indus life, the material remains understudied (Kenoyer and Miller 1999; Agrawal 2000; Bhan et al. 2002; Hoffman and Miller 2014). This represents a critical gap in the archaeological understanding of not only Indus craft traditions but socio-political and economic organization as well.

The site of Harappa is an ideal location to conduct detailed research on Indus Tradition copper/bronze metallurgy for a set of interconnected reasons. The first is that the site is a large, multiple occupation mound, urban center that covered around 150 hectares (Dales and Kenoyer 1989:72; Kenoyer 2014:415). In order to develop and sustain a site of the size and scale of Harappa, interaction networks would have been established to secure the regular flow of the raw materials used to establish and maintain the status hierarchies required in a complex urban civilization (Kenoyer 1989, 1991, 1997, 1998, 2000, 2014). One of those critical raw materials was the copper needed to fashion a diverse array of finished objects (Kenoyer and Miller 1999; Hoffman and Miller 2014). Taking those two factors together, the second reason for conducting this research project at Harappa comes into focus. The site sits within the Punjab plain (Law 2011:14 and 33-35) and is at least 120 kilometers from the nearest rock or mineral source location. This is potentially even further for copper sources. This means that copper and bronze artifacts from Harappa must have been made from non-local raw materials as no resources were available locally (Law 2011:35). Copper and bronze artifacts at Harappa were also fashioned using complex technologies. This provides the most potential for either control of production or restriction of access (see Figure 1.2) to finished goods. In turn, this means that archaeological

distribution of copper and bronze objects at Harappa could have a direct relationship to elite control and social hierarchies at the site in addition to aiding in the identification of economic interaction networks. Finally, Harappa is an excellent site to investigate the alloying patterns, raw material provenience, and distribution of copper/bronze metallurgy because of the unique comprehensive stratigraphic sequence at the site. The history of discovery and excavation at Harappa combines to provide a totally unparalleled setting to investigate specific questions regarding the Indus Tradition.

In 1829, Charles Masson was travelling through the Punjab when he passed through the Bari Doab and noticed ruined structures and pipal trees atop a large mounded area outside of the current village site (Lahiri 2005). A few years later in 1831, Alexander Burnes passed through the region and also commented extensively on the nature of the ancient remains he saw (Lahiri 2005). From these two travelers, the western world received its first accounts of South Asia's oldest civilization. Both men described the visible remains of the ancient site of Harappa, just outside the village of the same name. Harappa next made an appearance in history during the tenure of Alexander Cunningham as director of the newly constituted Archaeological Survey of India (Possehl 1991; Kenoyer 1998; Lahiri 2005; Wright 2010). Between 1853 and 1873, Cunningham made several visits to Harappa (Possehl 1991). His primary concern was to slow the destruction of the upper in situ layers of the site from the brick robbing activities of contemporary villagers and the construction of the Lahore-Multan railway (Kenoyer 1998). During his earlier visits to the site, Cunningham observed a massive brick-walled structure on the southernmost mounded area of the site. He believed this was the remains of a Buddhist stupa (Lahiri 2005). However, when he returned in 1872 to begin a program of limited excavations at the site, he found that almost the entire structure had been removed for railway ballast (Lahiri

2005). His surveys and limited excavations in search of Buddhist remains revealed an unexpected series of archaeological finds. He documented a variety of stone tools and a single stone seal (Kenoyer 1998; Lahiri 2005). It was this seal with the apparently unique system of characters carved into its surface that excited the curiosity of archaeologists and other scholars.

In 1901, John Marshall was named to the head of the Archaeological Survey of India. It was during Marshall's tenure as director that the true nature and extent of the archaeological remains at Harappa were understood (see Lahiri 2005 and Wright 2010 for further discussion). In 1920 Marshall sent Sahni to start fresh excavations at Harappa and in 1921 he deputed Banerjee to start digging at the site of Mohenjo-Daro (Kenoyer 1998). During the succeeding decades a series of large extensive excavations at the sites of Harappa and Mohenjo-Daro provided the material remains necessary to begin to piece together a detailed picture of South Asia's oldest urban civilization.

The excavations conducted at Mohenjo-Daro and Harappa during the 1920's and 1930's formed the core of the initial archaeological understanding of the nature of the Indus Tradition. From 1920-1925, Sahni excavated at Harappa while at the same time multiple officers from the Archaeological Survey were deployed to Mohenjo-Daro (Possehl 1991; Lahiri 2005; Wright 2010). While Sahni's excavations did uncover some aspects of the overall site layout and material assemblage at Harappa, it is not until the arrival of Vats in 1926, who was transferred from Mohenjo-Daro, that excavations begin in earnest (Kenoyer 1991; Possehl 1991; Lahiri 2005). Vats continued to work at Harappa through the 1933-1934 winter field season (Vats 1940; Possehl 1991; Kenoyer 1991). At the same time excavation at Mohenjo-Daro, under the leadership of a variety of officers of the Archaeological Survey, continued through 1931 (Marshall 1931; Mackay 1938).

After the close of the 1934 field season, archaeological excavations periodically continued at Harappa. However, much of this research remains unpublished (Possehl 1991; Dales and Kenoyer 1991, 1993.). Two important excavation programs were published during this period. Mughal's excavations of the cemetery area and Wheeler's 1946 season that documented the city wall along the western edge of Mound AB (see Figure 1.4 this volume and Kenoyer and Meadow 2005 Figure 1) and established the presence of a stratigraphic sequence that extended prior to the urban Indus period (Wheeler 1947; Mughal 1968; Possehl 1991; Kenoyer 1998; Law 2011). The earlier excavations combined with the fresh insights from Mughal and Wheeler's diggings, provide the basis for the beginnings of the latest project at Harappa.

In 1986 a collaborative project between the Department of Archaeology and Museums, Government of Pakistan and several American universities was begun. This was first termed the University of California-Berkeley Project (Dales and Kenoyer 1986, 1987, 1988, 1989, 1990) and then was designated as the Harappa Archaeological Research Project (HARP) (Meadow and Kenoyer 1992, 1993; Meadow et al 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001). Following the convention established by this collaborative research team and outlined in Law (2011:16), I will use the acronym "HARP" when referring to the 1986 to present archaeological research program at the site of Harappa (see Figure 1.4 for map of HARP excavations).

The annual reports by the HARP team document more than two decades of highly detailed problem-oriented excavation and research at the site. Kenoyer (1998; 2008; 2014) and Law (2011:16) provide overviews of the various detailed studies that have been outcomes of this ongoing research. The specifics of each study are not necessary to review here. The relevant point is that the excavations conducted by HARP have produced an incredible set of stratigraphic, chronological, and contextual information through which all of these detailed

research projects can be filtered. The primary features of the HARP excavated material culture assemblage are the scope of the available sample, comparability of samples across occupation mounds, and the long chronology present at the site.

Indus Tradition sites ranging from small rural outposts to large urban cities have been excavated over the years, but only Harappa has established a high precision chronology (Table 1.2). This chronology is based on over 100 radiocarbon analyses (Meadow and Kenoyer 2005:208-209; Meadow and Kenoyer 2008). This sequence of radiocarbon dates is linked to a secure and detailed stratigraphic sequence at the site (Kenoyer 1992a). This allows for links between cultural developments documented in the HARP excavations and diachronic changes to be constructed. Overall, HARP has identified 5 main periods of occupation at the site (see Table 1.2). The specifics of cultural developments seen during each of these periods have been both summarized and detailed by others (see Law 2011; Meadow and Kenoyer 2001, 2005, 2008; Kenoyer 1998, 2014) and cannot be improved upon here. What is necessary to point out is that the sequence at Harappa that began with an initial small village size occupation in the Ravi Phase (Period 1), grows into a pre-urban settlement during the Kot Diji Phase (Period 2), emerged as a complex urban center during the Harappan Phase (Period 3), and contracted and declined in a Late Harappan Phase (Periods 4-5) forms an unbroken stratigraphically controlled cultural sequence. This provides researchers with a unique ability to assess changes in artifact assemblages over the entire emergence, development, expansion, and decline of the Indus Tradition. Coupled with the chronological control, the HARP excavations have produced a sample set of material culture items that is comparable across all of the major occupation areas. It is possible to assess similarities and differences in individual artifact classes for each major

mounded area during Periods 1-3 at the site. This allows for changes over time to be identified and interpreted.

Overall, the HARP excavations have provided archaeologists with a unique venue to investigate a variety of components of the Indus Tradition. The current project is focused on attempting to fill in some of the gaps that can be identified in the current understanding of copper/bronze metallurgy in the Indus Tradition. By conducting this research at Harappa, a comprehensive model for all aspects of copper/bronze metallurgy can be built up. This leverages the unique aspects of the stratigraphic, chronological, and contextual components of the HARP project to address each of the project research questions in a data driven manner. This will allow a model for copper/bronze metallurgy at Harappa to be produced from fresh analytical data that can provide a baseline testable scenario for all other Indus Tradition copper and bronze using sites.

Figure 1.1: Map of Indus Tradition Area

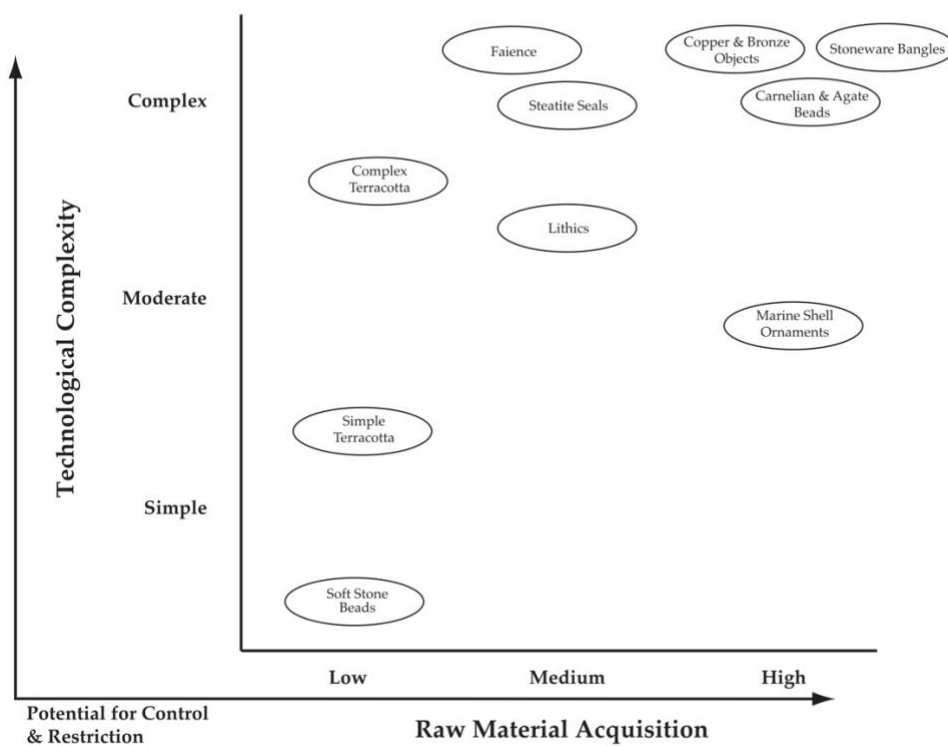


In the absence of readable written texts and other traditional markers of socio-political organization, craft technologies become a crucial avenue for the archaeological investigation and interpretation of Indus political economies (Schortman and Urban 2004; Vidale 2000). Specific studies of individual material culture components represent an ideal method through which to understand ancient trade and interaction networks (Schortman and Urban 1992). For the Indus region, the analysis of shell working (Kenoyer 1995; Kenoyer 1984), bead manufacture (Kenoyer 1991), lithic materials (Law 2011; Vidale 2000), pyro-technologies (Miller 1999), fishing industry (Belcher 1999), and pottery (Méry 1996) have demonstrated that the detailed study of craft technologies is an optimal way to better understand Indus political, economic, and social organization. Studies such as these have demonstrated that specific linkages between craft technologies and the social patterning of Indus cities can be constructed (Vidale 2000).

Previous studies of Indus craft technologies have produced a hierarchical scheme for ranking (Figure 1.2) the potential for a given craft industry to be an avenue for economic control based on the nature of the raw material and the degree of technological expertise involved in manufacture (Kenoyer 1992a; Vidale 2000). Copper metallurgy represents a specialized craft that would have applied a complex technology of production to a non-local raw material. The combination of non-local raw material and complex technology allows for the potential manifestation of the highest levels of segregation and control of craft production (Kenoyer 1991, 1992a). Copper metallurgy represents a raw material that was obtained via long-distance trade networks and a material that was incorporated into a craft technology requiring a high degree of technical knowledge. As a result, copper provides an ideal case study for determining the relationships between inter-regional interaction, craft production, and cultural processes related to the development and maintenance of a complex urban society.

Current models regarding the nature of Indus urbanization are based on concepts drawn from city-state analogues and the identification of control over production and the access to raw materials by groups within each city (Kenoyer 1997, 2000, 2014; Vidale and Miller 2000). In the absence of texts and other traditional archaeological markers of social hierarchies and class inequality, the study of the distribution and control of craft production provides the best avenue for investigating the social organization of Indus cities (Kenoyer 1998; Miller 2007; Vidale and Miller 2000). Research conducted at Indus sites has been designed to identify how individual technologies and production stages may have been subject to differential levels of control (see Bhan et al. 2002; Kenoyer 1998, 2014; Vidale 2000 for overview). The broad utilization of copper/bronze within Indus cities provides the potential to link metallurgical production to larger political, economic, and social processes.

Figure 1.2: Craft Hierarchies



Redrawn after Kenoyer 1992, Vidale 1992,
Vidale & Miller 2000, Miller 2009

Research Questions

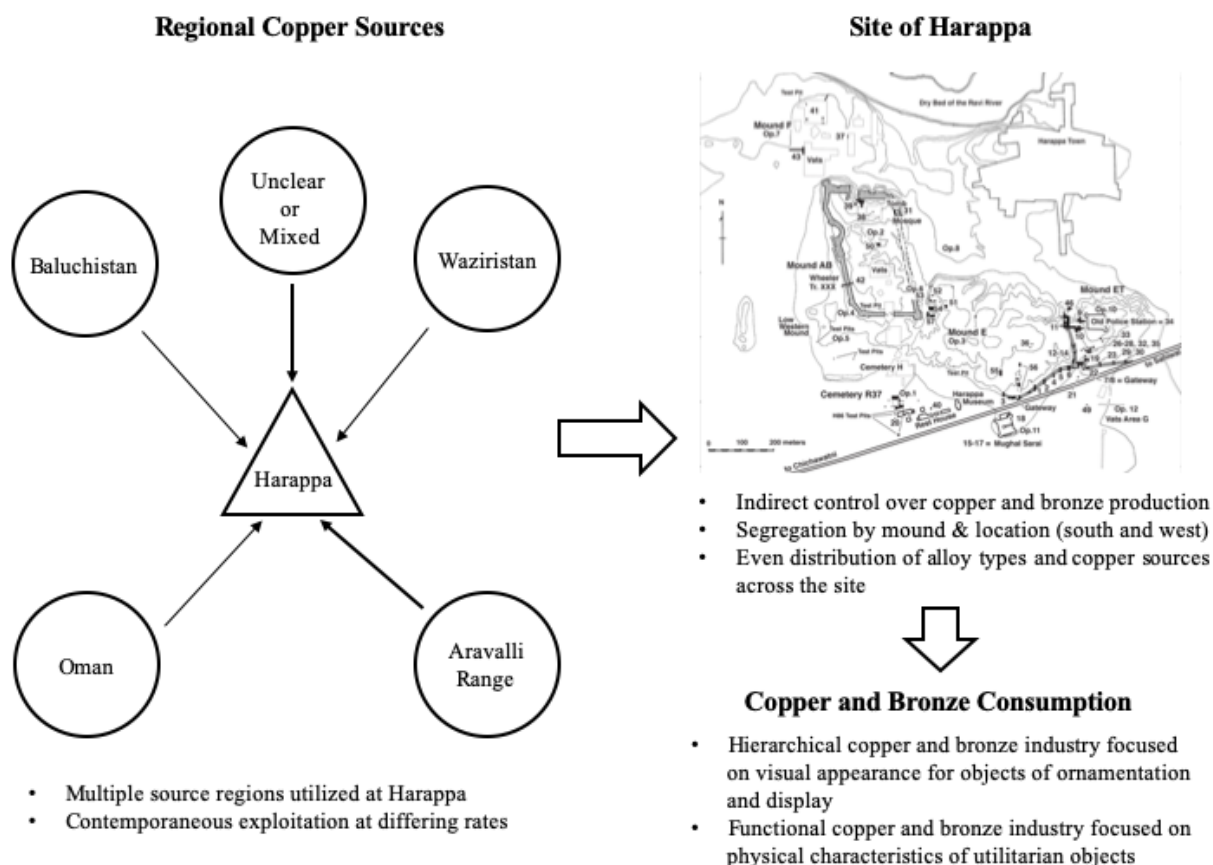
In order to more fully understand the nature of the copper metallurgy tradition and how it relates to social and cultural developmental trajectories at Harappa, the assemblage was studied from two main analytical lines of evidence at varying temporal and spatial scales. This project focused on metal resource procurement and access in order to determine the nature of interactions between metal source areas and Harappa and to trace how these contacts changed through time. This was accomplished by obtaining lead isotope data and compositional data on copper objects recovered from different chronological periods at Harappa. The project research strategy allowed for data on source area diversity to be combined with patterns in metal assemblage distribution at Harappa. These data were used to test specific expectations about Indus metallurgical traditions and its relationship to general political economy. A set of model expectations has been developed drawing on data from previous work conducted on the rock and mineral assemblage at Harappa combined with preliminary analytical results on the copper ore and copper/bronze materials from the site. The project model functions at two primary scales, regional and site level (Figure 1.3). At the regional level, the expectations are that Harappa will exhibit a pattern of exploiting copper raw materials from several source regions at the same time. Further, not all of these source regions are being utilized at the same frequency. Some source regions, such as Baluchistan and the Aravalli Range, would have supplied the site of Harappa in a greater amount than more distant sources, such as those in Oman. Once copper raw material entered the site of Harappa, production would have been indirectly controlled. Such indirect control is evident by the segregation of production to the south and west margins of each mounded area at the site within the boundary of the city walls (Dales and Kenoyer 1991; Kenoyer 2014, 1998, 1992a; Miller 1999). The repeated copper/bronze production on each

mounded area leads to an even distribution of all identified alloy types and copper sources across the entire city of Harappa during the urban Harappan Phase (2600-1900 BCE). It is possible that this pattern extends into the earlier Kot Diji Phase (2800-2600 BCE) and Ravi Phase (3300-2800 BCE) occupations as well, but additional analytical data is needed to confirm this aspect of the model. The first two components of the model address the acquisition of copper raw materials from multiple source regions and the production of finished copper objects from those raw materials at Harappa. The final component is focused on the consumption of the products of copper and bronze metallurgical production. Patterns of consumption at Harappa are exerting a strong influence on the modes of copper/bronze production. The analytical data from this project demonstrate that there were two related modes of copper/bronze production and consumption at Harappa. The first is a pattern focused on the final visual appearance of the object. Items of personal ornamentation and display were fashioned from a specific set of alloy types that would have imparted distinctive colors and hues to the finished artifact. These would have been important elements within the status and wealth hierarchies of the city (see Kenoyer 2014, 2000, 1998 1997; Vidale and Miller 2000 for discussion). A second pattern is represented by a wider array of alloy types and was focused on the physical properties of the final objects. This is the pattern seen in tools and other utilitarian objects. Such items would have not served a role in status or wealth hierarchies at Harappa and only needed to be fashioned from alloys that would have imparted the required strength and hardness for the item to perform the desired function. This purpose can be accomplished by a far broader set of alloy types than for objects that required a specific visual appearance and the analytical data reflects this.

The strength of this model is its chronological precision and application of appropriate archaeometallurgical, analytical, and interpretive perspectives to the copper assemblage at

Harappa. The model for copper metallurgy at Harappa is centered on the following series of interrelated hypotheses. These hypotheses have been used to generate a number of nested research questions. These questions are summarized here and discussed in detail and linked to previous research on copper and bronze artifacts from various Indus Tradition sites in Chapter 2.

Figure 1.3: Project Model



Research Question 1: What is the nature and distribution of the copper and bronze metal assemblage from Periods 1-3 of the cultural sequence at the Indus Tradition site of Harappa?

The bulk of the copper/bronze assemblage from Harappa comes from the Period 3A to 3C occupations during the Harappan Phase of the Integration Era (see Table 1.2). The other major component of the copper/bronze assemblage comes from Regionalization Era, Early

Harappan, Ravi Phase (Period 1) and the Kot Diji Phase (Period 2) (3300-2600 BCE). It should be noted that the earliest levels of the Ravi Phase may date to as early as 3700-3900 BCE (Kenoyer 2008, 2011), general dating is to approximately 3300 BCE and this convention has been followed here. Chapter 3 details the temporal, spatial, and artifact category distributions of the overall copper/bronze assemblage. While a variety of Indus sites have had copper/bronze assemblages identified during excavations, and more are added each year, few have been published or adequately described (see Chapter 2 for details). Aspects of the material uncovered by HARP has been previously outlined in a variety of works (HARP Reports 1986-2001; Kenoyer and Miller 1999; Miller 1999; Law 2011; Hoffman and Miller 2014), but it has not been fully published in one location in a systematic fashion. The first goal of the present project is to begin to address this gap. Chapter 3 outlines the spatial distribution of copper/bronze materials at the site as well as addressing any shifts over the span of Indus occupation. Additionally, the materials are classified according to an updated, flexible artifact categorization scheme that allows for ready comparison with previously published Indus copper/bronze assemblages, as well as any future materials uncovered during excavation. The categorization of the copper/bronze assemblage at Harappa allows for systematic comparison of the material to investigate the overall project research questions.

The results of this analysis indicate that artifact categories at Harappa remain relatively consistent over time and broadly distributed across the mounded occupation areas. Additionally, there is evidence for a variety of aspects of copper/bronze metallurgy at the site from production of finished objects from both copper and copper alloys, the smelting of copper minerals, to the caching and recycling of copper/bronze artifacts. During the course of the HARP excavations, a variety of finished copper and bronze artifact categories have been recovered from all areas of

the site. These range from utilitarian items such as saws, vessels, and chisels to objects of personal ornamentation such as beads, rings, and bangles. Additionally, copper slags from both the crucible smelting and furnace smelting of copper minerals have been identified. Further evidence for production of copper and bronze objects at Harappa has been documented in the

Table 1.2: Chronology for Harappa

(Kenoyer 1998; Meadow and Kenoyer 2005; Meadow and Kenoyer 2008; Kenoyer 2014; Kenoyer 2015)

Regionalization Era		c.5500 – 2600 BCE
	Early Harappan	
	Period 1 – Ravi Phase	3300 – 2800 BCE
	(aspect of the Hakra Phase)	
	Period 2 – Kot Diji Phase	2800 – 2600 BCE
Integration Era		2600 – 1900 BCE
	Period 3A – Harappa Phase A	2600 – 2450 BCE
	Period 3B – Harappa Phase B	2450 – 2200 BCE
	Period 3C – Harappa Phase C	2200 – 1900 BCE
Localization Era		1900 – 1300 BCE
	Period 4 – Harappa/Late	1900 – 1800 BCE
	Harappa Transition Phase	
	Period 5 – Late Harappa	1800 – 1300 BCE
	Phase	

form of technical ceramics and the presence of potential copper prills from working with molten copper/bronze. Finally, a combination of excavation data from Vats' original work at Harappa and new analytical data on artifact composition (see Chapter 2 and Chapter 4) supports the interpretation that some copper and bronze artifacts at Harappa were manufactured from melting down scrap copper and bronze. This wide distribution and the presence of secure archaeological evidence for a variety of aspects of metallurgical production allow conclusions about the access

and control of copper/bronze at Harappa to be directly addressed through the analysis of the project's major lines of empirical evidence; the data resulting from compositional (Chapter 4) and isotopic analysis of the sample set from Harappa (see Chapter 5). Consequently, copper/bronze artifacts can be used to address the nature of the political, social, and economic structures and networks at Harappa and compared with the models developed from other craft technologies such as seals, steatite and other minerals, beads, shell; and a variety of pyro-technologies (Kenoyer 1998, 2014; Miller 1999; Law 2011; Jamison 2017) that inform Indus scholars on the nature of the political, social, and economic structures and networks at Harappa.

Research Question 2: What are the alloying practices in use at Harappa from 3300-1900 BCE? Do the alloying practices that can be empirically identified demonstrate a consistent pattern by artifact category/class?

Any attempt to reconstruct the nature of the copper/bronze metallurgical tradition at Harappa must begin with identifying the presence of and determining the usage pattern for copper and copper alloys. Across the Old World during the 3rd Millennium BCE, a number of elements used to fashion copper alloys have been identified. These include, tin, lead, arsenic, zinc, nickel, and antimony; with the first three being common and the latter three being uncommon. In fact, nickel and antimony are uncommon enough to be viewed as limited to certain specific geologic ranges that fall outside of known Indus interaction spheres. However, it must be pointed out that it is important to eliminate these elements as a possibility. A detailed review of previous analyses of Indus copper and bronze objects demonstrated that nickel and antimony are sometimes present as accessory elements but have yet to be identified at levels that are indicative of intentional alloys (see Chapter 2). Still, the potential that any, or some combination of zinc, nickel, or antimony was present in the sample assemblage from Harappa

could not be excluded a priori. Therefore, all three elements were analyzed for during all phases of the analyses conducted for this research project (see Chapter 4 for details).

Based on a review of previous analyses of Indus Tradition copper/bronze assemblages (see Chapter 2 for details), the current project focused expectations on the identification of unalloyed copper, and tin, lead, and arsenic as potential alloying elements. This expectation was based on two underlying lines of logic. The first is that these are the copper alloys reported from previous analytical programs carried out on Indus period copper/bronze artifacts. The second is that, Harappa either would have had access to these alloying elements through interaction networks between Indus Tradition sites or through interaction networks that linked Harappa to resource areas adjacent to the core area of the Indus Tradition (see Figure 1.5). Overall, it is reasonable to focus a study of the alloying practices at Harappa on copper and the elements of arsenic, tin, and lead.

A review of contemporary copper metallurgical traditions from adjacent regions indicates that it is often common for copper alloys (i.e. “bronzes”) to be limited in their use. Typical explanations regarding this phenomenon are linked to the restricted nature of the supply of tin during the 3rd millennium, particularly in the southwest Asian context. Researchers usually infer that bronzes would have only been employed for those artifact classes that specifically required the additional strengthening properties that a copper-tin alloy (tin bronze) conferred. As discussed in subsequent sections of this work (see Chapter 2), this pattern of the use of copper-tin alloys in the limited context of items that needed specific strength and edge properties is not appropriate for the Indus setting. Particularly as these bronze artifacts in a Southwest Asian (Mesopotamian, etc.) context were often restricted to edged weapons from burial contexts. As

comparative archaeological contexts and artifact categories are rare in the Indus, it was seen as not appropriate to carry over existing hypotheses regarding the use of copper and copper alloys.

As a substitute, the project sought to empirically identify potential alloy types through a variety of analytical techniques on a sample set of copper/bronze materials from Harappa (see Chapter 4 for details). Once these alloy types were identified and documented, it was then possible to determine if the artifact categories developed during the classification of the HARP copper/bronze assemblage demonstrated any consistent or restricted patterns of alloy usage. Based on expectations regarding the availability of copper mineral sources, copper smelting in the 3rd millennium, and the nature of the Indus metallurgical tradition, it was anticipated that there would be little patterning of alloy usage by artifact type. The results of the analytical program on artifact composition, however, revealed that an underlying pattern of alloy practice and patterning does exist (see Chapter 4 & 6 for discussion). In fact, the copper metallurgical tradition at Harappa appears to employ two simultaneous alloying patterns; one focused on the functional requirements of the finished object and one focused on the final visual appearance of the finished object. Traditional explanations for alloying decisions have focused on the availability of alloying minerals and the technological skill of the metalworkers and tend to dominate the previous discussions of the Indus metallurgical tradition (see Chapter 2 for details). However, the idea that different alloying practices were in operation at the same time in order to produce metal objects for different applications has emerged as a potent explanatory model in other regions (Golden 2014:563; Thornton 2014:686-688) and supports the idea that Indus copper/bronze workers would have been proficient in a variety of alloying techniques. This would have allowed them to adapt to any irregularities in raw material supply to ensure that the copper and bronze objects needed by the residents of Harappa were available on a consistent

basis. Further, the types of alloying practices in use at Harappa can be directly tested through the compositional analysis of individual artifacts (see Chapter 4). The testing of the hypothesis that Indus alloying practices were split between an industry focused on the use of a restricted set of specific copper alloys to produce predictable and culturally important final visual appearances and another industry centered on the production of items that would fill specified functional requirements through the usage of a broader set of more generalized copper alloys is an important component for understanding the Indus copper/bronze metallurgical tradition. It helps to refine, and elaborate ideas proposed for other regions as well as to incorporate perspectives beyond solely considerations of supply and technical skill. The presence of an alloying tradition at Harappa based on object appearance allows for incorporating the possibility that some of the ethnographic (Lahiri 1993; Lahiri 1995) and textual (Chakrabarti and Lahiri 1996:137-150) evidence for the use of specific alloys to make specific object categories or for specific purposes, such as ritual, could have its roots in Harappan copper/bronze metallurgy.

Research Question 3: Does the development and expansion of copper interaction networks follow the pattern identified for lithic raw materials?

The potential source areas for copper are in similar geographic locations as many of the identified rock and mineral source areas (Figures 1.5 and 1.6). It is reasonable to hypothesize that the interaction networks for these materials would have also been similar. If patterns of copper acquisition and use over time and space at Harappa are the same as for rock and mineral resources (cf. Law 2011), then it is possible to assume that both sets of raw materials were acquired through similar trade and economic networks. If they are different then it is necessary to develop models for distinct networks that supplied lithics and metals to the city. The former is a collaborative model while the latter presents a situation where there would have been some competition between the two networks.

This project seeks to identify and document the connections between the city of Harappa and discrete copper source areas (Figure 1.6). The analytical determination of these interaction networks alone will provide new and valuable information on the nature of copper procurement at Harappa during the 3rd millennium, but it allows for only gross interpretations of specific economic and technological trajectories of metallurgical development at the site over time. In order to develop a fine grained and analytically potent set of chemical data, the site of Harappa was considered as two separate spatial units for the pre-urban periods and four specific spatial areas for the urban period, designated by the different walled mounded sectors of the city (Figure 1.4). Groups of artifacts from each mounded area for all time periods were analyzed for their isotopic signatures. The resulting dataset allowed for the number of sources present for each mound to be compared for individual time periods and to track shifts in source area utilization and distribution over time at Harappa. The identification of chronologically and spatially discrete patterns of source area utilization at Harappa provides empirical evidence for relating copper raw material use at Harappa with other known cultural patterns of development.

The precision of the chronology available from the site of Harappa allows for changes seen in copper source areas and interaction networks to be tested for correlation to the sequence of developmental phases at the site. This correlation allows for an evaluation of the impact of shifts in copper resource area exploitation on social, political, and economic development at the site of Harappa. The production of precise data on the nature of inter-regional metal exchange at Harappa allows for the relationship between the growth of complexity at the site and the role of long-distance trading to be directly tested. Law (2011) has demonstrated that for the entire Indus sequence, Harappa obtained lithic raw materials from areas to the north and northwest of the site. However, during the urban phase, there was an increase in access to specific rocks and minerals

from the south and southwest (Figure 1.5). Much of the potential source areas for copper ore are overlapping with the rock and mineral source areas identified for Harappa. If lithic and copper materials were obtained via the same interaction networks, it is expected that there would be a similar pattern of resource area exploitation and expansion over time. However, if lithics and copper and copper/bronze were acquired through different networks, then a distinctive pattern of resource area exploitation would be seen. The development of a comprehensive lead isotope database for the copper/bronze assemblage at Harappa allowed for the direct testing of the hypothesis that copper interaction networks were identical to the lithic interaction networks previously identified. The results of this component of the study indicate that copper ore sources were similar to those for other minerals with some important differences and a modified pattern of intensity.

Figure 1.4: Harappa Site Map

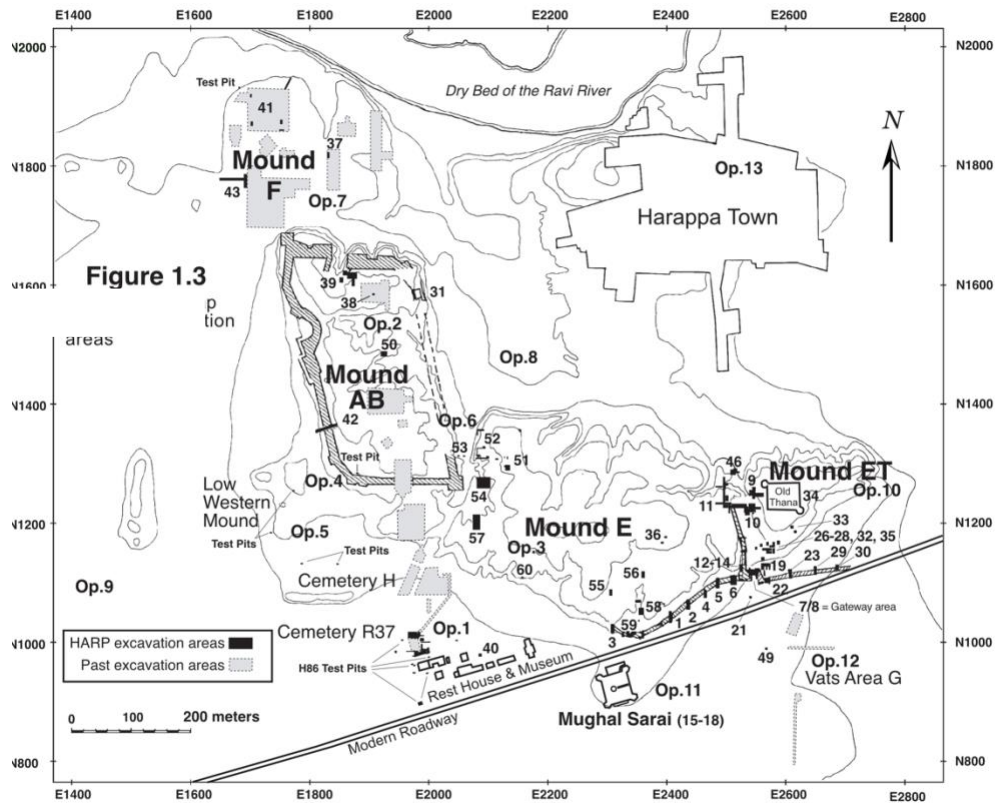


Figure 1.5: Lithic Interaction Networks Over Time
 (After Law 2011 Figures 13.2-13.7 pages 465-475)

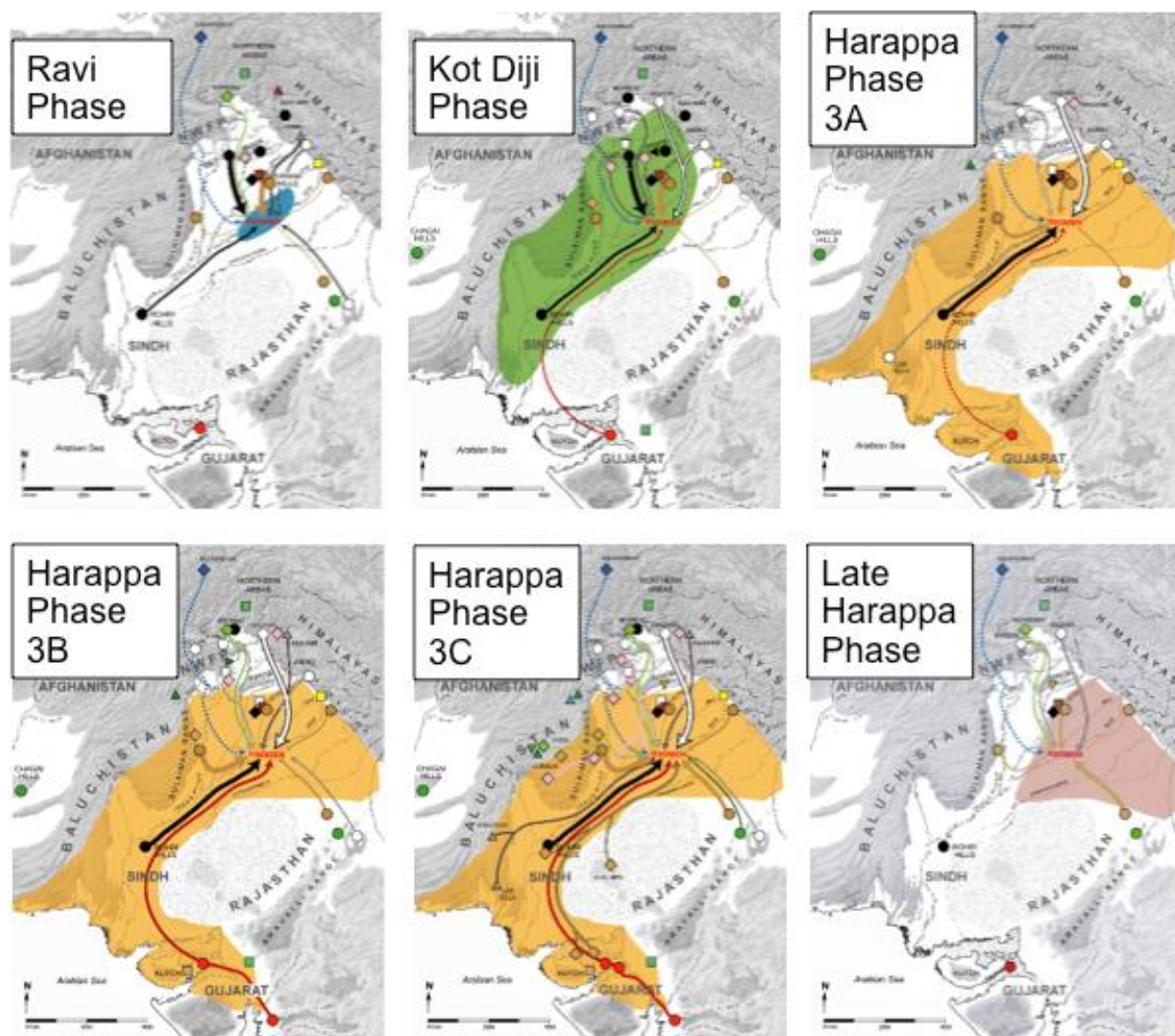
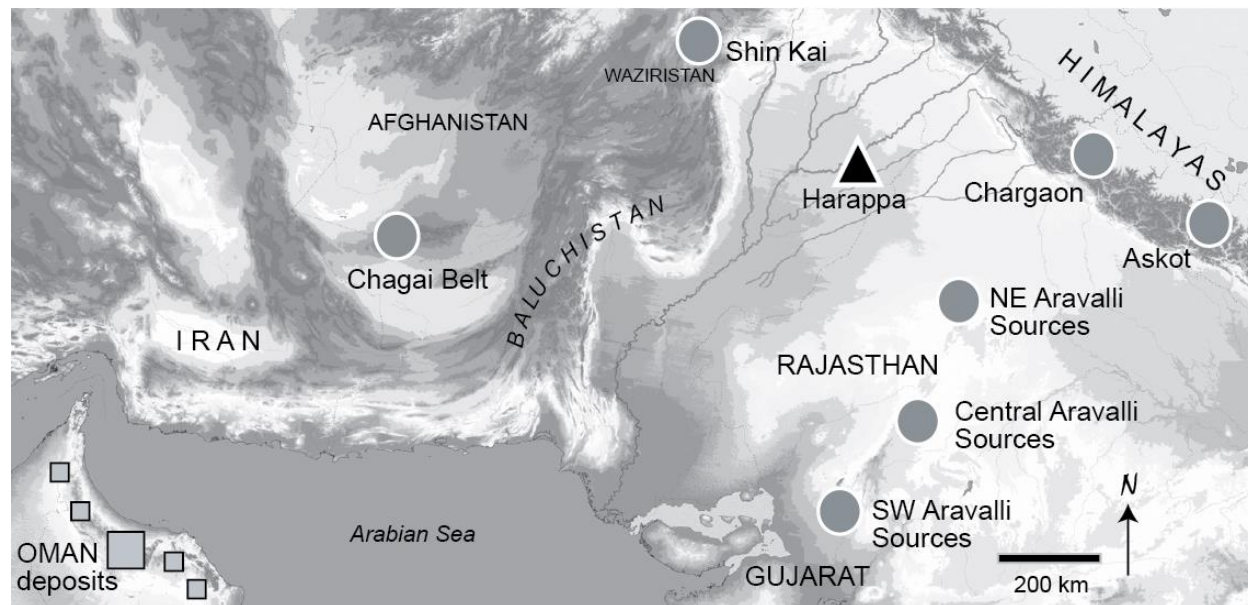


Figure 1.6: Location of Harappa and Regional Copper Sources



(Redrawn from Law 2011:448 Figure 12.45)

Research Question 4: Does copper exhibit a pattern of similar access to raw materials and artifacts on all major mounds?

Based on the pattern of similar access to lithic raw materials on all major occupation areas (cf. Law 2011) it is expected that copper will demonstrate a similar pattern of unrestricted access. However, if copper demonstrates differential patterns of access by mounded area then it can reasonably be assumed that there was some restriction of access to copper raw materials. If copper was a resource that was not subject to the competition for control over access; then the mounded areas should exhibit similar patterns of access to raw material sources and have identical suites of lead isotope data. Alternatively, if copper was a resource that was subject to restricted access, then each walled mound should demonstrate variation in the presence/absence of at least one source area.

To assess the potential for the restriction of access to copper raw materials at Harappa, each mound will be compared to the database of source areas. Through constructing both a synchronic and diachronic picture of spatial shifts in the use of specific resource areas it will be

possible to evaluate whether elite groups at Harappa were attempting to control and manipulate copper raw material exchange networks in order to further economic and political power strategies. It is anticipated, based on the data from the rock and mineral assemblage from the site, that there would have been generalized and unrestricted access to copper and copper/bronze materials at Harappa. The development of a comprehensive lead isotope database for the copper/bronze assemblage at Harappa allows for the direct testing of this hypothesis of unrestricted access. If this was indeed the case then the isotopic data should be broadly identical for each mound, with no unique sources indicating that the acquisition of copper and copper/bronze items was not a directly competitive or restrictive activity. However, if elite groups at Harappa attempted to control access to copper in order to achieve a competitive economic advantage over rival factions, then the isotopic data would exhibit a pattern of unique sources for the different spatial areas. Consequently, as urbanism emerged and developed at Harappa the access to copper raw materials was directly influenced by a pattern of competition over the resources that specific inter-regional interaction networks supplied to the city. The analysis of the lead isotope data (Chapter 6) supports the hypothesis that access to copper raw materials was not restricted and all occupational sectors were able to utilize a variety of copper sources.

The development of isotopic signatures for all artifact types for each mounded area during all occupation periods will provide documentation of any spatial and temporal variation in the use of copper source areas as well as any variation by artifact type. In order to understand the nature of the patterning seen in the lead isotope data, it is critical to determine whether the source of the variation stems from differential access to raw materials, choices made by metal manufacture or both. It is necessary to determine whether each of the walled mounded areas at

Harappa was producing identical copper/bronze objects, that is, objects made from the same raw material and the same technological processes, or if workshops were unique.

Compositional analysis and lead isotope analysis provide the investigator with substantially different sets of data that can be applied to differing scales of analysis. Lead-isotope analysis allows for the development of analytical data that can be used to link archaeological metal remains to source areas. These linkages are accomplished at a regional or inter-regional level. In contrast, compositional analysis will allow for archaeological materials to be linked to specific production locales and manufacturing techniques. The use of compositional analysis can provide an important indicator for the organization of production. Analysis of compositional patterns has been demonstrated to be applicable for reconstructions of both source area distributions and manufacturing/technological patterns (Pernicka 1999; Ixer 1999; Weeks 2003; Hauptmann 2007). While this is often addressed at a site level, at Harappa the copper/bronze materials from each of the walled sectors of the ancient city have been analyzed and the patterns from each area compared. This made it possible to determine if different sectors of the city were obtaining copper raw materials from the same or different sources, and, additionally, if they were processing the metals in similar or distinct ways.

The use of copper at Harappa follows a pattern similar to that documented by Law (2011) for the rock and mineral assemblage from the site. Law identified a pattern of consistent generalized access to both raw materials and finished goods by all sectors of the site and all time periods for a variety of rock and mineral resources. It is my hypothesis that a nearly identical situation exists for copper at Harappa. The overlapping nature of the isotopic and compositional evidence allowed for the source of patterns seen in the chemical data to be determined. The identification of what drives variation, or the lack of, in copper/bronze metallurgy at Harappa,

provides a new line of material evidence to the overall dataset used to construct models of Indus political and economic organization. Understanding if copper raw materials were subject to restricted access or if they were available equally across the site will be important for aiding in interpreting the nature of the relationships between each walled mounded area at Harappa. The distributions seen in the compositional data will provide another line of evidence to address this issue as well. The results of this project when combined with already completed and ongoing studies of other components of the material culture evidence at the site will provide a clearer picture on the relationship between long-distance exchange, craft production, and political and economic organization at Harappa.

Summary

The individual research questions outlined above identify and document the patterns evident in the copper metallurgy tradition at Harappa across time and space. Previous research conducted at Harappa and other Indus Tradition sites allows for some working hypotheses and expectations to be constructed. However, due to the limitations of some of the previous data sets and gaps in the existing knowledge of Indus copper metallurgical tradition(s) in the past, it was not possible to develop a robust explanatory model for this important component of Indus material culture. The lack of such a model makes it problematic to articulate copper/bronze metallurgy with current models for Indus economic, social, and political organization. It is this gap that this project seeks to insert itself into. While, the current work is by no means a complete or final statement on copper/bronze metallurgy for either Harappa specifically or the Indus in general; it does represent an up-to-date empirical attempt to model this important industry during the Regionalization, Integration, and Localization Eras at Harappa. This model can then be tested

in future research against data sets from additional Indus Tradition sites in order to identify critical regional and chronological differences and/or similarities.

In order to accomplish this goal and adequately address the stated research questions for the project, a program of review of archival data and previous research projects was pursued in conjunction with a series of fresh analytical investigations on artifacts from Harappa. The results of this are laid out in the following chapters. Each chapter focuses on specific aspect of the overall research, with the final chapter synthesizing and summarizing the results into a coherent whole. This introduction serves to outline the goals and expectations that form the basis for the project. The second chapter articulates those research questions with previous research on Indus copper and bronze metallurgy to highlight relevant background information and identify points of departure from traditional interpretations. The chapter is organized along several major thematic lines that demonstrate how the current project articulates with both previous and ongoing research on Indus copper and bronze metallurgy. Chapter 3 categorizes and reviews the archaeological context(s) for the entire copper/bronze assemblage from the HARP excavations. This detailed review of the archaeological contexts and artifact categories covered by the HARP copper/bronze assemblage provides the necessary backdrop for a detailed description and review of the project sample assemblage. Chapter 4 introduces the data sets for each stage of the compositional analyses. Chapter 5 details the results of the lead isotope analysis program. The full data sets for each analytical stage are also included as individual appendices. Chapter 6 provides conclusions stemming from the detailed analysis of the various project data sets. Finally, Chapter 7 sets out a summarized version of the project conclusions as well as highlighting how this project relates to research in adjacent regions. Based on a review of the analytical, archaeological, and archival data sets that are relevant to copper and bronze

metallurgy at Harappa, a model for the data developed is put forth. The final chapter reviews this model and places it within the framework of the overall project goals that are outlined above.

The goal is to lay out a framework of how each phase of the project intersected with one or more of the overall research questions.

This project attempts to build and expand on the recent copper studies carried out in other regions of the Indus (Bourgarit et al. 2005; Law 2011; Patel et al. 2014; Bisht 2015; Park and Shinde 2014;) through the creation of a data-driven set of conclusions for copper and bronze metallurgy at Harappa that can then be tested at other Indus Tradition sites. The primary conclusions are as follows:

- Although some of the specific types of copper and bronze artifacts produced at Harappa change over time, the same general categories of objects are found in all major periods and in all sectors of the site.
- During the Integration Era at Harappa, there were two main alloying practices in use. One was focused on producing consistent final visual appearances for artifacts of personal ornamentation and display. The other was centered on the production of utilitarian objects where alloy selection was determined by final function.
- Harappa exploited a number of copper source regions, often at the same time. The patterns of source area utilization are similar to that identified for other rock and mineral raw materials with differences in intensity. The available isotopic data for South Asian copper sources indicates that during the Integration Era at Harappa, copper supply networks were more focused on deposits across the Aravalli Range than deposits to the north or west of the site.

- At Harappa, there appears to be no restriction to specific copper raw material sources, artifact categories, or alloy types in terms of settled areas of the site as represented by walled or unwalled mounds. This unrestricted access to copper and bronze metallurgical materials is similar to the pattern found for other lithic and mineral resources at the site.

I interpret these data to mean that access to copper raw materials (either minerals or ingots) was not restricted or directly controlled by elites in any one sector of the city. While the location of copper and bronze production areas within the city walls of Harappa indicates an indirect mode of control, the presence of multiple copper workshops at the site indicates that this type of metal production was not heavily directly controlled by specific groups at Harappa during the Harappan Phase. The pattern of copper/bronze production at Harappa contrasts with that of a highly controlled craft such as seal making (Kenoyer 2000; Jamison 2017). Additionally, the presence of a variety of alloy types across the excavated extent of the ancient city indicates that access to copper and bronze objects was not restricted. I also propose that the variety of distinct alloying traditions indicates that copper and bronze artifacts, particularly items of personal ornamentation, were critical for the visual display of wealth and status both within the urban context and across the wider interaction networks of trade and exchange. The presence of multiple supply networks and alloying patterns at the site during any given period would have been necessary for craftspeople to make the varieties of copper and bronze jewelry or display items to express status and/or wealth.

Previous studies have created a series of archaeological indicators of wealth and power for the Indus Tradition (Kenoyer 1992a, 2000; Vidale and Miller 2000). Copper and bronze metallurgy are fall into a category that represents the most readily controlled and easiest to utilize in the creation of wealth items (Kenoyer 2000:92). During the Harappan Phase (2600-

1900 BCE), research at Harappa has documented the existence of similar ornament forms in a variety of raw materials (Kenoyer 2000:104-107). The existence of copper and bronze versions of these items of personal display articulates with the existing conceptualization of wealth and status in the Indus Tradition. Different raw material types would have signaled different levels of status and wealth at Harappa (Kenoyer 1992a, 1992b, 2000, 2014). The existence of ornament forms, such as bangles and rings, in copper and different copper alloys demonstrates that the results of some copper and bronze production was filtering in to the wealth and status hierarchies at the site. In contrast the broader and less restricted alloy pattern demonstrated by tools and other utilitarian objects indicates that they were not functioning within a hierarchical system and a separate channel of copper/bronze production existed to ensure that residents of the city had access to copper and bronze tools and everyday items. This is related to the continued use of multiple copper source areas. In order to ensure consistent and uninterrupted access to this important raw material, Harappa engaged in interactions with multiple source locations. Since the type and quality of the copper raw material each of these source locations supplied would have varied, Harappan copper-smiths became proficient at executing a wide range of alloying practices in order to ensure the visual and functional qualities desired by the urban consumers at the site.

The consumption of finished copper and bronze objects by the residents of Harappa provides an avenue for the broadest articulation with models and interpretations of daily economic interactions across a variety of world areas. At Harappa it is modelled that the exchange of goods, services, and other items of economic significance happened in a bazaar setting that would have engaged in a complex series of interactions and valuations to distribute goods from producers to consumers (Kenoyer 1997, 1998, 2000). Currently it is not believed that

these areas of economic interaction and exchange within Indus Tradition cities would have operated under any sort of monetary or market principles, the results of the research on copper and bronze materials indicates there still would have been a great deal of complexity and variation in how items were valued, the role they played in larger social and political spheres of the Indus Tradition, and how a consistent supply of the required raw materials was ensured. While the specifics for copper and bronze offer differences, the general pattern is similar to how a variety of other economic, craft industries, and raw material types are understood to function at Indus Traditions cities (Kenoyer 2000; Law 2011; Vidale and Miller 2000).

It is the linkage between analytical data and archaeological interpretations that forms the core of the current research project. Without a clear understanding of those linkages, meaningful reconstructions of behaviors in the past would not be possible. Of particular importance and relevance is how and why data derived from craft industries and technology are so critical to our reconstructions of Indus political, social, and economic networks. In order to understand how these factors, articulate with one another, a detailed review of previous research on copper and bronze in the Indus Tradition is presented in the following chapter. The patterns and expectations derived from these previous research programs form the foundations of the testable hypotheses used in the current project. The details of the relationship between these hypotheses, the project research questions summarized above, previous scholarship on Indus copper and bronze metallurgy, and the criteria used to construct the answers to major project research questions are laid out in the next chapter.

Chapter 2: Previous Research on Copper and Bronze Artifacts of the Indus Tradition: Trends and New Directions

Introduction

In Mohenjo-Daro and the Indus Tradition, Marshall states "...the discoveries at Mohenjo-Daro and Harappa have completely disposed of the hitherto accepted theory that bronze was not manufactured in India during the prehistoric age." (1931:31). That statement combined with the excavation and laboratory data presented, elevated the Indus Tradition into the larger discussion of "Bronze Age" civilizations. Previous to the finds from Mohenjo-Daro and Harappa, it was generally held that peoples in India rarely manufactured bronze and produced a limited number of objects from copper prior to the historic period (Smith 1905). It had been stated that the subcontinent lacked a true prehistoric "Bronze Age" and instead was largely a "Copper Age" development (see Smith 1905 and Marshall 1931). The finds and the associated chemical and chronological data that derived from the early excavations at Harappa and Mohenjo-Daro served as direct and indisputable proof that South Asia did indeed possess an indigenous prehistoric bronze making culture.

The discoveries at Mohenjo-Daro and Harappa did much to overturn existing notions regarding South Asian prehistory as well as to provide the first extensive archaeological documentation of an urban phenomenon during the 3rd millennium. Additionally, early researchers working on the Indus took several steps to analyze and interpret the nature of the copper and bronze metallurgy that their excavations were beginning to document. Primary among these efforts was the inclusion of chemical analyses of artifacts from Mohenjo-Daro and Harappa in the initial investigations (Marshall 1931; Mackay 1938; Vats 1940). The data, both archaeological and analytical, presented in these volumes laid the foundation for almost all future

conclusions and research programs focused on Indus copper/bronze metallurgy. The major conclusions of the metallurgical research from the early published reports are as follows:

1. Copper was abundant at Indus sites and was commonly used to create a range of materials from domestic utilitarian goods to items of display and ornamentation.
2. The use of bronze was restricted to objects that required the physical properties that the addition of tin provided.
3. While Indus metal workers had a high degree of skill and familiarity in working with copper and bronze, they did not produce either high numbers or types of weapons in the materials.
4. The presence of certain key elements in Indus Tradition copper/bronze artifacts indicates that the primary source areas for Indus copper are either in Rajasthan or Baluchistan.
5. Copper hoards with a variety of object and alloy types cached were encountered during the excavations at Harappa, Mohenjo-Daro, and Chanhudaro.
6. Indus cities were sites of secondary copper manufacture and lacked any substantial evidence for the primary smelting and refining of copper raw material.

While Marshall (1931), Desch (1931), Mackay (1938), Sana Ullah (1931), Vats (1940) and the others involved in the work on the copper/bronze artifacts found at the early excavations at Harappa and Mohenjo-Daro offered many other data points, interpretations, hypotheses, and statements on the nature of copper/bronze metallurgy in the Indus Tradition, it was the above conclusions that the majority of later research on Indus copper and bronze sought to confirm or refute. This research project is no different. Previously, the major project research questions were outlined and summarized. In this chapter these questions and the testable hypotheses they

generate are detailed and articulated with the major themes of previous research on Indus copper and bronze artifacts, production, and source provenience. Areas of continuity and alignment are highlighted but the focus is on establishing fresh determinative criteria for data analysis and hypothesis testing that often are at odds with previous expectations and approaches for Indus copper/bronze research. These departures and realignment of parameters are based on an extensive review of previous research from the Indus Tradition (see individual sites in this chapter for detailed references) and an evaluation of relevant archaeometallurgical perspectives from scholars working in other regions (see Scott 1991; Ixer 1999; Pernicka 1999, 2014; Stech 1999; Gale and Stos-Gale 2000; Hauptmann 2007; Pollard and Bray 2014 for examples).

Definitions of Bronze and Other Copper Alloys

A review of previous research on copper/bronze metallurgy in the Indus Tradition can identify not only the interpretive themes outlined above, but issues that require a resetting of definitional terms and evaluation criteria. In order to address the project research questions outlined in the previous chapter in a robust manner, it is necessary to link those questions to the interpretive trends identified in previous research programs and to specifically define key terms. Prior to addressing the bulk of both previous research and the questions addressed during the current investigations, it is necessary to define what the benchmarks parameters are for copper, and copper-based alloys; specifically, what is meant by the term “bronze”.

Figure 2.1: Map of Sites and Regions in Text



The determination and definition of what represents a bronze in archaeology is often problematic. There is little consensus on the specifics. The desired goal in attempting to construct a working definition for bronze is to determine at what point the presence of a particular element in a copper metal object can be taken as intentional. It is the act of intentionally adding a specific element/mineral to a metallurgical recipe that is critical to archaeological interpretations of ancient metal working practices. It is in this intentionality that aspects of human behavior can be located. In addition to identifying a threshold compositional signature for the intentional addition of specific alloying elements, it is necessary to also define what elements can be added to copper in order to produce a bronze.

Traditionally within scholarship on South Asian prehistory, the term “bronze” has been taken to mean only an alloy of copper and tin. However, as analytical research programs on ancient metals have expanded in both scope and precision, archaeology’s understanding of what constitutes a “bronze” has expanded as well. Throughout the Bronze Age world of Eurasia, a multiplicity of copper alloys has been recognized. Copper can and has been alloyed with antimony, arsenic, lead, tin, and various combinations of these elements. While it may not be advisable to group all of these copper alloy combinations under the heading of a bronze, some categorization and definition of terms is required.

An alloy of copper (Cu) and tin (Sn) with a tin content of 2 percent or greater can be confidently classified as a bronze. Research has demonstrated that below this threshold it is rare, but possible, for tin to be a natural addition to the parent copper ore body (Cleuziou and Berthoud 1982; Craddock 2010). While it has been argued that a tin content more in the 8-12 % range is the ideal alloying ratio for bronze, this is somewhat irrelevant. The designation of a baseline level of alloying material is only concerned with determining what exceeds the level found in nature. In other words, despite the fact that a tin content below 8 percent and above 2 percent may result in a low-grade bronze lacking in all or some of the desired characteristics of a bronze it is nevertheless an intentionally constructed alloy of copper and tin. This designation of greater than or equal to 2 percent tin content largely follows the arguments outlined in Stech (1999). It is worth noting that this cut-off point is useful in the context of Indus metallurgy for two additional reasons. Research on historic metal producers in South Asia has demonstrated that the color and/or the ability to resist oxidation of the final product is frequently more important than purely mechanical properties such as hardness or strength (Lahiri 1993, 1995; Chakrabarti and Lahiri 1996). The incorporation of color or resistance to oxidation into the definition of what

constitutes an intentional alloy mandates that the dividing line be dropped below the 4-5% that other researchers have employed (Marshall 1931:485; Hall 1991; see Miller 1999 for discussion).

Arsenic (As) and Copper (Cu) alloys are more problematic to define. This is because copper and arsenic can co-occur in mineral deposits. Such a co-occurrence makes it difficult to distinguish between intentional addition of arsenic as a separate mineral to copper in order to produce an alloy, or the production of an alloy through both copper and arsenic being smelted together via a poly-metallic ore (Lechtman and Klein 1991; Miller 1999; Craddock 2010). It can be argued that since both activities, smelting a joint ore or intentional addition of an arsenic bearing mineral, indicate a degree of selectivity each can be regarded as an intentional alloying practice (Stech 1999:64). Further, since arsenic is highly volatile, it is not possible to distinguish between either practice through laboratory analyses. The final amount of arsenic in the smelt would have been difficult for ancient smiths to control in either case (Stech 1999). Research has demonstrated that arsenic in amounts under 2% provide little to no advantage over pure copper as an alloy (Northover 1989:113). Much of the reported Indus arsenic contents are either traces or over between 1-5% (see Appendices 2.1-2.11). Therefore, following Stech (1999:64), 1% arsenic content is used as a logical point for defining a copper-arsenic alloy. This delineation follows the main body of research on arsenical copper across multiple world regions (see Budd and Ottaway 1990 for review). Finally, it must be noted that present research urges caution when attempting to define arsenical alloys, as the potential range of variation reported is fairly wide (Northover 1989). Alloys of this type are taken to fall under the heading of arsenical bronzes.

A third type of copper alloy is one that combines copper and antimony. However, this type of alloy is exceedingly rare in antiquity (Moorey 1994). Copper-Antimony alloys tend to be

produced only when antimony co-occurs with copper and arsenic in the parent ore deposit. Geochemical processes drive a replacement of arsenic with antimony. The resulting ore leads to a similar situation described above with arsenic, where it is unclear whether the alloying is the result of direct introduction of antimony to the copper during smelting or melting or the preferential selection of specific ores to produce an alloyed final product. In the case of copper-antimony alloys, it is much more likely that the final alloy was the result of co-occurrence in the original ore body rather than intentional alloying practices during a specific metallurgical production stage. Due to their high degree of rarity these alloys will not be considered in the current work (excepting for specific instances of unusually high levels of antimony) and antimony will be viewed as an accessory mineral to copper. It should be noted that the “antimony rods” noted by the original excavators in multiple reports from Indus sites refer to a specific type of copper rod that is hypothesized to have been used for the application of cosmetics. Additionally, although Sana Ullah notes that antimony appears in “appreciable quantities” in the copper/bronze assemblage from Mohenjo-Daro and Harappa (1931:485), but there is no evidence for the intentional addition of antimony to copper (Miller 1999:228).

A final potential alloying element found in all the Indus copper/bronze assemblages (except at Rangpur where only traces were identified) is lead (Pb). As lead is found ranging in amounts from a trace level impurity in a given analyzed copper/bronze object to 32.17% (see Appendix 2.1-2.11) for a copper object from the DK area of Mohenjo-Daro (ASI Report 1930-34), developing a minimum threshold value for the definition of an intentional lead alloy is a critical step in identifying and categorizing copper alloys in any analyzed Indus metal assemblage. A review of the literature indicates that while lead is clearly an alloying element, there is little consistent discussion of what amount of lead is necessary to define the intentional

addition of the element to copper during production. Additionally, it is clear that in the Indus lead was an accessory mineral to copper, an alloy, and a metal used itself in a variety of ways (Miller 1999; Law 2011). The common nature of lead in Indus assemblages and the multiple ways it was being used serve to make definitive statements regarding the material difficult. Lead can be used with copper in one of three main ways. It can be added to molten copper to aid in casting (Moorey 1994:293; Miller 1999:227). It can be an intentional addition as an alloy to change various properties of the final object (Miller 1999) or it can serve as a flux during production as evidenced by recent research at Dholavira (Bourgarit et al. 2005). In attempts to take this variation in lead use into account and using the previous analytical results as a guide, a level of 1% lead content has been chosen to represent an intentional addition to the copper artifact. This is consistent with previous discussions of Indus copper/bronze metallurgy (Agrawal 1971; Kenoyer and Miller 1999; Agrawal 2000). Additionally, there appears to be a divide in the analyzed results between copper with some lead in it and copper with lead over 1% percent (see Appendix 2.1-2.11).

Typically, discussion of Indus copper-based metallurgy does not consider zinc because there was no evidence for its use by Indus metal workers. Recently, results from analytical studies on Indus copper-based metal objects have reported the presence of significant amounts of zinc (see Kharakwal and Gurjar 2006; Park and Shinde 2014; Patel et al. 2014). The reported compositional percentages are of high enough levels that the authors argue that it is necessary to refer to these objects as a “brass” or a copper-zinc alloy. While brass is a metal industry with a long history within South Asia (see Kharakwal and Gujar 2006 for summary), it has previously not been reported prior to the latter portion of the 1st millennium BCE (Craddock 2010:309; Craddock et al. 1990). The identification of a number of copper-zinc alloys 1-2 millennia earlier

would serve to place the advent of brass metallurgy within South Asia far earlier than adjacent cultural regions. This would be an incredibly significant development in not only the technological history of South Asia, but the development of metallurgical processes around the globe as well.

In order to incorporate such claims into the overall data set for 3rd millennium BCE metallurgy in South Asia, it is necessary to review some relevant background information and data from a variety of previous studies. The first objective is to establish a benchmark for the discrimination between a copper artifact that contains some zinc (Zn) as an accessory element and that of an intentionally produced copper-zinc alloy, or a “brass”. Fortunately, a great deal of metallurgical research on the use of zinc and the production of brass in antiquity has been conducted and there is a wealth of data to draw from in order to better understand the relationships between copper, zinc, and other alloying elements in antiquity. A critical first step is the recognition that the production of copper and zinc alloys is significantly technologically more complex than the manufacture of other copper-based alloys, such as tin bronze (Thornton 2007:124; Craddock et al. 1990; Pollard and Heron 1996; Craddock 2010). Several detailed reviews of the production methods for zinc and brass can be found in the existing literature (Craddock 1990 et al.; Craddock and Eckstein 2003; Craddock 2010) and it is unnecessary to review all of the manufacturing steps and the specific chemical reactions that are undertaken. However, it should be noted that zinc is volatile above a temperature of 906° Celsius (Thornton 2007:124) and will sublime into a gaseous state before the reduction of the zinc ore (Forbes 1964:263). As a result, the intentional production of copper-zinc alloys requires complex technological adaptations in furnace technologies, technical ceramics, and smelting processes to combine zinc oxide with copper to produce an alloy. These technologies are not documented

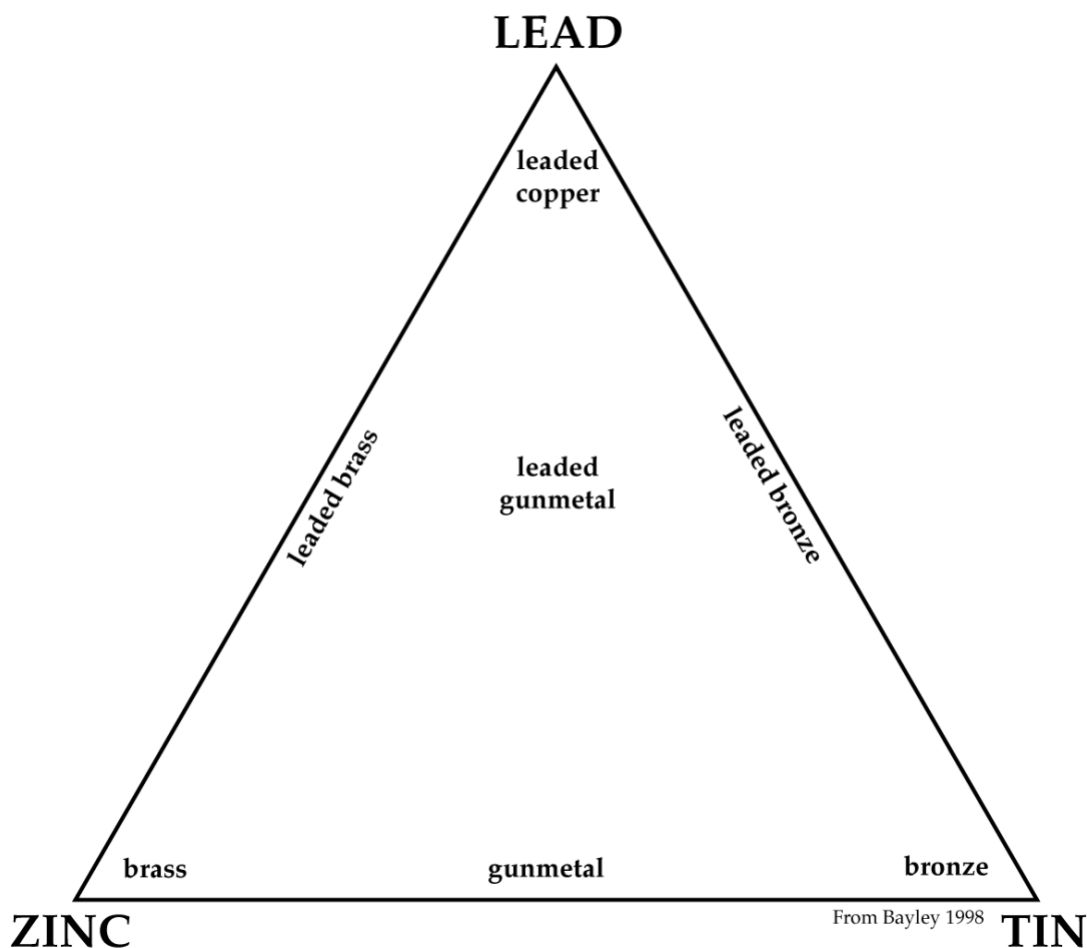
either textually or in the archaeological record prior to the 1st millennium BCE. However, copper and bronze artifacts with measurable amounts of zinc in them exist both within India and across southwest Asia from the 3rd millennium forward (Thornton 2007; Park and Shinde 2014). These data should not be either dismissed or marginalized because they do not fit within the existing conceptions of Indus metal production.

For the majority of the study of Indus copper/bronze metallurgy, it has been assumed that zinc played a minor role if it, in fact, played a role at all in the overall metallurgical tradition. With the general consensus being that zinc was not a significant alloying material until the large-scale production of brass began in the 1st millennium BCE. However, there have been recent publications and data sets that have begun to challenge this assumption (Park and Shinde 2014; Patel et al. 2014). The presence of zinc in copper metal objects, either by itself or with other elements (such as lead and/or tin) is an understudied phenomenon in 3rd millennium copper metallurgy in general. Examples can be found within a variety of southwest Asian copper/bronze assemblages (Thornton 2007). It should be noted that zinc can be combined with copper either singularly or with other elements to form a variety of distinct copper-based alloys (see Figure 2.2 and Bayley 1998).

The key difference between 3rd millennium copper-zinc metals and the varieties of copper zinc alloys (types of gunmetal and brass) is the amount of zinc in the finished product. Following the detailed and reasoned arguments laid out by Thornton (2007:124), an intentional copper-zinc alloy (a brass) is defined as any object containing more than approximately 8 percent zinc by weight. This allows for a separation of copper-based metal artifacts that contain zinc from those objects that were produced through intentional alloying processes. From the published analyses of metal objects from the 3rd millennium BCE it is possible to identify

copper objects with zinc contents below this 8% benchmark (Kharakwal and Gurjar 2006; Thornton 2007:126-127). These objects are potentially the result of the smelting of raw materials with a high zinc content (Pollard and Heron 1996) and can produce finished artifacts with up to 7% zinc. While this produces a metal that has some different properties than copper, it is not possible to identify the intentionality of this combination, as it may have strictly been an accidental result of the raw materials used in the smelting process. However, once the threshold of 8% is crossed, the finished artifacts takes on a distinctive golden color that would have surely been noticed by ancient metalworkers and may have been the desired final result.

Figure 2.2: Copper alloys with tin, zinc, and lead



Looking specifically at the copper and zinc containing artifacts identified at Indus sites, there appears to exist a certain degree of confusion. Kharakwal and Gurjar (2006:148-149) specifically address "...around half a dozen..." artifacts from Lothal and one artifact from Kalibangan that contain zinc. The claims for the presence of zinc at Lothal are problematic. One of the artifacts designated as representing a brass object (Lothal Antiquity No. 4189 listed in Rao 1985:660), is almost certainly a typographical error in the original analytical report. This has been pointed out previously (Kenoyer and Miller 1999:139) but bears repeating here. When testing 64 objects from the site of Lothal, Lal (Rao 1985:6651-660) reports only one object containing zinc. This reported zinc content (see Table XXIX in Rao 1985:660) is a typographical misprint and most likely was a duplication of the figure in the adjacent column; otherwise the analyzed values would sum to well over 100 percent. In addition, 5 other artifacts from the site that were not published in the original Lothal report are designated as copper-zinc alloys. In examining a series of publications and having the ability to do a detailed comparison after all the publications were produced, it appears a series of typographic errors has caused a great deal of confusion among a number of researchers attempting to understand this important and complex data set. A 1996 publication (Chakrabarti and Lahiri 1996:58) provides a table of analysis from Lothal that combines both Lal's original 64 analyses with a further 9 analyses conducted at another time by other researchers (Nautiyal et al. 1981). Unfortunately, this table reproduces the typographical error regarding zinc from the original Lothal report as well as introducing a new error of reporting zinc measurements for 5 of the 9 later analyses. Comparing these data to the original publication (see Nautiyal et al. 1981:49) it can be demonstrated that the 1981 analyses did not report zinc content for any artifacts from Lothal, but the figures reproduced in the 1996 publication are, in fact, the results for the element Arsenic (As). The corrected figures for all

analyses from Lothal can be found in Appendix 2.4 of this volume. The artifact cited as containing zinc from Kalibangan, a spear containing 3.4% zinc, represents the results of the analyses as originally published (see Lal et al. 2003:266).

Recent analyses on a number of copper metal objects from the site of Navinal (Patel et al 2014) report seven artifacts containing zinc (see also Appendix 2.10). The measured zinc contents range from 0.32 to 3.95%. All of these amounts fall below the outlined 8% threshold for an intentionally produced copper-zinc alloy and may more accurately represent the result of the use of a high zinc containing ore as the raw material during smelting (as discussed in Pollard and Heron 1996 and Thornton 2007). There is another intriguing possibility beyond that of a happy smelting accident to explain the presence of zinc in the Navinal copper metal assemblage. The objects with a zinc content could be explained as preferential selection of potentially polymetallic copper-zinc raw materials that would have resulted in a specific final visual appearance of the finished object.

A comparative review of zinc containing copper artifacts from across Southwest Asia (Thornton 2007) documented the presence of a number of copper-zinc-tin alloys, or what can also be referred to as some variety of gunmetal (see Figure 2.2). From the perspective of ancient metallurgical technology, copper alloyed with zinc and tin is not an obvious product, as the presence of tin significantly reduces the uptake of zinc (Craddock 1980; Thornton 2007). However, a consideration of the potential reason(s) that ancient metalworkers would have selected certain alloys points to a non-technological explanation. Aside from the commonly discussed properties such as hardness and ability to hold an edge, tin also imparts a golden hue to copper. Zinc does the same thing at around 8 or more percent (Thornton 2007:131). It is possible that Indus metalsmiths at sites like Navinal were recycling a variety of copper alloys based on

visual appearance. Adding support to this interpretation is that a gold wrapped copper bead has also been recovered from the site (Patel et al 2014:558); imparting more weight to the hypothesis that a golden color was the purposeful end goal of Indus craftspeople in certain situations. Such a hypothesis can also be seen within the analyzed compositional assemblage at Harappa (see Chapter 4 and 6 for discussion) where items of personal ornamentation and display are manufactured from a far more restricted set of alloys than utilitarian objects. Regardless of the motivations behind the alloys being selected and used to make the objects from Navinal, a small technical correction does need to be offered. The seven objects that contain zinc from the site do not contain enough zinc to be considered intentional brass alloys.

Recent research on copper-based metal objects from the sites of Kuntasi and Farmana have identified four or five objects that contain zinc in high enough percentages to be considered true brasses (Park and Shinde 2014). The text indicates five objects were identified as being copper-zinc alloys, but only four are reported in the data tables (Parke and Shinde 2014:130). All four are from the site of Farmana and contain between 16.5-23% zinc. This is well above the established intentionality threshold of 8% and represents brass by any definition. All of the brass objects identified at the site are also artifact types that would have been displayed as personal ornamentation (such as bangles and rings) or one artifact that is likely an unfinished bangle. This serves as an additional support for the hypothesis that the Indus use of zinc was driven by a desire to achieve a specific color hue in the finished product.

While it is possible to derive some reasons and explanations for the presence of copper-zinc alloys in metal artifact assemblages from sites such as Navinal, Kalibangan, and Farmana, the production of proper brass artifacts and not simply polymetallic gunmetal alloys or potentially accidental alloys from smelting, presents a challenge to the understanding of third

millennium metallurgy in South Asia. The production of brass would represent a significant metallurgical and technological development for the 3rd millennium BCE. Unfortunately, there are several problems with arguing for brass production during this time period. It would be unprecedented and to date the necessary associated technology for the concentration and alloying of metallic zinc has yet to be found. While this does not preclude the possibility that Indus metalsmiths were producing high zinc copper alloys during the 3rd millennium BCE, it is a hypothesis that will require significant additional research to properly understand – a sentiment the primary investigators appear to echo (Park and Shinde 2014). Additionally, there is no zinc in the analyzed samples from Harappa at any level indicative of intentional alloying as a result this element was not included in the identified alloy types (see Chapter 4).

With the above definitions and evaluation parameters for identifying and classifying copper and copper alloys in published Indus Tradition artifact assemblages it is possible to begin to link previous research trends to fresh interpretative questions and perspectives. This is a crucial initial step to creating an explanatory model for copper/bronze metallurgy at Harappa that integrates as many components of the Indus metallurgical tradition as possible within a data-driven framework.

Copper was abundant at Indus sites and was commonly used to create a range of materials from domestic utilitarian goods to items of display and ornamentation.

In summarizing and assessing the research done to date on this topic, one caveat must be introduced. For the purposes of this review, it is necessary to first examine all metal remains reported, both copper and bronze, collectively and then deal with bronze separately (see below). This is because many of the available published catalogs of copper/bronze materials from Indus sites are incomplete. They either do not report all of the artifacts recovered during excavations,

report on the composition of only a few, fail to report much beyond the presence or absence of copper/bronze objects, or some combination of all of these. Additionally, any bronze objects are an alloy of copper and should be included in an assessment of the use and abundance of copper as well as bronze.

To date, there are well published descriptions of copper/bronze metal artifacts from six Indus sites (Figure 2.1) (Mohenjo-Daro, Harappa, Chanhu-Daro, Lothal, Surkotada, and Kalibangan) and materials reported but not well published from a number of other sites (see Agrawal 2000 and Chakrabarti and Lahiri 1996). A comparison of the physical descriptions of these artifacts as well as an examination of the published visual representations (Chakrabarti and Lahiri 1996; Kenoyer and Miller 1999; Agrawal 2000; Hoffman and Miller 2014) demonstrates that the copper/bronze assemblages from these sites are numerous and share a high number of common forms and artifact types.

Recently the results of new analytical investigations of Indus copper/bronze objects from a number of sites (see Patel et al 2014; Shinde and Willis 2014; Srinivasan in Bisht 2015; Nath 2015; Park and Shinde 2014; Bisht et al 2015) have been published. These publications offer more than basic descriptions of artifacts and present a series of results from both compositional and isotopic analyses. A brief summary and discussion of each is necessary in order to articulate this emerging data with not only existing datasets on Indus copper/bronze (see above) but also the empirical data developed during the course of the present study.

Mohenjo-Daro

Mackay was responsible for the description of the copper/bronze objects recovered from Mohenjo-Daro in both Marshall's (1931:488-508) report and his own report (1938:441-494). Additionally, Sana Ullah and others contributed chemical analyses and technical remarks to both

volumes (Marshall 1931:481-488; Mackay 1938:479-494, 599-600). For all intents and purposes, it is the work conducted by Mackay in categorizing and describing the type of objects found at Mohenjo-Daro as well as offering hypotheses regarding the nature of the manufacture, use, and distribution of Indus copper metallurgy that forms the basis for all later understanding and interpretations of this craft industry.

In the two reports on Mohenjo-Daro, Mackay defines and provides typological specimens for approximately 27 different major categories and several sub-categories (see Table 2.1) of copper/bronze objects (Marshall 1931:488-508; Mackay 1938:441-494). In all 440 copper and bronze objects are described in detail. This is most likely only a small fraction of the numerous artifacts recovered from the site between 1922 and 1931 during the large-scale Archeological Survey of India (ASI) excavations. Mackay repeatedly stresses that the materials described are only representative examples of each type or sub-type and it can be reasonably assumed that numerous examples were uncovered.

Table 2.1: Object Categories

Tools and Weapons	Personal Ornaments	Vessels
•Axes •Spear & Lance heads •Arrows •Knives & Daggers •Swords •Razors •Sickle -shaped blades •Saws •Chisels •Awls & Reamers •Drills •Nedles •Fish hooks •Hooks •Spatula •Bolt •Scale pan & beam •Plumb-bob	•Mirrors •Ornaments •Beads •Bracelets •Earrings •Finger rings •Buttons	•Variety of forms that mimic ceramic •Frying pans with tubular handle

after Mackay 1938 and Marshall 1931

Overall the data provided in the two initial site reports from Mohenjo-Daro make it clear that copper/bronze was used to fashion a wide range of objects, both utilitarian and status items. Additionally, copper/bronze materials were recovered from all levels, proposed time periods, and spatial areas of the site. Taken together, the data from the Marshall and Mackay reports securely demonstrates that copper/bronze was utilized frequently to fashion a wide variety of objects. The types and sub-types that were outlined by Mackay between the two reports have also served as the baseline for all other published catalogs. The majority of subsequently published reports focused their descriptions of copper/bronze artifacts on whether or not they are similar or different to types encountered at Mohenjo-Daro.

Harappa

The discussion of copper/bronze artifacts found in the initial report on Harappa (Vats 1940) is in many ways an extension of what was done by Mackay at Mohenjo-Daro. Vats' report on the copper/bronze artifacts from Harappa is brief and mainly concerned with providing descriptions of representative samples of the types and sub-types outlined (see Vats 1940:383-391). In general, the types and sub-types enumerated for Harappa are either the same or broadly similar to the ones detailed by Mackay for Mohenjo-Daro (see Table 2.1). The discrepancies between the two sites in terms of copper/bronze artifact type distribution are not noteworthy enough to warrant detailed discussion. This is primarily because it is unclear if idiosyncratic types that appear at either site are the result of unique manufacture, differential curation and deposition, or a potential variety of other post-depositional factors that could have influenced recovery during any excavation program. It is also important to note that the 1938 Mohenjo-Daro report and the 1940 Harappa report were being compiled roughly simultaneously and Mackay and Vats both make reference to the fact that they have not yet reviewed all of the data from each other's sites. Overall, Vats made great use of the copper/bronze artifact types defined at Mohenjo-Daro by Mackay. An examination of the published material from the two sites indicates that there were broadly similar (Hoffman and Miller 2014) and the list from Mohenjo-Daro can be applied to Harappa with great utility.

While Vats comments that there are less copper/bronze artifacts uncovered than he expected (Vats 1940:383); he does go on to indicate that a "wide variety" of object types were fashioned from the material (Vats 1940:383). The best evidence provided for this is found in the detailed descriptions of the contents of the copper/bronze hoard found within Jar 277 (see Vats 1940:89-90 for detailed description). The contents of this jar contain an example of almost every

common copper/bronze object type. In addressing the presumed scarcity of metal items at Harappa, Vats (1940:383) notes that high salt content of the soils has heavily corroded much of the assemblage and hypothesizes that additional objects may have been destroyed post-deposition. Additionally, he indicates that there are numerous fragmentary or broken objects that have not been included in the published catalog. It can reasonably be assumed that if the three factors mentioned: incomplete publication of the entire excavated copper/bronze assemblage, no accounting for the post-depositional effects of high salinity soils, and no attempt to incorporate fragmentary or broken metal objects into the analysis; then the perception of the “scarcity” of copper/bronze at the site may not hold.

Again, the initial excavation report from Harappa indicates that a broad spectrum of artifacts was made from copper/bronze and that there was no shortage of metal at the site. This can be inferred with a fair amount of confidence by the proliferation of tools and weapons at the site that would have required a significant amount of metal for their production. This includes items such as axes, adzes, knives, and spears. While it remains possible that these items were continually manufactured and renewed through a program of recycling aimed at conserving metal material, this is unlikely (see this chapter for further discussion).

Chanhudaro

The excavation report from Chanhudaro, also written by Mackay (1943), makes reference to a “...large quantity of tools and implements...” from the site (Mackay 1943:174). The assemblage includes typical Indus copper/bronze items, such as axes, adzes, chisels, knives, razors, vessels, fishhooks, arrows, a variety of personal ornaments, etc. There are a few unique items, but this may, again, be a function of a variety of factors rather than a direct indication of a specific type of metal industry at Chanhudaro. In addition to the catalog published by Mackay

(1943) an additional group of artifacts (521 objects in possession of the Boston Museum of Fine Arts) was studied and summarized by Heidi J. Miller. Again, the types set out in Miller (1999) do not comprise a significant deviation from artifact types described from Mohenjo-Daro and Harappa. While it is possible that the frequency of types may shift between sites (see Hoffman and Miller 2014), the distribution of these types remains consistent between the published excavated sites.

Lothal

Approximately 1500 copper/bronze objects are reported as being excavated from the site; however only several hundred were able to be identified to a specific type due to corrosion and the (assumed) fragmentation of more than one thousand objects (Rao 1979:520). The exact numbers of both recovered specimens and those unable to be typed is not specifically reported. It is at most 500 artifacts and at least 130 (the number of illustrated artifacts in the report). The difference between the number of copper/bronze objects recovered and those that could be identified to type is incorrectly reported as "...1000..." in a synthetic review by Agrawal (2002:84).

Surkotada

The excavators for Surkotada report 129 copper/bronze objects plus a hoard of bangles and beads (Joshi 1990:266). The objects described conform to established Indus types and no significant deviation can be identified from the published examples.

Kalibangan

Although the excavators appear to indicate that there were a number of copper objects recovered from the site, only 19 were published in the site report and an additional 8 were published in other articles (Lal et al 2003 p. 22; p.266-65; Agrawal 1981). No images of any kind have been included with either of the available publications. However, the author was able to visit the site itself and the small museum display located there. The display contained an array of typical Indus copper types and was made up of several dozen objects. It is reasonable to conclude that the copper/bronze metal assemblage from Kalibangan was both numerous and is made up of a typical Indus diversity of forms and types.

Rakhigarhi

Although the extent and scope of the Indus city of Rakhigarhi has been well known since the ASI excavations conducted there a decade and a half ago; it is only recently that the results of these investigations have been brought forth in a site report (see Nath 2015). The site report offers a wealth of information on the physical and cultural geography of the site, but only briefly describes and illustrates a few categories of material culture recovered from Rakhigarhi. Unfortunately, the section on copper is far from complete at this time. The author, in a cover letter to the report, indicates that the ASI currently lacks the staff to handle the volume of material that were uncovered during excavations (See Nath 2015:2). As a result, the chapter on copper objects remains incomplete. There is one page of brief descriptive text outlining the parameters of the assemblage and another of two photographs of copper objects (Nath 2015:228-229). A tabulation table (counts of artifacts by categories) that is indicated in the text does not appear to have been finalized in time to be included in the report. Nath (2015:228) also indicates that chemical analyses are in process but have yet to be completed. While, this is admittedly not

a great deal of information to draw substantive conclusions from, it is possible to advance some broad interpretations regarding the copper bronze assemblage from Rakhigarhi.

The first is that the brief overview of the assemblage provided (Nath 2015:228) indicates a copper and bronze metal assemblage at Rakhigarhi that is similar in scope and number to all previously described Indus assemblages (see above). Additionally, the object categories that are provided, while certainly not an inclusive list, appear to align with the trends in artifact distributions seen at other Indus sites - essentially a large-scale break between tools and weapons and personal ornaments. At a more detailed level, tools and weapons are comprised of rods (see Chapter 3 this volume) and personal ornaments are dominated by bangles and ring forms.

At Rakhigarhi another trend that has also been reported at other large excavated Indus sites is the presence of a limited amount of copper in the Early Harappan levels and then an expansion of forms and proliferation of use during the (Mature) Harappan levels. This articulates well with existing models of Indus copper metallurgy development. Data from excavations across the Indus Tradition area have indicated that Early Harappan groups were already well versed in copper metallurgy and the origins of the technology are likely rooted in an earlier period, likely as far back as the fifth to fourth millennium BCE (Kenoyer and Miller 1999; Jarriage 1985). A hypothesis for the origins of what became the metallurgical traditions of the Indus Tradition being rooted in earlier Neolithic and Chalcolithic technological developments is further supported by the usage of lost wax copper casting at Mehrgarh during the 5th millennium BCE (Thoury et al 2016). A generalized trend of the expansion of the use and distribution of copper/bronze artifacts is seen during the transition from the Regionalization Era (Early Harappan) to the Integration Era (Harappan). This fits with current models of Indus cultural development as well. Regardless of the specific designation that is placed on Indus political

organization, it is clear that an expansion and intensification of both interaction networks and economic activity took place from the end of the Regionalization Era to the start of the Integration Era. That the copper/bronze assemblage from Rakhigarhi reflects this is not surprising.

A final manner in which the Rakhigarhi material aligns with general trends in copper metallurgy for the Indus Tradition is the approaches that are being utilized to study the assemblage. While none of these details were available for the submission of the final report, it is indicated that chemical analyses are in process, as well as a detailed categorization effort (Nath 2015:228). This puts the planned investigations of the Rakhigarhi assemblage in a similar position as most detailed studies of Indus copper/bronze assemblages. It seems the data will be focused on a combination of chemical data (most likely compositional) and detailed descriptions of forms. The presentation of the rest of the data from Rakhigarhi will comprise an important comparative line of evidence when attempting to model and reconstruct Indus copper metallurgical traditions. Additionally, the fresh excavations in 2015 by the team lead by Dr. V. Shinde from Deccan College are certain to provide important new artifacts and contexts for understanding the use and distribution of copper and bronze artifacts at Rakhigarhi.

Dholavira

A site report on the ASI excavations at Dholavira was also published in 2015 (Bisht 2015). This report is in a significantly more complete form than the Rakhigarhi report. It includes a breakdown of the categories used to classify the copper/bronze assemblage and presents the results of some initial compositional, metallographic, and isotopic analyses. Overall the report on the excavations at Dholavira allow for a number of conclusions regarding the distribution and character of the copper/bronze assemblage to be drawn.

The primary conclusion that can be drawn from the description and provided details of the copper/bronze materials from Dholavira, is that it is a large and diverse assemblage on par with those recorded from other large Indus urban centers - such as Mohenjo-Daro, Harappa, and Lothal. While specific numbers are not provided, the excavators do continually refer to types/classes of copper/bronze artifacts as “large number”, “many”, “abundant”, etc. Overall the assemblage is described as “very typical” and as having “parallels” with the other major published details of Indus copper/bronze artifacts (Bisht 2015:516). Based on the list of artifact classes identified (Bisht 2015:515-16), the associated photographs (Bisht 2015 516-5:24), and line drawings (Bisht 526-529) it can be reasonably argued that the copper/bronze materials uncovered during the excavations at Dholavira are almost identical in type and scope as those found at Harappa and Mohenjo-Daro. This is a crucial preliminary conclusion. It has long been assumed by Indus researchers that the material culture from Dholavira would have been broadly similar across multiple categories to what has been described for other major Indus sites, but this hypothesis remained unconfirmed. Based on the present report, it is now possible to confirm this hypothesis, albeit tentatively - as the full accounting of all the individual components of the copper/bronze assemblage at Dholavira is still forthcoming.

In addition to the broad descriptions of the overall assemblage, the results of some preliminary analyses conducted on objects from Dholavira are presented (Srinivasan 2015:803-814). The types of analyses and the inter-related nature of the analytical research program is an encouraging sign. The research team working on the Dholavira materials appears to have set an ambitious series of goals for understanding the nature of alloying practices at the site, source provenience, and the overall manufacturing technology employed at the site. Four analytical techniques have been employed to date; bulk chemical analysis, lead isotope analysis, micro-

structural analysis (metallography), and analysis by scanning electron microscope (SEM). While all of these techniques represent the appropriate analytical tools required to develop the empirical data necessary to understand the fundamental character of the copper metallurgy at Dholavira; their initial application is presented in a preliminary report that is quite incomplete and often confused in its presentation of critical data. However, it is still possible to derive some intriguing comparative information from this important series of preliminary findings. It is important to review how this new data does and does not articulate with previously published datasets and trends as well as the new data from Harappa developed during the current project.

Composition

The first part of the technical portion of the report that needs close examination is the combined data sets that are derived from the bulk chemical analysis and the related results from the micro-structural studies. Srinivasan (2015:806) reports the results of one “bulk chemical analysis for compositional analysis for major elements and trace elements.” Unfortunately, it is not made more explicit what specific technique or methodology was employed to produce the reported results. Based on the information provided in Table 1 (Srinivasan 2015:806) and an examination of the Atomic Mineral Directorate laboratories websites, it can be surmised that either Neutron Activation Analysis (NAA) or Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES - it should be noted that this is fundamentally the same technology as ICP-OES) were used. This would put the accuracy and precision of these results on par with the ICP-OES analyses from Harappa presented here (see Chapter 4), the results from the Physical Laboratory (see Nautiyal et al 1981) and the other recently published data from Dholavira (Bourgarit et al. 2005). The reported analysis was undertaken on a corroded copper object described as “copper waste” (Srinivasan 2015:806). Initially thought to be a slag of some

manner, the results of the analysis indicate an unalloyed copper with no other elements present in a significant way. In contrast to this unalloyed copper, the three reported micro-structural studies indicate three copper alloy objects. Two have 5 % or less of tin as an alloying element, while the third possess structures that indicate 12 % or more tin as an alloying element.

In summary, the report concludes that the preliminary results from Dholavira are part of an overall trend in Indus copper/bronze metallurgy of the predominant use of unleaded low tin bronze (Srinivasan 2015:804). This is a trend that was identified (see Srinivasan 2013) based on a re-examination of 140 previously published compositional results on copper/bronzes from a number of Indus sites (see Chakrabarti and Lahiri 1996:45-48). Unfortunately, this simply cannot be supported by the available evidence. The reason is that only using the 140-member dataset available from Chakrabarti and Lahiri's review vastly underestimates the corpus of compositional analyses available for re-examination. A detailed review of all primary source documents available in the published literature has identified 467 unique compositional analyses conducted on Indus copper/bronze artifacts in the past 90 years (see appendix 2.1-2.11 this volume). This is over 3 times the number employed by Srinivasan in the analysis that identified the non-leaded low tin bronze trend (Srinivasan 2014). In examining that dataset, only 105 alloyed artifacts containing tin (22.48% of total sample) can be identified. Of those, the majority do contain between 0 and less than 1% lead. While eight out of ten tin alloys across the previously analyzed assemblage contain "low lead" or no lead, a low lead tin bronze is not the dominant copper/bronze alloy pattern.

In examining all of the previous compositional analyses from a range of Indus sites (see Table 2.2 this chapter) it is clear that unalloyed copper is the predominant metal type identified across all the assemblages. Now, assuming that the previous review of the 140 samples was

focused on identifying the most frequent type of “bronze” or copper alloy employed across the Indus Tradition, then the designation of an unleaded low tin bronze being the most prevalent would appear to hold up under initial inspection. However, this needs to be tempered by an understanding of what the published corpus of compositional analyses on Indus copper/bronzes actually represents. As was reviewed previously, the published analyses from the earliest ASI excavations at Mohenjo-Daro and Harappa appear to represent only a small fraction of the total number of analyzed copper/bronze objects. For instance, at Mohenjo-Daro a total of 114 analyses are reported on copper and bronze objects (Marshall 1931; Mackay 1938) but a closer examination of two reports reveals that a further 440 objects were classified by raw material type, with 333 listed as copper and 97 listed as bronze. Even if the assumption that the 114 samples from Mohenjo-Daro not only comprise a representative sample for the site itself, but for Indus copper metallurgy overall (as 114 of the 140 analyses considered were from Mohenjo-Daro) is granted, then there still remains some obstacles to validating the hypothesis that the predominant metal type across the Indus was unleaded low tin bronze.

Primary amongst these is the emerging data from Dholavira itself. A team of researchers has included the initial results from their analyses on objects related to what they term “metallurgical activity” (Bourgarit et al 2005:27) and can easily be taken as comparable to the items classified as production debris in the present work (see Chapter 3). The analysis of these materials indicates “a surprising ubiquity of lead” (Bourgarit et al 2005:27). Specifically, the large-scale use of lead as a fluxing agent during either copper smelting or copper refinement (Bourgarit 2015:30). While the researchers have, at present, eliminated alloying as the explanation for the high amount of lead present in the metallurgical remains at Dholavira, it still indicates that lead was a common and widely used component of the copper metallurgical

tradition at Dholavira. Additionally, there is evidence from the recent analyses of tin alloying taking place on site (Bourgarit et al 2005:31). It remains to be demonstrated that there was not also alloying with lead. A final noteworthy item is that the analyses also found that “large amounts of arsenic is present in all samples” (Bourgarit et al 2005:32). Although the researchers argue that this is indicative of an arsenic rich parent ore, I would counter that the intentional alloying of copper and arsenic cannot be definitively excluded. Finally, a “bulk analysis” of a copper object included in the technical section of the report (Srinivasan 2015:806) is of a highly refined/purified copper. This indicates the possibility that unalloyed copper may have retained a high amount of usage at Dholavira.

Overall, the hypothesis that the Indus copper metallurgical tradition favored unleaded low tin bronze is a hypothesis not without merit. It certainly appears to be one of the more frequent alloy types. It should be noted that arsenical bronze (Cu-As) or some poly-alloy containing arsenic is the dominant alloy “type” if unalloyed copper is excluded. However, it is not possible, at present, to determine the proper context with which to view this phenomenon. For a variety of reasons, it remains unclear if the previous analyses are entirely representative. The more recent analyses that would help to clarify this, are still underway and remain to be published in their entirety. Caution is urged. It is clear that a low tin bronze that is lacking (or almost lacking) in lead is certainly one of the several alloys that were utilized by Indus copper metalsmith, but it is not altogether clear how this “final” alloy was arrived at. Issues pertaining to the recycling of bronze, site specific post-depositional alterations, the representativeness of individual sample sets, and the accuracy of previous analytical techniques remain to be worked through. Additionally, there is not enough data to currently advocate for a unitary model of Indus copper metallurgy. What can be achieved is the construction of models built on a foundation of

empirical data from specific sites and then to compare these across the Indus region in order to develop an overall picture of “typical” Indus copper metallurgy. It is entirely possible that there is no single “typical” model, but, rather, a variety of site or region-specific responses to local demand for copper/bronze and, as a result, the Indus possessed multiple overlapping copper metallurgical traditions.

Lead Isotope Analysis

The recent technical report on copper also includes the results of a single lead isotope analysis on a copper object (Srinivasan 2015: 804). For anyone interested in understanding ancient metal interaction and supply networks, this represents an incredible initial step forward. A robust dataset of lead isotope signatures from across the larger Indus region remains underdeveloped, in respect to both artifacts and ores. Any and all steps towards developing such a regional comparative database can be unquestionably taken as a welcome development. That being said, the interpretations of the lead isotope data proffered in the Dholavira report (Srinivasan 2015:804-805; 812) are preliminary and require further detailed publication to completely evaluate.

Typically, the results of lead (Pb) isotope analysis are presented in one of two ways; as either three unique ratios of Pb 204 or three unique ratios of Pb 206 (Gale and Stos-Gale 2000; Pollard and Bray 2014). In the Dholavira report, the results are presented as two ratios; Pb 208/207 and Pb 207/206. Although simple mathematical manipulation can provide a Pb 208/206 ratio, without the Pb 204 values a third ratio cannot be arrived at. Although it is not uncommon to omit reporting the Pb 204 values due to issues concerning instrumentation accuracy and precision (see Hoffman and Miller 2014; Law 2011; and Gale and Stos-Gale 2000), it is typically detailed why the Pb 204 data is not included. A closer look at the information provided in the

report (Srinivasan 2015:812) appears to indicate that the isotopic analysis was conducted on a multi-collector-inductively coupled plasma-mass spectrometer (MC-ICP-MS), an analytical instrument that is more than capable of accurately measuring Pb 204 (Gale and Stos-Gale 2000; Malainey 2011; Pernicka 2014). The absence of reporting the measured value for Pb 204 in the technical report must be the result of attempting to collate and analyze the large amount of data coming from the site. Hopefully, future publications will offer a clarification.

Taking the data that are reported (Srinivasan 2015:804; 812) it is possible to draw some initial conclusions and comparisons. However, there are differences between these initial conclusions based on a review of the literature, and the conclusions proffered in the Dholavira report (Srinivasan 2015:805). Srinivasan (2015:804-805) is correct that the construction of artifact-ore correlations is a difficult and often uncertain undertaking. This is complicated when dealing with the potential source areas for Indus copper, as there is a limited range of existing published isotopic analysis of ores to provide the necessary body of geological comparisons (Kenoyer and Miller 1999; Law 2011; Hoffman and Miller 2014). However, that does not mean that there are no appropriate comparisons available to researchers. The database of lead isotope analyses developed during Law's detailed survey of a variety of rock and mineral sources (see Law 2011) is an excellent starting point. However, confining the comparison set to only the galena samples is arguably not an ideal approach. A set of copper lead isotopes for artifacts from Harappa (albeit an extremely limited one) has been published (Hoffman and Miller 2014) as well as lead isotope data on copper minerals from the site (Law 2011). Finally, the beginnings of a regional comparative data set for lead isotopes on copper deposits has been produced (Law 2011; Hoffman and Miller 2014). In addition to the recent data provided on materials from Harappa, there are available lead isotope data points in the available published literature for a variety of

potential source areas for Indus copper. These include deposits in Rajasthan (Hegde and Ericsson 1985) and the very well documented deposits in Oman (Calvez and Lescuyer 1991; Prange 2001; Begemann et al 2010). What is lacking, are well defined data points for deposits in Baluchistan and Afghanistan.

Using all of these resources (see Chapter 6 this volume) two intriguing conclusions about the lead isotope data point from Dholavira can be reached. The most relevant conclusion is that the data point from Dholavira exhibits some overlap with a number of artifacts from Harappa (see Chapter 6 this volume for detailed comparisons). This is not to say that the two sites were completely dependent upon the same copper source for supply, but that there does appear to be some degree of overlap in the copper/bronze interaction networks between Dholavira and Harappa. The second is that the galena deposit of Amba Kela in Himachal Pradesh is both a poor comparative and an unlikely source region for Dholavira's copper supply. Data from copper deposits close to Amba Kela; Askot and Chargoan (see Law 2011:450-451 and Chapter 6 this volume) indicate that copper deposits in the Himalayan area plot well outside the isotopic signature of Indus copper minerals and artifacts from Harappa and, by extension, Dholavira as well. A third conclusion is that the nearest major source of copper to Dholavira, Ambaji, is not a match for the initial sample run from the site. The sample appears to be more similar to materials from Baluchistan or Oman. There is also the possibility that the artifact from Dholavira and its analogues from Harappa fall on a mixing line that is indicative of some degree of either source mixing, recycling of scrap copper/bronze, or both. As is well stated in the Dholavira report (Srinivasan 2015:805), only additional research into these complex issues will begin to discriminate between the multiple competing possibilities.

One final note is needed on the Dholavira report. The discussion of lead isotopes, techniques, and appropriate comparisons (Srinivasan 2015:804-805) is a valuable one but is not entirely accurate. It is correct, that Inductively Coupled Plasma- Mass Spectrometry (ICP-MS) is a less accurate (not necessarily less precise) form of analytical instrumentation for measuring lead isotopes than either TIMS or MC-ICP-MS. This is not always indicative of incomparable data points. Despite the differences in analytical instrumentation, the isotopic ratios for Pb 208, 207, 206 should all still be comparable. It is the measurement of Pb 204, the least abundant of the four isotopes of lead, that requires the increased accuracy of TIMS and MC-ICP-MS. Additionally the discussion of EDTA is somewhat inaccurate as well. EDTA is not a measurement technique, it is simply a method for “acquiring” lead ions from the target sample (Law 2011:398-400). The amounts of lead typically found in ancient galena and copper are far more than sufficient for lead isotope analysis. Therefore, EDTA is no more or less accurate than any other method of getting lead from the targeted samples into solution.

Farmana and Kuntasi

A series of SEM-EDS (scanning electron microscope-energy dispersive spectroscopy) compositional analyses on copper/bronze artifacts from the Indus sites of Farmana and Kuntasi has recently been completed (Park and Shinde 2014). In addition to the compositional analyses, some basic description and categorization of the copper/bronze assemblages from each site has been provided. Overall the description of the copper/bronze assemblage from each site appears to follow a similar morphological pattern to Harappa and other Indus sites. Typical forms are reported and depicted in the images and all objects can be accounted for in the category descriptions listed in Table 2.1 as well as the extended descriptions in Chapter 3 of this volume.

Between the two sites, Park and Shinde (2014:130-131) provide 56 additional compositional analyses. The significant part of this research is focused along two main lines. First is the significant presence of arsenic and tin as alloying elements (Park and Shinde 2014:130-131 and Appendix 2.11-2.11). Both sampled assemblages are dominated by bronzes, either arsenical, tin, or arsenic and tin mixtures. This fits with a trend seen in more recent compositional analyses of Indus sites (see below) that finds alloys of some type to be present in significantly higher ratios than the early ASI analyses from Mohenjo-Daro and Harappa. However, there is one way that recent data from both Farmana and Kuntasi do not align with expected patterns based on other analyzed Indus copper/bronze assemblages. There is almost no lead present in the artifacts analyzed to date. This is in stark contrast to recent compositional analyses from Dholavira, Harappa, and Kalibangan where leaded artifacts are common and has led the Dholavira analysts to hypothesize that lead was critical to Indus metallurgy as either an alloying element, a fluxing agent, or perhaps both (Bourgarit et al 2005). Further research will be needed to understand the significant difference in the presence/absence of lead between different Indus copper/bronze assemblages. It is possible it is a result of different ore sources, different smelting technologies, alloying traditions, recycling programs, an indicator of the presence of multiple distinct copper metallurgical traditions within the Indus sphere, or some combination of all of these factors. Only further compositional, elemental, experimental, and archaeological research will allow these possibilities to be discriminated between.

Other Indus Sites

Few other Indus sites provide publications with the necessary level of detail in order to assess the copper/bronze materials recovered separately. The site of Rangpur (Rao 1963) did produce some documentation, but the discussion of copper/bronze artifacts is not extensive. The

excavations at Rangpur uncovered typical Indus copper/bronze forms and seemed to have categorized them along lines analogous to Mackay. The excavators report the presence of the following types/forms: axe, knife, needle, pin; bangle, bead, finger-ring, and amulet (Rao 1963:149). Unfortunately, there were only 25 copper artifacts from the excavations and only 18 were identifiable to type. Twelve images have been published (Rao 1963:151). For this study, Rangpur is primarily included here due to the number of compositional analyses from the site, a total of 12 from the Harappan Phase occupation.

There are many other Harappan sites across the large geographic area encompassed by the Indus Tradition that have yielded copper/bronze artifacts during excavation, survey, or both. Unfortunately, too few of these are published in a comprehensive way (see Kenoyer and Miller 1999:110-11) for discussion and do not warrant individual attention here. It is only relevant to note that the finds reported (at least that this author is aware of) to date conform to the types/forms enumerated in the earliest excavations (see Chakrabarti and Lahiri 1996:61). The available data make it clear that the use of copper/bronze objects of typical Indus style was common and well distributed across the breadth of the Indus during the Integration Era (2600-1900 BCE). Additionally, it is clear that much work remains to be completed. Full publication of the copper and bronze catalogs from previously excavated sites as well as from recently excavated sites and the dissemination of the findings from ongoing excavation and survey projects around the Indus would be valuable. Further, targeted survey projects in Rajasthan and Cholistan to attempt to identify Integration era smelting, mining, processing, or other copper working sites is a major necessity. Particularly in the locations that Mughal (1982) reported large quantities of slag on the surface.

It is also relevant to note that the data from the HARP excavations at Harappa demonstrates that some amount of copper/bronze remains, often highly fragmentary, have been recovered from every trench at the site (see Chapter 3 for details). It can be inferred that from most excavated Indus sites that there were more copper remains than have been reported, as fragmentary finds and unidentifiable copper/bronze objects are typically not well reported in the available published materials (see the summaries for Harappa and Lothal above for examples). The data taken together demonstrate that a high number of copper/bronze artifacts have been recovered from most Indus sites. Further, it is clear that these artifacts share marked morphological similarities over the expanse of the Indus Tradition. The subsequent research undertaken on Indus sites has verified the validity of Marshall's claim that copper was abundant at Indus sites and was commonly used to fashion a variety of artifact types.

It is the seemingly ubiquitous distribution of copper and bronze material encountered during the HARP excavations that drives the first research question. An expected answer to the question of the nature of the distribution of the total copper and bronze at Harappa can be developed out of trends identified in previous research projects. It is anticipated that the copper and bronze metallurgy assemblage will be relatively even across the site and consistent throughout the cultural sequence. In order to assess this hypothesis a detailed review of the total copper and bronze metallurgical assemblage was undertaken (see Chapter 3 for details). This assessment involved considering material culture remains for all available stages of copper and bronze metallurgy from raw materials, to the remnants of metallurgical production, to the final finished artifacts themselves. Through categorization of artifacts and the application of the detailed spatial and temporal excavation contexts available at Harappa, a picture of the nature and distribution of the total copper and bronze assemblage was assembled. The regular

distribution of copper and bronze artifacts of all major categories in almost all excavation units and contexts across each of the major occupation areas at Harappa serves to support the hypothesis of even distribution. The consistent nature of the distributions of artifact categories across the city through each major cultural period also supports the expected outcome. If the distribution of specific artifact classes had been skewed or missing at certain areas of the site or during specific instances in the occupational sequence, this pattern would have necessitated a reformulation of the expectation of consistent and regular distribution for copper and bronze usage at Harappa during the Integration Era. In the absence of any such factor, at present, it appears that the nature of the copper and bronze assemblage at Harappa aligns with the trends seen in other Indus Tradition sites. There was a regular and consistent distribution of copper and bronze materials across all major sectors of the site and evidence for more than one manufacturing installation.

The use of bronze was restricted to objects that required the physical properties that the addition of tin provided.

Statements from the primary site reports (Vats 1940; Marshall 1931; Mackay 1938; Rao 1979, 1985) indicate that the impression left by the excavations of large urban Indus sites is that there was an appreciable quantity of bronze materials recovered. Marshall (1931:36) states that not only had copper and bronze replaced stone for the manufacture of weapons for both hunting and warfare but also that "...they had superseded stone for ordinary household implements and utensils." Sana Ullah (1931) remarks that bronze was used for its physical properties and is relatively common in the Mohenjo-Daro assemblage. Sana Ullah (1931:488) further observes that the amounts of tin seen in the analyzed objects "...leaves no doubt that the tin is not accidental but was added intentionally to produce an alloy suitable for cutting tools or other

purposes.” These and other statements make it clear that the majority of early and current researchers would describe major Indus cities as having easy access to copper metal items and would view bronze as material that Indus smiths were proficient in working.

It is important to note that the overall scarcity of tin and therefore the inability of Harappans to completely replace copper with bronze is remarked on more than once by Sana Ullah (in Mackay 1931 and Vats 1940). The “problem” of tin sources for South, Southwest, and Central Asia in the 3rd millennium BCE has been a subject of much scholarly debate for at least the last 90 years. It is constantly subject to revision and estimates of tin availability during this period are reformulated as potential new sources are reported (see Dayton 1971; Muhly and Wertime 1973; Crawford 1974; Pernicka et al. 1992; Yener and Vandiver 1993; Weeks 1999 to list only a few). The issue of how much tin was available and where it was found during the 3rd millennium is well beyond the scope of the present investigations. It is necessary to note here that a perception that there is a linear progression from the use of native copper to the smelting of first copper oxides and then copper sulfides to the use of copper alloys was pervasive at the time that the site reports from Mohenjo-Daro and Harappa were written. The use of unalloyed copper alongside tin bronze and other copper alloys, was taken in the early 20th century as indicating either that this process of replacement of copper by bronze was incomplete or the requisite raw materials (in this case, tin) were unavailable. Since the initial excavations of Indus cities documented the contemporaneous and proficient use of copper and tin bronze, the early excavators concluded that the supply of tin was restricted. This creates an implicit and foundational assumption that tin, and, by extension, bronze, was a scarce and rare commodity at Indus cities such as Harappa and Mohenjo-Daro. This type of thinking became ossified and the concept that tin and its alloys with copper was a rare and precious commodity at Indus sites

persists (see Agrawal 2000:72). However, examining both the previous data sets and the new data presented here, it becomes apparent that a new way of looking at the alloying practices and traditions of Indus metal smiths must be developed. It will be demonstrated that the twinned concept that a complete replacement of copper with bronze and that the failure to do so is an accurate proxy for the availability of tin within a given metallurgical system is an outmoded one and requires critical examination and reformulation. While it is clear that the available reports recognize the presence of a number of bronze artifacts, there remain reservations about the frequency of the use of the alloy due to the availability of tin raw materials.

However, what is not clear is what exactly is being classified as a bronze. Mackay in both the Marshall report (1931) and his own report (1938) on Mohenjo-Daro designates objects as either “copper” or “bronze” with little discussion of how these designations are being determined. Initially it was thought that these designations were linked to the chemical analyses reported in the same volumes. However, a careful review of the text and the tables from both reports revealed that this is not the case. There are 67 chemical analysis reported in the 1931 Mohenjo-Daro report and a further 47 analyses reported in the 1938 report on the same site. A review of the copper/bronze objects reported in detail from both reports by Mackay finds that of the 440 objects described, none are from the subset of objects submitted for chemical analyses. Of the 440 detailed artifacts, 333 are listed as “copper”, 97 are listed as “bronze”, 4 are listed as “copper or bronze”, 2 are listed as “copper and antimony”, no designation is given for 3, and 1 object is listed as made mainly of clay. Mackay (1938:58) indicates that objects listed in his 1938 catalog as “...bronze...have been definitely found to be so...” and that they contain an amount of tin beyond what can be reasonably projected as stemming from “...a natural impurity”. He further indicates that all the “important” metal objects have been analyzed (1938:58). Mackay in

the 1931 report on Mohenjo-Daro (Marshall 1931) makes no mention of how designations of “copper” or “bronze” were determined. It would further appear from a reading of the portions of both the 1931 and 1938 reports written by Sana Ullah, the archaeological chemist for the Archaeological Survey of India, that more objects were analyzed than are published in the compositional tables in each report. Further, the analyses conducted by Desch (Marshall 1931:486-487; Mackay 1938:480-483), were only on a small subset of materials. The clearest answer to how a determination of whether an object was a “bronze” or not is given in the 1938 report. Mackay states that the table of analyses provided is restricted to the “...full analyses...by Dr. Hamid” (1938:479) and that many other “partial” analyses were carried out by Hamid and Sana Ullah in order to “...ascertain the tin content of many other copper and bronze objects” (1938:479). It can reasonably be assumed that a dual program of full and partial analyses had been implemented at Mohenjo-Daro from the beginning and this explains the designations in the 1931 report as well. It is unfortunate that these partial, perhaps focused on only measuring tin, analyses are not published or included as an appendix. This would provide a valuable line of evidence on copper and tin alloying at Mohenjo-Daro specifically and serve as a comparative for the rest of the Indus.

A review of the Annual Reports of the Archaeological Survey of India from 1926 through 1935 (ASI 1926, 1927, 1928, 1929, 1930-34, 1935) demonstrates that copper/bronze objects from the large excavations at Harappa and Mohenjo-Daro were being sent to the office of the archaeological chemist for analysis and preservation. Summary reports issued for the Archaeological Chemist’s office indicate that more artifacts were analyzed than have been published, either in the annual reports or the individual site reports. In fact, four additional analyses from Harappa, four modified analyses from Harappa, and two analyses from Mohenjo-

Daro that were not included in the site reports were found. Although it is important to note that Prakash and Rawat (1965) have previously recorded these analyses in a review volume.

In the Vats (1940) report on Harappa there are 195 objects detailed and nine are listed as “bronze” and six are listed as “copper” with the rest receiving no mention of material type other than occasional remarks on the level of corrosion. It is entirely possible that the level of corrosion at the site precluded many of the recovered copper/bronze objects from being subjected to chemical analysis; something Vats appears to indicate (Vats 1940:383). Neither Vats nor Sana Ullah makes it clear how these determinations were made, but it is assumed that there were unpublished either full or partial analyses of many of the metal finds from the site. Sana Ullah remarks that the 16 complete analyses that were included in the report represent “typical” compositions from the site (1940:378) (Note: as with the Mohenjo-Daro reports, these 16 analyses are not the same as the reported “bronze” or “copper” designations found in the accompanying text catalog). Again, it is unfortunate that more details on how these determinations were made and the results of the (presumed) additional analyses were not included in the site report. Aside from providing clarification, it would constitute another line of evidence for alloying patterns.

In contrast, the Lothal report is much more explicit regarding how materials were analyzed and what distinctions were drawn from the results (Lal 1985). In total either 63 or 64 objects were analyzed (one object is a duplicate and it is unclear how to resolve the issue) and were classed as bronzes based on their tin content (Lal 1985; Kenoyer and Miller 1999). In the text catalog, no material designation is provided, thus eliminating some of the confusion and uncertainty found in the earlier reports. The report on the copper/bronze materials from Rangpur (Rao 1963) is organized along similar lines. Each report bases its distinctions on bronze versus

copper on published compositional analysis. This is not surprising as the same excavator (Rao) and analyst (Lal) are responsible the copper/bronze studies at both sites.

The critical point is that there appears to be no consistent methodology or classification system applied to the evaluation and categorization of copper-based alloys from Indus sites. Without such a framework it is difficult to evaluate statements and interpretations about abundance and scarcity, even at a relativistic level. In order to make meaningful comparative assessments it is necessary to both identify the potential copper alloys that could be in a given assemblage and to develop baseline criteria for their identification. Important work along these lines has been conducted by Agrawal (1971, 1981, 1995) and Nautiyal (1981) on a selected number of copper/bronze artifacts from all of the sites listed above, except for Dholavira and Rangpur. These analyses did report the analytical method used.

Evaluation of Previous Compositional Analyses

As discussed above, the majority of detailed reports and interpretations on copper/bronze assemblages from the Indus argue that bronze was in limited supply at any given Indus site. While they often remark on the fact that tin bronze is a common component of an overall copper metal assemblage, significant reservations are expressed regarding the overall amount of tin available for use both within individual Indus sites and across the range of Indus occupation as a whole.

Table 2.2: Alloy Frequency by Type in Analyzed Assemblage

Alloy Type	Number	% of Analyzed Assemblage
Lead (Pb)	30	6.42
Arsenic (As)	80	17.13
Tin (Sn)	69	14.78
Mixed	46	9.85
Unalloyed Copper	242	51.82

Despite commentary in the original site reports, a detailed review of the previously analyzed assemblage reveals a relatively high amount of use of alloyed copper (see Table 2.2). From the analyzed assemblage of 467 objects from 11 sites, just under half (225 or 48.18%) are comprised of intentional copper alloys of one type or another (see Appendix 2.1 for details). At first glance, it does not seem that an analyzed assemblage comprised of less than fifty percent alloyed copper would be a strong argument for overturning the entrenched concept that Indus sites were lacking in bronze materials. However, the results may potentially be skewed as a result of the methodological and research design limitations of some of the earliest ASI analytical programs conducted at Harappa and Mohenjo-Daro.

Examining the analyzed copper/bronze assemblage for all the Indus sites in the database (Appendix 2.1-2.11) more closely, a trend emerges. In sites that have been analyzed with more modern methodologies, the proportion of alloyed copper in the assemblage greatly increases (See Table 2.3). This presents a far different picture than the earlier reports from Mohenjo-Daro where only 28.97 percent of the (reported) analyzed assemblage of 145 copper/bronze objects was comprised of alloyed copper. Nautiyal (1981) reports an additional seven artifacts from Mohenjo-Daro; three of which are tin bronzes. It is therefore possible that the same trend seen at

other Indus sites of lower reporting of alloys in the overall copper/bronze assemblage is occurring at Mohenjo-Daro.

Table 2.3: Alloy Frequencies for Selected Sites

Site	Analyzed Total	% Copper Alloys	Estimated Analysis Date
Harappa	33	78.79	1981 and 1999
Surkotada	42	73.81	1981
Kalibangan	27	81.48	1981 and 2003
Kuntasi	25	84.00	2014
Farmana	31	54.84	2014

The trend of under-reporting the frequency of copper alloys in an assemblage from a site is related to two factors. The first being that the analytical programs of the 1920's and 30's were not able to measure with the accuracy and precision of more modern techniques and are therefore under-reporting the frequency of copper alloy usage in the analyzed assemblage. It should be noted that in some cases the accuracy of older analyses of compositional patterns in copper metal objects from archaeological sites has been substantiated by recent re-analysis (Bray and Pollard 2012). This type of research has yet to be conducted on any of the Indus materials. Even if the assumption that all previous analyses of Indus copper/bronze artifacts were accurate was to be granted, then there is still another reason why early reports from Harappa and Mohenjo-Daro in particular can be expected to have under-reported the frequency of copper alloy use at the site. Many of the results reported for Mohenjo-Daro did not include analyses for lead and arsenic. The lack of information for arsenic and lead may be leading to the misclassification of some items as non-alloyed copper simply because they are not tin bronzes, when in fact the possibility that they

are arsenical or leaded bronzes has not been considered. Overall, the focus of much of the analytical program at Mohenjo-Daro appears to be directed towards identifying tin and nickel contents. This was to accomplish the twin goals of the identification of tin bronzes and the sourcing of the copper raw material(s).

A review of the analyses of copper/bronze artifacts indicates that a complex alloying pattern can be identified at sites across the Indus. An expansion of the definition of bronze beyond solely those objects alloyed with high amounts of tin introduces a greater frequency of bronze into the overall picture. The frequency of alloy usage, often rising far above 50 percent of an analyzed assemblage, substantiates the argument that Indus sites were using a considerable amount of bronze. While alloy usage at Indus sites was not typically dominated by tin, thus leaving open the possibility that tin supplies were unpredictable, the use of other elements to produce copper alloys (bronzes) results in metal assemblages that are comprised of a considerable amount of bronze material.

The attempt to determine if the trends in alloying practices evident in other analyzed Indus Tradition copper and bronze assemblages can be extended to the materials recovered during the HARP excavations is central to evaluating the second major project research question. The analysis of the HARP sample assemblage will allow for the direct empirical identification and evaluation of alloying patterns at Harappa. Based on the results exhibited by the evaluation of previous compositional analyses on Indus copper/bronze assemblages, it is anticipated that the analyzed materials from Harappa will document a pattern of broad copper alloy usage with little specific patterning by artifact category. A pattern of a high frequency of copper alloy usage would fit with the precedent set by previous compositional research at other Indus sites. Some of these have identified the use of a high percentage of alloyed copper (see Figure 2.3).

Examinations of the compositional results (Chapter 4) indicate that this pattern is extended at Harappa. Understanding the alloying patterns in a given copper/bronze assemblage is a critical step in constructing a realistic interpretation of the nature of copper and bronze metallurgy at a particular site. The patterns seen in alloy usage can provide detailed insight into the nature of object use and metallurgical production.

If an analyzed assemblage were to exhibit a consistent low frequency of alloy usage across all artifact classes, this could be the result of several intriguing reasons. The first could be that unalloyed copper was preferred for an unidentified reason related to cultural preferences. Alternatively, it could be a signal that crucial alloying elements, such as tin, were scarce or had their access heavily restricted. A pattern of alloy usage for only specific artifact classes would be also be indicative of a series of potential explanations. Scarce alloying materials could be being restricted for use only in objects that absolutely required their presence, tin bronze saws for instance. Another possibility relates to issues of cultural preference, in this case color or status. An examination of the potential functional uses of the restricted set of alloyed objects would serve to discriminate between these different potential explanations. Alloying patterns could also be identified that would not be related to a narrowly confined usage of alloys. Primarily, there could be no consistent patterning of alloy type by artifact classification, function, or appearance. This scenario would most likely be the result of an alloy production sequence focused on the unrestricted recycling of scrap copper and bronze to fashion new objects. This would lead to the use a variety of multi-element alloy types as the use of reclaimed metal for a significant portion of supply would lead to unpredictability in final alloy make-up. It must be acknowledged that at a complex urban site, such as Harappa, it is possible that all of these diverse alloying practices could be evident. However, the results of previous research provide some solid foundation for

creating expected results. The available data, when analyzed from updated benchmarks for alloy identification, demonstrates that the HARP assemblage should contain a high percentage of copper alloys, the use of these alloys should be present in all artifact classes, and multi-element alloys that indicate recycling should be present as well.

While Indus metal workers had a high degree of skill and familiarity in working with copper and bronze, they did not produce either high numbers or types of weapons in the materials.

When Marshall (1931:35) spoke of weapons in the Indus Tradition, rather more pointedly, the lack of true weaponry and armor, he, perhaps unintentionally, set the stage for almost all future models of the Indus polity. This often-repeated description of Indus weapons as “primitive” (Marshall 1931:35) has entrenched an assumption of lack of weapons in the copper/bronze assemblages from Indus sites. As detailed in Cork (2005) this assumption has been echoed and commented upon by numerous researchers over the past eight decades. Essentially since the publication of the original site report from Mohenjo-Daro, it has been understood that Harappans fashioned few, if any, weapons of war out of copper and bronze. Unfortunately, the absence of significant weaponry at Indus sites has remained a relatively unchallenged assertion. The idea that Indus sites lacked weapons of warfare has had far reaching implications for the modeling of the social and political organization of the Indus Tradition. While Marshall provided commentary on the simplicity of copper/bronze weaponry, it is Mackay who provides the foundation for all later assumptions when he states, “...judging from the small number of weapons of offence and defence, the people of Mohenjo-Daro appear neither to have been a warlike people nor have feared invasion” (Marshall 1931: 282). It is this quote that is the

root of the generalized “peaceful Harappans” (Cork 1995) that has been pervasive in the literature throughout much of the research on the Indus.

A detailed examination of the copper/bronze assemblages from large Indus sites, such as Mohenjo-Daro and Harappa, demonstrates that many of the statements regarding the lack of weaponry at Indus sites do not hold up under empirical evaluation. Cork (2005) outlines many of these arguments and offers up comparative data between the Indus and a variety of contexts from the Near East that demonstrates that the perception of either inadequacy or absence of potential weapon forms in the Indus Tradition is erroneous. In fact, many of the common copper/bronze forms found at Indus sites could be considered either tools or weapons. As is detailed in Cork (2005:418-19) tool/weapon forms (after Chapman 1995) actually are more frequent in Indus copper/bronze assemblages than they are in comparable Near Eastern examples (Cork 2005:419 Figure 6). Further augmenting this discrepancy is the fact that a number of items from the “tool/weapon” and “weapon” categories come from burial contexts at many of the Near Eastern assemblages selected for comparison (Cork 2005:416). Burials are an intentional and choice driven archaeological assemblage often meant to communicate specific and perhaps exaggerated aspects of the individual being interred as well as being reflective of only a small segment of the overall population at a given site. Given the primacy of the iconography of warfare and linkages between status and warfare in Near Eastern 3rd millennium BCE cultures, it is highly likely that the inclusion of objects recovered primarily from burial contexts would serve to skew the frequency of weapons and tool/weapon objects upwards (see discussion in Cork 2005). In summary, it is possible that the differences between Indus and Mesopotamian assemblages that appeared so stark to early Indus excavators, such as Marshall and Mackay, may be primarily driven by the nature of the contexts excavated between the two cultural areas. Early Indus

excavations were dominated by residential contexts, while Mesopotamian excavations were focused on elite contexts such as palaces and temples. Given both Marshall's and Mackay's training and familiarity with Bronze Age materials and sites from Egypt and the Near East it is not surprising that they would have made unfavorable initial comparisons between the copper/bronze assemblages between the two regions. While the statements regarding the copper/bronze assemblages from Mohenjo-Daro and Harappa are sensible in the context of archaeological interpretative models and explanatory theories of the 1920's and 1930's, it is not useful to continue to accept these interpretations without any critical examination or reformulation in light of new data and shifting interpretative models.

Since the statements by Marshall, similar sentiments have been echoed by others (Agrawal 1971; Rao 1979, 1985; Chakrabarti and Lahiri 1996; Agrawal 2000). The hypothesis that Indus sites lacked quality weapons is typically advanced based on two lines of evidence. The first is that there is a relative lack of weapons in the excavated assemblages; essentially a quantitative argument. That line of evidence has been refuted above in summary and in detail by Cork (2005). The second line of evidence used is a qualitative one; that both the obvious weapons and any potential weapons in a given Indus copper/bronze assemblage are technologically inferior. This line of evidence is more difficult to refute since it relies on multiple inferences for its foundation.

The first of these inferences is that very few (if any) objects from the published corpus of Indus copper/bronze artifacts would have been strong enough to function as offensive or defensive weapons. This is based on increasingly outdated notions of the necessity of a reinforcing midrib along the axis of the blade. Mackay notes that some Indus blade tools or weapons have a medial thickening that would have served to add strength (1938). Further it is

possible to strengthen a blade through the haft itself. If the haft material were run along the length of the blade longitudinally, this would serve a similar function as a reinforcing midrib of metal. This is an argument that has been made by others previously (Cork 2005) but is often overlooked in discussions of Indus copper/bronze weaponry. A second inference is that the available copper/bronze artifacts found in Indus assemblages lack convincing weapon forms. Again, this can be demonstrated to be an assumption (Cork 2005) and not a convincing supporting argument for the inference that Indus copper/bronze assemblages were lacking in weapons. Following the concept of classifying things as “tool/weapons” (Cork 2005) or even “blade tools” or “tools” (Kenoyer and Miller 1999; Hoffman and Miller 2014) it is possible to read an Indus metal assemblage as possessing a high frequency of large, edged forms. Finally, the lack of socketed axes has been used to denigrate the metallurgical capabilities of the Indus copper/bronze industry. However, there are examples of socketed axes from Harappa, Surkotada, and Mohenjo-Daro. While there are not many, it is important to remember that if recycling of metal was as critical to the Indus system of copper/bronze use and production as has been previously argued, then socketed axes would have been ideal for such a supply system. This artifact type would have represented a large mass of metal that would have served metal-smiths well as a recycled raw material. Further, Cork (2005) convincingly demonstrates that the lack of socketed axes has little interpretative bearing on the category of “tools and weapons”.

When the available evidence is viewed from updated perspectives and interpretative lenses, it becomes clear that concepts of the lack of copper/bronze weapons at Indus sites are outmoded at least and likely completely incorrect. It must be noted that the overturning of this concept by no means is meant to imply that violence or coercive force needs to be reinserted into existing models of Indus political and social structures. It simply needs to be remembered that

despite the lack of overt images of violence and warfare, the technology of Indus metallurgy and the products of its metal craft workers includes forms that potentially could have been effectively used as weapons. This is an important point for a variety of reasons. The most relevant to the present research project is that the a priori expectations regarding weaponry that early investigators brought to their study of Indus cities highlights that there are no one set of explanations for artifact categories and alloying patterns that can be universally applied. Each copper and bronze assemblage requires evaluation within its own cultural context and through an interpretive lens suitable to the inferences that can be made about cultural preferences from analogous craft industries. There are a variety of culturally specific reasons that Indus weapons may not conform to expectations from other contemporary societies. This serves to highlight the issues previously discussed about alloy patterns. Specifically, that only the linkage of alloying patterns identified through compositional analysis to cultural patterns and styles seen in previous research can create useful explanatory models. However, the study of alloying patterns alone cannot adequately discriminate between all possibilities that could result from a suite of compositional analyses. It is necessary to consider the impact of copper supply sources as well.

The presence of certain key elements in Indus Tradition copper/bronze artifacts indicates that the primary source areas for Indus copper are either in Rajasthan or Baluchistan.

Beginning with the analyses carried out by Desch (in Marshall 1931) and Sana Ullah (in Marshall 1931; Mackay 1938; Vats 1940) at Mohenjo-Daro and Harappa, research into copper metallurgy in the Indus Tradition has been concerned with identifying source provenience areas of copper raw materials. Previous research on Harappan Phase metals was defined by available methods and interpretative trends. The early chemical characterization studies of copper/bronze artifacts focused on the analysis of elemental compositions as both a method for identifying

alloying practices and for constructing artifact-ore correlations (see Desch in Marhsall 1931 and Mackay 1938; Sana Ullah in Vats 1940). This approach has continued in more recent studies (Lal 1985) using the assumption that nickel and arsenic are reliable variables for defining regional ore sources. Such a methodology is now regarded as too simplistic for establishing definitive ore provenience designations, but for much of the last 100 years this approach was considered the most appropriate empirically driven methodology to identifying artifact-ore correlations (Pernicka 1999; Hauptmann 2007:27). A detailed review of the issues involved in source provenience research for ancient copper artifacts is outside the scope of the present work and excellent summary discussions exist in the literature (see Pernicka 1999; Gale 2000; Hauptmann 2007 for examples). For the present study, it is only necessary to examine the explanatory utility of a few key elements. This is related to both the geology of potential source regions for Indus copper raw material and the results of previous analytical studies conducted on Indus copper and bronze artifacts.

The history of research into the composition of different Indus copper assemblages provides a foundation for understanding the prevailing hypotheses and models for Indus copper ore source areas. Initial research programs set up by the Archaeological Survey of India (ASI) at Mohenjo-Daro and later extended to Harappa appear to have focused on the classification of objects as tin bronzes, copper-arsenic alloys, or copper. In addition, several other minor elements were targeted, including nickel (Ni), lead (Pb), and antimony (Sb). It is important to note that in the early ASI analyses it is often difficult to determine if a given element was not present in the sample or simply not tested for (Kenoyer and Miller 1999). However, even working only with the published numbers (see Appendix 2.1-2.11 for a complete list organized by site of all previous compositional analyses) it is clear that Tin, Lead, Nickel, Arsenic, and to a lesser extent

Antimony and Iron were the main discriminatory elements selected by the ASI analysts.

Conclusions drawn from the available data by ASI researchers further narrowed the list of elements that were important for source provenience hypotheses down to three - nickel, arsenic, and lead.

Sana Ullah (Marshall 1931:438) states that the Mohenjo-Daro copper could have come from Baluchistan, Afghanistan, or Rajasthan. This is based on the presence of lead, nickel, and arsenic in the copper/bronze artifacts and the presence of these elements in these potential copper source areas. By 1940 and the publication of the Vats' volume on the excavations at Harappa, Sana Ullah is able to clarify and extend his hypotheses on the source regions of Indus copper. He argues that due to the amounts of nickel and arsenic typically present in Indus copper/bronze artifacts that the mines in Rajasthan would have "supplied the bulk of the metal for the Indus Valley" (Vats 1940:379). Such a straightforward position has been taken in much of the subsequent research on the source(s) for Indus copper raw material. Rajasthan and the copper deposits of the Aravalli range specifically have emerged as the popular choice for sourcing Indus copper (Agrawal 1971; Agrawal 1984; Agrawal 2000; Agrawala 1984). However, positing only the mining areas in Rajasthan or even extending this to include the related ore bodies in Oman (Rao 1979, 1985) is an oversimplification of a complex problem.

Kenoyer and Miller (1999:114-118) provide a clear and concise overview of the potential source areas for copper during the time-span of the Indus. They identify three major potential copper source regions that surround the Indus. The copper deposits throughout the Aravalli Range; along the interior mountain ranges of Oman; and through the combined mountainous region of Baluchistan and Afghanistan (Kenoyer and Miller 1999; and see Figure 2.1 this chapter) are all discussed as potential source areas for Indus copper raw materials. The eastern

portions of Iran must also be mentioned as a more distant, but possible source of Indus copper raw materials (Miller 1999; Sana Ullah 1940). All of these areas demonstrate linkages with the Indus Tradition (Kenoyer and Miller 1999:112) and in particular the site of Harappa itself (Law 2011). Expanding discussions of potential Indus copper source areas beyond the geographically convenient distinctions drawn by earlier researchers using the presence or absence of arsenic as a primary discriminator. In addition to the likelihood that sources areas would have shifted during the span of the Indus Tradition it is possible that current ore geologies are not entirely accurate proxies for ancient ones (Kenoyer and Miller 1999). Arsenic bearing sulfide ore veins may have been mined out prior to research on Indus copper provenience.

A note of caution must be extended regarding using a selected array of accessory minerals to attempt to link Indus copper/bronze artifacts with their parent ore sources. For the Indus in particular, arsenic and its linkages to Rajasthan has been a major area of focus. However, recent research has demonstrated that while arsenic is a marker of both provenience and technology (Pernicka 1999); recycling of copper/bronze objects can markedly affect the arsenic content of object (Bray and Pollard 2012). If Indus copper/bronze artifacts were being recycled to a measurable extent (Kenoyer and Miller 1999; Miller 1999; Agrawal 2000) then it is possible that this mode of production from the re-melting of scrap materials would have a great impact on the arsenic content. This could serve to obscure or alter the perceived linkages to geologic source areas in critical manner. Previous researchers have noted the lack of arsenic from Indus sites in Gujarat, primarily Lothal (Rao 1979, 1985). While there are no analyses of copper/bronze objects that document the presence of arsenic in materials from Lothal, there are arsenic and copper alloys from Dholavira, Surkotada, and Rangpur – all of which are in Gujarat (see Appendix 2.1-2.11). Clearly the situation is complex for not only the Indus Tradition as a

whole, but for any individual site. There must have been shifts in the networks used to acquire copper raw materials, as well as finished goods, and the possibility of the existence of multiple contemporaneous overlapping networks must be allowed for.

Finally, the present study will demonstrate that the exclusive reliance on element fingerprinting to establish source provenience designations for copper is no longer the appropriate methodology. The accessory elements found in copper ores and in finished copper/bronze artifacts can be of utility in assisting in establishing correlations between artifacts and source areas (Ixer 1999; Pernicka 1999; Hauptmann 2007). However, they cannot perform this task alone and must be paired with isotopic analysis (Gale 2000; Weeks 2003; Hauptmann 2007; Pernicka 2014; Pollard and Bray 2014). The results of this study will demonstrate that it is necessary to expand the possible sources of Indus copper beyond those in Rajasthan and Baluchistan to include the more varied possibilities discussed in Kenoyer and Miller (1999) and Law (2011).

The development of a comprehensive lead isotope research program for copper/bronze artifacts from Harappa will allow for research questions related to source provenience and copper supply distribution to be addressed from an updated perspective. Transitioning models of Indus Tradition copper sources from a focus on elemental fingerprinting to one centered on lead isotope signatures will align the HARP dataset and the comparative geological database with current trends in not only recent Indus research projects but with global archaeometallurgical research. Previous research on other mineral and stone resources has established a generalized pattern of resource area utilization for Harappa (Law 2011). This pattern was summarized in the preceding chapter. Overall, the available data indicates that during the pre-urban Ravi (Period 1) and Kot Diji (Period 2) Phases, Harappa was sourcing its stone and minerals from locations and

regions primarily to the north and west of the site. Then during the succeeding Harappan Phase (Periods 3A-3C), supply networks began to integrate sources to the south and east of the site while retaining previously established networks (see Figure 1.5). This research establishes a baseline expectation to test the copper and bronze lead isotope data against. The key components of this assessment are split across project research questions three and four. Determining the nature of the answer to each question in sequence will allow for the potential results to be differentiated between.

In addition to the research on non-copper minerals and other stone, Law (2011) conducted an initial lead isotope analysis of copper minerals from Harappa (see Law 2011; Hoffman and Miller 2014; and Chapter 5 this volume for discussion). This initial pilot study substantiated the hypothesis that copper supply networks at Harappa would broadly function along the same lines as established for other materials; with a focus on sources to the north and west of the site. This research project represents an expansion of that preliminary effort. Both the amount and type of samples from Harappa has been greatly expanded. Additionally, the comparative geological database has been significantly increased (see Chapters 5 and 6 for details). This has allowed the central hypothesis that copper supply would follow the patterns identified in other materials to be evaluated in a robust manner. If copper and bronze artifacts from the HARP excavations were to correspond primarily to sources in Waziristan and Baluchistan with a lesser degree coming from the Aravalli Range, then the hypothesis that copper supply was repeating the patterns seen in other minerals would be substantiated. However, if the pattern of copper source exploitation at Harappa exhibited a differing series of source area usage, then a revised interpretation would need to be formulated. As detailed in Chapter 6, the data indicates that the initial expectation that copper supply would be focused on

sources to the north and west of Harappa is not supported by the new lead isotope dataset.

Overall, the patterns present in the data demonstrate components of both the traditional ideas regarding Indus Tradition copper supply and the trends seen in recent preliminary research from Harappa. The integration of existing ideas regarding the importance of copper deposits in the Aravalli Range along with the simultaneous exploitation of sources to the north and west of the site provides a new integrated model for copper supply from Harappa that can be tested at other Indus Tradition sites as the number of lead isotope analyses on archaeological artifacts continues to expand through the efforts of number of research teams.

The remaining research question regarding the nature of access to individual copper sources across the mounded occupation areas at Harappa can be evaluated once an identification of individual lead isotope source correlations has been undertaken. Previous research on a variety of Indus Tradition craft industries has demonstrated the potent explanatory utility of assessing whether or not the raw materials or finished products exhibit a pattern of restricted access (Kenoyer 1998; Miller 1999; Vidale 2000; Law 2011, Jamison 2017). In order to adequately determine if access to specific copper and bronze raw materials was restricted it is necessary to evaluate the spatial distribution of each source location identified in the HARP copper/bronze assemblage. If a specific source is apparent in a limited range of occupational mounds at the site, then the likely explanation would be that some factor, in this case elite control, is preventing all areas from having equivalent access to copper raw materials. This would be indicative of a competition regarding copper sources that are not present in the established patterns for other mineral resources. Alternatively, if copper sources are relatively even distributed across the site, then each area of Harappa would have had unrestricted access to copper raw materials. This would align with patterns of resource distribution previously established at the site. A similar

determination can be made for finished artifacts. If all artifact categories are made from a variety of copper sources, then the pattern of unfettered access to copper raw materials would be extended to production. If specific artifact classes are produced from specific raw materials but all sources were present on each mound, then the interpretation would be that ancient Indus coppersmiths were restricting the usage of certain raw materials for specific artifacts. This would present an intriguing line of analysis for issues related to cultural choice and status hierarchies within the copper and bronze assemblage at Harappa. Linking the patterns seen in the lead isotope analyses back to existing interpretive trends and emerging research at Harappa and other Indus sites will strengthen the utility of the overall model for copper//bronze metallurgy at Harappa.

Copper hoards with a variety of object and alloy types cached were encountered during the excavations at Harappa, Mohenjo-Daro, and Chanhudaro.

At the excavations of the above three Indus sites, an appreciable amount of copper/bronze material was derived from items intentionally cached in concentrations, essentially hoards of copper and bronze metal objects. Eight hoards are specifically highlighted in the two major Mohenjo-Daro reports (Marshall 1931; Mackay 1938), four hoards at Chanhudaro (Macaky 1943); and two hoards from Harappa (Vats 1940). Each of these hoards shares some important similarities. The first is that they were all carefully arranged and deposited caches of metal material. In most cases they were almost exclusively comprised of copper/bronze objects, although in some other artifacts of personal ornamentation made from a variety of raw materials (gold, silver, minerals, faience, etc.) have been found hoarded with copper/bronze objects. Second, each hoard was recovered from contexts associated with residential structures. Typically, hoards have been found underneath floor layers of house structures or in the adjacent

courtyards along walls or doorways. A final similarity is that, in general, large objects dominate each hoard of copper/bronze.

These similarities allow a series of preliminary conclusions to be drawn. The first is that copper/bronze objects of even the most utilitarian nature, such as axes, adzes, and chisels, carried a value designation beyond their mechanical purpose. While the use of copper/bronze tools to perform mundane utilitarian tasks and fashion other items across the spectrum of Indus craft industries would have certainly ensured that a certain amount of value be placed on the possession of these tools; the preponderance of copper/bronze tools in hoards is indicative of their having value beyond function. It appears that attempts were made to hoard a significant amount of metal therefore privileging more massive artifact types. Copper/bronze hoards at Indus sites are focused on the amount of metal in the cache rather than the value of the objects. Items of personal ornamentation and other decorative artifact forms, while not entirely absent, are very few in copper/bronze hoard contexts. This diversion of relatively large amounts of metal from a dynamic use context to a static hoard context and the deposition of the hoards near or within probable residential structures points towards a pattern of the caching of valuable materials with the implicit intent of future recovery/reuse. This practice of wealth caching to weather short-term emergencies is a consistent behavior across many early societies. It is not surprising that excavations at Indus sites, in particular large urban centers, would encounter caches of hoarded valuables. Particularly from the later period(s) of the site, prior to either abandonment or a significant reorganization of site occupation, as is the case with the hoards at Mohenjo-Daro and Harappa.

A second preliminary conclusion regarding hoards relates to their articulation with the manufacture of copper/bronze objects in the Indus Tradition. Currently the understanding of the

precise details of Indus copper/bronze manufacturing is poor (see this chapter for discussion). However, it has consistently been hypothesized that the recycling of scrap, broken, or whole copper/bronze objects would have formed a critical aspect of the Indus copper metallurgical industry (Mackay 1938; Kenoyer and Miller 1999; Miller 1999; Agrawal 2000; Hoffman and Miller 2014). This is because present evidence suggests that Indus sites were entirely dependent on the importation of copper raw materials such as ingots and potentially finished copper/bronze goods as well. This would make localized manufacture of copper/bronze objects highly sensitive to disruptions of supply. Sites situated along the alluvial plains of the river systems that comprised the center of the urbanized Indus would be especially sensitive to such disruptions of supply as they are far from any mineral source(s) (See Law 2011 for description at Harappa). As a result, it has been postulated that the recycling of metal mass was an important component of the manufacturing system at Indus sites, particularly larger sites such as Harappa and Mohenjo-Daro. The presence of hoards and the fact that they are typically made up of massive objects has been used to buttress this hypothesized reconstruction of Indus copper supply networks.

The fact that the documented hoards contain a mix of copper and bronze materials has led to the concept that the Indus tin bronze industry was dependent on recycled bronzes of varying contents for raw material. Mackay (1943) and others have argued that the varying tin contents, relatively scarce (as argued elsewhere in this chapter, the term scarce may be viewed as problematic) bronze remains, and the absence of the archaeological remnants of large scale production at any Indus site can be taken in concert (along with hoards) to indicate that Indus metal smiths would have had an inconsistent and highly varying supply. Additionally, the primary source of tin for bronzes would have been in the form of the scrapping and melting of existing bronzes. Much of this model has held for the past eight decades of research on the Indus

Tradition. It is based largely on the preliminary hypotheses and inferences of the earliest investigators and has remained largely, with a few exceptions (see Miller 1999), critically unexamined.

The current work takes the position that while aspects of this model of bronze and copper supply – that has in part been constructed to explain hoards of metal at three sites – are still of a high degree of explanatory utility, other portions are outdated and reliant upon improper assumptions. It is relevant to note that copper hoards from Indus sites represent large removals of metal from the overall system and were likely intended as way of conserving value or raw material during short term disruptions to normal economic, social, and political patterns. Unfortunately, the majority of the recovered hoards from Indus sites are from highly equivocal stratigraphic contexts and this makes providing a chronological designation highly problematic. However, the Jar 272 hoard from Harappa (Vats 1940) has a contextual association with some carved steatite seals. A comparative stylistic and iconographic analysis of these seals to other seals from more secure archaeological contexts at Harappa allows them to be placed within the overall chronology of the site (Kenoyer 2009; Jamison 2017). It is probable that the Jar 272 hoard dates to Period 3C of the Harappan Phase (see Chapter 1 of this volume for details of site chronology) or later – as the 3C style seals could have been curated and deposited later. Such a chronological designation would make sense. It places the deposition of the unrecovered hoard during a period of social and economic disruption at the site. As interaction networks, political, and economic structures appear to be undergoing dramatic shifts beginning with the latter portions of period 3C of the Harappan Phase and extending into the Late Harappan Phase (Kenoyer 1998, 2014), it would be entirely consistent with other historical and cultural

comparisons that this would have been a time where wealth and other valuable items would have been cached in hoards.

Indus cities were sites of secondary copper manufacture and lacked any substantial evidence for the primary smelting and refining of copper raw material.

The issue of where Indus copper production, from the processing of ore into ingots, to the crafting of finished copper/bronze objects, took place has been a topic of considerable discussion and debate since the earliest site reports. Recent synthetic reviews have covered the subject in detail (Kenoyer and Miller 1999; Chakrabarti and Lahiri 1996; Agrawal 2000; Bhan 2002; Hoffman and Miller 2014). Primary excavation reports have provided what data is available along with preliminary inferences (Marshall 1931; Mackay 1938; Vats 1940; Rao 1979). The most complete review of all available evidence and relevant analyses can be found in Miller (1999). It is relevant to review some of the most important conclusions from this detailed and exhaustive study.

The most important issue is that the evidence to date indicates that Indus cities were centers of secondary copper production. The evidence is indicative of a production sequence centered on the melting of existing ingots or the re-melting of finished objects to fashion new copper/bronze items rather than the smelting of ore (Miller 1994, 1999). In fact, it appears that Indus settlements were engaged in interaction networks to acquire copper (Kenoyer and Miller 1999; Miller 1999; Hoffman and Miller 2014). Miller's work demonstrates that Indus cities were engaging in copper production just not smelting. This stands in contrast to earlier discussions of copper furnaces and smelting operations. Further, no known Indus sites have been located in areas with evidence for smelting operations such as the Aravalli Range.

This influential interpretation regarding the nature of copper/bronze working at Indus sites stands as the best explanatory model of the available evidence. However, this study will present some intriguing new evidence from the site Harappa that may serve to document large furnace-based smelting of copper minerals on Mound AB. The presence of large smelting slag at an urban Indus site provides the analytical basis for reformulating and adding complexity to the traditional interpretation that Indus sites did not engage in the smelting of copper ores. The addition to smelting activities at an Indus urban site extends the pattern of copper source area utilization beyond the melting and casting of objects from semi-processed raw materials and into a production sequence that would include the processing of copper ore as well. This has significant implications for the interpretation of the project lead isotope data. With evidence for the smelting of copper minerals at the site, it is possible to further understand the issue of the recycling of scrap copper and bronze. Through a combination of alloying patterns (with multi-element alloys being a potential indicator of copper/bronze recycling) and refining the isotopic fingerprints for source regions, it will be possible to make fresh interpretations regarding the role that hoarding, and recycling played in copper/bronze metallurgy at Harappa.

Summary

Previous interpretative trends regarding Indus copper/bronze metallurgy provide an excellent starting point for attempting to understand the nature of metallurgy at a site like Harappa. However, it is clear that a number of traditionally accepted hypotheses need to be critically examined and modified or entirely reformulated in light of existing evidence and new interpretative frameworks for the understanding of ancient metallurgy. The most important aspect of this reworking is to discard many of the previous definitions for alloys in Indus

metallurgy as inappropriate. Along with an updated framework for alloying practices, it is necessary to introduce significant modifications to existing delineations between accessory elements as they relate to copper technology or copper provenience. These two topics are closely allied as the lowering of threshold margins of composition to determine alloys has an associated impact on the accessory minerals to copper that can be seen as related to provenience. This is of particular relevance for the element arsenic. As discussed by previous researchers (see Kenoyer and Miller 1999:116-18 for review) the presence or absence of arsenic has been applied by a number of previous studies to determine artifact-ore correlations.

Previously held definitions of bronze and its distribution at Indus sites needs modification and revision. These modifications serve to augment and extend our existing understandings of the copper/bronze metallurgical tradition of the Indus Tradition. This study will build on these previously identified interpretive trends to construct a model for copper/bronze metallurgy, particular the usage of alloys and the number of raw material sources employed, based on fresh analytical evidence from the site of Harappa. As previously discussed, the long history of excavation at Harappa combined with the detailed stratigraphic and chronological information produced during the HARP excavations make the site an ideal place to investigate Indus copper/bronze metallurgy. The first step in that process is to detail the distribution of the overall copper and bronze assemblage recovered during the HARP excavations. A review of the contexts and distribution of artifacts is the beginning of creating linkages between the previous research conducted on copper and bronze across the Indus Tradition and the fresh perspectives applied in the current study.

Chapter 3: The Copper/Bronze Assemblage from Harappa: Definitions and Distribution

Introduction

During the course of the Harappa Archaeological Research Project excavations at Harappa (1986-present) 2581 copper artifacts have been recovered from both excavation and surface contexts. These objects were initially sorted into the 15 major categories as shown in Table 3.1.

Table 3.1: HARP Copper and Bronze Artifact Categories and Totals

Sheets/Blades - 296	Rods/Wires/Pins - 440	Arrows - 83
Discs - 14	Rings - 85	Bangles - 65
Beads - 115	Mirrors - 2	Tablets - 10
Coins - 24	Unidentified & Miscellaneous Fragments - 1209	Modern/Historic Metal - 2
Prills - 47	Slag & Mineral - 100	Copper Crucible & Kiln Fragments - 83

This categorization scheme was developed by Kenoyer (Kenoyer and Miller 1999; HARP Reports 1986-2011) and provides an excellent way to expediently classify and record copper/bronze objects as they are received from the field. The system employed by the HARP team combines specific object categories based on morphology and function (beads, bangles, mirrors, scale pans, arrows, discs, rings, and tablets) with more generalized categories based on morphology (sheets/blades, rods/wires/pins, as well as a catch-all category for objects that lack any specific diagnostic features (miscellaneous) and a category for artifacts that do not date to the Indus occupation of the site (historic – such as coins). Finally, the current categorization scheme contains three categories that deal with the production/manufacture of copper/bronze objects: prills, mineral/ore, copper kiln fragments, and slag. It should be noted that while the

term “prill” is often used to refer to pieces of metallic copper that result from spilling and overflow during smelting and crucible-based production; the term is being more loosely applied here. The HARP copper/bronze collection classifies any smooth small round object as a “prill”. In many instances, the creation of this object during one of the stages of copper or bronze production remains to be confirmed. The application of this categorization system to the recovered copper/bronze objects produces the totals shown in Table 3.1.

Constructing A Classification System

An analysis of 2581 objects from the HARP excavations from all of the existing 15 categories demonstrated that it would be possible to refine and organize the existing groupings into a more detailed system. The goal was to create a flexible and adaptable categorization scheme that could be used both in the field and in the study of existing archival collections. Such a framework should allow for comparison of copper and bronze materials within a given Indus Tradition site and between sites. Much of the current system is based on the previous work conduct on Indus copper and bronze materials from a variety of sites (Kenoyer and Miller 1999; Miller 1999; Yule 1985a, 1985b), but it has been applied solely to the assemblage from Harappa in the present study.

In order to categorize and compare the individual items of the HARP copper/bronze assemblage, it was necessary to filter the objects through a system of categories and sub-categories based on macroscopic morphological attributes. The system implemented in this study is not intended to be a formal typology. Often a typology is based on a set of regimented forms, the precisely detailed metric attributes of those forms, and specific definitions of all encountered sub-types and variants. Of a critical concern is the completeness and thoroughness of the attribute list used to generate the type descriptions that form the basis for the typology under

consideration (Binford 1963). The system of categorization applied to the copper/bronze materials from Harappa does not function in this manner. Rather, it is utilized as a flexible system that can be manipulated in different ways in order to articulate with any changes in the analytical goals. In acknowledgement of the fact that the system outlined here does not adhere to the established parameters of typology building, it will be referred to as a categorization system and primarily used as an organizational construct.

The copper and bronze assemblage from Harappa is a complex data set that requires being sorted from multiple vectors in order to adequately address all relevant project research questions. Depending upon the research questions under consideration, the underlying attribute list will need to shift. The primary goal of categorizing and organizing the assemblage is to identify and quantify the kinds of artifacts recovered. This is of particular relevance in the Indus sphere since copper as a raw material has been employed to fashion objects in a multitude of forms and that cross-cut almost all aspects of life at and urban center such as Harappa (Hoffman and Miller 2014). To accomplish that goal a system based on 5 major initial categories was used. A number of increasingly restricted sub-categories were devised, and each object was classified through this system until there were no longer enough observable attributes to justify a more specific categorization. This system is an extension of that developed for the HARP project (see above) and has been applied, in a slightly modified form (see Hoffman and Miller 2014), to copper and bronze materials from a range of previously excavated Indus sites. The benefits of the system are that it allows for the rapid classification of artifacts as they are uncovered from excavation and it does not require complete objects in order to make categorical designations. Essentially, the attributes used to construct the present system are broad and held to a minimum in order to provide for the highest proportion of assemblage members to be categorized.

As discussed previously (Hoffman and Miller 2014; see Chapter 2), other categorization systems and typological frameworks have focused primarily on characteristics that can be best identified from complete objects; such as hafting technique and projected function. Additionally, the copper and bronze metal remains from Harappa are often highly corroded, as is common for copper remains. It can be argued that the issue of corrosion is more pervasive at Harappa than average (see Chapter 4), however, regardless of the level of post-depositional degradation present the corrosion of copper-based metal artifacts can be assumed to significantly obscure many details of the original artifact surface (Hodges 1988). This poses a significant challenge to the development of a strict typology that can account for the highest majority of artifacts, including those modified by corrosion or recovered in a highly fragmented condition. Overall, it was decided that a categorization system that relied primarily on readily identifiable attributes like cross-section shape, thickness, presence/absence of a working edge, or the presence of a perforation would be the best type of classification determinants in order to account for and organize the highest percentage of the HARP copper and bronze assemblage. It should be noted that while the present system was heavily influenced by the study of published complete objects from other Indus Tradition sites (Marshall 1931; Mackay 1938; Rao 1979, 1985; Joshi 1990; H. Miller 1999; Lal et al. 2003) and archival information regarding whole copper and copper alloy artifacts from Harappa (Vats 1940; HARP Project Records 1986-2011); the categories outlined here were devised to account for fragmentary and degraded objects that form the majority of the HARP study collection. It is entirely possible, that additional attributes will need to be considered in order to adopt this scheme to other the copper and bronze assemblages from other Indus sites. However, it is hoped that the flexibility offered in the present system will allow for this possibility.

Previous to the current study, artifacts were not formally catalogued into any further refined sub-categories. One of the goals of this project was to determine if valid sub-categories could be identified and defined for any (or all) of the major categories. The creation and refinement of additional categories for the copper and bronze assemblage from Harappa was based on a combination of morphology and limited metric analysis. The preliminary components of this process were discussed in Hoffman and Miller (2014) but need to be reviewed and extended here.

The publication of the results of the initial excavations at Mohenjo-Daro created some vital broad “types” (see Marshall 1931; Mackay 1938). These types were based on visual observations and limited measurements from complete objects encountered during the excavation program. The immediately succeeding excavations (Vats 1940; Mackay 1943) used these types, as did the majority of subsequent excavations at Indus sites (Rao 1979, 1985; Joshi 1990; Lal et al. 2003). It is worthwhile to note that while the typological categories developed, largely by Mackay, outline some broad metric data, they were based primarily on macroscopic morphological characteristics and proposed functions of forms found at Mohenjo-Daro. An examination of the original site reports appears to indicate that assumptions and inferences were made about the use of individual forms and subsequently accepted without further critical investigation. Subsequent excavations largely applied the categorization scheme and simply added new types as the need arose (see Chapter 2 this volume for further discussion). The result of this type of ad-hoc categorization is that the typology of Indus copper/bronze artifacts remains largely unrevised since the earliest archaeological study of the materials.

This is not to argue that there has been no work done towards creating a refined or more detailed typology or categorization system for the copper/bronze artifacts from Indus Tradition

sites. In particular the work of both Paul Yule (1985a, 1985b) and Heidi J. Miller (H. Miller 2000) have attempted to address this gap and provide an updated typological scheme for Indus copper/bronze materials. Yule's work provides a detailed classification system for vessels (1985a) and personal ornaments (1985b) but the study of tools and other forms remains uncompleted. Miller's system, developed from a study of representative materials excavated at Chanhudaro, offers a fuller range of specific typological categories. However, it does not address the categorization and study of incomplete objects (see Hoffman and Miller 2014:252 for additional discussion). This poses two major analytical problems when attempting to adapt the typology developed for Chanhudaro to other Indus sites. The first is that the majority of copper/bronze artifacts uncovered by modern excavations are fragmentary as a result of breakage due to a variety of pre- and post-depositional processes. As a result, many of the objects available for study from Indus sites, like Harappa, lack the diagnostic elements used to define types in the Chanhudaro system. The second drawback is that the Chanhudaro system does not clearly outline how to account for artifacts styles or additional types not present in the assemblage that was studied. The combination of these factors makes the typology difficult to apply to a fragmentary assemblage from another site, despite any obvious and ready similarities between the assemblages. As a result, it was determined that a modified scheme was required for the present study.

Previous typologies of Indus copper and bronze artifacts focused on the specific mundane function of the finished object as defined by a series of formal attributes. This interpretive trend was first applied to material from Mohenjo-daro by Mackay (Marshall 1931; Mackay 1938) and has been extended by subsequent research programs (See Chapter 2 this volume for details). More recent constructions of typologies or categorization systems for copper/bronze objects

from a variety of Indus sites (Yule 1985a, 1985b; H. Miller 2000) have focused on the end use of the object as it can be inferred from macroscopic morphological features. All of these systems have been effective in describing the nature of the excavated corpus of Indus copper and bronze materials. However, these systems have done little to aid in the understanding of how copper and bronze objects functioned in the larger social and economic setting of Indus society as a whole.

While previous research has made significant inroads in defining the various types and sub-types of objects fashioned by Indus copper metal-smiths, little progress has been made in adding to our shared understanding of how the material functioned within Indus society. This research project will apply a categorization scheme that incorporates much of the previous efforts but begins the process of developing a system that is more flexible and adaptable while identifying observable difference in object function such as between tools and personal ornaments.

Proposed Categorization System for the HARP Copper/Bronze Assemblage

The revision to the existing HARP copper/bronze classification system that is proposed here is based off of categories first proposed by the HARP team during tabulation and recording of finds from excavations (Kenoyer and Meadow 1993; Kenoyer and Meadow 1996) and later expanded to discuss copper and bronze metal finds from the Indus Tradition as a whole (Kenoyer and Miller 1999). The goal of the proposed categorization system is to develop a flexible system of classifying artifacts that relate to Indus copper metallurgy while at the same time, being as clear and systematic with category definitions as possible. This achieves two end goals. The first is to begin to clarify and systematize the multitude of different and/or overlapping terminology used in the discussion of Indus copper/bronze metal objects. The second is to allow for some

adaptability within and between the categories in order to move beyond simply counting and describing artifacts and types. Through the development and application of a nested set of categories, it is possible to move up and down the ladder of categories in order to adapt the system to research questions while at the same time incorporating the realities of the highly fragmented and degraded nature of many Indus copper/bronze assemblages.

The categorization system is based on the identification and division of the overall HARP copper/bronze assemblage into five major categories. These categories are based on readily observable macroscopic traits that can be easily and confidently visually identified. Three of the categories are based off of making broad classificatory distinctions on the nature of the basic cast object. As discussed in Miller (1999) and based on work detailed in the early excavation report from Harappa (Sana Ullah 1940; Wraight 1940) and later work conducted by other researchers on materials from the HARP copper/bronze assemblage (MASCA unpublished), the majority of copper/bronze objects at Harappa were cast and then subsequently shaped into their final forms. The first division is based on the distinction between the two major categories of basic cast forms found in Indus metal assemblages, rods, wires, and pins and sheets (Miller 1999:235). Rods, wires, and pins range in size and cross section shape, but are easily distinguished visually, even in fragmentary and/or corroded form, from sheets. The next major categorical division is a grouping of clearly cast objects that are not specifically and readily classifiable as either rods or sheets. The final two major categories are manufacturing debris, which are comprised of mainly non-copper or bronze metal artifact forms that are related to the production and processing of copper or bronze, and miscellaneous objects. Miscellaneous objects are those members of the HARP copper/bronze assemblage that lack sufficient diagnostic attributes to be assigned to

another one of the major categories. Further attributes and diagnostic features for each major category and its sub-categories are detailed below.

Rods, Wires, and Pins

The category of rods, wires, and pins is one of the larger categories of artifacts found in the HARP copper/bronze assemblage. Members of this category range in cross section from rectilinear to round. It is most likely that all members of this larger category and its constituent sub-categories were made by casting and then some type of additionally forging to shape the metal into its desired final form (Miller 1999). The currently identifiable mold types and experimentally reproduced casting and mold techniques would have all been ideal for producing either copper sheets (discussed below) or rectilinear to round “bars” that could have then been further worked into the variety of forms seen in this category (Kenoyer and Miller 1999; Miller 1999; Miller 2005). The larger category can be divided into two main sub-categories: rod tools and decorative objects.

Previous researchers have grouped rods into broad functional categories based almost exclusively on overall visual morphology (Mackay 1931, 1938). These shapes were then used as the basis for projections of the objects’ intended use. In the broadest, sense the current study follows a similar outline. However, I have chosen to collapse the individual categories included by previous researchers into only two categories: rod and point tools. This is to attempt to control for the highly fragmentary nature of the HARP assemblage. This is by no means an attempt to refute any of the categories of rod tools that have been previously documented at Harappa and other Indus sites. It is simply an acknowledgement that a large proportion of the studied HARP assemblage is not assignable to the same detailed level as previously documented copper/bronze assemblages. In an attempt to avoid problems of equifinality in category and/or sub-category

designations, this project has chosen a broader set of operational definitions and categorical designations. By applying less restrictive definitions and category parameters, I have been able to classify more of the HARP material. Rod tools are simply those objects that are rectilinear in cross section and have wedge shaped working ends. These are typically comprised of a variety of chisels forms (H. Miller 2000:315; Mackay 1931,1938). In contrast, point tools are also formed from rods, but are smaller, have a variety of cross sections, and a variety of working ends. At present this sub-category is comprised of morphologically similar objects that may have been used for a range of purposes and tasks.

The other major sub-category in this overall grouping is that of rods, wires, and pins that are used to fashion decorative objects. These can be divided into three main sub-categories: pins, rings, and solid bangles. While the initial excavation reports from Mohenjo-Daro, Harappa, and several other Indus Tradition sites report the existence of decorative pins, I have not included these artifacts in the present analysis. Of the materials uncovered during the HARP excavations, there is only one definitive decorative pin documented. As a result, I have excluded decorative pins as an analytical category, but I do, however, include them in the overall categorization system, as they are an artifact category that may be better identified during future studies. In fact, it is entirely possible that some of the more fragmentary members of the rod assemblage included in the study may in fact be broken sections from a copper or bronze decorative pin. This is impossible to discern without the diagnostic terminal section. Such decorative pins almost certainly would have been primarily fashioned from a thin copper rod but would have had additional elements added to them in order to complete the object.

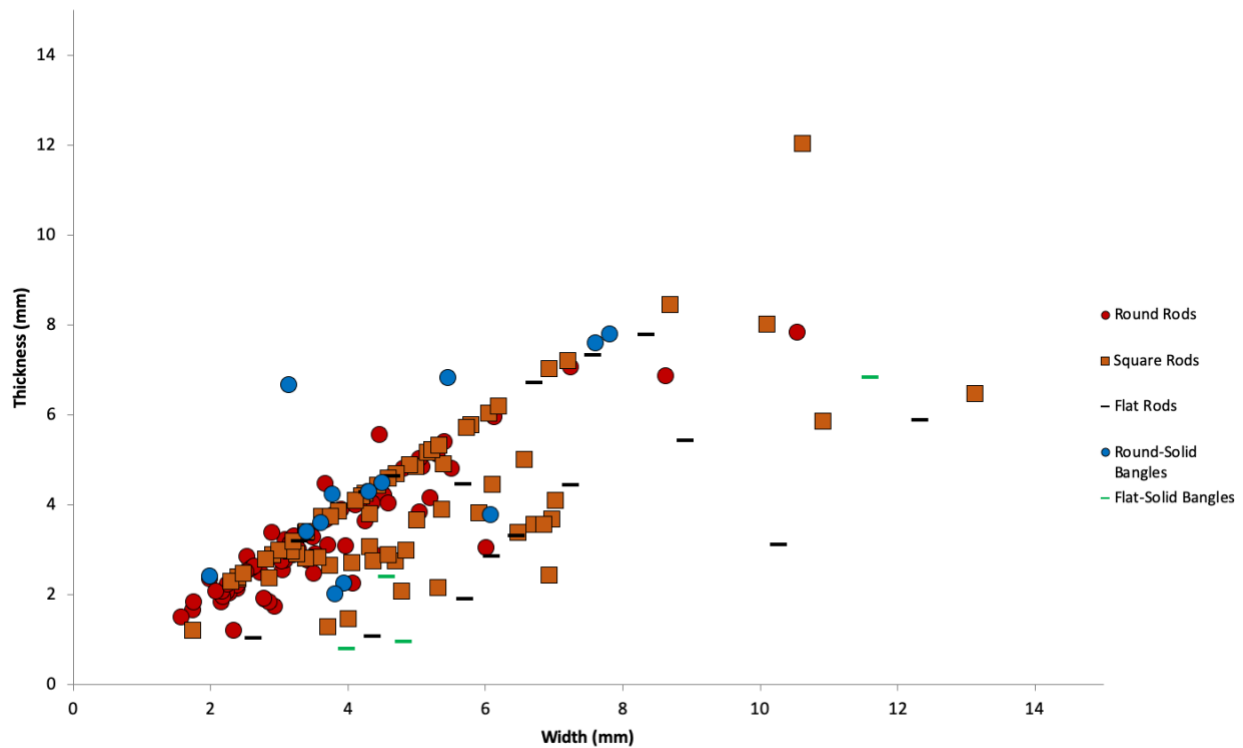
The remaining two categories of decorative objects are identifiable in the rods, wires, and pins sub-assemblage of the overall HARP copper/bronze assemblage. The first is that of rings.

These rings are of a variety of forms and sizes and may have functioned as ear, toe, or finger rings (Kenoyer and Miller 1999). They are all made of simple coils of copper wire and are either a single or double overlapped coil. Interestingly, there is, to date, no evidence for draw plates from any Indus Tradition site (Miller 1999; Kenoyer and Miller 1999; Bhan et al. 2002).

However, there is the possibility of using a copper drawplate rather than the more familiar steel (Bhan et al. 2002; Hodges 1971:76). The question of whether the copper/bronze rings from Harappa are “true” wire or, are instead, carefully cast and shaped round rods must remain unanswered until further metallographic and experimental studies can be carried out.

The final sub-category of rods, wires, and pins that functioned as decorative objects is that of solid bangles. Solid bangles are comprised of one of two sub-categories: flat or round. The cross-sections exhibited by solid bangles are identical to some of the cross sections seen in point tools. Additionally, the thickness and widths appear to be similar, although complete metrics for all HARP artifacts are still being documented. Based on measurements taken at the site and compiled from HARP records, there is considerable similarity between the two artifact types (Figure 3.1).

Figure 3.1: HARP Rods and Bangles Metric Comparison by Sub-Type



There are two possibilities to account for this. Some of the members of the point tools sub-category are highly fragmented solid bangles and have been misclassified during the research project. The second is that solid bangles and point tools start out as similarly sized and shaped cast rod “blanks” and are then fashioned into their final form using a variety of forging and shaping techniques. The latter possibility is the most likely for two main reasons. The first is that previous metallographic research indicates that a number of Indus copper/bronze objects were forged into their final form after being cast as more generalized bars or rods (see Miller 1999 for discussion). The second is that an analysis of a portion of the HARP point tool and solid bangle assemblages indicates that there is a significant overlap in metric and visual attributes. In some cases, alloy type is the only way to distinguish between the two. While this overlap would

appear to indicate that there would be some miss-categorization between point tools and solid bangles, the overall flexibility of the categorization scheme outlined prevents this from happening. Rods that lack definitive working ends of point tools and/or the distinctive curvature of a solid bangles are left at the classification level of rods, wires, and pins. This serves to prevent, or at least mitigate, interpretative and analytical difficulties stemming from categorization overlap.

It should be noted that solid bangles have an allied sub-category that occurs within another major categorical grouping of the HARP copper/bronze assemblage. This is the sub-category of hollow bangles in the sub-category of decorative objects within the major category of sheets. While it is not ideal to have the important and distinctive sub-category of bangles bifurcated between two other categories of copper/bronze objects, it was necessary in order to preserve and acknowledge the distinctive nature of the two major bangle sub-categories: solid and hollow. One is clearly made from shaped rods while the other is fashioned from rolled sheets of copper/bronze.

Sheets

Aside from rods, wires, and pins, copper/bronze sheets were the most popular starting form for Indus metal objects and comprise the second most numerous single category in the HARP assemblage that can be identified. Copper/bronze sheets would have been subsequently raised, hammered, rolled, cut, sunk, and subjected to a variety of forming techniques to achieve the desired final object shape and design (Miller 1999; Kenoyer and Miller 1999; Bhan et al. 2002). Copper/bronze sheets can further be divided into three major sub-categories: decorative objects, vessels, and tools/weapons. Each of these sub-categories has additional sub-categories within it, as well as a suite of readily distinguishable diagnostic attributes.

Decorative objects are the sub-category of sheets that are used as objects of display. Items in this category can be further sub-divided into two primary sub-categories: discs and hollow bangles. Discs are round objects with a concavity. Often these objects are perforated in the center/base of the concavity and it is hypothesized that they were either sewn into clothing or other fabrics as a decorative element (Kenoyer and Miller 1999; Hoffman and Miller 2014). It is possible that even non-perforated discs may have been incorporated into other objects or items of dress as a decorative component. Hollow bangles are a more definitive sub-category of sheet decorative objects. There are two distinct sub-categories of hollow bangles that can be identified in the HARP copper/bronze assemblage: flat hollow bangles and round hollow bangles. The description of flat and round here refers to the cross section of the bangle when viewed in profile (Figure 3.2). To date, only a few definitive examples of a hollow flat bangle has been identified in the HARP assemblage. However, it is readily visually distinct from the more curved hollow round bangles and may represent a distinct form. It is also possible that it represents an unfinished hollow round bangle or a fragment of another sheet object category altogether; only future research will be able to discriminate between these various possibilities.

Figure 3.2: Typical Hollow Harappan Bangles (HARP)



Vessels are a strictly functional category of copper/bronze objects from Harappa. In examining vessel forms from several sites, primarily Mohenjo-Daro, Chanhudaro, and Harappa, Yule (1985a, 1985b) determined that roughly half of the vessels have analogues in ceramic forms. The reason(s) for and function(s) of the unique forms still remains unclear (see Kenoyer and Miller 1999:113 for discussion). Vessels are manufactured from sheet copper using a variety of fabrication techniques (Kenoyer and Miller 1999) and broadly conform to the ceramic vessel categories outlined by Kenoyer and Dales (1986). For the purposes of this study, vessels will be further divided into two sub-categories: domestic vessels and scale pans (Figure 3.3). Domestic vessels all shared a common function as containers. It is likely that multiple examples of broken copper/bronze vessels exist within the HARP assemblage, but it is not typically possible to definitively differentiate vessel fragments from other large copper/bronze objects made from sheets when diagnostic features, such as rims or bases, are absent. And, for this reason, domestic vessels are excluded from this project with the acknowledgement of the possibility that many of the small non-diagnostic pieces that are only categorized to the level of copper/bronze sheets may, in fact, represent fragments of domestic vessels. In contrast, scale pans, while rare, are a readily identifiable component of the HARP copper/bronze assemblage. These shallow, circular pans would have been used as part of a composite object to weigh a variety of materials (Kenoyer 1998, 2014; Kenoyer and Miller 1999).

Figure 3.3: Scale Pans from Harappa (HARP)



Tools are the final sub-category of copper/bronze sheets for the HARP assemblage. The sub-category of tools shares the common attribute that they are all edged artifacts. There are two further sub-categories that of arrowheads and blades. Arrow heads are distinctive and have a typical common shape not only within the HARP assemblage, but across the Indus region (Figure 3.4). They are triangular in body with barbed tangs (Chakarabarti and Lahiri 1996; Miller 1999; Kenoyer and Miller 1999). It is likely that there are multiple sub-categories of blade tools/weapons. Previous research has identified saws, knives, spears, and razors (Marshall 1931; Mackay 1938; Mackay 1940; Vats 1940; Chakrabarti and Lahiri 1996). However, due to the fragmentary nature of the HARP assemblage it was not possible to assign these materials to a more distinct sub-category. It is only possible to classify them as items with a common attribute

that they would have been fashioned from sheets of copper/bronze and used to cut some material. Perhaps future research on the HARP materials will allow for more fine-grained distinctions to be identified and codified.

Figure 3.4: Selected Harappan Arrowheads showing range of variation (HARP)



Cast

Another primary category for the HARP copper/bronze assemblage is that of cast objects. While rods, wires, and pins and sheets are also all cast objects; the sub-categories so far identified within the larger major category of cast objects are distinctive. The primary distinction is that they are all not starting with the casting of a rod, wire, pin, or sheet. Based on the available visual and metallographic evidence they are cast as larger more massive objects and then shaped into their final forms (potentially) using a variety of forming techniques. The

currently identified sub-categories are administrative, tools/weapons, and decorative objects. In turn, each of these can be further refined into at least one distinct sub-categorization.

The administrative sub-category of cast objects is comprised of copper/bronze tablets. These tablets are relatively rare in the HARP copper/bronze assemblage but have been identified at least one other Indus Tradition site; Mohenjo-Daro (Marshall 1931; Mackay 1938; Parpola 1992). Although the tablets from Mohenjo-Daro differ in form from those from Harappa, they may have functioned in a similar manner as some sort of economic or administrative object at both urban centers (Kenoyer 1998; Kenoyer and Miller 1999; Fentress 1984; Rissman 1988). The tablets at Harappa appear to be flat rectilinear objects with raised molded designs on them (Kenoyer 1998).

Mirrors are a distinctive sub-category of decorative objects found at Harappa. They are round to oval in shape and have a small tang that would have likely attached to a handle. To date, mirrors have only been found in burial contexts by HARP (Kenoyer 1998). Another distinctive category of cast decorative objects is that of statuary. While excavations by HARP have not uncovered any copper/bronze statuary, it is a sub-category of cast decorative objects that is known from copper/bronze assemblages from other excavated Indus sites (Marshall 1931; Mackay 1938; Chakrabarti and Lahiri 1996). Current evidence suggests that Indus copper metallurgists were proficient in the lost-wax technique (Kenoyer and Miller 1999; Miller 1999; Bhan et al. 2002; Thoury et al. 2016) which would have been readily adaptable to producing a variety of copper/bronze statuary. Due to the lack of statuary documented during the HARP investigations, this has been excluded as an analytical category in the compositional and isotopic portion of the present research program. However, because it is a recognized and iconic (see the “dancing girl” from Mohenjo-Daro) component of known Indus copper/bronze assemblages it

was decided that the present categorization scheme needed to incorporate the specific sub-category within the larger system.

Beads are another sub-category of decorative objects. Within the larger sub-category of beads, there are five distinct further sub-category refinements that can be made based on the macroscopic visual morphology of individual beads; round, tube, cylinder, barrel, and spacer. In general, all members of this category are unified by their common characteristic of being perforated along on axis. Additionally, the individual sub-types of beads so far identified in the HARP assemblage align with the types developed by Heidi Miller (2000:309) for the material from Chanh-Daro. As was the case with vessels, several of the bead forms are analogous with beads fashioned from other raw materials, particularly a variety of hard stones.

The final sub-category of the major category of cast objects for the HARP copper/bronze assemblage is that of axes and adzes. All of the objects in the axe/adze category are morphologically similar and would have been used in comparable ways. In most cases the specific details of the hafting mechanism are absent or otherwise obscured. It is often not possible to securely differentiate between whether an object is an axe or an adze. Regardless, both forms likely would have been used primarily as heavy woodworking tools or even as weapons (Cork 2005). While earlier excavators distinguished between a variety of types within this category (see Marshall 1931; Mackay 1938; Mackay 1940; Vats 1940; Rao 1979, 1985; Chakrabarti and Lahiri 1996 for review) this has not been done here. This is due to the lack of definitive information on hafting technologies and locations. Additionally, no axes/adzes have been identified in the HARP copper/bronze assemblage. This stems from a variety of factors, not the least of which is the high potential for axe/adzes to be included in major metal hoards (see discussion in Chapter 2). Additionally, the issue of the perceived lack of shaft-hole axes should

be noted again. As previously discussed, the shaft-hole axe is not entirely absent from Indus copper/bronze assemblages, it has historically been present in levels that the earliest investigators deemed to be lacking. However, this may be due to other behavioral factors, rather than the critical lack of this bronze age icon in the Indus copper-based metal corpus (see Cork 2005 and Chapter 2 this volume for discussion). Just as with statuary, this sub-category is not included in the analytical portion of the present research category, but by necessity and acknowledgement of the frequent presence of these types of forms in other Indus copper/bronze assemblages they have been incorporated into the overall categorization scheme.

Manufacturing Debris

Manufacturing debris is a distinctive category within the copper/bronze assemblage at Harappa. It is the only category that contains a number of non-metallic object types. This is because, while there is little to no evidence for primary copper smelting, that is the reduction of copper ore to copper metal in ingot form, at Harappa there is significant evidence for the processing of semi-finished raw materials (ingots), recycling of scrap copper-bronze, and the production of finished copper-bronze objects (Miller 1994; Miller 1999; Kenoyer and Miller 1999; Miller 2005; Miller 2007; Hoffman and Miller 2014). All the archaeological manufacturing debris collected to date can be classified into one of four categories: prills, slag, technical ceramics, or minerals/ores.

Prills are a sub-category of manufacturing debris. In this proposed categorization system, the sub-category of prills replicates the category originally developed by HARP (HARP Report 1986). As noted above, prills are traditionally restricted to bits of metallic copper embedded in either metallic or non-metallic slags (Miller 1999). However, due to the lack of metallurgical slag(s) from the HARP excavations, the definition of prills has been expanded to encompass any

amorphous copper globule recovered during the HARP excavations. These objects may have resulted from spillage and overflow during casting, melting in crucibles, alloying molten metals, or other manufacturing activities. Previous research has demonstrated that the copper/bronze metallurgical industry at Harappa is focused on melting either semi-processed raw materials (ingots) or scrapped copper/bronze objects to support the manufacture of new copper-based metal items (Miller 1999; Kenoyer and Miller 1999; Miller 2005; Hoffman and Miller 2014).

Following Bachman (1982), slag here is applied as a broad term. It is taken to refer to any silicate material that had once been molten (cf. Bachman 1982:1, 3). Applying the term slag in this broader definition, rather than the more traditional archaeological interpretation of only referring to the reduction of metalliferous ores to metals, is following in the research pattern and terminology already established by HARP (Miller 1994; 1999). The manufacturing debris sub-category of slag can be further divided into two additional sub-categories; metallurgical and non-metallurgical slag(s) following after Miller (1994:500, 1999:244-46). Metallurgical slags are those materials that are the residual debris left behind as a result of the specific and restricted pyro-technological activity of reducing ore to metal (smelting) (Miller 1994:501). Very few, if any, metallurgical slags have been recovered from Indus settlement sites (Kenoyer and Miller 1999). However, recent discoveries at Harappa may be changing this (see Chapter 4 and 6 this volume). In contrast, non-metallurgical slags are the vitrified remains of the tools used in metal processing and manufacture (Miller 1994:501). A number of sub-types of non-metallurgical slags may be possible to identify, however they all share a unifying characteristic – they are all originally ceramics. These are ceramics that have been subjected to the high heat of metallurgical production and partially or completely vitrified. The metals used by 3rd millennium BCE metal workers in South Asia and other parts of Eurasia melt between 900-1200 degrees Celsius

(Martinon-Torres and Rehren 2014:108). Non-metallurgical slags are from the ceramic tools of metal production (tuyeres, crucibles, molds, kiln walls, etc.) being taken over their thermal threshold and melting or vitrifying. Experimental evidence indicates that this typically happens when temperatures exceed 1100 degrees Celsius (Martinon-Torres and Rehren 2014:108). For the purposes of this classification scheme, non-metallurgical slags are the vitrified/melted remains of another sub-category of manufacturing debris - technical ceramics.

The definition of technical ceramics used here is taken to be "...any ceramics used in metallurgical or other high-temperature operations..." (Martinon-Torres and Rehren 2014:107). Further it is necessary that these ceramics demonstrate three functional properties: the ability to withstand high temperatures (thermal refractoriness), the ability to withstand sudden changes in temperature (thermal shock resistance), and an ability to be manipulated while in an extremely hot state (mechanical/tensile strength) (Martinon-Torres and Rehren 2014:108). Current evidence indicates that metal and other high temperature craft workers in the 3rd and early 2nd millennium BCE did not have knowledge of refractory materials. Instead of using specialized raw materials to achieve the three primary physical properties of technical ceramics, craftspeople focused on improving the performance of locally available clays through the addition of secondary inclusions and a manipulation of wall thickness (Martinon-Torres and Rehren 2014:108). The available analyses of technical ceramics by HARP have indicated a use of sand, quartz, and chopped straw as tempers or inclusions in the clay in order to provide the thermal refractoriness, shock resistance, and tensile strength desired in the ceramic components of metallurgical processing and production (Miller 1999, 2005, 2007).

Based on the evidence at Harappa it is possible to further refine and categorize the materials grouped under the heading of technical ceramics. These definitions are not solely my

own, and I am following aspects of the definitions laid out in previous work at Harappa (Kenoyer and Miller 1999; Miller 1999) and technical ceramics in general (Martinon-Torres and Rehren 2014). Sub-categories of technical ceramics include furnaces/kilns, crucibles, tuyeres, and molds. Crucibles are movable ceramic containers that would have allowed metalworkers at Harappa to melt copper/bronze raw materials, and transport molten metal to molds. Tuyeres are ceramic tubes that are used to direct the airflow needed for combustion during the heating and melting of metals. Molds are structures that would have held molten metal during the casting of finished copper/bronze objects. It should be noted that metal casting molds at Harappa would have been made out of materials aside from ceramic, specifically sand. As has been previously noted, sand molds would have been ideal for casting flat objects (Kenoyer and Miller 1999) and experiments have demonstrated the ability to replicate Indus style copper/bronze artifacts using sand-based molds and simple casting techniques (Kenoyer personal communication). This type of production pattern would leave almost no archaeological traces (Kenoyer and Miller 1999). While there is evidence for the use of technical ceramic molds at Harappa (Miller 2005:250); ceramic mold forms likely only represent a fraction of the overall mold types used by Harappan metal-smiths.

The final category of technical ceramics is that of furnaces or kilns. These are non-mobile archaeological features that would have either held a charge for smelting or held semi-finished raw materials (copper/bronze ingots or scrap metal) for melting. Since few firing structures that are only for metal processing/melting have been located at Indus cities, including Harappa (Miller 1999; Kenoyer and Miller 1999) the term “furnace/kiln” has been used here. Experimental kiln firings conducted at Harappa have demonstrated that internal temperature of Harappan Phase pottery kilns reached at least 1000-1100 degrees Celsius in a reducing

atmosphere (Kenoyer and Miller 1999). This indicates that, even if there are no specific metal melting/processing furnace structures found in the archaeological deposits at Harappa, it is possible that existing pottery production installations could have been adopted for the purpose, as they likely would have been able to reach or exceed the required melting temperatures.

The final sub-category of manufacturing debris found at Harappa is that of minerals/ores. For reasons reviewed in detail previously (Kenoyer and Miller 1999; Miller 1999; Hoffman and Miller 2014) it is not appropriate to classify the small number of copper metal bearing mineral objects discovered at Harappa as “ores”. They are not in sufficient quantity to represent large-scale smelting. They are also not in solid contextual associations with metal processing structures or other similar artifacts. Finally, it must be noted that copper minerals could have been used for a variety of other purposes ranging from decorative stones to cosmetics to medicines or poisons.

Miscellaneous and Other Objects

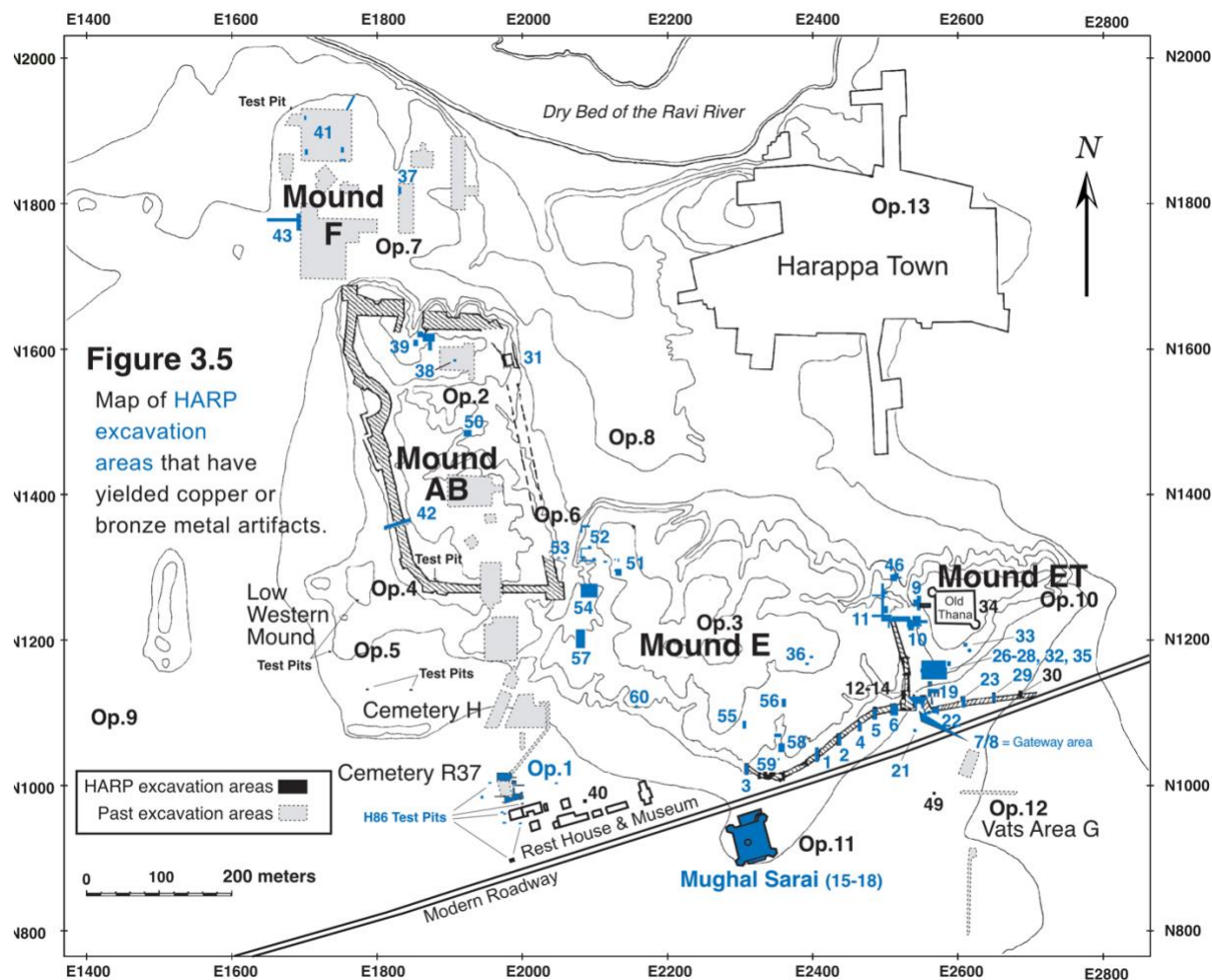
Miscellaneous objects are any copper/bronze metal artifacts that lack a clear diagnostic attribute. These range from amorphously shaped lumps to highly fragmented and/or corroded pieces of copper/bronze objects that are simply not possible to confidently assign to any of the other major categories. This category remains unchanged from the initial formulation of it during the recording and tabulation efforts of HARP. While continued research by the author and others has been able to provide enough detail to move some of the members of this category into other categories, miscellaneous objects still remain one of the largest categories of items for the HARP copper/bronze assemblage. I argue that with any Indus copper/bronze assemblage where fragmented and corroded objects are recorded and curated that this will be the case. The excavations conducted by the ASI in the 1920's and 1930's at Mohenjo-Daro (Marshall 1931;

Mackay 1938), Harappa (Vats 1940), and Chanhudaro (Mackay 1943) did not record or tabulate fragmentary finds. While later excavations at Lothal (Rao 1979, 1985) kept several hundred more pieces than these earlier projects, it is still likely not a total accounting of the fragments and non-diagnostic copper/bronze pieces. The full results of excavations at Kalibangan, Dholavira, Rhaki-Ghari, and other Indus sites are still unpublished. It is highly likely that these reports, when they are brought to press, will include a higher proportion of fragmentary objects than the earlier reports. This would bring the HARP copper/bronze assemblage into line with other comparable assemblages across the Indus Tradition. In other words, the copper/bronze assemblage at Harappa does not contain a high proportion of miscellaneous objects due to any unique metallurgical practices, presence or absence of highly specialized forms, or specific post-depositional factors. It is simply that HARP has applied more systematic recovery and recording procedures than has been typical for Indus archaeology until fairly recently.

Miscellaneous objects can also refer to objects that are only present in the HARP copper/bronze assemblage as a single instance. Often these objects are either not present or not published in the earlier Harappa excavations or other analogous Indus sites. The lack of examples and the associated descriptive data makes a more definitive categorization difficult. In order to not “over interpret” the dataset and force objects into categories and sub-categories that may not be wholly appropriate, these objects are simply classified under the Miscellaneous category.

Spatial Distribution of Copper Bronze Artifacts from HARP Excavations

Figure 3.5: HARP Excavation Areas with Copper or Bronze Artifacts



During the course of the ongoing HARP excavations, 53 distinct excavation areas (referred to from here on as “trenches”) have been opened. The majority of these trenches have yielded copper/bronze metal artifact remains (see Figure 3.5). The most important conclusion that can be drawn from this macroscopic evaluation of the spatial distribution of copper/bronze metal objects at Harappa is that these materials are present throughout the cultural sequence and widely distributed across the site. Copper/bronze metal artifacts have been discovered from all

periods at the site from the Ravi Phase to the end of the Harappan Phase (3300-1900 BCE). Additionally, metal remains are present in all archaeological contexts at the site, ranging from re-deposited secondary debris contexts to primary domestic and workshop settings. Overall, it is clear that copper/bronze was a significant and widely available component of the overall material culture assemblage from Harappa.

One of the stated project goals was to determine if any differences existed in the use and distribution of copper/bronze artifact types or alloys between the four distinct walled mounded occupational areas of the site. The presence or absence of distinct patterning across or between the mounded areas will be returned to in a latter portion of this work. Prior to any integration of the analytical data sets with the spatial distribution of the total copper/bronze assemblage from Harappa it is necessary to briefly outline where these materials are coming from. Rather than detailing each individual excavation unit separately, they have been grouped together whenever possible. When it was not possible to group trenches due to their contextual relationships they were grouped based on occupational mound. The number of individual objects from each trench has been tabulated and the percentage of the overall copper/bronze assemblage the excavated objects from each trench represents has been calculated. These are reported in a summary table for each trench grouping. There has been no attempt to control for excavated area. While it is appropriate to acknowledge that the size of a given trench and the cubic meters of earth removed from the unit can have an impact on the number of copper/bronze objects recovered; it cannot be assumed to be a simple linear correlation. The amount of a specific material culture class recovered from any individual trench will most likely be more related to the spatial location at the site and the specific archaeological contexts encountered during excavation. For instance, a small unit that is placed in a residential compound may yield more metal remains than a larger

unit placed in an erosion gully. For the following summary descriptions information was taken from HARP project records and the yearly interim reports provided between 1986 and 2001 (HARP Reports 1986-2001).

City Wall Trenches on the Southern Margin of Mound E and Mound ET

Table 3.2: Copper/Bronze Artifacts from City Wall Trenches on Southern Margin

Trench	Mound	Counts	% Overall Total
1	E	32	1.33%
2	E	41	1.71%
3	E	26	1.08%
4	E	7	0.29%
5	E	29	1.21%
6	E	4	0.17%
7/8	E/ET	37	1.54%
21	None	6	0.25%
22	ET	8	0.33%
23	ET	1	0.04%
29	ET	1	0.04%
Totals	-	192	8.00%

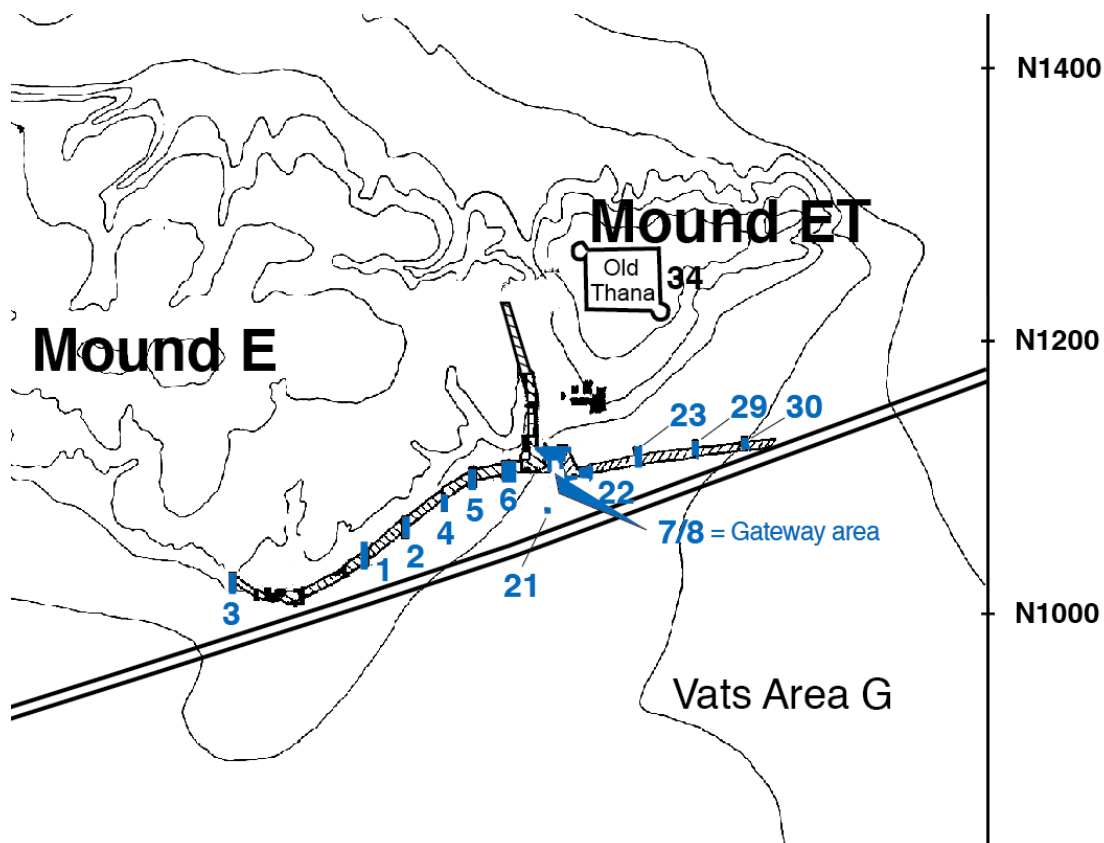
A series of trenches were placed along the southern margin of Mounds E and ET in order to locate and define the nature and extent of the Harappan Phase city wall (Figure 3.6). Of these, 12 yielded copper/bronze artifacts. Of these trenches, nine were placed in areas that directly intersect the city wall. In those cases, it is most likely that the copper/bronze objects recovered were in a secondary context. They are likely debris either dumped over the margins of the city wall or re-deposited fill used in the construction and maintenance of the wall itself. However, three of the trenches in Table 3.2 were placed in areas that did not directly intersect with Harappan Phase city walls. Trench 21 is on the plain south of the wall and would have been the edge of a street and drain complex. The small number of copper/bronze pieces recovered here is almost certainly from either a primary or secondary deposition context. Regardless of the specific nature of the deposition, they are in secure Harappan Phase deposits and represent either

primary points of deposition or they were moved in antiquity rather than during historic times.

Two trenches, the combined excavation units 7 and 8, are from the large gateway, drain, and street complex uncovered at the intersection between Mounds E and ET (Kenoyer 1998). These deposits are, again, either primary or secondary deposition during the Harappan Phase occupation of the city.

Overall these 12 excavation areas provide 192 objects of the total copper/bronze artifact assemblage from Harappa. These objects are most likely representative of Period 3B and 3C copper/bronze use and distribution from residential occupations across the interior of Mounds E and ET. The objects found in these trenches represent a cross-section of objects that were used and discarded by the residents of Mound E and its later extension, Mound ET (Kenoyer 1998).

Figure 3.6: HARP Trenches on Southern Margin of Mounds E and ET

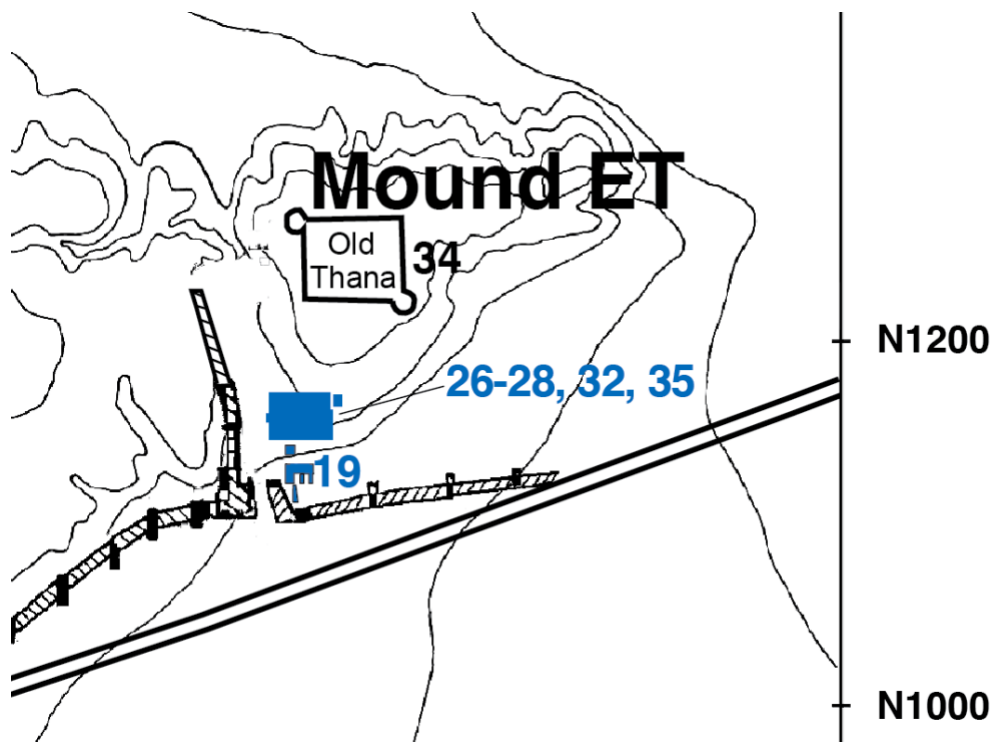


Residential Occupation Trenches on South Slope of Mound ET

Table 3.3: Copper/Bronze Artifacts from South Slope of Mound ET

Trench	Mound	Count	% Overall Total
19	ET	28	1.17%
26	ET	6	0.25%
27	ET	55	2.29%
28	ET	72	3.00%
32	ET	49	2.04%
35	ET	17	0.71%
Totals	-	227	9.46%

The 227 copper/bronze artifacts recovered from these six trenches (Table 3.3) represent materials uncovered during the excavation of Period 3B and 3C residential occupations on Mound ET (Figure 3.7). As was previously discussed (see Chapter 1 this volume) Mound ET formed as an extension of the major residential Mound E as the city expanded during the latter two thirds of the Harappan Phase occupations. The objects in these trenches represent the types of copper-based metal items that Harappan residents were using, breaking, and/or discarding during daily life in the city. While some excavation contexts close to the modern mound surface clearly exhibit some disturbance and mixing, as well as a limited number of excavation contexts that were disturbed during historic brick-robbing activities, the majority of the excavated contexts from these trenches represent primary deposition of materials during antiquity.

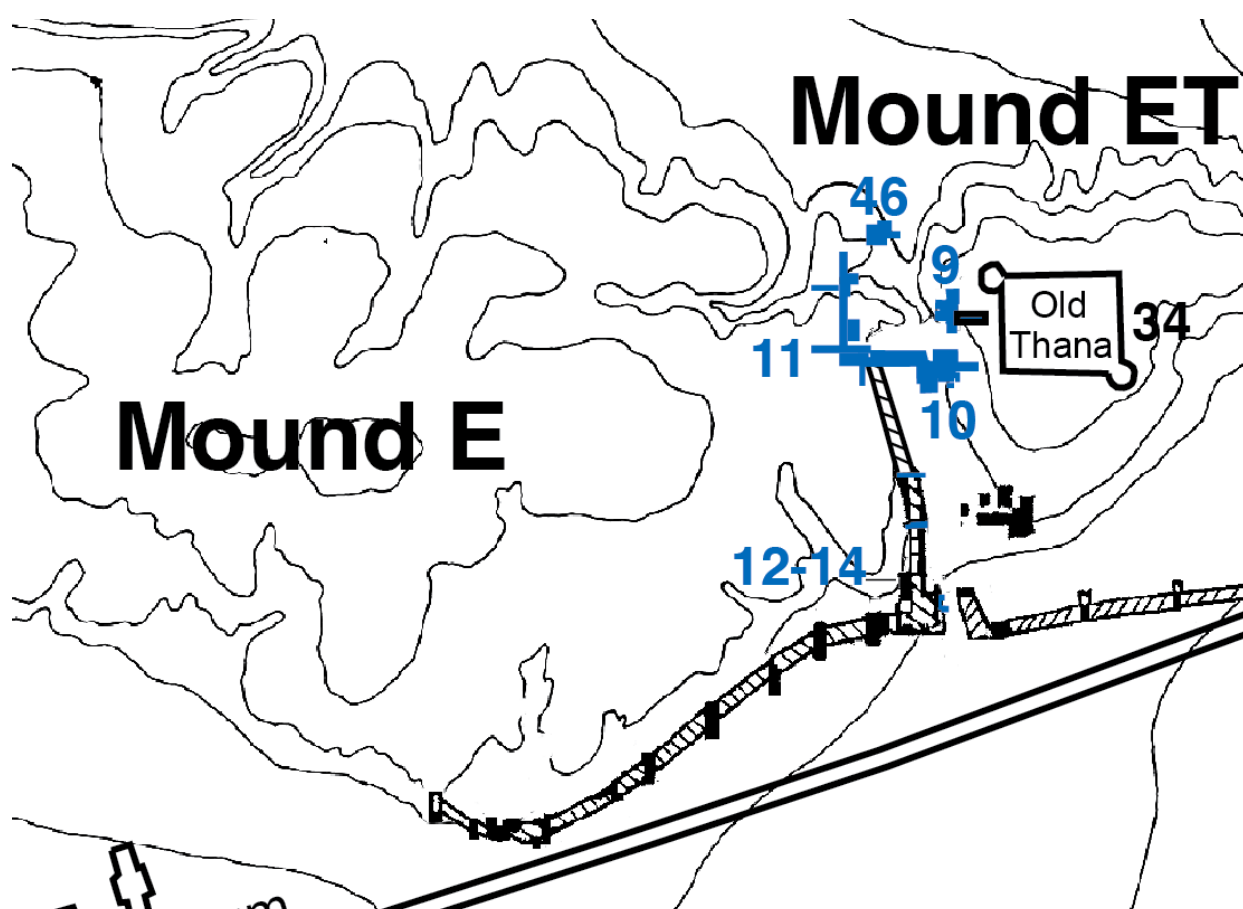
Figure 3.7: HARP Trenches on South Slope Mound ET**City Wall and Residential Occupations on Mound E and Mound ET****Table 3.4: Copper/Bronze Artifacts from Mound E and Mound ET**

Trench	Mound	Count	% Overall Total
9	ET	106	4.42%
10	ET	98	4.08%
11	E	317	13.21%
46	ET	1	0.04%
Totals	-	522	21.75%

North and west of the residential occupations uncovered on the southern slope of Mound ET is a similar set of deposits that straddles the city wall and streets running between the eastern edge of Mound E and the western edge of Mound ET (Figure 3.8). The excavation units in this area of the site have documented a series of residential complexes, streets, and city walls from Period 3B and 3C of the Harappan Phase. Again, as with the previous two areas reviewed, the

copper/bronze objects found in these units are in either primary or ancient secondary contexts. Overall, metal remains from these trenches represent a sample of the types of items that the residents of the two adjacent mounded residential areas were using and discarding during daily life at this large urban center. It is important to note that Trench 11, a large excavation unit that cuts across the two residential mounds and the Harappan city wall yielded the majority of copper/bronze objects from this group of trenches (Table 3.4). In this case, this is almost certainly related to the size of the unit in relative comparison to the other trenches in the group.

Figure 3.8: HARP Trenches on Mound E and ET



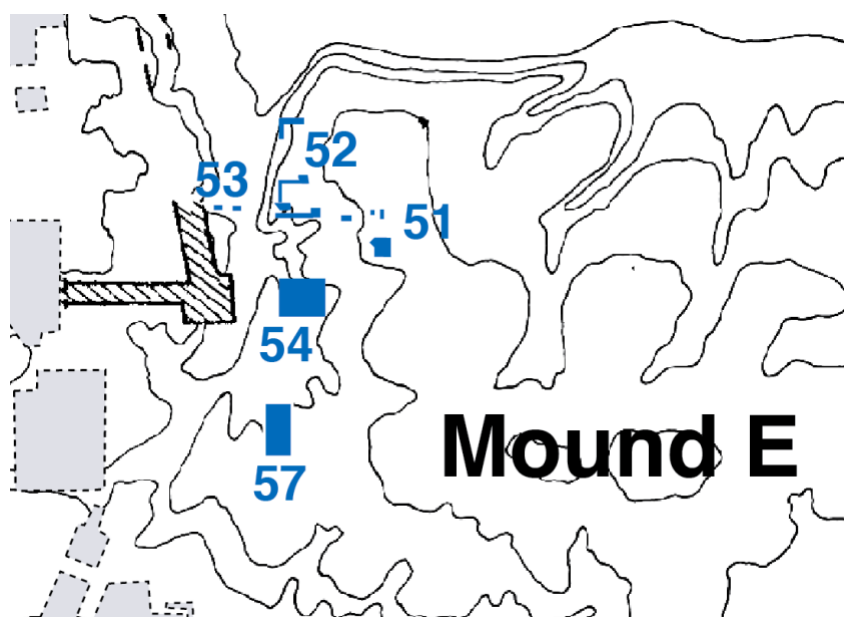
Street, Residential, and Workshop Areas on Western Slope of Mound E

Table 3.5: Copper/Bronze Artifacts from Western Slope of Mound E

Trench	Mound	Count	% Overall Total
51	E	12	0.50%
52	E	100	4.17%
53	AB/E	1	0.04%
54	E	597	24.88%
57	E	1	0.04%
Totals	-	711	29.63

Along the western margin of Mound E (Figure 3.9), starting at the top of the slope and working both west and south, are a series of trenches that document Harappan Phase streets, residences, and workshops along the edge of the large residential Mound E (Table 3.5). As with previous analogous areas on Mound E and Mound ET, these deposits represent either primary deposition of copper/bronze artifacts or ancient secondary deposition. It should be noted that some excavation lots/contexts in this area are either mixed surface deposits or brick-robber trenches.

Figure 3.9: HARP Trenches on Western Slope Mound E

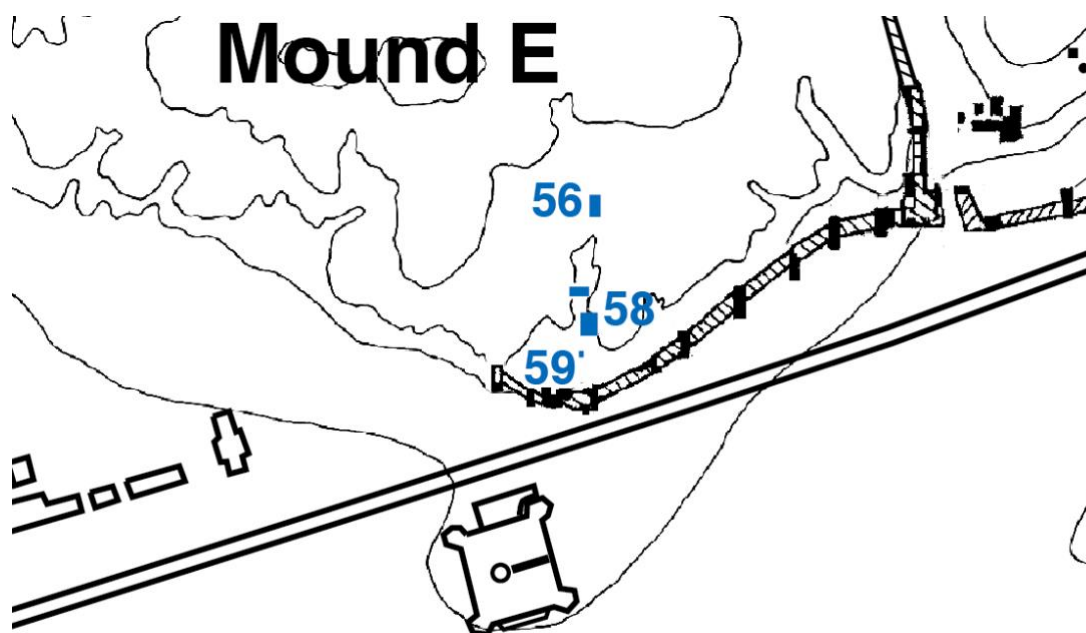


Street and Gateway Trenches on South of Mound E

Table 3.6: Copper/Bronze Artifacts from South of Mound E

Trench	Mound	Count	% Overall Total
56	E	15	0.63%
58	E	127	5.29%
59	E	36	1.50%
Totals	-	178	7.42%

The three trenches listed in Table 3.6 are all placed along a north-south erosion gully on the southern slope of Mound E (Figure 3.10). This area was target for significant excavation in order to exploit the deep cut into the mound the gully provided as well as to expose the southern margin of Mound E in order to determine if it was enclosed by a city wall (Should be noted that excavations in Trenches 56, 58, 59 occurred in an excavation season prior to the one that conclusively documented the extent and nature of the Mound E and Mound ET city walls.), as previous excavations had documented for Mound AB (Wheeler 1947). The excavation in these trenches uncovered extensive Harappan Phase street, gateway, and residential deposits starting from outside the city wall extending back up the south slope of Mound E, interior to the city wall. The street and residential areas found in these three trenches date as early as the Kot Diji Phase (Period 2 at Harappa, see Chapter 1 this volume for details) and continue through the Harappan Phase Period 3 occupation (Kenoyer 1991:47-9).

Figure 3.10: HARP Trenches on South Slope Mound E

Mughal Sarai and Thana Trenches

Table 3.7: Copper/Bronze Artifacts from Mughal Sarai and Thana

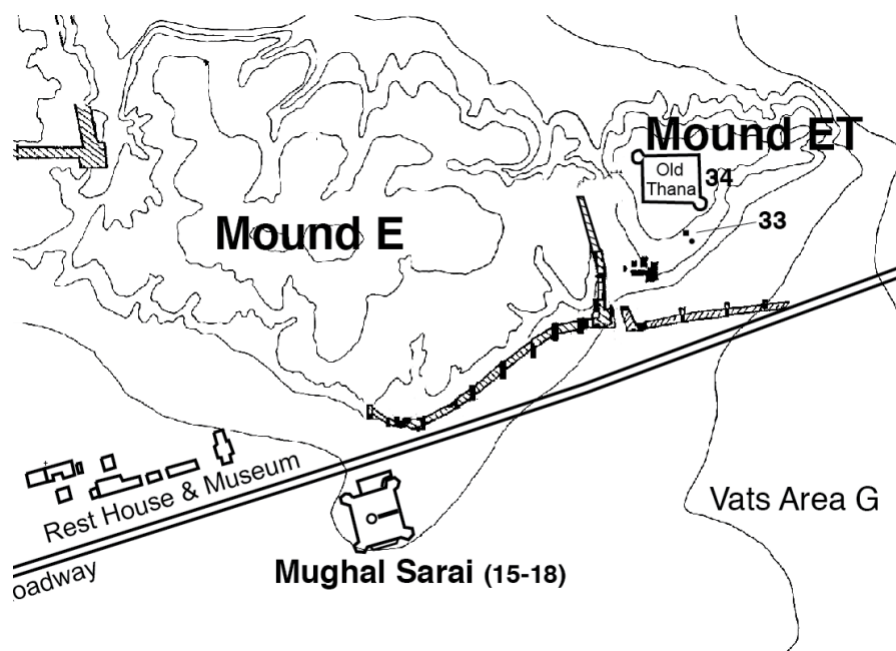
Trench	Mound	Count	% Overall Total
15-18	Mughal Sarai	8	0.33%
33	ET	1	0.04%
Totals	-	9	0.37%

Three trenches (Table 3.7) were placed approximately 30 meters south of the gateway complex on Mound E along a low mounded area (Figure 3.11) that is today topped by the remains of historical period sarai and stables compound (Kenoyer 1998). The evidence from the excavations in this area indicates the presence of Harappan Phase deposits below the historic occupation levels. These deposits included houses, drains, bathing platforms, and potentially a public well (Kenoyer 1998:55). It has been hypothesized by Kenoyer (1998:55) that this area

was used as a rest stop for merchants and other travels as they entered and left the city. While a low number of copper objects have been recovered from the excavations here, they again represent intact primary Harappan Phase deposits providing a comparative glimpse of copper/bronze artifacts from outside of the walled portions of the urban center.

The final trench in this grouping (Trench 33 Figure 3.11) was put in south of the Thana structure below a historic period wall. Beneath this more recent structure and the mixed deposits that historic era construction and modification caused, intact Harappan Phase street deposits were reached. While only a single artifact has been uncovered from the excavations in Trench 33, this is likely due to their limited scope and street context, as discarded items would have been pushed to the side or re-deposited in dumps during the maintenance of city streets during the Harappan occupation, rather than a lack of copper/bronze materials in this section of the site.

Figure 3.11: HARP Trenches at Mughal Sarai and Old Thana



Mound F Trenches

Table 3.8: Copper/Bronze Artifacts from Mound F

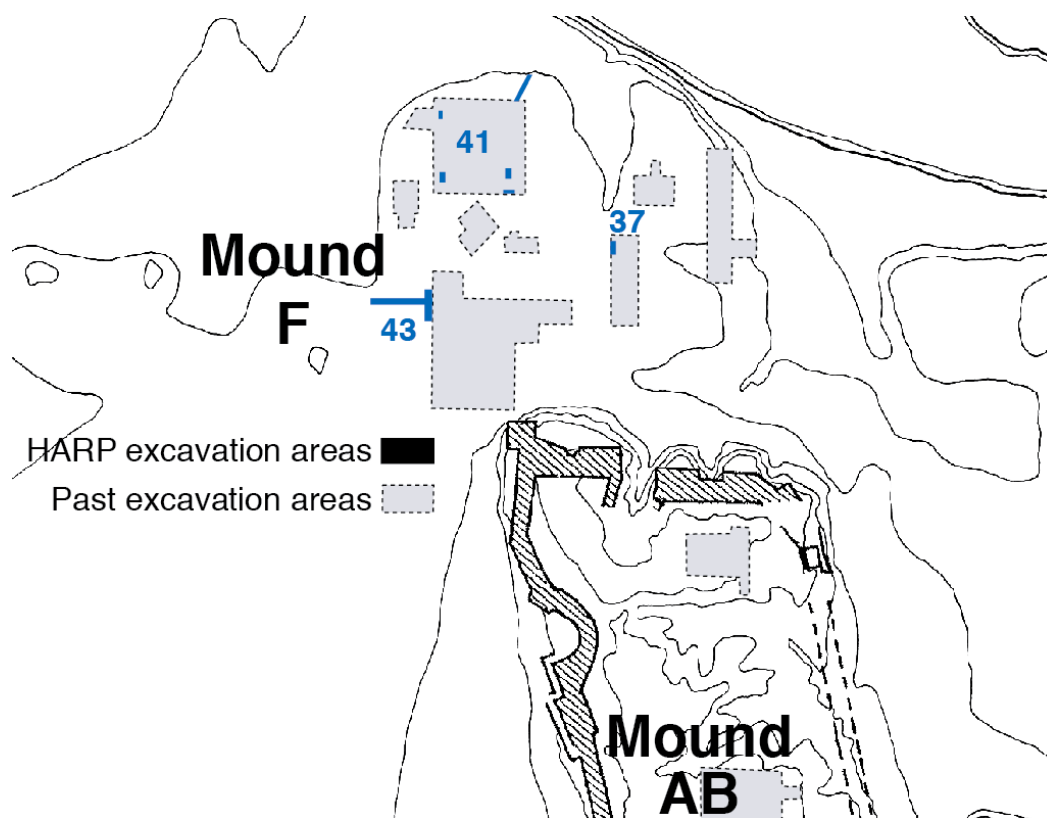
Trench	Mound	Count	% Overall Total
37	F	30	1.25%
41	F	12	0.50%
43	F	83	3.46%
Totals	-		

A series of excavation units designated Trenches 37, 41, and 43 (Table 3.8 and Figure 3.12) were put in and adjacent to previous excavation units begun by Sahni and then extended by Vats (Possehl 1991; Vats 1940). Trench 37 was focused on cleaning and reestablishing the stratigraphic relationships in Vats' Trench I. Trench I is detailed by Vats (1940:80-110) as an attempt to excavate a large trench through the entire occupation sequence on Mound F in order to establish stratigraphic relationships for the other trenches on Mound F and to articulate these units with those placed on Mound AB. In terms of copper/bronze studies, Trench I on Mound F is one of the more important previous workings. Vats uncovered the copper/bronze hoard designated Jar 277 as well as a piece of arsenic mineral (lollingite) that may be used for either cosmetics, poison, or alloying with copper (Vats 1940:85-90).

The other two trenches excavated by HARP on Mound F (41 and 43) were undertaken with the goal of extending and clarifying excavations begun by Sahni (Possehl 1991) and then extended by Vats (1940) on two enigmatic structures – the Granary and the Workers' (Circular) Platforms. Trench 41 was focused on re-excavating the Granary area (Vats 1940:15) in order to clarify the nature of the significant architectural complex identified during Vats' and Sahni's earlier excavations. The HARP excavations uncovered 3 successive building episodes during the Indus occupation of the site and were able to document that although the building was clearly an important structure, it most likely did not function as a grain storage facility. As with the earlier

excavations, the HARP trench also uncovered a small number of copper/bronze objects. In contrast, the excavations within HARP Trench 43, an extension to the west of Vats' Trench IV (Vats 1940:52-80). These excavations were focused on discerning the nature and extent of the circular (workers) platforms that are a prominent feature of Mound F. During the excavations for Trench 43, numerous copper objects were uncovered. Based on the excavation contexts encountered, these artifacts represent primary deposits from the Harappan Phase occupation of the site.

Figure 3.12: HARP Trenches on Mound F



Mound AB Trenches

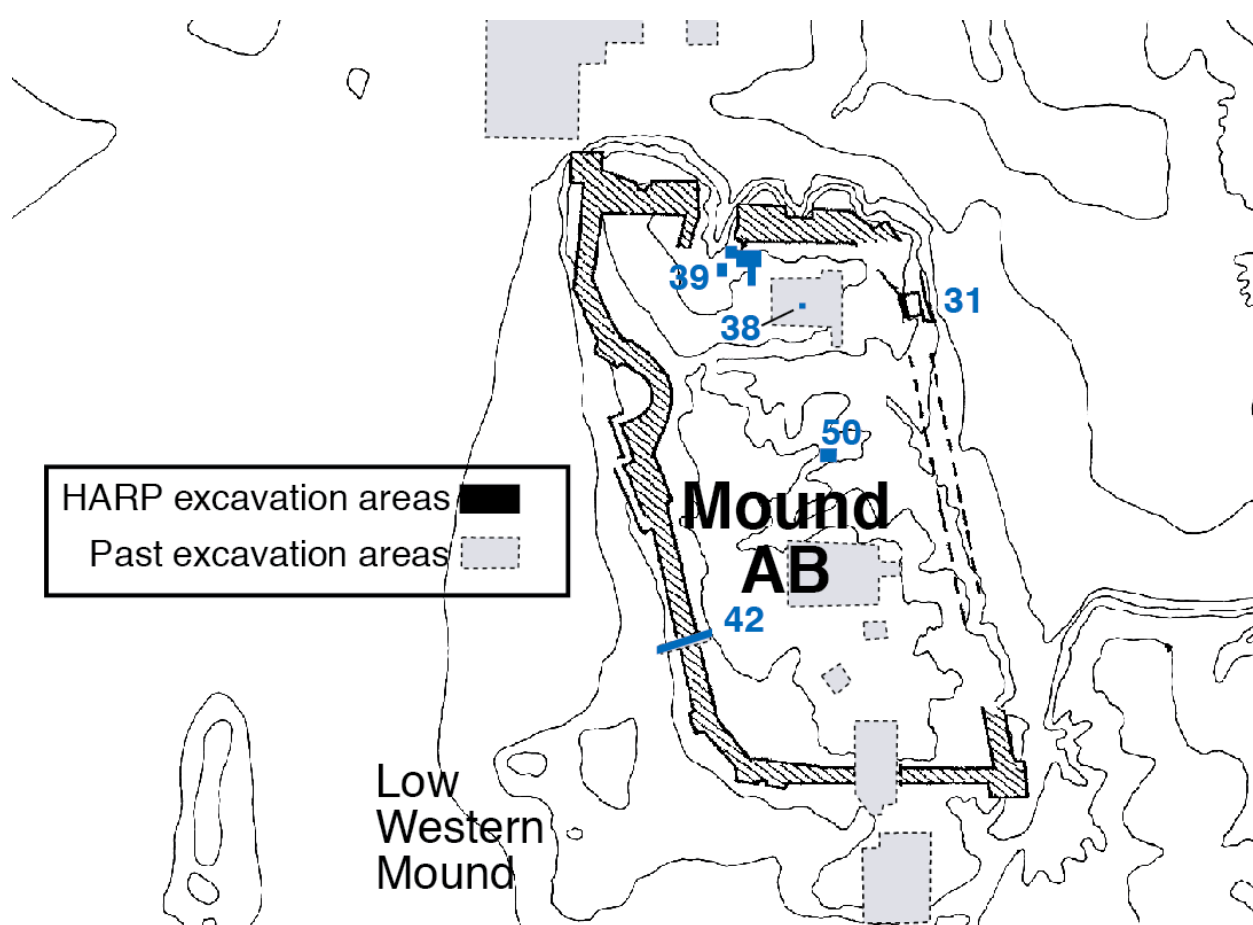
Table 3.9: Copper/Bronze Artifacts from Mound AB

Trench	Mound	Count	% Overall Total
31	AB	2	0.08%
38	AB	4	0.17%
39	AB	134	5.58%
42	AB	3	0.13%
50	AB	10	0.42%
Totals	-	153	6.38%

The HARP excavations have placed five trenches throughout Mound AB (see Table 3.9 and Figure 3.13). While all the trenches yielded copper/bronze artifact remains, only one of the trenches (39) contained significant amounts of copper/bronze artifacts. Trench 39 is a large deep trench that has exposed the entire cultural sequence at Harappa, from the earliest Ravi Period layers through to the Late Harappan Period. The depth and size of this excavation unit serves to partially explain the numerous amounts of copper/bronze artifacts recovered from the excavations. However, it is also critical to note that the archaeological contexts encountered during the excavation of Trench 39 are primarily intact secure Period 2-3C deposits. This indicates that the copper/bronze objects discovered here represent a snapshot of the types of metal items used during everyday life at Harappa from the earliest settlement of the site through to the end of the Harappan Phase occupations. The remaining trenches opened by HARP on Mound AB, were focused on conservation of existing structures or previous excavations and a deep sounding that was an initial attempt to understand and reveal the stratigraphy of the entire occupational sequence on Mound AB. Trench 31 was focused on diggings aimed at conserving the present Mosque on the northeastern corner of Mound AB. Trench 42 was focused on stabilizing, cleaning, and conserving the massive section cut that Wheeler's excavations (1947) had left on the southwestern edge of the Mound. The limited nature of the excavations in

Trenches 31, 38, and 42 explains why only a small number of copper/bronze objects were recovered. Finally, the restricted nature of the deep sounding in Trench 50, concerned primarily with identifying and documenting the stratigraphic sequence of the occupation layers on Mound AB, provides reason for why only a small handful of copper/bronze objects were recovered.

Figure 3.13: HARP Trenches on Mound AB

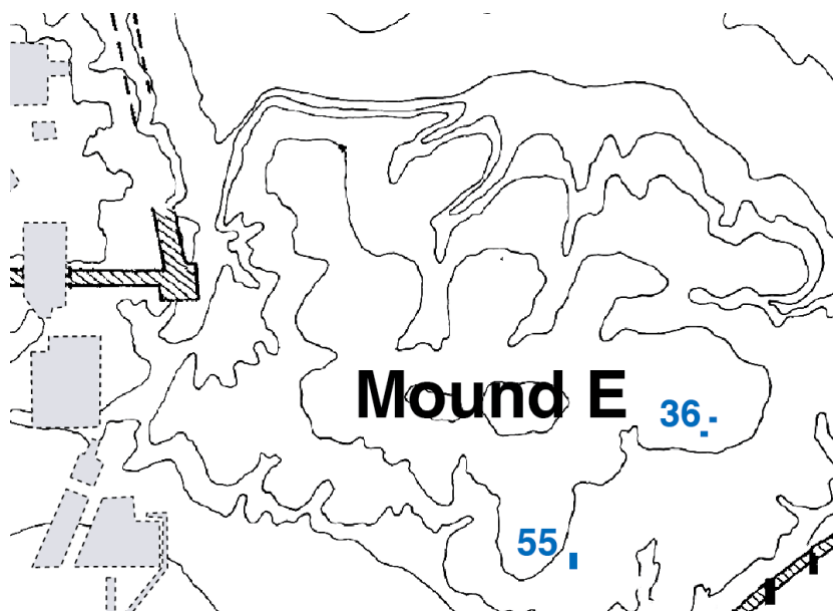


Mound E Trenches

Table 3.10: Copper/Bronze Artifacts from Mound E

Trench	Mound	Count	% Overall Total
36	E	13	0.54%
55	E	78	3.25%
Totals	-	91	3.79%

There are two additional HARP trenches on Mound E that have not been dealt with in previous groupings (Table 3.10 and Figure 3.14). Both were trenches aimed at enabling a detailed investigation of anomalous artifacts scatters located during intensive surface surveys for craft indicators conducted during the 1995 field season (Miller 1999). Trench 36 on the eastern edge of the center of Mound E was excavated in order to understand the exact nature of high concentration of chert (flint) drills that was found on the surface. A limited number of copper/bronze artifacts were recovered from this trench. The layers encountered during the excavation of Trench 36 represent either primary Period 3C Harappan Phase layers or mixed Harappan and Historic layers lying either on the surface or directly below in a disturbed setting. The metal materials found in this trench are all clearly Harappan style items, despite the mixed nature of small number of the excavation contexts. In contrast, Trench 55 revealed a number of copper/bronze artifacts. Those artifacts that were not recovered during an intensive surface survey of the area prior to excavation are all from secure Period 3C contexts. This area is currently interpreted as a copper/bronze workshop area and has been described in detail elsewhere by other HARP researchers (Miller 1999; Miller 2005).

Figure 3.14: HARP Trenches on Mound E**Trenches with No Copper/Bronze Artifacts****Table 3.11: Trenches Without Copper and Bronze Artifacts**

Trench	Mound	Count	% Overall Total
12-14	E	-	-
20	Cemetery R37	-	-
30	ET	-	-
34	ET	-	-
40	Cemetery R37	-	-
49	Area G	-	-
60	E	-	-
Totals	-	0	0.00%

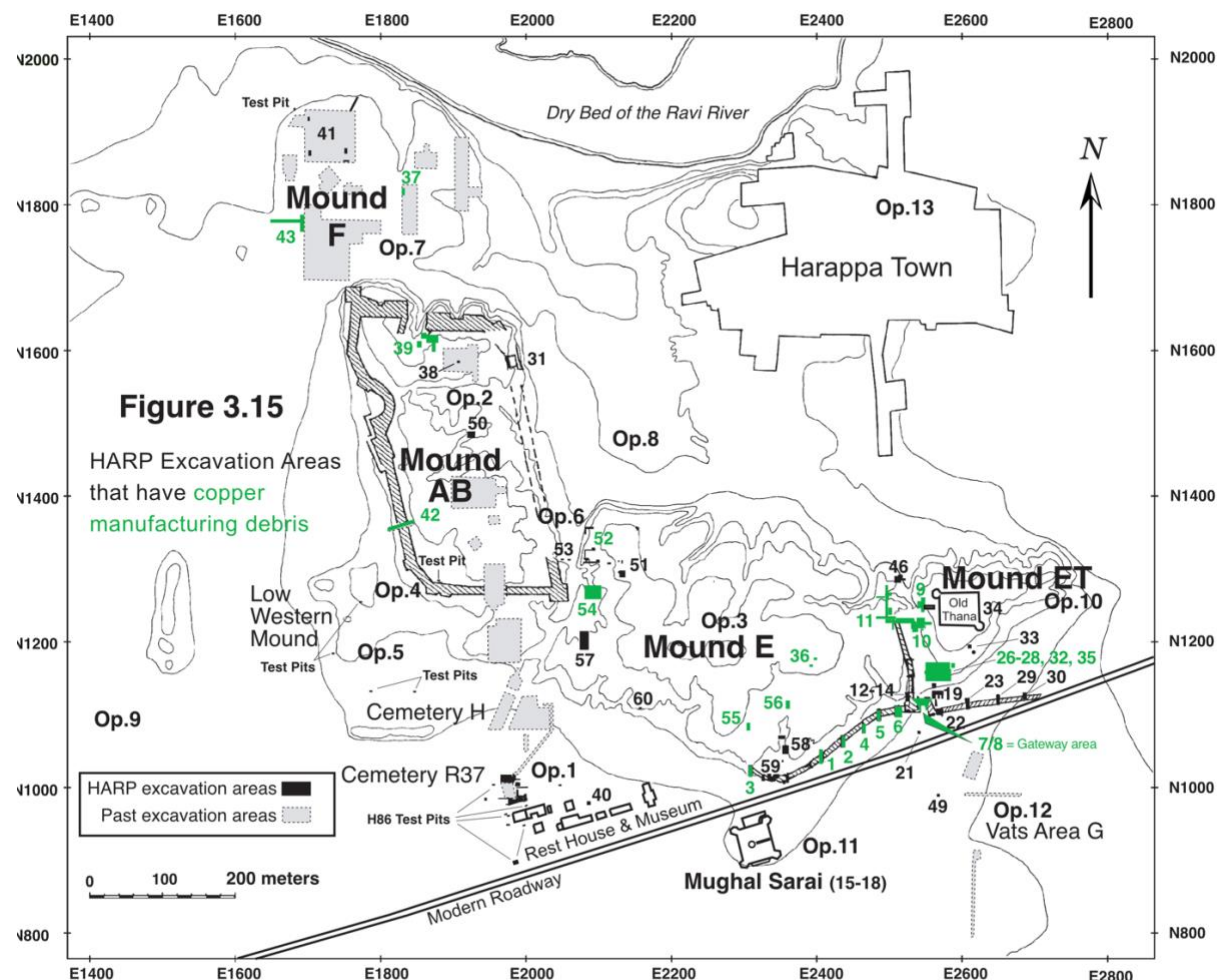
There are 9 trenches at Harappa that during the HARP excavations to date have not yielded any copper/bronze artifact remains (Table 3.11). All of these trenches, while spread across the site, have one commonality. They are all small exploratory trenches focused on discerning the presence or absence of specific archaeological features at Harappa. As a result, they did not recover a high number of artifacts in general, and no copper/bronze items specifically. The absence of metallic remains in these excavation areas should not be taken as a

lack of copper/bronze in any area of the site, as other trenches, both by HARP and previous excavators have documented copper/bronze artifacts from these zones.

Copper Manufacturing Debris

During the course of the HARP excavations a number of artifacts that represent copper manufacturing debris have been uncovered (Figure 3.15). These copper/bronze prills, copper slags of various types, and technical ceramics represent some of the best direct evidence, to date, for identifying and documenting the nature of copper metallurgical production occurring on-site during the Harappan Phase occupation of the city. In order to gain a better understanding of what the distribution of these various manufacturing debris means for reconstructing the nature of copper and bronze metallurgy at the site, it is necessary to examine their spatial locations along specific artifact category lines. Analyzing the results from the HARP excavations for each artifact class and then making comparisons between them has proven to be more useful than attempting to understand the entire manufacturing debris category at once. The following is a summary of these examinations and tentative series of conclusions for the individual categories as well as the larger manufacturing debris classification.

Figure 3.15: HARP Excavation Areas with Copper Manufacturing Debris



Prills

In archaeometallurgical studies, a prill is a spherical or ovate object that is formed during the cooling of molten copper/bronze. This commonly occurs during casting and smelting. At Harappa, a total of 47 objects designated as copper “prills” have been recovered during the course of HARP excavations and surveys (Figure 3.16 and Table 3.12). These objects are small, round to ovate metallic objects that may represent spillage from casting when pouring molten metal from a crucible to a mold, metallic copper that was not reclaimed when the debris from a smelt were sorted, or they may represent some other activity at the site not yet identified.

Figure 3.16
Map of HARP excavation areas where Copper/Bronze Prills have been recovered

The map shows the Harappa site with various mounds and excavation areas. Key features include:

- Mound F:** Located in the upper left, with Test Pit 41 and area 43.
- Mound AB:** Located in the center, with Test Pit 42 and area 50.
- Mound E:** Located in the center-right, with areas 51, 52, 53, 54, 55, 56, 57, and 60.
- Mound ET:** Located in the lower right, with areas 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.
- Other features:** Dry Bed of the Ravi River, Harappa Town, Low Western Mound, Cemetery H, Cemetery R37, Rest House & Museum, Mughal Sarai (15-18), Modern Roadway, and various test pits (H86, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100).

Legend:

- HARP excavation areas (solid black)
- Past excavation areas (dotted black)

Scale: 0 to 200 meters

Coordinates: E1400 to E2800, N800 to N2000

Table 3.12: HARP Trenches with Prills

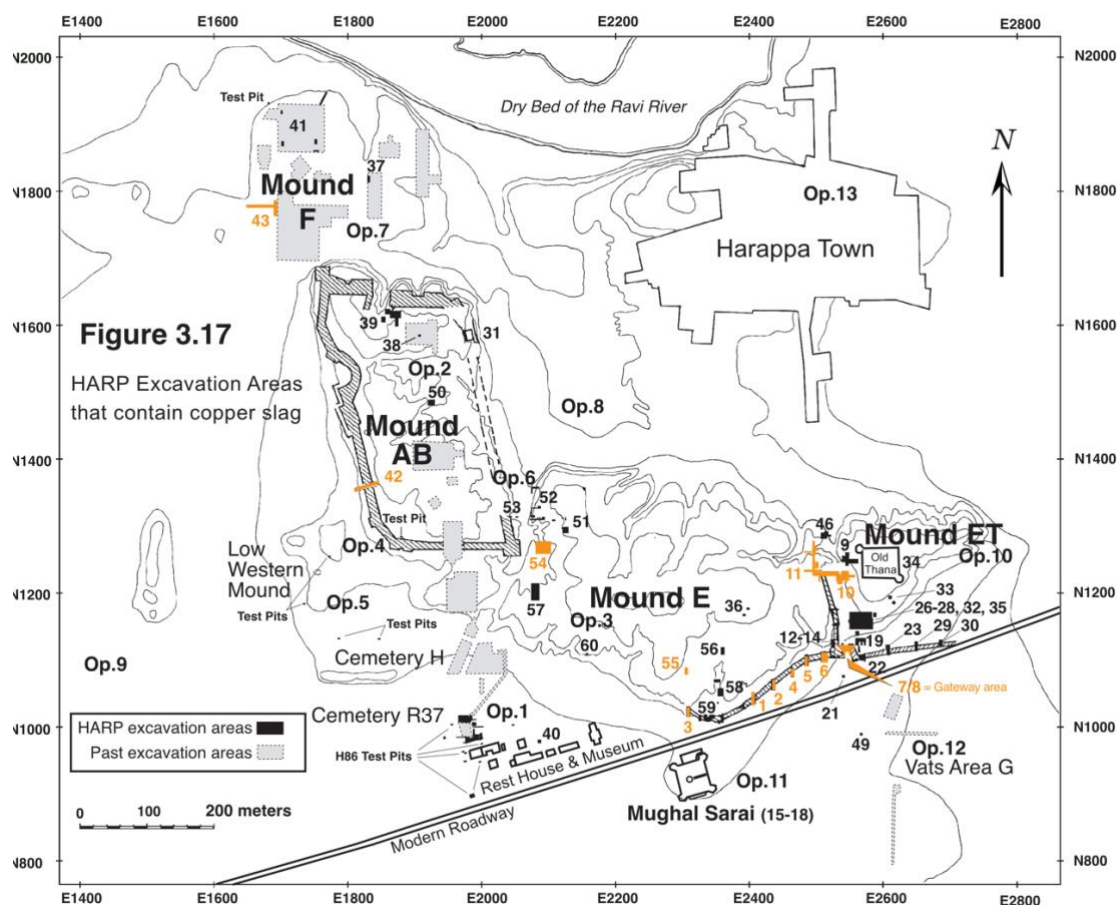
Trench	Mound	Count	% Total Prills (n=47)
43	F	2	4.25%
39	AB	6	12.77%
51-54	AB/E	5	10.64%
55	E	2	4.25%
56	E	1	2.13%
58	E	3	6.38%
36	E	1	2.13%
35	ET	5	10.64%
32	ET	1	2.13%
27	ET	1	2.13%
11	ET	7	14.89%
10	ET	4	8.51%
9	ET	3	6.38%
7/8	ET	4	8.51%
Surface	All	2	4.25%
Totals	-	47	99.99% (100.00 %)

The excavation areas that prills were recovered in primarily represent either of two contexts. The first context is areas that appear to be loci for craft activities, such as Trenches 51-54 on the margins of AB and E where various craft workshops have been documented or 55-58 on the slopes of E that likely represent another workshop area. The other is secondary contexts that represent the discard of debris and fill at the margins of occupation mounds along city walls or other dump areas. This most likely represents episodic cleaning and revitalization of copper/bronze activity areas within each mounded area. Overall, while current excavation and survey work by the HARP team has identified one copper workshop (Miller 1999), the distribution of prills at the margins of mounds and along with other crafting activities, provides support for the inference that multiple copper workshop areas would have been distributed across the site during the Harappan Phase and at least one copper manufacturing locale would have been present on each mound. This aligns well with the existing data from other craft industries (Kenoyer 1998, Miller 1999, Kenoyer and Miller 1999, Law 2011).

Slag

Some amount of copper slag has been recovered from HARP excavation units from all mounded areas at Harappa (Figure 3.17). However, the excavation unit from the copper workshop (Trench 55) and potentially associated dump contexts along the city wall at the southeast margin of mound E (Trenches 1-4) provide the overwhelming majority of the slag recovered by the HARP excavations at 79.13% of the total copper slag assemblage (Table 3.13). This is almost assuredly the result of significant copper and bronze manufacturing activities taking place along the edges of mound E (Miller 1999). It is important to note that while no other excavation unit or group of units contained more than a small amount of the overall total sample, the largest piece of metallurgical slag recovered from the site comes from Trench 42 on mound AB. This massive piece of copper smelting slag is detailed in Chapter 5 of this work and represents a significantly different type of slag than the other members of the assemblage.

The majority of the slag from Harappa represents melting and casting of copper raw materials to fashion finished objects. While it is possible there may have been re-smelting of lower quality ingots on the site, there is no evidence in the majority of the slag previously examined to support the hypothesis that copper smelting took place within the walled area of the city (Miller 1999; Kenoyer and Miller 1999; Hoffman and Miller 2014). However, the slag sample from Trench 42 represents the results of significant furnace-based smelting of copper ores somewhere in the vicinity of mound AB.

Figure 3.17: HARP Excavation Areas with Copper Slag**Table 3.13: HARP Excavations with Slag**

Trench	Mound	Count	% Total Slag (n=91)
43	F	2	2.20%
42	AB	1	1.10%
51-54	AB/E	3	3.30%
55	E	42	46.15%
1	E	4	4.40%
2	E	11	12.09%
3	E	11	12.09%
4	E	4	4.40%
5	E	3	3.30%
6	E	1	1.10%
7/8	ET	3	3.30%
10	ET	1	1.10%
11	ET	3	3.30%
Surface	All	2	2.20%
Totals	-	91	100.00 %

Technical Ceramics

Technical ceramics exhibit a similar distribution to prills and slag. The three categories would have most likely resulted from the same or similar activities – copper smelting, melting, and manufacturing. Therefore, it is not surprising that they are recovered from similar depositional contexts (Figure 3.18 and Table 3.14). As with previous categories related to copper production, the largest portion of the total technical ceramic assemblage is found in the area of Trench 55 and the copper workshop identified by HARP (Miller 1999). The other excavation areas the yielded copper slag were primarily secondary contexts along the margins of the city wall and represent the dumping of debris material during antiquity. This allows the inference that there were areas within each of the walled occupational mounds at Harappa consuming and discarding technical ceramics along with copper slag and prills. It is possible, perhaps even probable, that there are additional copper workshops remaining to be excavated at the site. Such a distributed repeated pattern of craft production within the confines of each mounded region of the site fits with patterns already identified from other craft industries at the site (Kenoyer 1998; Miller 1999; Law).

Figure 3.18: HARP Excavation Areas with Technical Ceramics

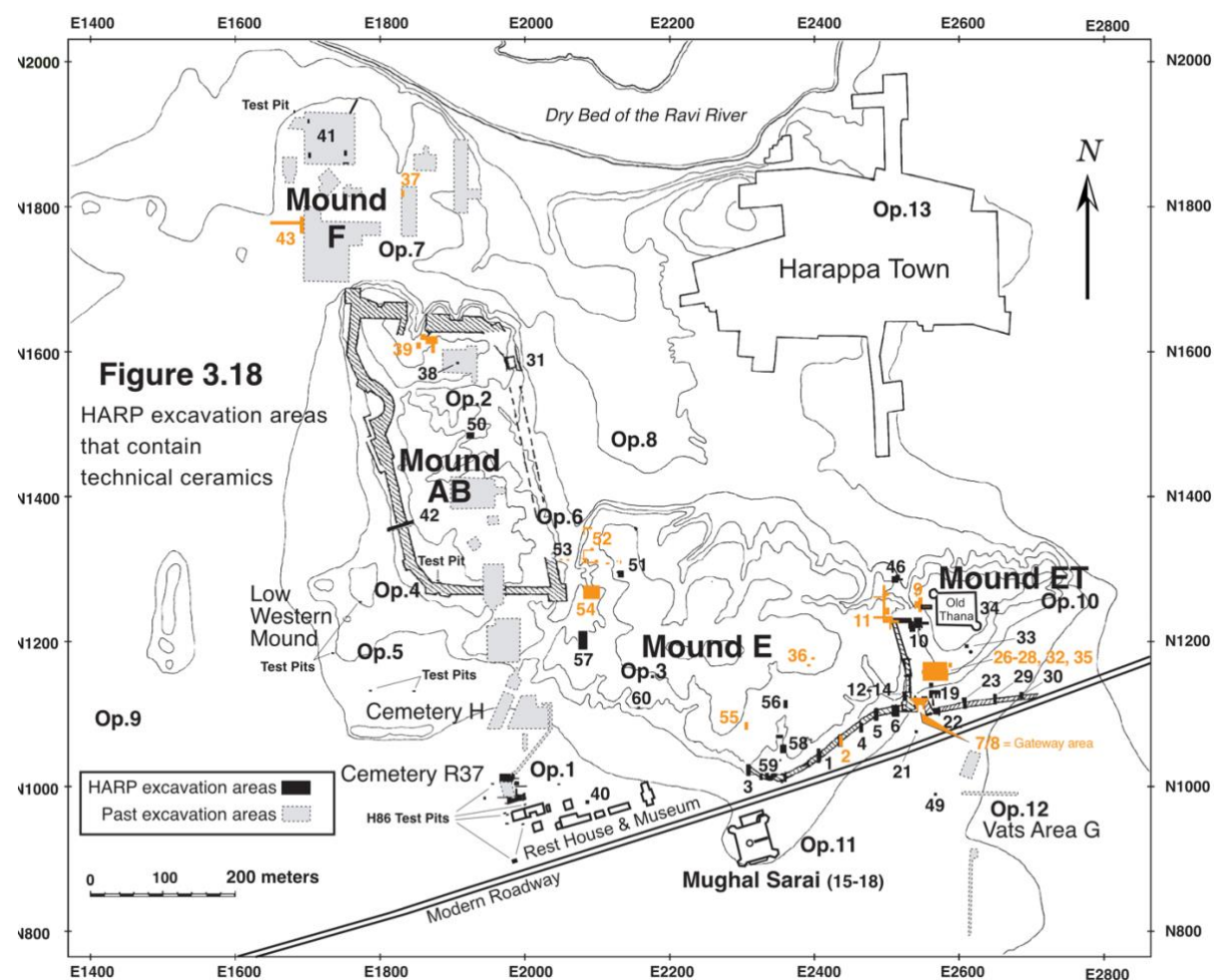


Table 3.14: HARP Excavations with Technical Ceramics

Trench	Mound	Count	% Total Technical Ceramics (n=83)
43	F	3	3.61%
37	F	1	1.21%
39	AB	10	12.05%
51-54	AB/E	7	8.43%
55	E	28	33.74%
36	E	2	2.41%
2	E	5	6.02%
11	ET	6	7.23%
9	ET	1	1.21%
7/8	ET	2	2.41%
27-28, 32	ET	5	6.02%
Surface	All	13	15.66%
Totals	-	83	100.00 %

Additional investigations along the border between Mound AB and E in the vicinity of Trenches 51-54 would seem to be a promising area to test the hypothesis that other copper workshops exist at Harappa. In a related inference, the copper objects and debris found in the Trench 9-11 area between Mound E and ET may represent another promising area for detailed survey work related to copper manufacturing installations. A final area is the source for debris from Trench 39 on Mound AB. This is especially intriguing because in addition to technical ceramics and some prills, the compositional analysis portion of this project identified at least 2 artifacts that currently are listed as Miscellaneous in the HARP copper assemblage but could represent small pieces of copper slag. Overall, the co-occurrence of all categories of manufacturing debris in similar excavation contexts and site locations lends credence to the hypothesis that copper production at the site during the Harappan Phase occupation was distributed across each of the mounded portions of the site. However, more excavation data is required to accurately assess this supposition and it is hoped that future work at the site by HARP will provide the necessary information.

Summary of HARP Copper and Bronze Assemblage

Much of the preceding has been discussed and reviewed previously (see Miller 1999; Kenoyer and Miller 1999; Hoffman and Miller 2014). However, it is necessary to review the spatial and categorical distribution of the HARP copper and bronze assemblage in order to provide the proper contextual framework to interpret the data obtained during the compositional and isotopic analyses portion of the project. Two major conclusions regarding the distribution of copper and bronze artifacts at Harappa need to be emphasized.

The first is that all artifact types are relatively evenly distributed across the occupation mounds. A detailed review of the materials from each excavation unit and occupation mound

reveals that variations in artifact frequency seem to be driven by the size of excavated units in the area, not a restriction in the distribution of artifacts during the Indus occupation of the site.

Residents of each major occupation mound would have had equivalent access to the entire array of copper and bronze artifacts available at Harappa (Miller 1999; Hoffman and Miller 2014).

The second conclusion that must be emphasized from a review of the copper and bronze artifact distribution at Harappa is that the distribution of manufacturing debris such as prills, slag, technical ceramics, and mineral fragments indicates that in addition to the copper working area identified on Mound E (Miller 1999; Kenoyer and Miller 1999) there is evidence for additional copper production zones on the remaining occupation mounds as well. This aligns with the multiple and distributed nature of production seen in other crafts at Harappa (Kenoyer 1998; Miller 1999, 2005; Law 2011).

Description and Categorization of the Project Sample Assemblage

The HARP sample assemblage totals 360 individual artifacts ranging over every major category except technical ceramics (crucible and kiln fragments). Details for each individual artifact can be found in Appendix 3.1. A summary table is provided below that provides a snapshot look at how the HARP copper and bronze sample assemblage is distributed (Table 3.15).

Table 3.15: HARP Copper and Bronze Sample Assemblage

Sheets/Blades - 44	Rod Tools - 2 Point tools – 79 Pin/Needle - 3	Arrows - 43
Discs - 2	Rings - 15	Bangles - 15
Beads - 17	Mirrors - 1	Tablets - 1
Coins - 0	Miscellaneous Fragments - 91	Modern/Historic Metal - 0
Prills - 38	Slag & Mineral - 9	Technical Ceramics - 0

The categories of sheet/blades, arrows, discs, mirrors, tablets, miscellaneous fragments, and prills contain no sub-categories and therefore require no further description at this point. The remaining categories; rods, rings, bangles, beads, and slags and mineral can be further classified to sub-types and are described below.

Table 3.16: Rod Sub-types in the HARP Copper and Bronze Assemblage

Point Tools (by cross section)	Other Types
Round - 26	Hook - 1
Square - 29	Chisel - 1
Indeterminate - 24	Pin/Needle - 3

The assemblage from the HARP excavations are dominated by point tool forms and contain few rod tools (Table 3.16). The majority of this portion of the assemblage is comprised of small fragmentary round or rectilinear in cross-section objects that either retain or project to have had a pointed or tapered working end. In other words, these appear to be fragments of small tools taking a variety of forms. Portions of this “point tool” sub-assemblage demonstrate an indeterminate cross-section due to corrosion crust and object fragmentation obscuring the

original cross-section. A small portion of the rod assemblage is comprised of larger tools such as hook, chisel, and pins/needles.

Table 3.17: Ring Sub-types in the HARP Copper and Bronze Assemblage

Flat-Single Coil	1
Flat-Double Coil	1
Round-Single Coil	8
Round-Double Coil	1
Indeterminate	4

Examples of all sub-types of rings are present in the sample assemblage (Table 3.17). The same is the case with the bangle category (Table 3.18). The final decorative object category, beads (Table 3.19), features an even representation of round and cylinder beads. With 4 beads being indeterminate. These beads were unclear enough that it was not possible to confidently assign them to one of the main sub-categories that exhibit potential overlap. For instance, the discrimination between cylinder, tube, and barrel beads requires detailed examination of object morphology. With the corroded condition of the copper and bronze beads in the HARP assemblage, it is not always possible to make such examinations. In order to keep the number of classification errors to a minimum, objects were left at the category designation where confidence in the accuracy of the designation was the highest.

Table 3.18: Bangle Sub-types in the HARP Copper and Bronze Assemblage

Round-Hollow	6
Round-Solid	4
Flat-Hollow	1
Flat-Solid	1
Indeterminate	3

Table 3.19: Bead Sub-types in the HARP Copper and Bronze Assemblage

Round	5
Cylinder	6
Indeterminate	6

In total the HARP copper and bronze sample assemblage represents all major artifact classes and sub-types. It provides a representational sample of the presently identified copper metallurgical forms produced and consumed at the site. The next stage in the overall project was to analyze the HARP sample set for composition using a variety of techniques. The category, spatial, and contextual classifications for the HARP copper/bronze assemblage outlined in this chapter were a component in the determination of analysis priorities and approaches. This was critical, as the results of each compositional analysis need to be related to object type, use, and location at the site in order to determine if patterns in artifact composition can be assigned to cultural preferences, technological factors, raw material selection, or a combination of all of these.

Chapter 4: Analytical Methodology and Results: Composition

Introduction

A total of 324 copper/bronze artifacts from the HARP excavations have been analyzed for their composition. (see Appendix 3.1 for total sample set and Chapter 3 for description). These artifacts covered all occupational periods, excavation areas, and copper/bronze artifact classes recorded for the site. In order to identify and define any patterning in copper metallurgical technology and practices at Harappa, a series of nested analytical procedures was implemented. Overall, this project is concerned with determining whether differences seen in the final composition of copper/bronze objects are the result of cultural choices related to technology (alloying practices or manufacturing techniques), the provenience of the raw material which can be linked to trade networks and socio-economic patterns, or some articulation between the two. Chapter 2 detailed how it is possible to use a combination of compositional and isotopic data points to discriminate between the potential cultural choices that could explain the patterns observed in the data. This chapter continues that discussion in regard to the compositional data. The data developed during this portion of the project are utilized to directly address issues related to technological versus cultural preferences in alloy usage and how patterns of alloy utilization can relate to status and wealth at Harappa. In addition to providing the empirical basis for addressing alloy usage at the site, the samples for the compositional analysis portion of the project were selected to identify whether or not the various alloys could have been produced in workshops at Harappa or were imported as finished objects. Specific issues of sample selection will be addressed in the discussion of each phase of the overall analytical research program.

In order to develop the data required to address these questions, three analytical techniques were selected: Portable X-Ray Fluorescence (PXRF), Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), and Lead Isotope Analysis (LIA). Additionally, one large sample of copper metallurgy slag was analyzed using Scanning Electron Microscopy (SEM) and Electron Microprobe analysis (EMPA). Each of these techniques provides a different type and level of analytical data. The application of any individual technique would not be able to develop all of the data required for a complete investigation of the major research questions. However, taken in concert, the analytical techniques utilized in this project are well suited to produce the necessary data needed to empirically evaluate the copper/bronze metallurgical tradition at Harappa. In the following sections, the methods and results from each portion of the overall analytical program will be detailed. Prior to that, it is necessary to describe the overall condition of the HARP copper/bronze sample set as background for certain methodological and data analysis decisions that were made during the research project.

Condition of the HARP Copper/Bronze Sample Set

The corrosion of copper and bronze metal artifacts in a given soil matrix has been demonstrated to be a complex interplay of factors that can be highly variable between archaeological contexts (Tylecote 1979; Nord 2005). Additionally, copper-based alloys interact differently with the local environment than unalloyed copper metals (Goidanich et al. 2008). Taking this into consideration, it is still possible to construct some general statements regarding the nature of post-depositional alteration of the copper/bronze assemblage from the HARP excavations. It must be cautioned that these statements do not serve as definitive explanations for the condition of individual objects from Harappa, but as a set of broad parameters that assist in

delineating the accuracy and relationship of the analytical data generated by this product to the original compositional status of the objects.

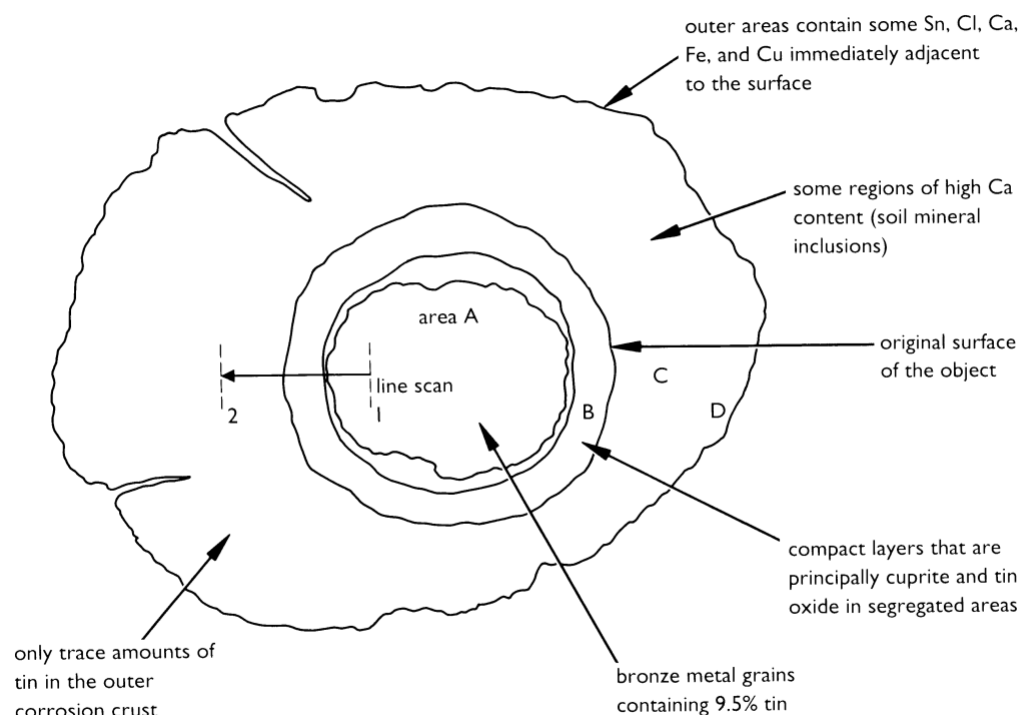
The copper/bronze artifacts recovered during the HARP excavations have been buried in the local soil for a period of time ranging from approximately 3,300 to 5,900 years. Over this considerable length of time, these objects had extensive chemical interaction with the surrounding soil matrix. The primary result of this is a buildup of corrosion products on the surface of the original metal artifact. In some cases, these corrosion products have replaced portions of the original metallic structure. The post-depositional degradation of copper metal objects at Harappa is typically fairly severe due to the elevated sodium and chloride levels in the local soil (Imran et al. 2010), as well as the moist alkali conditions in general (Pendall and Amundson 1990). The presence of these elements most likely serves to accelerate and intensify the corrosion of the copper and the migration of the major and minor elements through the original metallic object (Srivastava and Balasubramaniam 2005). Recent research indicates that the presence of chloride ions and the pH of the soil are critical factors in the level of corrosion and chemical reactions that produce post-depositional alterations to a given copper/bronze object (Scott 2000). The presence of chloride ions in the soil, salt rich soil, and well-aerated moist soils have been identified as significant accelerating factors in the corrosion of copper/bronze archaeological objects (Nord 2005). The soil at the archaeological site of Harappa has been documented to contain all of these corrosive factors (Pendall and Amundson 1990; Imran et al. 2010; Wright 2010).

Operating under the assumption that there have been significant post-depositional factors that altered the compositional and structural condition of archaeological copper/bronze items from the site of Harappa, it becomes crucial to understand the relationship between these

processes and the data sets needed to evaluate the project research questions. Perhaps the most important of these relationships is what was the nature of the alteration of the original copper, lead, arsenic, and/or tin content for each of the analyzed artifacts. While it is not possible, at present, to construct expected compositional patterns for Indus copper/bronze objects; it is possible to reach a number of significant conclusions regarding the composition of copper/bronze objects from Harappa and additional research programs will only aid in this. Each of the artifacts included in the analytical program was an unknown. Due to the nature of previous studies conducted on Indus copper and bronze artifacts (see Chapter 2 for details), only broad general expectations could be constructed. The available data indicate that there is the potential for significant amount of variation in parent ore sources, smelting technologies, casting procedures, details of manufacturing processes, and alloying traditions among Indus sites. Further complicating the picture is the fact that detailed study on the corrosion of metal artifacts over archaeologically relevant time spans has only recently begun to be more fully investigated (Nord 2005). Additionally, much of the literature focuses on surface patina and does not empirically address what happens to archaeological metals in a soil matrix over time, although it is clear that the two processes are different (Chase 1993). Much of the complicating issues related to understanding the compositional make-up of Indus copper and bronze artifacts was controlled for by looking only at artifacts from a single site. Post-depositional corrosion impacts should be broadly similar, and issues related to raw material source provenience and manufacturing can be addressed by examining the isotopic data from this project as well as the compositional data on manufacturing debris. Overall, the project was able to produce an internally consistent and highly useful set of compositional data points that allowed for alloy type determinations to be made for the majority of the total sample assemblage.

Figure 4.1: Typical Corrosion Sequence for Tin-Bronze

From Scott 1991:45



The above figure (Figure 4.1) is a generalized cross-section for a corroded tin-bronze copper rod. Based on visual inspection of the cut cross-sections of artifacts from Harappa by the author, the amount of zoning and corrosion crust detailed by Scott (1991:45) is fairly typical for the copper/bronze assemblage from Harappa. In general, the situation depicted in Figure 4.1 has been assumed to be the case for all members of the HARP sample assemblage unless it was possible to make a different determination. Typically, objects from the sample assemblage either fell into a highly corroded condition where much of the metal had been altered to cuprite and a thick corrosion crust had formed or they exhibited some surface patina with a thin layer of corrosion crust underlain by intact copper/bronze metal. The most important conclusion to be

reached from this model of corrosion in the analyzed assemblage is that there is potentially significant mobilization and migration of elements relevant to the overall research questions post-deposition. This factor must be taken into account at all stages of data acquisition and analysis. Additionally, research has indicated that when an object has corroded into multiple layers, elements (specifically tin) can be present in different amounts between layers or absent altogether (Schoukens et al. 2008). Even in objects where the outer layer is a patina rather than a complete corrosion crust, significant compositional differences can be exhibited between this outer layer and the bulk metal (Shackley 2011).

Taken together, the above factors describe a situation where a variety of post-depositional and analytical factors combine to indicate that significant compositional alteration can be assumed to have occurred for any given copper/bronze artifact from Harappa. This alteration is likely not uniform or consistent from artifact to artifact. Since there are also a variety of pre-depositional factors that could have affected the composition of the artifacts as well, there is no generalized correction possible that can account for all potential compositional changes. However, there are several things that can be applied to the overall analytical procedures that will allow for pre and post depositional alterations to the chemical make-up of the artifacts to be controlled for or at least discriminated between. The first is that the PXRF analytical procedures must be constructed in such a way that the x-ray beam is allowed to penetrate the object beyond the outer corrosion layer or layers. The second is that all other analyses must be conducted on bulk metal or bulk altered material to ensure a representative sample of the overall material was obtained. Finally, the results of each of the major analytical procedures must be understood as being filtered through a lens of potentially significant compositional alterations. Further detailed

discussions of the procedures developed during the course of the project to account for these realities are provided at the appropriate sections of this work.

Identification of Key Elements

Prior to starting any analytical program of sample analysis, it was necessary to identify what elements could be utilized to aid in developing explanatory models for alloying patterns, potential source provenience, and the social role of metals at Harappa during the pre-Harappan and Harappan occupation at the site (circa 3700-1900 BCE). Previous research at several Indus sites has generated data on a number of elements, but no consistent suite of elements has been applied across all the various analytical programs. A review of analytical programs from differing world areas focused on the compositional analysis of archaeological copper and bronzes reveals a varied set of target elements. These lists typically include the majority of the chalcophile elements (those that bond readily with sulfur) and a selection of siderophile elements (elements with no affinity for oxygen). The variations seen in the lists are most likely attributable to differences in regional ore geology, as the source material will exert a considerable influence on the compositional pattern of the final copper/bronze product. Researchers in a given geographical area may make choices about what elements to analyze the artifact assemblage for based on the likelihood of the raw material being derived from either copper sulfide ores or copper oxide ores. This is not to say that the linkages between ore geology and the compositional

make-up of an individual artifact can be assumed to be in such a direct relationship. A variety of research in the past several decades has demonstrated that the linkage between whole impurity patterns (all the elements that are not copper) in an artifact and the elemental composition of a given ore resource are not always conclusive (Gale 2000). However, it has been demonstrated that the elemental make-up of the parent ore can be seen to a certain degree in the finished artifact (Pernicka 1999; Ixer 1999) most prevalently in the form of accessory minerals (such as zinc, nickel, arsenic, lead, etc) and either siderophile or chalcophile impurities.

Focusing the issue of selecting specific elements of interest on Indus copper/bronze materials narrows the selection parameters to a degree. One of the goals of the current project was to ensure that the data generated during the analytical portion of the research was comparable with previously completed studies. This fact alone mandated the inclusion of certain elements, primarily sulfur (S), nickel (Ni), lead (Pb), Arsenic (As), and tin (Sn). These elements are necessary because they allow this project to make comparisons to the majority of the work already completed on Indus copper and bronze objects. The identification of additional elements of analytical interest was based on two primary factors. The first was if the element would be able to be used to investigate alloying and/or manufacturing patterns in the assemblage from Harappa. The second was if the element could also assist in providing information on the possible provenience of the copper raw material used in its manufacture. Considering the overall compositional analysis program from this perspective generated the following list of elements in Table 4.1 (after Pernicka 1999:170; Hauptmann:2007:19).

Table 4.1: Elements Analyzed in the HARP Copper/Bronze Assemblage

Element	Application
Copper	Technology
Lead	Technology and Provenience
Arsenic	Technology and Provenience
Tin	Technology and Provenience
Zinc	Technology and Provenience
Antimony	Technology and Provenience
Bismuth	Provenience
Gold	Provenience
Silver	Provenience
Nickel	Provenience
Sulfur	Technology
Iron	Technology
Cobalt	Provenience

PXRF Sample Set and Analytical Goals

A total of 317 copper/bronze artifacts from Harappa were analyzed using a portable X-Ray Fluorescence instrument (see Appendix 4.1 for all PXRF data). These samples were taken from the Harappa study collection of approximately 2581 objects uncovered during the HARP excavations (see Chapter 3). These 317 objects comprise the entire appropriate sample set from a total sample assemblage of 360 (see Appendix 3.1) copper/bronze artifacts that have been collected for study both by the author and previous HARP compositional analysis study programs. 24 samples were not analyzed because they had either been previously characterized as slag or copper mineral or were judged to be unable to interact properly with PXRF

instrumentation. Previous analytical programs (see analyses in Kenoyer and Miller 1999) and the current lead isotope pilot study (see Chapter 5) had expended 19 of the remaining 336 samples.

Due to quantitative limitations of the PXRF instrumentation, the goals for this portion of the project were limited. The primary aim of this portion of the overall project was to produce a rapid set of analyses that could be used to characterize individual members of the overall Harappa sample set as either copper objects or copper-alloys. Further, it was anticipated that the data produced from this series of analyses would allow for the samples to be assigned to particular alloy groups. This would allow for subsequent analytical procedures (i.e. ICP-OES and Lead Isotope Analysis) to be conducted on a preferentially selected target group of samples. It would also serve to aid in ensuring that data derived from copper objects and copper alloys would not be conflated.

X-ray fluorescence spectrometry has long been part of archaeological science research programs and since at least the 1950's, the technology has been applied to the analysis of copper and copper alloys (Heginbotham et al. 2010). In contrast, portable X-ray Fluorescence technology is relatively recent in its broad-scale application to archaeology (Shackley 2011; Potts and West 1998). Many of the studies involving PXRF instrumentation have been focused on the analysis of ceramics, glass, and obsidian (Shackley 2011; Glascock 2011). However, a variety of projects have begun to apply this technology to archaeological copper and bronzes (Alyward et al. 2011; Smith 2012). A review of these research projects and others reveals that the use of PXRF techniques and instrumentation in archaeology has encountered a number of interpretative and practical issues. As Shackley (2011) cogently points out, the major issues stem from an understanding of the capabilities and limitations of the technology and the underlying scientific principles.

While it is not the goal of the current study to refine or evaluate the discipline wide validity of PXRF data, it is critical to understand the applicability and utility of the PXRF data generated during the project. Primarily it is necessary to understand how accurate and precise the measurements for copper, lead, tin, and arsenic are and to what degree the results for these elements can be used to evaluate relevant project research questions. In this context, the crucial questions to be addressed regarding PXRF are as follows:

- What are the known limitations of the technology and what steps can be taken to account for those limitations in the evaluation of the data produced during the current study?
- Can the instrumentation and analytical set-up employed for this project consistently and accurately identify the key elements necessary to determine if an unknown artifact is either a copper or copper alloy?
- Does the data generated allow for quantitative definitions of alloy types or is the data more appropriately employed as a relativistic/qualitative measure?

A brief review of the analytical and instrumentation set-up employed in this study as well as a comparison to similar studies in the wider literature should serve to adequately address the above questions.

PXRF ANALYSIS PROCEDURE

All samples were analyzed using a Bruker Tracer IV portable X-ray Fluorescence instrument. The instrument was set at 40 kilovolts (kV) and 1.6 micro amps (1.6 μ A). The analysis time was set for either 120 or 180 seconds for all samples analyzed. A titanium (Ti) and aluminum (Al) sandwich filter was put into the instrument. These protocols were followed on the advice of representatives from Bruker (B. Kaiser personal communication) and are the

company's suggested set-up for the analysis of copper and copper alloys. Recent research at Troy used similar analytical procedures with success (Aylward et al. 2012). This analytical set-up eliminates the lighter elements (those below calcium on the periodic table). This filtering only allows x-rays from between 4keV to 40 keV to excite the sample (Smith 2012:42). Consequently, the instrumentation is more readily able to properly identify metallic elements without interference effects.

The Bruker Tracer IV portable X-ray Fluorescence instrument is best utilized as a rapid, non-destructive method for characterizing the compositional make-up of the copper/bronze materials from Harappa. Currently the instrumentation uses a best-fit curve, based on modern copper and copper alloy standards, to identify the composition of ancient copper artifacts. This is problematic in that ancient metallurgical production was not able to achieve the purity of modern technological standards. As a result, the compositional benchmarks used to construct the Bruker's calibration curve are neither wholly appropriate to nor representative of a 3rd millennium Bronze Age reality. However, this is not to say that the results are without explanatory utility. The instrument does produce what can best be termed qualitative results for ancient copper and copper/bronze metals. The compositional percentages reported by the XRF scanner for a given element are not precise enough to make specific determinations about the metallurgical "recipe" used to produce a given object, but they do allow for the identification and discrimination of copper alloys and the data produced provides for excellent relativistic intra-assemblage comparisons. While an identification of specific elemental percentages is not presently possible for 3rd millennium copper and bronze artifacts, the potential to develop a calibration procedure does exist.

It is important to note what the outlined instrument set-up allows the analyst to accomplish. The PXRF portion of this study is best suited for the identification of the presence or absence of key elements rather than the quantification of specific metallurgical recipes or suites of trace elements in copper/bronze objects (Aylward et al. 2012). This is primarily due to a lack of proper calibration procedures rather than an inherent limitation in the technology. Recent work with Renaissance bronzes has demonstrated that specific calibration procedures can be developed and adapted for implementation with the Bruker instrumentation as well as any other PXRF technology (Smith 2012). The work at the National Gallery of Art (Smith 2012:42-43) and that at Troy (Aylward et al. 2012) has also validated the instrument set-up outlined above. As the copper/bronze samples from Harappa were both cut samples with exposed interior faces and of sufficient size to interact with the x-ray beam, it should be possible to eventually develop a specific calibration for the quantification of the elemental composition of Indus copper/bronzes. The work of Smith (2012) can serve as an excellent model for future research along these lines.

A final example of some of the difficulties in quantifying PXRF data from copper and bronze objects is the overlap of peaks of similar energy. In copper-based alloys; lead, and arsenic can exhibit significant overlap between the arsenic K-Alpha and lead L-alpha peaks on the spectrum (Aylward et al. 2011). There is a secondary arsenic K-Beta peak that will allow for the identification of the presence of arsenic rather than having it be consistently masked by lead in any copper-lead-arsenic alloys (B. Kaiser personal communication). Again, it is necessary to stress that for this and other reasons, PXRF data for Indus copper/bronze metals must be viewed as qualitative. There are encouraging signs that this non-destructive, rapid, and portable technology may be adapted to produce high-resolution quantitative results in the future. This

would be beneficial to the comparative study of Indus copper metallurgy at a regional level. Future projects will seek to develop and implement a calibration for the Indus that will be based on the data generated during this thesis project.

The methods employed during the PXRF portion of the project ensured that the data collected could be utilized to address key overall research questions. The PXRF instrumentation was able to return results for each of the analyzed objects that produced two key lines of evidence. The first was the presence or absence of particular elements. The second was through a relative comparison of the amounts of any elements of interest it was possible to develop a relativistic ranking of the objects in the HARP assemblage. The rapid and accurate identification of copper alloys of different types was critical to the next stage of compositional analysis. Overall the PXRF returned a series of useful and intriguing results.

PXRF Results and Discussion

The results from the portable x-ray florescence component of the project are best characterized as a relative, comparison-based scanning mode of analysis. 317 objects were rapidly and non-destructively analyzed for their major compositional make-up. The results of these analyses were used to identify the range of copper alloy types present in the HARP copper/bronze assemblage, flag objects that appeared to have elevated levels of typical copper alloying elements or unusual compositional components, to test for patterning of compositional signatures both within and across artifact categories, and to define any patterning seen both within and across temporal and spatial divisions at Harappa.

Unalloyed copper metal objects and artifacts fashioned from one of 7 alloy types were documented during the PXRF analyses. These can be divided into “bronzes” and “alloys” (Table

4.2). “Bronzes” are the artifacts that exhibit one of three alloy types; copper (Cu) and tin (Sn) or tin bronze, copper and lead (Pb) or leaded bronze, and copper and arsenic (As) or arsenical bronze. In contrast, “alloys” are artifacts that demonstrate a pattern of alloying with copper but that do not fall into a clearly distinct category. These are alloys of copper, lead, and arsenic, copper, tin and lead, and copper, tin, lead, and arsenic. It is possible that the Cu-Sn-Pb alloy can be classified as a tin bronze, since the lead is most likely not added as an additionally alloying element to alter the final properties of the metal. Lead was either added as a fluxing agent to aid in casting or the lead could be from the parent ore, such as in the polymetallic copper ores from the Ambaji-Deri portion of the Aravalli Range copper deposits in Gujarat (see Chapter 6 for discussion). It is important to note that with the PXRF analysis it is not possible to determine the levels of arsenic and lead with a high degree of accuracy. For the purposes of alloy categorization, the presence or absence of these elements was all that can confidently be discriminated. It is uncertain in some cases whether or not arsenic or lead are the major alloying element. In other words, it is possible that Cu-Pb-As alloys are Cu-As-Pb alloys. For ease of presentation, all copper, lead, and arsenic alloys, regardless of potential ranked make-up, are classed as Cu-Pb-As. The raw spectra data for the PXRF analyses are provided in Appendix 4.1. One unique alloy, copper with silver, gold, and lead was identified during the PXRF analysis program. For this section, summary charts will be provided in order to readily highlight the important results of this portion of the compositional analysis program.

Table 4.2: Alloy Types in the HARP Assemblage (PXRF)

Alloy Type	Designation
Copper (Cu)	Unalloyed Metal
Copper-Arsenic (Cu-As)	(Arsenical) Bronze
Copper-Lead (Cu-Pb)	(Leaded) Bronze
Copper-Tin (Cu-Sn)	(Tin) Bronze
Copper-Tin-Lead (Cu-Sn-Pb)	Alloy
Copper-Lead-Arsenic (Cu-Pb-As)	Alloy
Copper-Lead-Tin-Arsenic (Cu-Sn-Pb-As)	Alloy
Copper-Silver-Gold-Lead (Cu-Ag-Au-Pb)	Alloy

Arrows

A total of 43 arrows were included in the sample set from Harappa. 1 of these was expended in a previous analytical research program, leaving a total of 42 to be analyzed via PXRF. The results are presented in Table 4.3 below.

Table 4.3: PXRF Results for HARP Arrows

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	0	-
Kot Diji (2800-2600 BCE)	2	1 Cu-As, 1 Cu-Pb
Harappan (2600-1900 BCE)	28	3 Cu, 4 Cu-As, 13 Cu-Pb, 2 Cu-Sn, 1 Cu-Sn-Pb, 5 Cu-Pb-As
Late Harappan (1900-1300 BCE)	0	-
Mixed & Unknown	12	6 Cu, 1 Cu-As, 4 Cu-Pb, 1 Cu-Sn

Arrows present a mixture of alloy types. They are fashioned from all of the bronze types and all of the alloy types, except Cu-Sn-Pb-As. Overall, arrows from Harappa are fashioned predominately (71.4%) from bronzes. It is important to note that the majority of the bronzes are some mixture of copper, lead, and/or arsenic with only 4 (9.5%) of the analyzed sample set containing tin.

Rods/Wires/Pins

A total of 80 rods, wires, and pins were part of the overall sample set from Harappa. Previous analytical work had expended one of these; leaving 79 of this object category for PXRF analysis (Table 4.4). Rods are made from all of the identified bronze and alloy types as well as unalloyed copper. 15 rods are fashioned from copper, 39 from bronzes, and 25 from alloys. Overall, 81 percent of the assemblage is made from either a bronze or an alloy. Examining the distribution of bronzes and alloys, further trends can be identified. A total of 25 of the 64 bronzes and alloys are made from either Cu-Sn or Cu-Sn-Pb. 18 items are manufactured from a leaded bronze and 13 use arsenical bronze. Eight are from a combination of Cu-Pb-As and Cu-Sn-Pb-As. In this category of objects from the HARP sample assemblage, bronzes, and specifically tin bronzes dominate the distribution of alloy types.

Table 4.4: PXRF Results for HARP Rods/Wires/Pins

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	3	3 Cu
Kot Diji (2800-2600 BCE)	7	2 Cu, 3 Cu-As, 1 Cu-Pb, 1 Cu-Pb-As
Kot Diji/Harappan (2800-2450 BCE)	2	1 Cu-As, 1 Cu-Pb-As
Harappan (2600-1900 BCE)	42	6 Cu, 6 Cu-As, 10 Cu-Pb, 6 Cu-Sn, 9 Cu-Sn-Pb, 3 Cu-Pb-As, 2 Cu-Sn-Pb-As
Mixed & Unknown	25	4 Cu, 3 Cu-As, 7 Cu-Pb, 2 Cu-Sn, 8 Cu-Sn-Pb, 1 Cu-Pb-As

Table 4.5: PXRF Results for HARP Sheets

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu-As
Kot Diji (2800-2600 BCE)	3	2 Cu, 1 Cu-Pb, 1 Cu-As
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu-Sn-Pb
Harappan (2600-1900 BCE)	13	2 Cu-As, 8 Cu-Pb, 1 Cu-Sn 1 Cu-Sn-Pb, 1 Cu-Pb-As
Harappan/Late Harappan (1900-1800 BCE)	1	1 Cu-Pb
Mixed & Unknown	19	4 Cu, 6 Cu-Pb, 1 Cu-Sn, 6 Cu-Sn-Pb, 2 Cu-Pb-As, 1 Cu-Sn-Pb-As

Sheets

Thirty-nine sheets were part of the total HARP sample assemblage. Previously one object had been analyzed using PIXE and returned to the museum collection at the site. This object was not reanalyzed since the compositional results from the PIXE were sufficient. The remaining 38 objects were analyzed using the PXRF instrumentation and were distributed as summarized in Table 4.5. Only 6 of the 38 analyzed sheets (15.8%) of the sheet sub-assemblage was made from unalloyed copper. Of the remaining members of this group, 21 were made from one of the three bronze types (65.3% of the sub-assemblage) with leaded bronzes being the dominant bronze type, and 12 were fashioned from one of the three alloy types. However, it is instructive to note that half of the alloy group is comprised of Cu-Sn-Pb alloys. If these were reclassified as a bronze, then 71 % of the assemblage would be fashioned from a bronze of one type or another. In summary, the objects from this category are overwhelmingly made from a copper alloy.

Miscellaneous Fragments and other Unclassified Objects

The HARP sample assemblage contains 90 miscellaneous or other unclassified objects. These are copper/bronze artifacts that do not fit into any other established category. Of these 90 objects, a total of 87 were available for PXRF analysis. The results for this category are summarized in Table 4.6.

Table 4.6: PXRF Results for HARP Miscellaneous & Unclassified Objects

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	4	1 Cu-As, 1 Cu-Pb, 1 Cu-Sn 1 Cu-Sn-Pb
Kot Diji (2800-2600 BCE)	4	1 Cu-As, 1 Cu-Sn, 2 Cu-Sn-Pb
Harappan (2600-1900 BCE)	37	13 Cu, 1 Cu-As, 12 Cu-Pb, 3 Cu-Sn, 4 Cu-Sn-Pb, 3 Cu-Pb- As, 1 Cu-Ag-Au-Pb
Harappan/Late Harappan (1900-1800 BCE)	2	1 Cu, 1 Cu-Sn-Pb
Mixed & Unknown	40	19 Cu, 4 Cu-Pb, 2 Cu-As, 4 Cu-Sn, 3 Cu-Sn-Pb, 7 Cu-Pb-As, 1 Cu-Sn-Pb-As

All of the alloy and bronze types that were previously identified have been documented in the miscellaneous and unidentified objects category. Over one third (37.9%) of the analyzed sub-assemblage is comprised of unalloyed copper. 36.7% is comprised of the three bronze types and 25.3% is made up of the three alloy types. A single object is comprised of a unique alloy type in the entire HARP sample assemblage. This object is made from an alloy of copper (Cu), silver (Ag), gold (Au), and lead (Pb). The more even distribution across the major categories of copper/bronze metal types is due to the fact that this category represents a catch-all placement for non-diagnostic artifacts and is more than likely comprised of fragments of artifacts from all

other categories found at the site. As a result, this category does not contribute directly to the identification of alloying patterns at Harappa.

Prills and Mineral/Ore

Twenty-five prills and one fragment of copper mineral/ore were included in the analyzed PXRF sample set. The single piece of ore appears to be a mixture of copper and iron, possibly chalcopyrite (CuFeS_2). The prills were primarily from the Harappan Phase or later and are summarized in Table 4.7.

Table 4.7: PXRF Results for HARP Prills and Minerals

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu-As
Kot Diji (2800-2600 BCE)	1	1 Cu-As
Harappan (2600-1900 BCE)	13	2 Cu, 3 Cu-As, 1 Cu-Pb, 2 Cu-Sn, 1 Cu-Sn-Pb, 3 Cu-Pb-As, 1 Cu-Sn-Pb-As
Mixed & Unknown	10	1 Cu, 3 Cu-Pb, 3 Cu-Pb-As, 2 Cu-Sn-Pb, 1 Cu-Sn-As

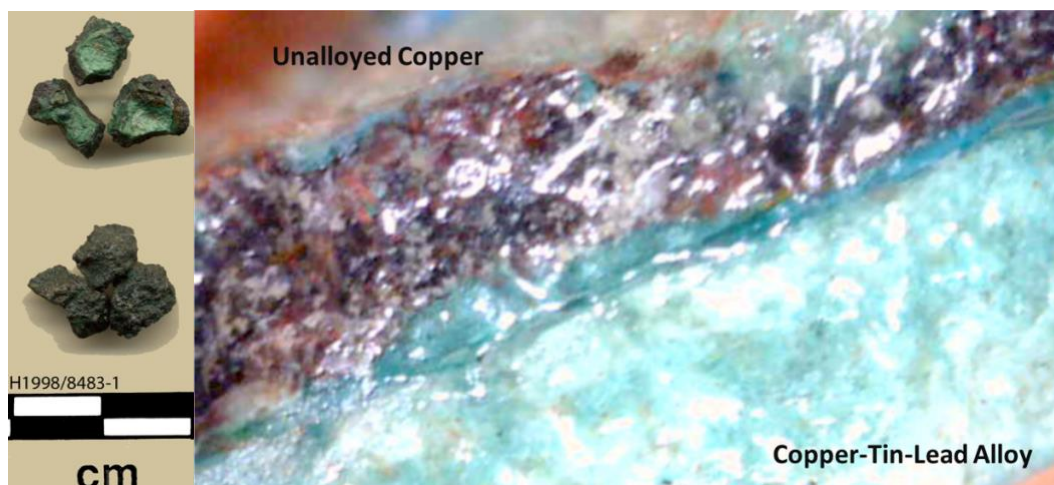
The alloy types exhibited in the prills cover all of the bronzes and alloys defined in the other categories of copper/bronze objects documented at Harappa. This is suggestive of the possibility of on-site manufacture of any alloy or bronze type. This category adds a unique alloy type, copper, tin, and arsenic. However, it is cautioned that it is possible that the arsenic result indicated here is actually lead and the element has been misidentified due to energy overlaps at diagnostic peaks in the XRF spectra.

Tablets

A single molded tablet was available for analysis using PXRF. This object was made from arsenical bronze (Cu-As).

Discs and Mirrors

A mirror from the Harappan Phase was also analyzed. This object was manufactured using unalloyed copper (Cu). Two discs from the Harappan Phase was available for analysis using PXRF. One was made from copper, tin, and lead alloy (Cu-Sn-Pb). A second disc presented a more intriguing compositional pattern. This object was made from a copper, tin, and lead alloy (Cu-Sn-Pb) as well as unalloyed copper (Cu). The nature of the disc is potentially unique in the sample set from Harappa. It appears to be a “laminated” object (Figure 4.2). This copper disc was recovered from Mound AB and dates to the initial portion of the urban phase at the site (Period 3A). Analysis of each side of the object revealed a face of the object that was made from unalloyed copper and another that was a copper alloy with tin and lead. It is hypothesized that this represents a copper object that was then coated with a tin bronze on one face to achieve a desired visual appearance. In this case the lead was added to the tin bronze to aid in casting. Such a composite structure and complex manufacturing process may have been a method employed by Harappan metalsmiths to achieve a desired final visual appearance for specific types of objects, such as disc ornaments, while using less tin bronze. It is possible that other copper-tin-lead alloy personal ornaments (beads, bangles, rings, and discs) from Harappa may also have been manufactured in this “laminated” manner, but, at present, there is only definitive evidence for this one disc in the sample assemblage.

Figure 4.2: Laminated Copper and Bronze Disc

Rings

Fifteen rings were analyzed using the PXRF instrumentation (Table 4.8). Seven out of the 15 rings are made using unalloyed copper metal while the remaining eight are made from some type of copper alloy, with leaded bronze being the most numerous. Overall it appears that rings were made from a wide range of alloyed and unalloyed materials.

Table 4.8: PXRF Results for HARP Rings

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	1	1 Cu
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu-Pb
Harappan (2600-1900 BCE)	11	6 Cu, 4 Cu-Pb, 1 Cu-Sn-Pb
Mixed & Unknown	2	1 Cu-As, 1 Cu-Pb

Bangles

A total of 12 bangles were analyzed during this portion of the overall analytical program. Bangles are predominantly manufactured from either a bronze or a copper alloy (Table 4.9). 8 of 12 bangles are either a tin bronze or a copper-tin alloy. Only three of the 12 bangles are made from unalloyed copper metal. Initial PXRF results strongly indicate that the visual appearance of tin bronze was a preferred raw material for the manufacture of bangles at Harappa.

Table 4.9: PXRF Results for HARP Bangles

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	3	3 Cu-Sn-Pb
Harappan (2600-1900 BCE)	5	1 Cu, 1 Cu-Pb, 2 Cu-Sn, 1 Cu-Sn-Pb
Mixed & Unknown	4	2 Cu, 1 Cu-Pb-As, 1 Cu-Sn-Pb

Beads

Fourteen beads out of a total of 15 from the overall HARP sample assemblage were analyzed during the PXRF portion of the research project (Table 4.10). Beads demonstrate a pattern broadly similar to that for bangles. The use of alloys or bronzes dominates the material identified using PXRF (Table 10) with 71.4% of the analyzed beads being manufactured from either a bronze or copper alloy. Preliminary conclusions indicate that the visual appearance of the finished object is the critical selective factor.

Table 4.10: PXRF Results for HARP Beads

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu
Kot Diji (2800-2600 BCE)	2	2 Cu-Sn-Pb
Harappan (2600-1900 BCE)	7	2 Cu, 1 Cu-As, 2 Cu-Sn, 1 Cu-Pb, 1 Cu-Sn-Pb
Mixed & Unknown	4	1 Cu, 1 Cu-Pb, 1 Cu-Pb-As, 1 Cu-Sn-Pb

Compositional Analysis with Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES)

After reviewing the data from the PXRF analyses, it was determined that additional analytical work was required on the HARP copper/bronze assemblage. The PXRF data was sufficient to document the potential for some intriguing and useful patterns in the HARP copper/bronze assemblage, but more accurate and precise data was needed to fully investigate all the potential compositional patterns and preliminary alloy types identified in the analysis of the x-ray data. Inductively coupled plasma-optical emission spectroscopy (ICP-OES) was selected for a variety of reasons. The first is that the technique has a well-documented record of producing the type of data required at this stage of the research program. The total dissolution of a portion of the artifact (typically a number of milligrams) accounts for inhomogeneous samples. A number of research projects that had a similar focus on the compositional signatures of copper and bronze archaeological artifacts have had success with the application of ICP-OES technology (Hauptmann 2007; Guimla-Mair 2005). Recent research has argued for the use of inductively coupled plasma mass spectrometry (ICP-MS) as the ideal means of analysis for ancient copper-based metals (Young et al. 1997; Young and Pollard 2000; White et al. 2000).

The major reason for advocating the use of this technique is that it allows for the simultaneous measurement of a large number of elements (Malainey 2011). However, for the materials analyzed in this project, this advantage was not necessary, and the less expensive and more traditional emission technique was selected. The primary reason for this is that a pre-selected list of target elements was all that was needed, rather than scanning each sample for a wide range of unknown elements. Overall, any analytical procedure that involves the dissolution and bulk analysis of the metallic material, rather than a target beam micro-analysis, such as electron microprobe or proton-induced x-ray emission spectroscopy (PIXE), will allow for a definitive analysis of the compositional signature of copper and copper alloy metals (Hauptmann 2007:31).

The compositional analysis conducted using ICP-OES was done in two stages, at two different laboratories. The first was conducted at the T. Douglas Price Laboratory for Archaeological Chemistry at the University of Wisconsin-Madison Department of Anthropology (Set 1). The second stage was conducted at the University of Wisconsin-Madison Soils and Plant Analysis Laboratory (Set 2). A total of 130 samples were analyzed during the first sample run and a prioritized sub-set of 54 of these samples was analyzed during the second run (See Appendix 4.2 and 4.3 for the ICP-OES raw data). This nested sampling strategy was implemented in order to accomplish two main goals. The first was to use a larger sample set (130) to test and verify the trends seen in the PXRF data. The second was to then sample artifacts from prioritized archaeological contexts that ensured there would be secure chronological and spatial components for the trends identified through the analytical program.

ICP-OES Analysis Procedure

The sample preparation and analysis procedures were similar for both sets of ICP-OES analyses. For each sample, a total of 15 milligrams (mg) of material was taken and dissolved in

0.75 milliliters (ml) of acid. After testing several acids for their effective dissolution of known copper and bronze standards, a one to three solution of nitric acid (HNO_3) and hydrochloric acid (HCL) was determined to be the most effective at dissolving all of the sample material. This acid mixture is most commonly referred to as aqua regia. The dissolved sample was then diluted with 14.25 milliliters of ultra-pure water (H_2O) for a total of 15 mL of solution. The only difference between the two sets of analyses was the addition of two certified reference materials for the study of archaeological bronzes to the sample set analyzed at the University of Wisconsin-Madison Soils and Plant Analysis Laboratory. This was done to provide an adequate internal standard that mimicked the expected results from the archaeological samples. After the initial run of data at the T. Douglas Price Laboratory for Archaeological Chemistry at the University of Wisconsin-Madison Department of Anthropology it was determined that existing laboratory reference materials were often not representative of the actual compositional levels found in ancient copper and bronze artifacts and proved to be somewhat problematic during calibration. The inclusion of the certified reference materials during the analysis of the second ICP-OE sample set served to eliminate, or at least, mitigate this concern.

ICP-OES Results and Discussion

The ICP-OES results are divided into two sets. The first set is 130 analyses (Appendix 4.2) that were conducted at the T. Douglas Price Laboratory for Archaeological Chemistry at the Department of Anthropology, University of Wisconsin-Madison (referred to hereafter as LARCH). The second set is 54 ICP-OES analyses (Appendix 4.3) that were conducted at the University of Wisconsin Soil Testing Laboratory, Madison (hereafter referred to as UW Soils). Of this second set, 30 were repeat analyses from the LARCH set to provide some potential for

comparison between the two data sets. The results for each ICP-OES analysis set are presented in turn below. As was done for the PXRF analyses, each artifact analyzed was investigated for the presence and amount of copper and the three potential alloying elements (arsenic, lead, and tin) for each artifact.

LARCH Analyses

Table 4.11: Alloy Types in the HARP Assemblage (LARCH)

Alloy Type	Designation
Copper (Cu)	Unalloyed Metal
Copper-Arsenic (Cu-As)	(Arsenical) Bronze
Copper-Lead (Cu-Pb)	(Leaded) Bronze
Copper-Tin (Cu-Sn)	(Tin) Bronze
Copper-Tin-Lead (Cu-Sn-Pb)	Alloy
Copper-Lead-Arsenic & Copper-Arsenic-Lead (Cu-Pb-As & Cu-As-Pb)	Alloy
Copper-Tin-Lead-Arsenic (Cu-Sn-Pb-As)	Alloy

The LARCH analyses documented the presence of unalloyed copper as well as the three bronze types previously identified via PXRF, as well as the three major alloy types (Table 4.11). This initial survey of the LARCH results is an important step in and of itself. It serves to verify and substantiate the PXRF results as identifying and distinguishing valid bronze and alloy types within the HARP copper/bronze assemblage. Additionally, the ICP-OES results indicate that there is a distinct split between the alloying of copper with lead and arsenic. Previously, this alloy type had been only classed as Copper-Lead-Arsenic, regardless of the perceived ranked order of lead and arsenic from the peak data taken from the PXRF analyses. This was because it is often difficult to distinguish between the two elements when attempting to make precise distinctions from the data. The more precise nature of the data from the LARCH analyses allows

for the separate and verified nature of this alloy to be confirmed. Regardless of the ranked order of lead or arsenic in the alloy, it should not change either the visual or structural properties of the final alloy. Both elements, in any combination above the established 1 percent benchmark, should server to alter the color and/or strength of the final object. For this reason, the two alloys, Cu-Pb-As and Cu-As-Pb are counted together in the following data summary.

Arrows

A total of 21 arrows were analyzed during the LARCH portion of the overall analytical program. The results are summarized in Table 4.12. Only 14.29 % of the analyzed arrows (2/14) were fashioned from unalloyed copper. Overall, 76.19 % of the arrow points analyzed were made of some alloy of copper, arsenic, lead or a combination of all three. Only 3 arrow heads contained appreciable amounts of tin.

Table 4.12: LARCH Results for HARP Arrows

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	0	-
Kot Diji (2800-2600 BCE)	2	2 Cu-As
Harappan (2600-1900 BCE)	14	1 Cu, 3 Cu-As, 4 Cu-Pb, 4 Cu-Pb-As, 1 Cu-Sn, 1 Cu-Sn-Pb
Mixed & Unknown	5	1 Cu, 1 Cu-As, 1 Cu-Pb, 1 Cu-Pb-As, 1 Cu-As-Sn

Rods/Wires/Pins

A total of 41 copper rods, wires, or pins were analyzed during the LARCH session. The results are summarized in Table 4.13. The results from the LARCH analyses only identified eight

out of a total of 41 objects from the category of rods, wires, and pins that were manufactured from unalloyed copper (19.51%). The overwhelming majority of this category, 80.49%, was made using some sort of bronze or other copper alloy. 14 objects are made from arsenical bronze and 8 are made with tin bronze. A remaining 8 contain a mixture of tin and other alloying elements while a final 4 objects are made from alloys of arsenic and lead. Not surprisingly for a category dominated by objects that serve a functional purpose, the majority are made from alloyed copper of one type or another.

Table 4.13: LARCH Results for HARP Rods/Wires/Pins

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	2	1 Cu, 1 Cu-As
Kot Diji (2800-2600 BCE)	4	1 Cu, 3 Cu-As
Harappan (2600-1900 BCE)	26	5 Cu, 10 Cu-As, 2 Cu-Pb-As, 1 Cu-Pb-As, 5 Cu-Sn, 3 Cu-Sn-Pb
Mixed & Unknown	9	1 Cu, 1 Cu-As-Pb, 3 Cu-Sn, 1 Cu-Sn-As, 2 Cu-Sn-Pb-As, 1 Cu-Pb-Sn-As

Sheets

A total of 18 copper-bronze sheets were analyzed for the LARCH portion of the research program. They are almost totally manufactured from bronzes or alloyed copper. Only three of the 18 analyzed artifacts were made with unalloyed copper (16.67%). Table 4.14 demonstrates that the most significant alloy types in the sheet assemblage is that of copper, arsenic, and lead alloys. Only 16.67% of this sub-assemblage contains tin, while 66.66% contains some combination of arsenic and/or lead with copper.

Table 4.14: LARCH Results for HARP Sheets

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu-As
Kot Diji (2800-2600 BCE)	2	2 Cu-As
Harappan (2600-1900 BCE)	8	2 Cu, 1 Cu-As, 2 Cu-Pb, 2 Cu-As-Pb, 1 Cu-Pb-As
Mixed & Unknown	7	1 Cu, 1 Cu-As, 1 Cu-Pb, 1 Cu-As-Pb, 3 Cu-Sn

Miscellaneous Fragments and other Unclassified Objects

During the LARCH segment of the analytical portion of this research project, 15 miscellaneous fragments or other unclassified objects were analyzed (Table 4.15). Although these artifacts lacked distinctive diagnostic features enabling them to be placed in any of the other broad categories that are used to classify the HARP copper-bronze assemblage, they did exhibit alloy signatures that are consistent with the results from the rest of the analyzed assemblage.

Table 4.15: LARCH Results for HARP Miscellaneous & Unclassified Objects

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	3	1 Cu, 1 Cu-As, 1 Cu-Sn-Pb-As
Kot Diji (2800-2600 BCE)	2	1 Cu-Sn-Pb, 1 Cu-Pb-As
Harappan (2600-1900 BCE)	9	5 Cu, 2 Cu-Pb, 1 Cu-As 1 Cu-Pb-As
Mixed & Unknown	1	1 Cu-Pb-As

The miscellaneous sub-assembly is roughly split between unalloyed copper (46.67%) and lead based copper alloys (33.33%). This is not out of line with the overall results from the analysis to date that exhibit a large use of lead in alloying alongside unalloyed copper items.

Prills

During the LARCH component of the analytical program, 20 prills were analyzed (Table 4.16). The results exhibited similar patterns as seen in the previous XRF results. All alloy types, including unalloyed copper were present in the prills sub-assembly. This is important because it is potentially indicative that alloying and/or recycling were occurring at metallurgical workshops within Harappa based either on the re-melting of scrap objects, the fashioning of new objects from semi-processed raw materials (ingots), or some combination of the two.

Table 4.16 shows that even during the earliest occupation phase at the site, the Ravi (3300-2800 BCE), there is evidence for the production of objects made from a copper-arsenic alloy. This is intriguing because it may reveal that the earliest metal craftspeople at Harappa were already familiar with working with bronze and other copper alloys.

Table 4.16: LARCH Results for HARP Prills

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu-As
Kot Diji (2800-2600 BCE)	1	1 Cu-As
Harappan (2600-1900 BCE)	12	2 Cu, 2 Cu-As, 1 Cu-Pb, 1 Cu-As-Pb, 2 Cu-Pb-As, 2 Cu-Sn, 1 Cu-Sn-Pb, 1 Cu-Sn-Pb-As
Mixed & Unknown	6	2 Cu-Pb-As, 2 Cu-Sn 1 Cu-Sn-Pb, 1 Cu-Sn-Pb-As

Discs

One disc from the Harappan Phase occupation of the site was analyzed during the LARCH session. It was made from a copper-tin-lead alloy. As it is hypothesized that discs were a decorative item within the overall Harappa copper-bronze assemblage it is not surprising that this object was fashioned from what would have been a visually distinct alloy type.

Rings

Only three rings were analyzed during this portion of the project (Table 4.17) and two were made from copper-arsenic based alloys and one was unalloyed copper.

Table 4.17: LARCH Results for HARP Rings

Occupational Period	# of Artifacts	Alloy Type
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu-As-Pb
Harappan (2600-1900 BCE)	2	1 Cu, 1 Cu-As

Bangles

Seven bangles were analyzed at LARCH (Table 4.18). All but one of the artifacts was made from a copper-tin based alloy. This fits the pattern of the use of visually distinctive alloys being used to make bangles that was seen in the PXRF results.

Table 4.18: LARCH Results for HARP Bangles

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	3	3 Cu-Sn-Pb
Harappan (2600-1900 BCE)	3	1 Cu, 1 Cu-Sn-Pb, 1 Cu-Sn-Pb-As
Mixed & Unknown	1	1 Cu-Sn-Pb

Beads

Four beads were analyzed at LARCH (Table 4.19) and fit the patterns already hypothesized for decorative object categories within the HARP copper-bronze assemblage. Three out of the four are fashioned from a copper alloy that would have provided the final object with a visual striking appearance.

Table 4.19: LARCH Results for HARP Beads

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	1	1 Cu-Sn-Pb
Harappan (2600-1900 BCE)	1	1 Cu
Mixed & Unknown	2	1 Cu-As-Pb, 1 Cu-Sn-Pb

UW Soils Analyses

A final set of 54 ICP-OES analysis was conducted (see Appendix 4.3). Of the 54 artifacts analyzed, 31 were also analyzed during the LARCH portion of the compositional analysis program. The UW Soils analysis also documented all of the previously identified alloys and bronzes (Table 4.20), except for copper-tin-arsenic-lead. As with the previous portions of the analytical segment of the project, each artifact category will be summarized in turn.

Table 4.20: Alloy Types in the Harappa Assemblage (UW Soils)

Alloy Type	Designation
Copper (Cu)	Unalloyed Metal
Copper-Arsenic (Cu-As)	(Arsenical) Bronze
Copper-Lead (Cu-Pb)	(Leaded) Bronze
Copper-Tin (Cu-Sn)	(Tin) Bronze
Copper-Tin-Lead (Cu-Sn-Pb)	Alloy
Copper-Lead-Arsenic & Copper-Arsenic-Lead (Cu-Pb-As & Cu-As-Pb)	Alloy

Arrows

Twelve arrows were analyzed during this part of the project and are summarized in Table 4.21. One third of the arrow sub-assemblage is made from unalloyed copper. However, the remaining two-thirds of this artifact category is manufactured from one of the three bronze types, with arsenical bronze (copper-arsenic) dominating over time.

Table 4.21: UW Soils Results for HARP Arrows

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	2	2 Cu-As
Harappan (2600-1900 BCE)	10	4 Cu, 2 Cu-As, 2 Cu-Pb, 2 Cu-Sn

Rods, Wires, and Pins

Fourteen objects from the category of rods, wires, and pins were analyzed at the UW Soils lab (Table 4.22). As has been previously discussed, this sub-assembly is mostly comprised of some form of alloyed copper or bronze (64.28%) with no clear specific alloying preference demonstrated. Although during the Harappan Phase (Period 3), there does seem to be an increase in the use of tin bronze rods, wires, and pins. This may relate to the expansion of economic networks and copper raw material supply routes during the most elaborate portion of the overall cultural sequence at the site.

Table 4.22: UW Soils Results for HARP Rods, Wires, and Pins

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu
Kot Diji (2800-2600 BCE)	6	4 Cu, 1 Cu-As, 1 Cu-Pb-As
Harappan (2600-1900 BCE)	7	1 Cu, 1 Cu-As, 4 Cu-Sn, 1 Cu-Sn-As

Sheets

Although only four sheets were analyzed during this portion of the research project, they do show an intriguing trend (Table 4.23). All four objects are made from a bronze and there is a change in the pattern over time. During the Ravi and Kot Diji Phase occupations at Harappa,

there is a use of arsenical bronze to manufacture metal sheets. During the later portion of the Kot Diji Phase and the Harappan Phase at the site, a switch is seen to the use of tin bronze.

Table 4.23: UW Soils Results for HARP Sheets

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	Cu-As
Kot Diji (2800-2600 BCE)	1	Cu-As
Kot Diji/Harappan (2800-2450 BCE)	1	Cu-Sn
Harappan (2600-1900 BCE)	1	Cu-Sn

Miscellaneous Fragments and other Unclassified Objects

Five miscellaneous fragments and other unclassified objects were analyzed at the UW Soils lab (Table 4.24). As with prior portions of the analytical program, these non-diagnostic artifacts exhibit trends seen in other categories of the overall copper-bronze assemblage at Harappa. There is an early use of bronze and a significant use of lead; either by itself or along with another alloying element.

Table 4.24: UW Soils Results for HARP Miscellaneous Fragments and other Unclassified Objects

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	3	1 Cu, 2 Cu-Sn
Harappan (2600-1900 BCE)	2	1 Cu-Pb, 1 Cu-Pb-As

Prills

Only one prill, from a Ravi level at the site was analyzed at the UW Soils lab. This artifact was manufactured from unalloyed copper.

Rings

Six rings were analyzed at the UW Soils lab and the sub-assembly was evenly split between unalloyed copper and bronzes (Table 4.25). This is potentially an indicator of a hierarchical use of copper alloys to make similar decorative items.

Table 4.25: UW Soils Results for HARP Rings

Occupational Period	# of Artifacts	Alloy Type
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu
Harappan (2600-1900 BCE)	5	2 Cu, 1 Cu-As, 2 Cu-Pb

Bangles

Of the eight bangles analyzed for this portion of the analytical program, only one was made of unalloyed copper (Table 4.26). Further, all of the copper alloys identified in the bangle sub-assembly are a form of tin bronze. This is indicative that the alloy type used in the manufacture of bangles was intentionally selected and of a high degree of importance at Harappa.

Table 4.26: UW Soils Results for HARP Bangles

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	3	1 Cu-Sn, 2 Cu-Sn-Pb
Harappan (2600-1900 BCE)	5	1 Cu, 3 Cu-Sn, 1 Cu-Sn-Pb

Beads

Two beads were analyzed at UW Soils and returned the potential for a patterned result (Table 4.27). The bead from the earliest phase at Harappa is made from unalloyed copper, while the Harappan Phase beads show the introduction of tin alloy beads. This may signal a similar elaboration in the use of decorative copper-bronze beads that was seen in the rings.

Table 4.27: UW Soils Results for HARP Beads

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu
Harappan (2600-1900 BCE)	3	2 Cu, 1 Cu-Sn-Pb

SEM and EMPA Results from Slag Sample

Oftentimes slag is an overlooked part of the archaeological record. It can sometimes simply be taken as a marker of metallurgical production by its mere presence at a site. However, a variety of detailed studies of slags, specifically copper metallurgical slags, have demonstrated that this artifact type can be a valuable line of evidence in reconstructing ancient metallurgical traditions (Tylecote 1974; Bachmann 1982; Hauptmann 2007; Craddock 2010). Typically, copper smelting slags are envisioned as innumerable quantities of dark, highly vitrified glassy pieces of waste material indicative of production on a large scale. This is often the case in other 3rd millennium metallurgical regions such as sites on Cyprus, Jordan, and Oman where there exists well-documented centers of copper smelting and production. Sites such as Singhana and Ganeshwar in the Khetri Copper Belt of the Aravalli Range also exhibit large heaps of vitrified metallurgical slag (Law 2011). To date, such activity areas remain absent from the archaeological record of Indus Tradition sites. This is not to say that they do not exist, simply that they have yet to be conclusively identified or securely chronologically linked to the 3rd

millennium BCE. While there may exist a common perception of how metallurgical slags from archaeological sites should appear, the reality is that this category of material is highly heterogeneous and diverse. Bachmann (1982:1) defines a slag as "...a once molten silicate or silicate structure, sometimes including oxides, phosphates, borates, sulphides, carbides, pure metals, etc.". He further defines a slag as potentially containing a variety of materials and "...admixtures [that] may not have reached their melting points during the formation of the bulk slag material." (Bachmann 1982:1). In other words, a slag, even a copper metallurgical slag is likely to have a highly variable composition and appearance. The slag phases in Table 4.28 are a representative, but not exhaustive, list of the potential individual components of a copper metallurgy slag. Additionally, when these phases are present, they also serve as diagnostic markers of copper smelting; that is the processing of raw copper ore to ingots in a high-temperature furnace or crucible. Specific examples from this table will be returned to later in the present chapter.

At the most basic definition, a "slag" is simply a waste material resulting from some pyrotechnic process or another. This can encompass archaeological materials ranging from the vitrified clay walls of a pottery kiln to the glassy silicates that are the waste products of metallurgical production. It is these last types of slags that are of interest here. Even more specifically, the types of slag and pyrotechnic waste material that can result from a variety of copper metallurgical processes. These could range from the roasting of ore, smelting (either in a furnace or a crucible), or the melting of copper-bronze materials either for casting or metal recycling. Each of the preceding metallurgical processes produces a "typical" type of waste or slag. Furthermore, each of the listed processes could conceivably have taken place in or near an Indus settlement or city.

Table 4.28: Typical Mineral Phases in Copper Metallurgy Slag

Slag Phase	Chemical Formula
Metals	
Copper	Cu
Copper Sulphides	
Covellite	CuS
Chalcocite	Cu ₂ S
Bornite	Cu ₅ FeS ₂
Iron and Copper Sulfides	
Wustite	FeO
Magnetite	Fe ₃ O ₄
Hematite	Fe ₂ O ₃
Delafossite	CuFeO ₂
Silica and Silicates	
Metal oxide + Silica	Various Metal Oxide + Si ₂
Glass	Fe-Al-Ca silicate
Secondary Minerals	
Copper Chlorides	CuCl ₂
Copper Carbonates	Cu ₂ (OH) ₂ CO ₃

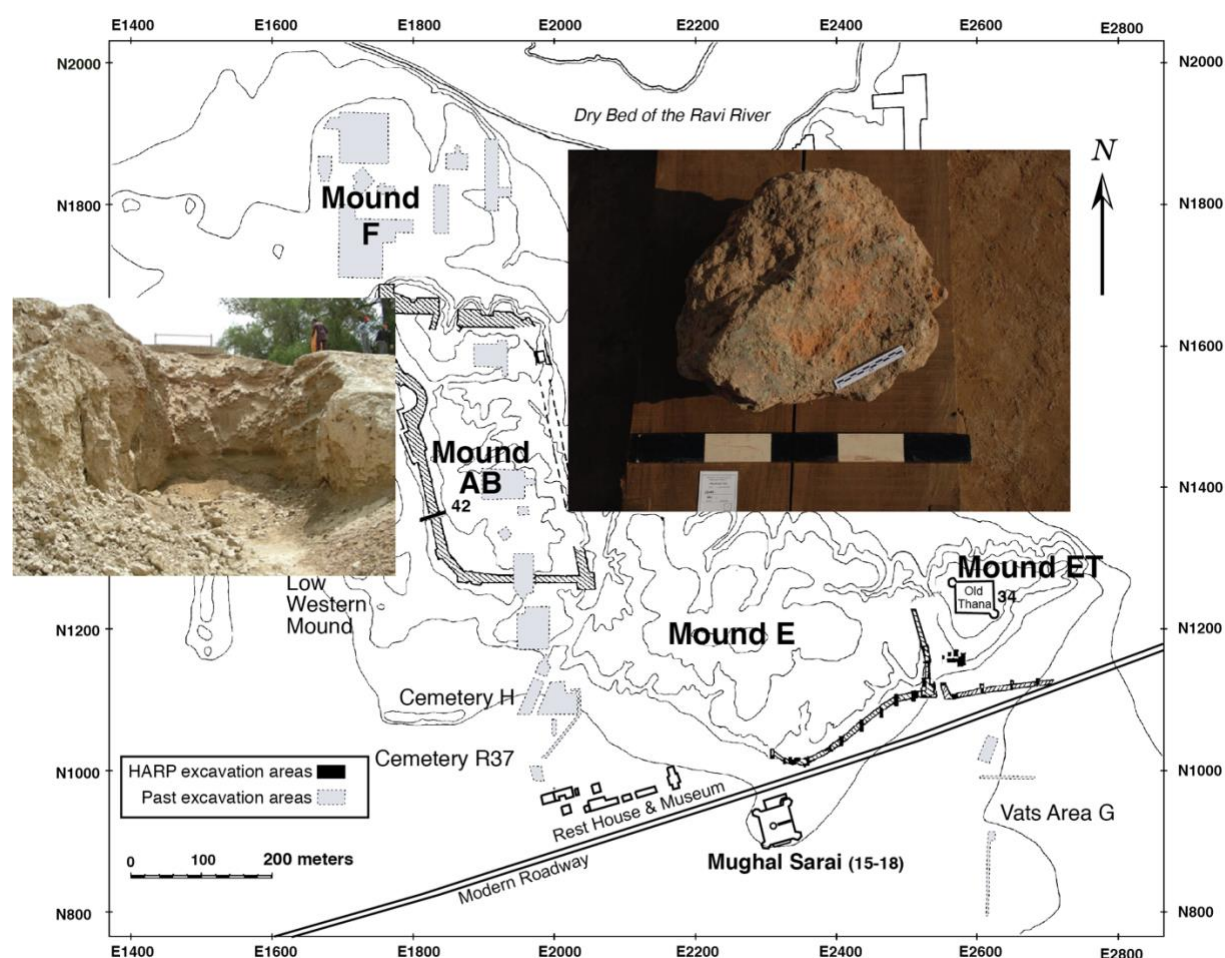
Adapted from Bachmann 1982; Hauptmann 2007

In the winter of 2009-2010 members of the HARP team discovered a large object that had eroded out of Trench 42 on the southwest corner of Mound AB (Figure 4.3). This object weighs just over 28 kilograms and exhibits a significant amount of green staining as well as a non-homogenous and laminated appearance. Based on initial inspection in the field, it was felt that this object potentially was the result of some type of furnace based metallurgical activity, possibly smelting of copper minerals (Kenoyer, personal communication). A sample from this object was collected for analysis at the University of Wisconsin, Madison.

Since the material was unlike anything previously examined from Harappa, it was decided that the best course of action was to develop an analytical program that provided a broad overview of the make-up of the slag sample. The first step was to produce a polished section in a

one-inch round epoxy mount. This section was then analyzed using a Scanning Electron Microscope (SEM) and an Electron Microprobe (EMPA), both at the Department of Geoscience, University of Wisconsin-Madison. The general analytical procedure was to use SEM to scan the section for areas of interest, as well as to perform quick initial characterizations of the phases seen. EMPA was then used for more detailed analysis of specific areas of the sample.

Figure 4.3: HARP Slag Sample and Location



Four areas were selected for analysis after the entire sample was mapped using the SEM (Figure 4.4A and Figure 4.4B). These areas were preferentially selected for either the existence of multiple phases or the potential presence of metallic copper. Each analysis area documented the presence of different mineral phases within the overall sample and combine to produce a diagnostic picture of a copper smelting slag.

Figure 4.4A: Polished Thin Section

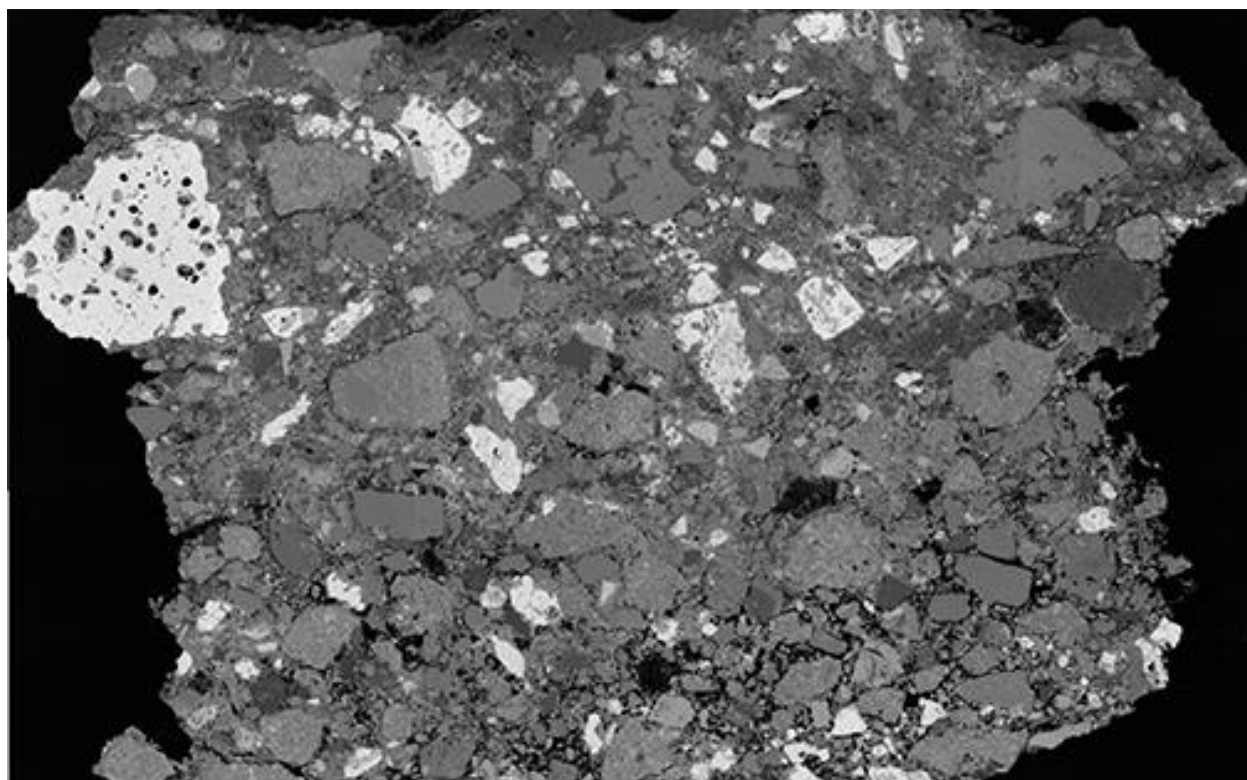
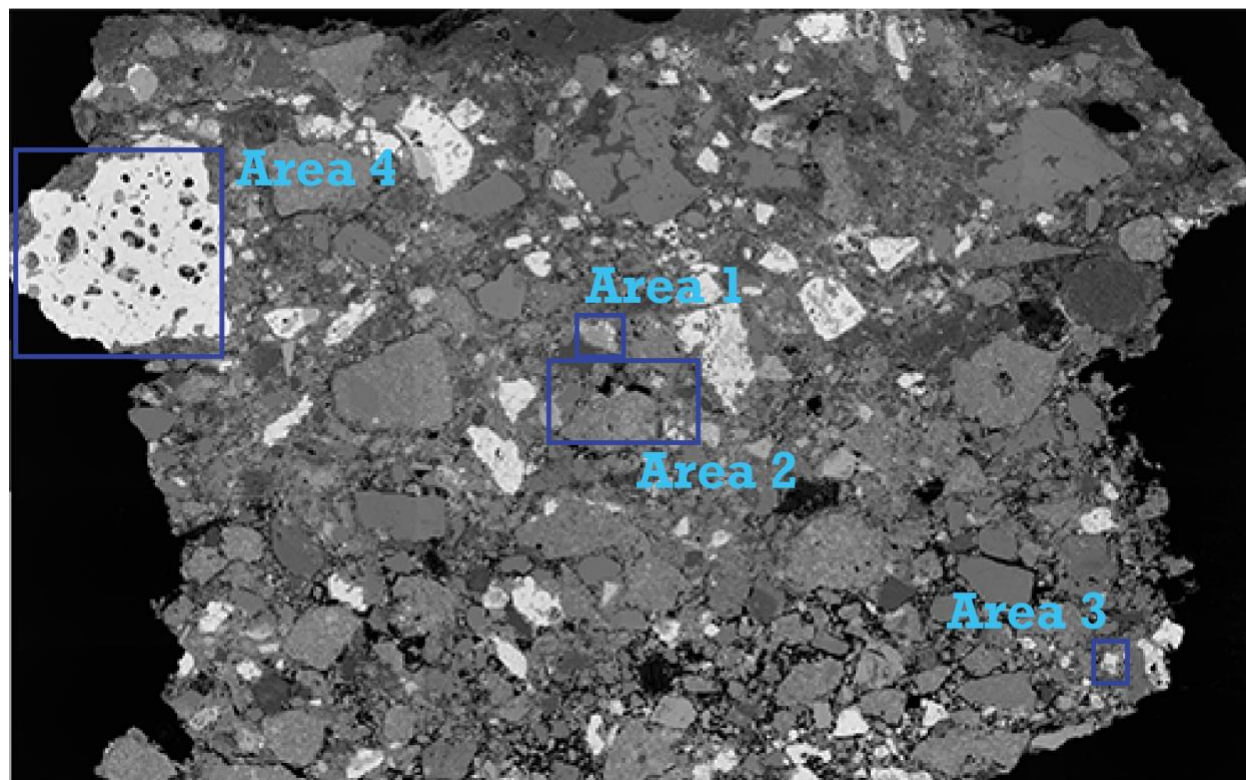
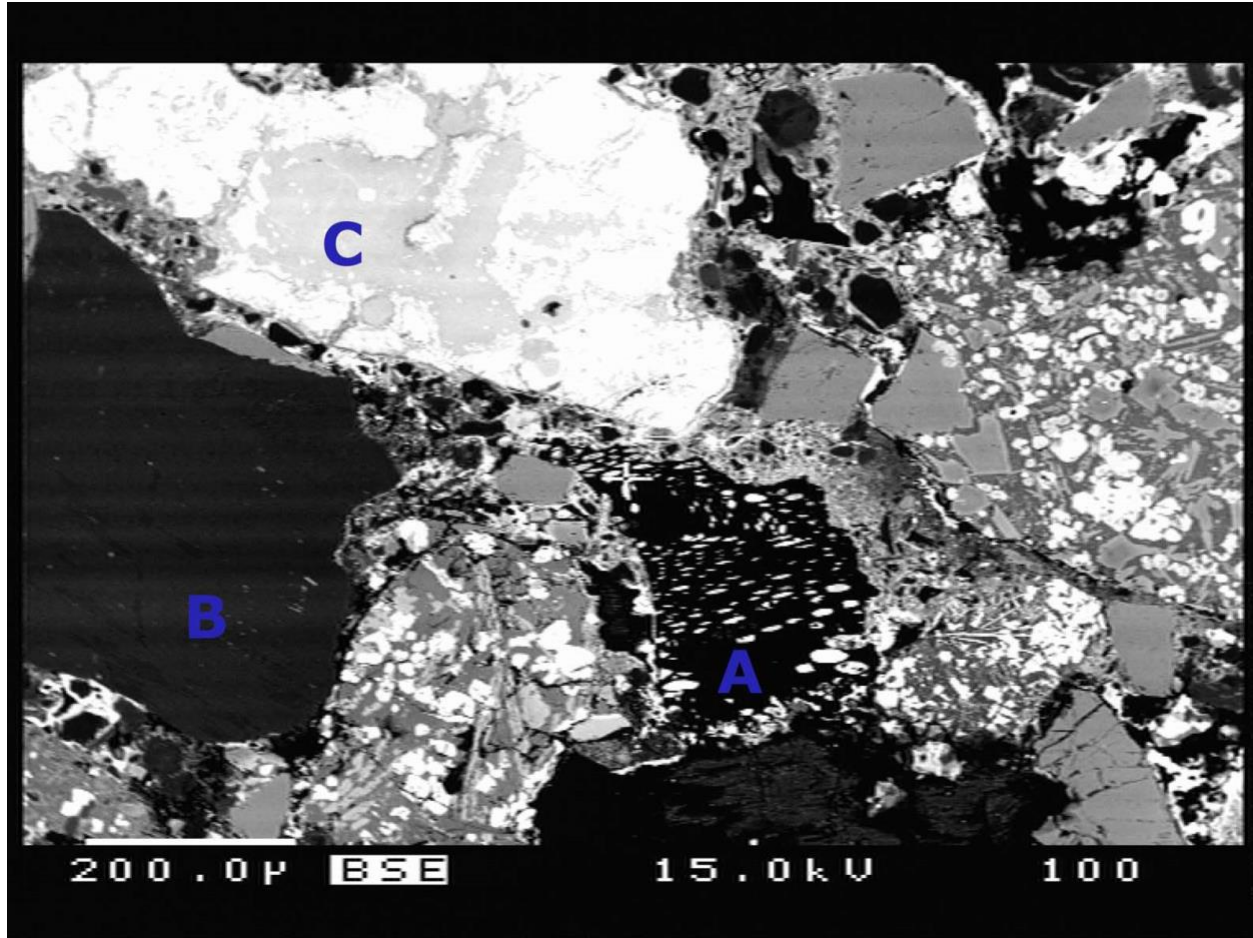


Figure 4B: Analysis Areas of Polished Thin Section



The first area analyzed, Area 1 in Figure 4.4B, is comprised of oval shaped phases of Cuprite (Cu_2S) surrounded by charcoal (Figure 4.5). Additionally, there is the presence of an iron rich glassy phase surrounding the Cuprite as well. Analysis of this area by SEM was able to document the presence of typical copper smelting slag phases. Fayalite (Fe_2SiO_4), quartz and iron oxides were indicated. Additionally, Delafossite (CuFeO_2), a copper-iron-oxide was identified as was the copper sulfide Bornite (Cu_5FeS_4). A phase of Wustite (FeO) was identified within the Bornite. This is not a natural occurrence and is evidence that this material was subject to a reducing environment at some point in its thermal history.

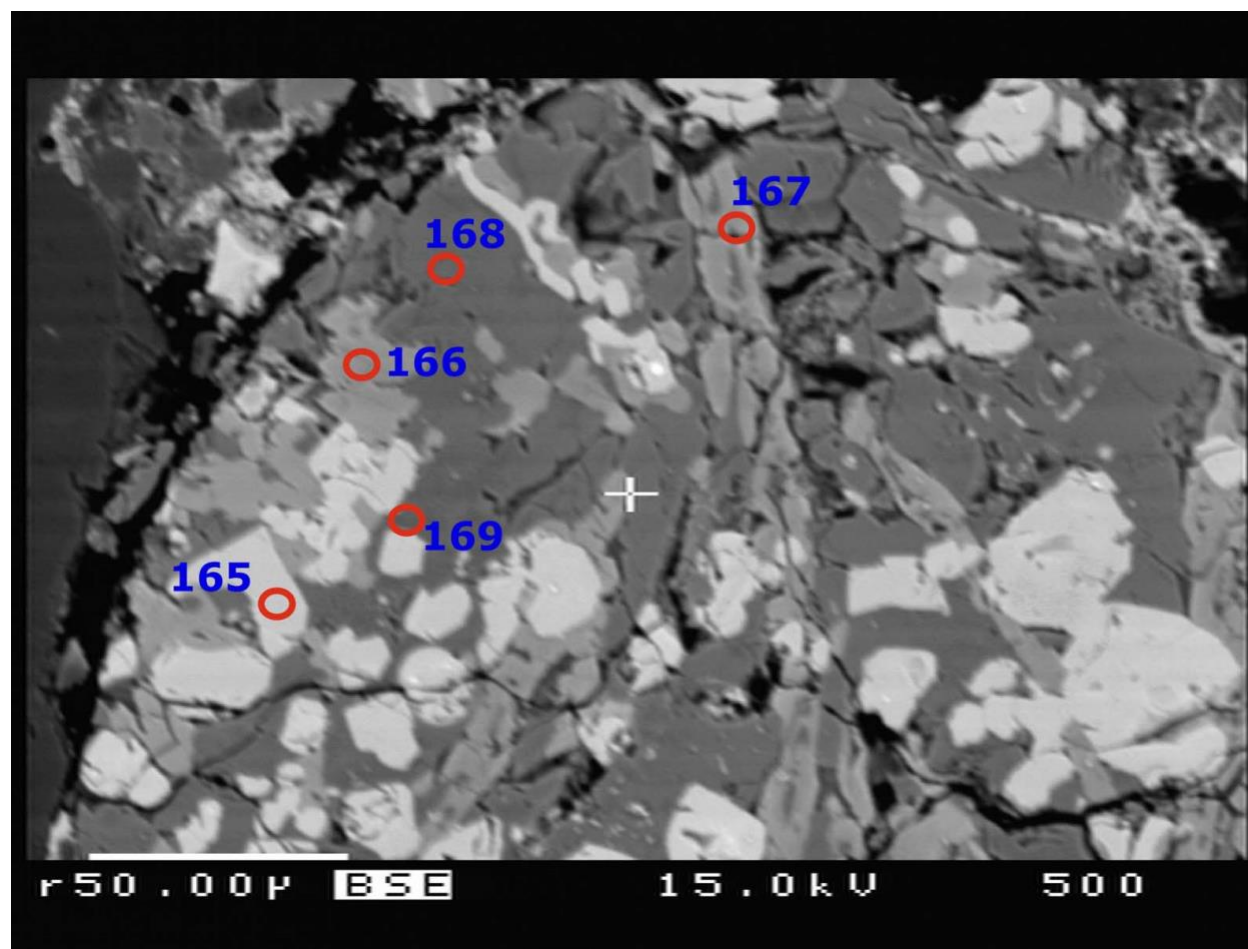
Figure 4.5: Detail of Area 1



Within the second analysis area, five points were selected for electron microprobe analysis (Figure 4.6). Point #'s 166 and 167 are an iron rich mineral with some calcium as well – occurring in a proportion that is not found in nature. These phases are the result of the melting and reforming of original mineral materials present in the furnace charge. Point #165 is hematite (Fe_2O_3). Points 168 and 169 are a glassy matrix, again indicative of the heating, melting and subsequent cooling of the object. SEM analysis of the same region found metallic copper within this melted matrix. As seen in repeatedly throughout the examined samples, this is not a natural

condition. The only way for this pattern to occur is through the heating and cooling of copper ore(s) within a smelting furnace or crucible.

Figure 4.6: Detail of Area 2



The third and fourth areas analyzed are similar. One (Figure 4.7) is a large crystal of bornite; while the other (Figure 4.8) is a copper sulfide mineral. The incomplete melting of the original mineral and the presence of bits of slag matrix and epoxy in this portion of the polished section has obscured the exact composition. It is important to note that the Bornite exhibits stress lines that are formed when the mineral is incompletely melted. Analysis of the elemental composition at points 2, 3, and 4 are all some admixture of copper-oxygen-carbon-sulfur and

various other elements. This is best explained as an example of the incomplete melting of the original copper sulfide mineral (such as Bornite) and during cooling portions of slag were incorporated into this region of the sample.

Figure 4.7: Detail of Area 3

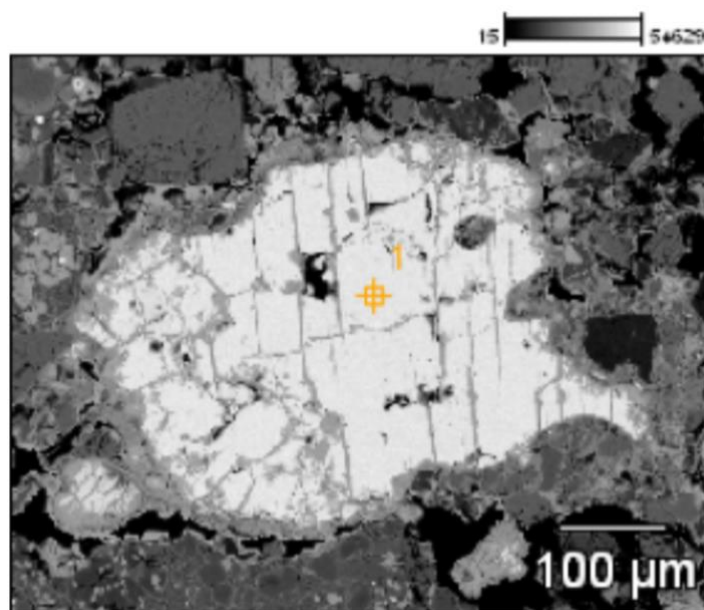
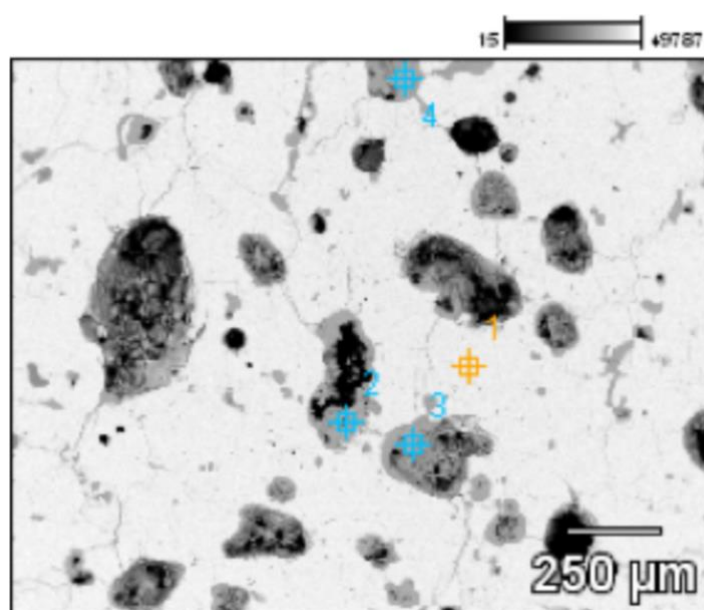


Figure 4.8: Detail of Area 4



In summary, the results of the SEM and EMPA analyses have identified the presence of incompletely melted copper sulfide mineral phases, metallic copper, iron oxide compounds (specifically Wustite) that document the existence of a reducing atmosphere, and the presence of multiple glass phases. All of these data are indicative of a slag formed from the smelting of copper ores. This is further corroborated by multiple mineral phases within the sample that can only exist if the artifact has undergone repeated episodes of heating and cooling. Whether it is the discarded waste slag, or the partially vitrified lining of a smelting furnace is not entirely clear. It is also worth noting, what is not present. Despite that uncertainty, it is clear that this object is the result of some large-scale copper metallurgical smelting activity. At this time, there is no evidence for lead or arsenic in the sample. This is significant because previous research has documented the presence of lead and arsenic in a large number of the copper artifacts from Harappa. This may be suggestive that these elements are intentional additions to copper metal for the purpose of creating bronze alloys and not simply accessory minerals from the original copper ore. However, evidence from one slag sample is not sufficient to substantiate this supposition.

Results of Compositional Analysis Programs

The analytical programs outlined above created a series of compositional data points for the HARP artifacts. In the majority of cases where an artifact was analyzed multiple times using different methodologies, the results agreed. In approximately one third of the cases where an artifact was analyzed using multiple techniques, there was some discrepancy between the techniques. This was primarily centered on the amount of lead present in the sample. For reasons outlined above, PXRF tended to overestimate the amount of lead in a sample and under-represent the amount of arsenic present. ICP-OES analyses conducted at the T. Douglas Price Laboratory

for Archaeological Chemistry at the University of Wisconsin-Madison Department of Anthropology (LARCH) and the University of Wisconsin-Madison Soils and Plant Analysis Laboratory (UW Soils) provided a critical corrective to this tendency. Additionally, the ICP-OES analyses were in general more sensitive to the presence of tin in individual artifacts than the PXRF analyses were. Again, this is the result in differences in the two techniques and the incomplete mobilization of tin to the surface of ancient bronze artifacts (see Figure 4.1). Overall, the results of the three sample sets taken together allow for a high degree of confidence in the alloy designations for each of the analyzed HARP artifacts.

Using the benchmark compositional percentages for identifying intentional alloys outlined in Chapter 3, it is possible to apply the three analytical runs in concert to provide final alloy designations for the analyzed HARP assemblage. This analysis provides compositional designations for 323 copper-bronze artifacts and one previously unrecognized copper mineral fragment. Overall, unalloyed copper, three types of bronze (arsenical, leaded, and tin), and five alloys can be identified (Table 4.30). As previously discussed, only a single object in the analyzed assemblage exhibited the Copper-Silver-Gold-Lead alloying pattern. While it is not definitive that no other objects at Harappa would have been fashioned from this copper and precious metal alloy, at present the alloy remains highly uncommon and not representative of a larger overall trend. Future researchers should be alerted to the potential for copper and precious metal alloys. It is also possible that this artifact is “electrum,” a naturally occurring alloy of gold and silver with some copper. However, based on the PXRF spectra, it appears that the bulk of the object is copper making the possibility that it was an intentionally produced alloy by Harappan copper workers the preferred interpretation.

Table 4.30: Copper and Copper Alloys Identified at Harappa

Alloy Type	Designation
Copper (Cu)	Unalloyed Metal
Copper-Arsenic (Cu-As)	(Arsenical) Bronze
Copper-Lead (Cu-Pb)	(Leaded) Bronze
Copper-Tin (Cu-Sn)	(Tin) Bronze
Copper-Tin-Lead (Cu-Sn-Pb)	Alloy
Copper-Tin-Arsenic (Cu-Sn-As)	Alloy
Copper-Lead-Arsenic (Cu-Pb-As) & Copper-Arsenic-Lead (Cu-As-Pb)	Alloy
Copper-Tin-Lead-Arsenic (Cu-Sn-Pb-As)	Alloy
Copper-Silver-Gold-Lead (Cu-Ag-Au-Pb)	Alloy

In reviewing the overall alloying patterns, it is most useful to divide the artifact classes at Harappa into four broad groups:

1. Personal Ornamentation or Display Objects: beads, bangles, rings, discs, tablets, and mirrors.
2. Utilitarian Objects: Arrows, rod/wire/pin, and sheets.
3. Objects Related to Copper/Bronze Manufacturing: prills, slags, and minerals
4. Non-Identifiable Objects: Miscellaneous fragments

Grouping the analyzed artifacts along these lines allows for patterns in alloy use to be brought into sharper focus. Primarily because examining the artifacts in this manner highlights an emerging distinction regarding alloy use at Harappa. Alloy usage at the site was divided by how the final finished object was to be used. Objects that whose finished form was intended to serve a primary visual purpose, objects of personal ornamentation or display, were manufactured from one suite of possible alloys. In contrast, objects that were intended for more utilitarian tasks such

as arrows, tools, and weapons were made of a different mixture of alloy types. This patterned use of alloy types is best seen when a distinction between the final role of the object is fully considered.

Alloy Patterns for Objects of Personal Ornamentation or Display

Tables 4.31-4.35 show the compositions for the analyzed display and personal ornament classes of artifacts. Overall, this group of artifacts displays a broadly similar pattern; the majority of the assemblage is a bronze or a related copper alloy. 39 of the 46 analyzed objects in this collective category was of some type of alloyed copper. Of those 39, 17 are of a traditionally recognized bronze type (arsenical, leaded, and tin). The remaining copper alloys also contain intentional amounts of lead in addition to the usual “bronze” alloying elements (tin and arsenic). In these cases, the presence of lead is almost certainly an intentional addition on the part of ancient craftspeople to aid in the casting and manufacture of the individual object. Since lead can be taken as an additive element related to production and not final appearance, a series of relatively restricted and repeated copper alloys used to fashion objects intended for personal ornamentation or other types of display is evident.

Table 4.31: Copper and Bronze Rings

(N=15)

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	1	Cu
Kot Diji/Harappan (2800-2450 BCE)	1	Cu
Harappan (2600-1900 BCE)	11	5 Cu, 4 Cu-Pb, 1 Cu-As, 1 Cu-Sn
Mixed & Unknown	2	1 Cu-As-Pb, 1 Cu-As

Table 4.32: Copper and Bronze Bangles

(N=12)

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	3	1 Cu-Sn, 2 Cu-Sn-Pb
Harappan (2600-1900 BCE)	5	1 Cu, 2 Cu-Sn; 2 Cu-Sn-Pb
Mixed & Unknown	4	2 Cu, 1 Cu-Pb-As, 1 Cu-Sn

Table 4.33: Copper and Bronze Beads

(N=15)

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu
Kot Diji (2800-2600 BCE)	2	2 Cu-Sn-Pb
Harappan (2600-1900 BCE)	8	2 Cu, 1 Cu-As, 2 Cu-Sn, 1 Cu-Pb, 1 Cu-Sn-Pb, 1 Cu-Sn-As
Mixed & Unknown	4	1 Cu, 1 Cu-Pb, 1 Cu-Sn, 1 Cu-As-Pb

Table 4.34: Copper and Bronze Discs and Mirrors

(N=3)

Occupational Period	# of Artifacts	Alloy Type
Harappan (2600-1900 BCE)	3	1 Cu Mirror, 1 Cu-Sn-Pb Disc, 1 Cu-Sn-Pb & Cu Laminated Disc

Table 4.35: Copper and Bronze Tablets

(N=1)

Occupational Period	# of Artifacts	Alloy Type
Mixed & Unknown	1	1 Cu-As

A review of this composite group of artifact classes demonstrates that the objects are overwhelmingly made from either arsenical bronze, leaded bronze, or tin bronze. While these

three types of copper alloys can impart objects with a variety of properties, in personal ornaments and display objects, Harappan copper workers would have been focused on the final visual appearance of the object. By skillfully exploiting different alloys, Indus metal producers would have been able to create a suite of visually distinct types of the same class of artifact. This is a critical point for understanding copper and bronze metallurgy at Harappa.

Previous research on Indus craft technologies has focused on the issue of a hierarchy of raw materials (Kenoyer 1992a, 2000; Vidale and Miller 2000) allowing the results of a variety of craft industries to be employed by urban consumers in status displays (Kenoyer 2000, 2014). By producing copper and bronze artifacts intended for display out of copper, arsenical bronze, leaded bronze, and tin bronze, Indus coppersmiths would have provided consumers with four visually distinctive presentations. During the Harappan Phase, personal ornaments and objects of display would have functioned to signal the status of their owners. Beads and rings (Tables 4.31 and 4.32) provide an excellent example of this. Both object classes were produced from unalloyed copper and the three types of bronze. Each of these alloy “recipes” would have produced a finished object with different final color. This visual distinctiveness would have allowed for the potential of categorical distinctions between beads and rings with copper, gold, and silver hues. In addition to providing a hierarchy of copper-based ornaments, these different colors may have played into additional visual hierarchies as they may have been used to mimic gold and silver beads and rings in a more readily available material.

Copper and alloyed bangles from Harappa demonstrate a similar but slightly different pattern of alloy usage. All but 3 of the total analyzed group of bangles was fashioned from an alloy of copper and tin. This would have imparted the finished product a distinctive visual appearance that could have marked the wearer as a high-status individual. It may also have been

related to concepts of purity based on tin bronze that has deep ethnographic documentation within South Asia in succeeding cultural periods (Kenoyer 1998; Lahiri 1993, 1995; Srinivasan 2013).

Copper discs exhibit another aspect of this pattern of alloy choice based on the desired visual appearance of the final product. Both of the discs in analyzed assemblage are copper-tin-lead (Cu-Sn-Pb). The PXRF analysis of both objects indicates the presence of lead. One of the objects (see discussion above), appears to have a “two-sided” or “laminated” final presentation. One side would have been a duller green color comprised of copper-lead (Cu-Pb) while the other side would have been a brighter colored silvery hued appearance due to the copper-tin-lead (Cu-Sn-Pb) alloy that was chosen during production. The second analyzed disc is made from the same Cu-Sn-Pb alloy and does not appear to have been laminated. However, it would have presented a similar visual appearance. These two objects draw into sharp focus the potential for copper workers at Harappa to produce similar end visual results through distinct but parallel means. The conclusion that objects of personal ornamentation and display were conceived of as objects with a specific desired final appearance is confirmed by an analysis of each of the alloy patterns seen in any given ornament or display artifact class.

Alloy Patterns for Utilitarian Objects

The identified alloy usage patterns for utilitarian objects are shown in Tables 4.35-4.37. For all artifact classes, roughly a quarter of the objects analyzed are fashioned from unalloyed copper with the remaining being made from a copper alloy. The types and patterns of alloy usage seen in rods/wires/pins, sheets, and arrows is far more variable and diverse than the pattern of alloy usage seen in personal ornaments and display objects. In the various utilitarian object classes, all of the alloy classes identified at Harappa are present. There is no readily apparent

pattern to the selection of an alloy for any given artifact type. However, by dividing the artifacts from Harappa into ornamental and utilitarian artifacts, a pattern of alloy usage for utilitarian objects can be identified. Ornamental objects had their alloy chosen to achieve a desired final visual appearance. In contrast, utilitarian items are regulated by alloy choice based on the desired physical properties of either manufacturing process or the functioning of the final product.

Table 4.35: Copper and Bronze Rods/Wires/Pins

(N=80)

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	3	2 Cu, 1 Cu-As
Kot Diji (2800-2600 BCE)	7	4 Cu, 2 Cu-As, 2 Cu-Pb
Kot Diji/Harappan (2800-2450 BCE)	2	1 Cu-As, 1 Cu-As-Pb
Harappan (2600-1900 BCE)	43	9 Cu, 13 Cu-As, 1 Cu-Pb, 11 Cu-Sn, 2 Cu-Pb-As, 2 Cu-As-Pb, 5 Cu-Sn-Pb
Mixed & Unknown	25	4 Cu, 3 Cu-As, 3 Cu-Pb, 3 Cu-As-Pb, 7 Cu-Sn, 4 Cu-Sn-Pb, 1 Cu-Sn-As

Table 4.36: Copper and Bronze Sheets

(N=39)

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu-As
Kot Diji (2800-2600 BCE)	3	1 Cu, 2 Cu-As
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu-Sn
Harappan (2600-1900 BCE)	15	3 Cu, 3 Cu-As, 3 Cu-Pb, 2 Cu-Sn, 2 Cu-As-Pb, 2 Cu-Pb-As
Mixed & Unknown	19	6 Cu, 1 Cu-As, 4 Cu-Pb, 1 Cu-As-Pb, 3 Cu-Sn, 4 Cu-Sn-Pb

Table 4.37: Copper and Bronze Arrows

(N=43)

Occupational Period	# of Artifacts	Alloy Type
Kot Diji (2800-2600 BCE)	2	2 Cu-As
Harappan (2600-1900 BCE)	29	4 Cu, 5 Cu-As, 13 Cu-Pb*, 2 Cu-Sn, 3 Cu-Pb-As, 1 Cu-Sn-As, 1 Cu-Sn-Pb *3 potentially Cu-Pb-As
Mixed & Unknown	12	6 Cu, 1 Cu-As, 5 Cu-Pb

The category of copper/bronze rods/wires/pins for the HARP analyzed assemblage is comprised primarily of two similar types of artifact. They are rods that are either square or round in cross section. Many fragments have pointed or tapered working ends. These objects are interpreted as tools for working a variety of materials. As they would have needed to be durable and hold their form during repeated use alloyed copper of one type or another would have been an ideal material. Recent research on seal carving techniques provides an example of bronze tools being preferred by craft workers to unalloyed copper (Jamison 2017). Understanding the analyzed rods, no wires or pins have been included in the current analyzed group, as a group of “point tools” that were shaped from cast blanks to the desired working shape clarifies the diverse alloy patterning. Harappan copper and bronze producers were selecting alloys that would have provided the finished product with the additional strength and durability of one or more of the alloying elements but without the specific color restrictions found in the ornamental artifacts. Overall, the pattern appears to be one where the only factor in alloy selection was the functional requirements of the finished tool, that it be durable and strong. This leads to a rod point tool assemblage that is comprised of 76.25% copper alloys of one type or another. Alloy selection appears driven by the functional requirements of the final object. In order to fashion the tools

required by Harappan consumers, copper-smiths at the site were alloying copper with a various combinations of arsenic (As), lead (Pb), and tin (Sn) to create strong durable tool forms.

Sheets and arrows follow a similar pattern. Again, both of these artifact classes would have been comprised of objects that were intended to perform a specific “work” function. Arrow points would have needed to be durable and hold an edge. Sheets were often fashioned into cutting tools and would have had similar requirements. It is possible that copper sheet fragments could have been initial aspects of the manufacture of non-utilitarian items such as hollow bangles, cylindrical beads, or vessels. However, the fragmentary pieces available in the current study assemblage are not diagnostic enough to make these identifications. Future research will be needed to determine the exact nature of these artifacts and their final placement into more specific artifact classes is ongoing.

A final note on this composite group of artifact classes needs to be addressed. Just over a third of the total grouping (37.65%) are artifacts that contain intentional additions of lead, often in combination with other alloying elements. The addition of lead is best understood as not only adding desired physical properties to the finished object, but also would have aided in making the molten metal flowing better during casting. Since almost all the objects in the utilitarian group of artifacts are reconstructed as being manufactured using shallow molds (Miller 1999; Kenoyer and Miller 1999) it is not surprising that lead would have been a common addition to the copper during the manufacturing process.

Alloy Patterns for Objects Related to Copper and Bronze Production

Table 4.38: Copper and Bronze Prills & Mineral

(N=26)

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	1	1 Cu
Kot Diji (2800-2600 BCE)	1	1 Cu
Harappan (2600-1900 BCE)	13	3 Cu, 3 Cu-As, 1 Cu-Pb, 3 Cu-Pb-As, 1 Cu-Sn, 1 Cu-Sn-Pb, 1Cu-Sn-Pb-As
Mixed & Unknown	10	1 Chalcopyrite (CuFeS_2), 3 Cu-Pb, 2 Cu-Pb-As, 1 Cu-As-Pb, 2 Cu-Sn, 1 Cu-Sn-Pb

There are 25 copper prills and one copper mineral fragment included in the analyzed compositional assemblage (Table 4.38). These are the best markers of site based copper and bronze production included in the overall analysis program, aside from the large slag piece described above. It is possible that the copper mineral fragment could have been used to make a variety of non-metal products (Kenoyer and Miller 1999; Miller 1999; Hoffman and Miller 2014). It is also possible that it could be a fragment of copper mineral used in crucible-based smelting for the production of finished copper and bronze artifacts at Harappa, perhaps in a workshop such as that found on the southern slopes of Mound E (Miller 1999). Regardless of the proper interpretation, the fragment of unprocessed copper mineral does not provide a great deal of insight into alloying practices and compositional patterning at Harappa. The objects identified as prills provide a much more direct vehicle for assessing this component of copper and bronze metallurgy at the site.

Prills are irregular roughly spherical to ovoid shaped bits of copper or bronze that formed during overflowing or spilling during the melting and/or casting stages of metal production at Harappa. The analyzed prills (Table 38) contain all but two of the identified copper and copper alloy types identified in the overall HARP copper/bronze sample assemblage (Table 30). All alloy type except copper-tin-arsenic (Cu-Sn-As) and copper-silver-gold-lead (Cu-Ag-Au-Pb) are present in at least one copper prill from the site. While somewhat indirect, this is indicative of a copper and bronze industry that was operating across the major occupation mounds at the site and crafting artifacts from a variety of alloy types in response to both the status based and practical needs of urban consumers (Hoffman and Miller 2014). Copper metal workers at Harappa were proficient in selecting and employing a diverse array of alloys in order to achieve preconceived visual or functional properties in the finished object. Additionally, these metal producers are able to achieve similar final properties through multiple methodologies, such as lamination or multi-metallic alloys.

Alloy Patterns for Non-Identifiable Objects

Ninety artifacts that cannot be assigned to one of the existing copper/bronze artifact categories have been analyzed for their composition (Table 4.39). It is not possible to discern a pattern of alloy usage for this category of artifact fragments from Harappa. In general, the indeterminate objects demonstrate the usage of all copper and copper alloy patterns identified in Table 4.30. Two results from this group of compositional analyses are worthy of additional discussion.

The first is that there is a continuation of a trend in the Ravi Phase artifacts. Although there is not a large sample of items from this time period, the available data indicates that Ravi Phase metal craftspeople at Harappa were proficient in both copper and copper alloys, including

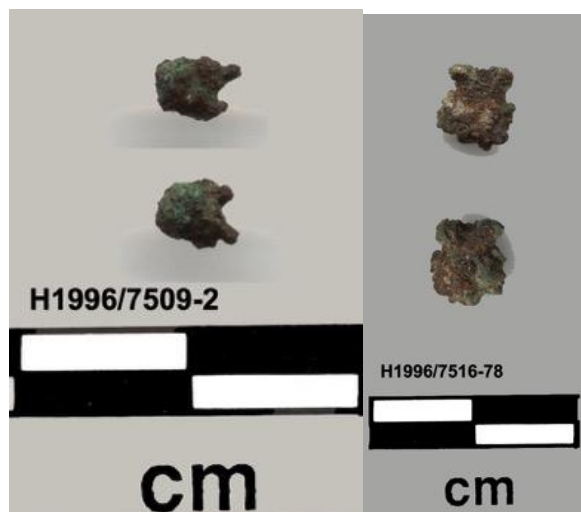
tin bronze. Therefore, the roots of the copper and bronze tradition that is present at Harappa pre-dates the initial occupation of the site. This aligns with the early complex metal working evidence emerging from Mehrgarh (Thoury et al 2016) and at other sites around South Asia and adjacent regions (Kenoyer and Miller 1999). However, while the copper and bronze tradition at Harappa almost certainly has its roots elsewhere, the tradition elaborated as the site developed into a complex urban polity during the Kot Diji and Harappan Phases. It is almost certain that the production techniques and copper supply networks evident in the Ravi Phase would have been different, but related to, then those seen during subsequent cultural time periods at the site.

A second significant data point from the miscellaneous fragments compositional data is the identification of two small pieces of copper smelting slag (Figure 4.9). These fragments represent the waste remains of crucible smelting of a copper sulfide ore. The compositional analysis identified levels of iron that are not present in any other analyzed artifact in the assemblage. This combination of iron and copper is typical of smelting remains (Bachmann 1982, Craddock 2010) and documents that some level of copper ore processing was taking place at the site as early as the Ravi Phase occupation. This is a significant revision of previous models and needs further exploration. Hopefully, continued excavations by HARP will uncover further Ravi Phase copper and copper processing remains so that these materials can be better understood and placed within the framework of a larger copper metallurgical tradition for the site.

Table 4.39: Copper and Bronze Miscellaneous Fragments

(N=90)

Occupational Period	# of Artifacts	Alloy Type
Ravi (3300-2800 BCE)	4	2 Cu*, 2 Cu-Sn *potentially Cu smelting slags
Kot Diji (2800-2600 BCE)	4	1 Cu-As, 2 Cu-Sn, 1 Cu-Sn-Pb
Kot Diji/Harappan (2800-2450 BCE)	1	1 Cu
Harappan (2600-1900 BCE)	39	14 Cu, 3 Cu-As, 7 Cu-Pb, 5 Cu-Pb-As, 4 Cu-As-Pb, 4 Cu-Sn-Pb, 1 Cu-Sn-Pb-As, 1 Cu-Ag-Au-Pb
Mixed & Unknown	42	20 Cu, 2 Cu-As, 4 Cu-Pb, 4 Cu-Sn, 5 Cu-As-Pb, 1 Cu-Pb-As, 4 Cu-Sn-Pb, 1 Cu-As-Sn-Pb

Figure 4.9: Ravi Phase Slags

Summary

The compositional analysis portion of the project was successful in achieving the goal of characterizing the alloy types at the site as well as identifying patterns in alloy usage. Overall this aspect of the research program identified the following in the HARP sample assemblage:

- Multiple intentional alloys produced by either Harappan copper and bronze workers or copper metalsmiths at other Indus Tradition production centers.
- The presence of two alloying industries at the site. One focused on visual display and one focused on object function.
- The identification of production debris from both the melting of copper ingots or scrap copper and bronze to fashion new objects.
- The identification of crucible smelting debris.
- It is possible to identify the alloy type in corroded copper and bronze objects.

Each of these represents a significant expansion or reformulation of previously held models for copper and bronze metallurgy at Indus sites (see Chapter 2 for discussion and review).

The identification and expansion of the types and frequency of copper alloys identified at Harappa drives a reformulation of how the use of copper and bronze at Indus sites should be viewed. While it remains possible that tin bronze was not an entirely common alloy type, the usage of bronze and alloyed copper at Harappa was far more common than most previous researchers recognized. Further, the use of these alloys at first glance appears rather random and scattered. This has played into the narrative that the majority of Indus copper and bronze production was centered around the re-melting of existing finished objects. However, an examination of alloy usage based on how the final copper, copper alloy, or bronze item was to be consumed by residents of the city contradicts this interpretation. Dividing the artifacts from

Harappa into items that would have been driven by either their final visual appearance or their final functional application reveals two parallel alloying traditions operating at the site. One is creating objects of personal ornamentation and display through a limited set of copper alloys and the other is creating durable tool forms through an unrestricted suite of alloys. Further, prills provide evidence for this final stage of manufacture and alloying taking place on site using either semi-processed raw materials (ingots) or the recycling of specific finished products. It is also clear that appreciable levels of ore smelting were taking place at Harappa through both crucibles and furnace installations. Future research is required to more fully understand this emerging data set.

The patterns identified in the compositional analysis aided in setting the criteria for the lead isotope component of the research program. In order to buttress the emerging hypothesis that copper alloying at Harappa was centered on determinations of either the final visual appearance or functional purpose of a given artifact; determinations of the source provenience of the copper raw materials used in production would be ideal. If objects with the same alloying patterns were being manufactured from different copper sources, it strengthens interpretation that the alloying patterns stem from cultural choices rather than technological or logistical requirements. The next chapter outlines the procedures for and results of the lead isotope analysis portion. Following that, the source provenience designations were compared to the patterns seen in alloying practices to determine if those practices were linked to copper raw material supply, technological issues related to the use of specific copper sources, cultural preferences, or a combination of these factors. The overall patterns from both the compositional and isotopic analyses support an interpretation of copper and bronze manufacturing at Harappa

focused on two parallel but distinct lines; one focused on visual appearance and one focused on functional purpose.

Chapter 5: Analytical Methodology and Results: Lead Isotopes

Introduction

A significant portion of the project research questions required identifying and understanding where the raw materials used to manufacture copper and bronze artifacts at Harappa came from. Lead isotope analysis has emerged as the leading methodology for linking archaeological artifacts to copper ore source locales (Gale and Stos-Gale 2000; Pernicka 2014). Establishing these linkages provides the empirical data required to address whether or not copper supply networks at Harappa are similar to or different from those established for rock and other mineral resources (Law 2011). The same isotopic data are critical in assessing the level of access each mounded sector of Harappa had to different copper resource zones. This provides a mechanism for determining the degree of restriction in access to specific copper ore resources across the city during the Indus cultural sequence. Additionally, isotopic data that assign specific artifacts to individual source areas assists in the interpretation of the compositional data collected. Understanding the nature of the parent copper ore aides in distinguishing between artifact compositional signatures that are related to ore geology and those related to aesthetic or technological choices made during manufacturing.

In order to obtain the needed isotopic data, a subset of the copper and bronze assemblage from the HARP excavations was selected for lead isotope analysis (see Appendix 3.1 and Appendices 5.1-5.5 for full descriptions). Samples were selected on a preferential basis. The total sample was chosen to provide representative examples of all artifact categories from each of the major occupational mounds at Harappa from the Regionalization and Localization Era components at the site (see Chapter 1 for chronology). From this sample set, a further subset of

artifacts was chosen for isotopic analysis. These selections were made in three stages, a pilot study to determine overall project viability, an initial exploratory analysis to confirm the fundamental project methodology for isotopic analysis, and a final analysis set to achieve the desired representational data coverage. For the pilot study, existing samples of unaltered copper minerals from the site were chosen in order to confirm the ability to construct isotopic correlations between archaeological samples and regional ores and slags. Once this linkage was confirmed, a set of copper/bronze artifacts was analyzed to determine if lead isotope measurements could be obtained from finished metal objects from Harappa. These artifacts were selected by macroscopic visual inspection and weight to provide the most amount of material for analysis in order to ensure that viable data could be returned from lead isotope analysis.

Following the successful completion of this pilot study component, a suite of artifacts was selected for a two-stage analysis. The criteria for this exploratory analysis were copper/bronze artifacts that exhibited a solid metallic core overlain by a corrosion rind of oxidized material. During the initial analytical procedure, separate lead isotope measurements of the metal and oxidized material were conducted to demonstrate a strong correspondence between the two components of the archaeological artifacts. The confirmation that both the metallic “core” and the oxidized “corrosion rind” of artifacts from excavations at Harappa both returned useable lead isotope measurements enabled the project to move to the final stage of analysis. In this stage of analysis, a series of artifacts were selected that exhibited the least amount of corrosion based on both visual inspection and measurements of weight. Additionally, the artifacts were chosen to provide as representative a sample of all excavation areas, artifact classifications, and time periods as possible.

Sourcing Materials: Elements, Isotopes, Archaeology, and Provenance Studies

From the earliest days of archaeological investigations into metal using communities, researchers have been interested in determining the source of the metal(s) used in the manufacture of individual artifacts. The earliest efforts were focused on the use of artifact impurity and trace element composition to construct artifact and ore correlations. Archaeologists were highly interested in reconstructing and understanding the trade networks that linked ancient peoples as well as documenting the spread of metallurgical technologies. The specifics of how these efforts relate to Indus Tradition archaeology can be found in Chapter 2. A more general discussion of compositional analysis, artifact-ore correlations, and their relationship to lead isotope analysis will be presented in this section.

Archaeology has a long history of adapting techniques and methodologies from other disciplines in order to develop a better understanding of the past. One of the fundamental principles of the conduct of archaeology, stratigraphy, is borrowed from its original discipline of geology. Archaeological chemistry is heavily reliant on adapting and refining techniques and analytical procedures that originally had their home in either chemistry or geology. These archaeometric techniques are then added to the growing array of tools that archaeology employs to reach a more detailed and empirical understanding of specific phenomenon in the past. Relevant to the current study is the use of elemental composition and lead isotope analysis to source provenance studies.

Metal bearing ores are comprised of a variety of base metals as both major and minor elements (Villa 2009). With modern smelting technologies, it is possible to separate and preferentially recover one or more of these metals from a target ore. In antiquity such refined control was not possible, and a number of impurities and accessory minerals would have made

their way into the final cultural artifact. At least, this represented a version of the fundamental logic and assumptions made in the early portion of the 20th century regarding chemical “fingerprinting” metal artifacts in order to trace them back to their ore source. An example of this is the attempts during the ASI excavations of Mohenjo-Daro and Harappa to use compositional analysis to link Indus copper-bronze metal artifacts to copper ores throughout the region (see Chapter 2 for discussion). Similar analytical programs were implemented at copper and bronze using sites in the Mediterranean and Europe. Unfortunately, these projects did not meet with much success. Almost universally, they foundered on the same basic seemingly unresolvable issues.

The first issue that is encountered is the difficulty in determining the availability, nature, and composition of ancient ores. Restricting the discussion to the relevant copper ores, the first concern is what type of copper ore was being exploited in antiquity. Approaching a reasonable inference to this involves the application of a great deal of fundamental ore geology, deposit specific geochemical data, and mineralogy (Pollard and Heron 1996; Ixer 1999; Baron et al. 2014). The initial difficulty arises when attempting to delineate between “mineral” and “ore”. A mineral is commonly taken to be a naturally formed compound with one specific chemical composition. An ore is a type of rock that contains minerals in sufficient quantities that important elements including metals can be economically extracted from them (Gilbert and Park 1986:1). At present, archaeologists have little consistent information on ancient value systems and therefore it is rarely possible to determine what value(s) ancient peoples would have placed on metals. Therefore, by extension, it is highly problematic to determine what minerals and/or ores would have been selected for extraction. Furthering this difficulty is that ore deposits are divided into different zones and each zone has a different mineralization. Miners in antiquity would have

had access to mineralized zones that have been now been mined out. Each of these different metalliferous zones would have had a unique elemental composition. Further, as the technological base of the group acquiring the metal changed over time, the designation of different deposits or locations within mineralized zones as “ore” would necessarily have shifted. Taking all of these factors into account the only realistic conclusion is that it is not possible to project modern ore mineralization onto the ancient landscape.

The next issue that needs resolved to allow for the use of compositional characterization to identify artifact-ore correlations is the determination of which elements are accessory minerals and which are anthropogenically added alloying elements or fluxes. As discussed in Chapter 2, each of the primary alloying elements with copper has its own unique set of challenges when attempting to delineate between intentional addition and accessory mineral. While determinations for tin, antimony, and lead can be determined to some degree through experimentation and other analysis; the volatility of arsenic its frequent co-occurrence with copper minerals in ore bodies makes any determination for arsenic extremely problematic {Hauptman 2007; Pernicka 1999; Stech 1999}. Further, ancient furnaces were often inconsistent and metallurgical “recipes” may have exhibited significant variation that would have obscured the linkages between parent ore and finished copper-bronze object (Pernicka 1999; Hauptman 2007).

Moving beyond considerations of alloying other metals to copper, the impact of other processing steps undertaken between extraction of the raw ore and the deposition of the finished product into the archaeological record must be assessed. Roasting, ore beneficiation, smelting, melting, casting, and forging all can alter the elemental fingerprint of a metal object. In some cases, significantly altering its composition when compared to the parent ore (Pollard and Heron

1996; Pernicka 1999). This alteration is inconsistent, difficult to model, and prevents the analyst from making secure linkages between ores and artifacts.

The final point that can impact compositional comparisons of artifacts and ores is what chemical alterations occur post-deposition. For the purposes of the current research project, the discussion presented by Scott (1991) serves as a useful summary. The main conclusion being that as a copper or bronze metal object corrodes it is chemically altered by the differential migration of elements between the core of the artifact, the corroded surface, and the surrounding soil. The nature of chemical alteration of copper and bronze objects in surrounding soil matrix has been outlined in Chapter 4 of this work. A more detailed review is not necessary for two reasons. The first is that the acknowledgement that copper and bronze artifacts can potentially undergo significant chemical alteration is sufficient to cast serious doubt on the efficacy of compositional analysis to link artifacts and ores. The second is that compositional research into both the soil matrix and copper and bronze metal artifacts from Harappa demonstrates noticeable compositional alteration (see Chapter 4) that is sufficient to make elemental fingerprinting a highly problematic methodology for determining source provenance of Indus copper and bronze objects.

Numerous projects across the Mediterranean, the ancient Near East, the Arabian Peninsula, and Europe has demonstrated that lead-isotope analyses have the ability to narrow and potentially discriminate between sources of copper (Yener et al. 1991; Amov 1999; Weeks 1999; Begemann et al. 2001; Gale 2001). Despite earlier negative outlooks on its viability as a provenance technique (Budd et al. 1993, 1996), continuing research confirms the utility of such an approach to the provenance of copper ore fields {Gale and Stos Gale 2000; Sos-Gale and Gale 2009; Pernicka 2014}.

Lead isotope analysis was first developed to date geologic deposits (Faure 1986; Dickin 1995). Three of the isotopes of lead (^{206}Pb , ^{207}Pb , and ^{208}Pb) are the products of the decay of uranium and thorium, while the fourth (^{204}Pb) is taken to be a stable reference isotope (Faure 1986). Since there are only four isotopes of lead, three distinct ratios exist. Based on the principles of radiogenic decay and the known half-lives of the daughter products, geologists have used lead isotope abundance ratios to develop models for extrapolating the age of geological samples (Faure 1986; Dickin 1995). In practice samples are grouped and categorized based on a comparison of the three distinct isotopic ratios. In actuality these ratios are functioning as a stand in for the age of the geologic deposits the sample was collected from. A variety of mathematical and geologic models are used to extrapolate an age from a given set of lead isotope ratios (Faure and Mensing 2009; White 2001, 2015). Additionally, it is possible to determine the nature of the reservoir(s) that contributed to the lead content of a given geologic formation (Faure and Mensing 2009; White 2001, 2015). The specific characteristics of the Uranium-Lead system of isotopes has proven to be useful for both determining the age and type of geologic deposit that a given sample would have originated from. Over the past 30 years, archaeologists have adopted and applied this technique to the study of archaeological metal remains (Gale and Stos-Gale 2000).

In order to understand how measuring lead isotope ratios in copper and bronze metal artifacts is able to provide the archaeologist with secure linkages back to the parent copper ore, it is necessary to review a few key points about the overall functioning of the lead isotope system. Excellent reviews can be found in both isotope geology and archaeometallurgy focused texts (see Faure and Mensing 2009; White 2001, 2015; Gale and Stos-Gale 2000; Pernicka 2014; Pollard and Heron 1996; and Law 2011 for examples) and only key issues will be detailed here. First

critical point is recognizing what can be understood from the measurements of the isotopes of lead and their ratios alone. Three of the four isotopes of lead (208, 207, & 206) are time dependent (i.e. radiogenic). They are the products of the radioactive decay of either uranium or thorium and the more time that passes since the formation of the ore and the laboratory measurement of the isotopic ratios - the more of these radiogenic lead isotopes that will be present in the sample. The remaining isotope (204 Pb) is stable or time independent. The ratio of lead 204 is constant (essentially fixed) since the formation of the earth. As a result, it is often referred to as primeval lead. Taking these two basic facts about the lead isotope system together, it is possible to already begin to make inferences about the nature of the ore deposit that would have contained the copper ore used to fashion a given archaeological artifact. The age of the deposit can be calculated as well as some characteristics of the ore formation based on solely the isotope ratios themselves (see Faure and Mensing 2009; White 2001, 2015; Gale and Stos-Gale 2000; Pernicka 2014). It is the combination of these two basic facts about the lead isotope system along with the two key assumptions discussed below, that allow it to be employed as an archaeological provenance technique (Pernicka 2014:247-248).

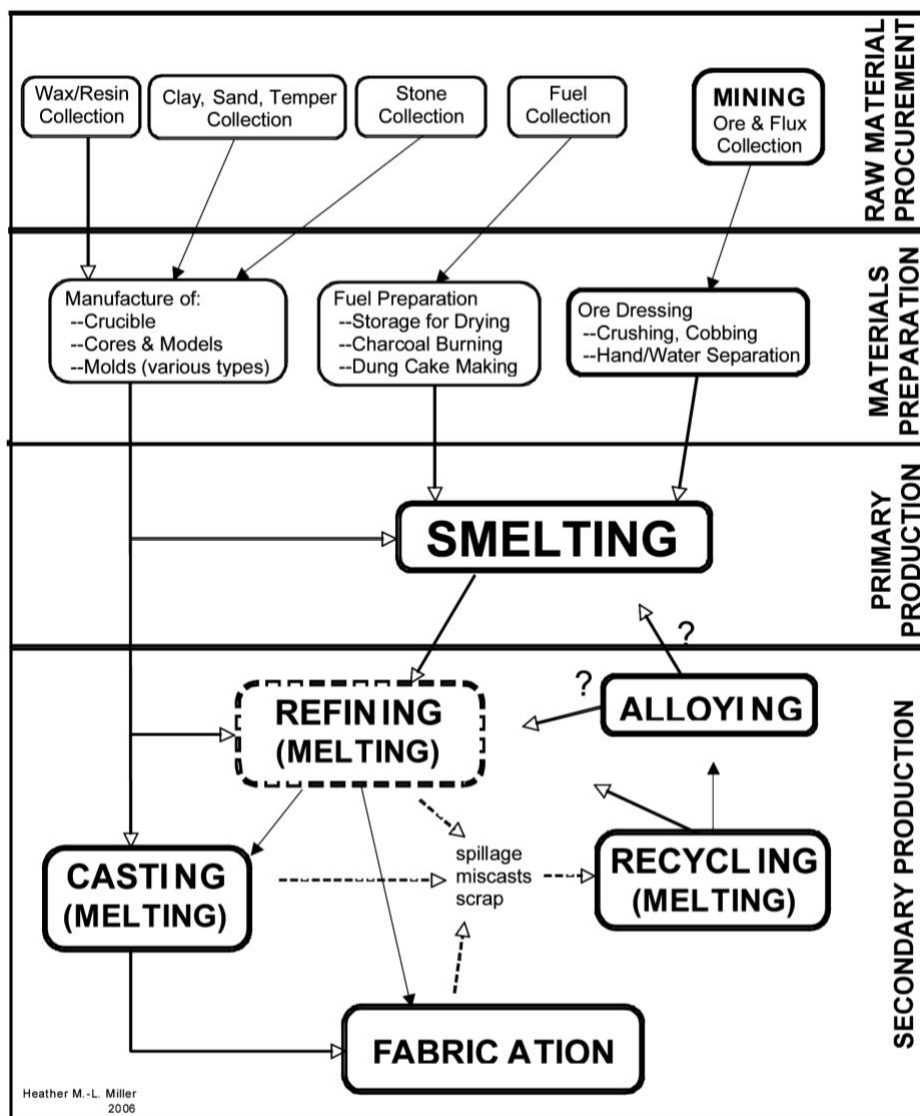
There are two key assumptions for using the measurement of lead isotopes to correlate archaeological artifacts with their geologic source. Through the combination of these two assumptions, fractionation and the degree of isotopic heterogeneity in an ore field, source provenance correlations between artifacts and ores can be constructed. The first is that there are no anthropogenic activities that produce isotopic fractionation (Gale and Stos-Gale 2000; Pollard and Bray 2014; Pernicka 2014). That is to say that between the harvesting of the parent copper ore and all of the conceivable steps in a given metallurgical tradition (see Figure 5.1 for generalized example), there is no process or series of processes that will significantly alter the

ratios of the 4 isotopes of lead. This allows for the isotopic ratios seen in archaeological artifacts to be securely linked to the original parent ores. In the context of copper metallurgy this would include, ore roasting, beneficiation of the ore, smelting, melting, and a variety of manufacturing techniques. Additionally, there would also need to be no fractionation of the isotopes after the archaeological artifact was deposited into the soil matrix. A review of a series of analytical studies demonstrates that this assumption can be held as valid (see Pollard and Heron 1996: 324-326). While it is theoretically possible for the isotopic ratios to be altered during the various pyro-technological steps that ancient metalworkers could have employed (Budd et al. 1995; Pollard and Heron 1996; Pollard and Bray 2014) due to non-equilibrium evaporation; experimental and analytical research have been unable to demonstrate significant change in isotopic ratios due to these processes (Budd et al. 1995; Pollard and Heron 1996). Therefore, the extraction, refining, and manufacturing technologies applied to copper ore in the creation of copper and bronze artifacts should have no measurably significant impact on lead isotope ratios (Gale and Stos-Gale 2000; Stos-Gale and Gale 2009). In other words, while there may be less lead in a finished archaeological artifact than its parent ore deposit, the three distinct ratios will remain identical. Therefore, an artifact containing lead can be said to retain the original isotopic composition of its parent deposit. As a result, lead isotopes have demonstrated a high degree of utility in establishing source provenance correlations for archaeological metals. Of course, for copper artifacts this is a best-case scenario. It is always a problematic possibility that copper from two or more sources could be mixed and other metals or materials may be added during the manufacturing process; any one of which could alter the isotopic characteristics of the finished object. It must be acknowledged that under laboratory conditions lead can be volatilized and

fractionation can occur. However, there are no known parallels to these specific conditions in copper and bronze metallurgy (Pernicka 2014:249).

The second assumption is that an ore field must have a definable extent. This has been the subject of an intense amount of debate throughout the literature (Gale and Stos-Gale 2000; Budd et al.1995; Scaife et al. 1999). While the issue of the normality of lead isotope data remains in question; this mainly pertains to the issue of how exactly to isotopically define the limits of an ore field not that the exercise is impossible. The main concern is the underlying isotope geology of the ore field. The natural variation of lead isotopes within a given ore field needs to be greater than the variation in the ability to measure isotopes – error factor, instrument resolution, etc. Current standard instrumental techniques of measuring lead isotopes (thermal ionization mass spectrometry and multiple collector inductively coupled plasma mass spectrometry) are capable of measuring the isotopes of lead between 0.05% and 0.01% (Pollard and Heron 1996; Gale and Stos-Gale 2000). The isotopic variation within a given ore deposit is typically between 0.1 % and 0.3 % (Gulson 1986) although some deposits can vary to a much higher degree than that (Pollard and Heron 1996). Using these minimums, it can be seen that lead isotope ratios are able to be reliably measured to an order of magnitude greater than the variation within an ore field. This means that the isotopic boundaries of an ore field can be identified and defined.

Figure 5.1: Generalized Steps in Copper and Bronze Production



In addition to the underlying isotopic principles and the key assumptions, metal provenance studies should endeavor to address the following critical points (adapted from Gale and Stos-Gale 2000):

1. Understand the geologic context of the hypothesized ancient ore source(s).
2. Use representative ore samples from a geological perspective.
3. Establish the relevance and utility of each comparative ore source.
4. Adapt and employ an appropriate scale of analysis for the provenance study.

Each of these points needs to be considered and accounted for in order for the conclusions extrapolated from the lead isotope data to have an ability to aid in reconstructing ancient behaviors and interactions. The first two points are related and caution researchers to ensure that they are approaching the construction of the geological comparative database with a clear understanding of how the fundamental geology and characteristics of each ore deposit can impact the interpretation of the results. For instance, is the deposit isotopically homogeneous or does it have a wide variation? Have the samples selected for analysis accounted for that or attempted to account for said variation? While it should be acknowledged that samples availability is often guided and constrained by factors aside from geological realities, it should still be possible to understand and account for localized geological variables. The third and fourth points are again related and serve to encourage the limiting of isotopic comparisons to sources that can be seen as reasonable based on current archaeological understandings of regional prehistory. Deposits across the globe have similar isotopic signatures and global comparisons may lead to spurious conclusions that have metal being imported from a geographically implausible location. In the current study, I have constrained the comparisons to locations within South Asia and adjacent regions that have archaeologically demonstrated connections with the Indus region during the 3rd millennium BCE.

Pilot Study to Assess Viability of Lead Isotope Analysis on Indus Materials

Despite the success and acknowledged viability of lead isotope analysis in other similar settings, the technique has not been deployed widely in the study of South Asian prehistory. There are a handful of excellent examples of using lead isotopes to source provenance archaeological artifacts (see Law 2011 and Srinivasan 1999) and a few initial attempts to begin

to develop a lead isotope database for the subcontinent (Law 2011; Hegde and Ericson 1985; Ericson and Shirahata 1985) but not the directed series of overlapping studies that has characterized other regions. As a result, there exists serious questions regarding the utility of the technique for source provenance studies for Indus Tradition copper and bronze artifacts. In order to address this concern and test the applicability of the technique to the materials available for analysis from Harappa, a pilot study of seven minerals and twelve copper-bronze metal artifacts from the HARP study collection was undertaken. The study had two goals. The first was to determine if these representative samples had enough lead to return viable results. The second goal was to compare the analytical results to potential regional geologic sources to determine if the reported lead isotope ratios were consistent with expected results.

Lead isotope analysis (LIA) was conducted at the Laboratory for Archaeological Chemistry (LARCH) at the University of Wisconsin-Madison to analyze the isotopic characteristics of seven archaeological copper mineral specimens from Harappa (Appendix 5.1) and compared them to samples from potential source areas within and adjacent to northwestern South Asia (Tables 5.1-5.2 and Figure 5.2). Wherever possible minerals were obtained, but slags were also analyzed for some sites (Appendix 5.2). Additionally, the data from South Asia was compared to published LIA values for copper deposits in Oman (Calvez and Lescuyer 1991; Weeks 2003). The results of this research have been presented in full elsewhere (Law 2011; Hoffman and Miller 2014) and needs only be summarized here.

Table 5.1: Regional Ore Deposits

Deposit	Location	Sample Type
Ambaji	Northern Gujarat	Ore
Ganeshwar	Northern Rajasthan	Slag
Singhana	Northern Rajasthan	Slag
Chagai Hils	Baluchistan	Ore
Shin Kai	Waziristan	Ore
Chargaon	Himachal Pradesh	Ore
Askot	Uttaranchal	Ore
Various	Oman	Published Ore Data

Table 5.2: Copper Minerals from Harappa

Sample	Mineral Type	Location	Period
H94/4999-529	chalcocite	misc. surface find	Unknown
H90/3008-13	chalcocite	Mound E – survey	Harappan or Later
H90/2070-12	chalcocite	Mound E – survey	Harappan or Later
H90/3008-14	chalcocite	Mound E – survey	Harappan or Later
H90/3022-98	malachite	Mound E – Tr. 58	Harappan or Later
H95/4943-8	malachite	Mound ET – Tr. 28	Harappan or Later
H90/3126-1	malachite	Mound E – Tr. 56	Harappan

Figure 5.2: Map of Regional Copper Sources in Pilot Study

A series of initial conclusions was drawn from these results, through the analysis of a bivariate plot of the LIA results (Figure 5.3A). The samples from both of the Himalayan sources are not only clearly distinct from each other, but all of the other sample regions as well. All seven of the archaeological copper minerals from Harappa that were analyzed clearly do not exhibit an isotopic relationship to the Himalayan sources. These samples can be eliminated from further analysis of this dataset and the other samples can be examined in greater detail (Figure 5.3B). None of the samples from Harappa are isotopically related to the modern ore samples from Amabaji. Five, or perhaps, six of the minerals do appear to be related to one of the sources to the west or south of Harappa, that is Baluchistan, Waziristan, and Oman. Many of the copper mineral samples from the site fall in the area where the isotopic values for these three sources overlap. The overlap exhibited by these sources is likely the result of the similarity in geologic age for these three ophiolitic metalogenic zones (Law 2011:456). One of the seven copper mineral samples from Harappa may be isotopically analogous to the slag samples from northern Rajasthan, specifically those from Ganeshwar (Figure 5.3B). Based on these seven archaeological copper mineral samples from Harappa, the following conclusions were drawn. It is unlikely that either Ambaji or the central Himalayan sources were supplying Harappa with copper minerals. Harappa may have procured a small portion of its copper minerals from sources in northern Rajasthan. The data from this small-scale pilot study indicates that the majority of Harappa's copper minerals were obtained from sources to the west or south of the site. If mineral procurement parallels copper ingot procurement, sources to the west or south likely supplied the majority of Harappa's needs.

Figure 5.3A: Lead Isotope Pilot Study Results

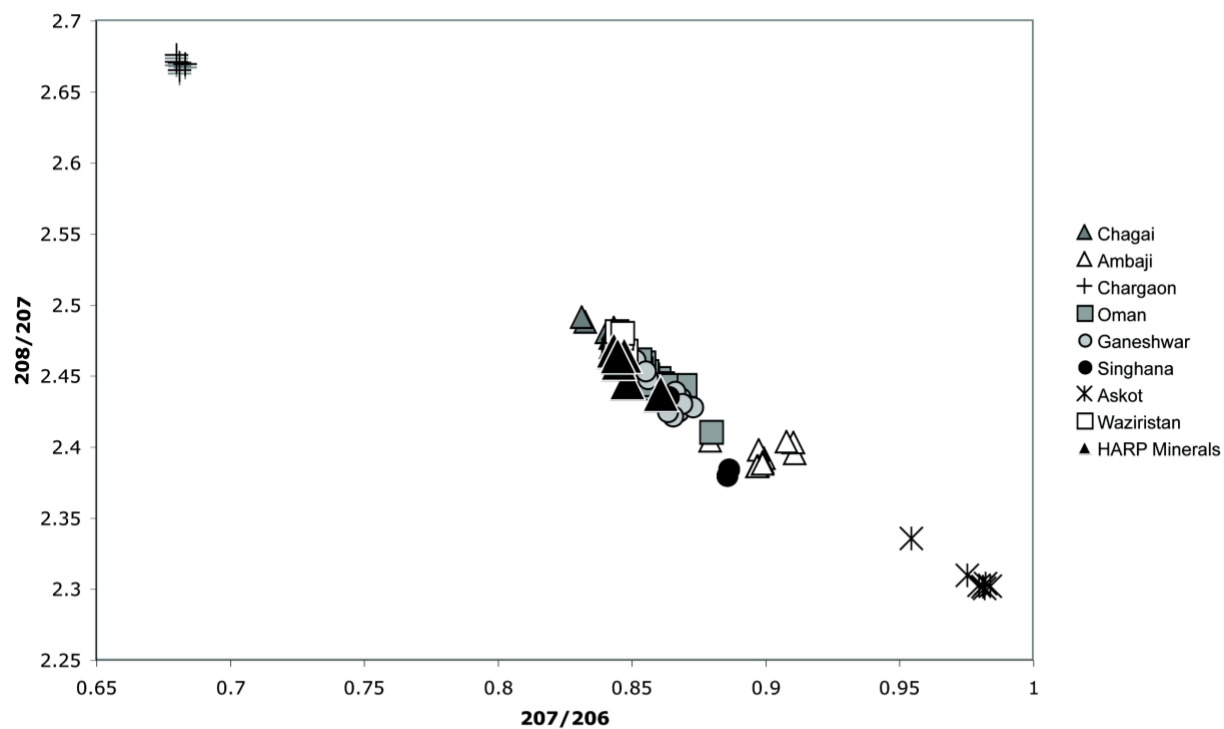
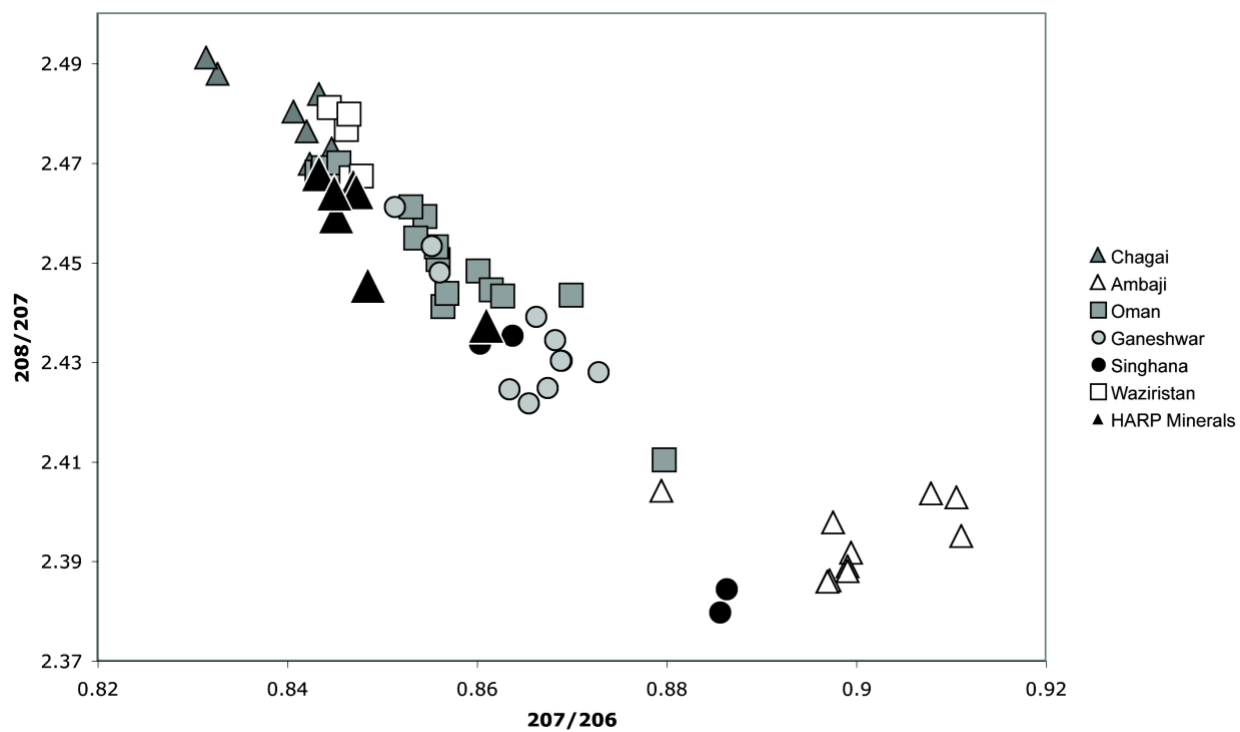


Figure 5.3B: Lead Isotope Pilot Study Results



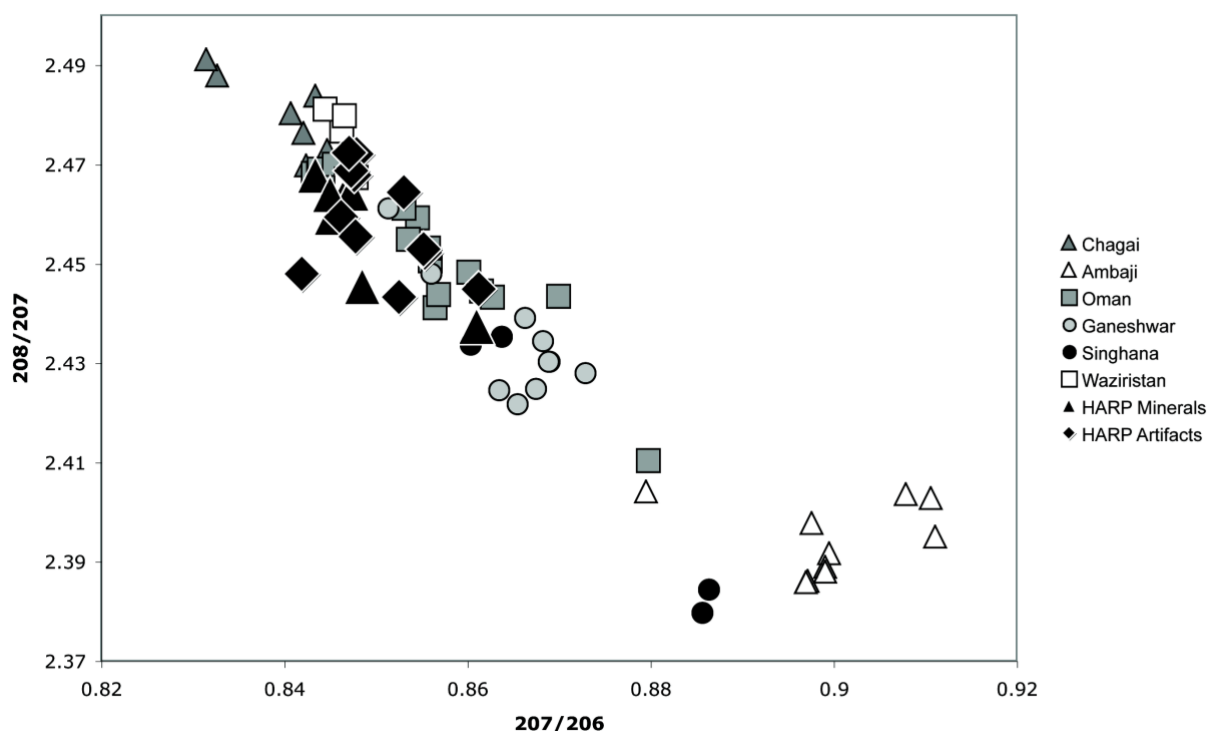
This component of the pilot study did have some limitations. Namely the lack of solid lead isotope data for the copper bearing metal deposits throughout Rajasthan and the lack of accurate lead 204 data. Both of these concerns were cogently addressed by Law (2014:447-456) and in terms of the pilot study itself, there is nothing to add. However, it needs to be pointed out that the present study has been able to correct these limitations along multiple fronts. A more robust set of regional lead isotope values has been developed (see Appendix 6.1) that includes published data, and new analyses of a number of key samples from the previously under-represented copper bearing localities within Rajasthan supplied by Law (personal communication). Additionally, selected slag samples from the pilot study were reanalyzed and accurate lead 204 data was obtained (Law personal communication). Chapter 6 discusses the implications and revised conclusions that this new more robust dataset allows.

The second component of the pilot study was to analyze the lead isotope signature of 12 copper or copper alloy artifacts from Harappa (Appendix 5.3); compositional analysis was not completed on these objects. Examples of beads, bangles, rods, and sheets were analyzed. All artifacts were from the Harappan Phase (Integration Era) and from either Mound E, ET, or F (Table 5.3). This analysis was conducted at the University of Michigan Department of Geosciences on a Thermal Ionization Mass Spectrometer (TIMS). Archaeological applications of Lead Isotope Analysis have demonstrated the utility of using the technique to determine the number of potential source areas present even in the absence of geologic comparisons (see Weeks 2003 for further references) or in the case of this pilot study – highly limited source area comparative data. The results of this portion of the initial pilot study have been previously discussed (Hoffman and Miller 2014) and only two main points are relevant to the overall research project.

Table 5.3: Copper or Copper Alloy Artifacts from Harappa

Year	Lot	Rec.	Type	Feature	Trench	Mound	Phase
H2000	2102	1447	Sheet/Blade	1	54	E	Harappan
H2000	2226	40	Sheet/Blade	1	54	E	Harappan
H2000	2357	3	Bead	475	54	E	Harappan
H2001	2394	3	Bead	534	54	E	Harappan
H1996	6913	45	Bangle	686	11	E	Harappan
H1996	6958	61	Rod	730	11	E	Harappan
H1994	4343	3	Sheet/Blade	283	11	E	Harappan
H1995	4638	1	Bangle	538	10	ET	Harappan
H1995	4968	12	Bangle	174	28	ET	Harappan
H1996	7227	32	Rod	30	37	F	Harappan
H1996	7248	1	Rod	56	37	F	Harappan
H1998	8627	18	Rod	37	43	F	Harappan

The first is that the same broad pattern seen in the archaeological minerals, that of being primarily related to copper ore sources west or south of Harappa, is also evident in the data from the artifacts (Figure 5.4). The results from the beginning stages of analysis of the copper assemblage from Harappa indicate that during the Harappan Phase, the city was obtaining copper raw material primarily from sources to the west or south of the site in Oman, Baluchistan, and Waziristan. The artifacts from Harappa also demonstrate this pattern. Initial results from the artifacts echoed the early analysis from the minerals and preliminary conclusions were focused in this direction. Discussion was oriented towards sources to the west and south of Harappa and while acknowledging the possibility of Rajasthan forming a component of copper supply at the site, admittedly, this source region was largely marginalized in the early phases of research (Hoffman and Miller 2014). As is discussed extensively in Chapter 6, new data has mandated the almost total revision of these conclusions and the associations between copper and bronze objects at Harappa and sources across Rajasthan currently appears stronger than any other potential source area either within South Asia or adjacent regions.

Figure 5.4: Detail of Lead Isotope Pilot Study Results

The second point is the most critical to the overall research project. The pilot study on copper minerals and artifacts from archaeological contexts at Harappa as well as slags and ores from regional copper sources serves as a relatively robust validation of the research design. It was proven possible to obtain lead isotope data from archaeological artifacts, minerals, and slags. Further the data from all three of these sources was comparable and consistent with one another and between each set. This demonstrates the potential for the construction of artifact-ore correlations for Indus copper and bronze materials. While this conclusion should not be viewed as unexpected based on the wide body of literature, it does represent one of the first attempts at testing and confirming this expectation. Previous work had demonstrated the applicability of similar approaches to galena (Law 2011), copper from later periods (Srinivassan 1999), and copper ores (Hegde and Ericson 1985; Ericson and Shiratha 1985; Deb 1989, 2000; Law 2011)

but the combination of all elements on 3rd millennium copper and bronze materials had not been previously attempted.

Initial Sample Set

After the twelve-sample pilot study demonstrated the viability of measuring lead isotopes from copper and bronze metal artifacts from Harappa, a further set of exploratory analyses were undertaken to address the potential limitations of the pilot study. The primary concern was that the pilot study dissolved large quantities of metallic sample in order to develop isotopic signatures. Scattered throughout the literature on lead isotope analysis on ancient copper metallurgy are repeated concerns that in the absence of bulk metallic copper-bronze to dissolve it may not be possible to derive sound isotopic data from corrosion products. However, outside of two small studies (Snoek et al. 1999; Gale and Stos-Gale 2000) there are no empirical tests of the difference between lead isotope measurements from metal and those from oxidized corrosion products. To determine what, if any, limitations the issue of moderately to highly corroded samples presented for isotopic analysis of the HARP sample set a comparative examination of eight samples from the HARP (Appendix 5.4) dataset was undertaken. This work was undertaken at the University of Florida (UF) Department of Geological Sciences on a Thermal Ionization Mass Spectrometer (TIMS).

Table 5.4: Lead Isotope Ratios from Metallic & Oxidized Portions of HARP Samples

UF LIA Sample #	Sample Material Designation	208/204	207/204	206/204	208/206	207/206
1	metal	37.97651	15.65405	17.90593	2.12087	0.8742487
1	oxide	37.95591	15.64838	17.90152	2.120248	0.8741363
7	metal	37.29144	15.62636	17.32427	2.15253	0.9019998
7	oxide	37.29365	15.62715	17.32785	2.152284	0.9018639
12	metal	38.68137	15.68429	18.52024	2.088605	0.8468636
12	oxide	38.67422	15.68178	18.51715	2.08862	0.8468859
16	metal	38.91048	15.68718	18.33856	2.121835	0.855444
16	metal	38.9137	15.68809	18.33938	2.121855	0.8554396
16	oxide	38.92005	15.68665	18.34297	2.121821	0.8552042
21	metal	38.61074	15.68548	18.42585	2.095458	0.8512712
21	oxide	38.59955	15.68171	18.42246	2.095264	0.8512263
32	metal	38.61669	15.67203	18.51948	2.085184	0.8462674
32	oxide	38.62065	15.67374	18.522	2.085215	0.8462631
41	metal	38.68161	15.682	18.51949	2.088815	0.8468035
41	oxide	38.68263	15.68171	18.51842	2.088879	0.8468135
44	metal	38.46545	15.67127	18.352	2.096038	0.8539516
44	oxide	38.46106	15.66998	18.35267	2.095671	0.8538168

The focus of this aspect of the analytical program was to measure the lead isotope signature of both the metallic core and the oxidized outer corrosion layer from each artifact in Table 5.4. The goal was to empirically determine measurements from different portions of the same object were significantly different as to be meaningful. To make this determination, sample material was taken from the outer oxidized corrosion layer (oxide in Figure 5.5A and Figure 5.5B) and from the inner metallic core (metal in Figure 5.5A and Figure 5.5B) and prepared using standard techniques. The results are displayed in Table 5.4. While a cursory comparison of the results would seem to indicate the two sample sets are nearly identical, a graphical comparison on a bivariate plot provides a succinct mode of comparison.

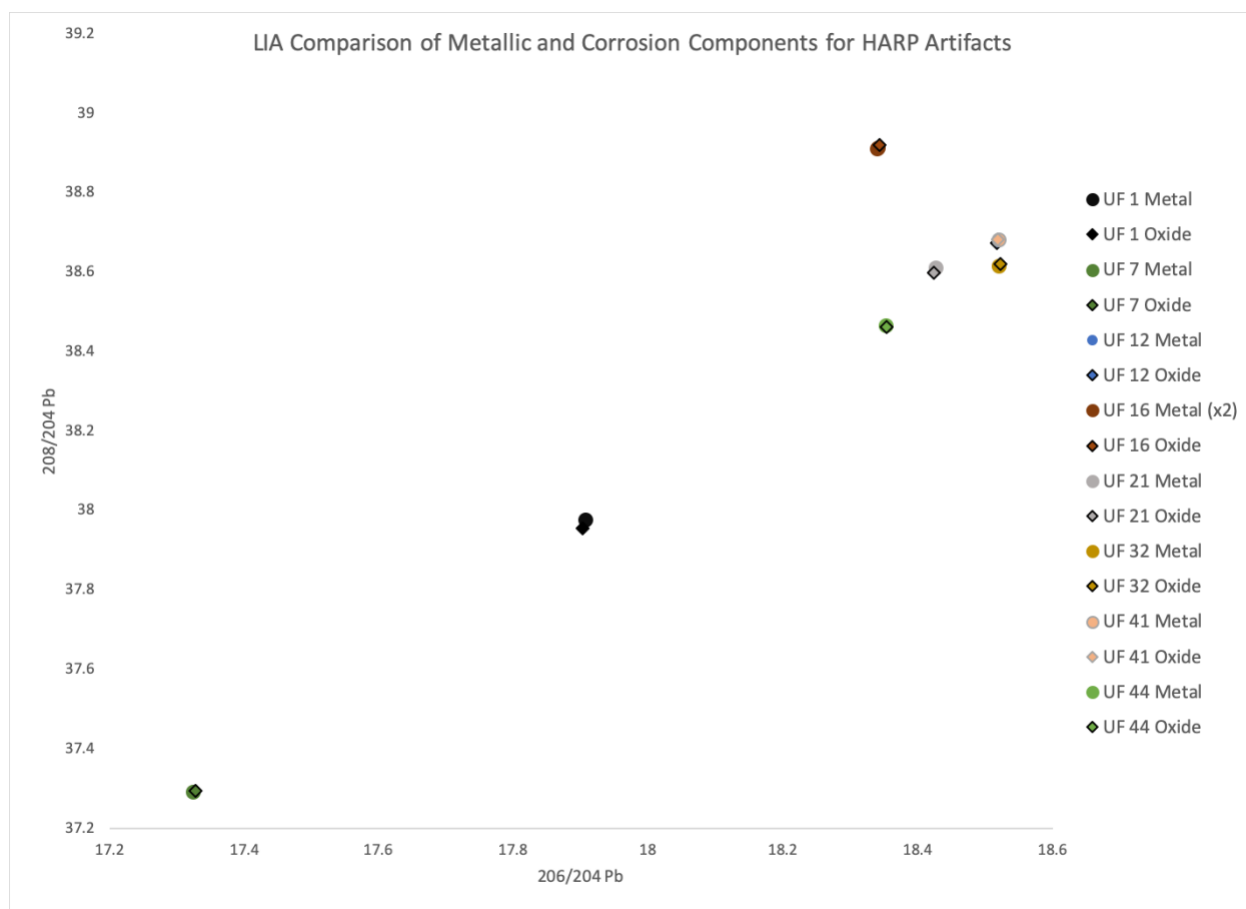
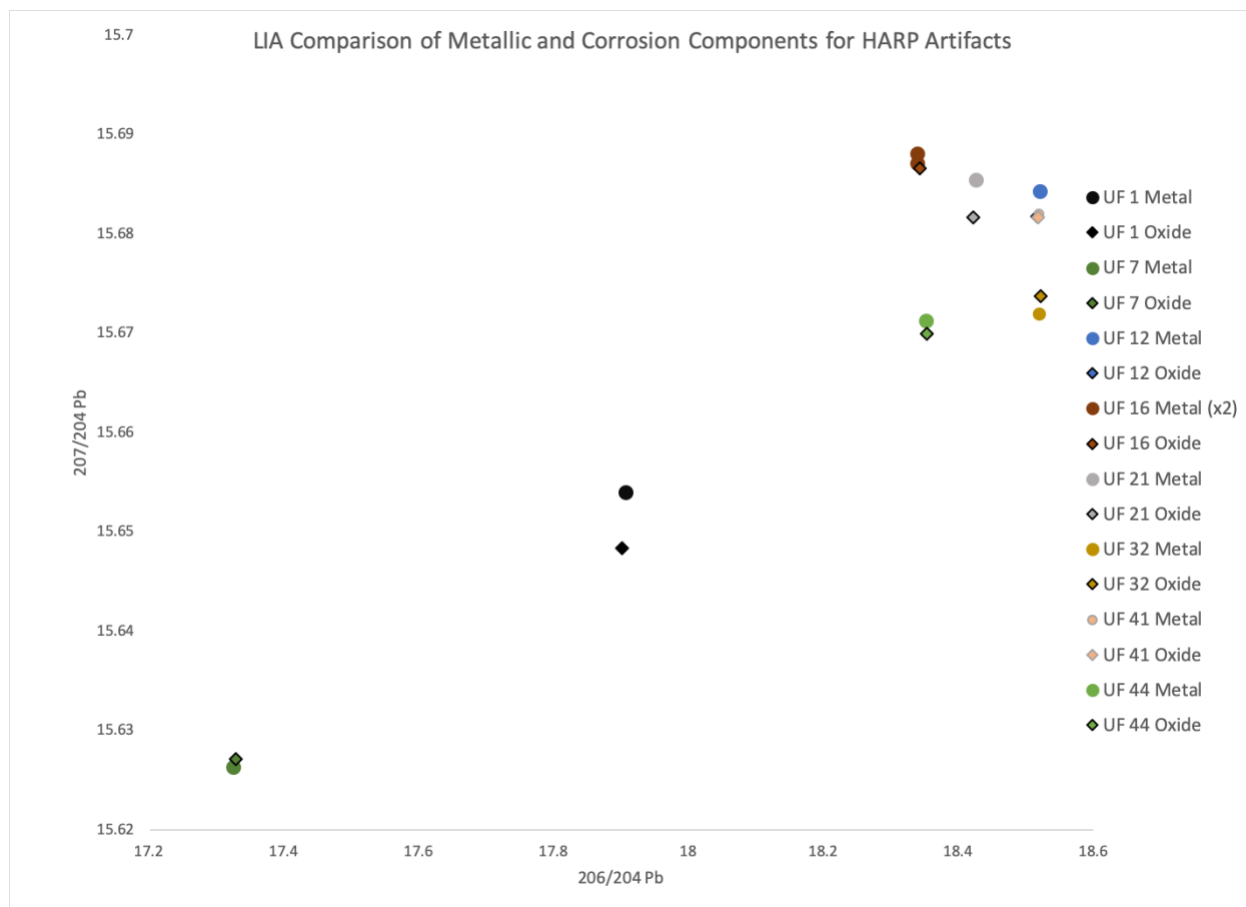
Figure 5.5A: LIA Comparison of Metallic and Corrosion Components for HARP Artifacts

Figure 5.5B: LIA Comparison of Metallic and Corrosion Components for HARP Artifacts

As has been previously discussed, the nature of the relatively close origin relationship between lead 208 and 206 will represent a highly linear display of data points when the ratio of lead 208/204 is graphed against the ratio of lead 206/204 that can sometimes exaggerate the degree of overlap between individual data points. Alternatively, since the relationship between lead 207 and 206 is different, a graphical representation of the ratio of lead 207/204 against the ratio lead 206/204 more readily displays the spread between data points. Both views can be seen in Figures 5.5A and 5.5B. Moving forward, a single graph displaying the ratio of lead 207/204 against the ratio of lead 206/204 will be used to highlight the results from this preliminary aspect of the analytical program.

An examination of the results of the lead isotope analyses on the eight-member preliminary sample set demonstrates two main conclusions. The first is that the measured difference between the corrosion and the metallic components of a given sample from the HARP set is negligible. It should be cautioned, that for some of the samples (specifically UF 1, 12, and 21) the degree of separation between the oxidized portion and the metallic portion was noticeable – particularly within the lead 207/204 ratio. This is in line with the results from previously conducted similar tests (Snoek et al. 1999; Gale and Stos-Gale 2000).

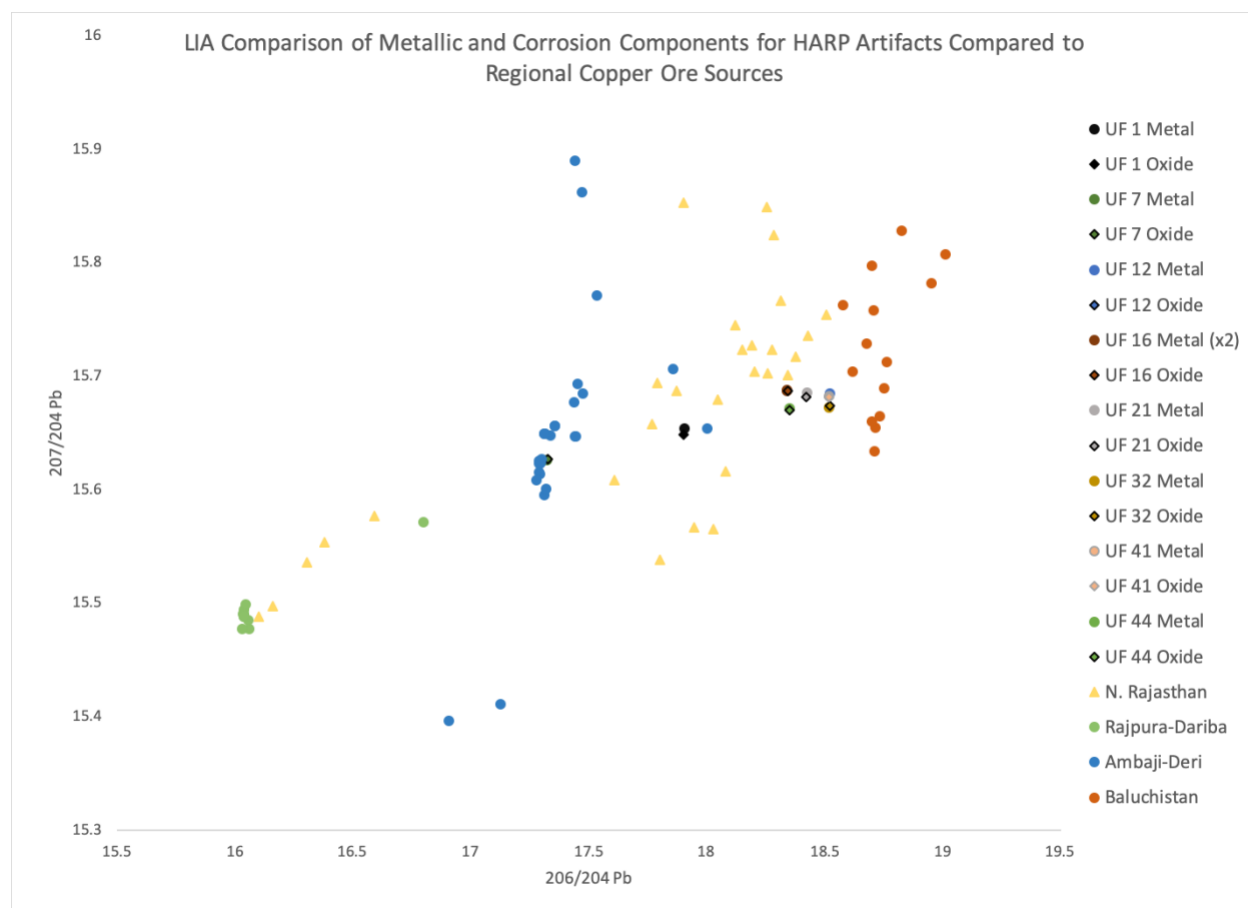
While it is important to document the presence of a degree of variation between the measurement sets, the critical objective is to make an assessment of how impactful that variation will be in the application of lead isotope data to source provenance studies. In other words, is the variation between the oxide and metal components of an artifact in the overall HARP analytical assemblage going to be greater than the isotopic variation both within and between likely copper source areas?

Figure 5.6 is a comparison of the lead isotope results of the preliminary analytical set to four potential regional copper source locales (north Rajasthan, Rajpura-Dariba in central Rajasthan, Ambaji-Deri in southern Rajasthan and northern Gujarat, and Baluchistan). The critical dimension is the clustering of the four regional source locales into relatively narrow bands along the vertical lead 207/204 axis. The isotopic data from sources within northern Rajasthan are more isotopically diverse than any of the other 3 sources and this is useful for the current discussion.

The northern Rajasthan region is represented by three different source locales in Figure 7; polymetallic ores and slags from Dariba, slags from Ganeshwar, and slags from Singhana. There

is more isotopic diversity within and between these sources from northern Rajasthan than there is between the oxidized corrosion and metallic components of individual HARP artifacts.

Figure 5.6: LIA Comparison of Metallic and Corrosion Components for HARP Artifacts and Regional Copper Ores



Further analysis of Figure 5.6 indicates that there is more isotopic difference between and within any source area, even the more isotopically homogenous source locales, than there is between the oxidized corrosion and metallic components of individual HARP artifacts.

A survey of experimental and analytical results in the literature lends further support to the idea that the isotopic ratios between the metallic core and the corroded outer surfaces of a copper object should be the same. In general, copper artifacts containing between 50 parts per

million (ppm) and 4% lead are viable for copper source provenance studies by lead isotope analysis (Gale and Stos-Gale 1982; 2000). Table 5.5 shows the difference between the metal and oxide measurements for the eight samples and converts that difference to a percent of the measured metal lead isotope value. These values range between 0.001% and 0.05%. This is within the range of known error for TIMS measurements of lead isotope values as well as being at least one order of magnitude smaller than the natural variation in ore deposits (Gulson 1986).

Taken together, this forms a strong basis for the conclusion that the lead isotope analysis of HARP artifacts will not be adversely impacted by the level of oxidation or corrosion. The results developed during this portion of the project provide direct evidence that as long as an archaeological artifact retains enough lead content to measure, then the degradation of the original metal is not a problematic concern for either analysis or sample selection. This conclusion is in line with both the results of previous analytical studies (Snoek et al. 1999; Gale and Stos-Gale 2000) and inferences based on Shackley (2011), Schoukens (2008), and Scott (1991, 2000) (see Figure 4.1 Chapter 4). With confirmation that the nature of the samples available for analysis would not create additional difficulties for data interpretation, the major isotopic analysis portion of the research project could be undertaken.

Table 5.5: Comparison of Metallic and Oxide Lead Isotope Measurements for HARP Samples

UF LIA Sample #	Sample Material Designation	208/204	207/204	206/204	208/206	207/206
1	metal	37.97651	15.65405	17.90593	2.12087	0.8742487
1	oxide	37.95591	15.64838	17.90152	2.120248	0.8741363
Difference		0.0206	0.00567	0.00441	6.22000E-04	1.12400E-04
Percent		0.05424%	0.03622%	0.02463%	0.02933%	0.01286%
7	metal	37.29144	15.62636	17.32427	2.15253	0.9019998
7	oxide	37.29365	15.62715	17.32785	2.152284	0.9018639
Difference		-0.00221	-7.90000E-04	-0.00358	2.46000E-04	1.35900E-04
Percent		-0.0059%	-0.0051%	-0.0207%	0.0114%	0.0151%
12	metal	38.68137	15.68429	18.52024	2.088605	0.8468636
12	oxide	38.67422	15.68178	18.51715	2.08862	0.8468859
Difference		0.00715	0.00251	0.00309	-1.50000E-05	-2.23000E-05
Percent		0.01848%	0.01600%	0.01668%	-0.00072%	-0.00263%
16	metal	38.91048	15.68718	18.33856	2.121835	0.855444
16	metal	38.9137	15.68809	18.33938	2.121855	0.8554396
16	oxide	38.92005	15.68665	18.34297	2.121821	0.8552042
Difference		-0.00957	5.30000E-04	-0.00441	1.40000E-05	2.39800E-04
Percent		-0.02459%	0.00338%	-0.02405%	0.00066%	0.02803%
Difference		-0.00635	0.00144	-0.00359	3.40000E-05	2.35400E-04
Percent		-0.01632%	0.00918%	-0.01958%	0.00160%	0.02752%
21	metal	38.61074	15.68548	18.42585	2.095458	0.8512712
21	oxide	38.59955	15.68171	18.42246	2.095264	0.8512263
Difference		0.01119	0.00377	0.00339	1.94000E-04	4.49000E-05
Percent		0.02898%	0.02403%	0.01840%	0.00926%	0.00527%
32	metal	38.61669	15.67203	18.51948	2.085184	0.8462674
32	oxide	38.62065	15.67374	18.522	2.085215	0.8462631
Difference		-0.00396	-0.00171	-0.00252	-3.10000E-05	4.30000E-06
Percent		-0.01025%	-0.01091%	-0.01361%	-0.00149%	0.00051%
41	metal	38.68161	15.682	18.51949	2.088815	0.8468035
41	oxide	38.68263	15.68171	18.51842	2.088879	0.8468135
Difference		-0.00102	2.90000E-04	0.00107	-6.40000E-05	-10.00000E-06
Percent		-0.00264%	0.00185%	0.00578%	-0.00306%	-0.00118%
44	metal	38.46545	15.67127	18.352	2.096038	0.8539516
44	oxide	38.46106	15.66998	18.35267	2.095671	0.8538168
Difference		0.00439	0.00129	-6.70000E-04	3.67000E-04	1.34800E-04
Percent		0.01141%	0.00823%	-0.00365%	0.01751%	0.01579%

HARP Artifact Sample Set

A total of 125 samples from Harappa were submitted for lead isotope analysis, including the eight used for the initial determination of lead isotope signatures of metal versus oxidized corrosion (Appendix 5.5). Of these samples, 118 returned viable data. The remaining seven determinations were too low in lead to produce usable results (see notations in Appendix 5.5). This work was undertaken at the University of Florida (UF) Department of Geological Sciences on a Thermal Ionization Mass Spectrometer (TIMS). Standard TIMS lead isotope sample preparation procedures were used (see Gale and Stos-Gale 2000 and Stos-Gale and Gale 2009 for details).

The results of these analyses and the twelve artifacts from the pilot study (Appendix 5.3) are displayed graphically in Figure 5.7A and Figure 5.7B. These two analytical sample sets provided a total of 130 lead isotope signatures. An initial review of this data establishes that the lead isotope results of the HARP artifacts fit within expected parameters based on the results from the pilot study and the initial sample set. Overall, the results of the pilot study, the initial sample set, and the HARP sample set fulfill all of the requirements outlined above for lead isotope data as well as empirically demonstrating the absence of significant methodological hurdles in constructing source provenance designations from the artifact side. The analysis and implications of the possible artifact-ore correlations that the results support will be discussed in the following chapter.

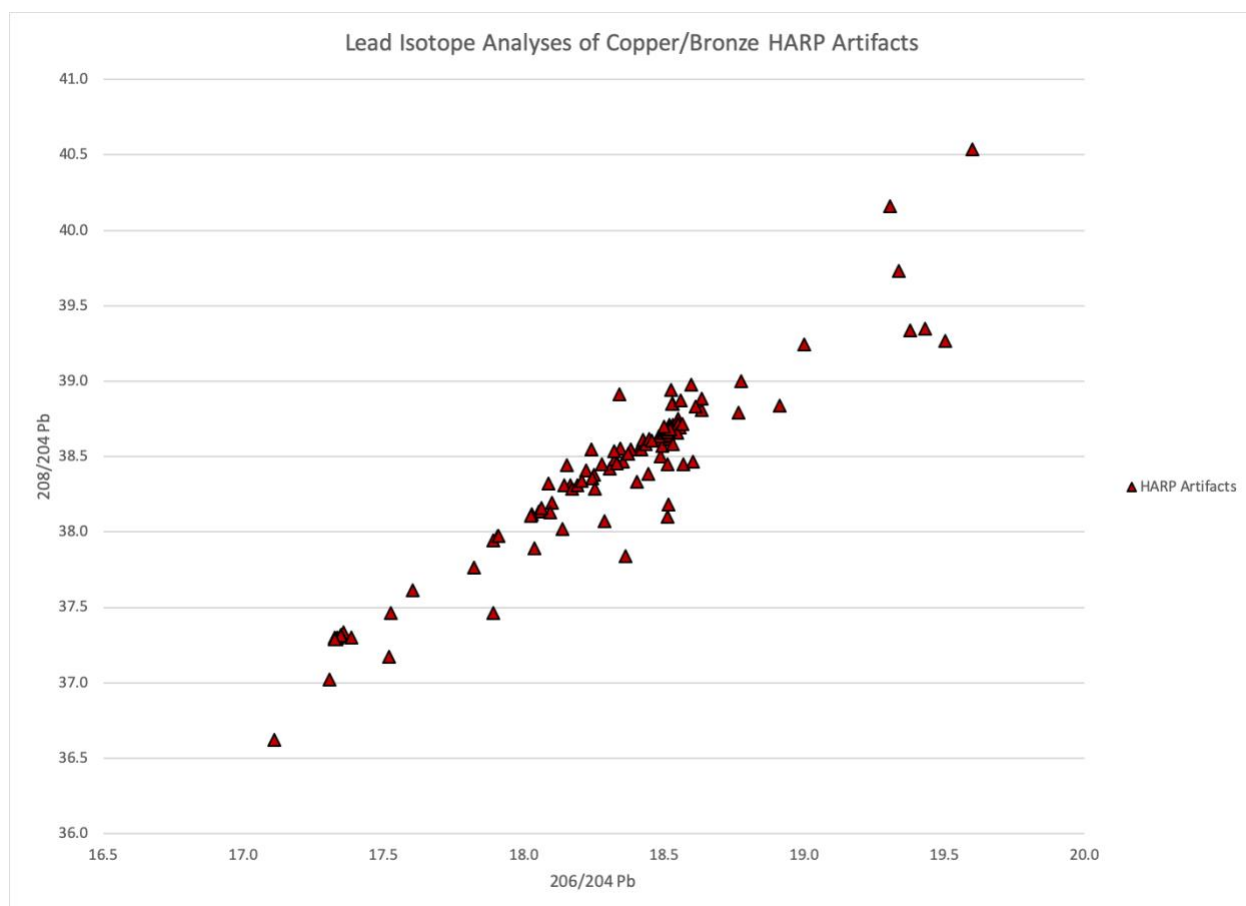
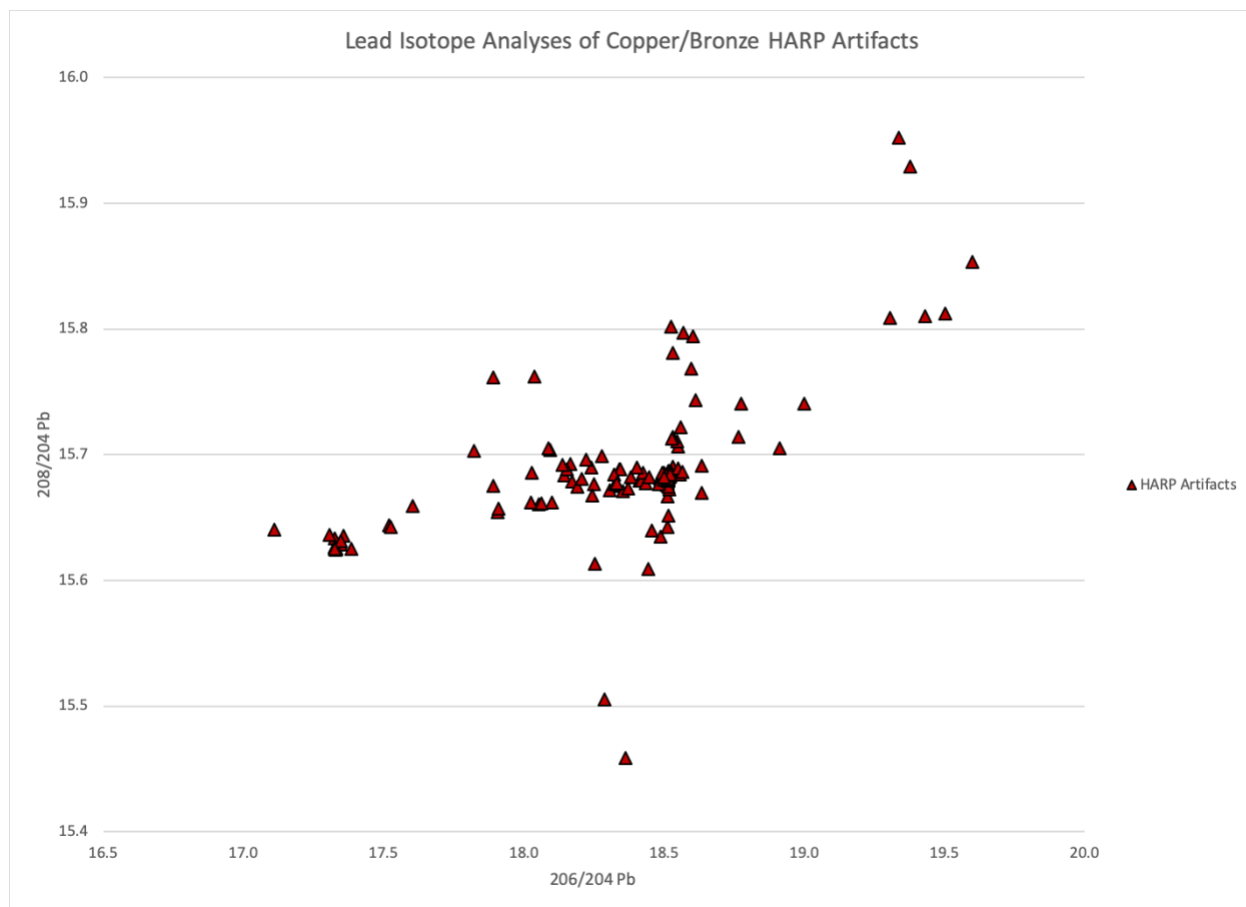
Figure 5.7A: Lead Isotope Results for HARP Sample Assemblage

Figure 5.7B - Lead Isotope Results for HARP Sample Assemblage

Comparative Lead Isotope Database

In order to make source provenience designations using the lead isotope signatures of the copper and bronze artifacts from Harappa, it is necessary to develop a robust regionally appropriate database of geologic comparisons. Typically, this is comprised of lead isotope characterizations of copper bearing ores. However, it is possible to substitute slags for ores. Since it has been confirmed that lead isotopes do not fractionate as a result of any of the processes outlined in Figure 5.1 (Gale and Stos-Gale 2000; Stos-Gale and Gale 2009; Pollard and Heron 1996; Baron et al. 2014), then as long as copper ore from multiple sources is not used to charge the furnace; smelting slags will have the same lead isotope ratios as the parent ore (Gale and Stos-Gale 2000). Following this principle, smelting slags have been included in the

database when available and provided they can be reasonably linked to a specific ore deposit or locale. The comparative databases have been divided into multiple parts and are comprised of published and fresh analytical lead isotope data on ores, artifacts, and slags from the Aegean to South Asia (Appendix 6.1). Each of these comparative data sets provides another dimension of analysis and explanatory context for the artifacts from Harappa.

The construction of source provenience designations for the HARP artifacts analyzed for their lead isotope signatures is the final component in the development of a data driven model for copper and bronze metallurgy at the Indus Tradition site of Harappa. During the compositional analysis portion of the project, a series of patterns were identified that have been assigned to intentional alloying decisions made by Indus metalworkers during production. In order to buttress this interpretation, the alloying patterns need to be correlated with the patterns in source locales to determine if any of the decisions made during alloying bear some relationship to the raw material (either copper ores or ingots) used in their manufacture. If different raw materials were being utilized to produce similar final alloy products, it will strengthen the model of concurrent copper and bronze industries at Harappa focused on either the visual appearance or functional performance of the final object. Further, the designation of specific source provenience relationships for finished copper and bronze artifacts will impact and potentially point out instances of production from recycling rather than manufacturing from ores or semi-processed raw materials (ingots).

In the following chapter, the potential for various regions to contribute to copper and bronze supply at the Indus Tradition site of Harappa will be assessed. This assessment will focus on outlining and defining the isotopic signatures for source regions (i.e., Oman or Baluchistan). Then these source regions will be compared to the analyzed assemblage from Harappa in order

to construct artifact-source provenience designations. This allows for a data driven consideration of copper raw material supply networks, their comparison to other acquisition networks, whether these networks shifted over time, a consideration of whether access to certain copper sources and finished copper/bronze artifact classes was spatially restricted, and the relationship between alloying and raw material supply.

Chapter 6: Copper and Bronze Metallurgy at Harappa: Analysis and Discussion

Identification of Distinct Copper Industries at Harappa

The results of the compositional analysis of 324 artifacts from Harappa across each major classification category documented the existence of two distinct copper industries at Harappa. One industry produced personal ornaments and display objects from specific bronze types. These bronze types would have resulted in finished items with specific color based visual appearances. The other industry would have produced utilitarian items that followed an alloy pattern determined by the functional requirements of the usage of the final item. This suite of copper-based alloys represented the entire suite of alloys identified at the site and displayed no overall consistency of alloy usage other than functional artifacts being predominately made from copper plus at least one alloying metal that would have increased the strength and durability of the finished tool or weapon. Additionally, this industry utilized the properties of lead as one of the intentionally added alloy elements to aid in casting and production processes. The distinction in alloy choice between bangles (tin bronze) and point tools (variety of alloy types) of similar shape and cross section demonstrates that the choices in alloy were intentional and not based on availability or production process.

It is likely that these industries are not the result of separate copper and bronze craftspeople at Harappa. Based on the available evidence of one certain copper workshop at the site (Mound E) and the indications of at least 3 others (one each on Mounds F, AB, and ET), it is probable that the same workshops would have been turning out products of both industries. This leads to the inference that Harappan metalworkers were extremely proficient in employing and controlling the use of copper and copper alloys through a variety of production methods and

artifact classes. Further this production was taking place at multiple locations across the site (Figure 6.1). This represents a significant reappraisal from the traditional interpretations that Indus copper and bronze working is not as complicated or technological complex as contemporary metallurgical traditions across Southwest Asia.

Revised Evidence for Copper-Bronze Production at Harappa

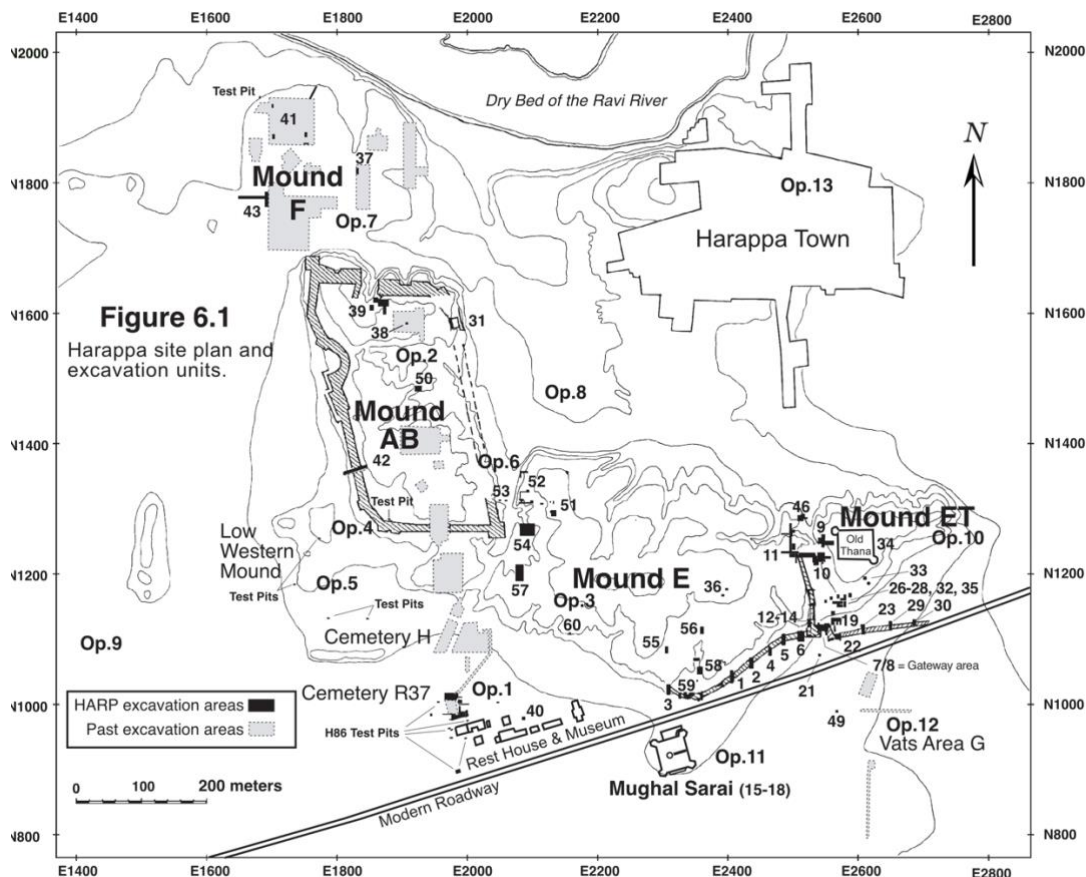
Currently it is generally accepted that Indus urban centers did not undertake any large-scale smelting of copper ores (see Miller 1999; Kenoyer and Miller 1999; and Hoffman and Miller 2014 for discussion). Despite earlier claims of evidence that was suggestive of smelting operations (see Mackay 1938:49-50, 452; Vats 1940:470-73; Rao 1979:522), recent research (Miller 1999) and synthetic reviews (Kenoyer and Miller 1999; Agrawal 2000; Bhan et al. 2002; Hoffman and Miller 2014) have tended to accept the model that Indus cities engaged in the melting of copper materials, either in the form of semi-processed raw materials, such as ingots, or recycled metal rather than the smelting of primary copper ores. As clearly argued by Miller (1999) most previous statements of archaeological evidence for the smelting of copper at Indus sites were the result of mischaracterizations of the material in secondary sources. Further, Miller's research demonstrated that the evidence for any copper metal production at major Indus settlements, such as Harappa and Mohenjo-Daro, is best viewed as restricted to the processing of metal materials, likely ranging from ingots to recycled scrap, in crucibles rather than any large-scale furnace smelting of copper ores and minerals.

To date the best evidence for copper/bronze metal production has come from the results of craft surveys at both Mohenjo-Daro and Harappa (Miller 1999; Bondioli et al. 1984; Pracchia et al. 1985). The results of both the IsMEO survey at Mohenjo-Daro and the work of the HARP

team at Harappa has documented the presence of metal production/processing localities that are most likely the result of crucible melting for either the refining of ingots and/or scrap copper/bronze material or the casting of finished objects. Some of the most complete evidence that exists for workshop type copper production comes from Miller's (1999) work on the southern portion of Mound E at the site of Harappa. Research in this area has documented crucible fragments, copper impregnated kiln/furnace fragments, as well as some potential mold fragments. Essentially, while the archaeological evidence from Harappa and other Indus cities supports the hypothesis of crucible melting, it does not support any models of furnace smelting. It is important to note that the evidence does not eliminate the possibility of crucible-based smelting on a small scale (see Miller 1999; Pigott 1999; Craddock 2010; Tylecote 1974). However, a small number of recent finds from Harappa are challenging this model of Indus copper/bronze production.

The majority of modern models of metallurgical production at Indus urban sites based on the melting of ingots and/or the recycling of existing copper-bronze artifacts to manufacture new objects (see Chapter 2 for discussion). Copper and bronze manufacturing at Harappa is hypothesized to be focused on the melting of material to manufacture objects rather than smelting of ores (Miller 1999; Kenoyer and Miller 1999; Hoffman and Miller 2014). Based on the data available from other excavated Indus sites of all sizes, this model appears to fit the overwhelming majority of the evidence. Intriguingly, new evidence has emerged from Harappa that necessitates a revaluation of the existing model of copper-bronze metallurgical production at Harappa.

Figure 6.1: Harappa Site Plan and HARP Excavations



The identification of a large copper smelting slag fragment from the southwestern margin of Mound AB at Harappa (see Chapter 4 for details) requires that this existing hypothesis be revised to include the existence of the furnace smelting of raw copper ores directly within the confines of walled sectors of the city during the Harappan Period. Additionally, the results of the PXRF portion of the compositional analysis program (see Chapter 4 and Appendix 4.1) identified two small pieces from other dump contexts along the northern margins of the AB city wall dating to the Ravi Period (see Table 6.1) occupation that may represent the smelting of chalcopyrite ores. Taken together, it raises the possibility of the presence of at least a small-scale ore smelting operation within the confines of Mound AB from the earliest period at the site.

Based on the admittedly sparse evidence, it is possible to hypothesize that these smelting activities grew and intensified along with the development of both craft production and the city as a whole. The presence of a series of kiln installations and other evidence for pyro-technologies on Mound AB throughout the occupation sequence further buttress this reconstruction (Kenoyer 1998; Miller 1999).

Table 6.1: Chronology for Harappa

(Kenoyer 1998; Meadow and Kenoyer 2005; Meadow and Kenoyer 2008; Kenoyer 2014; Kenoyer 2015)

Regionalization Era	c.5500 – 2600 BCE
Early Harappan	
Period 1 – Ravi Phase	3300 – 2800 BCE
(aspect of the Hakra Phase)	
Period 2 – Kot Diji Phase	2800 – 2600 BCE
Integration Era	2600 – 1900 BCE
Period 3A – Harappa Phase A	2600 – 2450 BCE
Period 3B – Harappa Phase B	2450 – 2200 BCE
Period 3C – Harappa Phase C	2200 – 1900 BCE
Localization Era	1900 – 1300 BCE
Period 4 – Harappa/Late	1900 – 1800 BCE
Harappa Transition Phase	
Period 5 – Late Harappa	1800 – 1300 BCE
Phase	

Previous research at Harappa has documented the existence of a copper workshop area on Mound E (See Miller 1999 Chapter 3 for discussion). The remains from work on this area include crucible fragments, possible mold fragments, and other indicators of intensive copper metalworking. Miller (1999) argues that this area was likely the result of workshop level crucible

melting and fabrication of finished copper objects. Additionally, survey of the site had uncovered seven copper mineral fragments. Three are malachite, a copper oxide, from Mound E and Mound ET, and four are Chalcocite, a copper sulfide, three from Mound E and one from general surface. Prior to the research discussed in this project, that was the extent of the definitive evidence for copper/bronze metal-working at Harappa.

Analysis conducted during this project has documented additional material remains that are suggestive of metal production and smelting occurring at Harappa. During the course of the PXRF portion of the analytical program (see Chapter 4 for details) an additional copper mineral, potentially chalcopyrite, was identified. This would appear to fit with the set of seven copper minerals that have been previously identified. During the PXRF analysis of the Ravi Phase materials, two more small pieces of slag were identified. Both objects are from the northwestern portion of Mound AB and are comprised of a high amount of iron and a low amount of copper. This is best explained by the crucible-based smelting of copper sulfide ores. Additionally, the large slag piece found on Mound AB was from the furnace-based smelting of copper sulfide ores as well. Taken together, the evidence from the slag and ores documents a copper smelting program at Harappa that developed from the crucible smelting of copper sulfides during the early Ravi Phase occupations to larger scale furnace smelting of those same copper sulfides during the urban Harappan Phase. It is likely that crucible smelting of copper ores never went away at the site, as copper and bronze workers selected the smelting method based on the needs of a given production run.

The spatial distribution of the copper minerals and slags as well as the workshop at Harappa is highly intriguing. On Mound AB there is a large copper smelting slag from the Harappan Phase as well as small bits of slag from the Ravi Phase. This would seem to document

the presence of a copper smelting and production area somewhere on Mound AB that may have been in operation throughout the Indus occupation of the site. The exact location of this production area is not known, as all three of the slag samples are likely from dump contexts just outside the Harappan Phase city wall. A final element of the spatial distribution of copper production remains at the site is the documented existence of a copper workshop area on the southern portion of Mound E. It is not clear what this pattern is indicating at this point. Perhaps there are multiple copper working areas on the site using similar types of ores. Perhaps the two areas are connected more directly. This relationship will require further study. Overall the slags are beginning to provide evidence that copper metallurgical production at Harappa may have extended beyond the crucible-based melting that has been hypothesized previously and included the furnace smelting of copper ores as well. The relationship between the copper smelting and copper workshop at Harappa will require further detailed study in order to more fully understand if the two areas are connected or are perhaps examples of replicated craft industries on two of the occupation mounds. At this point, the existence of copper smelting and copper working at the site would seem to continue to document that at Harappa, unlike other contemporary 3rd millennium urban sites, copper metallurgy was not a centrally elite controlled craft.

Modelling Copper Raw Material Acquisition at Harappa

In order to evaluate the data collected during the Lead Isotope Analysis (LIA) portion of the project, it is necessary to develop a series of expectations regarding the acquisition of copper raw materials at the site of Harappa during the Indus occupation periods. While previously published datasets are insufficient to provide clarity on where copper raw materials were coming from and what specific interaction networks were being exploited to supply the city with the

sought-after metal, it is possible to construct an outline of potential possibilities. Such a framework can be used to develop a series of nested hypothesis that can be tested against the LIA data developed during the project. It should be noted that the data may not serve to prove a particular hypothesis or cluster of hypotheses but do allow for the elimination of possibilities. The approach utilized in this project focused on the elimination of competing possibilities to create a limited suite of potential explanations for the reconstruction of copper interaction networks and copper-bronze usage at Harappa spanning Period 2-3C (2800-1900 BCE) at the site (Table 6.1).

The final goal is to establish a series of artifact-ore correlations that provide for a data-driven model of copper-bronze supply and raw material utilization at Harappa from the Ravi Phase through the Harappan Phase occupation of the site. To achieve that goal, a number of steps needed to be completed. The first several steps were outlined in the preceding chapter and focused on determining the viability of LIA as an analytical technique for Indus Tradition copper and bronze metal objects. With a sample set of 130 metal artifacts and seven archaeological mineral samples from Harappa, the next step was to develop a database of lead isotope characterizations from copper ore sources to compare to the archaeological material. This posed a series of significant challenges. The underpinning theory behind lead isotope correlations between artifacts and ores has been outlined previously (see Chapter 5). Overall, the most important factor is the suitability of the comparative database. It must be constructed and delineated in such a fashion as to present the most reasonable series of potential ore sources for the archaeological artifacts under consideration. A determination of what is or is not “reasonable” is a two-stage process. The first stage is qualitative while the second stage is more quantitative.

Bounding the potential copper bearing locales or regions for comparison to a set of archaeological artifacts is a somewhat nebulous task. Part of this is attributable to the fundamental characteristic of lead isotope data. At its root, lead isotope signatures for archaeological objects are an age model for the parent deposit of the metal in the artifact. In the case of this project, it is an estimate of the geologic age of the copper ore deposit that was the source of the metal used to make the individual artifact. Specifically, the time period that the individual ore deposit was formed from some metallogenic process. This can create overlaps in lead isotope signature between ore deposits widely separated in space that were formed at similar times. In theory, Bronze Age artifacts from central Asia could show isotopic overlap with ores from South America, eastern Europe, and central Asia. In this hypothetical, the ore from central Asia would be the most appropriate comparison with the potential for eastern European ores to be a source location as long as interaction between the two regions could be archaeologically demonstrated. Finally, South American ores would be an unreasonable comparative in light of current archaeological evidence regarding trans-Atlantic interactions during the Bronze Age. The implications of this for the current research project are possible to control for using the existing body of data regarding interactions between the Indus Tradition and surrounding copper ore bearing regions.

A review of the literature regarding Indus interaction networks and trade networks reveals a documented series of connections between the core of the Indus and other cities, states, and regions stretching to the Mediterranean, the Persian Gulf, central Asia, Mesopotamia, and throughout northwestern South Asia. This encompasses the geographic extent of the “Bronze Age World System” posited by Ratnagar (2001) and is similar to the scope of the “Middle Asian Interaction Sphere” (Possehl 2007; Thornton 2013), as well as corresponding with interregional

interactions documented by the research of Law (2011) and Kenoyer (1998, 2014).

Differentiating and debating between these various iterations of Indus interaction networks is well beyond the current inquiry. The important point is that these various studies provide a sound basis to construct the boundaries of a reasonable series of comparative datasets for the lead isotope signatures of copper-bronze artifacts from Harappa.

The second stage is to construct a series of lead isotope characterizations for individual copper bearing ore deposits across the regional areas identified in stage one. In order to accomplish this, data on ore types, regional geology, and lead isotope measurements on metal bearing ores are required. For this project, a series of comparative regional databases were developed. All of these regions have archaeologically demonstrated connections with the Indus and also presented the necessary data on copper ore sources. Lead isotope signatures for a variety of source regions ranging from the Aegean, Afghanistan, the Persian Gulf region, the eastern Mediterranean, and South Asia were compiled. The lead isotope information was obtained from a combination of previously published material on ores, new analytical data from ores and published lead isotope data on archaeological artifacts. These data are compiled and attributed in Appendixes 6.1-6.10. All comparative lead isotope data referenced in this chapter is taken from that source.

Unfortunately for the potential copper sources within South Asia this information is either sparsely published, incomplete, or lacking altogether. Resulting in uncertain reconstructions of the potential ores and source locales available for exploitation during the third millennium BCE. However, recent data from the ongoing research of Law (personal communication; Bisht et al. 2015) and Kenoyer (personal communication) has helped to alleviate some of these gaps. Additionally, the work of Grover (2004) and Deb and collaborators (1989,

2001) has done much to clarify the complicated geology of copper bearing regions within South Asia; specifically, the various metalliferous belts within the Aravalli Range region of Rajasthan and Gujarat.

Aegean Sources

Recent work has documented a small number of distinctive stone beads whose manufacturing techniques and/or raw material types link them to the Indus Tradition (Ludvik et al. 2014; Ludvik et al. 2015)). This emerging research extends the sphere of Indus interaction networks to mainland Greece. At this time, it is not possible to identify the nature of the interaction between these two regions. Indus goods may have been reaching this region indirectly rather than directly. Additionally, the dating of the archaeological contexts containing the beads is not totally secure. Based on the best available evidence a broad attribution to sometime the Harappan Phase of the Integration Era (2600-1900 BCE) seems warranted. Despite the uncertainty in the chronology and the lack of specificity in the determination of how beads were entering sites within the broad Aegean region, these small archaeological finds do document a connection to the Indus and raise the potential for Aegean copper filtering into the Indus.

To test this potential movement of copper into the Indus from Greek sources, data developed over the last several decades by the working group at Oxford Isotrace laboratory was used. These data have been compiled and shared via numerous publications (currently over 140) and an internet database. The Oxford Archaeological Lead Isotope Database (OXALID) has lead isotope data on 802 ore samples from across Greece (<http://oxalid.arch.ox.ac.uk/TheDatabase/TheDatabase.htm>) that form an excellent comparative dataset for copper-bronze objects from Harappa (see Appendix 6.1). The comparison for Greek ores was further narrowed to only those from Lavrion. This was based on the locations of the bead finds as well as

published reconstructions of Bronze Age copper mining and ore correlation research that has demonstrated the potential for Lavrion to have been a supplier of copper ore during the Harappan Phase.

Recently there has been some question regarding the validity of the Lavrion mine as a source for Bronze Age copper (Muhly 2009; Pollard and Bray 2014). If the Lavrion mine was not the major source for copper that it has been previously argued to be (Gale 1999, 2001) then a significant re-evaluation of the copper trade throughout the Aegean and the eastern Mediterranean may be in order. It is possible that the calls for assessing the impact of recycling and ancient ore compositions (see Pollard and Bray 2014) on the hypothesis of the significance of the Lavrion mine are correct. However, reassessing existing interpretations about early and late Bronze Age mining in the Aegean is not the purpose of the current project. Whether or not the Lavrion mine retains its place of primacy as a regional copper supply, it still serves as a well-documented proxy marker for the lead isotope characteristics of the region. A comparison of the robust lead isotope data set from metal ores from this source location with the lead isotope signatures of the HARP artifacts, allows for empirical testing of the hypothesis that copper ore from Greece was filtering into the copper supply for Harappa. The stacked bivariate plots (Fig 6.2) display the relationships between these two datasets.

An examination of the plots demonstrates that the Lavrion ore plots within a gap in the HARP lead isotope signatures. The majority of artifacts from Harappa do not exhibit any correlation with the Lavrion ore source. There are four artifacts that show a potential for overlap with the Lavrion source. With one artifact, a copper-arsenic sheet fragment from the Ravi Period (3300-2800 BCE) that corresponds with the edges of isotopic distribution of the Lavrion ore field. While this does not totally rule out the possibility that copper from Lavrion or other

Aegean sources is making its way into the copper-bronze supply system for Harappa and other Indus sites, it does validate a conclusion that this is not occurring at a significant level. Overall, this result is consistent with the current understanding of Indus interaction networks. It is not unreasonable to posit a connection between the Indus and sites and polities on the Greek mainland during the third millennium BCE. The difficulty is modelling the nature of the interaction. At present, a single metal artifact from Harappa having a possible source-provenance designation of Lavrion conforms to a model of a low-level of interaction between the two regions. While this conclusion lacks specificity, a more definitive conclusion is that the present lead isotope data from Harappa do not support Greek copper sources as comprising a meaningful component of copper-bronze metal supply.

While outside of the Aegean itself, Cyprus can reasonably be grouped with the mainland Greece sources such as Lavrion, as multiple research projects have demonstrated the strong trade and cultural connections between these two regions during the Bronze Age (Knapp et al. 1994; Gale and Stos-Gale 2002, 2012; Stos-Gale and Gale 2009). OXALID provides data on over 200 ore samples. The result of decades of collaborative research on ancient metal artifacts, ores, and slags, this dataset provides a detailed characterization of the various potential copper sources from Cyprus (Appendix 6.1). Just as with Lavrion, the isotopic field is well characterized and tightly bounded. A comparison of the lead isotope characteristics of the HARP artifacts to the Cypriot ores demonstrates that copper sourced from these locations does not exhibit a strong correlation (Figure 6.3). Analysis of these two data sets indicates that a small number of artifacts from Harappa potentially could be sourced to metal originating on Cyprus. However, it is unlikely that Cypriot ores contributed directly to the copper and bronze metal supply at Harappa. Taken together, the data from Lavrion and Cyprus points to a similar conclusion.

Figure 6.2: HARP Artifacts Compared to Lavrion Ore Lead Isotope Signatures



It is possible that during the broad period of time from 2800-1900 BCE, material from Aegean copper sources was entering Indus Tradition interaction networks. Copper metal, either as finished artifacts or semi-processed raw materials, could have then entered the copper-bronze assemblage at Harappa during the Early Harappan and Harappan occupations. However, further analysis of the lead isotope signatures from the HARP assemblage indicates that copper source points from regions closer to the Indus Tradition also appear to account for many of these same objects. It is more likely that sources that are both more localized and tightly integrated into Indus economic interaction networks would have served as the source points for copper and bronze artifacts from Harappa.

The OXALID database also contains a number of samples from copper sources in Anatolia (Appendix 6.1). It is possible to organize this portion of the data set by region, in order to refine any potential linkages between the artifacts from Harappa and a variety of copper deposits in Anatolia. Comparing these data to the HARP artifacts reveals several ready conclusions. The first is that ores from both the Elaziğ and Çannakale (Figure 6.4) regions do not exhibit an isotopic correspondence with the HARP material. Second, there is a potential for a small degree of isotopic correspondence between two HARP artifacts and two different lead-zinc-copper sources within the Izmir region. However, this connection is not highly secure and is subject to being superseded by a better isotopic correspondence. Analysis of the relationships between sources within South Asia appear to demonstrate a better degree of isotopic overlap between the HARP artifacts and copper bearing source locales. It is possible that during the broad period of time during the Integration Era of the Indus Tradition, when inter-regional interactions would have been at their greatest and most varied extent, that copper and bronze material from Anatolian sources was entering Indus sites. However, areas more tightly connected

to the Indus region demonstrate a better isotopic correspondence. And, although it is certain that copper and bronze raw materials, semi-processed material, and finished artifacts were exchanged from Anatolian sources into a variety of 3rd millennium BCE inter-regional interaction networks, it is the most parsimonious to view this metal production as a critical strategic resource that would have been leveraged and integrated by more local elites than those residing in Indus centers (Lehner and Yener 2014).

Figure 6.3: HARP Artifacts Compared to Cyprus Ore Lead Isotope Signatures

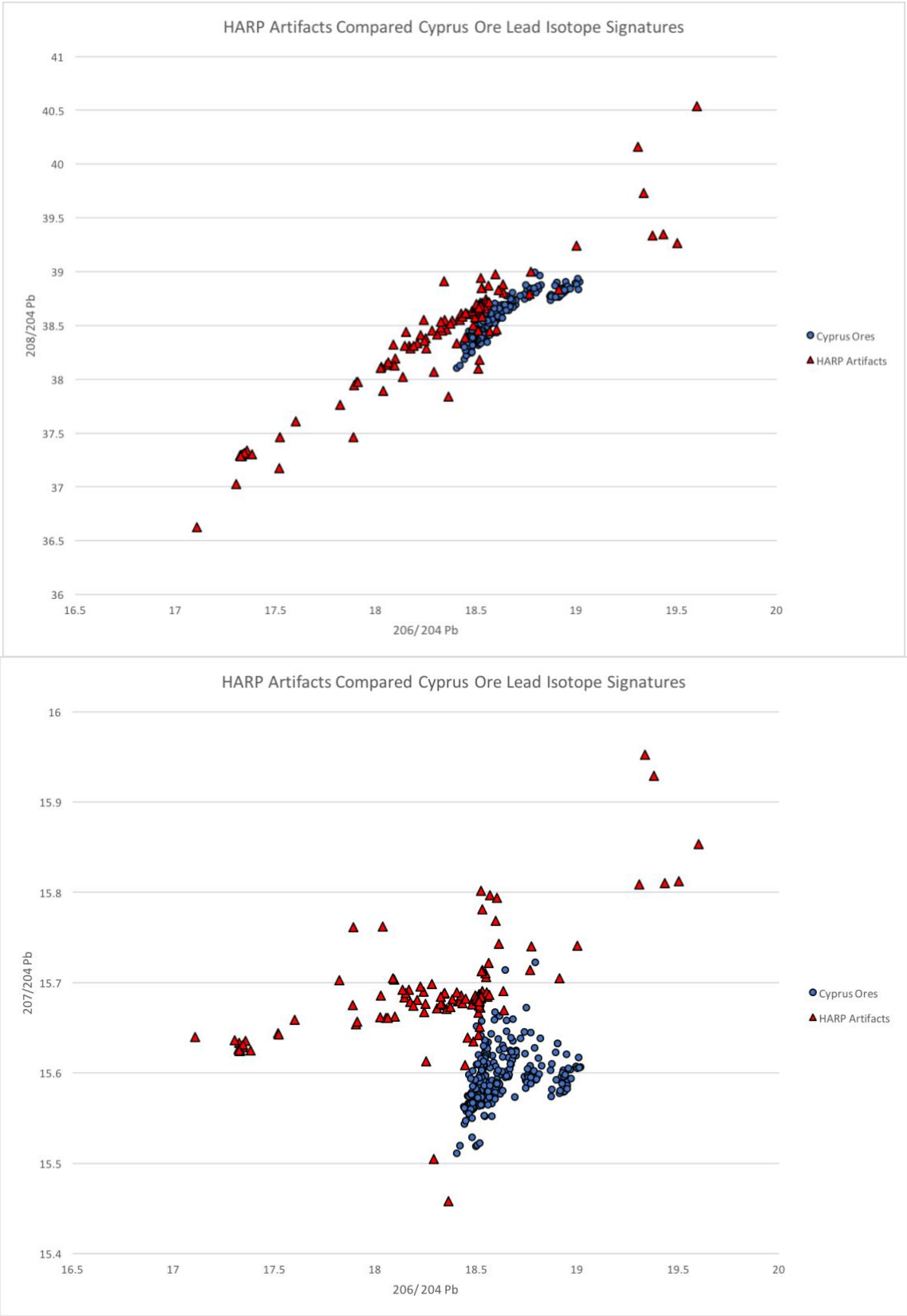
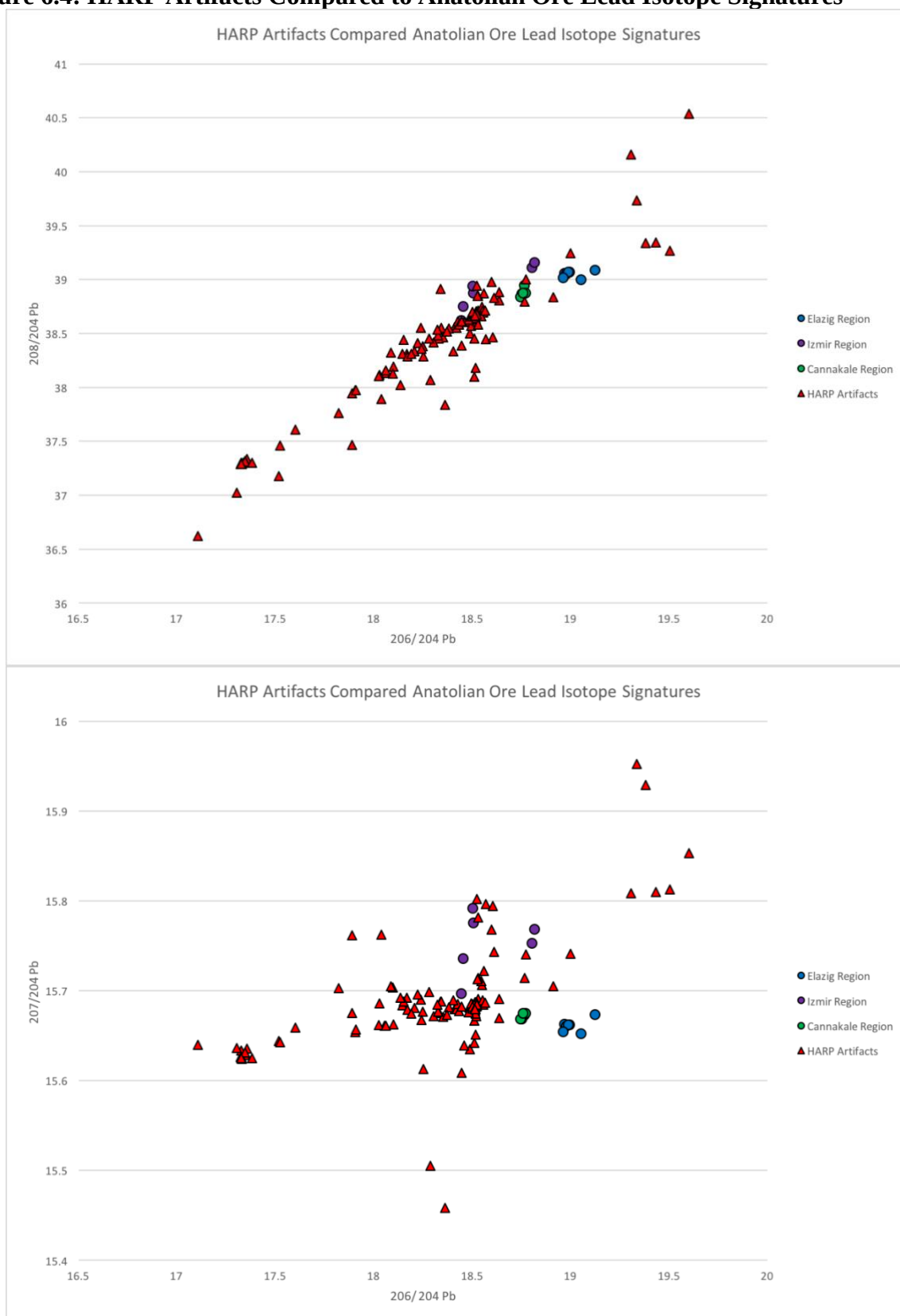


Figure 6.4: HARP Artifacts Compared to Anatolian Ore Lead Isotope Signatures



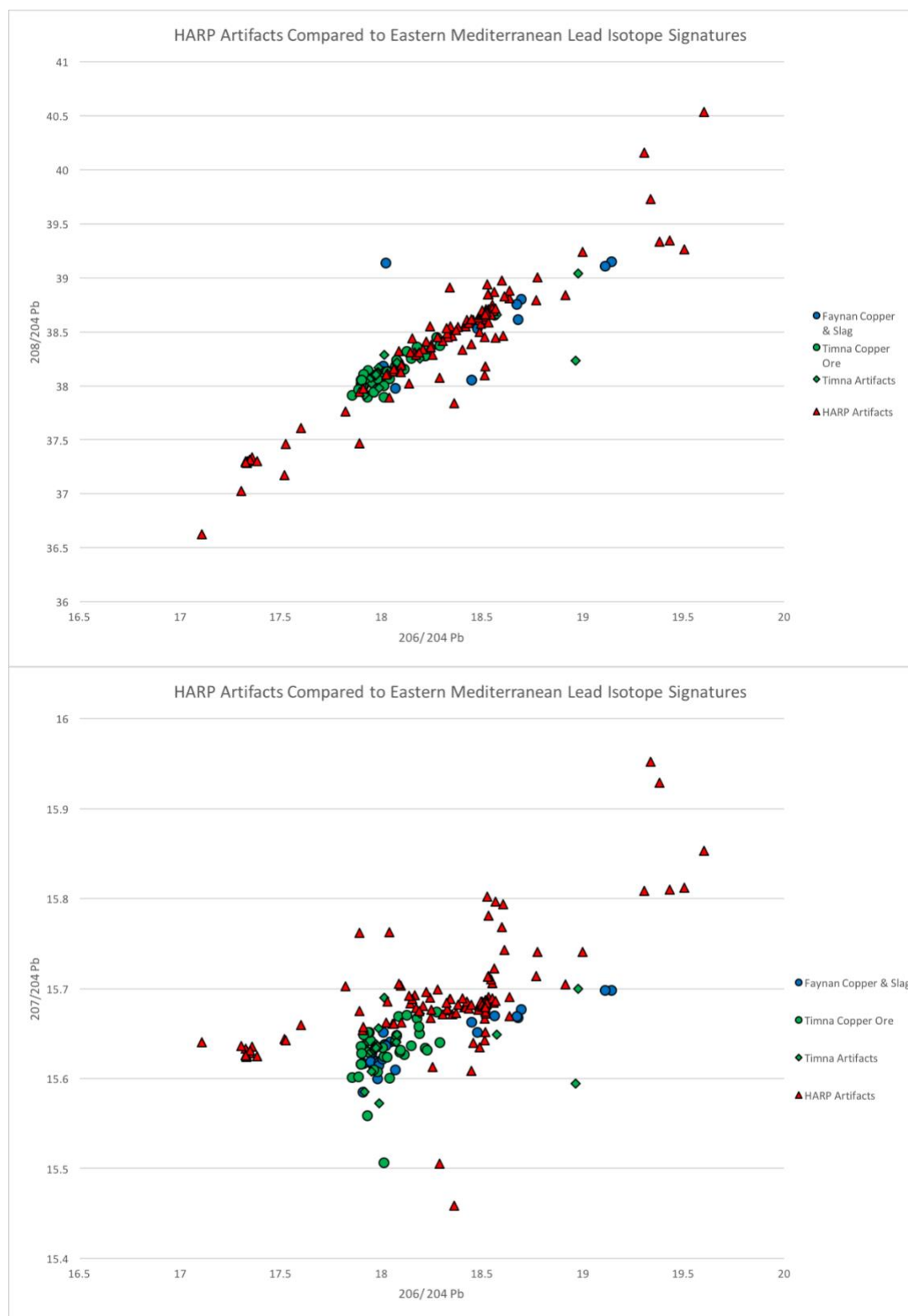
Eastern Mediterranean Sources

During the 3rd millennium BCE, copper sources in the eastern Mediterranean played a prominent role in copper and bronze supply across not only the Levantine region, but larger Southwest Asia as well. The key question for the present study is whether or not these important metal source areas played a significant role in metal exchange networks in the Gulf region and South Asia. Recent studies have concluded the geologically related deposits at Timna and Faynan must be considered to have a shared history of development and exploitation (Hauptmann 2007). Beginning in the 4th millennium BCE and stretching into Roman times, these two copper source areas were heavily exploited for both local and non-local production (Hauptmann 2007; Golden 2014). Hauptmann (2007:302-304) concludes that both copper sources were producing material far beyond the limits of local demand and would have been participating in inter-regional exchange networks as exporters of copper raw materials. In order to assess whether or not these significant sources were a component of Indus copper and bronze metal supply, a series of published lead isotope ratios were compared to the isotopic signatures exhibited by the HARP artifacts. For Faynan, only isotopic analyses from copper ores coming from archaeological contexts dating to the Chalcolithic through the Early Bronze Age III period were used in order to maintain the closest chronological parallel with the Indus Tradition possible. 28 ores and production debris from Faynan, 40 ores from Timna, and 22 artifacts from Timna (see Appendix 6.2) were compared to the HARP sample set.

An examination of Figure 6.5 demonstrates that the majority of the ores from Faynan and Timna demonstrate no affinity with the artifacts from Harappa. Despite the archaeological and analytically documented large-scale exploitation and production centered on these two major source areas during the 3rd millennium BCE, they do not appear to have been a noticeable

component of metal supply for the site of Harappa. One ore from Timna and one ore sample from Faynan demonstrate a potential correspondence with isolated artifacts from Harappa. However, none of the other ores from either location exhibit a similar isotopic overlap. In fact, the general isotopic signature from Faynan and Timna plots in a distinct grouping that segregates from the lead isotope signatures of the HARP artifact sample set. The ore samples from either Faynan or Timna also appear to account for the overwhelming majority of the artifacts from the region (here using the 22 artifacts from Timna as a proxy). Taken together, the lead isotope data indicates that metal supply from the Eastern Mediterranean did not form a significant role in metal supply at Harappa nor did a great deal of copper from South Asia find its way into Eastern Mediterranean sites.

Figure 6.5: HARP Artifacts Compared to Eastern Mediterranean Lead Isotope Signatures

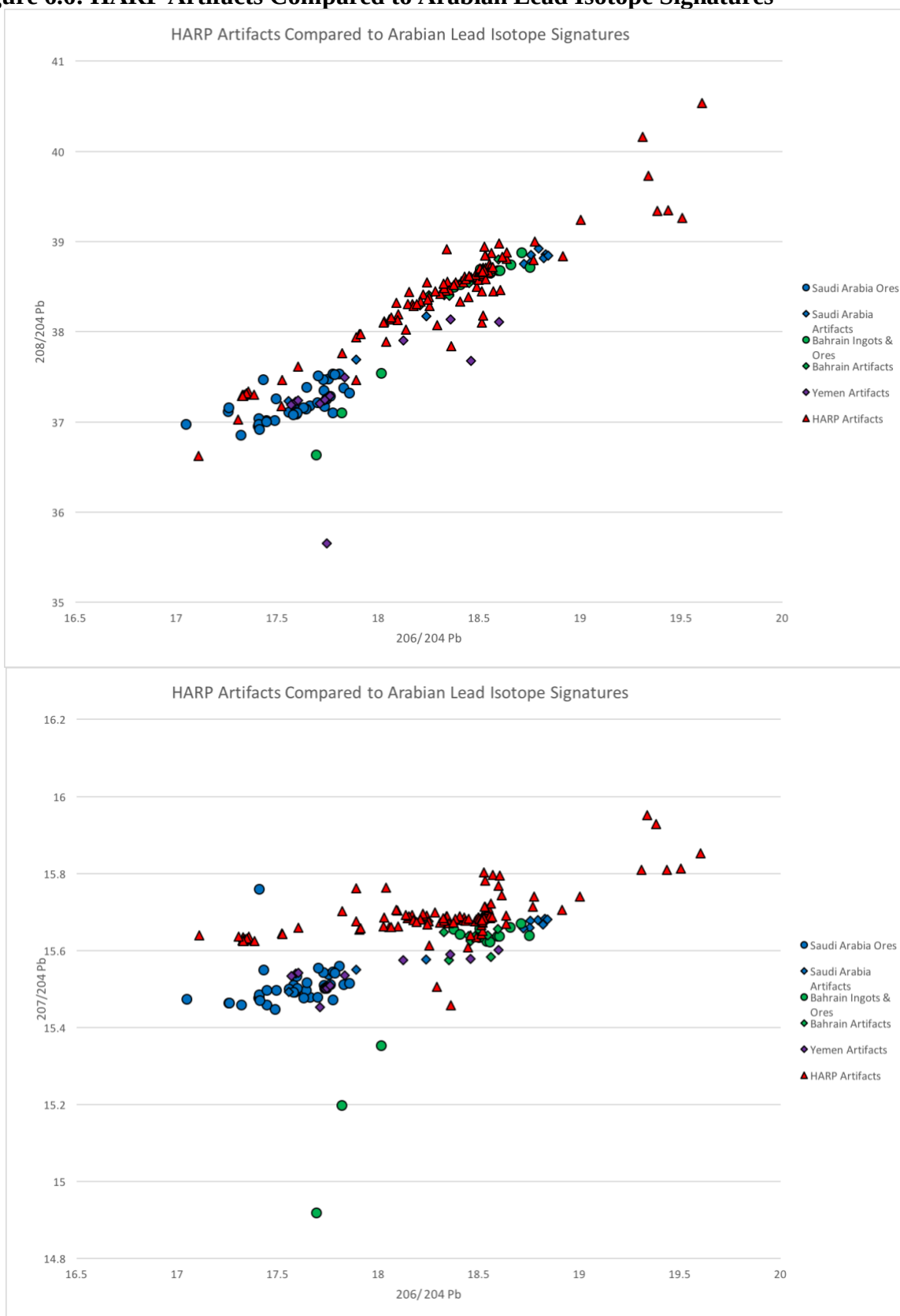


Arabian Peninsula Sources – Group 1

The next group of potential source areas for the copper and bronze material from Harappa is comprised of areas that, while not within South Asia proper, are in regions directly adjacent and possess multiple archaeologically and sometimes textually demonstrated linkages to the Indus Tradition. The first of these is a series of copper source areas and copper-bronze artifacts from Saudi Arabia, Bahrain, and Yemen. Connections between the Indus and Bahrain (ancient Dilmun) is extensively documented and excellent sources and summaries can be found in a variety of publications (Potts 1990; Edens 1992; Glassner 1996; Crawford 1998; Kenoyer 1998, 2014; Ratnagar 2004; Weeks 2003; Possehl 2007; Law 2011; Thornton 2013). In contrast, there is little direct archaeological or textual evidence for economic interactions between the Indus, Saudi Arabia, and Yemen during the third millennium BCE. However, much of that may be due to a lack of exploration rather than a total lack of evidence. Copper-bronze material from Yemen appears to be documenting previously unknown local production (Weeks et al. 2009). While emerging research from oases sites within Arabia, such as Tayma, documents the potential for extensive copper and bronze exchange from at least the Middle Bronze Age and possibly earlier (Liu 2015). Ongoing studies of stone beads indicate the potential for interactions between this region and South Asia (Kenoyer, personal communication). While it must be acknowledged the data from Tayma was obtained from artifacts from later archaeological periods (Liu 2015), it represents the only (and best) data available for comparison.

Figure 6.6 shows the lead isotope results for the HARP artifacts and 17 artifacts from Yemen, 14 ingots and ore samples from Bahrain, 11 copper and bronze artifacts from Bahrain, 40 ore samples from Saudi Arabia, and 10 artifacts from Saudi Arabia (see Appendix 6.3). From even a cursory examination of the results, it is clear that ores from Saudi Arabia and the artifacts

from Yemen plot well away from the HARP material and demonstrate no correspondence. Additionally, the artifacts from Saudi Arabia, comprised of furnace and crucible fragments from the oasis settlements (Liu 2015 and Appendix 6.3), do not exhibit a correspondence with the analyzed HARP materials. Interestingly, the production materials also do not show a correspondence with local ores but may demonstrate an isotopic linkage with ores from Faynan. While the source of the copper raw material for production at Tayma remains uncertain, it does demonstrate that this region is an understudied and poorly understood component of copper and bronze supply, production, and exchange during the Bronze Age in general and the third millennium BCE specifically. At present, it appears that the copper sources and processing sites of western and northwestern Arabia do not impact copper and bronze metal supply networks at Harappa in a significant way, if at all. The data from Yemen in southern Arabia appears to corroborate this conclusion. The copper and bronze industry that is only beginning to be documented at Yemeni sites, initially appears to have a westward facing focus towards Saudi Arabian and Eastern Mediterranean sources. Overall, a picture emerges that orients sources and production centers along the Eastern Mediterranean and western Arabian Peninsula towards one another in potentially overlapping and integrated production and exchange networks (Liu 2015). In contrast, artifacts, ingots, and ores from the eastern Arabian Peninsula (modern Bahrain and ancient Dilmun) demonstrate strong affinity with one another and some potential correspondence with the HARP analyzed set (Figure 6.6).

Figure 6.6: HARP Artifacts Compared to Arabian Lead Isotope Signatures

The majority of the artifacts analyzed from Bahrain exhibit isotopic correspondence with ingots and ores from the region. This is most likely a marker of local production with the specific copper raw material sources remaining to be determined by future investigations. However, a limited number (2-3) of artifacts from Bahrain, demonstrate significant overlap and correlation with the isotopic signatures of a number of artifacts from Harappa. Further, a number of artifacts from Harappa may correspond to ingots and ores from archaeological sites in Bahrain. This is unsurprising in light of the well-established interaction networks linking the two regions. Unfortunately, with the data presently available, it is not clear either the direction or ultimate source of this trade in copper raw materials (ores/minerals) and semi-processed goods (ingots). It remains a possibility that these items could have originated in locations outside of Bahrain or South Asia. Despite the equivocal nature of the connection at present, it remains clear that the two regions are linked, at least indirectly, through a series of copper and bronze metal interaction networks during the course of the third millennium BCE. While some of this metal was almost surely showing up in the assemblage at Harappa, it does not appear to be one of the major supply lines.

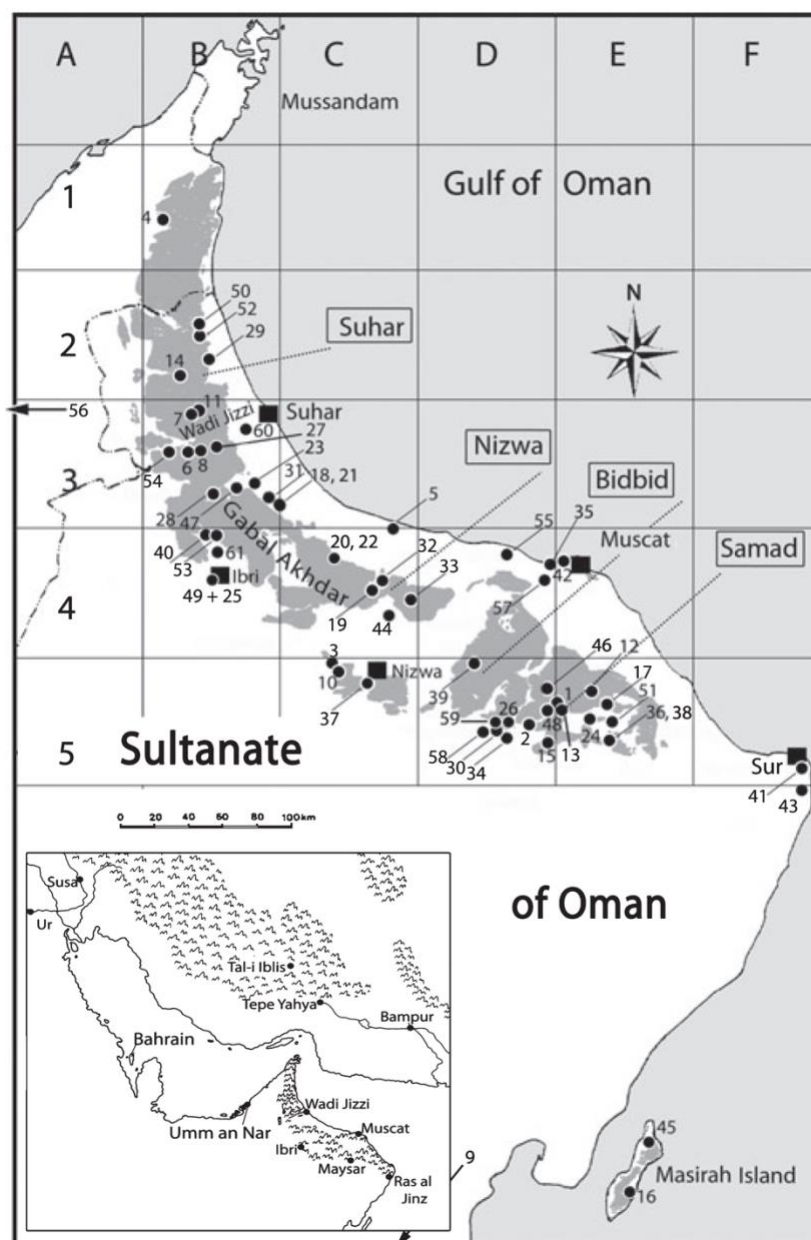
Arabian Peninsula Sources – Group 2

There is a second group of sources and artifact data for the Arabian Peninsula that provides a more secure series of comparisons for the HARP material than those in Group 1. Just as the samples from Bahrain represent ancient Dilmun, a region with documented connections to the Indus; samples from Oman and the United Arab Emirates (UAE) represent Magan (Begemann et al. 2010; Weeks 2003), another region with well-established interactions with the Indus Tradition (Potts 1990; Edens 1992; Glassner 1996; Crawford 1998; Kenoyer 1998, 2014; Ratnagar 2004; Weeks 2003; Possehl 2007; Cleuziou and Tosi 2007; Laursen 2010; Thornton

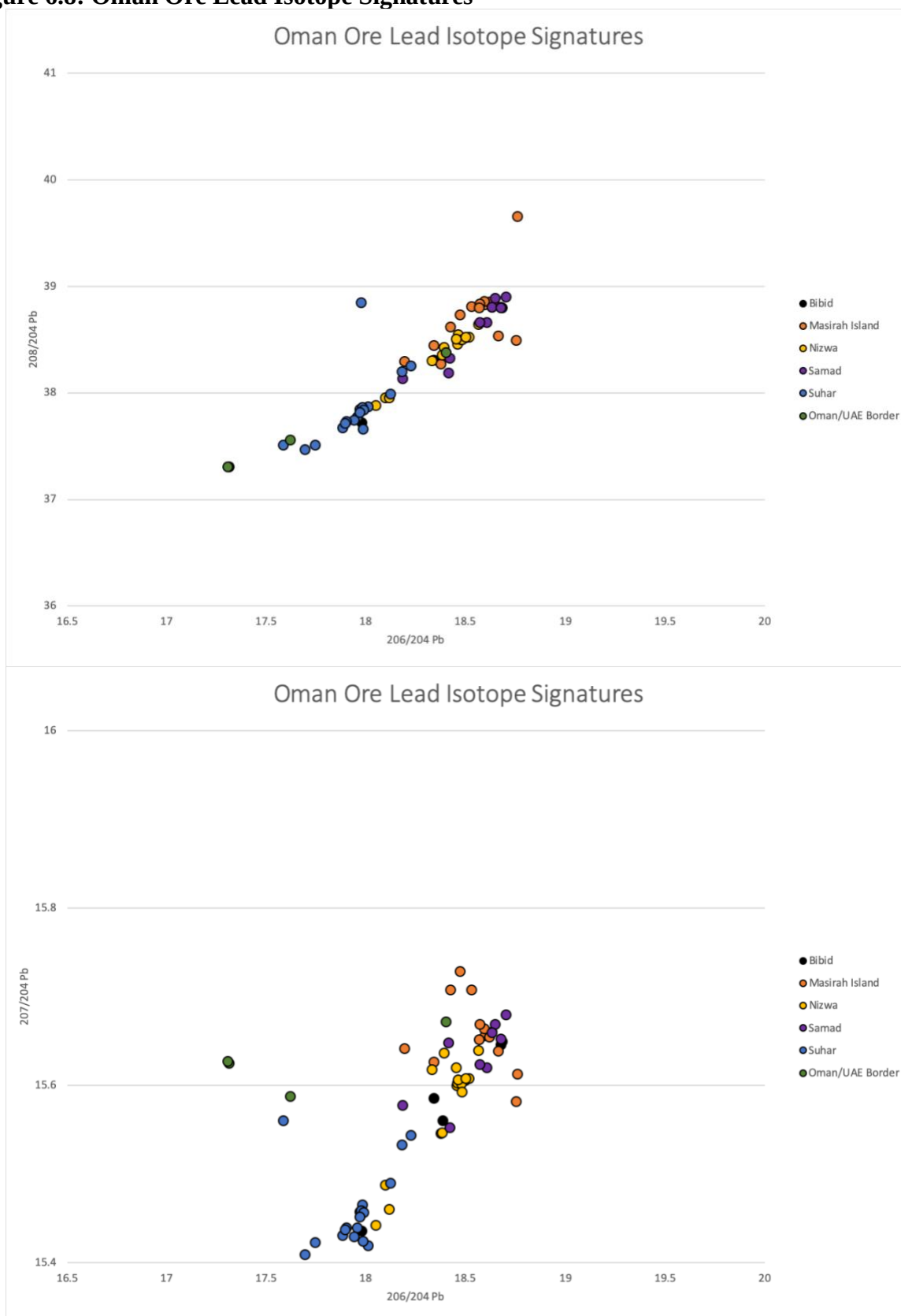
2013; Law 2011; Weeks 2014). Additionally, there is an emerging consensus that the interaction between the Indus area and eastern Arabia was more extensive than previously considered and was not confined to coastal settlements but spread to the interior as well (Frenez et al 2016).

One of the more important and archaeologically visible items moving throughout 3rd millennium interaction networks in this region was copper (Weeks 2003, 2014; Cleuziou and Tosi 2007; Thornton 2013; Law 2011; Hoffman and Miller 2014). As a result, there have been several research projects focused on developing source provenience data on copper from this region. Culling through the available material, a comparative data set of lead isotope signatures from geologic ores and third millennium BCE archaeological material has been developed (see Appendix 6.4). In total 81 lead isotope values from a mixture of copper ores, galena ores, and archaeological smelting debris were developed from the literature (see Appendix 6.4 for references) and ongoing research projects (Kenoyer personal communication). This data was sorted using the five-region scheme for copper deposits in Oman outlined by Begemann et al (2010:5) and reproduced here as Figure 6.7. The results of this are displayed in Figure 6.8. A sixth area, the Oman/UAE border, is introduced in these graphs in order to account for copper ore sample locations that do not fall within Begemann et al's 2010 framework. Overall, the copper source regions exhibit isotopic distinctiveness from one another. It must be noted that the spread of isotopic signatures from the Nizwa region overlaps with sources from Bibid, Samad, and Suhar. This should not be surprising as Nizwa occupies a central position across the copper bearing localities in Oman and therefore must contain some deposits of similar geologic ages and isotopic fingerprints as the surrounding regions.

Figure 6.7: Map of Copper Deposits and Regions Across Oman



From Begemann et al. 2010:5 Figure 1

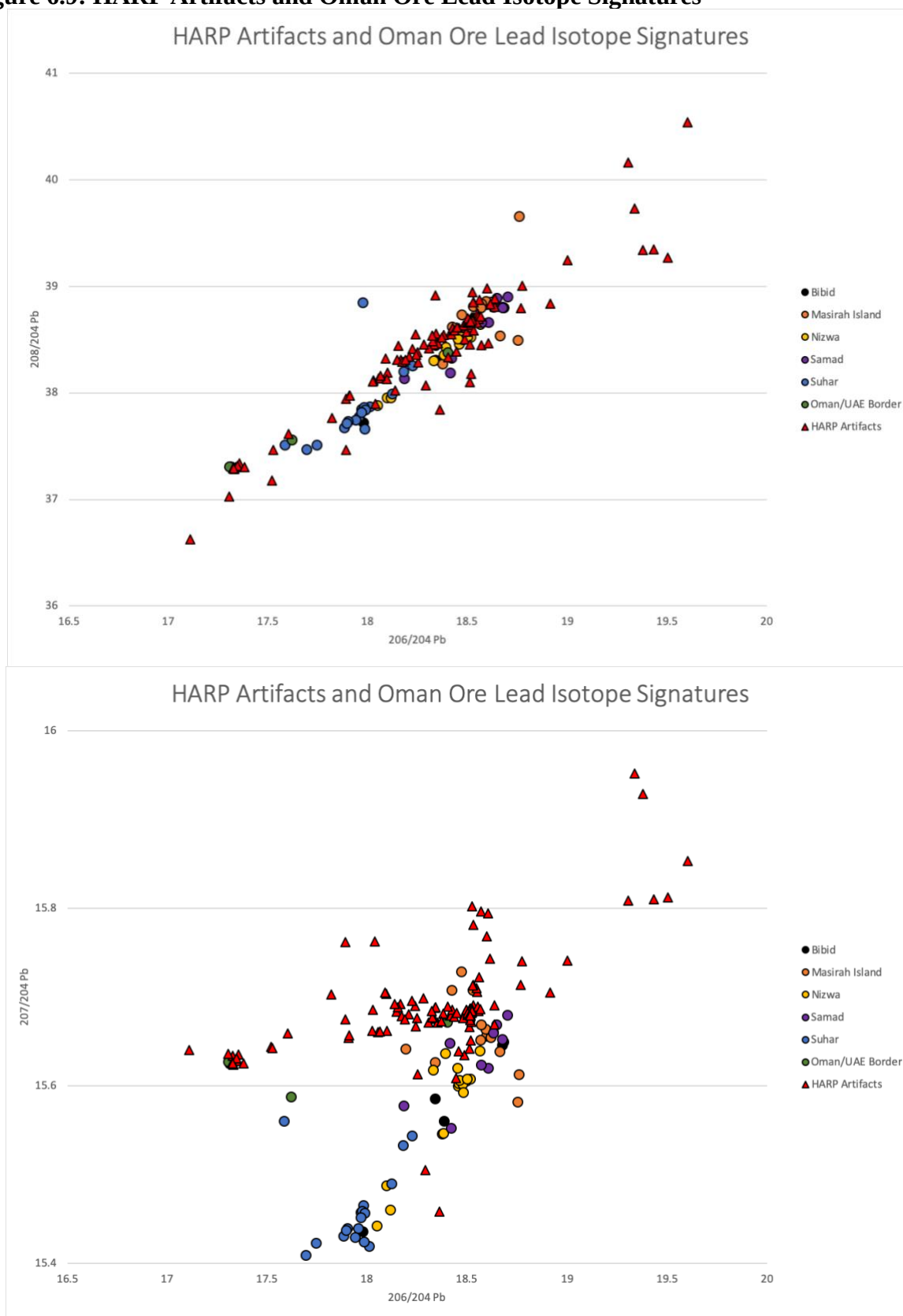
Figure 6.8: Oman Ore Lead Isotope Signatures

Overlaying the HARP artifact assemblage lead isotope data on that from the Arabian Peninsula Group 2 sources (Figure 6.9), two conclusions stand out. The first is that the majority of the HARP artifacts do not exhibit much correspondence with copper sources across Oman. The second is that only two artifacts from Harappa demonstrate definitive linkages with sources within Oman. There is a half-dozen objects that may represent either correspondence with Omani ores or the mixing of sources. Finally, one of the data points from copper ore sources along the UAE-Oman border appears to exhibit a strong affinity for a number of copper-bronze objects from Harappa. However, as will be discussed in a subsequent section, it is possible these artifacts are a better match for copper deposits within the Ambaji-Deri belt in the Aravalli Range region of India.

Turning to the potential isotopic linkages between Harappa and Oman copper sources, it appears likely that limited amounts of copper originating in Oman were making its way into Indus copper-bronze supply networks. This conclusion is in line with all existing data available that demonstrates consistent artifact, raw material, and other cultural linkages between Oman Umm al Nar period sites and the Indus Tradition during the second-half of the 3rd millennium (Weeks 2014; Law 2011; Frenez 2016). Examining the results of the comparison of lead isotope signatures from the HARP artifacts and a variety of copper sources within Oman, a series of inferences can be made.

During the Harappan Phase copper that can be linked to sources on Masirah Island or the Nizwa region (see Begeman et al. 2010:5 and Figure 6.9) is represented in the HARP artifact assemblage. It is possible that there is a limited correspondence with at least one source in the Samad region as well, although this is potential a case of overlap in the isotopic signatures between related deposits in the Nizwa and Samad regions. Additionally, there may be limited

correspondence with Suhar region sources, but the two artifacts that fall in that portion of the graph may also be an extension of the Nizwa region isotopic signature. At present it appears that the Bibid played no role in supplying copper to the analyzed HARP artifact assemblage. The deposits in Oman and on the border between Oman and the UAE represent significant copper raw material source locations for a variety of copper-bronze metallurgical traditions during the 3rd millennium BCE. However, the data from Harappa indicates that copper from this region was not forming the majority of metal supply at the site. Rather, copper from Magan was entering the Indus copper supply networks and filtering through exchange networks to make its way to large urban centers like Harappa. Until more isotopic data from a variety of Indus sites is developed it remains difficult to determine the exact nature of this interaction and how specific exchange networks would have functioned. In particular, it is hard to determine if copper from Oman was entering the Indus as semi-processed raw material (ingots), finished artifacts, or raw ore. Still it is both possible and reasonable to identify a movement of copper from sources in Oman to the Indus region – specifically the urban center of Harappa.

Figure 6.9: HARP Artifacts and Oman Ore Lead Isotope Signatures

An intriguing question is whether or not South Asian copper sources can be identified within the published lead isotope data for 3rd millennium BCE artifacts from Oman and the UAE. Two major bodies of published lead isotope data for artifacts exist that provide an overview of the region (Prange 2001; Weeks 2003; Begemann et al. 2010). Weeks (2004) provides 42 lead isotope analyses from copper-bronze artifacts from sites in the UAE (see Table 6.2 and Appendix 6.5). All the artifacts are from Umm al-Nar period tombs and while the materials analyzed are too fragmentary (Weeks 2003:62-69) to make definitive conclusions, other artifacts from the same contexts share clear stylistic affinities with the copper and bronze forms found at Indus Tradition sites (Weeks 2003). Being that the UAE assemblage is comprised of artifacts from funerary contexts, it is not clear if this is a representative picture of all the metal in circulation at these sites or a preferential sample of high-status material related to wealth and prestige; as is often the case with artifact assemblages from tombs. Prange (2002) and Begemann et al (2010) provide 61 lead isotope signatures from a variety of artifacts spread across multiple sites and cultural periods. From that overall dataset, 18 lead isotope signatures from Umm al-Nar period (2600-2000 BCE) sites were selected for comparison with both the regional ore sources and the HARP artifacts (see Appendix 6.5) while the remaining lead isotope data points were not used because they belong to Omani cultural time periods outside the Indus chronology. 15 of the 18 objects from Oman are ingots, slags, or copper prills and are taken to represent a local manufacturing signature.

Table 6.2: Tomb Sites with Lead Isotope Samples

Tomb Site	# Artifacts	Cultural Period	Date
Al Sufouh	5	Umm al-Nar	2450-2300 BCE
UNAR 1 (Shimal)	9	Umm al-Nar	2400-2200 BCE
UNAR 2 (Shimal North)	10	Umm al-Nar	2200-2000 BCE
Tell Abraç	18	Umm al-Nar	2200-2040 BCE

In Figure 6.10 the data from Oman artifacts is compared to both the UAE artifacts and regional copper sources from within Oman. Two conclusions can be drawn from examining the isotopic data. The first aligns with what has already been discussed by the original researchers (Prange 2001; Weeks 2003; Begemann et al. 2010); specifically, that the copper from 3rd millennium BCE sites across Oman appears to be primarily the result of the extraction of and production with local ores. In contrast, the objects from tomb sites in UAE do not completely correspond isotopically with either ores from Oman or the local Oman manufacturing signature. This has previously been attributed to incomplete data for both the UAE and sources across Oman (Weeks 2003). It is almost certain that some of the currently unattributed artifacts from the UAE were fashioned with copper from sources in the southeastern Arabian Peninsula that are not currently sampled. However, if the artifacts from UAE and Oman are plotted along with the HARP artifacts (Figure 6.11), a correlation between HARP artifacts and artifacts from the UAE can be seen. The implications for this connection between copper and bronze from tomb sites in the UAE and artifacts from an Indus urban center will be explored in a subsequent section. It should be noted that the available data paints an intriguing picture of metal trade across the Gulf. It would seem that metal is moving out of the Indus across the Gulf with, at least at Harappa, little metal material travelling in the opposite direction.

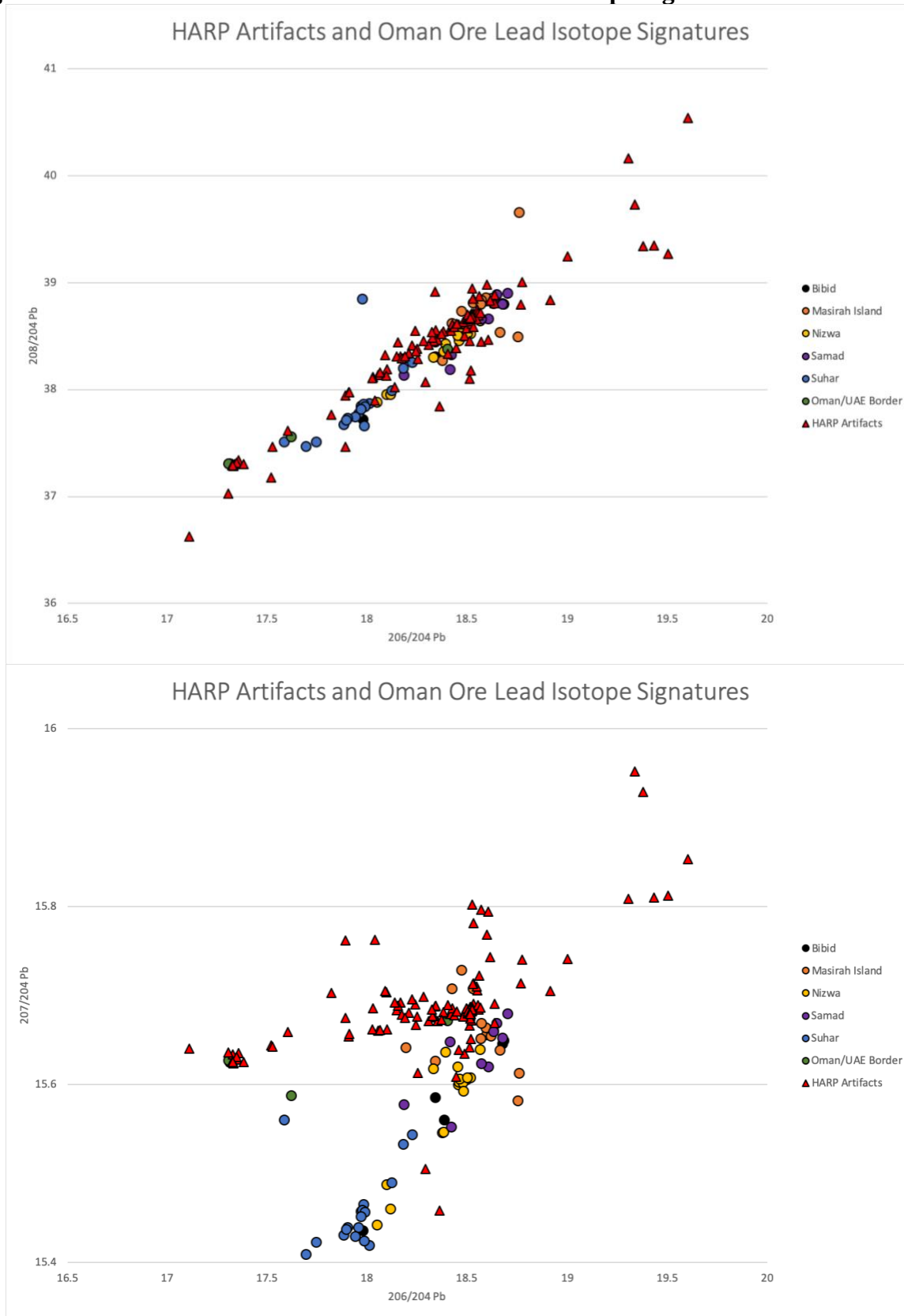
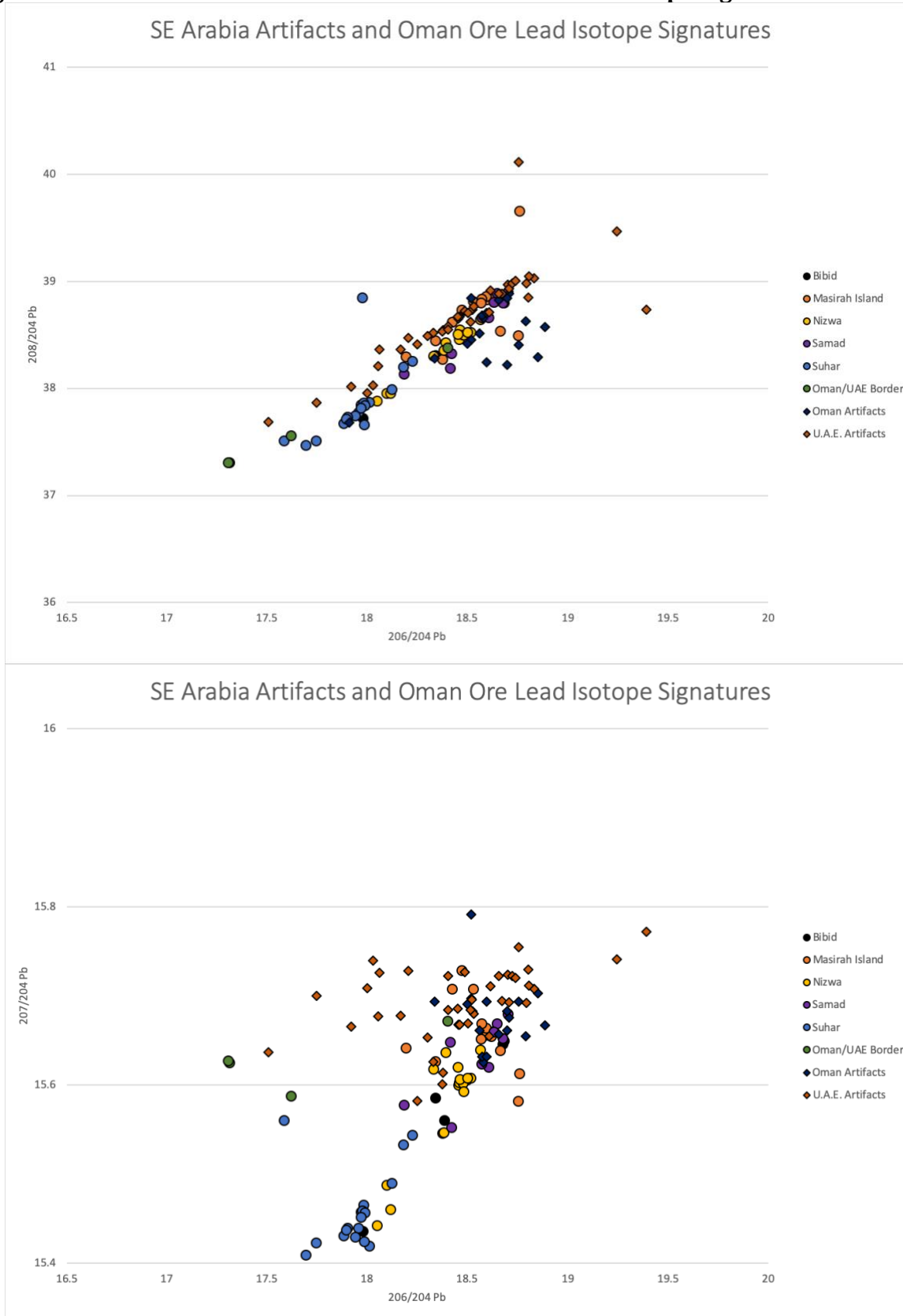
Figure 6.10: SE Arabia Artifacts and Oman Ore Lead Isotope Signatures

Figure 6.11: SE Arabia Artifacts and HARP Artifacts Lead Isotope Signatures

Afghanistan Sources

Previous considerations of the potential sources of copper and bronze metal in the Indus Tradition have suggested the possibility of Afghanistan serving as a source region (Chakrabarti and Lahiri 1996; Kenoyer and Miller 1999; Miller 1999; Agrawal 2000; Law 2011; Hoffman and Miller 2014). This suggestion rests on two main supports. The first is the abundance of copper resources within Afghanistan. There are 3 major localities for copper deposits within the Afghan copper belt; headlined by the massive reserves at Mes Aynak (Afghan Geologic Survey 2005). Interestingly, these deposits appear to be geologically related to copper sources within Baluchistan (such as Reko Diq) and Iran (Sarchesmeh) along the Tethyan Metallogenic Belt. Porphyry copper deposits within this geologic zone are often extremely large and have been exploited throughout human history. The details of the geology of this region are still emerging and, at present, the specific relationships between deposits within Afghanistan as well as with those in adjacent regions remains uncertain. However, archaeological investigations have demonstrated that Mes Aynak was actively being exploited by the 3rd century BCE with potential evidence for occupation during the late Bronze Age, if not earlier (<http://mom.gov.af/en/page/mes-aynak-project/mes-aynak-archaeology>). The second support for placing Afghan copper into Indus copper and bronze supply networks is because research has documented an Indus presence in the region. Sites such as Shortugai (Kenoyer 1998) and research on other rock and mineral raw materials (Law 2011) has demonstrated the validity of both an Indus presence and a strong interaction connection(s) with resource areas within Afghanistan.

While both geological and archaeological evidence supports the inclusion of Afghanistan as a potential source region for Indus copper raw materials, the available data makes it difficult

to assess this hypothesis. A survey of the available literature was only able to identify 18 lead isotope characterizations from Afghan copper ores, copper slags, and galena (see Appendix 6.6). For comparison with the HARP material, the two data points from galena were excluded. Additionally, five previously unpublished copper ore and slag samples from Mes Aynak were provided by Dr. J.M. Kenoyer and graciously shared with this project (Kenoyer personal communication). Figures 6.12-6.13 display the lead isotope signatures of copper ore and slag from Afghanistan compared to the HARP artifacts. However, prior to assessing any potential correlations between HARP artifact lead isotope signatures and those from copper ores and slags from Afghanistan, it is necessary to examine the lead isotope data from Afghanistan first. Figure 6.13 display the lead isotope analysis results for eighteen published and five unpublished data points from across the copper bearing areas of Afghanistan.

Looking at the geological data from Afghanistan, there is one striking conclusion from even a cursory examination. Four of the ore data points plot well outside anything else in the current lead isotope database compiled for the project (see highlighted box in Figure 6.13). This includes newly derived laboratory data and existing published isotopic measurements. One potential reaction to this would be discard the data as extreme outliers resulting from either contaminated sample, laboratory error, or some combination of those two factors. Since the four samples come from different sample sets and different analytical sources, it seems far more likely that copper bearing ores across the mountainous zones of Afghanistan are incredibly isotopically diverse. As the specific geologic history and metallogeny of deposits in this region is only recently beginning to be understood, it remains for further study to determine the source of this complexity and to develop far more specific delineations for the major copper resources within this region. Further, much of the data from Afghanistan lies outside of area that contains

the lead isotope signatures for the artifacts from Harappa. Overall, this means that much of the existing data from Afghanistan is excluded. Intriguingly, one previously unpublished slag sample from Mes Aynak points to the potential for correlation with the extremes of the lead isotope signature spectrum from Harappa, much more comparative data needs to be developed in order to empirically assess this potential. While those long-term tasks remain, the present project can offer preliminary discussion of the potential for correlation between Afghan sources and copper artifacts from Harappa.

Returning to Figure 6.12, there is a potential correlation between five of the HARP artifacts and copper ores from western Afghanistan from a source that Begemann and Schmitt-Strecker (2009:44) list as Shaida in Herat Province. It is possible that there exists a slight correlation between HARP artifacts and copper sources in western Afghanistan, but this correlation does not appear to be strongly supported by an analysis of the isolated artifacts and ores in question using all 3 lead isotope ratios. As was discussed above with the Mes Aynak materials, there are simply not enough lead isotope data points to make a definitive determination. At present, correlations between copper sources in Afghanistan and copper-bronze artifacts at Harappa remain an intriguing but tentative possibility. Future research needs to be directed towards this region. Numerous other rock and mineral resources from the region have been identified at Harappa and other Indus sites (Law 2011) as well as the potential for the exploitation of tin, a crucial 3rd millennium raw material, sources in the region (Kenoyer 1998; Kenoyer and Miller 1999; Hoffman and Miller 2014).

Figure 6.12: HARP Artifacts Compared to Afghanistan Ore & Slag Lead Isotope Signatures

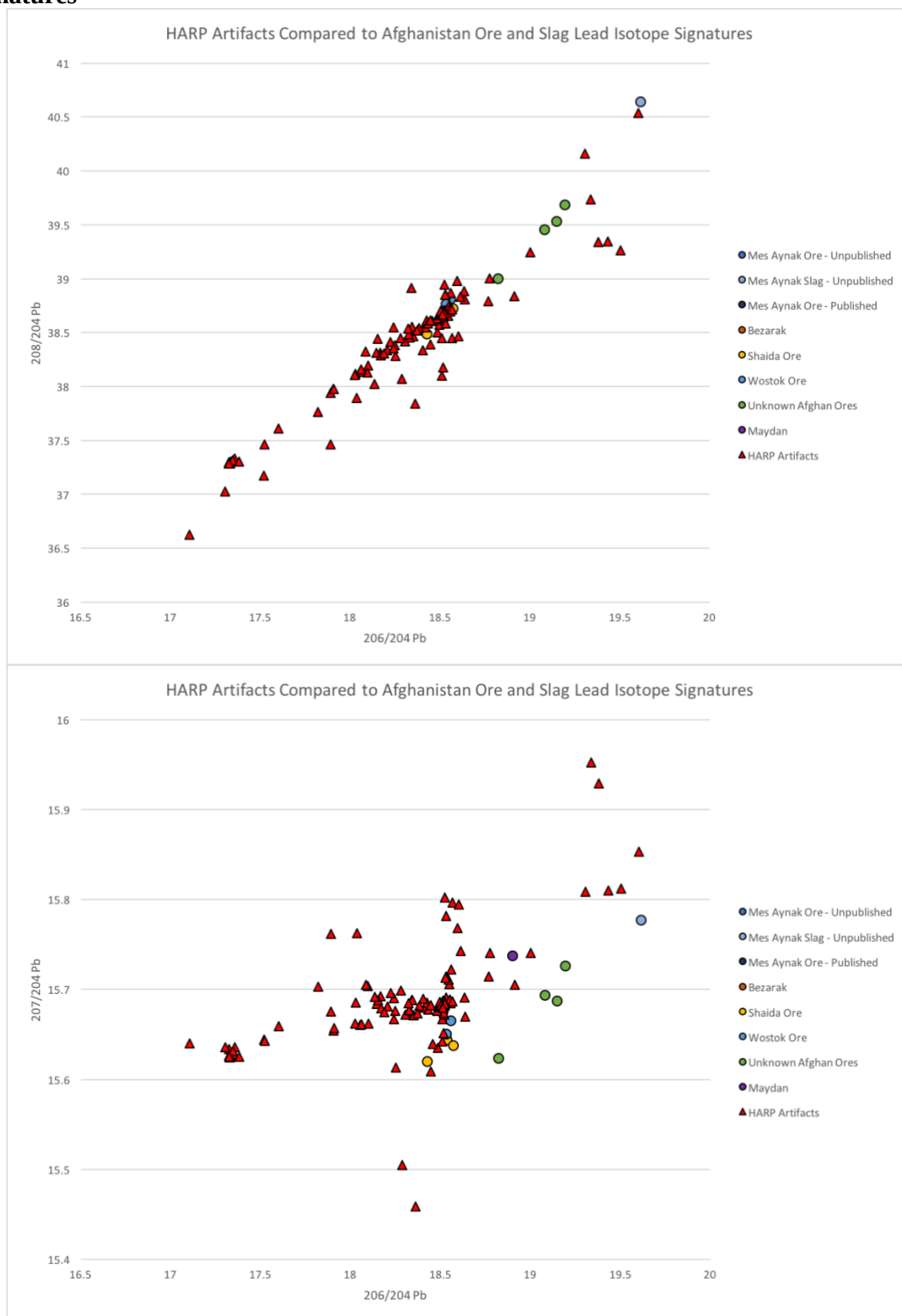
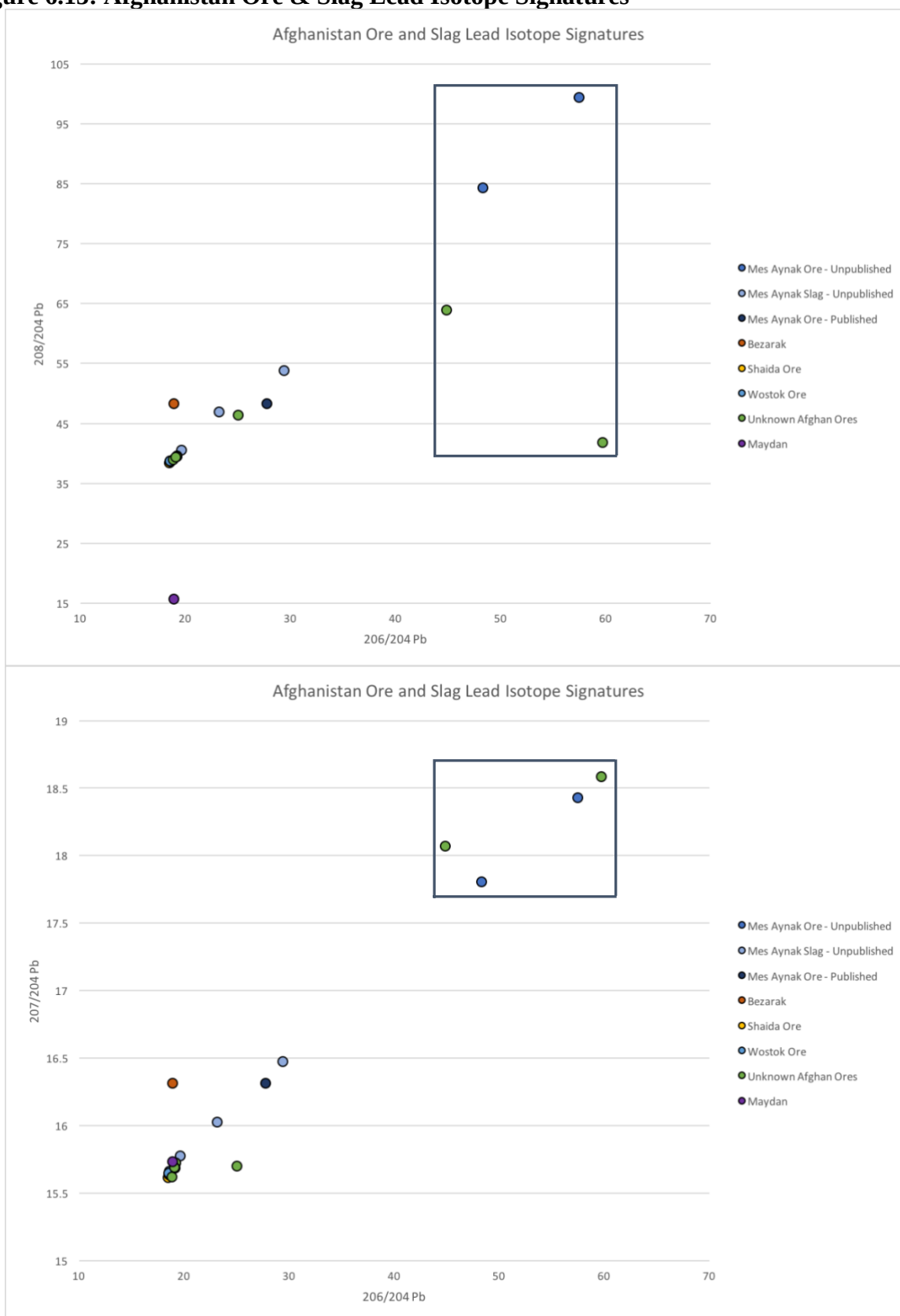


Figure 6.13: Afghanistan Ore & Slag Lead Isotope Signatures



South Asian Sources

The final series of copper source areas that should be compared to the isotopic signatures of the HARP artifacts are those from within greater South Asia (Figure 6.14). The examination of the isotopic signatures of copper source locales from regions outside of South Asia has demonstrated a limited degree of correlation with the copper and bronze artifacts from Harappa. However, the most likely source or sources for Indus Tradition copper raw material has traditionally been hypothesized to be from any number of deposits within South Asia (Chakrabarti and Lahiri 1996; Kenoyer and Miller 1999; Law 2011; Hoffman and Miller 2014). The current comparative database is assuredly not an exhaustive sample of all potential copper mineralization that could have served as significant source locations during the 3rd millennium BCE, but it does represent the most complete and robust comparative database yet developed. The compilation of the comparative geologic database for copper sources within South Asia has been drawn from previously published analyses and new analytical results from ongoing research conducted by Dr. R.W. Law and graciously shared for this project (personal communication). All of the lead isotope analyses used for this portion of the project are presented in Appendices 6.7-6.10. Overall the sources can be divided into four main sub-regions: the Himalayas, the Waziristan ophiolitic sources, copper deposits in the Chagai belt of Baluchistan, and sources throughout the Aravalli Range.

Figure 6.14: Location of Harappa and Regional Copper Sources in South Asia



(Redrawn from Law 2011:448 Figure 12.45)

Himalayan Sources

Previous researchers have often hypothesized that copper sources within the mountainous regions surrounding the Himalayas could have been exploited by the Indus Tradition (Agrawal 2000; Agrawal 1981). This has remained untested. Work undertaken during the course of this research project has begun to empirically test the idea that copper from Himalayan sources formed a component of metal supply at the site of Harappa. The results of this research have been previously published (Law 2011; Hoffman and Miller 2014) and will only be briefly summarized here.

For the current project, two sources from the Himalayan region, Chargaon in Himachal Pradesh and Askot from Uttarakhand. The results of the analyses conducted on copper ore samples from these locations has been previously discussed by Law (2011:447-459) and Hoffman and Miller (2014:703-708). The additional detail that can be offered here is that a comparison with the full suite of lead isotope signatures available from the HARP artifacts

continues to demonstrate no correspondence with the isotopic signal of the two Himalayan copper sources (Figure 6.15A and 6.15B). A final note on Himalayan sources. There is one finger ring from the HARP assemblage that may demonstrate a correlation with copper from Chargaon. However, the laboratory conducting the isotopic analysis indicated that they have an extremely low confidence in the accuracy of that isotopic signature and the ring has been excluded from the current analysis. It is hoped that future research on the HARP copper and bronze assemblage will include the re-analysis of this intriguing artifact. Further, if the artifact does indeed represent copper sourced from the Himalayas it is far more likely that the artifact represents the movement of an individual from the Himalayan region rather than the significant importation of copper or bronze from the region. While it may be possible that other Himalayan regional copper source locations or other artifacts from Harappa or other Indus sites will demonstrate an isotopic correlation, it is not presently supported.

Figure 6.15A: HARP Artifacts and Himalayan Ores Lead Isotope Signatures

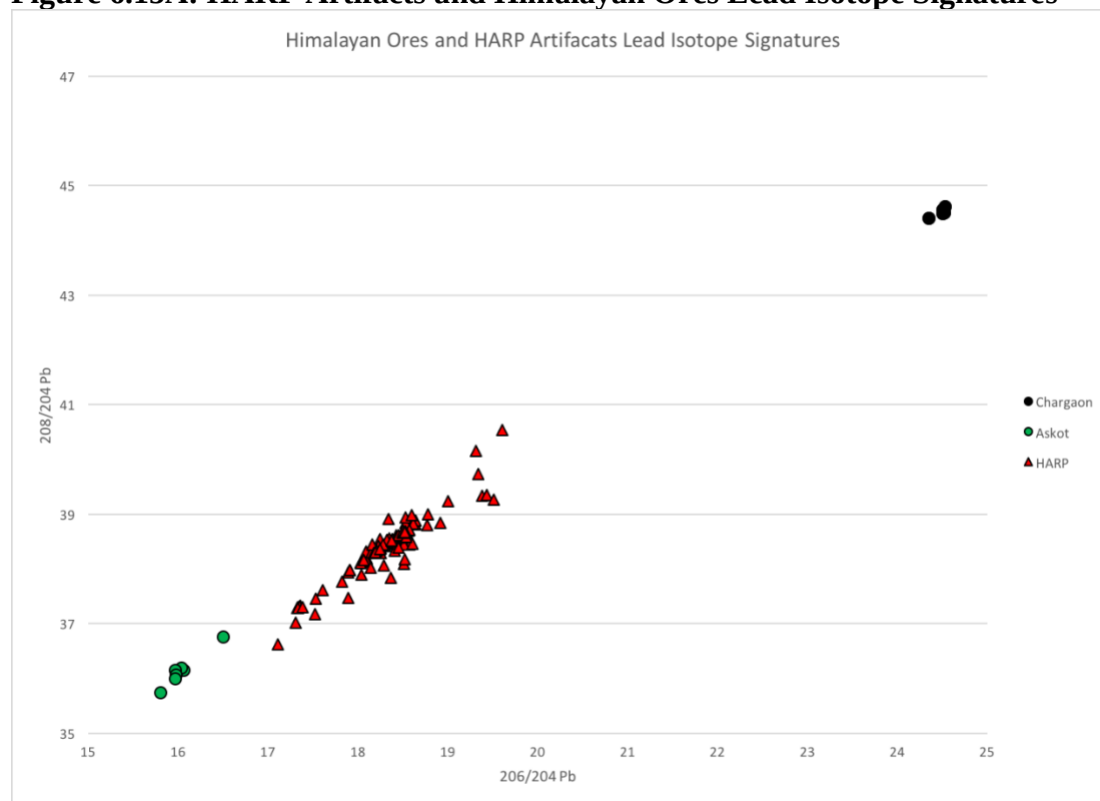
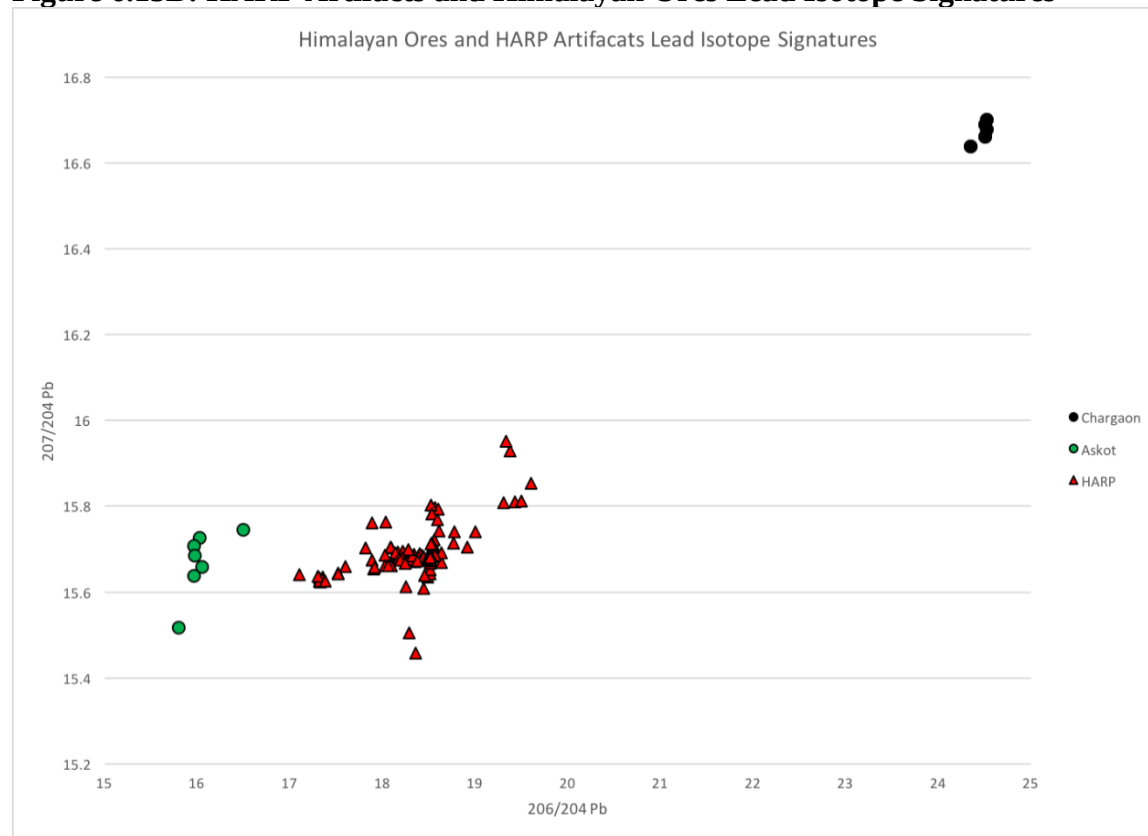


Figure 6.15B: HARP Artifacts and Himalayan Ores Lead Isotope Signatures

Waziristan Sources

Previous publications (Law 2011; Hoffman and Miller 2014) have presented the results of lead isotope analyses on copper ores from the Shin Kai copper prospect in Waziristan (see Law 2011:451-452 for description). In total, five copper ores (chalcopyrite and malachite) were collected from this region and analyzed for their lead isotope signatures (Law 2011:452 for location description and Appendix 6.8 this work). An initial presentation of these lead isotope results was provided by Law (2011:454-459) and then a comparison of the results to initial copper artifacts from Harappa was completed during the pilot study portion of this research project (Hoffman and Miller 2014). The results are replicated here in order to extend the

comparison of this copper bearing region to the entire suite of lead isotope analysis from copper and bronze artifacts from Harappa.

Examining the comparative results between the HARP artifacts and the copper ores from Waziristan (Figure 6.16), an intriguing potential correspondence can be identified. There is a tight cluster of HARP artifacts at roughly 18.50 206/204 Pb and 15.67 207/204 Pb (see Figure 6.17). This group of artifacts is not fully correlated with other major potential source regions. It does display a rough correspondence with the copper ores from Shin Kai. It must be acknowledged that this correspondence does not initially appear to be to a high degree. However, the available lead isotope data for the Shin Kai copper prospect does not include high resolution measurements for 204 Pb. If the data for 204 Pb is not used to construct the bivariate plots and instead 206 Pb is used (see Gale and Stos-Gale 2000:507 for discussion of the use of 206 Pb in archaeological research), the initial correspondence between HARP artifacts and the Waziristan copper is strengthened (Figure 6.16).

At present, it is not possible to definitively conclude that the Shin Kai copper is forming a major component of the copper supply infrastructure at Harappa. The data does support the hypothesis that copper from somewhere within the Waziristan ophiolite is forming a significant portion of copper supply at Harappa. There are a number of potential copper sources in the geological zone that could have been exploited in the 3rd millennium (Law 2011:452). As stated by Law (2011:452-453) another ophiolite sequence at Las Bela contains potentially viable copper sources. Additionally, the available isotope data from both galena and copper ores indicates that the Las Bela copper sources may correlate with this same lead isotope signature (Law 2011:456-458). Further research will need to be conducted on copper sources from the Waziristan and Las Bela ophiolites in order to determine the isotopic and geological

relationships between these potentially important copper source areas. Additionally, further comparisons will need to be conducted between the HARP artifact data and an expanded lead isotope database from these two regions. Until further analytical data is collected, the present conclusion that sources from South Asia located within a series of geologically related ophiolites comprised a component of copper supply for the city of Harappa is the most specific that can be offered. This aligns with data from other rock and mineral resources (Law 2011). It must also be noted that the available data from this region overlaps with some of the lead isotopic signatures from Oman. Attributing HARP artifacts with similar isotopic characteristics to deposits within South Asia instead of Oman, represents the most parsimonious explanation based on geographic distance and current understandings of trade networks during the Indus period. Further research and isotopic characterizations of a variety of copper deposits across Pakistan will be required to definitively discriminate between copper deposits in Pakistan and Oman that possess similar lead isotope signatures. However, at present, the deposits in Pakistan represent a slightly better “fit” for some of the HARP artifacts.

Aravalli Range Sources

Since the earliest discussions on the sources for Indus copper and bronze, the copper deposits spread throughout the Aravalli Range has been hypothesized as a significant source location (Marshall 1931; Mackay 1938; Vats 1940). This supposition continues through many reviews of Indus copper metallurgy over the subsequent decades (Agrawal 1971; Agrawal 1984; Agrawal 2000; Agrawala 1984; Kenoyer and Miller 1999; Chakrabarti and Lahiri 1996; Law 2011; Hoffman and Miller 2014). The core of this hypothesis is the occurrence of significant copper, lead, and tin deposits within the geographical range of multiple cultural groups during the 3rd millennium BCE. The presence of copper deposits lying within easy transport distance of

Indus settlements has traditionally been the logical basis for the proposal of sources within the Aravalli Hills region serving as a major source of copper and bronze raw material for Indus sites. There have been only limited attempts to analytically test this hypothesis. Some of these were reviewed previously (see Chapter 2) and only a few are relevant to an evaluation of lead isotope data from Harappa and will be discussed below.

Figure 6.16: HARP Artifacts and Waziristan Ores Lead Isotope Signatures

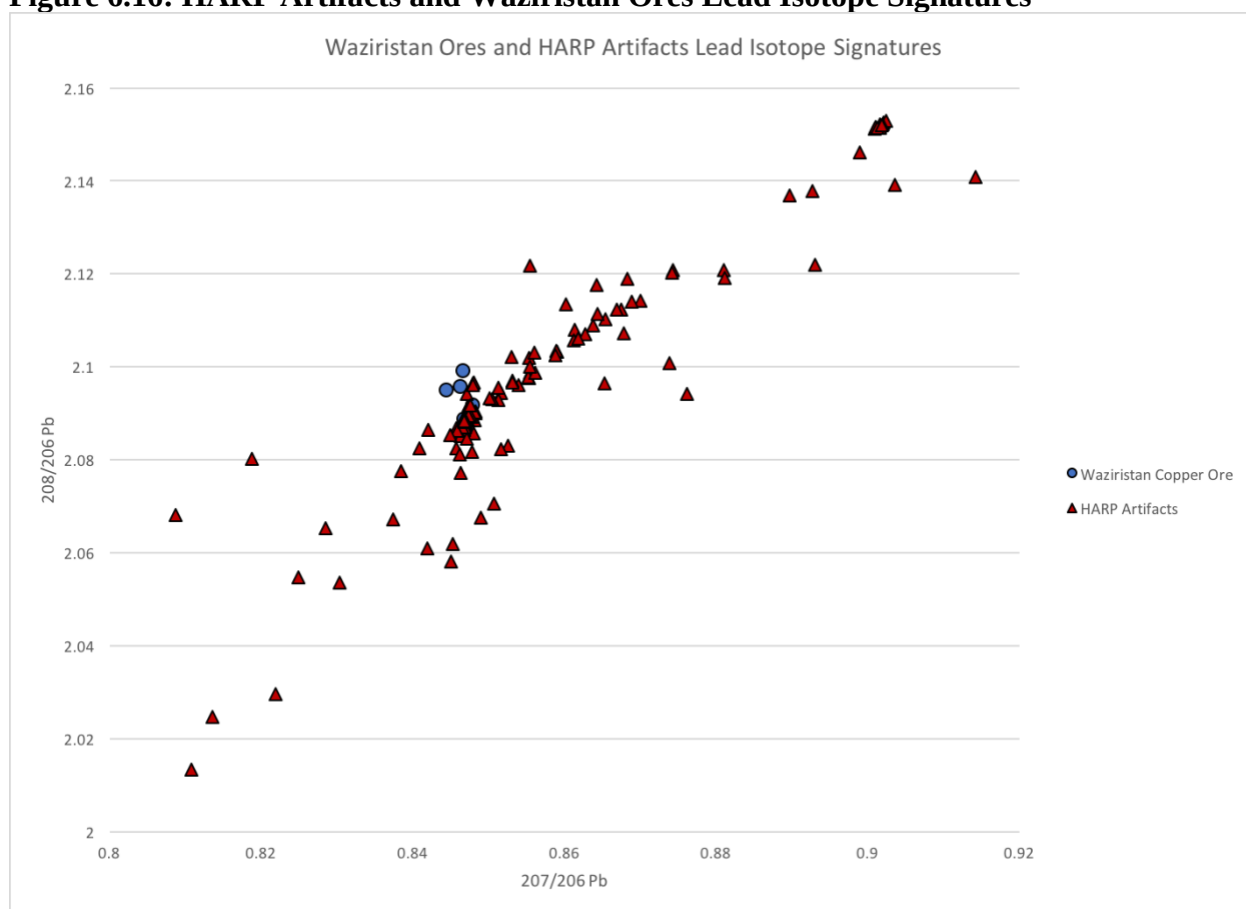
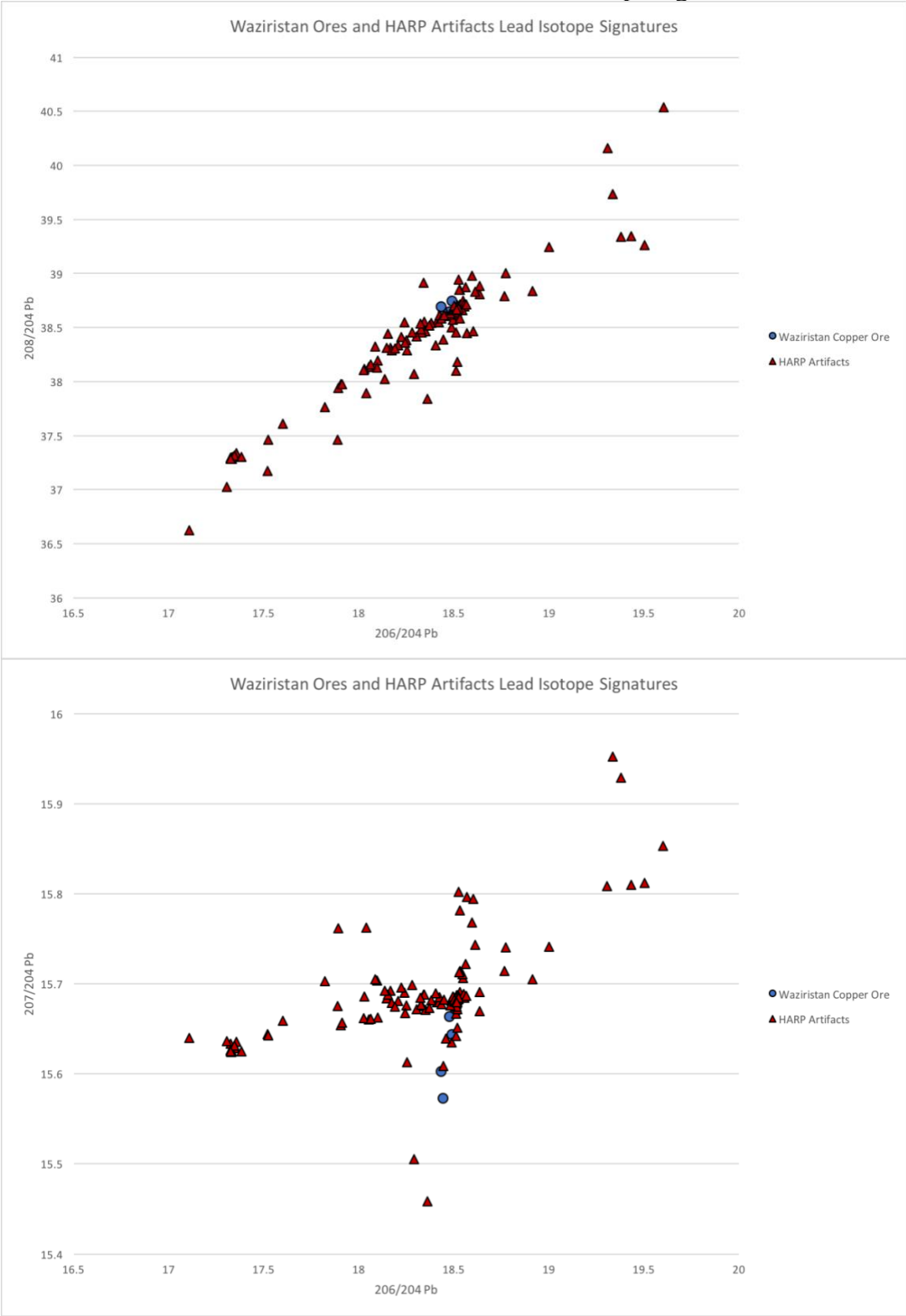


Figure 6.17: HARP Artifacts and Waziristan Ores Lead Isotope Signatures



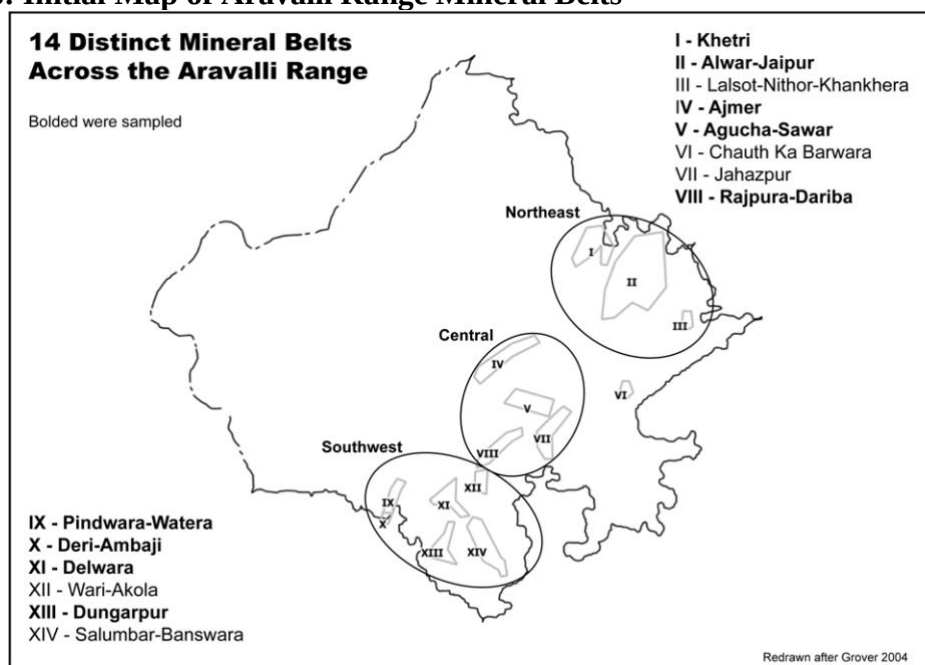
The same metal deposits that are hypothesized to have attracted prehistoric miners to the Aravalli Range region are still relevant to mineral exploitation today. As a result, an increasing amount of research has been conducted on the complex geology of the Aravalli Range and the associated metal deposits (see Powar and Patwardhan 1984; Deb et al. 1989; Deb and Sarkar 1990; Deb et al. 2001; Geological Survey of India 2001; Sinha-Roy 2000; Sarkar 2000; Patil and Roy 2000; Deb 2000; Murao et al. 2000; Abu-Hammatteh 2002; Pandit et al. 2003; Porwal et al 2006; Van Lente et al 2009) for examples of research on metallogeny, isotopic signatures, and geological characterization). All of this research has created a series of different, overlapping, and unclear systems for organizing and categorizing the numerous metal deposits across the entire Aravalli metallogenic province. In order to systematically organize comparative lead isotope information and evaluate sources within the Aravalli Range as potential supply locales for Indus copper raw materials, some method for classifying the Aravalli Range deposits needed to be employed.

An initial examination of the lead isotope values compiled both from previously published sources and new analyses conducted by Dr. R.W. Law (see Appendix 6.10) for a variety of metal ore deposits throughout the Aravalli range demonstrated two anomalous features. The first is that there was a significant amount of variability in material from the northeastern portion of the range. Numerous samples from the same deposit returned different isotopic values. In contrast, samples from metal deposits in the central and southwest portion of the Aravalli Range returned much more consistent lead isotope values. Second, an initial examination of the compiled database reveals a number of samples that plot well outside of expected lead isotope values. In order to assess the utility of the database moving forward, preliminary explanations for these anomalies were sought. A linkage between the variance

exhibited by the lead isotope data and the fundamental geology of the parent ore formations needed to be identified.

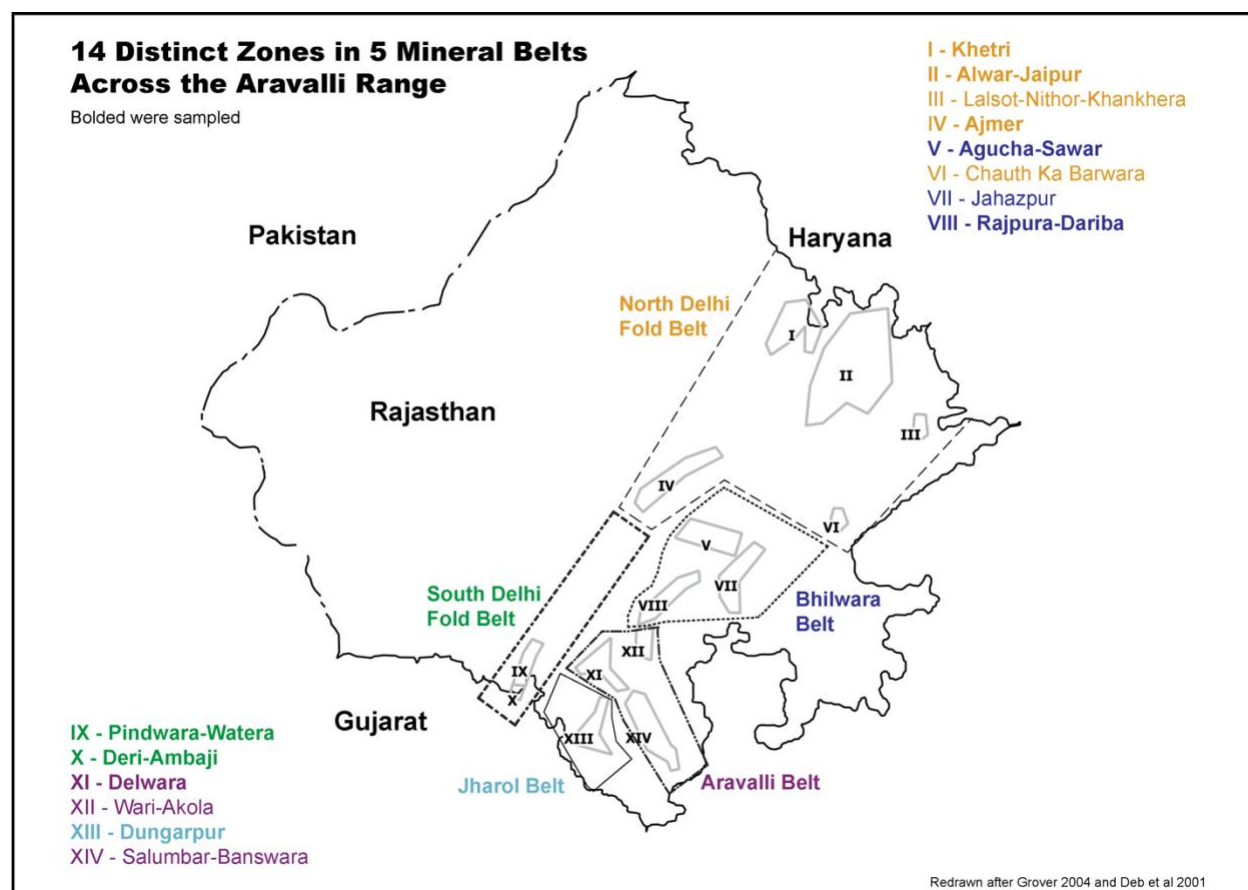
A survey of published studies on the ore formation, geological age, tectonic framework, and stratigraphic relationships across the Aravalli Range revealed a great deal of complexity and ongoing debate (Deb et al. 1989; Deb and Sarkar 1990; Sinha-Roy 2000; Sarkar 2000; Deb 2000; Deb et al. 2001; Abu-Hamattah 2002; Pandit et al. 2003; Porwal 2006; Van Lente et al. 2009). Initially, a version of the organization scheme for documented mineral deposits and slag locations proposed by Grover (2004) was applied to the collated lead isotope database (see Figure 6.18). This provide a solid basis for grouping the isotopic data within a related geographic and geologic context. An initial analysis of the lead isotope data exhibited strong regional patterning. Overall, material from the southwest, central, and northeast portions of the Aravalli Range plot together. However, there were several exceptions to this pattern and multiple data points that fell outside of the majority of isotopic values.

Figure 6.18: Initial Map of Aravalli Range Mineral Belts



In order to assess and understand this variation a more detailed methodology for classifying the sampled ore deposits was necessary. Traditional explanations grouped all of the Aravalli Range under the heading of the Delhi supergroup (Heron 1953). However, continued research has demonstrated that the metal bearing formations across the Aravalli Range can be divided into geologically distinct belts (Deb et al. 1989; Deb and Sarkar 1990; Deb 2000; Deb et al. 2001). Deb et al (2001) and Deb (2000) outline a division for the metal bearing portions of the Aravalli Range into a series of distinct but related belts (see Figure 1 Deb et al. 2001:197 and Figure 6.19) that provides a highly useful framework for understanding and describing the complex geology of the region. The most important takeaway from this scheme, is that the central and southwestern portions of the Aravalli Range deposits do not share the exact same geological history as the portions containing the northeastern deposits. While the underlying geological processes and models for ore formation are highly complex and not yet completely understood (see Sinha-Roy 2000; Sarkar 2000; and Deb 2000 for discussion), an empirical model for the age of the major metal bearing belts has been developed. This is the critical piece for understanding and interpreting archaeologically relevant lead isotope data. Lead isotope signatures are the result of the age of the parent ore deposit whether the sample was ore, slag, ingots, or artifacts (Pollard and Heron 1996; Gale and Stos-Gale 2000; Pernicka 2014). It is this principle that allows for the provenance designations to be constructed. Plotting the compiled lead isotope values for copper deposits across the Aravalli Range demonstrated a strong correlation between geological belts and isotopic signatures (Figure 6.20)

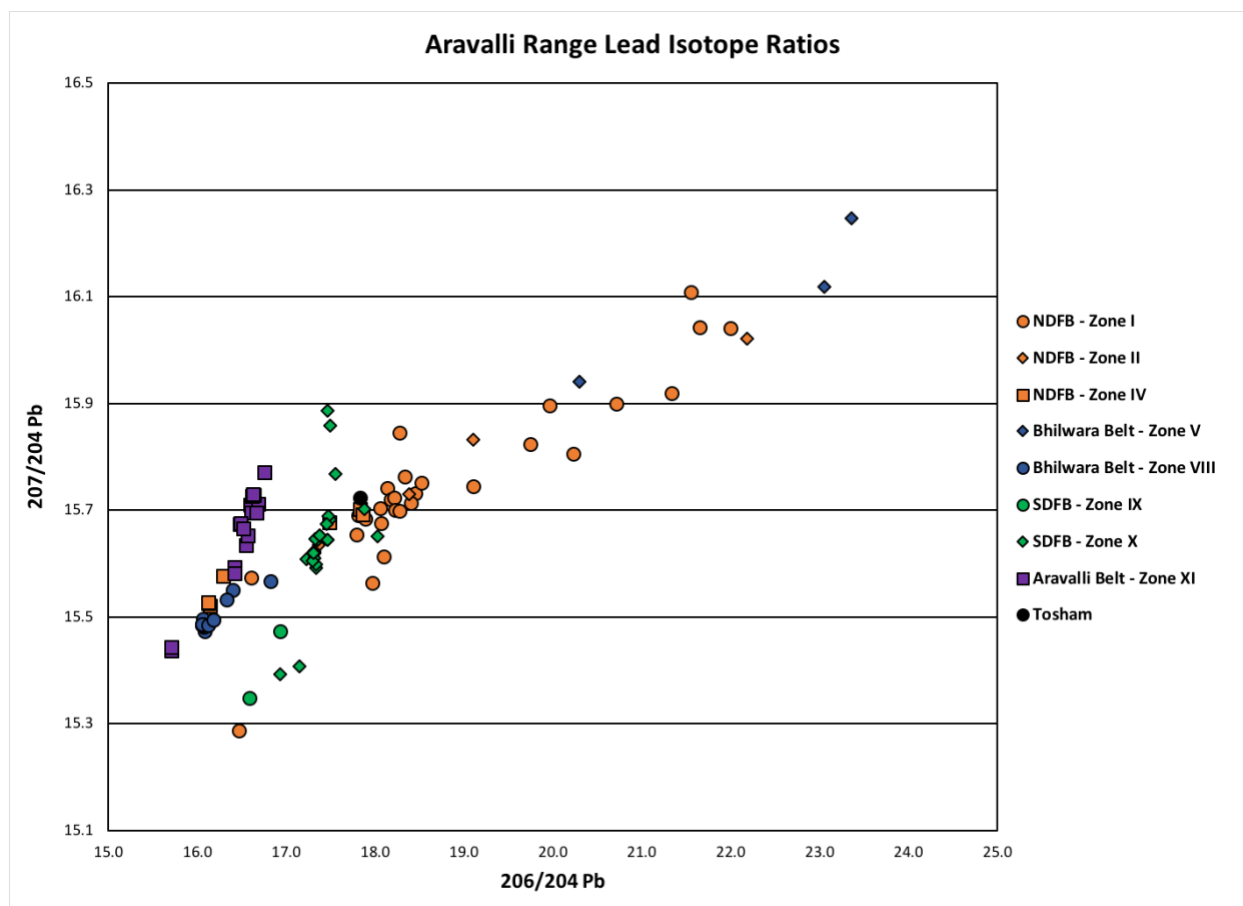
Figure 6.19: Revised Map of Aravalli Range Mineral Belts



Looking at the current model for geochronology of the metal bearing belts across the Aravalli Range, several following conclusions can be advanced (following Deb et al 2001: 209-210). The first is that the North Delhi Fold Belt (NDFB) (Figure 6.19) can be separated from the South Delhi Fold Belt (SDFB) based on a variety of factors. Geochronology indicates the southern portion dates to around 1.0 billion years ago. In contrast the North Delhi Fold Belt is best modelled as approximately 1.8 billion years old. Using the same model and a variety of isotopic data, the Bhilwara Belt (containing the Rajpura-Dariba deposit) has an age of 1.8 billion years ago and the Aravalli Belt (containing the Zawar deposit) has a model lead age of 1.7 billion years ago. Overall, this model of a distinct geochronology for each belt appears to support the

variation identified in the compiled lead isotope database for copper bearing metal deposits in the Aravalli Range.

Figure 6.20: Aravalli Range Lead Isotope Signatures by Mineral Belt



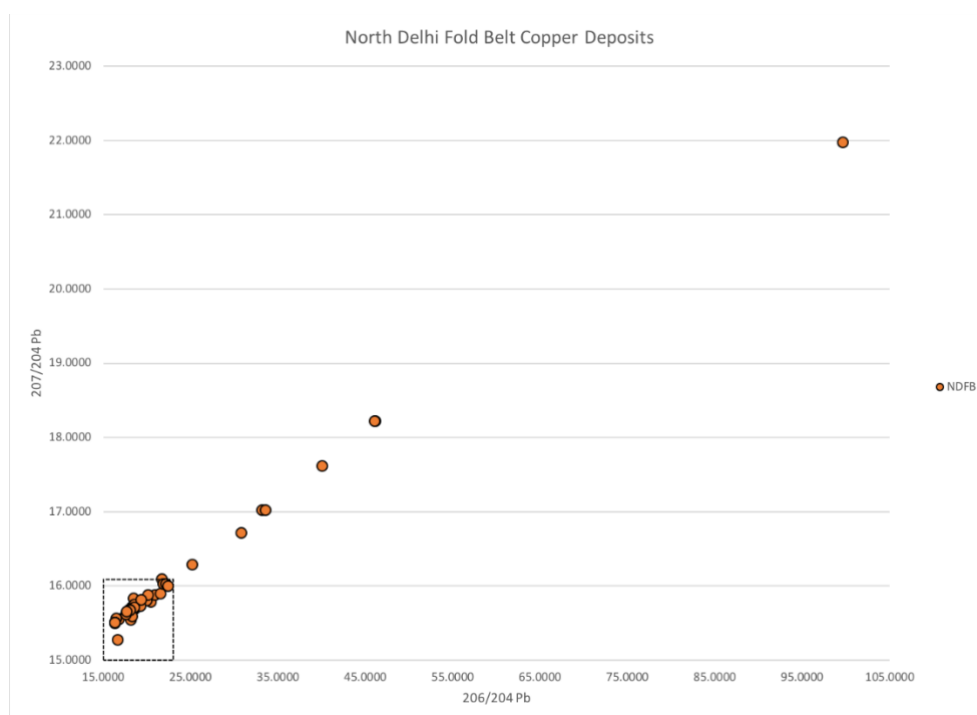
The proposed model ages correspond well to the lead isotope ratios in the database for samples from the central and southwestern portions of the Aravalli Range (Bilwara, Aravalli, and South Delhi Fold belts). Despite this strong correspondence, the database seemingly contradicts the model age for metal deposits from the northeastern portion of the region. Current models indicate that the metals from the North Delhi Fold Belt (Zones I and II in Figure 6.17 and the North Delhi Fold Belt in Figure 6.18) should be roughly 1.8 billion years old (Deb et al. 2001:210) and therefore should plot to the left of the younger samples from the central and

southwest in any lead isotope plot (see Figure 4 Deb et al. 1989:14). However, almost all the available data for North Delhi Fold Belt copper bearing deposits in the current database plot to the right therefore, younger than the deposits from the South Delhi Fold Belt, the Aravalli Belt, and the Bhilwara belt (Figure 6.19).

Figure 6.21 plots the isotopic signatures of the samples from northeastern Rajasthan from the North Delhi Fold belt currently in the database. Following White (2001:344 Figure 8.18), a boundary of expected isotopic values for these deposits can be outlined. This is represented by the dotted rectangle in the figure and outlines the lead isotope values that correlate with known terrestrial reservoirs. While most of the samples plot within this zone, several do not. At present, it is unclear how these isotopic values are best explained. 206/204 lead isotope ratios greater than about 22.0 may represent complex ore formation scenarios that are the result of multiple episodes of lead enrichment (Pollard and Heron 1996; White 2001; Faure and Mensing 2009). Such multi-stage deposits are termed anomalous and represent (despite the name) the majority of mineral deposits known globally (Pollard and Heron 1996). It is possible that many of the copper bearing deposits in the North Delhi Fold Belt were initially formed in the 1.8 GA period posited by existing models (Deb et al. 2001:210) and then experienced one or more episodes of enrichment from radiogenic upper crust during subsequent geological phenomena (Pollard and Heron 1996). This may provide an explanation of their seemingly “younger” isotopic signatures that initially appear to not conform to existing models for the age of Aravalli Range copper deposits, but overall expectations for lead isotope values based on current geochronological models. However, as previously mentioned, the uncertain nature and formation processes for the North Delhi Fold Belt (Sinha-Roy 2000; Sarkar 2000; and Deb 2000) preclude a definitive explanation at the present time. Further research on the basic geology, ore formation, and

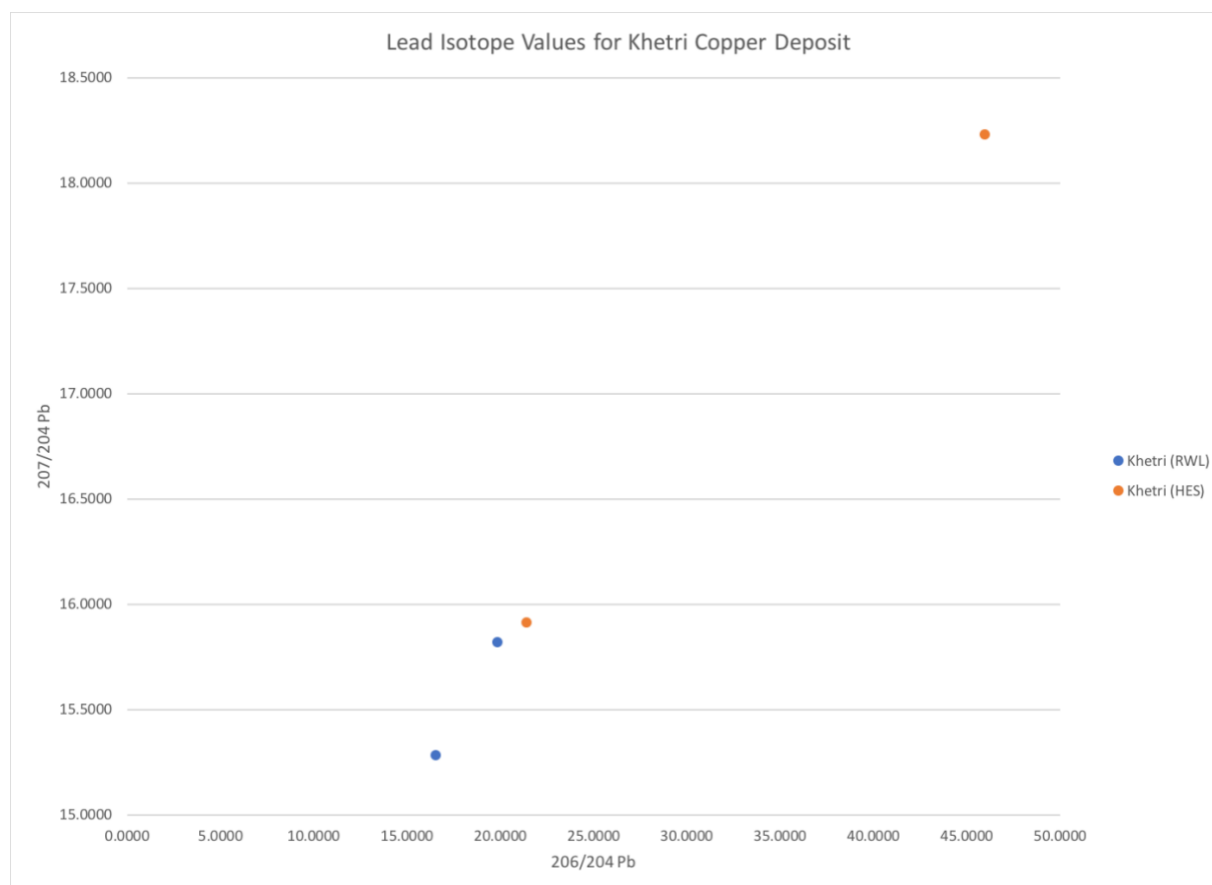
geochronology of the area is required in addition to the analysis of more ore samples for their isotopic signatures.

Figure 6.21: Lead Isotope Signatures for the North Delhi Fold Belt



An additional element of support for the 1.8 GA model age and the preliminary suggestion that many copper bearing deposits in the North Delhi Fold Belt have undergone enrichment with lead from a radiogenic source(s) after their initial formation can be found in the available lead isotope data from the Khetri copper deposit. Figure 6.22 plots the lead isotope values for four samples from the Khetri locale. Two were recently analyzed by Law and two were previously published (Hegde and Ericson 1985; Ericson and Shirata 1985). A fifth data point listed as Ghatiwali (Ericson and Shirata 1985) was omitted as a duplicate of another Khetri Sample (Hegde #7 in Appendix 6.10). Previous research (Cumming and Richards 1975; Gulson 1986; and see Pollard and Heron 319-321 for discussion) has demonstrated that anomalous lead

isotope signatures from the same mineral deposit may be explained by the formation of a secondary mixing line that demonstrates the admixture of lead from an older and younger source during episodes of ore formation. This mixture can often be determined by the construction of a linear array between the end members of the isotopic field for a given deposit. Figure 6.22 demonstrates the potential for a linear relationship between both data points generated during Law's recent analyses. However, it is problematic, at best, to demonstrate a similar linear relationship between the Khetri data from Law and that published in Hegde (1985) and Ericson and Shirata (1985). Further, the extreme isotopic values exhibited in the previously published data (Khetri (HES) in Figure 6.22) is currently not understood. Returning to only the data produced by Law (Khetri (RWL) in Figure 6.22), it is possible to speculate that the data points represent an initial older formation that conforms broadly to the model laid out by Deb and colleagues (2001) and then a subsequent enrichment by a radiogenic source producing a tentative explanation for a complex isotopic "signature" for the Khetri copper deposit.

Figure 6.22: Khetri Copper Deposit Lead Isotope Values

Overall, the assembled database of lead isotope data points for copper bearing deposits throughout the Aravalli Range (Table 6.3) demonstrate both confirmation and variation from the expected isotopic model for the entire metallogenic province. Broadly, data derived from deposits in the central and southwest portion of the Aravalli Range conforms with expected lead isotope values and model lead ages. Represented in the database primarily by the Ambaji-Deri polymetallic deposit in the South Delhi Fold Belt and the several deposits in the Bilwhara Belt, these data appear to represent an alignment with currently understood ore formation and geochronology. In contrast, the elements of the database from copper bearing deposits in the North Delhi Fold Belt, do not universally align with expectations based on a review of ore formation and geochronology models. However, elements of the database may provide a

preliminary explanation. It is possible that the copper bearing deposits in the North Delhi Fold Belt represent multi-stage lead evolutions with intricate ore formation sequences involving multiple episodes of lead input into each ore system. Such complex ore geology requires significant additional research to document. At present the current database can be used in constructing archaeological provenance designations with a moderate caution. Specifically, that more data is needed from copper deposits in the North Delhi Fold Belt in order to confidently construct definitive isotopic fields for these deposits. However, rather than withhold the data until some indeterminate future point, a series of reasonable, albeit tentative, lead isotope signatures for the sourcing of copper and bronze artifacts to deposits within the North Delhi Fold Belt section of the Aravalli Range can be developed.

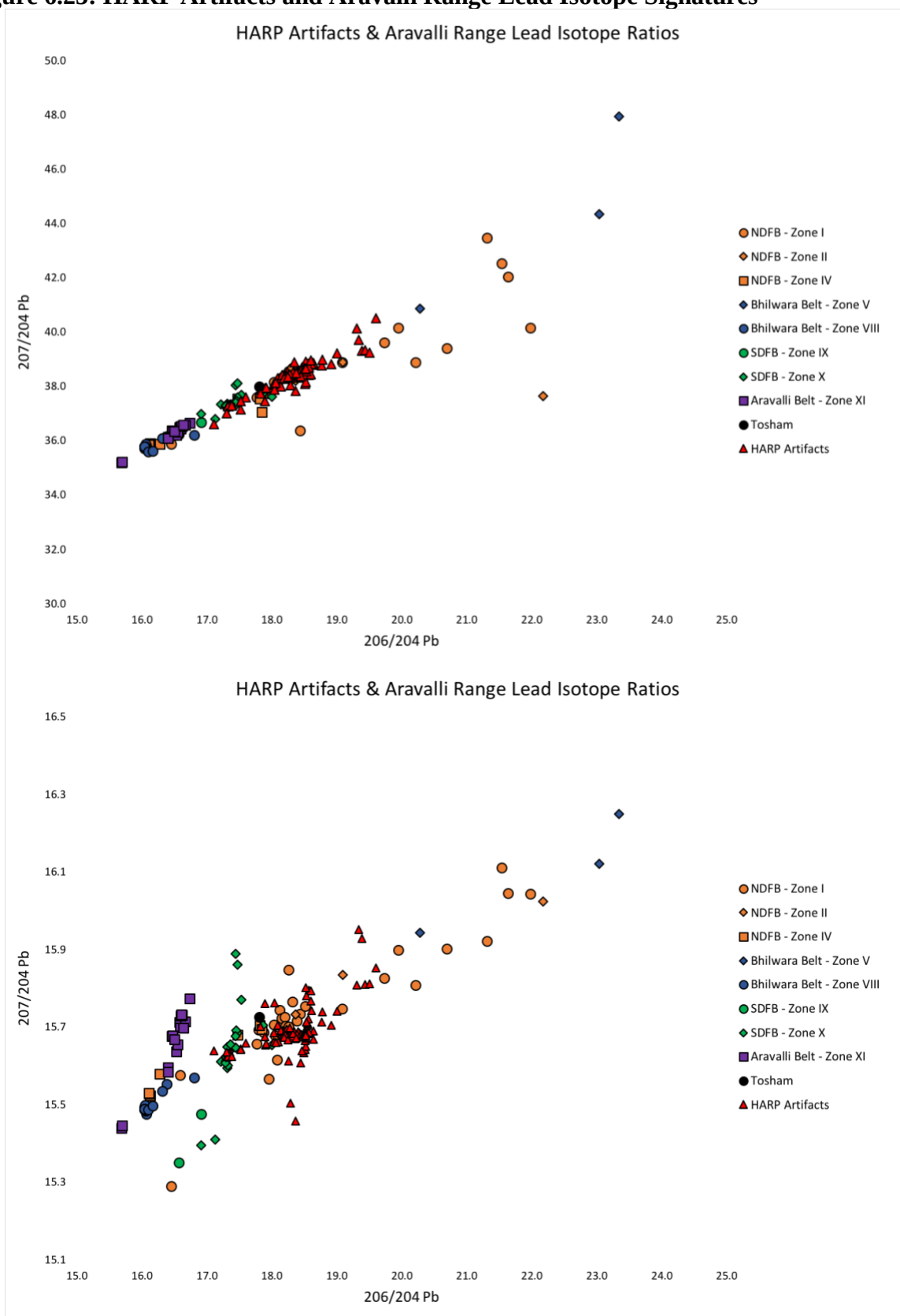
Table 6.3: Lead Isotope Data Points for Aravalli Range Regions

Location	Sample Type	# Data Points	Key Deposit
NDFB - Zone I	Ore and Slag	30	Khetri
NDFB - Zone II	Ore and Slag	8	Kho-Dariba
NDFB - Zone IV	Ore and Slag	5	-
Bhilwara - Zone V	Ore and Slag	3	-
Bhilwara - Zone VIII	Ore and Slag	14	Rajpura-Dariba
SDFB - Zone IX	Ore	2	-
SDFB - Zone X	Ore and Slag	29	Ambaji-Deri
Aravalli - Zone XI	Ore and Slag	17	Zawar

Looking at the isotope ratios for the Aravalli Range samples, and the samples from Harappa (Figure 6.23), a strong correlation between the isotopic ratios for some of the copper sources and the artifacts from Harappa is exhibited. Additionally, the artifacts from Harappa do not correspond with at least two of the major copper source zones within the Aravalli Range. Currently, no artifacts from Harappa appear to be manufactured using copper raw material from the Bhilwara Belt or the Aravalli Belt. Meaning that there is, at present, no evidence from Harappa for exploitation of either the Rajpura-Dariba copper source in the central portion of the

Aravalli Range or the Zawar source in the southwest portion. While during later periods of South Asian prehistory and history, these sources would be heavily utilized, this does not appear to be the case during the Harappan Phase (2600-1900 BCE). During the same period, the data from Harappa indicates that sources within the North Delhi Fold Belt and the South Delhi Fold Belt were supplying a significant portion of the copper raw material used to fashion the copper and bronze artifacts at the site. The NDFB encompasses a number of copper rich locales, with the Khetri and Kho-Dariba sources being two of the most noteworthy. The SDFB copper is focused on the Ambaji-Deri copper bearing area. Comparing the isotopic data for the entire analyzed HARP assemblage, it can be seen that almost half of the artifacts were manufactured with copper sourced to either the South Delhi or North Delhi Fold Belts. This represents the single largest contributing source region in the current study.

Figure 6.23: HARP Artifacts and Aravalli Range Lead Isotope Signatures



The Source Provenience of the Analyzed Lead Isotope HARP Assemblage

After testing the HARP lead isotope signatures against the comparative lead isotope database, 87 out of 130 artifacts can be attributed to five distinct regional isotopic signatures. The remaining artifacts exhibit a sixth distinct, but uncertain isotopic signature. Table 6.4 provides a summary of the provenience designations for the analyzed artifacts from the HARP assemblage. Copper deposits from within South Asia account for 63.8 percent of the sample set.

Table 6.4: Lead Isotope Source Region Designations

Source Region	# of HARP Artifacts	Percent Total
Aravalli Range - North Delhi Fold Belt	36 main body & 6 high range	27.7 & 4.6
Aravalli Range - South Delhi Fold Belt	15	11.5
Baluchistan – Chagai Hills Deposits	20	15.4
Waziristan	6	4.6
Oman – All Deposits	4	3.1
Unclear or Potentially Mixed	43	33.1
Total	130	100.0

Overall, the analyzed HARP copper/bronze assemblage is dominated (approximately two-thirds of all analyzed artifacts) by artifacts manufactured from copper from two isotopic zones; the North Delhi Fold Belt (NDFB) and a signature that has been classified as “Unclear or Mixed” since the specific attribution of this isotopic ratio is not possible at present. Figure 6.24 shows the bi-variate plots for the 3 unique lead isotope ratios for the analyzed HARP assemblage categorized by each distinct isotopic region identified in the comparative lead isotope database (Appendices 5.6 and 6.10).

The attribution of the HARP artifacts to individual isotopic regions is based on an examination of the bivariate plots for each region as outlined above. Based on the present comparative database for copper sources within South Asia and adjacent regions, it is possible to

distinguish between regions based on lead isotope signatures (Figure 6.25). Due to the limited number of samples for specific source locales (mineral deposits) in the comparative database, it is not always possible to construct source provenience linkages between artifacts from Harappa and specific copper deposits. Instead, it is possible to determine source proveniences to a lead isotope region. Future research will need to expand the available comparative database in order to allow development of source provenience designations to specific copper deposits. The ability to isolate the lead isotope fingerprint of the Ambaji-Deri deposit and to isotopically discriminate between sections of the Aravalli Range demonstrates that it will be possible to refine the provenience designations from regions to deposits with the expansion of the comparative database.

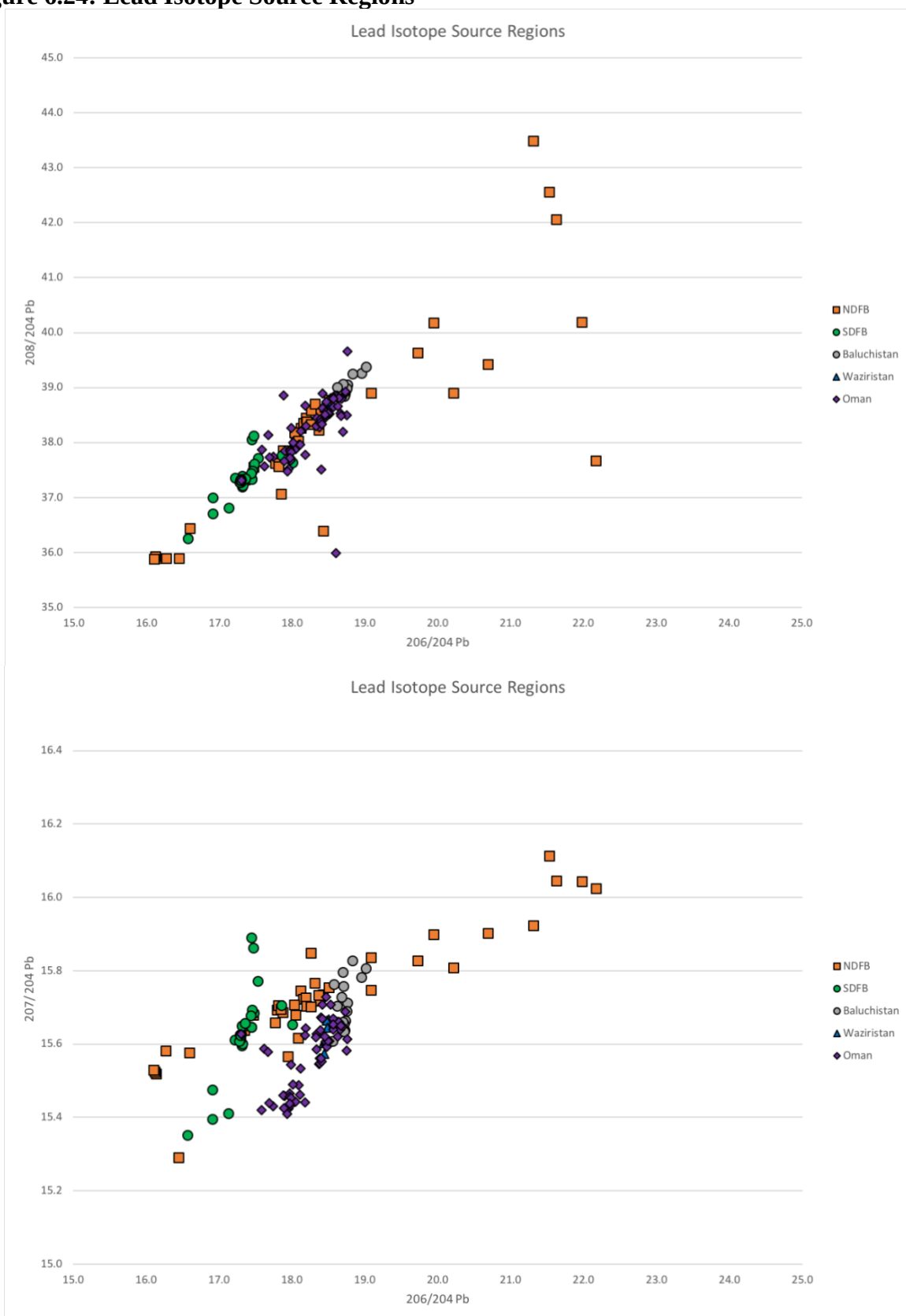
Figure 6.24: Lead Isotope Source Regions

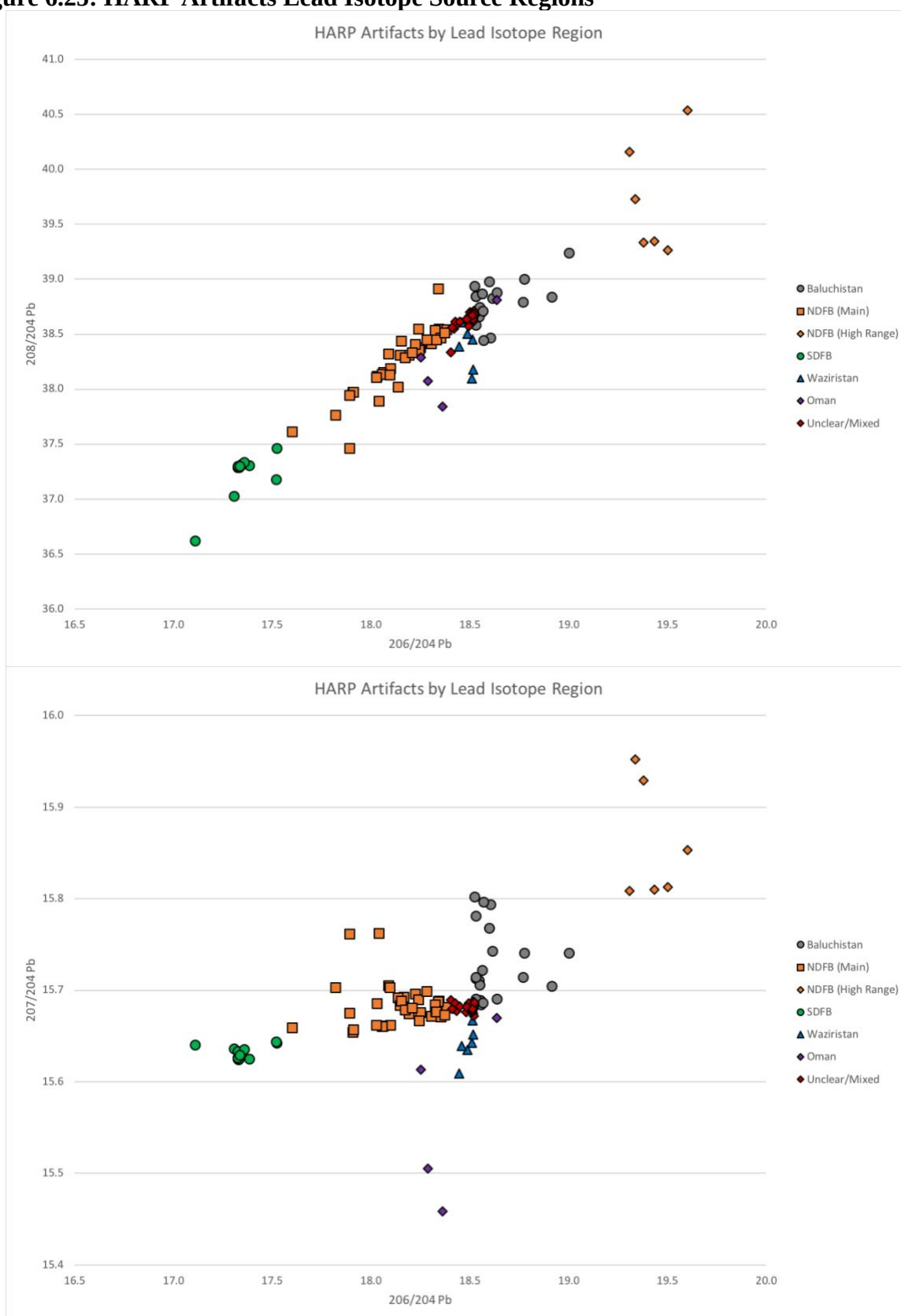
Figure 6.25: HARP Artifacts Lead Isotope Source Regions

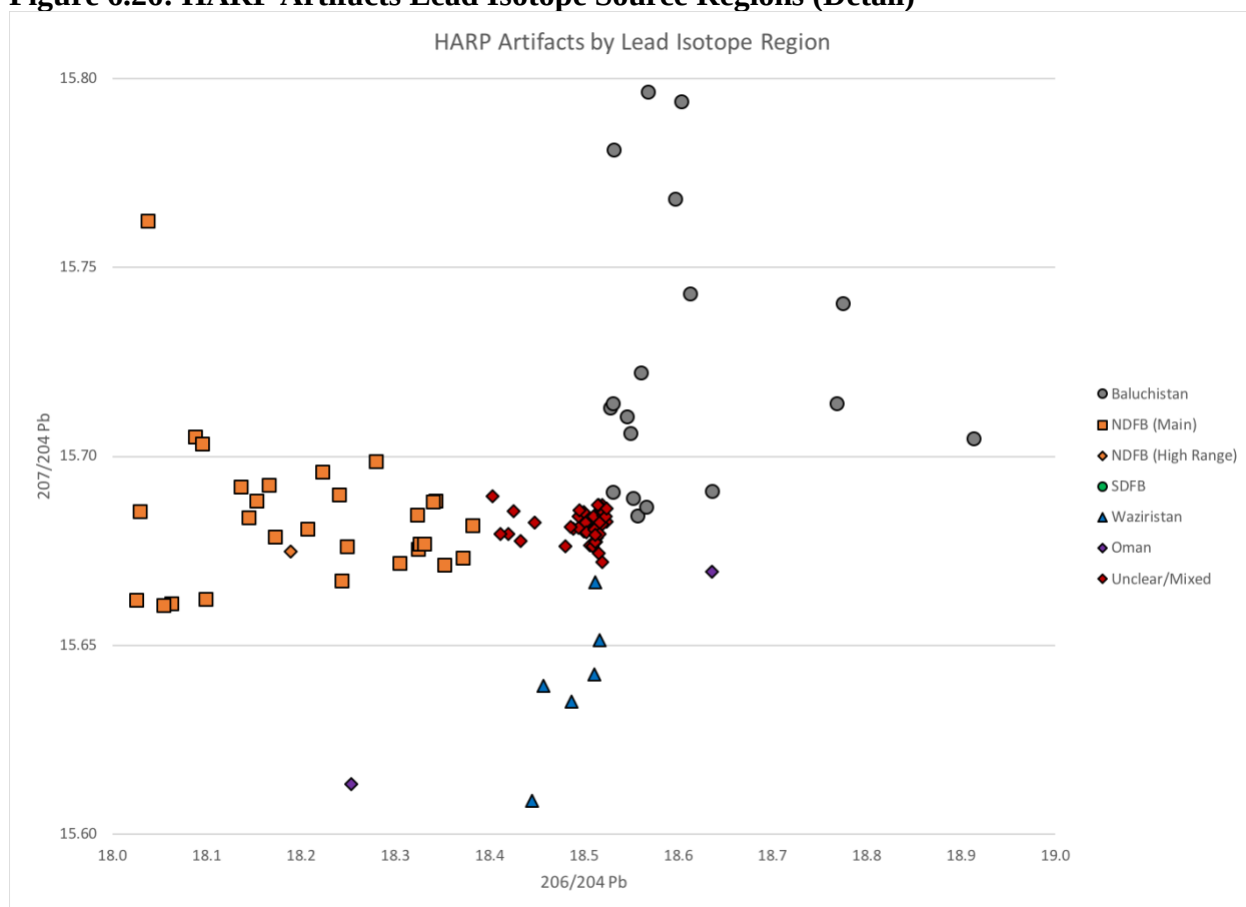
Figure 6.26: HARP Artifacts Lead Isotope Source Regions (Detail)

Figure 6.26 provides a detailed plot of the 207/204 lead isotope ratio against the 206/204 ratio. The 43 HARP artifact samples that plot in the “Unclear/Mixed” region of the isotope graph is highlighted in red, as with the previous graphs. There are three potential explanations for these samples:

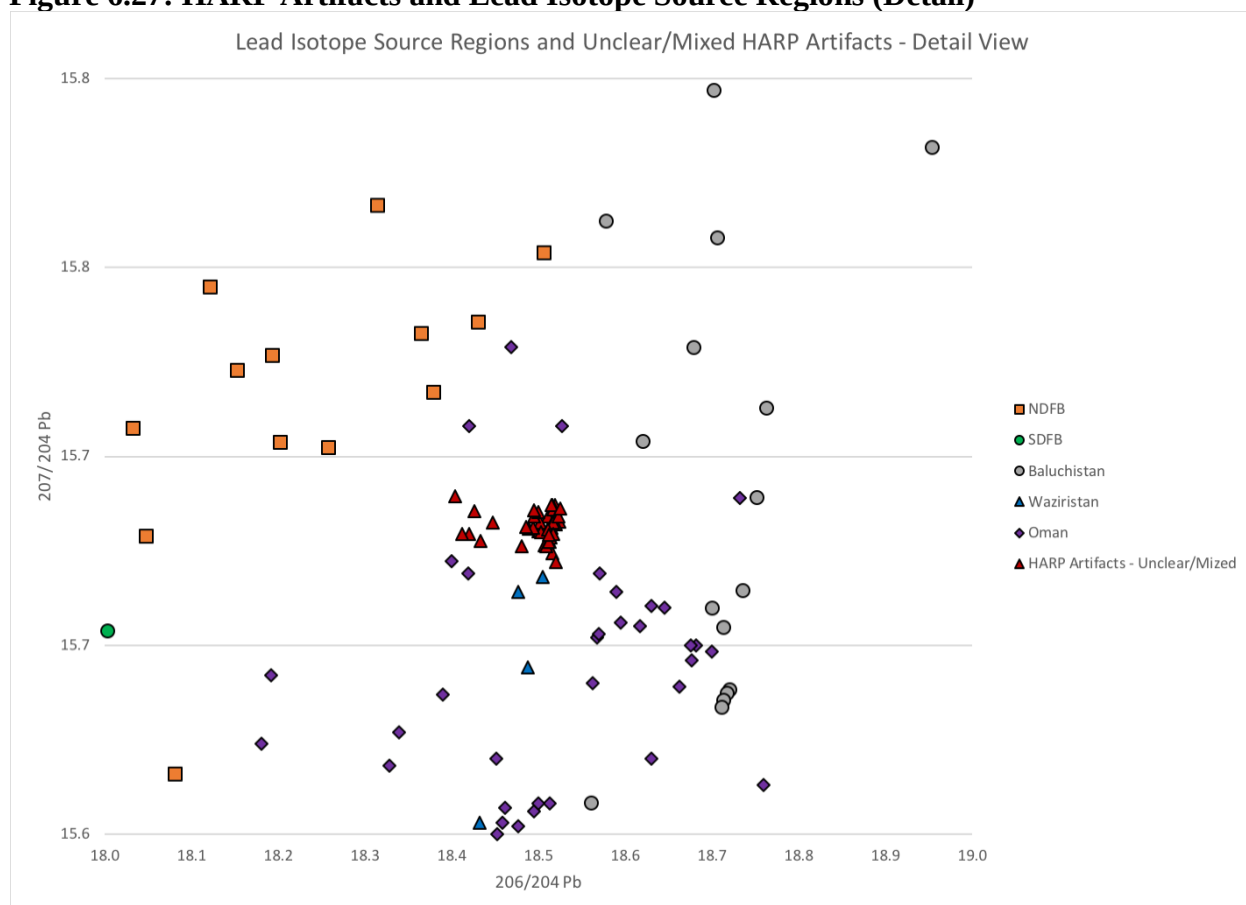
- They are from an existing source region in the comparative database and have been incorrectly assigned to the “Unclear/Mixed” group.
- These samples represent the results of source mixing between one or more of the source regions already identified in the comparative database.
- The samples identified as “Unclear/Mixed” represent a source within South Asia that has not yet been sampled for inclusion in the comparative database.

The current comparative database is not complete enough to conclusively discriminate between these possible explanations but based on a variety of lines of evidence, a preferential hypothesis can be constructed.

The samples in this category are tightly clustered around a 206/204 lead isotope ratio of 18.5 and a 15.68 207/204 ratio. The “clustering” represented within this category is more pronounced than almost any other lead isotope region in the comparative database. The South Delhi Fold Belt isotopic region, represented primarily by a group of samples for the Ambaji-Deri deposit, exhibits similar tight grouping around a restricted set of isotopic values (see Figure 6.25). Similarly, the samples from the Rakah locale within the Nizwah region of Oman (see Figure 6.8) demonstrate a strongly clustered plot. In each of these groupings, the variation in the lead isotope ratios is at the low end or below the natural variation in most ore deposits (Gulson 1986). Looking at the overall consistency in the isotopic ratios for the “Unclear/Mixed” category, it is reasonable to infer that 37 out of the 43 HARP artifacts within this category are manufactured from copper from the same source. That is, their isotopic ratios are essentially identical, and indicative of artifacts made from the same specific copper source. If the artifacts were made from a mixture of multiple copper sources or recycled/re-melted scrap copper objects, such consistency would not be expected. It is not unreasonable to expect a higher degree of variation in artifacts constructed from copper from mixed sources or recycled material. Ancient smiths were not always able to exhibit consistent and repeated control over their smelts. Further, recycled copper objects would not have been of predictable or repeatable provenience. Both of these realities would have precluded objects providing the same isotopic signature across the Kot Diji and Harappan Phases on all main occupation mounds and within each major artifact class.

Further, the HARP objects demonstrating this isotopic signature have also exhibited a range of copper alloys. The 7 copper prills from this isotopic group are of 5 different copper alloy mixtures. Additional alloys are present in the other artifact classes. Overall, the HARP artifacts in the “Unclear/Mixed” category exhibit a suite of characteristics that indicate the repeated use of the same copper source over time to fashion a variety of object categories, alloy types, and had an even distributed across each major occupation mound along with the R37 cemetery.

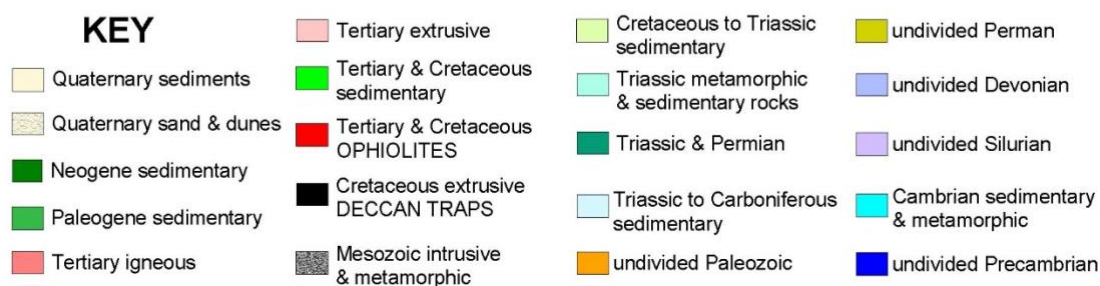
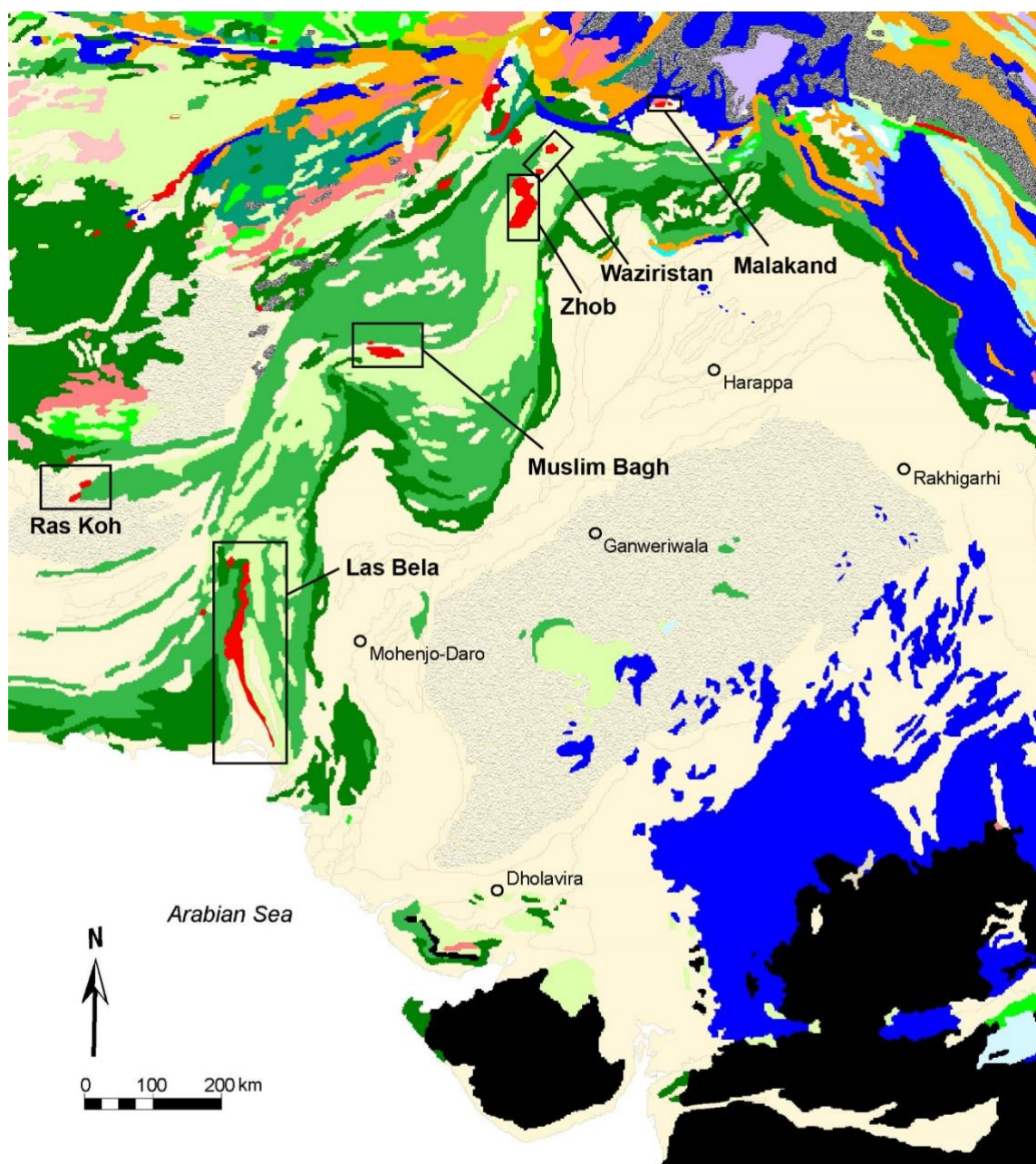
The specific identification of that source is not clear at present (Figure 6.27). However, the available evidence from both the lead isotope signatures of the artifacts and the geologic background of portions of Pakistan and Oman provide some evidence to base a preliminary hypothetical reconstruction of the unknown source. The existing regions within the comparative lead isotope database provide a series of clues to the type, age, and possible geographic location of the unknown source exhibited in the HARP artifacts. Copper deposits within Pakistan are of two main types. One is large porphyry type deposits, such as those found in the Chagai Hills region of Baluchistan (Sillitoe 1978; Jankovic 1997; Perello et al. 2008; Hou et al. 2011; Richards et al 2012) and the other is a series of copper deposits emplaced within ophiolites (see Figure 6.28) related to the copper bearing ophiolites in Oman and the southeastern Arabian Peninsula (Chen and Pallister 1981; Gnos et al. 1997; Gnos et al. 1998; Zaigham and Mallick 2000; Begemann et al. 2010; Ghose et al. 2014). It is these ophiolitic zones that may be the ultimate source location of the HARP artifacts from the “Unclear/Mixed” category.

Figure 6.27: HARP Artifacts and Lead Isotope Source Regions (Detail)

Copper deposits in ophiolites in Oman have similar lead isotope signatures to the “Unclear Mixed” category, as do the ore samples from the ophiolite in Waziristan. The available literature indicates that this should be the case, as the ophiolites all formed around the same time via similar geological processes (Chen and Pallister 1981; Gnos et al. 1997; Gnos et al. 1998; Zaigham and Mallick 2000; Begemann et al. 2010; Ghose et al. 2014). The Bela, Muslim Begh, Zhob, and Waziristan-Khost ophiolites are of a similar geological age, have the fundamentally same underlying geology (Ghose et al. 2014), and all contain copper deposits, often of significant size that are being exploited currently. The best explanation for this category based on the currently available evidence is that it represents a diverse array of copper/bronze artifacts

from Harappa that have the same single source provenience. At present, this source is not known and remains to be sampled. The most likely location for this source is somewhere in one of the four main ophiolites across Pakistan. Already documented rock and mineral trade networks during the Integration Era would have connected Harappa to these locales (Law 2011). This currently unknown source represents a third of the sampled HARP copper/bronze assemblage. Determining the location of this crucial resource zone and understanding how it articulated with existing and potentially overlapping trade networks would be enormously beneficial to our understanding of the economic realities of Indus urban centers. Future research will be needed to collect copper ore and/or slag samples to develop a definite isotopic correspondence to locate this important copper source. Additionally, further samples will be required to see if any of the samples fall within the Aravalli Range, particularly deposits within the North Delhi Fold Belt (NDFB). However, the available data strongly points towards 43 samples from Harappa that are categorized as “Unclear/Mixed” to be attributed to a copper source locale within one of the ophiolites across northern and western Pakistan. Based on previous work conducted by Law (2011:456-458), the copper deposits located within the Las Bela ophiolite represent the most likely candidate.

Figure 6.28: Map of Copper Bearing Ophiolites in Pakistan



Modified version of Figure 2.2 from Law 2011 (which is itself an adapted and simplified map from Wandrey and Law 1998).

Copper Provenience at Harappa – Alloy Classes

In the analyzed HARP lead isotope assemblage, seven distinct copper or copper alloy classes and a series of unknowns can be distinguished based on compositional analyses (see Chapter 4 for details and Table 6.5 for summary).

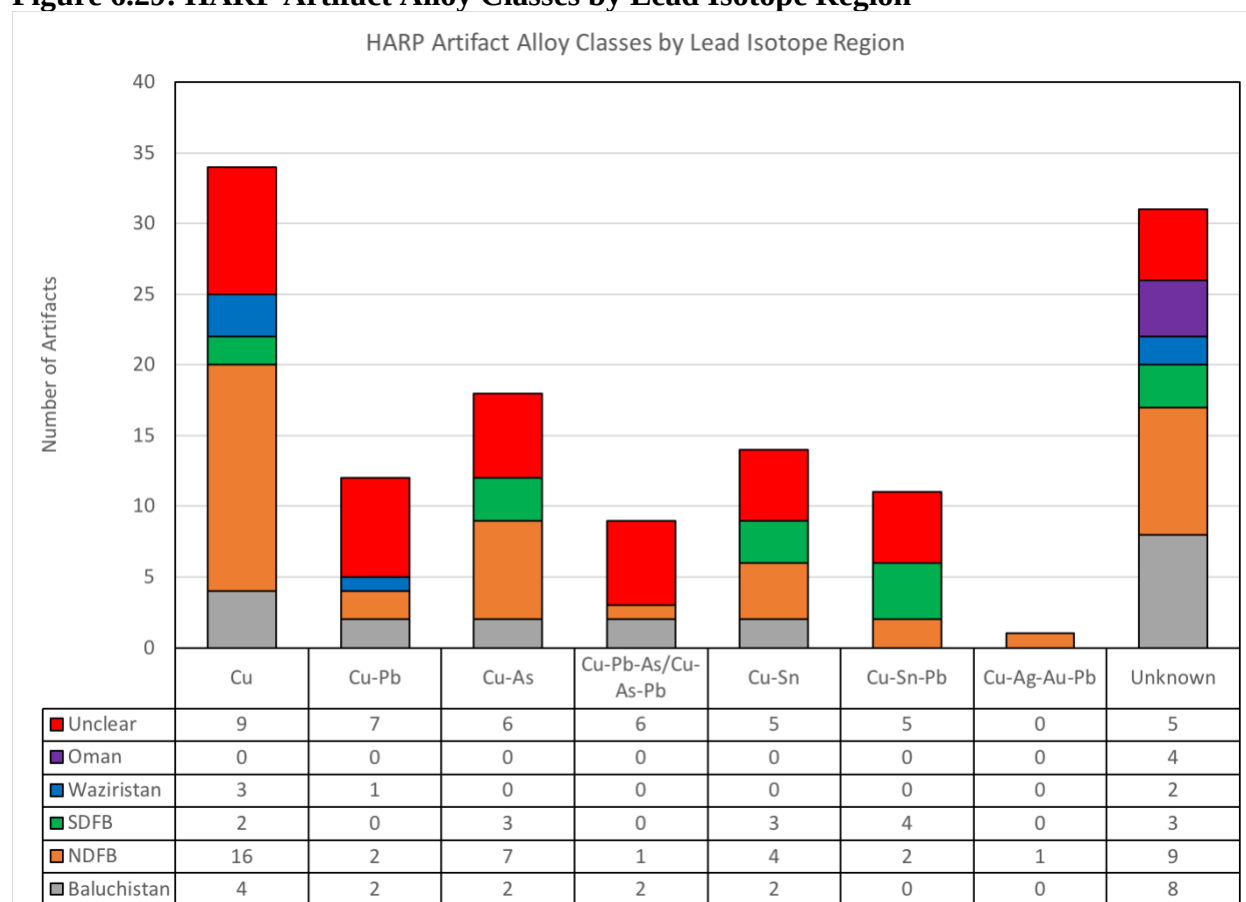
Table 6.5: Alloy Class Distribution at Harappa

Alloy Class	# of HARP Artifacts (LIA Assemblage)	Percent Total
Copper (Cu)	34	26.15
Copper-Arsenic (Cu-As)	18	13.85
Copper-Lead (Cu-Pb)	12	9.23
Copper-Tin (Cu-Sn)	14	10.77
Copper-Tin-Lead (Cu-Sn-Pb)	11	8.46
Copper-Lead-Arsenic/Copper-Arsenic-Lead (Cu-Pb-As/Cu-As-Pb)	9	6.92
Copper-Silver-Gold-Lead (Cu-Ag-Au-Pb)	1	0.77
Unknown	31	23.85
Total	130	100.0

These alloy classes can be grouped by the lead isotope regions identified above (Figure 6.29). Several conclusions can be reached from examining the artifacts analyzed for composition and lead isotopes from Harappa. The first is that the South Delhi Fold Belt (SDFB) lead isotope region, represented by the Ambaji-Deri source, does not appear in any of the copper alloys that contain lead. Artifacts fashioned from copper sourced to Oman do not currently have compositional data available due to involvement in either the initial pilot study or a later analysis run that returned no data due to laboratory errors. Two of the lead isotope regions, the Unclear/Mixed source, Baluchistan, and the North Delhi Fold Belt (NDFB), appear across all

alloy classes comprised of multiple artifacts. This is not wholly unexpected, as together these three regions comprise just two-thirds percent of the total analyzed assemblage (Table 6.4). A third isotopic region, Baluchistan, is represented in all of the alloy classes except two. The examination of the analyzed lead isotope artifacts by alloy classes is perhaps more instructive by what it does not exhibit than the patterns that are evident.

Figure 6.29: HARP Artifact Alloy Classes by Lead Isotope Region

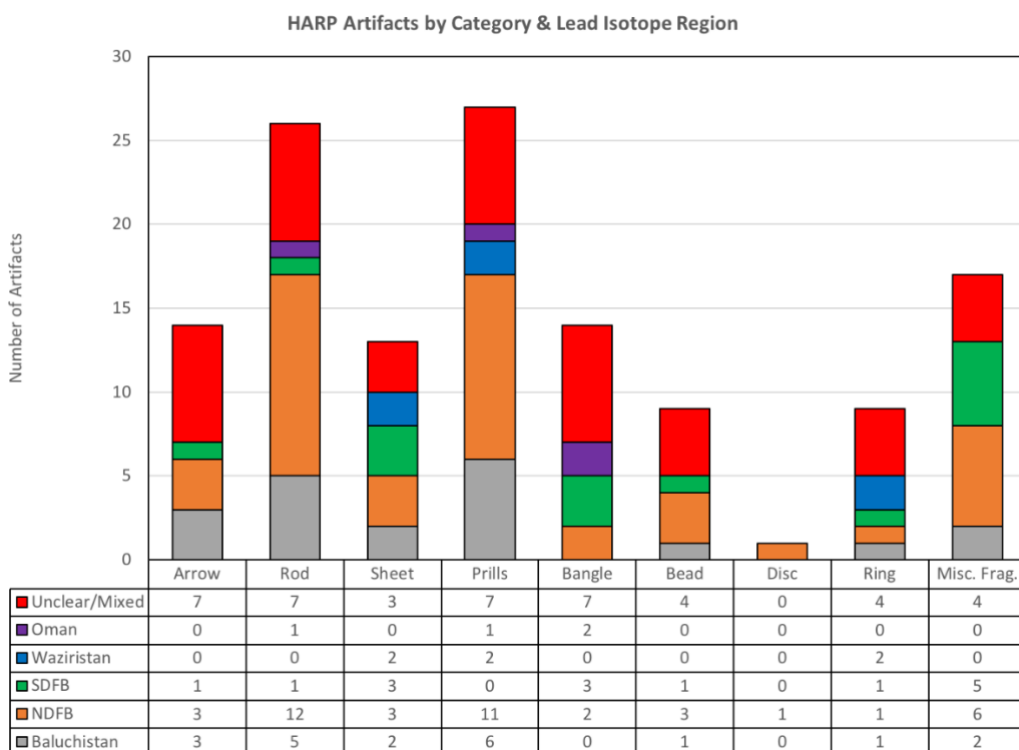


The most striking aspect of the distribution of copper source regions by alloy class is that there is no restrictive patterning. Artifacts from both unalloyed and alloyed copper are made from a variety of copper sources. For instance, tin bronzes are fashioned from at least four distinct copper source regions. This indicates that copper and bronze metallurgy at Harappa was not focused on the preferential use of a certain copper source region for specific copper alloy.

Instead, there appears to be usage of each lead isotope source region within each of the identified alloy classes without pattern or restriction. Overall, it appears that Indus copper-smiths were using copper from a several source regions to make a variety of alloys without seemingly to favor any one source for specific applications. It can be hypothesized that this was due to Indus copper workers overall confidence and competency in fashioning the desired finished product from a variety of starting points. This is not unlike Harappan craft workers abilities to transform multiple different steatite sources into the desired finished product (Law 2011). In both craft industries, steatite and copper/bronze, we see a proficiency by Indus craftspeople to transform a series of different inputs into a final desired output. Each industry would have used a number of transformative steps to accomplish this, but the principle remains the same – a focus on the desired end product rather than the source provenience of the starting raw material.

Copper Provenience at Harappa – Artifact Categories

Figure 6.30: HARP Artifacts by Category and Lead Isotope Region



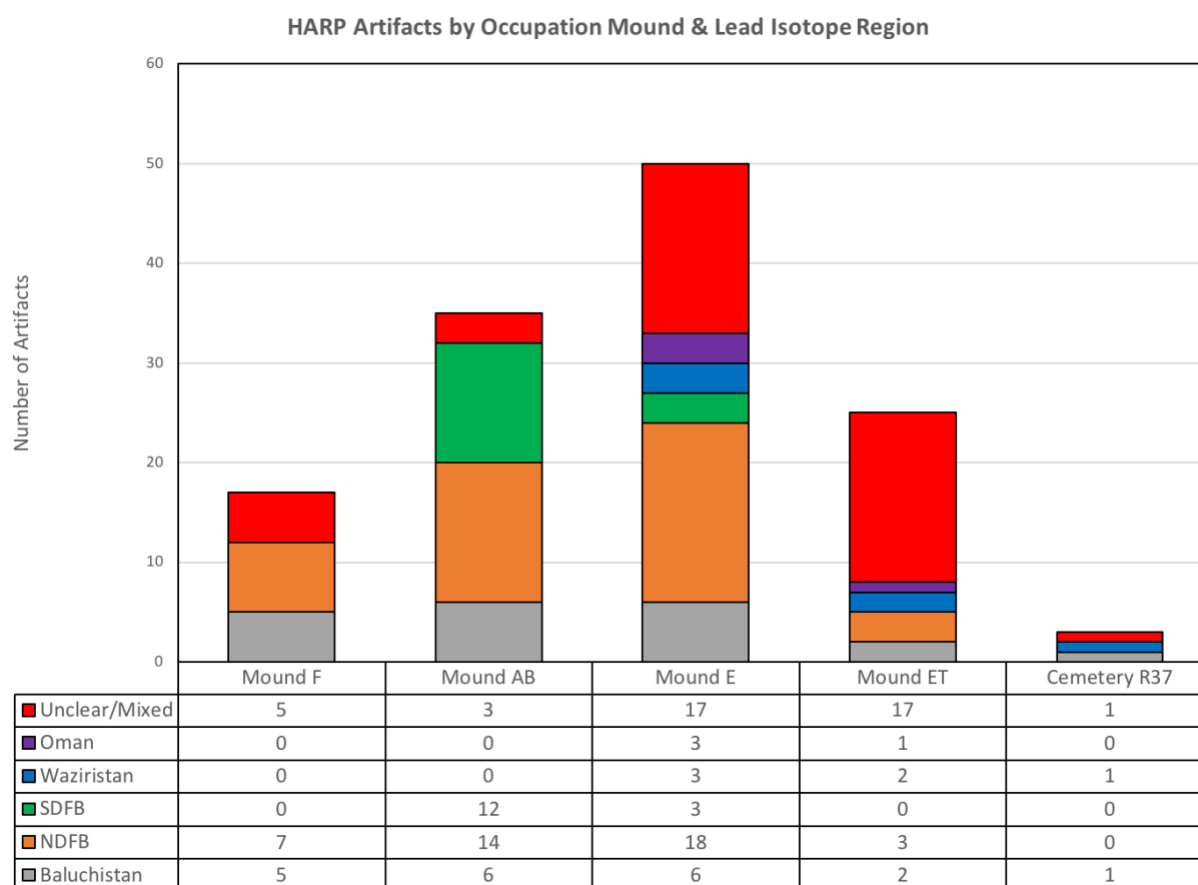
An examination of the suite of available lead isotope source data from the HARP assemblage by artifact category (Figure 6.30) continues the trend outlined for alloy types. All of the artifact categories except discs are fashioned from multiple copper source areas. In the case of copper discs, there is only one object in the sampled assemblage, and it should be expected additional artifacts from this category would demonstrate a similar isotopic diversity. While there is a trend in how alloys are used across different artifact categories (see above this chapter and Chapter 4 for discussion), this has not impacted the type of copper raw material being selected for use during the initial manufacturing steps by Indus copper and bronze metal workers. Looking at the lead isotope source regions by alloy type and artifact class serves to support this interpretation. Although final visual appearance for display artifacts and final functional characteristics for utilitarian items were determinative factors in alloy choice, they do not appear to play a role in raw material selection. Again, we see the ability of Indus craft workers to adapt to a variety of raw material starting points in order to achieve pre-determined end results.

Copper Provenience at Harappa – Occupation Areas

A small degree of variation begins to appear in the HARP assemblage when the isotopic data is grouped by occupation area at the site (Figure 6.31). The most obvious patterning is that only Mounds AB and E have evidence for the South Delhi Fold Belt (SDFB) source region. However, rather than this being indicative of a restricted distribution for copper and bronze artifacts fashioned from SDFB raw material it is most likely that this is related to diachronic patterns in copper supply at Harappa. Excavation areas along the margins of Mound AB and Mound E have been some of the primary sources of material from the Ravi, Kot Diji, and Harappa 3A occupation of the site. It is therefore, not surprising that these mounds would exhibit

a strong correlation with the one source region that may be chronologically restricted (see below for discussion).

Figure 6.31: HARP Artifacts by Occupation Mound and Lead Isotope Region



The only other lead isotope regions that do not appear across all occupation mounds (F, AB, E, and ET) are Oman and Waziristan. These are only present on Mound E, ET, and Cemetery R37. This initially appears to make an argument for the restricted distribution of copper raw material from both Oman and Waziristan with potentially an associative connection between Cemetery R37, Mound E and its extension, Mound ET. However, it is far more likely that this is simply related to sample size at this point. Materials from Waziristan and Oman form such a small component of the overall analyzed Lead Isotope assemblage at the site, that it is best to view their restricted patterning as highly speculative at present. As a result, the pattern of

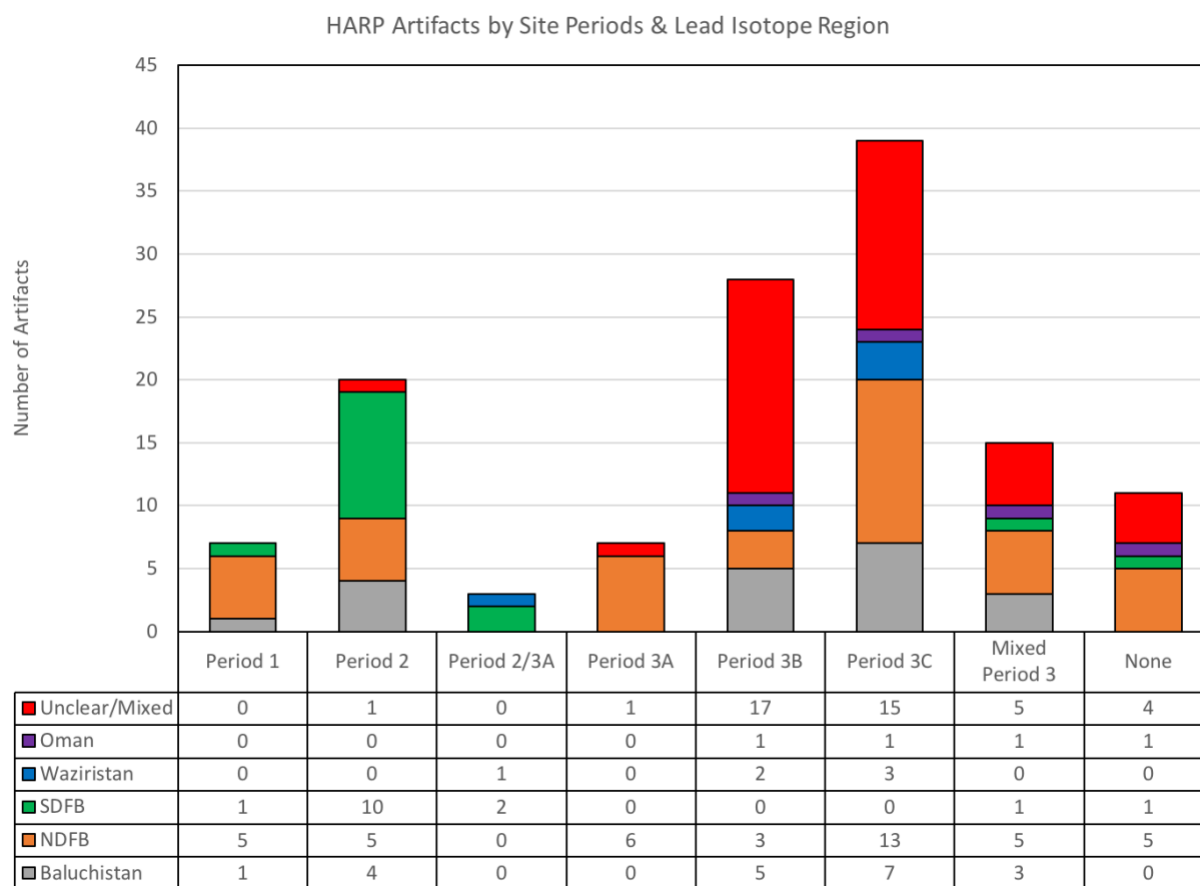
copper source regions by occupation area is the same as the previous analytical lenses and does not appear to identify a restricted or significantly patterned utilization of specific raw material source areas by occupation sector at Harappa.

Copper Provenience at Harappa – Chronological Periods

Looking at the analyzed lead isotope artifacts by chronological period at the site reveals the most significant variation in isotopic regions (Figure 6.32). Two main trends emerge from a diachronic viewpoint. The first is that during the initial periods at the site (Periods 1-2/3A), the analyzed copper and bronze artifacts are predominantly from the Ambaji-Deri source in the South Delhi Fold Belt (SDFB). This supply is supplemented primarily by copper sourced to the North Delhi Fold Belt (NDFB) and Baluchistan. Further, during Period 3, including all sub-periods, Harappa seems to experience a reorientation of copper supply networks. The use of the SDFB source falls off almost completely and is replaced by copper from the Unclear/Mixed isotopic region. Again, this region is most likely representative of the utilization of a copper source or related sources within one of the major ophiolites across Pakistan. The presence of Oman only in Period 3 contexts would appear to fit with chronologies for copper working within Oman (Weeks 2003). It must be noted that the current database of lead isotopes on artifacts on Harappa represents only a small percentage of the overall copper and bronze assemblage from the site and it is entirely possible that any trends seen over time could be the result of sampling rather than representing significant shifts in copper source exploitation during the different chronological periods at the site. However, the overall trend of expansion and reorientation of copper supply networks over time, particularly during the transition from the pre-urban Period 1-2 occupation of the site to the urban period would fit with overall models of Indus economic complexity. During the Harappan Phase (Period 3A-3C, 3, and Mixed), the site would have been

able to access the widest array of trade and exchange networks from the most diverse base of resource areas (Kenoyer 1998, 2014; Law 2011). This trend appears to be reflected in the use of more and new copper sources during the urban periods.

Figure 6.32: HARP Artifacts by Site Periods and Lead Isotope Region



Indus Isotopic Signature and South Asian Copper in Other Regions

During the course of the analysis of lead isotope data generated by this project on artifacts from Harappa and the compilation of comparative geological and artifactual lead isotope databases an unexpected pattern emerged. In a published compilation of lead isotope data points for artifacts from a number of Mesopotamian sites (Begemann and Schmitt-Strecker 2009), there are 13 artifacts from the 3rd millennium BCE that do not correspond with other known sources

of Mesopotamian copper (see Table 6.6). What researchers hypothesized that the unidentified copper source area was comprised of rocks a billion years old or older. This was based on the concept that lead isotopes are the result of the age of the deposit being analyzed (White 2001; Faure and Mensing 2009). Further, the unknown artifacts in the overall Mesopotamian assemblage had the unifying characteristic of exhibiting a lead (Pb) 207/206 isotope ratio of greater than 0.8780 (Begemann and Schmitt-Strecker 2009). Further the researchers suggested that copper deposits across the Aravalli Range may be a potential fit based on initial age models (Begemann and Schmitt-Strecker 2009). However, a robust enough comparative database for copper deposits across the Aravallis was not accessible.

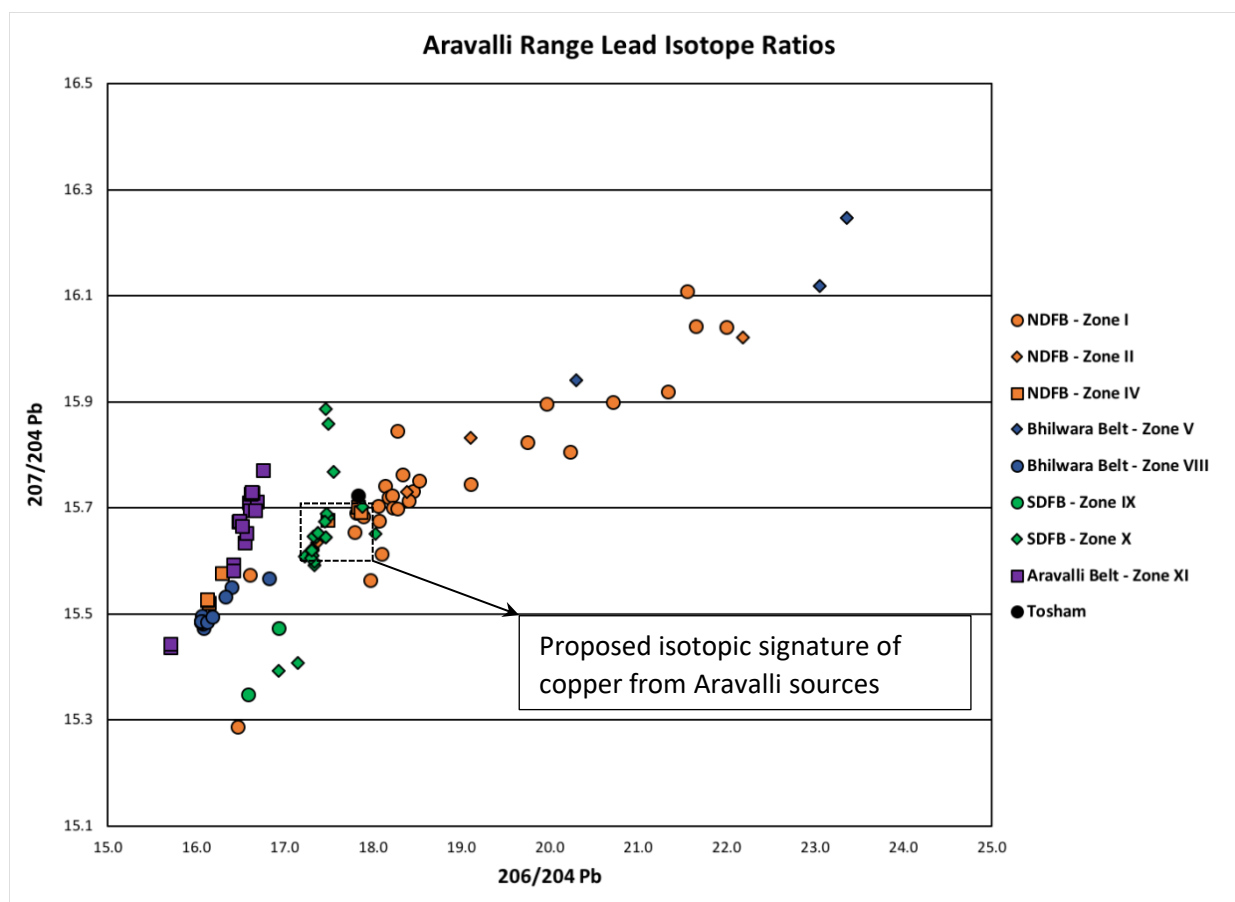
Table 6.6: Copper and Bronze Objects with Indus Signature from Mesopotamia

Site	Period	Material	207/206 Pb Isotope Ratio
Gaura	Jemdet Nasr	Bronze artifact	0.8923
Uruk	Jemdet Nasr	Cu artifact	0.8847
Hafagi	Early Dynastic III	Bronze artifact	0.8797
Ur	Early Dynastic III	Bronze artifact	0.8782
Ur	Early Dynastic III	Bronze artifact	0.8832
Ur	Early Dynastic III	Bronze artifact	0.8847
Ur	Early Dynastic III	Bronze artifact	0.8850
Ur	Early Dynastic III	Bronze artifact	0.8854
Ur	Early Dynastic III	Bronze artifact	0.8918
Ur	Early Dynastic III	Bronze artifact	0.8953
Gaura	Akkadian	Cu artifact	0.8899
Nippur	Akkadian	Bronze artifact	0.8818
Ur	Akkadian	Bronze artifact	0.8850

During the course of this project, a far more robust suite of data points for copper deposits throughout the Aravalli Range has been developed. This database consists of previously published results and the ongoing research conducted by Dr. R.W. Law and his collaborators

(see above for discussion and details). Looking at the lead isotope data from sources within the Aravallis (Table 6.2), the lead (Pb) 207/206 ratio of greater than 0.8780 can be identified in a number of data points. The proposed isotopic signature for copper from the Aravalli Range (Figure 6.33) encompasses the samples from the South Delhi Fold Belt (SDFB) and portions of the available data for the North Delhi Fold Belt (NDFB) essentially demarcating the southwestern and northeastern extremes of the Aravalli Range deposits (Figure 6.19). Overall, the available lead isotope data for copper sources in the Aravallis aligned with the hypothesis that some Mesopotamian copper and bronze artifacts were made with raw material from old deposits within South Asia.

Figure 6.33: Aravalli Range Lead Isotope Ratios and “Indus Signature”



A review of the lead isotope datasets compiled during this project identified 13 artifacts from Mesopotamia (Table 6.6), 18 artifacts from Harappa, and 11 artifacts from Dholavira (Bisht et al 2015) that exhibited the appropriate isotopic signature (Figure 6.34). All but two of the artifacts, a copper object from the Jemdet Nasar Period at Uruk and a round copper rod from a mixed Harappan Phase context on Mound AB at Harappa, plotted within the boundaries of a proposed Aravalli Range or Indus isotopic signature. A combination of isotopic signatures from copper mineral deposits and artifacts from Harappa and Dholavira plot with the isotopic signatures of the 13 artifacts from Mesopotamia. The correspondence of copper ores and Indus artifacts furthers the idea that the unknown copper and bronze artifacts originally identified by Begemann and Schmitt-Strecker (2009) are manufactured from raw material originating in South Asia, specifically the Aravalli Range.

Figure 6.34: Artifacts Exhibiting “Indus Signature”

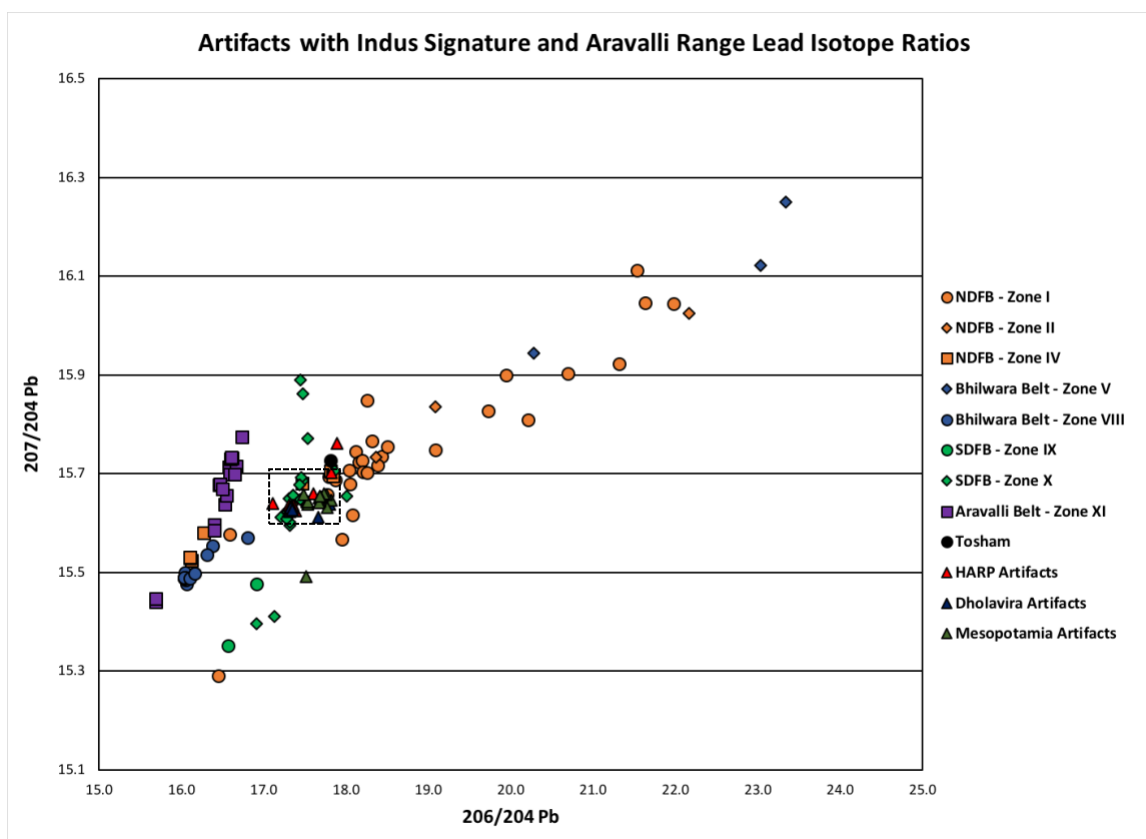


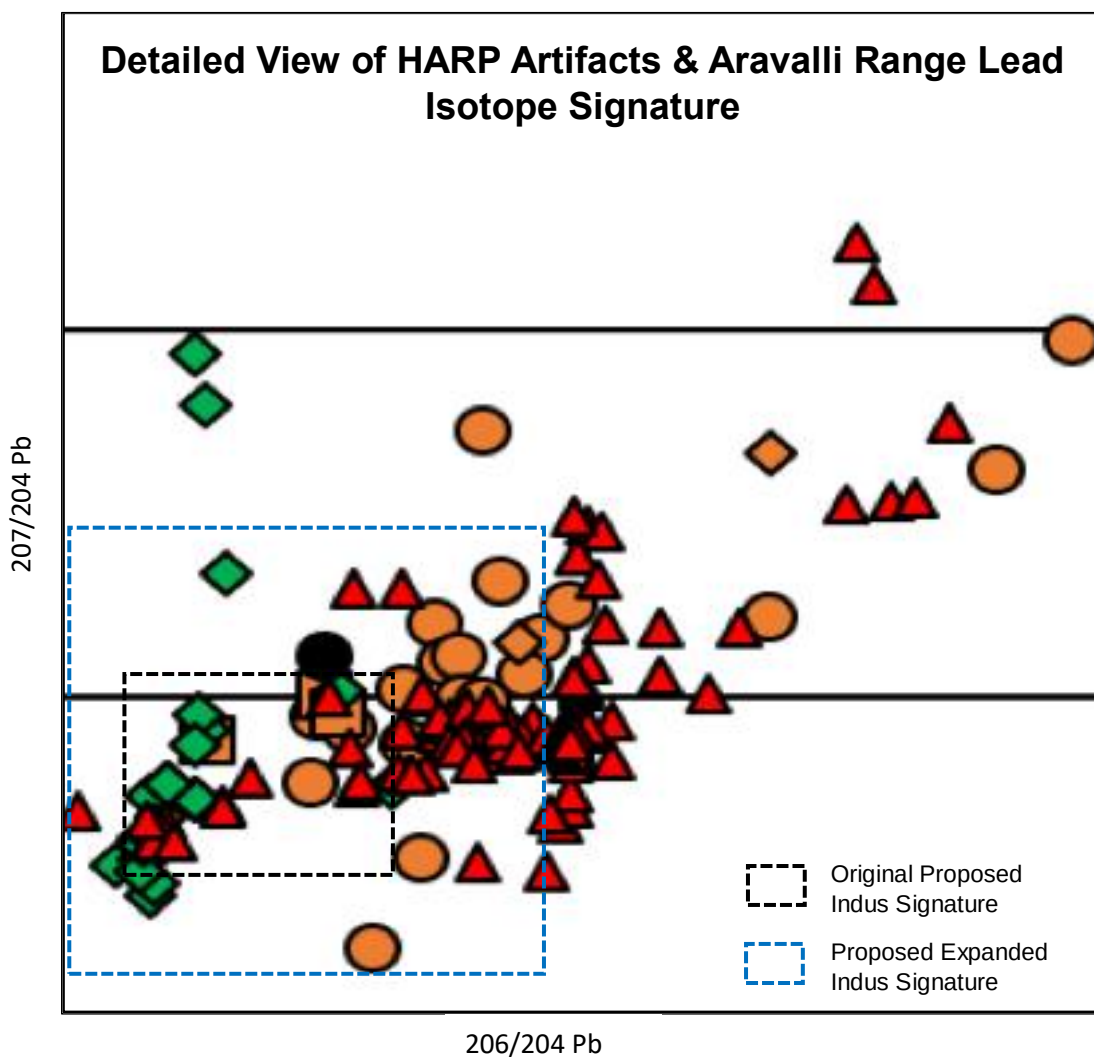
Figure 6.35 shows a plot of Aravalli Range lead isotope signatures from copper sources in the North Delhi Fold Belt (NDFB) and the South Delhi Fold Belt (SDFB) compared to the full set of analyzed artifacts from Harappa. The smaller dashed box demarcates the rough outlines of an Indus isotopic signature defined by a lead 207/206 ratio of greater or equal to 0.878. The larger dashed box approximates a revised and expanded Indus isotopic signature defined by a lead 207/206 isotopic ratio of greater than or equal to 0.850. This is based on the isotopic correlation of artifacts from Harappa with copper deposits in the NDFB. However, much of the current data for the NDFB is preliminary and research is still ongoing. At present, any expansion of the Indus signature beyond the original lead 207/206 0.878 boundary is tentative and must be evaluated against additional lead isotope data for deposits in the North Delhi Fold belt, specifically those of Khetri and Kho-Dariba.

Even when using the more narrowly defined Indus signature, copper sourced to South Asia, specifically the Aravalli Range deposits appears in a number of copper and bronze artifact assemblages. The Indus signature appears in Mesopotamian sites (Begemann and Schmitt-Strecker 2009), tomb sites in the United Arab Emirates (Weeks 2003) and may be present at Troy and other Anatolian sites (Pernicka et al 1984; Stos-Gale et al. 1984; Begemann et al. 2008). Intriguingly, the Indus signature is absent from artifact assemblages from Oman, Bahrain, Yemen, or Iran (Begemann et al. 2008; Weeks et al. 2009; Begemann et al. 2010).

Based on the lead isotope data from Harappa and published datasets from adjacent regions, the Indus appears to be exporting far more copper raw material and/or finished copper and bronze items than it is importing from locations outside of South Asia. In order to further extend and amplify this interpretation, additional lead isotope data from other Indus Tradition sites is necessary. The initial results from Dholavira (Bisht et al. 2015) align with the hypothesis

that Indus Tradition sites acquired copper raw material and finished copper and bronze items from locations within South Asia predominantly. Overall the utilization of “local” resources over “non-local” aligns with a generalized pattern across the larger region during the 3rd millennium BCE. When possible, sites appear to be primarily using copper material from local sources. This trend appears in Oman, Yemen, Iran, and Bahrain. It is now possible to identify this trend of localized exploitation of copper sources at Harappa and, therefore, propose its extension to the Indus Tradition overall. In a very real sense, Mesopotamia’s total reliance on copper from sources outside the local region is seemingly increasingly unique across the Bronze Age world of South and Southwest Asia during the 3rd millennium BCE. Further, the appropriateness of models of restricted consumption and distribution of copper base metallurgy for areas outside of Mesopotamia may need to be seriously questioned. If Indus cities like Harappa are able to obtain copper raw materials from multiple sources within South Asia simultaneously, then copper and bronze items may have likely been widely and readily available. However, the available isotopic and archaeological datasets need to be more robustly developed and final confirmation of these types of ideas awaits additional analytical data.

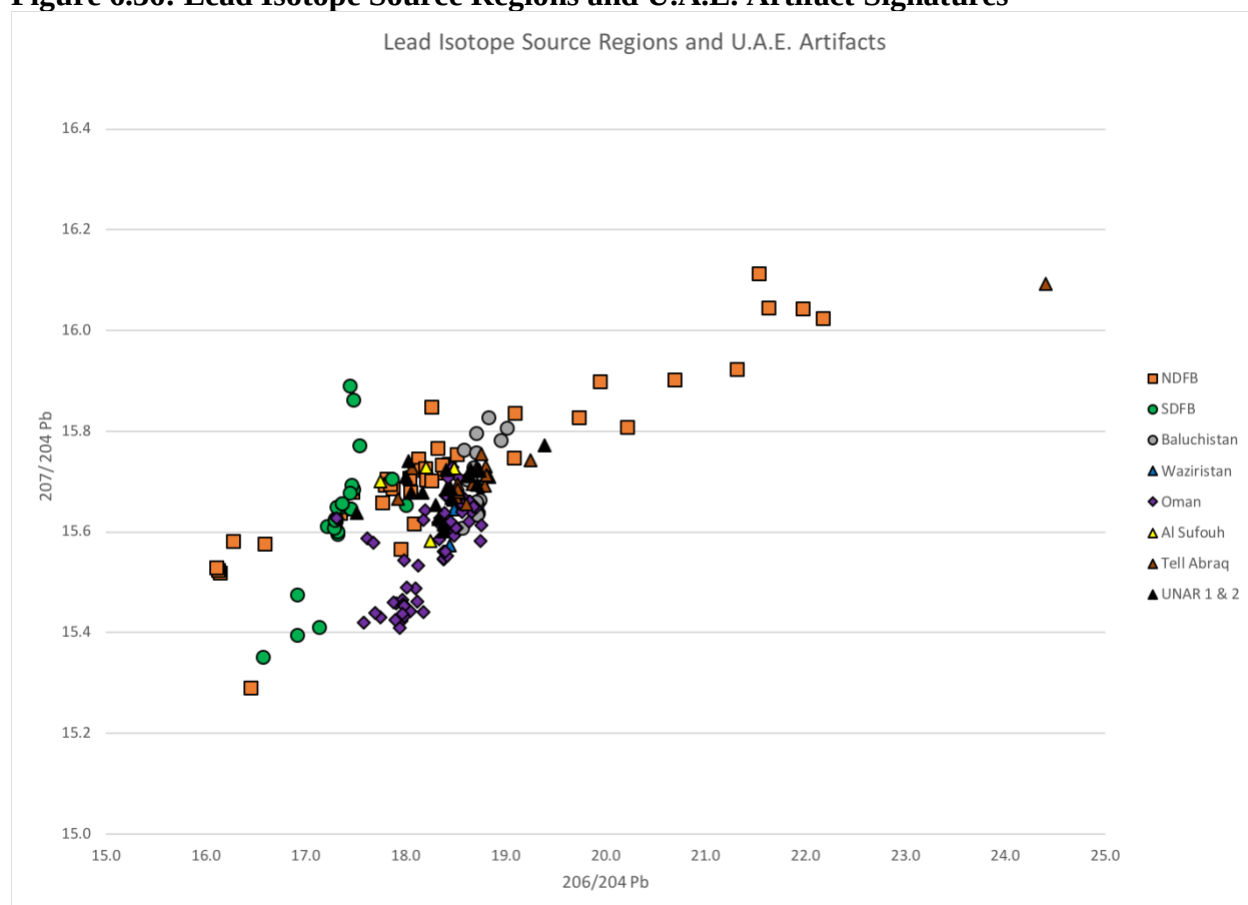
Figure 6.35: HARP Artifacts and “Indus Signature” (Detail)



The results of a series of analysis from copper and bronze artifacts from tombs in the U.A.E provides a counterpoint to the discussion of localized copper resource exploitation. The apparent isotopic correspondence between a number of the U.A.E. tomb artifacts and both artifacts from Indus and copper sources within South Asia has been briefly outlined previously. Figure 6.36 shows the artifacts from the three tomb sites in the U.A.E. compared to the lead isotope regions. Three significant interpretations can be drawn from this graph. The first is that several of the U.A.E. artifacts correspond with ores from Oman. Due to the short distance

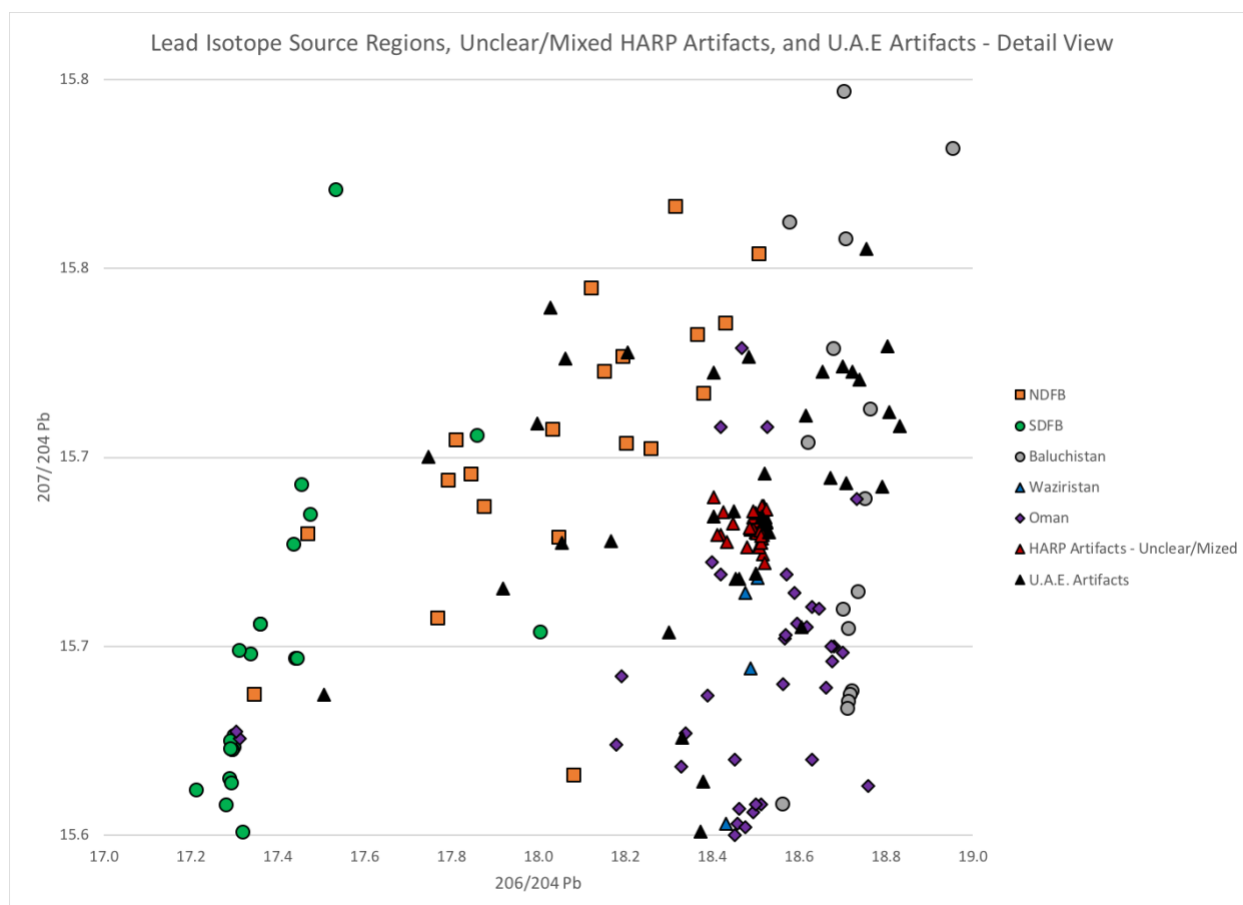
between these sources and the tomb sites, this is not unexpected nor surprising and has been previously discussed by the original investigator (Weeks 2003). What was not expected is the strong correspondence of 3 artifacts with the restricted Indus isotopic signature and an additional 7 artifacts that would correspond with an expanded Indus isotopic signature. Further, 12 artifacts correspond with the Baluchistan source region, and 5 artifacts correspond with the “unclear” source (see Figure 6.37). Overall, 27 of the 42 (64.29%) analyzed artifacts from U.A.E. tomb contexts appear to have a stronger correlation with sources within South Asia than Oman. It is highly likely that the majority of the analyzed objects are fashioned from copper sourced to Baluchistan and the Aravalli Range rather than deposits from Oman.

Figure 6.36: Lead Isotope Source Regions and U.A.E. Artifact Signatures



It should not be viewed as unexpected that copper from South Asian sources shows up in tomb sites in the U.A.E. as extensive interactions between the two regions during the 3rd millennium is well documented (Potts 1990; Edens 1992; Glassner 1996; Crawford 1998; Kenoyer 1998, 2014; Ratnagar 2004; Weeks 2003; Possehl 2007; Cleuziou and Tosi 2007; Laursen 2010; Law 2011; Thornton 2013; Weeks 2014; Frenez 2016). However, that copper sourced to South Asia and therefore the Indus Tradition was the dominant component of the assemblages was somewhat surprising. At present, the best explanation is related to the specific archaeological context the material was recovered from; tombs. It is entirely possible that this assemblage represents a skewed sample of copper and bronzes that were intentional selected for inclusion in funerary deposits because they were of non-local manufacture. The mobilization of items fashioned from non-local raw materials for signaling status is well documented in the anthropological record (Helms 1993) and was a significant part of Indus craft production (Kenoyer 1998; Vidale and Miller 2000). While the pieces sampled by Weeks (2004) are too fragmentary to identify, it is possible (perhaps even probable) that they represent artifacts that were specifically selected and valued because of their associations with non-local centers. Hopefully future research projects develop lead isotope signatures for objects from non-funerary contexts which would provide a critical contrasting dataset to test they hypothesis that Umm al-Nar period tombs were selectively targeting copper and bronze from South Asia for interment.

Figure 6.37: HARP Artifacts, U.A.E. Artifacts, and Lead Isotope Source Region Signatures (Detail)



Summary

The results of the compositional and isotopic analyses on copper and bronze artifacts from Harappa provides fresh insight into the alloying patterns and source provenience for copper and bronze metallurgy at the site during the Regionalization and Integration Era occupations. A revised model for copper alloying practices, raw material procurement and processing, production, and distribution of copper and bronze artifacts can be constructed utilizing analytical data derived from leading techniques. For the first time, copper/bronze metallurgy at a major Indus Tradition urban center can be placed on the same footing as other contemporary copper and bronze producing and consuming civilizations across South, Southwest Asia, and the Gulf

regions. The implications for the model of copper/bronze metallurgy for both an understanding of this important craft technology for Indus Tradition itself, how it fits into a comparative framework for other 3rd millennium BCE contexts, as well as future directions is undertaken in the final chapter.

Chapter 7: Copper and Bronze Metallurgy at Harappa: Summary and Conclusions

The combined compositional and isotopic dataset from Harappa represents the largest analytical investigation into Indus copper and bronze metallurgy since the initial research at Mohenjo-Daro and Harappa by the Archaeological Survey of India (Marhsall 1931; Mackay 1938; Vats 1940). It is also one of the most detailed and extensive analytical research programs on any Bronze Age site that the author is currently aware of, although research conducted at a variety of Mesopotamian sites (see Begemann and Schmitt-Strecker 2009), a combination of sites in Oman (see Weeks 2003 and Begemann et al. 2010), and research from the Faynan area in Jordan (see Hauptmann 2007) have similar broad and robust analytical data sets for copper and bronze. While more data and additional analyses are always desirable, the present dataset from Harappa allows for the major project research questions to be adequately addressed. A review of each research question posed in Chapter 1, the linkages with past research trends outlined in Chapter 2, and the analytical conclusions detailed in Chapter 6 serve to provide the best available answers to the questions based on present data from Harappa.

Research Question 1: What is the nature and distribution of the copper and bronze metal assemblage from Periods 1-3 of the cultural sequence at the Indus Tradition site of Harappa?

The first step in developing an answer to this research question was to define a series of terms, specifically what was meant by copper and bronze. This was done through examining the available literature from both archaeology and geology to identify minimum percentage levels of the key alloying elements (tin, arsenic, and lead) that are most likely to represent intentional addition and not incomplete separation of copper and accessory minerals during ore processing and smelting (Chapter 2 for details). Undertaking this process accomplished two goals. The first is that it reset the benchmarks for identifying copper and coppery alloys in Indus assemblages

and the second was that it provided concrete parameters for identifying bronzes within the analyzed HARP assemblage. With these parameters established, it was possible to identify copper alloys and plot their distribution across time, space, and artifact categories at Harappa.

Table 7.1: Chronology for Harappa

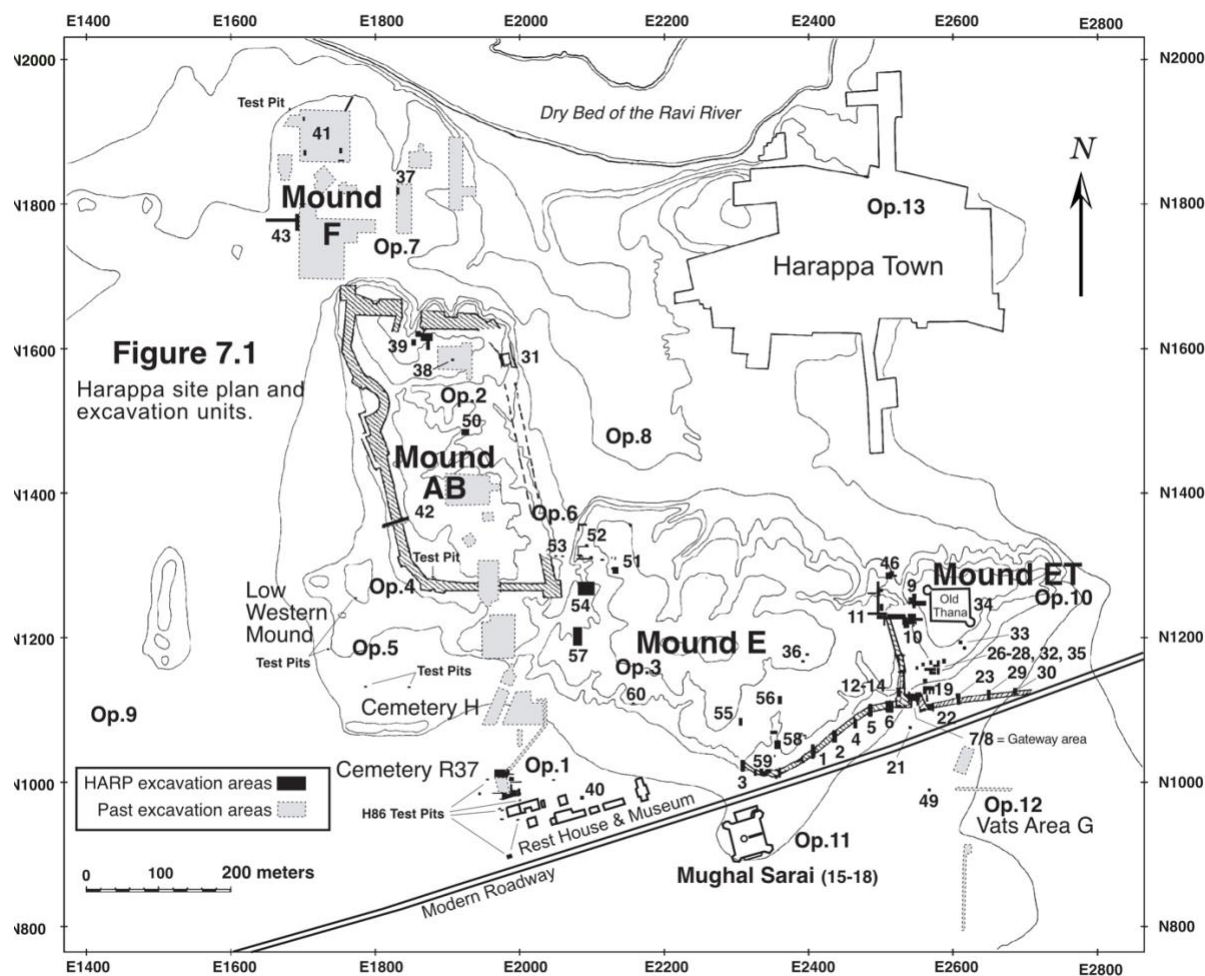
(Kenoyer 1998; Meadow and Kenoyer 2005; Meadow and Kenoyer 2008; Kenoyer 2014; Kenoyer 2015)

Regionalization Era		c.5500 – 2600 BCE
	Early Harappan	
	Period 1 – Ravi Phase	3300 – 2800 BCE
	(aspect of the Hakra Phase)	
	Period 2 – Kot Diji Phase	2800 – 2600 BCE
Integration Era		2600 – 1900 BCE
	Period 3A – Harappa Phase A	2600 – 2450 BCE
	Period 3B – Harappa Phase B	2450 – 2200 BCE
	Period 3C – Harappa Phase C	2200 – 1900 BCE
Localization Era		1900 – 1300 BCE
	Period 4 – Harappa/Late	1900 – 1800 BCE
	Harappa Transition Phase	
	Period 5 – Late Harappa	1800 – 1300 BCE
	Phase	

During the Ravi, Kot Diji, and Harappan Phases at Harappa (Table 7.1), the distribution of the copper and bronze assemblage is fairly consistent. During the initial Ravi occupation, there is evidence for both the consumption of a variety of copper and copper alloys as well as some small-scale production on Mound AB (Figure 7.1). During the subsequent Kot Diji Phase, the use of copper expands with the size and extent of the site and by the Harappan Phase (Period 3A-3C) there is evidence for copper and bronze consumption at all areas of the site (Hoffman and Miller 2014) as well as the evidence for at least one workshop (Miller 1999; Kenoyer and

Miller 1999) with a detailed examination of the distribution of prills, slags, and technical ceramics indicating the potential for at least one copper workshop for each major occupation mound and potentially more than one for Mounds AB and E. Overall, the evidence from the HARP excavations outline a pattern of copper and bronze metal use that is consistent throughout Periods 1-3 at Harappa. During each cultural period, copper and bronze are prevalent at the site and there is consistent evidence for crucible-based smelting and melting at the site with the presence of furnace-based smelting during the Harappan Phase.

Figure 7.1: Harappa Site Plan and HARP Excavations



Research Question 2: What are the alloying practices in use at Harappa from 3300-1900 BCE? Do the alloying practices that can be empirically identified demonstrate a consistent pattern by artifact category/class?

Over the same period of time and across the occupation areas of the site, the identified alloying practices remain relatively stable and consistent. A total of three types of bronze, four distinct multi-element copper alloys, and unalloyed copper were used by Harappan copper/bronze metalworkers. Of the identified alloys at Harappa, each is distributed across all spatial and temporal units at the site.

At first, there appears to be little to no patterning to the alloy practices at Harappa. A more detailed examination demonstrates that there are consistent alloying patterns when the final function of the artifact is taken in to account. Copper-smiths at Harappa were employing different manufacturing practices for different types of metallurgical products. Objects that would have played a role in signaling status and membership in social groups were fashioned from specific copper alloys. The use of unalloyed copper, tin bronze, arsenical bronze, and leaded bronze to make bangles, rings, beads, and discs would have created a scenario where producers and consumers could have selected morphologically similar objects with a variety of color differences in final appearance. The presence of multiple alloying patterns for copper and bronze objects of personal ornamentation at Harappa, points towards complex patterns of consumption and use that played a role in social hierarchies during the Indus period. It is known from research on other objects of personal ornamentation (Kenoyer 1997, 1998, 2000, 2014) that similar objects with different visual appearances often were used to indicate the placement of the wearer within status and wealth hierarchies. The specific nature of how different alloys would have articulated with the social order at Harappa between 3300-1900 BCE will require additional research to fully understand. A preliminary hypothesis is that tin-bronze would have held a prime

position due to its ability to be polished to a golden hue, as gold and gold wrapped beads are documented at Harappa and other Indus sites.

In contrast, items that would have been used in a more utilitarian manner were made from a generalized group of copper alloys. This pattern is best explained by understanding that for these items the final appearance was unimportant. Artifacts that display this alloying pattern would have been used as tools to accomplish a specific task. As a result, they would have needed certain final physical properties such as durability, hardness, ability to maintain a keen edge, or the ability to be shaped a certain way during manufacture. For these reasons, the metalsmith can be less precise and exacting in alloy selection. Arsenical bronze and tin bronze and leaded bronze may each provide an acceptable final product because they would have provided equivalent final physical properties. Alternatively, a mixture of all of these as a general “bronze” could provide acceptable performance as well. While copper and copper alloy tools were used to create a variety of items that served important roles in economic, social, and political spheres at Harappa, the tools themselves were not functioning in this manner. As a result, the alloys they were constructed from exhibit far broader trends than those found in decorative objects.

A final note should be offered. Looking at source provenience designations and potential manufacturing processes reveals that the patterns seen in alloying practices at the site are not causally linked to copper raw material sources. Similar final objects were made with different starting raw materials. Additionally, rods (tools) and bangles (decorative) that would have been manufactured along similar lines display differing alloying patterns. Further, copper prills that are potential proxy markers for the production of finished objects at the site exhibit examples of all of the major identified bronze and alloy types, which would indicate that many of the copper/bronze objects consumed at Harappa were made there as well.

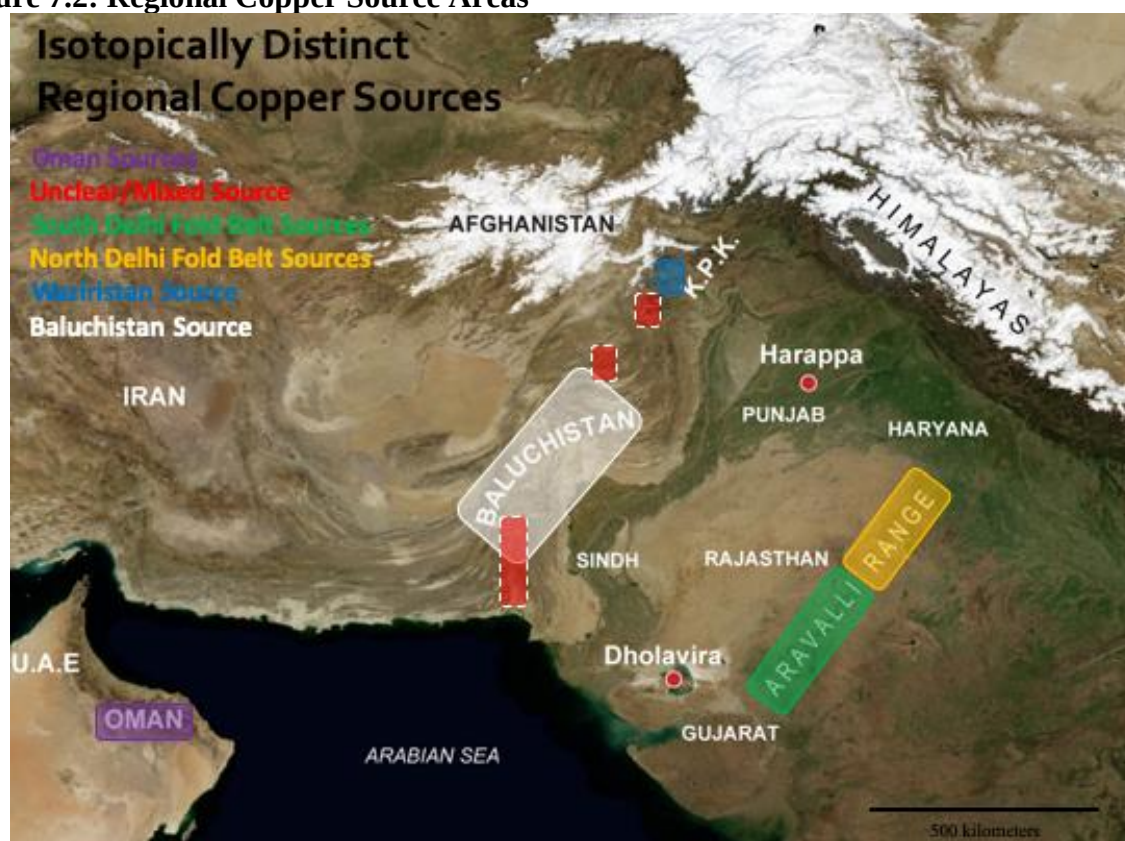
Table 7.2: Copper and Copper Alloys Identified at Harappa

Alloy Type	Designation
Copper (Cu)	Unalloyed Metal
Copper-Arsenic (Cu-As)	(Arsenical) Bronze
Copper-Lead (Cu-Pb)	(Leaded) Bronze
Copper-Tin (Cu-Sn)	(Tin) Bronze
Copper-Tin-Lead (Cu-Sn-Pb)	Alloy
Copper-Tin-Arsenic (Cu-Sn-As)	Alloy
Copper-Lead-Arsenic (Cu-Pb-As) & Copper-Arsenic-Lead (Cu-As-Pb)	Alloy
Copper-Tin-Lead-Arsenic (Cu-Sn-Pb-As)	Alloy
Copper-Silver-Gold-Lead (Cu-Ag-Au-Pb)	Alloy

Research Question 3: Does the development and expansion of copper interaction networks follow the pattern identified for lithic raw materials?

Since potential copper sources are located in many of the same regions previously identified as source locations for other rocks and minerals at Harappa (Law 2011; Chapter 1 this work) it was expected that copper sources would follow a similar pattern. Specifically, that during the early periods at the site (Period 1 and 2) copper sources from the north and west would function as the primary sources of raw material. During the subsequent Harappan Phase, these sources would continue but additional sources to the south would be incorporated into an increasingly robust network of copper supply. In fact, the pattern of copper source utilization seen in the lead isotope data from the HARP sample assemblage is the inverse of this expectation. During the Harappan Phase, the copper supply network at the site is predominantly focused on sources to the south of the site in the Aravalli Range region, specifically the North Delhi Fold Belt (NDFB).

Figure 7.2: Regional Copper Source Areas



The only potential pattern identified in raw material sources at Harappa is the possibility that over time, acquisition networks shifted away from copper sources in the South Delhi Fold Belt (SDFB), centered on the Ambaji-Deri locale, to an as of yet identified source in the ophiolitic zone of Baluchistan. At the same time sources in the North Delhi Fold Belt (NDFB) and the Chagai Hills region of Baluchistan continued to be utilized (Figure 7.2). This result was unexpected and is not presently understood. Additional research on copper and bronze objects from Harappa dating to the Ravi and Kot Diji periods recovered from the site is needed to further determine the validity of this initial trend. Additionally, work at other Indus Tradition sites from similar periods is needed to determine what copper supply networks they were linked to. It is possible factors not identified in this research were governing the interaction networks that each

major Indus center was participating in. Perhaps as regional demand for copper and bronze increased over the development and extension of the Indus Tradition, sites were forced to reorient their supply networks in order to meet their demands. Investigating what other Indus sites were also exploiting sources in the SDFB and when that use was taking place will be a critical direction of future research for copper source provenience studies. At present, it appears that copper supply networks at Harappa did not follow the exact same pattern as identified in stone and mineral raw materials. While it is possible that in some instances existing interaction networks were expanded to also bring copper raw materials and semi-processed raw materials to the site, the data show that new interaction networks were forged to ensure a secure supply of these desired items.

Research Question 4: Does copper exhibit a pattern of similar access to raw materials and artifacts on all major mounds?

Turning to the source of the copper raw material used to manufacture individual copper and bronze artifacts at Harappa a pattern related to the unrestricted alloying patterns and metal consumption can be identified. All of the major source regions that can be identified isotopically are evenly distributed among the artifact classes and the occupation areas at Harappa. This buttresses the conceptualization that Harappan copper and bronze producers were adaptable and proficient at manipulating a number of raw material source starting points to achieve the desired final end result. There was no consistent linkage identified between alloying patterns and raw material source. As was the case for the majority of other stone and mineral resources (Law 2011) there is a pattern of generalized access for both copper sources as well as copper and copper alloy artifacts for each occupation mound at Harappa (Figure 7.1).

As has been previously discussed, the lack of the restriction of access to either raw materials or finished objects is indicative of copper/bronze metallurgy not being a directly elite controlled craft industry at Harappa. The patterning seen in alloy usage does demonstrate that some components of the overall copper/bronze assemblage (decorative items) could have played an important role in status and wealth hierarchies at the site during the Regionalization and Integration eras. The production of similar ornaments in multiple visually distinct appearances through the selection of specific alloys during production would have created a range of copper and bronze status goods that could have been mobilized into existing wealth hierarchies (Kenoyer 1992a, 1992b, 2000). However, this focuses on the use of specific object categories and alloy types and does not appear to reflect interference in the availability of the objects themselves or access to the raw materials needed to produce them. Further, the evidence for production is distributed across the site (see Chapter 3) and replicates a pattern of multiple workshop locations on each mounded area that is exhibited in other craft industries. Each of these workshops would have had equivalent access to raw materials and would have been producing broadly similar final objects without artificial limitation or restriction. Copper and bronze production was indirectly controlled because of its locations within the walled area of the city but was not directly controlled in the same manner as seal production (Kenoyer 2000; Jamison 2017).

Summary and Future Directions

The model for copper and bronze metallurgy for Harappa that emerges from the isotopic and compositional data is a multi-faceted one. The first facet is that all areas of the site during all major cultural periods that there is data for (the project has no data for the Late Harappan Phase

occupation) demonstrate a consistent pattern of unrestricted access to artifact classes, alloy types, and raw material sources. The second is that there is a two-fold division in copper alloy usage at the site. Items that require a specific final visual appearance employ specific alloy types while objects that require a specific functional attribute utilize a wider range of equivalent alloy types. The third is that copper interaction networks demonstrate a similar but not identical pattern to those identified for rocks and minerals. The similarity lies in the fact that, just as with rocks and minerals, the residents of Harappa were obtaining similar raw materials from multiple source locations at the same time. Where the two differ is that the regions being exploited during each cultural phase are not strictly identical. So, while it remains possible that copper interaction networks were built on the backs of existing rock and mineral trade routes and inter-regional connections it cannot be definitively determined at present. The current data indicates that while copper and rock and mineral interaction networks were operating along similar lines initially, copper interaction networks branched out along independent lines as they developed and elaborated during the Regionalization and Integration eras.

Harappa exhibits a complex but typically “Indus style” copper-bronze metallurgical tradition. Meaning that the focus of the tradition appears to be the manipulation of raw materials through a variety of alloying and manufacturing techniques to achieve a multitude of final results. These varying results, particularly with items of personal ornamentation, would have almost certainly been used to reinforce status and wealth hierarchies just as with other craft products (Kenoyer 1998, 2000, 2014; Vidale and Miller 2000). Further, residents at Harappa integrated themselves into multiple overlapping and simultaneous copper supply networks in order to secure a reliable input of copper and bronze raw materials to the site. As a result, copper and bronze objects were common items in the overall artifact assemblage at Harappa. In general,

Harappa exhibits a distinct copper and bronze metallurgical tradition in comparison to many of the contemporary sites in surrounding regions. Copper and bronze materials, while clearly involved in status and wealth displays at Harappa, were not restricted to a small elite class. The metal was common enough that a diverse array of products was fashioned from it, often in different alloys, and distributed evenly across occupation areas. This even distribution and the potential presence of multiple workshops at the site with seemingly equivalent access to all raw material types leads to the interpretation that there were not significant amounts of elite control exercised over copper and bronze metallurgical consumption or production. Again, this is not the case for other regions where copper and bronze acquisition, production, and consumption were highly regulated by either individual elites or elite groups. The model for Indus copper and bronze metallurgy that can be constructed from the Harappa data now needs to be extended to other Indus sites. Once suites of isotopic and compositional data are developed, the model can be tested and revised to develop a more precise picture of the copper and bronze metallurgy of the Indus Tradition. Specifically, the individual patterns identified and described for Harappa can be directly compared to the patterns identified in other Indus Tradition sites. While that process is underway, the presently available data support the reconstruction of the copper and bronze metallurgical tradition for the Indus, at least at Harappa, as being oriented along different lines than those of Mesopotamia, Iran, and Oman. Unlike those neighboring regions where copper and bronze supply is often dependent on outside supply (Weeks 2003; Hauptman 2007; Thornton 2013, 2014), the Indus is focused on copper source areas within South Asia and little metal from external regions is showing up at sites like Harappa. Further, while the presence of two production modes (visual appearance and physical properties) may have some limited parallels in the Gulf region (Weeks 2003), it does not appear to be the fundamental feature in other regions

that it does at Harappa. Finally, the amount of copper and bronze consumed at Harappa and other Indus sites is of a greater amount than other regions (Hoffman and Miller 2014; Kenoyer and Miller 1999; Weeks 2003; Thornton 2007, 2013).

The evaluation of the compositional and lead isotope data from the HARP copper and bronze assemblage has provided a data centered foundation to construct a model of copper/bronze metallurgy at Harappa during the first 3 periods at the site (3300-1900 BCE). This model allows for answers for each of the major project research questions to be advanced. The project had the ambitious goal of developing a model for Indus Tradition copper and bronze metallurgy that revised aspects of traditional interpretations, incorporated some previously held ideas, and proposed new components based on fresh analytical data sets. The results enable a model for copper and bronze to be set forth that addresses all major steps in the process, from raw materials, to processing, to production, to usage, and recycling. Overall, a relatively unique sequence and pattern for the Indus Tradition copper and bronze metallurgical tradition emerges from the data. Copper supply is almost entirely filled from sources within South Asia, unlike the import focused supply networks of many comparable 3rd millennium BCE copper using societies. The processing of copper raw materials, both ore and ingots, appears to be taking place, even in large urban centers, through a combination of furnace and crucible smelting. The resulting copper and bronze objects are evenly and broadly distributed across the site, representing an unrestricted access to all categories and alloy types by residents of Harappa. This is not a common scenario for Bronze Age cultures. Often access to specific alloy types or artifact classes is heavily restricted and these items appear only in highly specific contexts, such as funerary assemblages. Further, metalworkers at Harappa were highly adept at manipulating copper alloys to achieve either specific final visual appearances through the application of

specific alloys, or functional purposes through the use of multiple equivalent alloy patterns. This aligns with other Indus crafts where the detailed and multi-faceted manipulation of different raw material sources is a distinguishing feature. All of this allows for a revised formulation of copper and bronze metallurgy at Harappa. This model can be tested at other Indus Tradition sites. This provides the first baseline set of data driven expectations for the Indus Tradition using updated perspectives that other researchers can compare their data with. This is a critical initial step towards filling in the gaps in the understanding of Indus copper and bronze metallurgy.

In addition to identifying a number of source regions within the assemblage from Harappa, the lead isotope analyses indicate the existence an “Indus signature” in the lead isotope data sets from a number of other copper and bronze consumers in adjacent regions. Intriguingly, copper and bronze artifacts manufactured from sources outside of South Asia are uncommon in the assemblage analyzed to date (approximately 3%). Couple this with the emerging data from across the Aravalli Range that during the 3rd millennium BCE local tin sources were being mined and processed, and the unexpected possibility that the Indus Tradition was able to fulfill its own copper ore and alloying mineral supply needs from sources within or directly adjacent to its own borders emerges as a potential explanation. Further, Indus traders were able to divert some of this supply to external markets either as semi-processed raw materials or as finished goods. This preliminary hypothesis requires further testing and is one of several future directions the current project points towards. The extension and refinement of the comparative lead isotope database for copper deposits in the Aravalli Range, particularly those in the northeast portion, is one important future direction that can assist in refining and testing the interpretations that have emerged from this project. Additionally, more isotopic testing of copper ores from the ophiolitic deposits across Pakistan is needed. It is possible that the “unclear/mixed” signature in the

assemblage from Harappa is correlated to one of these sources and does not represent source mixing, but rather the significant utilization of a single copper locale. The issue of source mixing is always a significant one for any lead isotope project dealing with human-made objects.

Unfortunately, there has been little experimental or analytical research on what the mixing of copper raw materials in antiquity would have looked like. Initial steps in this process have been taken by Dr. J.M. Kenoyer (Kenoyer personal communication) and a preliminary set of isotopic signatures for mixed source copper smelting have been produced. The results indicate that identifying source mixing in antiquity will be a complex process, requiring detailed knowledge of localized ore geology (particularly lead content), smelting techniques, and the application of experimental archaeology to approximate the ancient results. Work along these lines is ongoing and should help to contextualize the understanding of Indus Tradition copper source usage.

Finally, work is underway to compare the destructive sampling techniques for acquiring lead isotopes used in this project to the results for the non-destructive EDTA methodology used by Law (2011). Initial results are promising, and comparative lead isotope analyses are ongoing. It is hoped that the use of EDTA to get lead isotopes into solution along with a more robustly calibrated PXRF methodology could lead to the minimally destructive sampling of copper and bronze archaeological materials for both composition-based analysis and source provenience studies. Such a methodology would allow for the rapid increase in comparative samples across the Indus Tradition and other regions because analysis would no longer be restricted to destructive methods.

Another crucial avenue for future research is to conduct a detailed metallographic study on artifacts from Harappa in order to empirically assess the linkages between production techniques, alloy choice, and raw material type. Currently it is hypothesized that Harappan metal

producers would have been able to progress from any raw material to a variety of finished objects and alloys through proficiency in a variety of production techniques and alloying practices. However, detailed metallographic studies would allow for this hypothesis to be directly tested, rather than inferred from the current data set.

Future research may result in the revision or even rejection of the explanations provided here but deriving those explanations from analytical data using up-dated methodologies and perspectives is a necessary step in moving the study of Indus copper and bronze metallurgy beyond the repetition of hypotheses derived from the initial investigations at Mohenjo-Daro and Harappa. Further, the application of the approaches in this project begins the process of aligning Indus archaeometallurgy with the methods, theories, and perspectives that other scholars are applying with success in other regions. The continued research on the compositional and isotopic characteristics of copper and bronze artifacts from other Indus sites, such as Dholavira, Farmana, Kuntasi, and Rakhigarhi, will allow for the model from Harappa to be tested at other Indus sites. It is important to assess if one copper and bronze metallurgical tradition and pattern was in operation across the entire massive geographic extent of the Indus Tradition or if multiple regional patterns may have been in contemporary operation.

Appendices 2.1-2.11

The appendices in this section are compilations of previously published compositional analyses on copper and bronze artifacts from Indus Civilization sites. This represents the most complete and up to date compendium. Attempts have been made to highlight duplicate analyses that have been previously published in multiple locations and to correct typographic errors in previously compiled list of compositional data for Indus Civilization copper and bronze artifacts. Whenever possible, objects that have been previously published with multiple different compositional data have been listed as duplicates.

Appendix 2.1 – Summary of overall results from previous compositional analyses by archaeological site and by the alloy types used to categorize the HARP material.

Appendix 2.2 – All located published data for Mohenjo-Daro. One hundred fifty-two unique samples with ten duplicates. Some duplicates are published with different analytical results.

Appendix 2.3 – All published and unpublished data from Harappa. Sixty-six unique samples with five duplicate analyses. Some duplicates are published with different analytical results. Data is compiled from all previous excavations; including the Harappa Archaeological Research Project (HARP).

Appendix 2.4 – All previously published data from Lothal. This represents 71 unique analyses with 2 duplicates. Typographic errors in the Lothal data that have been previously noted (see Kenoyer and Miller 1999) have been corrected here as well.

Appendix 2.5 - All published analyses on copper and bronze artifacts from Surkotada. Seven of the analyses were corrected to values reported in a subsequent publication. This was an attempt to provide the most reliable set of compositional data possible for the site.

Appendix 2.6 – All Chanu-Daro analytical data compiled from different publications. Twenty-nine unique analyses with two duplicates with different published results.

Appendix 2.7 – Compiled results from two different sets of analyses on copper and bronze artifacts from the site of Kalibangan.

Appendix 2.8 – Compiled listing of previously published compositional analyses from the site of Rangpur.

Appendix 2.9 – Previously published results from Dholavira. These results have been published in the Dholavira site report as well.

Appendix 2.10 – Previously published results from the site of Navinal. Analysis method is inferred from the information presented in the publication.

Appendix 2.11 – Combined data from the sites of Kuntasi and Farmana. This data was previously published jointly and is represented in this manner here as well.

Appendices 2.1-2.11 Key

Cu – Copper

Sn – Tin

As – Arsenic

Ni – Nickel

Zn – Zinc

Sb – Antimony

Fe – Iron

S – Sulfur

Ag – Silver

Au – Gold

Bi – Bismuth

Co – Cobalt

Cl – Chlorine

O – Oxygen

O₂ – Oxide

SiO – Silicon Oxide

Tr – Trace

NA – Not Applicable/Not Analyzed

Unknown method – analytical technique was not published and cannot be reasonably inferred

PIXE – Proton Induced X-Ray Emission

AAS – Atomic Absorption Spectroscopy

SEM-EDS – Scanning Electron Microscope with Energy Dispersive X-Ray Spectroscopy

Appendix 2.1

Summary of Previously Published Compositional Analyses

Site	Samples Recorded	Duplicate Samples	Unique Samples	As Alloys	Pb Alloy	Sn Alloy	Cu-As-Pb	Cu-Pb-Sn	Cu-Sn-As	Cu-As-Pb-Sn	Total Alloys	% Alloyed	% Mixed	Total Mixed
Mohenjo-Daro	162	10	152	5	2	24	1	7	4	0	43	28.29%	27.91%	12
Harappa	71	5	66	28	2	10	6	1	4	1	52	78.79%	23.08%	12
Lothal	73	2	71	0	4	8	0	0	0	0	12	16.90%	0.00%	0
Surkotada	42	0	42	9	7	5	2	7	1	0	31	73.81%	32.26%	10
Chanu-Daro	31	2	29	9	1	5	0	0	0	0	15	51.72%	0.00%	0
Kalibangan	27	0	27	1	14	5	1	1	0	0	22	81.48%	9.09%	2
Rangpur	12	0	12	0	0	7	0	0	0	0	7	58.33%	0.00%	0
Dholavira	2	0	2	1	0	0	0	0	0	0	1	50.00%	0.00%	0
Navinal	10	0	10	2	0	0	0	0	2	0	4	40.00%	50.00%	2
Kuntasi	26	1	25	9	0	5	0	0	6	1	21	84.00%	33.33%	7
Farmana	31	0	31	16	0	0	0	0	1	0	17	54.84%	5.88%	1
TOTALS	487	20	467	80	30	69	10	16	18	2	225	48.18%	20.44%	46
% of Total				17.13%	6.42%	14.78%	2.14%	3.43%	3.85%	0.43%				9.85%
% of Alloys				35.56%	13.33%	30.67%	4.44%	7.11%	8.00%	0.89%				20.44%

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% S
Mohenjo-Daro	9022	Fulrum bar	Not in site reports	Unknown method by Hamid	ASI Annual Report 1930-34	96.16	0.88	2.23	0.10	--		--	--	0.63
Mohenjo-Daro	DK 1679		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		present	tr				
Mohenjo-Daro	DK 2155		Copper is summed	Unknown method by Desch	Marshall 1931	99.47	0		???	0.53				
Mohenjo-Daro	DK 3479		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 3566		Copper is summed	Unknown method by Desch	Marshall 1931	99.19	0		0	0.81				
Mohenjo-Daro	DK 3611		Copper is summed	Unknown method by Desch	Marshall 1931	99.86	0		0	0.14				
Mohenjo-Daro	DK 3612		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3630		Copper is summed	Unknown method by Desch	Marshall 1931	88.40	11.6		0	tr				
Mohenjo-Daro	DK 3648		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 3712		Copper is summed	Unknown method by Desch	Marshall 1931	99.76	0		0	0.24				
Mohenjo-Daro	DK 3731		Copper is summed	Unknown method by Desch	Marshall 1931	99.78	0		0	0.22				
Mohenjo-Daro	DK 3735		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3748		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3756		Copper is summed	Unknown method by Desch	Marshall 1931	99.32	0		0	0.68				
Mohenjo-Daro	DK 3833		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 3846		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 3849		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3914		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 3935		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3939		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 3955		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3956		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 3992		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 4005		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 4035		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 4041		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 4059		Copper is summed	Unknown method by Desch	Marshall 1931	99.85	0		0	0.15				
Mohenjo-Daro	DK 4068		Copper is summed	Unknown method by Desch	Marshall 1931	89.30	10.7		0	tr				
Mohenjo-Daro	DK 4087		Copper is summed	Unknown method by Desch	Marshall 1931	99.74	0		0	0.26				
Mohenjo-Daro	DK 4128		Copper is summed	Unknown method by Desch	Marshall 1931	99.14	0		0	0.86				
Mohenjo-Daro	DK 4173		Copper is summed	Unknown method by Desch	Marshall 1931	99.49	0		0	0.51				
Mohenjo-Daro	DK 4185		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 4260		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 4303		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 4330		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 4361		Copper is summed	Unknown method by Desch	Marshall 1931	80.90	19.1		0	tr				
Mohenjo-Daro	DK 4378		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 4384		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 4396		Copper is summed	Unknown method by Desch	Marshall 1931	99.95	0		0	0.05				
Mohenjo-Daro	DK 4400		Copper is summed	Unknown method by Desch	Marshall 1931	99.93	0		0	0.07				
Mohenjo-Daro	DK 4431		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 4451		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 4565		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	DK 4568		Copper is summed	Unknown method by Desch	Marshall 1931	89.70	10.3		0	tr				
Mohenjo-Daro	DK 4585		Copper is summed	Unknown method by Desch	Marshall 1931	89.80	10.2		0	0				
Mohenjo-Daro	DK 4586		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	faint tr				
Mohenjo-Daro	DK 4588		Copper is summed	Unknown method by Desch	Marshall 1931	85.40	14.6		0	0				
Mohenjo-Daro	DK 4599		Copper is summed	Unknown method by Desch	Marshall 1931	99.96	0		0	0.04				
Mohenjo-Daro	DK 4600		Copper is summed	Unknown method by Desch	Marshall 1931	94.19	5.6		0	0.21				
Mohenjo-Daro	DK 4642		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	DK 542		Copper is summed	Unknown method by Desch	Marshall 1931	99.70	0		0	0.3				
Mohenjo-Daro	DK 7860	lump	Not in site reports	Unkown method by Sana Ullah	ASI Annual Report 1929-30	93.56	0.79	4.38	0.9	0.41		-	-	-
Mohenjo-Daro	DK 8649		Not in site reports	Unkown method by Hamid	ASI Annual Report 1930-34	97.79	0.07	trace	0	0.13		0.77	1.24	--
Mohenjo-Daro	DK 8663		Not in site reports	Unkown method by Hamid	ASI Annual Report 1930-34	65.27	0.01	0.81	32.17	0.23		--	1.51	--
Mohenjo-Daro	DK 8725		Not in site reports	Unkown method by Hamid	ASI Annual Report 1930-34	99.63	0	0	0	0.28		0	0.09	--
Mohenjo-Daro	DK 8896	celt	Not in site reports	Unkown method by Sana Ullah	ASI Annual Report 1929-30	95.45	2.47	0.48	1.03	0.21		-	0.36	-

Appendix 2.2

Mohenjo-Daro Analyses

*Italicized items indicate duplicate analyses*Compiled From: ASI Reports 1926-1935, Marshall 1931,
Mackay 1938, and Nautiyal et al 1981.

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% S
Mohenjo-Daro	DK 8969		Not in site reports	Unknown method by Hamid	ASI Annual Report 1930-34	98.20	trace	trace	trace	0.18		0.33	1.29	--
Mohenjo-Daro	DK 8998		Not in site reports	Unknown method by Hamid	ASI Annual Report 1930-34	99.02	0	trace	0	0.76		--	0.22	--
Mohenjo-Daro	DK 9366		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	87.7	4.9		6.3	tr			1.1	
Mohenjo-Daro	DK 9368		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	0		0	tr			tr	
Mohenjo-Daro	DK 9376		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	0		tr	tr			tr	
Mohenjo-Daro	DK 9392		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	86.30	13.7		0	tr			tr	
Mohenjo-Daro	DK 9421		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	0		tr	tr			tr	
Mohenjo-Daro	DK 9442		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	63	22.1		14.9	tr			tr	
Mohenjo-Daro	DK 9446		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.04	0		tr	0.96			tr	
Mohenjo-Daro	DK 9457		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.66	0		0	0.34			0	
Mohenjo-Daro	DK 9460		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			0	
Mohenjo-Daro	DK 9472		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			0	
Mohenjo-Daro	DK 9474		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	98.92	0		tr	tr			1.08	
Mohenjo-Daro	DK 9476		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100	0		tr	0			tr	
Mohenjo-Daro	DK 9477		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	98.6	tr		tr	tr			1.4	
Mohenjo-Daro	DK 9478		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	tr		tr	0			tr	
Mohenjo-Daro	DK 9483		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			0	
Mohenjo-Daro	DK 9497		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	82.87	15		1.37	tr			0.76	
Mohenjo-Daro	DK 9503		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			0	
Mohenjo-Daro	DK 9509		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	98.9	0		tr	0.4			0.7	
Mohenjo-Daro	DK 9514		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	83.3	12.3		3	tr			1.4	
Mohenjo-Daro	DK 9531		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	93.1	3.3		3.6	tr			tr	
Mohenjo-Daro	DK 9548		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	88.5	11.5		tr	tr			tr	
Mohenjo-Daro	DK 9549		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	92.8	1.2		tr	1.9			4.1	
Mohenjo-Daro	DK 9555		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	97.2	0		tr	0.6			2.2	
Mohenjo-Daro	DK 9562		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100	0		tr	tr			tr	
Mohenjo-Daro	DK 9567		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	73.1	26.9		tr	0			tr	
Mohenjo-Daro	DK 9583		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	tr		0	tr			tr	
Mohenjo-Daro	DK 9597		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9617		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100	tr		tr	tr			tr	
Mohenjo-Daro	DK 9620		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100	0		tr	tr			tr	
Mohenjo-Daro	DK 9666		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9676		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9682		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.40	0.6		0	0			tr	
Mohenjo-Daro	DK 9714		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9715		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.63	tr		tr	0.37			tr	
Mohenjo-Daro	DK 9722		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	76.19	22.2		0.86	0.75			tr	
Mohenjo-Daro	DK 9728		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.75	tr		tr	0.25			tr	
Mohenjo-Daro	DK 9734		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100	0		tr	tr			tr	
Mohenjo-Daro	DK 9740		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	87.77	12		tr	0.23			tr	
Mohenjo-Daro	DK 9742		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9744		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9765		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9767		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9770		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.30	0.7		0	tr			tr	
Mohenjo-Daro	DK 9784		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	0		0	0			tr	
Mohenjo-Daro	DK 9789		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	present		0	0			tr	
Mohenjo-Daro	DK 9808		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	99.18	tr		0	0.82			tr	
Mohenjo-Daro	DK 9825		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	91.22	8.3		tr	0.48			tr	
Mohenjo-Daro	DK 9828		Copper is Summed	Unknown method by Desch & Carey	Mackay 1938	100.00	0		0	0			tr	
Mohenjo-Daro	E 602		Copper is summed	Unknown method by Desch	Marshall 1931	85.60	14.4		0	tr				
Mohenjo-Daro	HR 1152		Copper is summed	Unknown method by Desch	Marshall 1931	99.61	0		0	0.39				
Mohenjo-Daro	HR 1472		Copper is summed	Unknown method by Desch	Marshall 1931	98.51	0		0	1.49				
Mohenjo-Daro	HR 4964	Bronze Rod	Not in site reports	Unknown method by Sana Ullah or Hamid	ASI Annual Report 1927-28	69.76	6.65		22.83	0.33			0.41	
Mohenjo-Daro	HR 6186	Bronze Buttons	Not in site reports	Unknown method by Sana Ullah or Hamid	ASI Annual Report 1927-28	89.1	10.6						0.3	
Mohenjo-Daro	L 111 X		Copper is summed	Unknown method by Desch	Marshall 1931	98.96	0		0	1.04				

Appendix 2.2

Mohenjo-Daro Analyses

*Italicized items indicate duplicate analyses*Compiled From: ASI Reports 1926-1935, Marshall 1931,
Mackay 1938, and Nautiyal et al 1981.

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% S
Mohenjo-Daro	L 3767		Copper is summed	Unknown method by Desch	Marshall 1931	96.36	0		0.3	3.34				
Mohenjo-Daro	No # Reported	buttons	Completely oxidized (#9 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		8.22	Tr	0	Tr	2.6	0.29	0.84	
Mohenjo-Daro	No # Reported	copper lump	Unaltered Core (#1 p.484)	Unknown method by Sanna Ullah	Marshall 1931		0	0.15	0.02	1.27	0.88	0.03	0.98	
Mohenjo-Daro	No # Reported	copper lump	Partially Oxidized (#3 p.484)	Unknown method by Sanna Ullah	Marshall 1931		0	0	0.09	0.35	-	0	0.36	
Mohenjo-Daro	No # Reported	slab	metallic core, partially oxidized (#11 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		13.21	1.17	0.11	0.56	0.33	0.42	0	
Mohenjo-Daro	No # Reported	lump	Partially Oxidized (#13 p.484)	Unknown method by Sanna Ullah	Marshall 1931		12.13	0.00	0.17	0.17	Tr	0.00	0	
Mohenjo-Daro	No # Reported	rod	Unaltered Core (#8 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		4.51	1.96	0.17	-	1.15	0.15	0.16	
Mohenjo-Daro	No # Reported	celt	Unaltered & very hard metal (#6 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		0.09	4.42	0.26	0.14	-	0.15	-	
Mohenjo-Daro	No # Reported	chisel	Completely oxidized (#10 p. 484)	Unknown method by Sanna Ullah	ASI 1926-27 Report/Marshall 1931		12.38	-	0.70	0	0.35	0.35	-	
Mohenjo-Daro	No # Reported	frag. of implement	Unaltered Metal (#5 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		0	0.74	1.58	0.25	0.72	0.12	0.61	
Mohenjo-Daro	No # Reported	chisel (?)	Unaltered portion (#7 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		0.00	3.42	3.28	0.15	0.1	0.59	0.05	
Mohenjo-Daro	No # Reported	chisel	Partially Oxidized (#12 p.484)	Unknown method by Sanna Ullah	Marshall 1931		11.09	0.07	Tr	0.16	Tr	0.18	0.11	
Mohenjo-Daro	No # Reported	copper lump	Unaltered Core (#2 p. 484)	Unknown method by Sanna Ullah	Marshall 1931		0	0.98	Tr	0.31	Tr	0.49	1.15	
Mohenjo-Daro	No # Reported	copper lump	Partially Oxidized (#4 p.484)	Unknown method by Sanna Ullah	Marshall 1931		0.37	1.3	Tr	1.06	Tr	1.51	2.26	
Mohenjo-Daro	None	Refined Copper Lump	Not in site reports	Unknown method by Sana Ullah or Hamid	ASI Annual Report 1927-28	99.93				0.26		0.41		
Mohenjo-Daro	P-106	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		1.04	0.18		0.16				
Mohenjo-Daro	P-107	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		0.25	0.39		0.09				
Mohenjo-Daro	P-110	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		0.75	0.34		0.09				
Mohenjo-Daro	P-121	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		0.20	0.13		0.01				
Mohenjo-Daro	P-126	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		Not Detected	0.57		0.02				
Mohenjo-Daro	P-130	Not Listed	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		1.39	0.07		0.03				
Mohenjo-Daro	P-181	Bowl pieces	Not in site reports	Atomic Absorption Spectrometry	Nautiyal et al 1981		3.31	0.16		0.20				
Mohenjo-Daro	Pit-Dk 5316	Copper Ore	see page 600	Unknown method by Desch	Mackay 1938				traces	0.23				
Mohenjo-Daro	SD 1405		Copper is summed	Unknown method by Desch	Marshall 1931	99.47	0		0.36	0.17				
Mohenjo-Daro	SD 1932		Copper is summed	Unknown method by Desch	Marshall 1931	90.62	0		tr	9.38				
Mohenjo-Daro	SD 2683 (A)		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		present	tr				
Mohenjo-Daro	SD 2683 (B)		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	0				
Mohenjo-Daro	SD 2683 (C)		Copper is summed	Unknown method by Desch	Marshall 1931	100.00	0		0	tr				
Mohenjo-Daro	VS 1416		Copper is summed	Unknown method by Desch	Marshall 1931	99.91	0		0	0.09				
Mohenjo-Daro	VS 1572		Copper is summed	Unknown method by Desch	Marshall 1931	80.77	19		0	0.23				
Mohenjo-Daro	Dk 5360	pan with handle	Site Report #s	Unknown method by Hamid	Mackay 1938	81.94	0.37	0.8	0.05	0.21	0.18	0.33	0.14	
Mohenjo-Daro	DK 5360	frying pan	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	97.53	0.44	0.95	0.06	0.25	0.22	0.39	0.16	
Mohenjo-Daro	Dk 5486	axe	Site Report #s	Unknown method by Hamid	Mackay 1938	80.56	1.76	2.10	0.20	0.58	Tr	0.34	0	
Mohenjo-Daro	DK 5486	celt	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	94.19	2.06	2.45	0.23	0.68	Tr	0.39	-	
Mohenjo-Daro	Dk 6043	chisel	Site Report #s	Unknown method by Hamid	Mackay 1938	86.92	8.56	1.58	Tr	0.68	0.54	0.02	0.07	
Mohenjo-Daro	DK 6043	bar	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	88.39	8.70	1.60	Tr	0.69	0.55	-	0.07	
Mohenjo-Daro	Dk 7343	chisel/square rod	Site Report #s	Unknown method by Hamid	Mackay 1938	97.23	0	0.24	0.81	0.89	0	0.29	0.1	
Mohenjo-Daro	DK 7343	crow bar	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	97.66	-	0.24	0.81	0.90	-	0.29	0.10	
Mohenjo-Daro	Dk 7535	axe/celt	Site Report #s	Unknown method by Hamid	Mackay 1938	91.01	6.14	0.66	0.59	0.48	0.25	0.33	0.12	
Mohenjo-Daro	DK 7535	celt	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	91.40	6.16	0.67	0.59	0.48	0.25	0.33	0.12	
Mohenjo-Daro	Dk 7853	axe/celt	Site Report #s	Unknown method by Hamid	Mackay 1938	94.64	0.31	0.4	0.71	0.33	0.06	0.28	0.69	
Mohenjo-Daro	DK 7853	celt	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	97.15	0.32	0.40	0.73	0.34	0.06	0.29	0.71	
Mohenjo-Daro	Dk 7854	axe/celt	Site Report #s	Unknown method by Hamid	Mackay 1938	90.18	7.66	0	0.95	0.20	0.43	0.5	0.07	
Mohenjo-Daro	DK 7854	celt	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	90.19	7.66	-	0.95	0.20	0.43	0.50	0.07	
Mohenjo-Daro	Dk 7856	chisel	Site Report #s	Unknown method by Hamid	Mackay 1938	75.25	7.84	0.00	0.39	0.61	1.25	0.51	0	
Mohenjo-Daro	DK 7856	chisel	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	87.66	9.14	-	0.45	0.71	1.45	0.59	-	
Mohenjo-Daro	Dk 7859	spear/knife	Site Report #s	Unknown method by Hamid	Mackay 1938	95.23	0.00	0.24	0.82	0.41	0	0.56	0.48	
Mohenjo-Daro	DK 7859	lump	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	97.43	-	0.25	0.84	0.41	-	0.58	0.49	
Mohenjo-Daro	Dk 7861	portion of axe	Site Report #s	Unknown method by Hamid	Mackay 1938	88.49	9.88	0	0.22	0.30	0.14	0.10	0.06	
Mohenjo-Daro	DK 7861	lump	Reproduced with different #s	Unknown method by Hamid	ASI Annual Report 1929-30	89.21	9.97	-	0.22	0.3	0.14	0.10	0.06	

Appendix 2.3
Harappa Analyses
Italicized items indicate duplicate analyses

Compiled From: ASI Reports 1926-1935, Vats 1940, Agrawal 1981,
Nautiyal et al 1981, Unpublished HARP records (MASCA),
and Kenoyer and Miller 1999.

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% S	% Ag	% Cl
Harappa	1208	dagger		unknown method	ASI Annual Report 1930-34	91.00	6.76	0.04	0.88	0.14	-	0.44	0.74	*		
Harappa	4255	dagger		unknown method	ASI Annual Report 1934-35	91.87	6.42	0.26	0.98	Tr	-	-	0.47	*		
Harappa	5133	rectangular rod		unknown method	ASI Annual Report 1930-34	97.20	0.84	0.70	0.00	0.09	-	0.19	0.98	*		
Harappa	11859	needle		unknown method	ASI Annual Report 1934-35	92.55	0.29	2.96	3.72	0.21	0.07	-	0.20	*		
Harappa	B1754	chisel		unknown method	ASI Annual Report 1930-34	92.61	6.43	0.36	Tr	0.20	-	0.31	0.09	*		
Harappa	H1986/Surface-A	Copper Misc. Fragment	Kenoyer and Miller 1999	PIXE	MASCA	96.4	0.018	2.26	0.39	0.24		0.019	0.34	0.096	0.015	0.008
Harappa	H1986/Surface-C	Copper Misc. Fragment	Kenoyer and Miller 1999	PIXE	MASCA	96.5	0.014	2.08	0.32	0.23		0.018	0.34	0.12	0.002	0.052
Harappa	H1987/515-	Copper Sheet or Scoop	Kenoyer and Miller 1999	PIXE	MASCA	97.0	0.017	1.860	0.170	0.265		0.071	0.261	0.094	0.013	0.0110
Harappa	H1988/325-8D	Copper Rod/Wire/Pin	Kenoyer and Miller 1999	PIXE	MASCA	97.0	0.014	1.95	0.19	2.73		0.021	0.202	0.074	0.012	0.019
Harappa	H1988/325-8E	Copper Rod/Wire/Pin	Kenoyer and Miller 1999	PIXE	MASCA	96.7	0.011	1.17	0.65	0.52		0.014	0.314	0.294	0.009	0.074
Harappa	H1988/346-27	Copper Bead	Kenoyer and Miller 1999	PIXE	MASCA	83.2	14.8	0.67	0.34	0.402		0.058	0.083	0.052	0.03	0.043
Harappa	H1988/374-1	Copper Rod/Wire/Pin	Kenoyer and Miller 1999	PIXE	MASCA	98.6	0.013	0.58	0.032	0.105		0.017	0.3	0.035	0.036	0.037
Harappa	H1988/413-A	Copper Ring	Kenoyer and Miller 1999	PIXE	MASCA	99.5	0.011	0.009	0.012	0.091		0.016	0.05	0.01	0.012	0.016
Harappa	H1988/444-1	Copper Mirror	Kenoyer and Miller 1999	PIXE	MASCA	77.2	0.038	0.93	0.5	0.25		0.057	0.051	0.38	0.29	18.9
Harappa	H1988/751-21	Copper Arrow Point	Kenoyer and Miller 1999	PIXE	MASCA	93.6	2.93	1.53	0.15	0.169		0.046	0.18	0.164	0.025	0.3
Harappa	H1988/761-1A	Copper Rod/Wire/Pin	Kenoyer and Miller 1999	PIXE	MASCA	97.4	0.011	1.91	0.017	0.23		0.015	0.104	0.015	0.009	0.037
Harappa	H1988/761-1B	Copper Rod/Wire/Pin	Kenoyer and Miller 1999	PIXE	MASCA	97.2	0.01	1.95	0.012	0.226		0.013	0.138	0.018	0.008	0.14
Harappa	H1989/1038-14	Copper Rod/Wire/Pin		PIXE	MASCA	95.1	0.06	2.79	0.26	0.205		0.04	0.223	0.052	0.021	0.017
Harappa	H1989/1054-24	Copper Misc. Fragment		PIXE	MASCA	97.9	0.029	0.07	0.63	0.023		0.034	0.051	0.078	0.1	0.087
Harappa	H1990/3000-D	Copper Rod/Wire/Pin		PIXE	MASCA	96.2	0.013	2.97	0.034	0.167		0.02	0.082	0.041	0.012	0.0067
Harappa	H1990/3014-24	Copper Rod/Wire/Pin		PIXE	MASCA	95.8	0.3	2.29	0.16	0.18		0.015	0.261	0.115	0.028	0.45
Harappa	H1990/3025-20	Copper Bead		PIXE	MASCA	94.6	0.023	0.88	2.26	0.312		0.004	0.148	0.681	0.019	0.068
Harappa	H1990/3025-21	Copper Sheet/Blade		PIXE	MASCA	92.4	0.03	3.24	2.72	0.233		0.039	0.156	0.126	0.069	0.098
Harappa	H1990/3056-3	Copper Rod/Wire/Pin		PIXE	MASCA	84.6	9.51	1.77	0.49	0.365		0.038	0.156	0.192	0.032	2.71
Harappa	H1990/3059-11	Copper Bead		PIXE	MASCA	87	9.67	1.16	0.46	0.37		0.046	0.112	0.154	0.023	0.47
Harappa	H1990/3072-4	Copper Bead		PIXE	MASCA	97.0	0.011	1.12	0.64	0.329		0.015	0.086	0.455	0.019	0.43
Harappa	H1990/3072-5	Copper Misc. Fragment		PIXE	MASCA	73.3	22.8	1.22	1.01	0.538		0.046	0.057	0.088	0.032	0.078
Harappa	H1990/3087-19	Copper Sheet/Blade		PIXE	MASCA	95.8	0.087	1.77	0.16	0.039		0.035	0.314	0.082	0.042	0.43
Harappa	H1990/3101-20	Copper Misc. Fragment		PIXE	MASCA	97.7	0.025	0.27	0.047	0.504		0.037	0.158	0.29	0.019	0.031
Harappa	H1990/3101-21	Copper Misc. Fragment		PIXE	MASCA	94.8	0.031	3.05	0.03	0.092		0.064	0.357	0.07	0.0142	0.24
Harappa	H1990/3115-24	Copper Prill		PIXE	MASCA	97	0.011	1	0.46	0.364		0.016	0.06	0.05	0.009	0.51
Harappa	H1990/3122-3	Copper Misc. Fragment		PIXE	MASCA	84.7	12.4	0.14	0.031	0.423		0.038	0.082	0.055	0.016	1.57
Harappa	H1990/3135-14	Copper Ring		PIXE	MASCA	96.8	0.023	0.76	0.042	0.376		0.036	0.406	0.027	0.018	0.52
Harappa	H1990/3153-24	Copper Rod/Wire/Pin		PIXE	MASCA	95.5	0.026	2.28	0.049	0.996		0.074	0.06	0.008	0.046	0.0019
Harappa	H1990/3191-14	Copper Misc. Fragment		PIXE	MASCA	98.6	0.018	0.016	0.039	0.05		0.028	0.079	0.256	0.013	0.0112
Harappa	H1990/3242-1	Copper Rod/Wire/Pin		PIXE	MASCA	95.8	0.021	1.26	1.09	0.472		0.035	0.102	0.278	0.017	0.059
Harappa	H1990/3247-30	Copper Misc. Fragment		PIXE	MASCA	95.6	0.024	1.05	1.99	0.341		0.037	0.142	0.375	0.02	0.028
Harappa	H1990/3247-39	Copper Misc. Fragment		PIXE	MASCA	97.4	0.022	0.052	0.041	0.168		0.033	0.361	0.429	0.016	0.61
Harappa	H1990/3257-4	Copper Rod/Wire/Pin		PIXE	MASCA	94.3	0.012	3.15	1.17	0.235		0.016	0.255	0.09	0.021	0.084
Harappa	H1995/4623-17	Copper Misc. Fragment		PIXE	MASCA	97.7	0.025	0.42	0.6	0.023		0.039	0.211	0.073	0.02	0.008
Harappa	H1995/4663-1	Copper Tablet (Molded)		PIXE	MASCA	93.1	0.027	5.19	0.37	0.074		0.036	0.07	0.078	0.018	0.16
Harappa	H1995/5680-17	Copper Misc. Fragment		PIXE	MASCA	92.7	0.031	3.24	2.24	0.1		0.047	0.162	0.219	0.025	0.014
Harappa	H1995/6509-1	Copper Rod/Wire/Pin		PIXE	MASCA	93.9	0.58	2.63	0.87	0.114		0.038	0.215	0.089	0.039	0.59
Harappa	H1997/7755-1	Copper Sheet/Blade		PIXE	MASCA	95.8	0.037	2.54	0.05	0.023		0.041	0.066	0.01	0.164	0.017
Harappa	J125	spearhead		unknown method	ASI Annual Report 1930-34	97.66	0.33	0.06	0.70	0.14	-	-	1.11	*		
Harappa	Lot 277	folded sheet		unknown method	ASI Annual Report 1930-34	97.69	0.15	1.19	0.85	0.05	-	Tr	0.07	*		
Harappa	Lot 277a/19	celt		unknown method	ASI Annual Report 1930-34	98.37	0.00	1.40	0.11	0.10	-	-	0.02	*		
Harappa	Lot 277e/2	lancehead		unknown method	ASI Annual Report 1934-35	98.69	0.1	0.68	Tr	0.40	-	-	0.13	*		
Harappa	Lot 277g/2	saw		unknown method	ASI Annual Report 1930-34	98.12	0.33	0.65	0.1	0.39	-	-	0.41	*		
Harappa	Lot 277k/3	chisel		unknown method	ASI Annual Report 1930-34	94.92	3.60	0.60	0.20	0.29	-	-	0.39	*		
Harappa	No # Reported	bronze needle	not in site report	unknown method	ASI Annual Report 1930-34	88.79	8.75	0.40	0.10	0.17		0.42	1.37			
Harappa	No # Reported	Copper Celt	not in site report	unknown method	ASI Annual Report 1930-34	98.36		1.41	0.11	0.10			0.02			
Harappa	No # Reported	bronze celt	not in site report	unknown method	ASI Annual Report 1930-34	91.32	7.85	trace	0.20	0.22			0.41			
Harappa	No # Reported	Copper lance head	not in site report	unknown method	ASI Annual Report 1926-27	97.87				0.40			0.13	1.6 (listed as oxygen, sulfur, etc)		
Harappa	P-100	Cu Bead		Atomic Absorption Spectrometry	Agrawal 1981		0.2	-	3.78							

Appendix 2.3

Harappa Analyses

*Italicized items indicate duplicate analyses*Compiled From: ASI Reports 1926-1935, Vats 1940, Agrawal 1981,
Nautiyal et al 1981, Unpublished HARP records (MASCA),
and Kenoyer and Miller 1999.

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% S	% Ag	% Cl
Harappa	P-101	Cu Bead		Atomic Absorption Spectrometry	Agrawal 1981		0.07	-	2.8							
Harappa	P-102	Cu Bead		Atomic Absorption Spectrometry	Agrawal 1981		0.07	1.3	0.67							
Harappa	P-103	Cu Bead		Atomic Absorption Spectrometry	Agrawal 1981		0.05	0.13	0.94							
Harappa	P-104	Cu Fragment		Atomic Absorption Spectrometry	Agrawal 1981		0.1	1	0.87							
Harappa	P-105	Cu Fragment		Atomic Absorption Spectrometry	Agrawal 1981		0.03	0.44	1.75							
Harappa	X	chisel		unknown method	ASI Annual Report 1930-34	87.42	10.45	1.10	0.52	0.17	-	-	0.34	*		
Harappa	150 A (6)	Needle or Awl	modified Af150	unknown method	ASI Annual Report 1930-34	88.35	9.16	0.42	0.10	0.18	-	0.42	1.37	*		
Harappa	Af150	awl		unknown method	Vats 1940	88.38	9.16	0.40	0.10	0.17	-	0.42	1.37	*		
Harappa	-	dagger		unknown method	Vats 1940	90.05	0.00	6.58	2.80	0.18	-	-	0.39	*		
Harappa	?	Fragment of dagger	modified "-" dagger	unknown method	ASI Annual Report 1930-34	89.88	0	6.69	2.85	0.18		0	0.40			
Harappa	P-113	Cu Fragment	modified P-113	Atomic Absorption Spectrometry	Agrawal 1981		5.8	0.36	2.91							
Harappa	P-113	Not Listed	modified P-113	Atomic Absorption Spectrometry	Nautiyal et al 1981		1.02	0.11	0.09							
Harappa	Lot 277	fragment		unknown method	Vats 1940	98.60	0.07	0.66	Tr	0.26	-	-	0.41	*		
Harappa	Lot 277a/21	celt		unknown method	Vats 1940	91.10	7.850	0.420	Tr	0.220	-	Tr	0.41	*		
Harappa		Fragment of Casting	modified Lot 277	unknown method	ASI Annual Report 1930-34	98.32	0.07	0.66	trace	0.26		0	0.41	0.28		
Harappa		Bronze celt	modified Lot 277 a/21	unknown method	ASI Annual Report 1926-27	91.52	7.85		trace	0.22		trace	0.41			

Appendix 2.4
Lothal Analyses

Arsenic (As) was tested for, but no traces were
found in any object

* two different analyses published
** Typographical error in original.

Site	Object #	Description	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Fe	% Ag	% O	% Insoluble	Total %
Lothal	10918*	axe/celt *	Unknown	Lal 1985	97.20	-		0.91	-	-	-	-	1.89	-	100.00
Lothal	15073	fragment	Unknown	Lal 1985	59.00	-		0.95	Tr	-	1.56	-	25.38	13.11	100.00
Lothal	5578	fish hook	Unknown	Lal 1985	60.65	-		1.3	Tr	-	Tr	-	32.16	5.99	100.10
Lothal	4813	lump	Unknown	Lal 1985	93.65	-		1.51	1.55	-	Tr	-	2.80	0.49	100.00
Lothal	10918*	axe with sleeves*	Unknown	Lal 1985	96.27	-		2.51	Tr	-	Tr	-	1.22	-	100.00
Lothal	4759	fragment	Unknown	Lal 1985	79.89	-		3.6	Tr	-	Tr	-	16.31	0.20	100.00
Lothal	15295	pin	Unknown	Lal 1985	96.76	0.57		-	1.92	-	Tr	-	0.75	-	100.00
Lothal	P 242	No Description	AAS	Nautiyal et al 1981	Cu	1.09	0.78	-	0.03	-	-	-	-	-	1.90
Lothal	15217	spear/knife	Unknown	Lal 1985	39.07	2.27		-	Tr	-	Tr	-	36.08	12.58	90.00
Lothal	15079	engraver	Unknown	Lal 1985	49.64	3.96		-	Tr	-	Tr	-	35.68	10.72	100.00
Lothal	15030	mirror	Unknown	Lal 1985	54.78	5.47		-	-	-	Tr	-	31.58	8.17	100.00
Lothal	13886	rod with grooves	Unknown	Lal 1985	57.75	9.02		-	Tr	-	Tr	-	29.92	3.31	100.00
Lothal	11893	chisel	Unknown	Lal 1985	74.28	9.62		-	Tr	-	Tr	-	13.02	3.06	99.98
Lothal	12143	bangle	Unknown	Lal 1985	74.34	11.2		-	Tr	-	Tr	-	11.24	3.22	100.00
Lothal	15209	bangle	Unknown	Lal 1985	55.32	11.82		-	-	-	-	-	28.97	3.89	100.00
Lothal	15155	pin	Unknown	Lal 1985	51.89	13.8		-	-	-	Tr	-	28.91	5.40	100.00
Lothal	625	arrow head	Unknown	Lal 1985	97.70	-		-	Tr	-	-	-	2.30	-	100.00
Lothal	1344	bangle	Unknown	Lal 1985	94.90	-		-	0.45	-	2.14	-	2.51	-	100.00
Lothal	3091*	shaft hole axe*	Unknown	Lal 1985	88.27	-		-	0.19	-	Tr	-	10.75	0.79	100.00
Lothal	3091*	hand axe/celt*	Unknown	Lal 1985	94.33	-		-	Tr	-	-	-	5.30	0.37	100.00
Lothal	3872	arrow head	Unknown	Lal 1985	70.30	-		-	1.5	-	Tr	-	27.70	0.50	100.00
Lothal	4148	fragment	Unknown	Lal 1985	74.84	-		-	Tr	-	0.61	-	20.10	4.43	99.98
Lothal	4189	object	Unknown	Lal 1985	70.69	-		-	Tr	-**	0.90	-	22.37	6.04	100.00
Lothal	4744	ring	Unknown	Lal 1985	95.31	-		-	-	-	-	-	4.69	-	100.00
Lothal	5373	spear head	Unknown	Lal 1985	87.34	-		-	-	-	-	-	12.66	-	100.00
Lothal	5501	rod	Unknown	Lal 1985	88.60	-		-	Tr	-	Tr	-	11.10	0.30	100.00
Lothal	5590	object	Unknown	Lal 1985	87.08	-		-	Tr	-	Tr	-	2.92	-	90.00
Lothal	5971	bangle/ring	Unknown	Lal 1985	72.95	-		-	-	-	-	-	17.09	9.96	100.00
Lothal	6030	nail/pin	Unknown	Lal 1985	90.79	-		-	0.63	-	Tr	-	8.58	-	100.00
Lothal	6040	fish hook	Unknown	Lal 1985	99.01	-		-	0.28	-	Tr	-	0.71	-	100.00
Lothal	7700	chisel	Unknown	Lal 1985	90.44	-		-	Tr	-	Tr	-	9.56	-	100.00
Lothal	8110	chisel	Unknown	Lal 1985	88.53	-		-	Tr	-	Tr	-	10.99	0.48	100.00
Lothal	8480	spear head	Unknown	Lal 1985	48.26	-		-	Tr	-	Tr	-	38.09	13.65	100.00
Lothal	10842	dagger/chisel	Unknown	Lal 1985	59.64	-		-	1.62	-	0.85	-	37.89	-	100.00
Lothal	11971	figurine	Unknown	Lal 1985	83.31	-		-	-	-	Tr	-	13.58	-	96.89
Lothal	12125	lump	Unknown	Lal 1985	90.68	-		-	-	-	4.02	-	5.025	0.275	100.00
Lothal	12147	arrow head	Unknown	Lal 1985	97.21	-		-	Tr	-	Tr	-	2.79	-	100.00

Compiled From: Lal 1985 and Nautiyal et al 1981

Appendix 2.4
Lothal Analyses

Arsenic (As) was tested for, but no traces were
found in any object

* two different analyses published
** Typographical error in original.

Site	Object #	Description	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Fe	% Ag	% O	% Insoluble	Total %
Lothal	12264	bangle	Unknown	Lal 1985	72.26	-		-	Tr	-	-	-	19.85	7.89	100.00
Lothal	12378	axe	Unknown	Lal 1985	70.00	-		-	-	-	-	-	7.00	23.00	100.00
Lothal	12432	fragment	Unknown	Lal 1985	72.50	-		-	2.48	-	0.95	-	16.65	7.42	100.00
Lothal	12455	pin	Unknown	Lal 1985	89.95	-		-	-	-	Tr	-	1.04	9.01	100.00
Lothal	13134	pin	Unknown	Lal 1985	57.76	-		-	-	-	-	-	28.92	13.32	100.00
Lothal	13140	hook	Unknown	Lal 1985	87.34	-		-	Tr	-	0.40	-	11.48	0.78	100.00
Lothal	14087	piece	Unknown	Lal 1985	88.76	-		-	Tr	-	Tr	-	10.66	0.58	100.00
Lothal	14211	spear head	Unknown	Lal 1985	43.38	-		-	-	-	0.99	-	**	**	44.37
Lothal	14302	hook	Unknown	Lal 1985	77.44	-		-	-	-	-	-	22.56	-	100.00
Lothal	14535	ingot	Unknown	Lal 1985	99.81	-		-	Tr	-	Tr	-	0.19	-	100.00
Lothal	14841	ornament	Unknown	Lal 1985	63.58	-		-	-	-	Tr	-	21.18	15.24	100.00
Lothal	14855	ring from burial	Unknown	Lal 1985	58.36	-		-	Tr	-	Tr	-	28.60	13.04	100.00
Lothal	15036	lump	Unknown	Lal 1985	83.90	-		-	Tr	-	0.32	-	12.46	3.32	100.00
Lothal	15063	fish hook	Unknown	Lal 1985	82.90	-		-	Tr	-	Tr	-	15.90	1.20	100.00
Lothal	15085	fragment	Unknown	Lal 1985	66.60	-		-	Tr	-	0.80	-	32.6	Tr	100.00
Lothal	15169	fragment	Unknown	Lal 1985	75.60	-		-	Tr	-	Tr	-	23.90	0.50	100.00
Lothal	15176	knife handle	Unknown	Lal 1985	46.57	-		-	-	-	-	-	49.23	4.20	100.00
Lothal	15194	lump	Unknown	Lal 1985	81.07	-		-	Tr	-	0.64	-	15.74	2.55	100.00
Lothal	15196	lump	Unknown	Lal 1985	72.83	-		-	Tr	-	0.55	-	24.09	2.53	100.00
Lothal	15208	pin	Unknown	Lal 1985	77.40	-		-	Tr	-	0.50	-	5.90	16.20	100.00
Lothal	15210	engraver	Unknown	Lal 1985	70.45	-		-	Tr	-	Tr	-	12.45	17.10	100.00
Lothal	15251	lump	Unknown	Lal 1985	57.68	-		-	-	-	-	-	35.38	6.94	100.00
Lothal	-	Revetted jar	Unknown	Lal 1985	43.00	-		-	-	-	1.00	-	53.77	2.23	100.00
Lothal	P 235	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.07	-	-				0.07
Lothal	P 236	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.32	-	-				0.32
Lothal	P 237	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.44	-	-				0.44
Lothal	P 238	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.33	-	-				0.33
Lothal	P 239	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.03	-	-				0.03
Lothal	P 241	No Description	AAS	Nautiyal et al 1981	Cu	-		-	0.06	-	-				0.06
Lothal	P 243	No Description	AAS	Nautiyal et al 1981	Cu	-	0.13	-	0.04	-	-				0.17
Lothal	P 244	No Description	AAS	Nautiyal et al 1981	Cu	-	0.15	-	-	-	-				0.15
Lothal	SRG-324	fish hook	Unknown	Lal 1985	91.6	-		-	Tr	-	-	-	8.40	-	100.00
Lothal	SRG-B (20)	hand axe/celt	Unknown	Lal 1985	91.87	-		-	0.80	-	Tr	-	7.11	0.20	99.98
Lothal	5957	celt	Unknown	Lal 1985	97.18	Tr		-	0.31	-	Tr	-	1.17	1.34	100.00
Lothal	15137	rod	Unknown	Lal 1985	60.30	Tr		-	Tr	-	Tr	-	26.26	13.44	100.00
Lothal	15139	ear ornament	Unknown	Lal 1985	48.24	Tr		Tr	Tr	-	0.70	-	34.70	16.36	100.00

Compiled From: Lal 1985 and Nautiyal et al 1981

Appendix 2.5

Surkotada Analyses

Bolded Objects from Agrawal 1995 published data

Compiled From: Agrawal 1981, Nautiyal et al 1981,
and Agrawal 1995

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Sn	% As	% Pb	% Ni	% Zn	% Fe
Surkotada	P-14	Cu Piece	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	-	0.495	1.081	N.P.		0.609
Surkotada	P-15	Cu Piece	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	-	1	N.P.	0.0189		1.044
Surkotada	P-16	Cu Fragment		AAS	Agrawal 1981	3.47	-	3.92			
Surkotada	P-17	Not Listed		AAS	Nautiyal et al 1981		Not Detected		0.09		
Surkotada	P-18	Cu Fragment		AAS	Agrawal 1981	0.42	-	0.58			
Surkotada	P-19	Cu Fragment		AAS	Agrawal 1981	1.26	0.51	0.97			
Surkotada	P-2	Cu Piece	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	8.08	0.153	16.09	0.0015		0.1603
Surkotada	P-20	Cu Fragment		AAS	Agrawal 1981	0.49	-	0.68			
Surkotada	P-21	Cu Fragment		AAS	Agrawal 1981	7.47	1.29	0.16			
Surkotada	P-22	Cu Fragment		AAS	Agrawal 1981	-	1.07	0.29			
Surkotada	P-23	Cu Fragment		AAS	Agrawal 1981	-	1.31	0.16			
Surkotada	P-24	Cu Fragment		AAS	Agrawal 1981	-	1.87	0.48			
Surkotada	P-25	Cu Fragment		AAS	Agrawal 1981	-	-	1.12			
Surkotada	P-26	Cu Fragment		AAS	Agrawal 1981	0.05	0.73	0.35			
Surkotada	P-27	Cu Fragment		AAS	Agrawal 1981	2.14	0.07	0.60			
Surkotada	P-28	Cu Fragment		AAS	Agrawal 1981	0.56	0.28	3.73			
Surkotada	P-29	Cu Fragment		AAS	Agrawal 1981	0.46	0.27	1.85			
Surkotada	P-3	Cu Fragment		AAS	Agrawal 1981	0.27	-	0.08			
Surkotada	P-30	Cu Axe		AAS	Agrawal 1981	0.12	0.99	0.93			
Surkotada	P-30	Cu Axe		AAS	Agrawal 1981	0.12	0.99	0.93			
Surkotada	P-31	Cu Fragment		AAS	Agrawal 1981	0.36	0.82	-			
Surkotada	P-32	Cu Fragment		AAS	Agrawal 1981	0.54	1.62	-			
Surkotada	P-33	Cu Fragment		AAS	Agrawal 1981	0.51	1.19	0.26			
Surkotada	P-34	Cu Fragment		AAS	Agrawal 1981	0.58	0.87	0.48			
Surkotada	P-35	Cu Fragment		AAS	Agrawal 1981	0.16	1.87	1.04			
Surkotada	P-36	Cu Fragment		AAS	Agrawal 1981	0.1	0.46	-			
Surkotada	P-37	Cu Fragment		AAS	Agrawal 1981	0.16	0.4	-			
Surkotada	P-38	Cu Fragment		AAS	Agrawal 1981	-	-	20.23			
Surkotada	P-39	Cu Fragment		AAS	Agrawal 1981	5.45	-	2.33			
Surkotada	P-40	Cu Fragment		AAS	Agrawal 1981	4.26	-	0.65			
Surkotada	P-41	Cu Fragment		AAS	Agrawal 1981	2.96	-	3.7			
Surkotada	P-42	Cu Fragment		AAS	Agrawal 1981	4.68	0.81	0.22			
Surkotada	P-43	Cu Fragment		AAS	Agrawal 1981	2.09	0.12	0.25			
Surkotada	P-44	Cu Fragment		AAS	Agrawal 1981	-	-	-			
Surkotada	P-45	Cu Fragment	Agrawal 1995 reports presence of tin	AAS	Agrawal 1981	-	0.48	0.95			
Surkotada	P-46	Cu Fragment		AAS	Agrawal 1981	0.26	-	6.32			
Surkotada	P-47	Cu Fragment		AAS	Agrawal 1981	-	0.13	-			
Surkotada	P-48	Dish Fragment		AAS	Agrawal 1981	-	-	-			
Surkotada	P-5	Cu Piece (bangle piece?)	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	2.46	0.12	16.45	0.0009		0.0125
Surkotada	P-6	Cu Ring	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	N.P.	1.491	1.3326	0.0092		0.192
Surkotada	P-8	Cu Bangle	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	4.3	0.113	13.25	0.0022		1.959
Surkotada	P-9	Cu Point	Analysis changed based on Agrawal 1995	AAS	Agrawal 1981	N.P.	0.587	1.253	0.0067		1.995

Appendix 2.6
Chanu-Daro Analyses

Compiled From: Agrawal 1981, Nautiyal et al 1981,
and Agrawal 1995

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Sn	% As	% Pb	% Ni	% Zn
Chanu-Daro	P-49	Not Listed		AAS	Nautiyal et al 1981		Not Detected	0.87		0.04
Chanu-Daro	P-50	Cu Fragment		AAS	Agrawal 1981	-	1.13	N.P.		
Chanu-Daro	P-78	Cu Chisel		AAS	Agrawal 1981	-	1.34	-		
Chanu-Daro	P-79	Cu Chisel		AAS	Agrawal 1981	7.17	0.3	-		
Chanu-Daro	P-80	Bangle		AAS	Agrawal 1981	0.005	0.09	-		
Chanu-Daro	P-81	Dish Fragment		AAS	Agrawal 1981	0.74	0.89	0.9		
Chanu-Daro	P-82	Spearhead Tip		AAS	Agrawal 1981	0.22	0.66	16.57		
Chanu-Daro	P-83	Cu Fragment		AAS	Agrawal 1981	0.54	-	-		
Chanu-Daro	P-84	Cu Fragment		AAS	Agrawal 1981	3.64	0.35	-		
Chanu-Daro	P-85	Cu Fragment		AAS	Agrawal 1981	2.82	0.12	0.05		
Chanu-Daro	P-88	Spearhead Fragment		AAS	Agrawal 1981	-	-	0.12		
Chanu-Daro	P-111	Cu Fragment		AAS	Agrawal 1981	0.39	-	-		
Chanu-Daro	P-112	Cu Fragment		AAS	Agrawal 1981	-	2.74	-		
Chanu-Daro	P-114	Cu Fragment		AAS	Agrawal 1981	-	0.87	-		
Chanu-Daro	P-117	Cu Fragment		AAS	Agrawal 1981	-	0.07	-		
Chanu-Daro	P-119	Cu Fragment		AAS	Agrawal 1981	-	0.43	-		
Chanu-Daro	P-120	Cu Fragment		AAS	Agrawal 1981	0.55	1.27	0.28		
Chanu-Daro	P-122	Cu Fragment		AAS	Agrawal 1981	0.38	3.24	-		
Chanu-Daro	P-124	Cu Fragment		AAS	Agrawal 1981	-	-	-		
Chanu-Daro	P-125	Cu Fragment		AAS	Agrawal 1981	0.03	0.33	-		
Chanu-Daro	P-126	Cu Fragment		AAS	Agrawal 1981	9.92	-	-		
Chanu-Daro	P-127	Cu Fragment		AAS	Agrawal 1981	1.42	1.77	-		
Chanu-Daro	P-128	Cu Fragment		AAS	Agrawal 1981	-	0.04	-		
Chanu-Daro	P-129	Cu Fragment		AAS	Agrawal 1981	10.74	0.22	-		
Chanu-Daro	P-176	Cu Fragment		AAS	Agrawal 1981	1.56	0.56	0.28		
Chanu-Daro	P-178	Not Listed		AAS	Nautiyal et al 1981		1.23	4.28		0.24
Chanu-Daro	P-180	Cu Fragment		AAS	Agrawal 1981	-	0.46	0.19		
Chanu-Daro	P-177	Broken Celt		AAS	Agrawal 1981	(none in original analysis) & (present in Agrawal 1995)		1.81	0.26	
Chanu-Daro	P-177	Not Listed		AAS	Nautiyal et al 1981		Not Detected	3.29		Not Detected
Chanu-Daro	P-182	Cu Fragment		AAS	Agrawal 1981	-		2.88	0.22	
Chanu-Daro	P-182	Not Listed	listed as wire in Agrawal 1995	AAS	Nautiyal et al 1981		Not Detected	6.99		0.48

Appendix 2.7
Kalibangan Analyses

Compiled From: Lal et al 2003 and Agrawal 1981

Site	Object #	Description	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Fe	% SiO ₂	% O ₂	Total %
Kalibangan	KLB-1 15228	Copper chisel	Unknown method	Lal et al 2003	97.52	-		1.27	-	-	0.65	0.94	-	100.38
Kalibangan	KLB-1 17575	Copper spear head	Unknown method	Lal et al 2003	53.62	1.8		3.47	-	trace	1.68	4.6	34.83	100.00
Kalibangan	KLB-1 2387	Copper arrow head	Unknown method	Lal et al 2003	83.51	0.22		2.48	trace	-	2.92	-	10.87	100.00
Kalibangan	KLB-1 8249	Copper piece	Unknown method	Lal et al 2003	63.69	2.37		2.34	-	-	3.64	-	27.96	100.00
Kalibangan	KLB-1 8373	Copper piece	Unknown method	Lal et al 2003	56.68	-		0.4	-	-	8.5	5.57	28.85	100.00
Kalibangan	KLB-2 14983	Copper celt	Unknown method	Lal et al 2003	96.86	-		0.54	-	-	1.64	0.39	0.57	100.00
Kalibangan	KLB-2 15294	Copper needle	Unknown method	Lal et al 2003	94.27	-		1.37	-	-	1.38	2	0.98	100.00
Kalibangan	KLB-2 15294	Copper long spear head	Unknown method	Lal et al 2003	53.37	0.17		2.05	trace	3.4	0.22	4.72	36.07	100.00
Kalibangan	KLB-2 16930	Copper chisel	Unknown method	Lal et al 2003	93.53	-		2.46	trace	trace	2.33	-	1.68	100.00
Kalibangan	KLB-2 16948	Copper bar, celt, or chisel	Unknown method	Lal et al 2003	85.00	6.08		1.5	trace	trace	2.57	1.24	3.61	100.00
Kalibangan	KLB-2 1980	Copper ring	Unknown method	Lal et al 2003	98.97	-		-	-	-	1.04	-	-	100.01
Kalibangan	KLB-2 2857	Copper piece	Unknown method	Lal et al 2003	37.16	1.65		2.07	-	-	2.6	3.4	53.12	100.00
Kalibangan	KLB-2 4649	Copper piece	Unknown method	Lal et al 2003	96.18	1.46		1.27	trace	-	1.94	-	-	100.85
Kalibangan	KLB-2 4778	Copper antimony rod	Unknown method	Lal et al 2003	75.75	0.68		1.56	nil	trace	1.2	7.75	13.06	100.00
Kalibangan	KLB-2 4852	Copper antimony rod	Unknown method	Lal et al 2003	73.62	3.85		0.67	nil	trace	1.37	10.29	10.2	100.00
Kalibangan	KLB-2 683	Copper object	Unknown method	Lal et al 2003	95.18	0.2		1.63	trace	trace	2.68	-	0.31	100.00
Kalibangan	KLB-2 8502	Copper plate (broken)	Unknown method	Lal et al 2003	30.05	0.59		1.75	-	-	1.38	9.4	56.83	100.00
Kalibangan	KLB-2 8600	Copper object	Unknown method	Lal et al 2003	99.26	-		-	-	-	-	-	0.74	100.00
Kalibangan	KLB-2 8692	Copper rod	Unknown method	Lal et al 2003	82.26	0.32		2.06	trace	-	4.14	-	11.22	100.00
Kalibangan	P-89	Cu Fragment	AAS	Agrawal 1981		0.31	1.22	0.85						
Kalibangan	P-90	Cu Ring Piece	AAS	Agrawal 1981		2.18	-	-						
Kalibangan	P-91	Bangle Fragment	AAS	Agrawal 1981		0.2	1.37	4.12						
Kalibangan	P-92	Cu Piece	AAS	Agrawal 1981		2.21	-	-						
Kalibangan	P-93	Cu Piece	AAS	Agrawal 1981		0.08	0.66	-						
Kalibangan	P-94	Cu Piece	AAS	Agrawal 1981		0.1	0.1	-						
Kalibangan	P-95	Cu Piece	AAS	Agrawal 1981		3.48	0.74	0.74						
Kalibangan	P-96	Cu Bead	AAS	Agrawal 1981		0.04	0.24	1						

Appendix 2.8
Rangpur Analyses

Compiled From Rao 1963

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% Ag	% O ₂
Rangpur	RP 141	pin, needle		Unknown method	Rao 1963	65.40	6.78	-	-	0.51	-	-	0.24	-	27.08
Rangpur	RP 169	bangle		Unknown method	Rao 1963	57.70	6.94	-	-	tr	-	-	tr	-	35.46
Rangpur	RP 170	amulet		Unknown method	Rao 1963	77.60	tr	-	-	0.10	-	-	0.57	-	21.73
Rangpur	RP 260	bead		Unknown method	Rao 1963	96.66	tr	-	-	0.38	-	-	1.4	-	1.56
Rangpur	RP 324	celt		Unknown method	Rao 1963	91.2	2.60	-	tr	2.10	-	-	-	-	4.1
Rangpur	RP 330	Pin (period III)	Not Harappan period	Unknown method	Rao 1963	91.8	0.6	-	-	5.88	-	-	1.88	-	-
Rangpur	RP 417	knife		Unknown method	Rao 1963	94.80	0.70	-	-	0.40	-	-	tr	-	4.1
Rangpur	RP 437	bangle		Unknown method	Rao 1963	86.40	11.07	tr	tr	1.80	-	-	-	-	0.73
Rangpur	RP 442	pin, rolled head		Unknown method	Rao 1963	96.60	tr	-	-	0.80	-	-	1.86	-	0.74
Rangpur	RP 525	knife		Unknown method	Rao 1963	59.60	2.69	-	-	-	-	-	1.08	-	36.63
Rangpur	RP 526	knife		Unknown method	Rao 1963	59.00	5.28	-	-	tr	-	-	tr	-	35.72
Rangpur	RP 635	ring, finger		Unknown method	Rao 1963	96.10	tr	-	-	0.20	-	-	0.45	-	3.25
Rangpur	RP 663	celt		Unknown method	Rao 1963	91.35	4.09	tr	tr	tr	-	-	-	-	4.6

Appendix 2.9
Dholavira Analyses

Compiled from Bourgarit et al 2005

Site	Object #	Description	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% Sb	% Fe	% Bi	% Co	% Au	% Ag
Dholavira	L 29537	Copper Pin Fragment	PIXE	Bourgarit et al 2005	95.8	<0.1	3.3	<0.1	0.4	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1
Dholavira	L 29830	Copper Waste	PIXE	Bourgarit et al 2005	98.3	<0.1	0.8	<0.1	0.2	<0.1	<0.1	0.5	<0.1	0.1	<0.1	<0.1

Appendix 2.10
Navinal Analyses

Compiled From Patel et al 2014

Site	Object #	Description	Analysis Method	Original Publication	% Cu	% Sn	% As	% Pb	% Ni	% Zn	% S	% Cl	% O ₂
Navinal	NVL 16	Sheet/Blade	SEM-EDS	Patel et al 2014	90.07	0.14	-	-		0.58	-	5.70	3.51
Navinal	NVL 2.1	Sheet/Strip	SEM-EDS	Patel et al 2014	82.64	0.80	-	-	-	-		2.99	3.57
Navinal	NVL 29	Wire	SEM-EDS	Patel et al 2014	65.99	5.79	2.37	0.52		2.23	-	1.18	21.36
Navinal	NVL 35	Ring	SEM-EDS	Patel et al 2014	55.87	14.59	1.17	0.51		1.10	0.38	0.65	20.19
Navinal	NVL 36	Ring	SEM-EDS	Patel et al 2014	85.20	0.75	-	1.91		0.32	-	-	11.82
Navinal	NVL 38	Nail	SEM-EDS	Patel et al 2014	86.11	0.30	-	4.27	-	-		2.16	6.22
Navinal	NVL 39	Wire	SEM-EDS	Patel et al 2014	85.02	0.07	1.38	0.28		0.84	-	-	4.86
Navinal	NVL 41	Hook	SEM-EDS	Patel et al 2014	76.89	0.07	1.77	-	-	-		0.38	5.59
Navinal	NVL 44	bead	SEM-EDS	Patel et al 2014	62.09	0.42	-	-		0.42	-	5.28	19.10
Navinal	NVL 53	Folded Sheet/Tube	SEM-EDS	Patel et al 2014	67.53	0.42	-	-		3.95	-	11.61	16.49

Appendix 2.11
Kuntasi and Farmana Analyses

Compiled From Park and Shinde 2014

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Sn	% As	% Pb	% Ni	% Zn	% Fe	% S
Kuntasi	5589	Ring	#1 in Table 2. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	7.0	-	-	-	0.5	0.5
Kuntasi	4777	Rings	#2 in Table 2. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	5.5	-	1.0	-	0.5	1.0
Kuntasi	2107	Spearhead Blade	#3 in Table 2. Severely cold worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	4.5	-	-	-	0.5	0.5
Kuntasi	2107	Spearhead Tail	#3 in Table 2. Severely cold worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	6.0	-	-	-	0.5	trace
Kuntasi	5564	Ring	#4 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	5.5	-	0.5	-	0.5	0.5
Kuntasi	5621	Blade	#5 in Table 2. Severely worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.0	-	-	-	0.5	1.0
Kuntasi	5734	U-shaped rod	#6 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	2.0	-	-	-	-	trace
Kuntasi	5723	Casting splatter	#7 in Table 2. Cast	SEM-EDS	Park and Shinde 2014	-	1.5	-	0.5	-	trace	0.5
Kuntasi	5612	Awl	#8 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	1.0	-	-	-	0.5	trace
Kuntasi	4960	Double spiral	#9 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	1.0	-	1.0	-	-	0.5
Kuntasi	5101	Bangle	#10 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	0.5	-	-	-	-	0.5
Kuntasi	4819	Ring	#11 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	7.5	0.5	-	-	-	-	0.5
Kuntasi	4819	Ring	#12 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	7.0	0.5	-	-	-	-	0.5
Kuntasi	4819	Ring	#13 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	6.5	0.5	-	-	-	-	0.5
Kuntasi	5161	Blade	#14 in Table 2. Severely worked and annealed	SEM-EDS	Park and Shinde 2014	5.5	2.5	-	-	-	0.5	0.5
Kuntasi	NA	Sheet fragment	#15 in Table 2. Severely worked and fully annealed	SEM-EDS	Park and Shinde 2014	5.5	2.0	-	-	-	0.5	0.5
Kuntasi	5623	Bangle	#16 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	5.0	1.0	4.0	-	-	-	1.0
Kuntasi	5623	Ring	#17 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	4.0	-	-	-	-	-	0.5
Kuntasi	5623	Ring	#18 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	4.0	-	-	-	-	-	0.5
Kuntasi	5617	Curved plate	#19 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	3.0	1.5	-	-	-	0.5	0.5
Kuntasi	5486	Fishhook	#20 in Table 2. Worked and fully annealed	SEM-EDS	Park and Shinde 2014	2.5	2.0	-	-	-	-	0.5
Kuntasi	5623	Ring	#21 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	2.0	3.5	-	-	-	-	0.5
Kuntasi	5623	Ring	#22 in Table 2. Worked and annealed	SEM-EDS	Park and Shinde 2014	2.0	3.5	-	-	-	-	0.5
Kuntasi	526	Ring	#23 in Table 2. Forged	SEM-EDS	Park and Shinde 2014	0.5	-	-	0.5	-	-	trace
Kuntasi	5568	Axe	#24 in Table 2. Cast and fully annealed; intermediary	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	1.5
Kuntasi	4278	Tube (bead)	#25 in Table 2. Cast and fully annealed	SEM-EDS	Park and Shinde 2014	0.5	2.0	14.0	-	6.5	1.5	1.0
Farmana	1F308008	Ring	#1 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	7.5	-	-	-	trace	trace
Farmana	0307015	Rod	#2 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	7.0	-	-	-	-	1
Farmana	1B308009	Bangle	#3 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	5.5	-	-	-	-	0.5
Farmana	1B308009	Rod in 2 pieces	#4 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	4.5	-	-	-	-	-
Farmana	3T1709002	Rod	#5 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	4.0	-	-	-	-	1.0
Farmana	1D208009	Ring	#6 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	4.0	-	-	-	-	0.5
Farmana	3TI709007	Rod	#7 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.5	-	-	-	-	1.5
Farmana	1F108005	Plate	#8 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.5	-	-	-	-	0.5
Farmana	2D909006	Rod	#9 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	1.0	3.5	-	-	-	-	0.5
Farmana	2XD4005	Plate axe	#10 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.0	-	1.0	-	-	0.5
Farmana	Surface	Bangle	#11 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.0	-	-	-	0.5	0.5
Farmana	3Z1709023	Ring	#12 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	3.0	-	-	-	-	0.5
Farmana	Surface	Bangle	#13 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	3.0	-	-	-	0.5	0.5
Farmana	1C1109011	Rod	#14 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	2.5	-	-	-	-	1.5
Farmana	1F308007(v1)	Wire	#15 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	2.0	-	-	-	-	0.5
Farmana	1F308008	Rod	#16 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	1.0	-	-	-	-	1.0

Appendix 2.11
Kuntasi and Farmana Analyses

Compiled From Park and Shinde 2014

Site	Object #	Description	Notes	Analysis Method	Original Publication	% Sn	% As	% Pb	% Ni	% Zn	% Fe	% S
Farmana	2XE409031	Ring	#17 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014		1.0	-	-	-	-	0.5
Farmana	BAO1k	Rod	#18 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014		0.5	-	-	-	-	1.0
Farmana	3U1809013	Ring	#19 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	0.5
Farmana	3X08005	Ring	#20 in Table 1. Worked and partially annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	1.5
Farmana	2XE50902	Bangle	#21 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	0.5
Farmana	2C909006	U rod	#22 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	0.5
Farmana	1C408003	Rod	#23 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	0.5
Farmana	1D809015	Rod	#24 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	0.5
Farmana	2C510005	Rod	#25 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	-
Farmana	2XD509006	Fish hook	#26 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	-
Farmana	1B308009	Bangle	#27 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-	-	-	-	-	-	-
Farmana	1A909006	Flat rod	#28 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014		1.0	trace		23.0	-	-
Farmana	1B1009003	Bangle	#29 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-		trace		22.0	0.5	0.5
Farmana	1D1109001	Ring	#30 in Table 1. Cast and annealed	SEM-EDS	Park and Shinde 2014	-		6.0		20.0	-	0.5
Farmana	1F809007	Bangle	#31 in Table 1. Worked and annealed	SEM-EDS	Park and Shinde 2014	-		trace		16.5	-	0.5

Appendix 3.1

This appendix is listing of all three hundred sixty Harappa Archaeological Research Project (HARP) copper/bronze artifact, ore, and slag samples.

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1986/Surface-A	H1986	Surface	A	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-B_face	H1986	Surface	B/Face	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-B_lrg	H1986	Surface	B/Large	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-C	H1986	Surface	C	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-D	H1986	Surface	D	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-E	H1986	Surface	E	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-F	H1986	Surface	F	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-G	H1986	Surface	G	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-H	H1986	Surface	H	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-I	H1986	Surface	I	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-J	H1986	Surface	J	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-K	H1986	Surface	K	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-L	H1986	Surface	L	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1986/Surface-M	H1986	Surface	M	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1987/11-37	H1987	11	37	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1987/20-2	H1987	20	2	AB	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1987/322-19	H1987	322	19	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1987/505-37	H1987	505	37	AB	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1987/515-	H1987	515		AB	3C	Harappan	Copper Sheet/Blade	Scoop
H1987/Surface-AB	H1987	Surface	AB	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1988/325-8A	H1988	325	8A	E	3C	Harappan	Copper Misc. Fragment	
H1988/325-8B	H1988	325	8B	E	3C	Harappan	Copper Misc. Fragment	
H1988/325-8C	H1988	325	8C	E	3C	Harappan	Copper Misc. Fragment	
H1988/325-8D	H1988	325	8D	E	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1988/325-8E	H1988	325	8E	E	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1988/341-2	H1988	341	2	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1988/346-27	H1988	346	27	E	3C	Harappan	Copper Bead	TBD
H1988/353-5	H1988	353	5	E	3C	Harappan	Copper Misc. Fragment	

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1988/374-1	H1988	374	1	E	3C	Harappan	Copper Rod/Wire/Pin	Hook
H1988/413-A	H1988	413	A	R37	3B	Harappan	Copper Ring	TBD
H1988/413-B	H1988	413	B	R37	3B	Harappan	Copper Misc. Fragment	
H1988/413-C	H1988	413	C	R37	3B	Harappan	Copper Misc. Fragment	
H1988/444-1	H1988	444	1	R37	3B	Harappan	Copper Mirror	TBD
H1988/532-4	H1988	532	4	AB	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1988/532-5	H1988	532	5	AB	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1988/539-11	H1988	539	11	AB	3C	Harappan	Copper Misc. Fragment	
H1988/539-11B	H1988	539	11B	AB	3C	Harappan	Copper Misc. Fragment	
H1988/725-3	H1988	725	3	E	3C	Harappan	Copper Misc. Fragment	
H1988/725-47	H1988	725	47	E	3C	Harappan	Copper Misc. Fragment	
H1988/730-1	H1988	730	1	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1988/751-21	H1988	751	21	E	3C	Harappan	Copper Arrow Point	Arrow
H1988/754-2	H1988	754	2	E	3A	Harappan	Copper Misc. Fragment	
H1988/758-1	H1988	758	1	E	3A/B	Harappan	Copper Misc. Fragment	
H1988/758-16	H1988	758	16	E	3A/B	Harappan	Copper Misc. Fragment	
H1988/761-1A	H1988	761	1A	E	2/3	KD/Harp Trans.	Copper Rod/Wire/Pin	Needle
H1988/761-1B	H1988	761	1B	E	2/3	KD/Harp Trans.	Copper Rod/Wire/Pin	TBD
H1988/766-28	H1988	766	28	E	3B	Harappan	Copper Misc. Fragment	
H1989/1009-8	H1989	1009	8	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1989/1009-9	H1989	1009	9	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1989/1038-13	H1989	1038	13	AB/E	3	Harappan	Copper Misc. Fragment	
H1989/1038-14	H1989	1038	14	AB/E	3	Harappan	Copper Rod/Wire/Pin	TBD
H1989/1038-13B	H1989	1038	13B	AB/E	3	Harappan	Copper Misc. Fragment	
H1989/1054-24	H1989	1054	24	E	2/3	KD/Harp Trans.	Copper Misc. Fragment	
H1989/2006-7	H1989	2006	7	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1989/2006-8	H1989	2006	8	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/1171-22	H1990	1171	22	E	2/3	KD/Harp Trans.	Copper Sheet/Blade	TBD
H1990/1185-1A	H1990	1185	1A	E	2	Kot Diji	Copper Sheet/Blade	TBD
H1990/1185-1C	H1990	1185	1C	E	2	Kot Diji	Copper Rod/Wire/Pin	TBD
H1990/2070-12	H1990	2070	12	E	Mixed	Harp.-Hist.	Slag and Mineral	Mineral
H1990/3000-D	H1990	3000	D	Other	Surface	Unk.	Copper Rod/Wire/Pin	TBD

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1990/3003-12	H1990	3003	12	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3008-13	H1990	3008	13	E	Mixed	Harp.-Hist.	Slag and Mineral	Mineral
H1990/3008-14	H1990	3008	14	E	Mixed	Harp.-Hist.	Slag and Mineral	Mineral
H1990/3014-24	H1990	3014	24	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Square/Chisel
H1990/3014-23A	H1990	3014	23A	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1990/3014-23B	H1990	3014	23B	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3014-23C	H1990	3014	23C	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3014-23D	H1990	3014	23D	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3022-98	H1990	3022	98	E	Mixed	Harp.-Hist.	Slag and Mineral	Mineral
H1990/3025-20	H1990	3025	20	E	Mixed	Harp.-Hist.	Copper Bead	TBD
H1990/3025-21	H1990	3025	21	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1990/3037-3	H1990	3037	3	E	3B	Harappan	Copper Misc. Fragment	
H1990/3037-4	H1990	3037	4	E	3B	Harappan	Copper Misc. Fragment	
H1990/3038-23	H1990	3038	23	E	3B	Harappan	Copper Misc. Fragment	
H1990/3044-1	H1990	3044	1	E	3B	Harappan	Copper Misc. Fragment	
H1990/3056-3	H1990	3056	3	E	3B	Harappan	Copper Rod/Wire/Pin	TBD
H1990/3056-30	H1990	3056	30	E	3B	Harappan	Copper Rod/Wire/Pin	TBD
H1990/3059-11	H1990	3059	11	E	3C	Harappan	Copper Bead	TBD
H1990/3072-4	H1990	3072	4	E	3C	Harappan	Copper Bead	TBD
H1990/3072-5	H1990	3072	5	E	3C	Harappan	Copper Misc. Fragment	
H1990/3074-1	H1990	3074	1	E	3C	Harappan	Copper Sheet/Blade	TBD
H1990/3076-2	H1990	3076	2	E	3C	Harappan	Copper Misc. Fragment	
H1990/3078-1	H1990	3078	1	E	3B/C	Harappan	Copper Rod/Wire/Pin	TBD
H1990/3087-19	H1990	3087	19	E	3B	Harappan	Copper Sheet/Blade	TBD
H1990/3095-7	H1990	3095	7	E	3C	Harappan	Copper Bangle	TBD
H1990/3101-20	H1990	3101	20	E	3C	Harappan	Copper Misc. Fragment	
H1990/3101-21	H1990	3101	21	E	3C	Harappan	Copper Misc. Fragment	
H1990/3115-24	H1990	3115	24	E	3C	Harappan	Copper Prill	
H1990/3122-3	H1990	3122	3	E	3B	Harappan	Copper Misc. Fragment	
H1990/3124-1	H1990	3124	1	E	3B	Harappan	Copper Misc. Fragment	
H1990/3126-1	H1990	3126	1	E	3C	Harappan	Slag and Mineral	Mineral
H1990/3127-1	H1990	3127	1	E	3B	Harappan	Copper Sheet/Blade	TBD
H1990/3135-14	H1990	3135	14	E	3B/C	Harappan	Copper Ring	TBD
H1990/3150-3	H1990	3150	3	E	3C	Harappan	Copper Rod/Wire/Pin	TBD

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1990/3153-19	H1990	3153	19	E	3B	Harappan	Copper Bangle	TBD
H1990/3153-24	H1990	3153	24	E	3B	Harappan	Copper Rod/Wire/Pin	TBD
H1990/3189-24	H1990	3189	24	E	Mixed	Harp.-Hist.	Copper Bangle	TBD
H1990/3191-13	H1990	3191	13	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3191-14	H1990	3191	14	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3191-15	H1990	3191	15	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3242-1	H1990	3242	1	E	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1990/3247-30	H1990	3247	30	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3247-39	H1990	3247	39	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1990/3257-4	H1990	3257	4	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H1990/3257-5	H1990	3257	5	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H1990/3273-26	H1990	3273	26	E	3C	Harappan	Copper Sheet/Blade	TBD
H1993/3650-1	H1993	3650	1	E	3A/B	Harappan	Copper Arrow Point	Arrow
H1993/3803-2	H1993	3803	2	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H1993/3812-1	H1993	3812	1	E	3C	Harappan	Copper Arrow Point	Arrow
H1993/3812-12	H1993	3812	12	E	3C	Harappan	Copper Arrow Point	Arrow
H1993/3812-14	H1993	3812	14	E	3C	Harappan	Copper Rod/Wire/Pin	Round
H1993/3875-1	H1993	3875	1	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H1993/4074-10	H1993	4074	10	ET	3B/C	Harappan	Copper Rod/Wire/Pin	square w/taper
H1993/4074-9A	H1993	4074	9A	ET	3B/C	Harappan	Copper Rod/Wire/Pin	square
H1993/4074-9B	H1993	4074	9B	ET	3B/C	Harappan	Copper Rod/Wire/Pin	unclear/taper to point
H1993/4098-20	H1993	4098	20	ET	3B	Harappan	Copper Arrow Point	Arrow
H1993/4099-5	H1993	4099	5	ET	3B	Harappan	Copper Prill	
H1994/3909-1	H1994	3909	1	E	3C	Harappan	Copper Sheet/Blade	TBD
H1994/3978-1	H1994	3978	1	ET	2/3A	KD/Harp Trans.	Copper Ring	Solid-flat-single coil
H1994/3990-15	H1994	3990	15	E	3C	Harappan	Copper Sheet/Blade	TBD
H1994/3994-5	H1994	3994	5	E	3C	Harappan	Copper Misc. Fragment	
H1994/4297-1	H1994	4297	1	ET	3C	Harappan	Copper Prill	
H1994/4297-2	H1994	4297	2	ET	3C	Harappan	Copper Prill	
H1994/4353-2	H1994	4353	2	E	3C	Harappan	Copper Prill	
H1994/4353-3	H1994	4353	3	E	3C	Harappan	Copper Sheet/Blade	TBD
H1994/4375-8	H1994	4375	8	E	3C	Harappan	Copper Sheet/Blade	TBD
H1994/4509-1	H1994	4509	1	ET	3B	Harappan	Copper Bangle	Round-solid

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1994/4544-13	H1994	4544	13	ET	3B	Harappan	Copper Bangle	Round-hollow
H1994/4557-8	H1994	4557	8	ET	Mixed	Harp.-Hist.	Copper Prill	
H1994/4999-529	H1994	4999	529	Surface	Unk.	Unk.	Slag and Mineral	Mineral
H1994/5421-1	H1994	5421	1	ET	3B	Harappan	Copper Ring	Solid-round-single coil
H1994/5433-9	H1994	5433	9	ET	3B	Harappan	Copper Misc. Fragment	
H1994/5433-10	H1994	5433	10	ET	3B	Harappan	Copper Misc. Fragment	
H1994/5434-1	H1994	5434	1	ET	3B	Harappan	Copper Arrow Point	Arrow
H1994/5476-1	H1994	5476	1	ET	3B	Harappan	Copper Arrow Point	Arrow
H1995/4416-54	H1995	4416	54	E	3C	Harappan	Copper Ring	Solid-round-single coil
H1995/4451-8	H1995	4451	8	E	3C	Harappan	Copper Prill	
H1995/4606-9	H1995	4606	9	ET	3B	Harappan	Copper Rod/Wire/Pin	flat/taper
H1995/4609-76	H1995	4609	76	ET	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	pointed tip
H1995/4613-54	H1995	4613	54	ET	3B	Harappan	Copper Arrow Point	Arrow
H1995/4623-17	H1995	4623	17	ET	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1995/4623-18	H1995	4623	18	ET	Mixed	Harp.-Hist.	Copper Bead	Round
H1995/4623-19	H1995	4623	19	ET	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square
H1995/4623-20	H1995	4623	20	ET	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	round/curved
H1995/4623-37	H1995	4623	37	ET	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square/flat
H1995/4638-1	H1995	4638	1	ET	3	Harappan	Copper Bangle	Round-Solid
H1995/4649-1	H1995	4649	1	ET	3B	Harappan	Copper Misc. Fragment	
H1995/4651-26	H1995	4651	26	ET	Mixed	Harp.-Hist.	Copper Prill	
H1995/4661-2	H1995	4661	2	ET	3B	Harappan	Copper Sheet/Blade	TBD
H1995/4663-1	H1995	4663	1	ET	Mixed	Harp.-Hist.	Copper Tablet (Molded)	Tablet
H1995/4663-2	H1995	4663	2	ET	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Round
H1995/4943-8	H1995	4943	8	ET	Mixed	Harp.-Hist.	Slag and Mineral	Mineral
H1995/4953-45	H1995	4953	45	ET	3C	Harappan	Copper Rod/Wire/Pin	square
H1995/4953-46	H1995	4953	46	ET	3C	Harappan	Copper Rod/Wire/Pin	square
H1995/4953-47	H1995	4953	47	ET	3C	Harappan	Copper Misc. Fragment	
H1995/4968-12	H1995	4968	12	ET	3C	Harappan	Copper Bangle	Round-Solid
H1995/4982-223	H1995	4982	223	ET	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1995/4989-75	H1995	4989	75	ET	3C	Harappan	Copper Prill	
H1995/5145-19	H1995	5145	19	E	3C	Harappan	Copper Prill	
H1995/5145-175	H1995	5145	175	E	3C	Harappan	Copper Rod/Wire/Pin	square w/taper
H1995/5182-42	H1995	5182	42	E	3C	Harappan	Copper Prill	

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1995/5182-43	H1995	5182	43	E	3C	Harappan	Copper Prill	
H1995/5182-44	H1995	5182	44	E	3C	Harappan	Copper Prill	
H1995/5182-46	H1995	5182	46	E	3C	Harappan	Copper Arrow Point	Arrow
H1995/5603-21	H1995	5603	21	ET	Mixed	Harp.-Hist.	Copper Bangle	Round-hollow
H1995/5641-21	H1995	5641	21	ET	3B	Harappan	Copper Arrow Point	Arrow
H1995/5680-17	H1995	5680	17	ET	3B	Harappan	Copper Misc. Fragment	
H1995/5706-8	H1995	5706	8	ET	Mixed	Harp.-Hist.	Copper Prill	
H1995/5729-113	H1995	5729	113	ET	3C	Harappan	Copper Bead	Cylinder
H1995/5751-26	H1995	5751	26	ET	3C	Harappan	Copper Sheet/Blade	TBD
H1995/5766-37	H1995	5766	37	ET	3C	Harappan	Copper Sheet/Blade	TBD
H1995/5789-1	H1995	5789	1	ET	3C	Harappan	Copper Bead	Cylinder
H1995/6509-1	H1995	6509	1	E	2	Kot Diji	Copper Rod/Wire/Pin	TBD
H1995/6509-112	H1995	6509	112	E	2	Kot Diji	Copper Bead	TBD
H1995/6543-65	H1995	6543	65	E	Unk.	Unk.	Copper Arrow Point	Arrow
H1995/7000-10	H1995	7000	10	AB	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H1996/6226-57	H1996	6226	57	ET	3C	Harappan	Copper Prill	
H1996/6237-56	H1996	6237	56	ET	3C	Harappan	Copper Prill	
H1996/6237-57	H1996	6237	57	ET	3C	Harappan	Copper Prill	
H1996/6237-58	H1996	6237	58	ET	3C	Harappan	Copper Prill	
H1996/6242-4	H1996	6242	4	ET	Mixed	Harp.-Hist.	Copper Prill	
H1996/6256-8	H1996	6256	8	ET	3C	Harappan	Copper Arrow Point	Arrow
H1996/6304-6	H1996	6304	6	ET	3C	Harappan	Copper Misc. Fragment	
H1996/6908-8	H1996	6908	8	E	Mixed	Harp.-Hist.	Copper Prill	
H1996/6913-45	H1996	6913	45	E	3B/C	Harappan	Copper Bangle	Flat-Solid
H1996/6920-43	H1996	6920	43	E	3C	Harappan	Copper Arrow Point	Arrow
H1996/6930-8	H1996	6930	8	E	3C	Harappan	Copper Prill	
H1996/6945-30	H1996	6945	30	E	3C	Harappan	Copper Sheet/Blade	TBD
H1996/6949-19	H1996	6949	19	E	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1996/6958-60	H1996	6958	60	E	3B	Harappan	Copper Rod/Wire/Pin	square w/taper
H1996/6958-60	H1996	6958	61	E	3B	Harappan	Copper Rod/Wire/Pin	square tapered w/pointed tip
H1996/6958-62	H1996	6958	62	E	3B	Harappan	Copper Rod/Wire/Pin	Round
H1996/6958-131	H1996	6958	131	E	3B	Harappan	Copper Rod/Wire/Pin	Round
H1996/6966-14	H1996	6966	14	E	3C	Harappan	Copper Arrow Point	Arrow
H1996/7106-34	H1996	7106	34	E	3C	Harappan	Copper Arrow Point	Arrow

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1996/7126-1	H1996	7126	1	E	3C	Harappan	Copper Prill	
H1996/7200-36	H1996	7200	36	F	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square
H1996/7210-11	H1996	7210	11	F	3C	Harappan	Copper Bangle	Round-hollow
H1996/7211-34	H1996	7211	34	F	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Round
H1996/7227-32	H1996	7227	32	F	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square flat point tool
H1996/7232-2	H1996	7232	2	F	3C	Harappan	Copper Rod/Wire/Pin	round/curved
H1996/7232-65	H1996	7232	65	F	3C	Harappan	Copper Misc. Fragment	
H1996/7236-1	H1996	7236	1	F	3C	Harappan	Copper Misc. Fragment	
H1996/7241-16	H1996	7241	16	F	3C	Harappan	Copper Sheet/Blade	TBD
H1996/7248-1	H1996	7248	1	F	3C	Harappan	Copper Rod/Wire/Pin	Wire or Pin
H1996/7257-1	H1996	7257	1	F	3B	Harappan	Copper Misc. Fragment	
H1996/7291-2	H1996	7291	2	F	3B	Harappan	Copper Arrow Point	Arrow
H1996/7293-1	H1996	7293	1	F	3B	Harappan	Copper Arrow Point	Arrow
H1996/7400-47	H1996	7400	47	AB	3A	Harappan	Copper Ring	Solid-round-single coil
H1996/7410-4	H1996	7410	4	AB	3A	Harappan	Copper Ring	TBD
H1996/7431-2	H1996	7431	2	AB	2	Kot Diji	Copper Sheet/Blade	TBD
H1996/7457-1	H1996	7457	1	AB	2	Kot Diji	Copper Prill	
H1996/7467-962	H1996	7467	962	AB	3A	Harappan	Copper Ring	Solid-round-single coil
H1996/7467-963	H1996	7467	963	AB	3A	Harappan	Copper Rod/Wire/Pin	Round
H1996/7467-965	H1996	7467	965	AB	3A	Harappan	Copper Rod/Wire/Pin	square
H1996/7490-32	H1996	7490	32	AB	2	Kot Diji	Copper Arrow Point	Arrow
H1996/7509-2	H1996	7509	2	AB	1	Ravi	Copper Misc. Fragment	
H1996/7512-9	H1996	7512	9	AB	1	Ravi	Copper Misc. Fragment	
H1996/7513-59	H1996	7513	59	AB	1	Ravi	Copper Bead	Round
H1996/7516-78	H1996	7516	78	AB	1	Ravi	Copper Prill	
H1996/7531-9	H1996	7531	9	AB	1	Ravi	Copper Misc. Fragment	
H1997/6650-6	H1997	6650	6	ET	3C	Harappan	Copper Ring	Solid-round-single coil
H1997/6655-20	H1997	6655	20	ET	3C	Harappan	Copper Rod/Wire/Pin	Round
H1997/6660-30	H1997	6660	30	ET	3B	Harappan	Copper Disc	TBD
H1997/6688-1	H1997	6688	1	ET	3B	Harappan	Copper Rod/Wire/Pin	Round
H1997/7623-1	H1997	7623	1	F	Unk.	Unk.	Copper Rod/Wire/Pin	Round
H1997/7755-1	H1997	7755	1	AB	3A	Harappan	Copper Sheet/Blade	Denticulated Saw
H1997/8012-16	H1997	8012	16	E	3B	Harappan	Copper Prill	
H1997/8017-61	H1997	8017	61	E	3B	Harappan	Copper Bead	TBD

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1997/8017-62	H1997	8017	62	E	3B	Harappan	Copper Rod/Wire/Pin	square
H1997/8019-1	H1997	8019	1	E	3B	Harappan	Copper Ring	Solid-round-single coil
H1997/8022-24	H1997	8022	24	E	3C	Harappan	Copper Arrow Point	Arrow
H1997/8022-25	H1997	8022	25	E	3C	Harappan	Copper Rod/Wire/Pin	square/flat
H1997/8026-13	H1997	8026	13	E	3B	Harappan	Copper Arrow Point	Arrow
H1997/8059-19	H1997	8059	19	E	3B	Harappan	Copper Bead	Cylinder
H1997/8103-5	H1997	8103	5	E	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1997/8103-6	H1997	8103	6	E	3C	Harappan	Copper Prill	
H1997/8103-7	H1997	8103	7	E	3C	Harappan	Copper Misc. Fragment	
H1997/8110-8	H1997	8110	8	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1997/8133-1	H1997	8133	1	E	Unk.	Unk.	Copper Prill	
H1997/8248-1	H1997	8248	1	E	3C	Harappan	Copper Rod/Wire/Pin	square
H1988/529-120	H1998	529	120	Unk.	Unk.	Unk.	Copper Misc. Fragment	
H1998/8172-2	H1998	8172	2	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H1998/8172-80	H1998	8172	80	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H1998/8314-23	H1998	8314	23	AB	3C	Harappan	Copper Arrow Point	Arrow
H1998/8314-44	H1998	8314	44	AB	3C	Harappan	Copper Arrow Point	Arrow
H1998/8336-68	H1998	8336	68	AB	3C	Harappan	Copper Rod/Wire/Pin	square/flat
H1998/8355-64	H1998	8355	64	AB	3B	Harappan	Copper Rod/Wire/Pin	Round
H1998/8407-36	H1998	8407	36	AB	2	Kot Diji	Copper Rod/Wire/Pin	round/curved
H1998/8412-23	H1998	8412	23	AB	3	Harappan	Copper Prill	
H1998/8412-24	H1998	8412	24	AB	3	Harappan	Copper Prill	
H1998/8412-122	H1998	8412	122	AB	3	Harappan	Copper Prill	
H1998/8412-123	H1998	8412	123	AB	3	Harappan	Copper Prill	
H1998/8422-15	H1998	8422	15	AB	3	Harappan	Copper Sheet/Blade	TBD
H1998/8432-8	H1998	8432	8	AB	2	Kot Diji	Copper Prill	
H1998/8433-37	H1998	8433	37	AB	2	Kot Diji	Copper Rod/Wire/Pin	square
H1998/8439-58	H1998	8439	58	AB	3	Harappan	Copper Arrow Point	Arrow
H1998/8455-1	H1998	8455	1	AB	2	Kot Diji	Copper Sheet/Blade	TBD
H1998/8483-1	H1998	8483	1	AB	3A	Harappan	Copper Disc	TBD
H1998/8486-5	H1998	8486	5	AB	2	Kot Diji	Copper Misc. Fragment	
H1998/8487-1	H1998	8487	1	AB	2	Kot Diji	Copper Bangle	Round-hollow
H1998/8488-11	H1998	8488	11	AB	2	Kot Diji	Copper Bangle	Round-hollow
H/1998/8488-12	H1998	8488	12	AB	2	Kot Diji	Copper Misc. Fragment	

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H1998/8488-13	H1998	8488	13	AB	2	Kot Diji	Copper Misc. Fragment	
H1998/8500-17	H1998	8500	17	AB	1	Ravi	Copper Rod/Wire/Pin	square
H1998/8506-3	H1998	8506	3	AB	1	Ravi	Copper Rod/Wire/Pin	Round
H1998/8522-1	H1998	8522	1	AB	1	Ravi	Copper Sheet/Blade	TBD
H1998/8562-36	H1998	8562	36	AB	1	Ravi	Copper Misc. Fragment	
H1998/8604-12	H1998	8604	12	F	3C	Harappan	Copper Prill	
H1998/8627-18	H1998	8627	18	F	3C	Harappan	Copper Rod/Wire/Pin	Square point tool
H1998/8657-4	H1998	8657	4	F	3C	Harappan	Copper Rod/Wire/Pin	square/flat
H1999/8492-116	H1999	8492	116	AB	2	Kot Diji	Copper Bangle	Flat-hollow
H1999/8753-1	H1999	8753	1	F	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1999/8754-43	H1999	8754	43	F	3C	Harappan	Copper Rod/Wire/Pin	Round
H1999/8768-88	H1999	8768	88	F	3C	Harappan	Copper Rod/Wire/Pin	square
H1999/8776-4	H1999	8776	4	F	3C	Harappan	Copper Rod/Wire/Pin	round/curved
H1999/8776-5	H1999	8776	5	F	3C	Harappan	Copper Rod/Wire/Pin	Round
H1999/8776-6	H1999	8776	6	F	3C	Harappan	Copper Ring	TBD
H1999/8831-1	H1999	8831	1	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1999/8844-8	H1999	8844	8	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H1999/8950-12	H1999	8950	12	AB	2	Kot Diji	Copper Rod/Wire/Pin	square
H1999/8950-14	H1999	8950	14	AB	2	Kot Diji	Copper Arrow Point	Arrow
H1999/8950-15	H1999	8950	15	AB	2	Kot Diji	Copper Rod/Wire/Pin	Round
H1999/8957-2	H1999	8957	2	AB	2	Kot Diji	Copper Bead	Round/Cylinder
H1999/9108-3	H1999	9108	3	F	3C	Harappan	Copper Ring	Solid-round-two coils
H1999/9702-2	H1999	9702	2	F	3C	Harappan	Copper Sheet/Blade	TBD
H1999/9732-1	H1999	9732	1	F	3C	Harappan	Copper Rod/Wire/Pin	TBD
H1999/9756-4	H1999	9756	4	F	3C	Harappan	Copper Rod/Wire/Pin	square
H1999/9773-7	H1999	9773	7	F	3C	Harappan	Copper Rod/Wire/Pin	round/curved
H2000/2085-2	H2000	2085	2	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2085-3	H2000	2085	3	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H2000/2090-479	H2000	2090	479	E	Mixed	Harp.-Hist.	Copper Bead	Round
H2000/2090-772	H2000	2090	772	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H2000/2091-84	H2000	2091	84	E	Mixed	Harp.-Hist.	Copper Prill	
H2000/2102-1446	H2000	2102	1446	E	3B/C	Harappan	Copper Sheet/Blade	TBD
H2000/2102-1447	H2000	2102	1447	E	3B/C	Harappan	Copper Sheet/Blade	TBD
H2000/2102-1515	H2000	2102	1515	E	3B/C	Harappan	Copper Arrow Point	Arrow

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H2000/2102-1516	H2000	2102	1516	E	3B/C	Harappan	Copper Arrow Point	Arrow
H2000/2102-1517	H2000	2102	1517	E	3B/C	Harappan	Copper Arrow Point	Arrow
H2000/2102-1654	H2000	2102	1654	E	3B/C	Harappan	Copper Arrow Point	Arrow
H2000/2109-72	H2000	2109	72	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Round
H2000/2110-7	H2000	2110	7	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H2000/2110-79	H2000	2110	79	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2110-82	H2000	2110	82	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2110-173	H2000	2110	173	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2110-174	H2000	2110	174	E	Mixed	Harp.-Hist.	Copper Ring	Solid-round-single coil
H2000/2110-175	H2000	2110	175	E	Mixed	Harp.-Hist.	Copper Ring	Solid-round-single coil
H2000/2110-180	H2000	2110	180	E	Mixed	Harp.-Hist.	Copper Bangle	Round-solid
H2000/2110-186	H2000	2110	186	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square
H2000/2112-89	H2000	2112	89	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2116-21	H2000	2116	21	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2128-22	H2000	2128	22	E	3A	Harappan	Copper Bead	Round
H2000/2133-33	H2000	2133	33	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H2000/2137-11	H2000	2137	11	E	3A	Harappan	Copper Arrow Point	Arrow
H2000/2165-93	H2000	2165	93	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square/flat
H2000/2174-116	H2000	2174	116	E	Mixed	Harp.-Hist.	Copper Prill	
H2000/2226-38	H2000	2226	38	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square
H2000/2226-40	H2000	2226	40	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2226-55	H2000	2226	55	E	Mixed	Harp.-Hist.	Copper Bead	Cylinder
H2000/2226-56	H2000	2226	56	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Round
H2000/2226-57	H2000	2226	57	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H2000/2227-36	H2000	2227	36	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2227-37	H2000	2227	37	E	Mixed	Harp.-Hist.	Copper Bangle	Round-hollow
H2000/2227-38	H2000	2227	38	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	square
H2000/2227-39	H2000	2227	39	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2000/2227-41	H2000	2227	41	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H2000/2227-42	H2000	2227	42	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	Round
H2000/2227-43	H2000	2227	43	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	round/curved
H2000/2227-44	H2000	2227	44	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	round/curved
H2000/2357-3	H2000	2357	3	E	3B	Harappan	Copper Bead	Round
H2000/2358-15	H2000	2358	15	E	Mixed	Harp.-Hist.	Copper Prill	

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type
H2000/2715-28	H2000	2715	28	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H2000/2727-5	H2000	2727	5	E	3C	Harappan	Copper Arrow Point	Arrow
H2000/2730-1	H2000	2730	1	E	3C	Harappan	Copper Misc. Fragment	
H2000/2769-7	H2000	2769	7	E	3C	Harappan	Copper Arrow Point	Arrow
H2000/2797-21	H2000	2797	21	E	3C	Harappan	Copper Misc. Fragment	
H2000/8990-78	H2000	8990	78	AB	2	Kot Diji	Copper Ring	Solid-flat-two coils
H2000/8990-80	H2000	8990	80	AB	2	Kot Diji	Copper Misc. Fragment	
H2000/9514-6	H2000	9514	6	AB	2	Kot Diji	Copper Rod/Wire/Pin	square/flat
H2000/9845-54	H2000	9845	54	F	3C	Harappan	Copper Sheet/Blade	TBD
H2000/9954-1	H2000	9954	1	AB	2	Kot Diji	Copper Misc. Fragment	
H2000/11064-1	H2000	11064	1	AB	1	Ravi	Copper Rod/Wire/Pin	TBD
H2001/2378-1	H2001	2378	1	E	3C	Harappan	Copper Prill	
H2001/2387-1	H2001	2387	1	E	3B	Harappan	Copper Arrow Point	Arrow
H2001/2394-3	H2001	2394	3	E	3B	Harappan	Copper Bead	Cylinder/Rolled Sheet
H2001/2394-4	H2001	2394	4	E	3B	Harappan	Copper Rod/Wire/Pin	Round
H2001/2919-2	H2001	2919	2	E	3B	Harappan	Copper Rod/Wire/Pin	Round
H2001/2920-31	H2001	2920	31	E	Mixed	Harp.-Hist.	Copper Misc. Fragment	
H2001/2920-32	H2001	2920	32	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2001/2920-35	H2001	2920	35	E	Mixed	Harp.-Hist.	Copper Rod/Wire/Pin	TBD
H2001/2923-5	H2001	2923	5	E	Mixed	Harp.-Hist.	Copper Sheet/Blade	TBD
H2001/9059-23	H2001	9059	23	E	3C	Harappan	Copper Arrow Point	Arrow
H2001/9090-2	H2001	9090	2	E	3C	Harappan	Copper Arrow Point	Arrow
H2001/11543-2	H2001	11543	2	E	3C	Harappan	Copper Arrow Point	Arrow
H2001/11701-2	H2001	11701	2	E	Mixed	Harp.-Hist.	Copper Arrow Point	Arrow
H2001/11905-1	H2001	11905	1	E	3C	Harappan	Copper Arrow Point	Arrow
H2009/1801-89	H2009	1801	89	AB	3	Harappan	Slag and Mineral	Slag
Surface/17_ore	Unk.	Surface	17/Ore	Unk.	Unk.	Unk.	Slag and Mineral	Mineral
Surface/17_prill	Unk.	Surface	17/Prill	Unk.	Unk.	Unk.	Copper Prill	
Surface/17_sheet	Unk.	Surface	17/Sheet	Unk.	Unk.	Unk.	Copper Sheet/Blade	TBD

Appendices 4.1-4.3

The appendices in this section are compilations of compositional analyses on artifacts from the Indus Civilization site of Harappa uncovered during the Harappa Archaeological Research Project's (HARP) ongoing excavation program. The appendices are divided by analytical technique. Further explanations can be found in Chapter 4 of the main body of text.

Appendix 4.1 – This is the raw portable X-ray fluorescence (pXRF) data outputted through the Artax software program provided by Bruker, the instrument vendor for the pXRF equipment. Each column represents a primary element peak in the x-ray spectrum.

Abbreviations used are as follows:

Mn – manganese	As – arsenic	Au – gold
Fe – iron	Zr – zircon	Pb – lead
Ni – nickel	Ag – silver	Bi – bismuth
Cu – copper	Sn – tin	
Zn – zinc	Sb – antimony	

Appendix 4.2 – This appendix is the one hundred thirty Harappa Archaeological Research Project (HARP) samples analyzed for their elemental composition at the T. Douglas Price Laboratory for Archaeological Chemistry at the Department of Anthropology, University of Wisconsin-Madison (LARCH) using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). This appendix shows the final alloy designation for each analyzed sample. Abbreviations used are as follows:

Cu – copper

Sn – tin

As – arsenic

Pb – lead

Appendix 4.3 – This appendix is the fifty-four Harappa Archaeological Research Project (HARP) samples analyzed for their elemental composition at the University of Wisconsin Soil Testing Laboratory, Madison (UW Soils) using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). This appendix shows the final alloy designation for each analyzed sample. Abbreviations used are as follows:

Cu – copper

Sn – tin

As – arsenic

Pb – lead

Appendix 4.1
HARP Samples Analyzed via pXRF

Filtered Through Artax Software
Results are Net Counts/Element

Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
H1986/surface-17_ore	406	801	36	521	40	1	725	480	57	55	39	80	-2
H1986/surface-17_prill	124	2136	612	257939	513	6127	681	366	449	49	-4	3406	11
H1986/surface-17_sheet	53	4204	466	180303	503	1972	448	197	34	87	21	183	5
H1986/surface-b_face	70	767	1195	212634	505	4161	421	316	19466	18	15	545	18
H1986/surface-b_lrg	44	3466	298	215061	645	483	573	403	119	34	27	145	-1
H1986/Surface-C	57	9519	2585	1029418	6194	18863	10364	718	34	115	-5	6259	5
H1986/surface-d	143	266	121	346881	997	484	1170	314	102	6	22	244	79
<i>H1986/surface-e</i>	<i>66</i>	<i>52164</i>	<i>78</i>	<i>150120</i>	<i>335</i>	<i>1509</i>	<i>415</i>	<i>397</i>	<i>33</i>	<i>116</i>	<i>-5</i>	<i>5895</i>	<i>9</i>
<i>H1986/surface-e_002</i>	<i>37</i>	<i>72086</i>	<i>107</i>	<i>101003</i>	<i>182</i>	<i>1258</i>	<i>158</i>	<i>331</i>	<i>71</i>	<i>61</i>	<i>8</i>	<i>6299</i>	<i>11</i>
H1986/surface-f	32	1201	181	159035	269	4526	336	262	27795	50	3	6049	34
H1986/surface-g	112	1248	280	278321	732	8804	945	300	362	49	5	2672	0
H1986/surface-h	84	2807	328	261007	598	1578	746	330	124	53	14	6852	7
H1986/surface-i	35	1995	378	192078	348	1063	403	249	174	53	24	4415	1
H1986/surface-j	43	1831	165	64169	1	1	396	228	83	50	-12	69763	307
H1986/surface-k	72	185	172	210265	1	1	3028	326	339	84	6	13022	22
H1986/surface-l	161	1583	547	346745	832	2673	1328	302	71	37	8	121	27
H1986/surface-m	139	914	278	371386	1019	318	1420	258	65	25	4	174	10
H1987/11-37	144	1872	629	338507	879	1293	1086	294	42	25	2	116	5
<i>H1987/20-2a</i>	<i>112</i>	<i>5304</i>	<i>466</i>	<i>211138</i>	<i>608</i>	<i>2930</i>	<i>519</i>	<i>253</i>	<i>8</i>	<i>68</i>	<i>47</i>	<i>420</i>	<i>10</i>
<i>H1987/20-2b</i>	<i>28</i>	<i>853</i>	<i>552</i>	<i>220243</i>	<i>439</i>	<i>3565</i>	<i>423</i>	<i>169</i>	<i>41</i>	<i>12</i>	<i>18</i>	<i>3762</i>	<i>10</i>
H1987/505-37	38	1264	372	208284	593	1984	467	196	5186	38	12	362	0
H1987/515-A	204	39314	1317	726400	3235	4899	5359	1369	133	53	16	4488	-1
H1987/515-B	86	1146	576	305631	1368	1209	2601	310	45	45	-5	4918	6
H1987/surface-39	63	3415	139	210163	617	22	511	324	882	68	22	132	8
H1988/322-19	65	1968	727	260231	509	7690	699	287	17059	39	-2	3795	5
H1988/325-8A	69	839	415	224948	491	397	498	244	16596	-6	-3	189	0
H1988/325-8B	54	970	107	242710	639	1577	563	300	129	44	3	933	17
H1988/325-8C	132	333	326	262218	665	2107	659	294	1524	9	2	1073	24
<i>H1988/325-8D</i>	<i>144</i>	<i>1992</i>	<i>376</i>	<i>279162</i>	<i>762</i>	<i>3694</i>	<i>518</i>	<i>574</i>	<i>101</i>	<i>134</i>	<i>50</i>	<i>982</i>	<i>0</i>
<i>H1988/325-8D_b</i>	<i>160</i>	<i>19423</i>	<i>184</i>	<i>288113</i>	<i>1218</i>	<i>6790</i>	<i>1095</i>	<i>981</i>	<i>125</i>	<i>93</i>	<i>9</i>	<i>1122</i>	<i>5</i>
<i>H1988/325-8D_c</i>	<i>216</i>	<i>19575</i>	<i>355</i>	<i>419550</i>	<i>1438</i>	<i>12907</i>	<i>1801</i>	<i>935</i>	<i>151</i>	<i>108</i>	<i>2</i>	<i>873</i>	<i>0</i>
H1988/325-8E	27	5521	389	543755	1533	8853	2439	677	97	153	-2	1831	8
<i>H1988/341-2a</i>	<i>49</i>	<i>3591</i>	<i>898</i>	<i>204318</i>	<i>434</i>	<i>1367</i>	<i>476</i>	<i>277</i>	<i>62</i>	<i>59</i>	<i>6</i>	<i>3702</i>	<i>7</i>
<i>H1988/341-2b</i>	<i>59</i>	<i>788</i>	<i>549</i>	<i>242053</i>	<i>517</i>	<i>1288</i>	<i>539</i>	<i>203</i>	<i>18</i>	<i>30</i>	<i>-1</i>	<i>6803</i>	<i>22</i>
<i>H1988/346-27</i>	<i>158</i>	<i>2216</i>	<i>2864</i>	<i>937273</i>	<i>5146</i>	<i>2469</i>	<i>8257</i>	<i>835</i>	<i>53494</i>	<i>91</i>	<i>-9</i>	<i>3938</i>	<i>25</i>
<i>H1988/346-27-002</i>	<i>126</i>	<i>1380</i>	<i>1029</i>	<i>510280</i>	<i>1491</i>	<i>2787</i>	<i>2345</i>	<i>754</i>	<i>59953</i>	<i>6</i>	<i>12</i>	<i>4900</i>	<i>62</i>
H1988/353-5	38	3041	352	212876	556	832	459	284	41	80	12	1903	0
H1988/374-1	73	7249	6515	1170119	12086	5091	16038	796	41	40	13	701	5
H1988/413-A	95	8424	140	547512	1998	33	2389	861	41	118	32	152	2
H1988/413-B	133	1560	548	244159	614	4056	682	285	36	100	6	1491	3
H1988/413-C	127	1029	516	303766	678	492	1045	284	9	43	1	8060	21
<i>H1988/529-120</i>	<i>237</i>	<i>12163</i>	<i>944</i>	<i>804581</i>	<i>4193</i>	<i>93919</i>	<i>6238</i>	<i>1172</i>	<i>67</i>	<i>65</i>	<i>50</i>	<i>1808</i>	<i>1</i>
<i>H1988/529-120-002</i>	<i>285</i>	<i>14207</i>	<i>2279</i>	<i>953032</i>	<i>7496</i>	<i>88806</i>	<i>9606</i>	<i>867</i>	<i>101</i>	<i>85</i>	<i>75</i>	<i>2091</i>	<i>1</i>
H1988/532-4	25	1909	242	243907	643	1272	555	216	197	33	6	719	7
H1988/532-5	24	2001	71	221200	463	130	875	378	60	95	13	343	0

317 unique artifacts analyzed
345 spectra reported due to repeat analyses

Repeated analyses italicized

Appendix 4.1
HARP Samples Analyzed via pXRF

Filtered Through Artax Software
Results are Net Counts/Element

Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
H1988/539-11	38	137	295	157911	374	279	255	158	7456	6	6	1133	0
H1988/539-11b	36	2845	302	182444	417	1259	362	206	13911	31	13	1638	24
H1988/725-3	59	1984	90	219440	637	3178	551	3536	167	15	20	1137	0
H1988/725-47	132	5921	85	185096	541	48	518	308	3306	84	17	695	3
H1988/730-1	58	3548	147	125625	263	73	357	275	12283	82	-6	2455	3
H1988/754-2	38	975	292	128477	272	905	158	231	64	53	10	707	3
H1988/758-1	95	7207	365	209892	587	1776	520	371	39	87	44	243	3
H1988/758-16	92	2408	135	92804	1	1067	174	8549	171	115	11167	2198	0
<i>H1988/761-1A</i>	<i>292</i>	<i>20896</i>	<i>112</i>	<i>295721</i>	<i>1100</i>	<i>1877</i>	<i>1208</i>	<i>857</i>	<i>95</i>	<i>96</i>	<i>39</i>	<i>199</i>	<i>0</i>
<i>H1988/761-1A-002</i>	<i>168</i>	<i>7781</i>	<i>194</i>	<i>236780</i>	<i>835</i>	<i>1807</i>	<i>509</i>	<i>574</i>	<i>48</i>	<i>45</i>	<i>48</i>	<i>272</i>	<i>0</i>
<i>H1988/761-1A-003</i>	<i>176</i>	<i>7126</i>	<i>468</i>	<i>728250</i>	<i>2884</i>	<i>7443</i>	<i>4104</i>	<i>906</i>	<i>149</i>	<i>164</i>	<i>13</i>	<i>197</i>	<i>0</i>
H1988/761-1B	213	22375	192	337275	1430	2481	1548	943	54	95	13	337	5
H1988/766-28	63	2423	195	254098	765	75	739	315	810	60	33	19	9
H1988/8488-13b	49	762	111	157522	310	1	257	422	29827	9	26	5329	107
H1988/Surface-A	286	17143	1637	700780	2467	8781	4224	1197	55	118	7	709	0
H1989/1009-8	83	305	317	213312	438	1552	526	339	15274	57	-2	5968	38
H1989/1009-9	50	4877	673	153572	429	753	236	245	36	37	15	99	3
H1989/1038-13	72	6639	691	179543	494	2433	486	313	55	36	6	1389	1
H1989/1038-13B	184	4334	158	274270	587	1204	732	257	63	41	3	7865	28
H1989/1038-14	166	4768	331	165425	484	5878	447	294	115	97	17	678	0
H1989/1054-24	62	2554	149	214861	555	4	573	234	81	104	15	260	11
H1989/2006-7	135	2993	122	241239	506	1	1317	311	102	53	42	186	3
H1989/2006-8	173	2341	94	270196	782	166	711	350	64	109	12	48	6
H1990/1171-22	33	2035	91	158906	448	1	351	284	25222	51	5	2240	46
H1990/1185-1A	26	3965	96	238131	635	787	586	225	236	23	16	160	19
H1990/1185-1C	46	1179	152	216963	589	3606	478	219	54	49	24	99	6
<i>H1990/3000-D</i>	<i>30</i>	<i>114</i>	<i>68</i>	<i>196869</i>	<i>565</i>	<i>1782</i>	<i>537</i>	<i>231</i>	<i>88</i>	<i>50</i>	<i>28</i>	<i>125</i>	<i>0</i>
<i>H1990/3000-D002</i>	<i>134</i>	<i>401</i>	<i>377</i>	<i>370373</i>	<i>1004</i>	<i>8250</i>	<i>1350</i>	<i>216</i>	<i>17</i>	<i>67</i>	<i>-2</i>	<i>133</i>	<i>1</i>
H1990/3003-12	49	784	279	266027	661	506	621	356	12	17	15	177	12
H1990/3014-23A	27	771	265	245887	730	189	567	283	5390	54	14	1268	10
H1990/3014-23B	80	999	611	260434	452	1641	675	227	71	97	2	8831	16
H1990/3014-23C	117	278	243	368845	1060	25	1402	205	46	20	4	22	32
H1990/3014-23D	40	1609	340	174805	396	1801	340	255	4459	75	21	511	0
<i>H1990/3014-24</i>	<i>70</i>	<i>1910</i>	<i>239</i>	<i>317403</i>	<i>760</i>	<i>3833</i>	<i>952</i>	<i>220</i>	<i>858</i>	<i>64</i>	<i>9</i>	<i>732</i>	<i>9</i>
<i>H1990/3014-24B</i>	<i>105</i>	<i>1363</i>	<i>331</i>	<i>266563</i>	<i>574</i>	<i>4842</i>	<i>668</i>	<i>255</i>	<i>345</i>	<i>96</i>	<i>8</i>	<i>329</i>	<i>18</i>
H1990/3025-20	36	603	527	221787	372	804	454	209	58	49	3	2980	4
H1990/3025-21	82	1093	337	231544	811	1823	550	285	63	30	1	8911	12
H1990/3037-3	45	1982	482	269275	624	1225	744	295	56	45	29	291	4
H1990/3037-4	61	3031	71	163298	116	1	796	292	923	109	-7	33175	91
H1990/3038-23	59	3863	904	216405	546	1952	521	294	29	90	28	1587	1
H1990/3044-1	108	5547	1210	261791	539	4025	744	277	38	35	11	550	0
H1990/3056-3	36	1821	364	128462	274	324	195	235	779	55	4	1855	1
H1990/3056-30	100	1675	148	80211	172	1694	132	212	7880	31	4	2434	9
H1990/3072-4	55	1466	479	306850	756	2732	945	294	38	17	11	1302	0
H1990/3074-1	8	4935	624	202774	495	2141	481	216	57	95	6	700	3

317 unique artifacts analyzed
345 spectra reported due to repeat analyses

Repeated analyses italicized

Appendix 4.1
HARP Samples Analyzed via pXRF

Filtered Through Artax Software
Results are Net Counts/Element

Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
H1990/3076-2	37	1273	117	255981	785	286	720	295	31	62	44	193	17
H1990/3078-1	157	1228	730	276476	667	2793	751	202	18400	5	8	1653	-1
H1990/3087-19	105	2692	191	220525	610	4015	521	338	41	68	20	292	0
H1990/3095-7	85	4724	233	162574	453	86	338	259	4426	110	18	292	-1
H1990/3103-20	106	963	1711	399113	1048	816	1647	225	29	65	32	157	20
H1990/3124-1	119	4871	115	121688	328	319	263	249	11440	34	15	1589	1
H1990/3127-1	159	3764	319	224671	515	522	543	253	13679	4	21	2207	0
H1990/3135-14	46	909	312	166110	423	737	264	226	52	51	18	97	22
H1990/3150-3	111	1268	697	180249	469	4020	398	206	27911	-14	37	350	41
H1990/3153-19	147	4941	166	270721	731	1484	732	323	888	103	33	323	1
H1990/3153-24	71	1302	2921	186363	311	10102	384	249	49	102	24	152	2
H1990/3189-24	66	7187	229	185116	665	856	472	434	14	48	21	266	-1
H1990/3191-13	116	4040	72	261870	849	1157	676	377	61	38	22	903	2
H1990/3191-14	86	439	349	395689	1251	1	1617	229	2	46	25	65	4
H1990/3191-15	28	1259	217	174898	393	1	387	328	18	30	18	100	10
H1990/3242-1	86	730	1235	336999	765	2130	1150	297	33	57	2	3720	11
H1990/3247-30	86	5056	1414	215689	439	2782	524	386	23	56	18	1874	0
H1990/3247-39	102	724	309	366808	916	41	1325	270	34	24	19	57	-3
H1990/3257-4	123	1477	467	358453	850	7833	1262	196	27	68	13	1051	7
H1990/3257-5	43	5076	563	226477	643	379	506	257	79	76	30	109	5
H1990/3273-26	114	3532	339	187371	463	715	425	339	29	31	7	1164	1
H1993/3650-1	1891	6935	400	760571	3199	39077	4635	807	61	19	-8	1206	0
H1993/3803-2	288	4126	384	764894	2727	19947	4644	782	867	124	6	2672	0
H1993/3812-1	155	8285	314	447710	1398	101	1399	767	70	72	11	3099	0
<i>H1993/3812-12</i>	<i>69</i>	<i>2598</i>	<i>2407</i>	<i>297764</i>	<i>611</i>	<i>4953</i>	<i>527</i>	<i>650</i>	<i>82</i>	<i>109</i>	<i>25</i>	<i>10081</i>	<i>-1</i>
<i>H1993/3812-12B</i>	<i>149</i>	<i>3638</i>	<i>931</i>	<i>466353</i>	<i>1344</i>	<i>816</i>	<i>1536</i>	<i>764</i>	<i>64</i>	<i>114</i>	<i>-1</i>	<i>14885</i>	<i>40</i>
H1993/3812-14	81	4149	563	591999	1714	4218	2735	843	51	39	-3	20942	38
H1993/3875-1	87	15959	622	521960	1869	4696	2235	686	3895	95	22	1331	1
<i>H1993/4074-10</i>	<i>179</i>	<i>2471</i>	<i>3778</i>	<i>983073</i>	<i>6113</i>	<i>8002</i>	<i>9404</i>	<i>715</i>	<i>36903</i>	<i>22</i>	<i>18</i>	<i>6763</i>	<i>8</i>
<i>H1993/4074-10B</i>	<i>182</i>	<i>1294</i>	<i>5167</i>	<i>1018187</i>	<i>7602</i>	<i>7605</i>	<i>10674</i>	<i>840</i>	<i>48425</i>	<i>21</i>	<i>-11</i>	<i>7484</i>	<i>31</i>
<i>H1993/4074-10C</i>	<i>306</i>	<i>20433</i>	<i>1467</i>	<i>876219</i>	<i>4497</i>	<i>1439</i>	<i>7008</i>	<i>1153</i>	<i>4338</i>	<i>58</i>	<i>-4</i>	<i>689</i>	<i>1</i>
<i>H1993/4074-10D</i>	<i>112</i>	<i>1589</i>	<i>3097</i>	<i>965680</i>	<i>5650</i>	<i>5992</i>	<i>8933</i>	<i>815</i>	<i>35760</i>	<i>67</i>	<i>7</i>	<i>6638</i>	<i>25</i>
<i>H1993/4074-9A</i>	<i>206</i>	<i>27091</i>	<i>383</i>	<i>591697</i>	<i>2207</i>	<i>244</i>	<i>3412</i>	<i>1033</i>	<i>6786</i>	<i>11</i>	<i>0</i>	<i>1775</i>	<i>4</i>
<i>H1993/4074-9B</i>	<i>28</i>	<i>10339</i>	<i>347</i>	<i>613386</i>	<i>1798</i>	<i>33540</i>	<i>2871</i>	<i>843</i>	<i>24</i>	<i>101</i>	<i>30</i>	<i>2048</i>	<i>1</i>
H1993/4098-20	414	25531	1258	921530	5660	2000	7996	1134	21161	74	7	698	114
H1994/3909-1	262	18347	1732	634554	2279	1115	3135	995	102	118	-17	15700	9
H1994/3978-1	188	8290	436	508560	1510	8865	2493	1042	97	149	33	20795	33
H1994/3990-15	89	3837	2223	976409	4620	2318	8694	773	113	67	18	7209	36
H1994/3994-5	240	30905	225	452627	1594	270	2835	1427	106	132	26	957	-2
H1994/4297-1	126	47569	36	297842	837	1	853	962	65	97	5	23698	59
H1994/4297-2	38	6965	175	424741	1210	251	1369	766	35	97	1	4767	9
H1994/4353-2	43	7907	519	505839	1332	793	1940	709	28740	58	42	29858	97
H1994/4375-8	231	9170	825	494328	1551	1532	2029	785	37	135	23	1925	0
H1994/4509-1	66	6471	319	189420	459	4423	472	658	33444	43	35	14520	77
H1994/4549-13	171	7385	1006	792468	3682	144	5302	676	42076	1	12	26365	56

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H1994/4557-8	86	9937	100	361647	965	127	1110	734	32	111	9	24157	58
H1994/5421-1	151	20016	127	525235	1597	6043	2195	875	506	171	25	27495	45
H1994/5433-10	27	3807	166	480634	1272	1	1548	533	190	147	38	17337	54
H1994/5433-9	74	1346	171	375599	991	128	1055	673	90	70	-7	7066	29
H1994/5434-1	18	58388	75	323078	838	669	929	862	67	72	-10	17188	25
H1994/5476-1	369	35586	329	352756	1120	1980	2161	1338	124	168	48	12755	0
H1995/4416-54	110	6481	1160	355367	953	201	1074	852	48	134	20	808	1
H1995/4451-8	136	6836	646	783932	3237	2739	5101	912	358	5	-1	6800	0
H1995/4606-9	414	48083	78	241342	753	7929	6404	2383	87	297	88	3846	0
H1995/4609-76	80	5894	291	289479	743	1146	920	442	12253	35	66	4214	0
H1995/4613-54	86	6934	217	512378	1700	1664	2037	897	41	106	5	681	0
<i>H1995/4623-17</i>	<i>197</i>	<i>2212</i>	<i>1896</i>	<i>1020932</i>	<i>6665</i>	<i>2125</i>	<i>9966</i>	<i>983</i>	<i>125</i>	<i>112</i>	<i>3</i>	<i>3935</i>	<i>1</i>
<i>H1995/4623-17B</i>	<i>62</i>	<i>1914</i>	<i>901</i>	<i>920056</i>	<i>4557</i>	<i>1065</i>	<i>7372</i>	<i>849</i>	<i>113</i>	<i>116</i>	<i>11</i>	<i>6965</i>	<i>9</i>
H1995/4623-18	119	5522	648	575044	1716	1813	2814	905	20466	34	17	7876	36
H1995/4623-19	71	5123	1338	684971	2331	11499	3697	890	32690	31	41	11903	4
H1995/4623-20	63	8294	616	493772	1407	16981	2359	879	28900	57	2	3295	0
H1995/4623-37	50	1456	501	542957	1682	8316	2134	569	4563	41	24	4752	13
H1995/4649-1	223	3321	1166	714300	2104	3199	5005	690	299	193	-22	24680	16
H1995/4651-26	112	3601	523	424635	1213	18	1301	626	20007	103	21	1189	0
<i>H1995/4661-2</i>	<i>94</i>	<i>15780</i>	<i>348</i>	<i>690167</i>	<i>2054</i>	<i>15247</i>	<i>5507</i>	<i>835</i>	<i>570</i>	<i>90</i>	<i>0</i>	<i>13795</i>	<i>0</i>
<i>H1995/4661-2B</i>	<i>233</i>	<i>22984</i>	<i>412</i>	<i>682094</i>	<i>2773</i>	<i>3308</i>	<i>4085</i>	<i>1149</i>	<i>80</i>	<i>91</i>	<i>24</i>	<i>1324</i>	<i>2</i>
H1995/4663-1	94	879	223	320580	782	17073	1018	251	51	76	3	920	3
H1995/4663-2	86	2503	374	373497	1517	1964	1422	796	21509	28	21	3964	15
H1995/4953-45	168	3101	840	664829	2010	12532	3437	672	148	64	-1	4915	3
H1995/4953-46	171	3797	4276	1083413	6838	1654	11624	691	89	28	-11	264	42
H1995/4953-47	237	912	7106	1183723	11874	320	16453	678	881	180	2	4775	8
H1995/4982-223	106	5446	1133	399450	945	2412	1317	757	23	62	58	259	-1
H1995/4989-75	420	14842	1044	753076	3030	6759	4697	854	44	78	-7	2052	1
H1995/5145-175	185	2390	5142	1118321	9580	6558	13614	647	113	23	22	15116	13
H1995/5145-19	133	10523	1267	542378	2017	3436	2316	1094	122	144	7	865	4
H1995/5182-46	747	30538	267	210469	711	34	1704	1362	206	87	49	1965	-1
<i>H1995/5603-21</i>	<i>287</i>	<i>5120</i>	<i>699</i>	<i>681319</i>	<i>2581</i>	<i>908</i>	<i>3684</i>	<i>738</i>	<i>51184</i>	<i>-10</i>	<i>17</i>	<i>6116</i>	<i>12</i>
<i>H1995/5603-21B</i>	<i>238</i>	<i>7967</i>	<i>523</i>	<i>712676</i>	<i>3023</i>	<i>384</i>	<i>4197</i>	<i>851</i>	<i>32969</i>	<i>-10</i>	<i>12</i>	<i>4058</i>	<i>3</i>
<i>H1995/5641-21</i>	<i>93</i>	<i>6433</i>	<i>908</i>	<i>637481</i>	<i>2136</i>	<i>594</i>	<i>3178</i>	<i>871</i>	<i>7840</i>	<i>41</i>	<i>-11</i>	<i>989</i>	<i>-6</i>
<i>H1995/5641-21 002</i>	<i>82</i>	<i>5107</i>	<i>344</i>	<i>405255</i>	<i>1352</i>	<i>204</i>	<i>1382</i>	<i>751</i>	<i>4807</i>	<i>63</i>	<i>46</i>	<i>924</i>	<i>19</i>
<i>H1995/5680-17</i>	<i>60</i>	<i>5189</i>	<i>86</i>	<i>152087</i>	<i>416</i>	<i>1958</i>	<i>453</i>	<i>347</i>	<i>55</i>	<i>50</i>	<i>12</i>	<i>583</i>	<i>-3</i>
<i>H1995/5680-17B</i>	<i>51</i>	<i>512</i>	<i>43</i>	<i>130804</i>	<i>326</i>	<i>3052</i>	<i>306</i>	<i>146</i>	<i>51</i>	<i>43</i>	<i>4</i>	<i>1571</i>	<i>2</i>
H1995/5706-8	175	7100	164	492897	1692	3624	1944	782	22	106	33	399	12
H1995/5729-113	66	2529	723	683270	2185	1011	3690	600	13126	51	21	3718	13
H1995/5751-26	343	33700	361	525343	2220	15216	3061	1297	96	129	23	1919	0
H1995/5766-37	109	2823	358	529546	1711	2305	2033	678	147	81	32	607	-2
H1995/5789-1	87	3194	473	423608	1214	6880	1364	580	174	48	32	994	0
H1995/6509-1	112	7223	90	164863	413	674	632	394	1909	95	8	1291	15
H1995/6509-112	275	4819	442	211868	535	395	496	481	25054	81	40	3838	21
<i>H1995/6543-65</i>	<i>357</i>	<i>19857</i>	<i>641</i>	<i>425475</i>	<i>1343</i>	<i>1710</i>	<i>1671</i>	<i>972</i>	<i>69</i>	<i>105</i>	<i>39</i>	<i>6423</i>	<i>11</i>

317 unique artifacts analyzed
345 spectra reported due to repeat analyses

Repeated analyses italicized

Appendix 4.1
HARP Samples Analyzed via pXRF

Filtered Through Artax Software
Results are Net Counts/Element

Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
<i>H1995/6543-65B</i>	25	760	4	23558	113	21	116	150	20	85	8	213	8
H1995/7000-10	231	17583	117	1463	425	1	3401	1818	3	72	80	1522	20
H1995/8059-19	108	3541	366	347870	849	609	863	735	5454	24	3	1245	12
H1996/6226-57	186	17835	68	229877	683	142	1059	865	72	51	66	298	0
H1996/6242-4	99	14161	1159	569982	2139	2206	2471	10324	266	72	2044	965	0
H1996/6256-8	251	13377	1246	548512	1703	2347	2462	883	69	127	0	4857	0
H1996/6304-6	106	7838	796	904927	4345	2075	7228	926	94	33	-5	7727	0
H1996/6908-8	80	6942	140	340420	908	2	1067	615	21837	40	59	1790	2
H1996/6920-43	86	8355	438	175078	587	953	482	818	91	166	12	1365	6
H1996/6930-8	184	7986	926	646014	1980	5353	3220	767	8388	58	1	28506	25
H1996/6945-30	90	9013	3657	580682	1981	10715	2513	860	65	126	9	1371	5
H1996/6949-19	86	2023	363	452891	1277	3773	1532	670	14466	2	18	3976	13
H1996/6958-131	31	1376	1183	712450	2088	6836	4165	693	20789	-36	-7	8865	6
H1996/6958-60	102	1127	903	365517	766	6344	1077	595	201	122	38	10912	2
H1996/6958-62	58	962	589	673752	2306	2295	3434	868	16837	56	10	4285	0
H1996/6966-14	70	33715	1	294932	896	6052	872	690	71	58	6	2143	7
H1996/7106-34	54	2758	946	457111	1104	1771	1503	711	21	109	3	3380	-1
H1996/7126-1	61	1647	897	506672	1610	248	2081	725	7094	20	9	271	15
H1996/7200-36	210	14549	897	674466	2501	1102	3674	954	1464	165	8	2092	-3
H1996/7210-11	217	17995	134	534627	2017	642	2252	852	113	149	19	1700	-3
H1996/7211-34	31	12783	288	522610	1514	7337	2223	933	32009	-7	30	9642	42
<i>H1996/7232-2</i>	65	3218	775	436853	1181	12562	1316	590	56	103	12	352	17
<i>H1996/7232-2B</i>	667	7284	406	434764	1295	5735	1493	649	75	69	10	333	12
H1996/7232-65	231	8248	164	364490	1262	478	1121	693	37	84	47	200	3
H1996/7236-1	144	4377	351	236008	238	1	4371	1282	103	229	18	2273	0
H1996/7241-16	334	45194	357	519036	2077	26	3347	1469	80	-1	-14	10851	15
H1996/7257-1	75	22738	331	667211	2418	6337	3700	895	78	107	-2	546	7
H1996/7291-2	230	83897	54	283284	987	1348	1320	1061	93	106	33	5752	14
H1996/7293-1	298	82281	72	398566	1314	559	1879	1285	71	113	15	755	12
H1996/7400-47	25	1238	1273	562332	1473	3039	2351	599	99	94	26	213	12
H1996/7410-4	50	4151	508	786048	2891	182	5004	700	77	35	9	55	17
H1996/7431-2	308	10886	11792	721081	1552	6576	4263	865	15	538	1	400	50
H1996/7467-962	17	2696	403	330180	784	2589	877	494	14256	56	33	2674	14
H1996/7467-963	86	909	465	807462	3044	1	5333	784	35	192	13	285	1
H1996/7467-965	4	853	2373	384102	806	5460	1112	673	55	67	48	184	2
H1996/7490-32	209	15571	390	655243	2600	6771	3695	1065	1175	197	35	2783	0
H1996/7509-2	210	130337	351	220653	640	7105	420	776	105	143	57	1138	24
H1996/7512-9	86	19549	299	705727	2380	3264	3935	777	88	65	9	379	3
H1996/7513-59	95	1520	564	747985	2504	3093	4378	744	128	124	-3	267	-1
H1996/7516-78	35	247604	682	134945	73	158	1578	1182	94	151	38	980	0
H1996/7531-9	129	11672	278	304715	1012	70	1158	822	7649	167	31	555	0
H1997/6650-6	42	3380	308	345342	1172	368	858	543	65	39	0	4944	2
H1997/6655-20	35	725	135	68256	239	269	217	374	4026	11	82	475	13
H1997/6660-30	168	5821	1089	538617	2461	1872	2604	949	120142	9	4	9666	367
H1997/6688-1	196	4554	124	168614	588	1204	364	437	430	88	33	678	46

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Repeated analyses italicized

Appendix 4.1
HARP Samples Analyzed via pXRF

Filtered Through Artax Software
Results are Net Counts/Element

Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
H1997/7623-1	56	4933	842	469654	1094	11342	1643	653	184	212	10	3563	10
H1997/8012-16	126	9698	330	587829	2033	551	2448	862	118	219	2	1381	1
H1997/8017-61	140	11274	182	328563	1150	70	1060	724	2274	49	36	577	0
H1997/8017-62	12	3944	431	373628	956	5966	993	550	10974	79	8	6725	5
H1997/8019-1	29	520	322	241867	656	1171	454	764	76	6	22	3257	0
H1997/8022-24	206	18777	134	513905	1940	16767	2501	1122	207	34	23	1781	1
H1997/8022-25	59	829	660	474213	1286	2154	1587	586	30905	71	18	196	20
H1997/8026-13	246	5551	591	635449	2319	1168	3461	1109	90	88	-2	3372	0
H1997/8103-5	52	714	254	134816	304	4162	171	187	107	34	25	2650	7
H1997/8103-6	80	1021	94	190222	547	76	346	262	282	37	8	931	3
H1997/8103-7	43	1040	52	194974	551	22	387	246	25	62	24	60	8
H1997/8110-8	98	318	581	236266	502	6160	636	299	9779	27	-3	1685	10
H1997/8133-1	21	378	25	11288	23	636	64	148	17	-3	0	1619	5
H1997/8248-1	89	3064	596	312175	564	578	703	392	42	74	7	11620	16
H1998/8134-44	120	3546	345	386580	1092	7108	904	422	72	66	17	743	4
H1998/8172-2	110	1287	484	427837	909	2499	1199	287	177	22	8	9090	29
H1998/8172-80	117	3180	401	250748	648	413	472	400	59	30	14	447	1
H1998/8314-23	72	2226	265	328229	989	15551	754	371	43	53	43	472	2
H1998/8336-68	125	150	837	376328	856	28	1128	285	14765	23	0	3911	16
H1998/8355-64	28	625	63	57150	196	50	69	215	3801	12	17	180	21
H1998/8407-36	38	3285	329	343921	856	5313	820	688	339	911	22	775	1
H1998/8432-8	191	6214	5586	260387	250	1503	510	331	75	78	41	182	1
H1998/8433-37	54	2170	60	126291	387	1	264	303	47	107	31	180	9
H1998/8439-58	95	6421	132	277044	926	5485	569	375	33	40	26	87	9
H1998/8456-1	61	3027	65	270739	793	223	551	450	59	27	36	64	7
<i>H1998/8483-1</i>	<i>347</i>	<i>3165</i>	<i>247</i>	<i>325946</i>	<i>1032</i>	<i>131</i>	<i>708</i>	<i>359</i>	<i>149</i>	<i>31</i>	<i>32</i>	<i>417</i>	<i>9</i>
<i>H1998/8483-1b</i>	<i>50</i>	<i>1283</i>	<i>575</i>	<i>213000</i>	<i>468</i>	<i>3389</i>	<i>419</i>	<i>395</i>	<i>27110</i>	<i>86</i>	<i>31</i>	<i>5606</i>	<i>9</i>
H1998/8486-5	44	1929	101	290399	819	1	670	321	12286	62	5	1243	8
H1998/8487-1	28	2925	80	195062	604	5	334	310	9712	13	5	2099	7
H1998/8488-11	78	1819	94	275533	757	1	586	422	22409	21	-1	2534	27
H1998/8488-13	30	4053	101	237452	597	1	783	381	17172	2	26	809	3
H1998/8500-17	38	1447	83	91640	284	37	92	260	31	49	15	66	11
H1998/8506-3	10	207	114	107215	335	804	124	197	24	50	40	146	3
H1998/8522-1	584	4480	312	346288	913	8249	807	372	80	84	23	261	11
H1998/8562-36	33	1881	173	104506	227	1299	159	219	5000	32	5	1397	17
H1998/8657-4	119	3086	291	399263	1012	11952	1006	724	95	56	27	560	8
H1999/8492-116	61	3277	78	131348	367	1	274	261	9883	27	11	2962	16
H1999/8753-1	47	11098	326	266709	733	396	633	562	54	82	5	18782	66
H1999/8754-43	67	324	320	358570	1040	902	894	364	47	58	1	1977	7
H1999/8768-88	131	2441	459	375189	846	2134	902	348	88	52	19	923	10
H1999/8776-4	63	414	379	314073	800	1933	668	433	2049	1	15	651	-1
H1999/8776-5	77	2278	689	347888	695	9002	882	416	17377	63	1	2664	35
<i>H1999/8776-6</i>	<i>43</i>	<i>1401</i>	<i>62</i>	<i>99323</i>	<i>248</i>	<i>971</i>	<i>114</i>	<i>152</i>	<i>18</i>	<i>66</i>	<i>10</i>	<i>4577</i>	<i>12</i>
<i>H1999/8776-6b</i>	<i>20</i>	<i>2247</i>	<i>53</i>	<i>68815</i>	<i>247</i>	<i>284</i>	<i>137</i>	<i>277</i>	<i>42</i>	<i>64</i>	<i>20</i>	<i>1511</i>	<i>11</i>
H1999/8831-1	86	8453	115	207883	559	1269	433	359	66	96	5	300	0

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H1999/8844-8	132	1003	502	351067	683	25194	739	314	38	59	6	4532	8
H1999/8950-12	78	3816	283	179897	508	1756	362	222	7	64	22	162	10
H1999/8950-14	84	1940	67	85913	274	2901	171	282	39	45	47	166	6
H1999/8950-15	55	2786	356	185003	544	4580	313	305	26	89	45	207	9
H1999/8957-2	64	701	71	87790	198	1	75	224	2237	67	22	1744	18
H1999/9108-3	109	1453	245	235316	604	2431	356	586	718	74	10	266	9
H1999/9732-1	21	1647	87	109448	340	627	110	222	182	20	25	149	1
H1999/9756-4	42	3218	350	242729	623	1487	486	419	12851	29	8	581	0
H1999/9773-7	77	1235	199	278060	744	8581	525	222	34	47	43	110	5
H2000/2085-2	75	2178	168	193695	673	9727	328	269	67	65	22	409	0
H2000/2085-3	63	2607	83	101736	345	1481	152	208	41	85	29	133	-2
H2000/2090-479	86	815	1626	496015	954	3512	1623	354	310	93	-11	12773	49
H2000/2090-772	130	1546	341	168519	437	820	219	252	114	105	24	1432	3
H2000/2091-84	242	7462	233	300843	982	1915	619	380	78	79	32	1195	4
H2000/2102-1446	107	1138	951	296185	617	3755	567	312	21764	47	7	802	20
H2000/2102-1515	126	2729	576	206442	554	1514	383	222	27	104	9	1496	0
H2000/2102-1516	81	4378	248	213045	704	478	413	205	60	15	24	223	7
H2000/2102-1517	56	1230	189	205384	589	271	254	342	61	125	36	955	4
H2000/2102-1654	47	3036	77	245384	634	2737	361	368	63	149	26	749	3
H2000/2109-72	222	6420	251	208317	726	187	517	384	5755	18	30	134	6
H2000/2110-173	28	9831	170	214537	448	4443	674	374	18561	83	47	2601	23
H2000/2110-174	76	2399	201	246148	569	8827	464	357	59	111	11	2879	0
<i>H2000/2110-175</i>	<i>113</i>	<i>7903</i>	<i>70</i>	<i>105955</i>	<i>301</i>	<i>4193</i>	<i>423</i>	<i>377</i>	<i>19</i>	<i>1</i>	<i>31</i>	<i>270</i>	<i>10</i>
<i>H2000/2110-175B</i>	<i>45</i>	<i>2335</i>	<i>70</i>	<i>64767</i>	<i>145</i>	<i>1947</i>	<i>140</i>	<i>262</i>	<i>83</i>	<i>50</i>	<i>28</i>	<i>132</i>	<i>9</i>
H2000/2110-180	79	7339	1070	348491	861	1806	861	419	24	104	34	815	11
H2000/2110-186	116	1676	183	202868	510	594	287	364	6859	6	34	477	26
H2000/2110-7	30	581	472	262779	720	854	561	273	14161	18	22	189	-1
H2000/2110-79	124	11588	577	320965	812	904	859	500	47	66	33	927	0
H2000/2110-82	155	1788	376	396557	923	3007	1001	419	228	56	-2	1866	0
H2000/2112-89	129	3200	398	341637	671	400	722	329	29	38	-6	10453	35
H2000/2116-21	88	4278	98	240547	738	1	452	347	3562	56	21	1182	3
H2000/2128-22	110	3159	530	363662	793	189	939	370	36	21	5	722	3
H2000/2133-33	124	9277	329	232796	677	1781	473	399	4352	59	2	2086	11
H2000/2137-11	55	8805	146	370298	888	11644	847	360	193	131	30	465	16
H2000/2165-93	60	542	367	228080	555	3486	361	333	171	59	6	1262	4
H2000/2174-116	82	4969	2	133609	358	3127	200	339	55	58	28	738	5
H2000/2226-38	24	2778	705	253612	656	606	448	396	18898	52	0	1018	3
H2000/2226-55	72	1960	669	494159	1218	3454	1471	363	75	34	12	1581	25
H2000/2226-56	78	768	374	295850	689	1324	648	292	22	36	5	600	0
H2000/2226-57	57	2290	448	163758	408	1658	181	329	27	38	22	713	-1
H2000/2227-36	52	6268	223	256295	701	664	548	417	12859	22	11	1725	8
H2000/2227-37	57	5010	270	138954	363	3432	320	422	40	94	28	1938	1
H2000/2227-38	49	1924	303	362682	708	14800	1059	392	188	56	-1	7548	31
H2000/2227-39	33	880	502	206978	414	918	278	325	41	107	0	3070	6
H2000/2227-41	125	2523	388	182078	420	97	373	459	18900	49	1	3732	13

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HARP Samples Analyzed via pXRF

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Sample ID	Mn (K Aplha)	Fe (K Aplha)	Ni (K Aplha)	Cu (K Aplha)	Zn (K Aplha)	As (K Aplha)	Zr (K Aplha)	Ag (K Aplha)	Sn (K Aplha)	Sb (K Aplha)	Au (L Alpha)	Pb (L Alpha)	Bi (L Alpha)
H2000/2227-42	85	2109	89	105943	345	2971	119	278	68	47	32	540	5
H2000/2227-43	87	334	248	286045	592	6542	508	278	52	56	10	671	7
H2000/2227-44	40	3771	351	154974	317	5330	235	414	63	33	40	489	16
H2000/2358-15	84	2100	801	289133	735	7725	544	313	52	31	8	1621	0
H2000/2715-28	73	5246	772	255960	579	1281	513	318	31	62	1	2183	4
H2000/2727-5	11	1500	145	190155	465	26	244	328	7160	24	12	1993	37
H2000/2730-1	74	3960	378	102362	296	579	132	267	29	238	43	739	1
H2000/2769-7	32	2782	195	126100	283	402	252	195	92	68	35	516	0
H2000/2797-21	96	3614	486	278072	749	210	689	338	32	70	14	132	12
H2000/8990-78	55	4704	710	267436	495	5079	710	400	61	37	32	310	0
H2000/8990-80	68	2785	57	234372	658	288	494	344	3883	3	63	328	3
H2000/9514-6	141	558	678	388813	773	5372	970	739	74	1475	8	10374	31
H2000/9845-54	67	5402	323	341781	1063	447	845	482	2361	8	30	235	10
H2000/9954-1	89	2776	237	456462	1158	9578	1375	426	73	47	32	108	19
H2001/11064-1	160	1442	644	870641	3421	986	6505	747	65	43	6	286	-1
H2001/11543-2	90	6444	1079	596763	2013	2007	2902	893	88	69	22	3522	0
H2001/11701-2	137	16553	745	439256	1483	6292	1623	985	73	132	1	4603	25
H2001/11905-	35	680	397	560668	1808	21580	2403	601	172	173	17	6236	19
H2001/2378-1	164	7123	1551	729861	2434	4700	4382	883	343	174	12	8825	25
H2001/2387-1	395	10294	210	382278	1300	12515	1025	639	259	74	22	9659	26
<i>H2001/2394-4</i>	<i>109</i>	<i>3441</i>	<i>496</i>	<i>513753</i>	<i>1359</i>	<i>5071</i>	<i>2030</i>	<i>762</i>	<i>1010</i>	<i>77</i>	<i>2</i>	<i>11902</i>	<i>14</i>
<i>H2001/2394-4B</i>	<i>35</i>	<i>3825</i>	<i>387</i>	<i>438354</i>	<i>1159</i>	<i>6156</i>	<i>1415</i>	<i>771</i>	<i>877</i>	<i>30</i>	<i>19</i>	<i>10099</i>	<i>5</i>
H2001/2919-2	27	4469	467	521501	1690	2503	1979	732	9117	42	5	3703	3
H2001/2920-31	70	2781	537	373584	1021	5134	1058	592	4993	28	9	6595	-1
<i>H2001/2920-32</i>	<i>131</i>	<i>2547</i>	<i>2312</i>	<i>643072</i>	<i>2952</i>	<i>14984</i>	<i>3920</i>	<i>1083</i>	<i>139884</i>	<i>-58</i>	<i>26</i>	<i>10798</i>	<i>142</i>
<i>H2001/2920-32B</i>	<i>305</i>	<i>20981</i>	<i>403</i>	<i>668251</i>	<i>2853</i>	<i>1519</i>	<i>3784</i>	<i>1055</i>	<i>1775</i>	<i>4</i>	<i>8</i>	<i>1575</i>	<i>0</i>
H2001/2920-35	223	10468	695	660981	2317	2659	3583	931	122	126	9	3490	-12
H2001/2923-5	64	3816	675	628503	1810	1627	3101	699	111	70	1	7783	8
H2001/9059-23	48	1999	332	228508	558	5759	372	765	77	195	9	5586	0
H2001/9090-2	77	7537	504	390253	1093	842	1255	929	9	55	42	3995	1

317 unique artifacts analyzed
345 spectra reported due to repeat analyses

Repeated analyses italicized

Appendix 4.3
HARP Samples

Samples Analyzed via ICP-OES
at UW Soils

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type	UW Soils Alloy
H1988/413-B	H1988	413	B	R37	3B	Harappan	Copper Misc. Fragment		Cu-Pb-As
H1988/413-C	H1988	413	C	R37	3B	Harappan	Copper Misc. Fragment		Cu-Pb
H1990/1171-22	H1990	1171	22	E	2/3	KD/Harp Trans.	Copper Sheet/Blade	TBD	Cu-Sn
H1990/1185-1C	H1990	1185	1C	E	2	Kot Diji	Copper Rod/Wire/Pin	TBD	Cu
H1990/3056-30	H1990	3056	30	E	3B	Harappan	Copper Rod/Wire/Pin	TBD	Cu-Sn
H1990/3095-7	H1990	3095	7	E	3C	Harappan	Copper Bangle	TBD	Cu-Sn
H1990/3127-1	H1990	3127	1	E	3B	Harappan	Copper Sheet/Blade	TBD	Cu-Sn
H1990/3150-3	H1990	3150	3	E	3C	Harappan	Copper Rod/Wire/Pin	TBD	Cu-Sn
H1990/3153-19	H1990	3153	19	E	3B	Harappan	Copper Bangle	TBD	Cu-Sn
H1993/3812-12	H1993	3812	12	E	3C	Harappan	Copper Arrow Point	Arrow	Cu-Pb
H1993/4098-20	H1993	4098	20	ET	3B	Harappan	Copper Arrow Point	Arrow	Cu-Sn
H1994/3978-1	H1994	3978	1	ET	2/3A	KD/Harp Trans.	Copper Ring	Solid-flat-single coil	Cu
H1994/4509-1	H1994	4509	1	ET	3B	Harappan	Copper Bangle	Round-solid	Cu-Sn
H1994/4544-13	H1994	4544	13	ET	3B	Harappan	Copper Bangle	Round-hollow	Cu-Sn-Pb
H1994/5421-1	H1994	5421	1	ET	3B	Harappan	Copper Ring	Solid-round-single coil	Cu-As
H1995/4416-54	H1995	4416	54	E	3C	Harappan	Copper Ring	Solid-round-single coil	Cu-Pb
H1995/4613-54	H1995	4613	54	ET	3B	Harappan	Copper Arrow Point	Arrow	Cu
H1995/5641-21	H1995	5641	21	ET	3B	Harappan	Copper Arrow Point	Arrow	Cu-Sn
H1996/6256-8	H1996	6256	8	ET	3C	Harappan	Copper Arrow Point	Arrow	Cu-Pb
H1996/7210-11	H1996	7210	11	F	3C	Harappan	Copper Bangle	Round-hollow	Cu
H1996/7291-2	H1996	7291	2	F	3B	Harappan	Copper Arrow Point	Arrow	Cu
H1996/7293-1	H1996	7293	1	F	3B	Harappan	Copper Arrow Point	Arrow	Cu
H1996/7410-4	H1996	7410	4	AB	3A	Harappan	Copper Ring	TBD	Cu
H1996/7431-2	H1996	7431	2	AB	2	Kot Diji	Copper Sheet/Blade	TBD	Cu-As
H1996/7490-32	H1996	7490	32	AB	2	Kot Diji	Copper Arrow Point	Arrow	Cu-As
H1996/7512-9	H1996	7512	9	AB	1	Ravi	Copper Misc. Fragment		Cu
H1996/7513-59	H1996	7513	59	AB	1	Ravi	Copper Bead	Round	Cu
H1996/7516-78	H1996	7516	78	AB	1	Ravi	Copper Prill	Prill	Cu
H1996/7531-9	H1996	7531	9	AB	1	Ravi	Copper Misc. Fragment		Cu-Sn
H1997/8017-61	H1997	8017	61	E	3B	Harappan	Copper Bead	TBD	Cu-Sn-Pb
H1997/8017-62	H1997	8017	62	E	3B	Harappan	Copper Rod/Wire/Pin	square	Cu-Sn
H1997/8059-19	H1997	8059	19	E	3B	Harappan	Copper Bead	Cylinder	Cu
H1998/8336-68	H1998	8336	68	AB	3C	Harappan	Copper Rod/Wire/Pin	square/flat	Cu-Sn-Pb & C-Sn
H1998/8407-36	H1998	8407	36	AB	2	Kot Diji	Copper Rod/Wire/Pin	round/curved	Cu

Appendix 4.3
HARP Samples

Samples Analyzed via ICP-OES
at UW Soils

HARP Artifact Number	Year	Lot	Rec #	Mound	Period	Phase	Category	Type	UW Soils Alloy
H1998/8433-37	H1998	8433	37	AB	2	Kot Diji	Copper Rod/Wire/Pin	square	Cu
H1998/8439-58	H1998	8439	58	AB	3	Harappan	Copper Arrow Point	Arrow	Cu
H1998/8487-1	H1998	8487	1	AB	2	Kot Diji	Copper Bangle	Round-hollow	Cu-Sn-Pb
H1998/8488-11	H1998	8488	11	AB	2	Kot Diji	Copper Bangle	Round-hollow	Cu-Sn
H1998/8522-1	H1998	8522	1	AB	1	Ravi	Copper Sheet/Blade	TBD	Cu-As
H1998/8562-36	H1998	8562	36	AB	1	Ravi	Copper Misc. Fragment		Cu-Sn
H1998/8657-4	H1998	8657	4	F	3C	Harappan	Copper Rod/Wire/Pin	square/flat	Cu-As
H1999/8492-116	H1999	8492	116	AB	2	Kot Diji	Copper Bangle	Flat-hollow	Cu-Sn-Pb
H1999/8754-43	H1999	8754	43	F	3C	Harappan	Copper Rod/Wire/Pin	Round	Cu
H1999/8776-6	H1999	8776	6	F	3C	Harappan	Copper Ring	TBD	Cu-Pb
H1999/8950-12	H1999	8950	12	AB	2	Kot Diji	Copper Rod/Wire/Pin	square	Cu
H1999/8950-14	H1999	8950	14	AB	2	Kot Diji	Copper Arrow Point	Arrow	Cu-As
H1999/8950-15	H1999	8950	15	AB	2	Kot Diji	Copper Rod/Wire/Pin	Round	Cu-As
H1999/9108-3	H1999	9108	3	F	3C	Harappan	Copper Ring	Solid-round-two coils	Cu
H2000/2128-22	H2000	2128	22	E	3A	Harappan	Copper Bead	Round	Cu
H2000/2137-11	H2000	2137	11	E	3A	Harappan	Copper Arrow Point	Arrow	Cu-As
H2000/9514-6	H2000	9514	6	AB	2	Kot Diji	Copper Rod/Wire/Pin	square/flat	Cu-Pb-As
H2000/11064-1	H2000	11064	1	AB	1	Ravi	Copper Rod/Wire/Pin	TBD	Cu
H2001/2919-2	H2001	2919	2	E	3B	Harappan	Copper Rod/Wire/Pin	Round	Cu-Sn
H2001/11905-1	H2001	11905	1	E	3C	Harappan	Copper Arrow Point	Arrow	Cu-As

Appendices 5.1-5.6

The appendices in this section are the results of the different lead isotope analysis (LIA) portions of the project. Copper and bronze artifacts from the Harappa Archaeological Research Project (HARP) excavations were analyzed for their lead isotope content at different project stages. For specific details please refer to Chapter 5 in the text and the individual appendix summaries below. All appendices display the various ratios of the four isotopes of the element lead (Pb): ^{208}Pb , ^{207}Pb , ^{206}Pb , and ^{204}Pb .

Appendix 5.1 – This is the results from an initial run of seven copper minerals from the site of Harappa. Samples were provided by Dr. R.W. Law and have been previously published in Law 2011 and Hoffman and Miller 2014.

Appendix 5.2 – These are the results of lead isotope analyses on a series of copper deposits from across South Asia. This was the initial comparative data set for the project pilot study. Samples were provided by Dr. R.W. Law and have been previously published in Law 2011 and Hoffman and Miller 2014.

Appendix 5.3 – This appendix contains the lead isotope analyses on an initial set of twelve copper-bronze objects from Harappa. These artifacts come from the HARP excavations and the results of this have been previously published in Hoffman and Miller 2014.

Appendix 5.4 – This appendix is the data from a set of HARP copper and bronze artifact samples that were analyzed in order to compare the lead isotope measurements for the oxidized/corroded portions and the metallic aspects of each object. This was done to ensure viability of the larger project data set.

Appendix 5.5 – This is the total of one hundred twenty-five samples from HARP analyzed for their lead isotope signatures after the initial pilot study. This includes the samples from Appendix 5.4. This includes all data returned from the lab.

Appendix 5.6 – The final complete one hundred thirty sample lead isotope database for copper and bronze artifacts from the HARP excavations at Harappa. Copper minerals and slag are not included in this database. This includes the data from Appendix 5.3, 5.4, and 5.5. All samples that had lead isotope measurements that demonstrated too large of an error factor for confident application to this study were excluded.

Appendix 5.1
HARP Minerals

Lead (Pb) Isotope Analyses for Copper Minerals
from Harappa

Analytical Samples Provided
by Dr. R.W. Law

Year	Lot	Rec #	Type	BCH Refined	Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206	Reference
H1990	2070	12	Ore	Mineral		E	3+	Chalcocite	38.06750	15.4790	18.31401	2.07860036	0.8452	Law 2011
H1990	3008	13	Ore	Mineral		E	3+	Chalcocite	37.77955	15.3090	18.15153	2.08134252	0.8434	Law 2011
H1990	3008	14	Ore	Mineral		E	3+	Chalcocite	36.92022	15.1480	17.59350	2.0985153	0.861	Law 2011
H1990	3022	98	Ore	Mineral		E	3+	Malachite	38.28702	15.5310	18.33648	2.0880244	0.847	Law 2011
H1990	3126	1	Ore	Mineral		E	3c	Malachite	37.99087	15.4190	18.24734	2.0819955	0.845	Law 2011
H1994	4999	529	Ore	Mineral		Surface	Unknown	Chalcocite	37.44396	15.3120	18.04596	2.0749219	0.8485	Law 2011
H1995	4943	8	Ore	Mineral		ET	3+	Malachite	37.46323	15.2030	17.94288	2.08791666	0.8473	Law 2011

Appendix 5.2
Copper Ores and Slags

Lead (Pb) Isotope Analyses for Regional South Asia
Copper Deposits Used in Initial Pilot Study

Analytical Samples Provided
by Dr. R.W. Law

Region	Source	Material	Reference	Analysis #	208/207	207/206	207/204	206/204	208/204
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu1	2.4878	0.8327	15.782	18.95280413	39.2624596
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu2	2.4802	0.8407	15.828	18.82716784	39.2566056
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu3	2.4763	0.8421	15.729	18.67830424	38.9497227
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu4	2.4697	0.8424	15.758	18.70607787	38.9175326
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu5	2.4728	0.8447	15.797	18.70131408	39.0628216
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu6	2.4838	0.8434	15.704	18.61987195	39.0055952
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu7	2.4911	0.8315	15.807	19.01022249	39.3768177
Gujarat	Ambaji	ore	Law 2011	GN-01	2.395	0.9111	15.89	17.44045659	38.05655
Gujarat	Ambaji	ore	Law 2011	GN-02	2.4027	0.9106	15.396	16.90753349	36.9919692
Gujarat	Ambaji	ore	Law 2011	GN-03	2.4035	0.9079	15.862	17.47108712	38.124317
Gujarat	Ambaji	ore	Law 2011	GN-04	2.3916	0.8995	15.771	17.53307393	37.7179236
Gujarat	Ambaji	ore	Law 2011	GN-05	2.4041	0.8795	15.706	17.85787379	37.7587946
Gujarat	Ambaji	ore	Law 2011	GN-06	2.3977	0.8976	15.685	17.47437611	37.6079245
Gujarat	Ambaji	ore	Law 2011	GN-07	2.3889	0.8991	15.693	17.45412079	37.4890077
Gujarat	Ambaji	ore	Law 2011	GN-08	2.3861	0.8972	15.647	17.43981275	37.3353067
Gujarat	Ambaji	ore	Law 2011	GN-09	2.3858	0.897	15.647	17.44370123	37.3306126
Gujarat	Ambaji	ore	Law 2011	GN-10	2.3879	0.8991	15.677	17.43632521	37.4351083
Gujarat	Ambaji	ore	Hegde and Ericson 1985	no #	2.3891	0.904	15.649	17.31084071	37.3870259
Himachal Pradesh	Chargaon	ore	Law 2011	HP1	2.6692	0.6834	16.639	24.34738074	44.4128188
Himachal Pradesh	Chargaon	ore	Law 2011	HP2	2.6706	0.6801	16.662	24.49933833	44.4975372
Himachal Pradesh	Chargaon	ore	Law 2011	HP3	2.6701	0.6813	16.69	24.4972846	44.563969
Himachal Pradesh	Chargaon	ore	Law 2011	HP4	2.6756	0.6801	16.678	24.52286428	44.6236568
Himachal Pradesh	Chargaon	ore	Law 2011	HP5	2.665	0.6812	16.702	24.51849677	44.51083
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 96	2.4891	0.8348	15.639	18.73382846	38.9270349
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 101/1	2.4935	0.8341	15.643	18.754346	39.0058205
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 137	2.4934	0.8336	15.631	18.75119962	38.9743354

Appendix 5.2
Copper Ores and Slags

Lead (Pb) Isotope Analyses for Regional South Asia
Copper Deposits Used in Initial Pilot Study

Analytical Samples Provided
by Dr. R.W. Law

Region	Source	Material	Reference	Analysis #	208/207	207/206	207/204	206/204	208/204
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 145	2.4861	0.812	15.661	19.28694581	38.9348121
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 148	2.4933	0.8319	15.617	18.77268903	38.9378661
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 156A	2.4898	0.8193	15.656	19.10899548	38.9803088
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 161	2.495	0.8329	15.624	18.75855445	38.98188
Iran	Chechel Kureh	ore	Hauptmann et al. 2003	E 127/4111	2.4899	0.8394	15.657	18.65260901	38.9843643
Iran	Chechel Kureh	ore	Hauptmann et al. 2003	E 128/4112	2.4879	0.8389	15.659	18.66611038	38.9580261
Iran	Qaleh Zari	ore	Hauptmann et al. 2003	E 128/4286	2.4913	0.8349	15.662	18.75913283	39.0187406
Iran	Qaleh Zari	ore	Hauptmann et al. 2003	E 130/4661	2.4906	0.8347	15.665	18.76722176	39.015249
Oman	Aarja	ore	Chen and Pallister 1981	Aarja	2.4484	0.8601	15.459	17.97349145	37.8498156
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS12	2.4104	0.8797	15.668	17.81061726	37.7661472
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS18	2.4435	0.8699	15.501	17.81928957	37.8766935
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS17	2.4446	0.8615	15.515	18.00928613	37.927969
Oman	Bayda	ore	Chen and Pallister 1981	Bayada	2.4433	0.8627	15.438	17.89498087	37.7196654
Oman	Daris 1	ore	Calvez and Lescuyer 1991	PS5	2.4507	0.8559	15.488	18.09557191	37.9564416
Oman	Daris 1	ore	Calvez and Lescuyer 1991	PS4	2.4532	0.8557	15.443	18.04721281	37.8847676
Oman	Daris 2	ore	Calvez and Lescuyer 1991	PS2	2.4676	0.8454	15.6	18.45280341	38.49456
Oman	Daris 2	ore	Calvez and Lescuyer 1991	PS1	2.467	0.8459	15.547	18.37924105	38.354449
Oman	Gaddamah (near Lasail)	ore	Calvez and Lescuyer 1991	CU54	2.4593	0.8545	15.533	18.1778818	38.2003069
Oman	Hayl as Safil	ore	Calvez and Lescuyer 1991	CJ55	2.4647	0.8453	15.603	18.45853543	38.4567141
Oman	Hayl as Safil	ore	Calvez and Lescuyer 1991	PS16	2.455	0.8535	15.461	18.11482132	37.956755
Oman	Lasail	ore	Chen and Pallister 1981	Lasail	2.4412	0.8564	15.427	18.01377861	37.6603924
Oman	Maqa'il	ore	Calvez and Lescuyer 1991	CU73	2.4613	0.853	15.544	18.22274326	38.2584472
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS9	2.465	0.8466	15.62	18.45027167	38.5033
Oman	Rakah	ore	Calvez and Lescuyer 1991	CJ58	2.4678	0.8444	15.602	18.47702511	38.5026156
Oman	Rakah	ore	Calvez and Lescuyer 1991	CJ57	2.468	0.8438	15.606	18.49490401	38.515608
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS6	2.4682	0.8431	15.608	18.51263195	38.5236656

Appendix 5.2
Copper Ores and Slags

Lead (Pb) Isotope Analyses for Regional South Asia
Copper Deposits Used in Initial Pilot Study

Analytical Samples Provided
by Dr. R.W. Law

Region	Source	Material	Reference	Analysis #	208/207	207/206	207/204	206/204	208/204
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS8	2.4683	0.8437	15.608	18.49946664	38.5252264
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS7	2.4691	0.8438	15.593	18.47949751	38.5006763
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS10	2.4701	0.8454	15.607	18.46108351	38.5508507
Oman	Zuha	ore	Calvez and Lescuyer 1991	CU24	2.4439	0.8568	15.451	18.03338002	37.7606989
Rajasthan	Ganeshwar	slag	Law 2011	RNSG_13	2.4613	0.8513	15.754	18.50581464	38.7753202
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2.2	2.4481	0.856	15.701	18.34228972	38.4376181
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2.2_14	2.4345	0.8682	15.849	18.25501037	38.5843905
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2.5	2.4249	0.8674	15.567	17.94673738	37.7484183
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_10	2.4534	0.8552	15.717	18.37815716	38.5600878
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_11	2.4304	0.8689	15.745	18.12061227	38.266648
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_12	2.4392	0.8662	15.723	18.15169707	38.3515416
Rajasthan	Ganeshwar	slag	Law 2011	RNSG7	2.4281	0.8728	15.538	17.80247479	37.7278178
Rajasthan	Ganeshwar	slag	Law 2011	RNSG6	2.4304	0.8688	15.679	18.04673112	38.1062416
Rajasthan	Ganeshwar	slag	Law 2011	RNSG8	2.4218	0.8654	15.824	18.28518604	38.3225632
Rajasthan	Ganeshwar	slag	Law 2011	RNSG9	2.4246	0.8634	15.565	18.02756544	37.738899
Rajasthan	Singhana	slag	Law 2011	RNSS4	2.3798	0.8856	15.853	17.90085818	37.7269694
Rajasthan	Singhana	slag	Law 2011	RNSS5	2.3845	0.8863	15.608	17.61028997	37.217276
Rajasthan	Singhana	slag	Law 2011	RNSS7	2.4338	0.8603	15.723	18.27618273	38.2666374
Rajasthan	Singhana	slag	Law 2011	RNSS8	2.4354	0.8637	15.616	18.08035197	38.0312064
Rajasthan	Piplawas	ore	Hegde and Ericson 1985	no #	2.2803	0.9844	15.444	15.68874441	35.2169532
Rajasthan	Kankaria	ore	Hegde and Ericson 1985	no #	2.3141	0.963	15.524	16.12045691	35.9240884
Uttaranchal	Askot	ore	Law 2011	UT1	2.3351	0.9547	15.746	16.49313921	36.7684846
Uttaranchal	Askot	ore	Law 2011	UT10	2.3094	0.9755	15.659	16.05228088	36.1628946
Uttaranchal	Askot	ore	Law 2011	UT2	2.3013	0.9813	15.727	16.02669928	36.1925451
Uttaranchal	Askot	ore	Law 2011	UT4	2.3034	0.9823	15.518	15.79761784	35.7441612
Uttaranchal	Askot	ore	Law 2011	UT5	2.3017	0.9841	15.708	15.9617925	36.1551036

Appendix 5.2
Copper Ores and Slags

Lead (Pb) Isotope Analyses for Regional South Asia
Copper Deposits Used in Initial Pilot Study

Analytical Samples Provided
by Dr. R.W. Law

Region	Source	Material	Reference	Analysis #	208/207	207/206	207/204	206/204	208/204
Uttaranchal	Askot	ore	Law 2011	UT6	2.3001	0.982	15.686	15.97352342	36.0793686
Uttaranchal	Askot	ore	Law 2011	UT7	2.3023	0.9799	15.639	15.95979182	36.0056697
Waziristan	Shinkai	ore	Law 2011	WAZ-1	2.4671	0.8467	15.668	18.50478328	38.6545228
Waziristan	Shinkai	ore	Law 2011	WAZ-2	2.4674	0.8478	15.664	18.47605567	38.6493536
Waziristan	Shinkai	ore	Law 2011	WAZ-3	2.4768	0.8462	15.644	18.48735524	38.7470592
Waziristan	Shinkai	ore	Law 2011	WAZ-4	2.4812	0.8444	15.573	18.44268119	38.6397276
Waziristan	Shinkai	ore	Law 2011	WAZ-5	2.4799	0.8465	15.603	18.43236858	38.6938797

Appendix 5.2
Copper Ores and Slags

Lead (Pb) Isotope Analyses for Regional South Asia
Copper Deposits Used in Initial Pilot Study

Analytical Samples Provided
by Dr. R.W. Law

Region	Source	Material	Reference	Analysis #	208/207	207/206	207/204	206/204	208/204
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu1	2.4878	0.8327	15.782	18.95280413	39.2624596
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu2	2.4802	0.8407	15.828	18.82716784	39.2566056
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu3	2.4763	0.8421	15.729	18.67830424	38.9497227
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu4	2.4697	0.8424	15.758	18.70607787	38.9175326
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu5	2.4728	0.8447	15.797	18.70131408	39.0628216
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu6	2.4838	0.8434	15.704	18.61987195	39.0055952
Baluchistan	Chagai-Saindak	ore	Law 2011	ChCu7	2.4911	0.8315	15.807	19.01022249	39.3768177
Gujarat	Ambaji	ore	Law 2011	GN-01	2.395	0.9111	15.89	17.44045659	38.05655
Gujarat	Ambaji	ore	Law 2011	GN-02	2.4027	0.9106	15.396	16.90753349	36.9919692
Gujarat	Ambaji	ore	Law 2011	GN-03	2.4035	0.9079	15.862	17.47108712	38.124317
Gujarat	Ambaji	ore	Law 2011	GN-04	2.3916	0.8995	15.771	17.53307393	37.7179236
Gujarat	Ambaji	ore	Law 2011	GN-05	2.4041	0.8795	15.706	17.85787379	37.7587946
Gujarat	Ambaji	ore	Law 2011	GN-06	2.3977	0.8976	15.685	17.47437611	37.6079245
Gujarat	Ambaji	ore	Law 2011	GN-07	2.3889	0.8991	15.693	17.45412079	37.4890077
Gujarat	Ambaji	ore	Law 2011	GN-08	2.3861	0.8972	15.647	17.43981275	37.3353067
Gujarat	Ambaji	ore	Law 2011	GN-09	2.3858	0.897	15.647	17.44370123	37.3306126
Gujarat	Ambaji	ore	Law 2011	GN-10	2.3879	0.8991	15.677	17.43632521	37.4351083
Gujarat	Ambaji	ore	Hegde and Ericson 1985	no #	2.3891	0.904	15.649	17.31084071	37.3870259
Himachal Pradesh	Chargaon	ore	Law 2011	HP1	2.6692	0.6834	16.639	24.34738074	44.4128188
Himachal Pradesh	Chargaon	ore	Law 2011	HP2	2.6706	0.6801	16.662	24.49933833	44.4975372
Himachal Pradesh	Chargaon	ore	Law 2011	HP3	2.6701	0.6813	16.69	24.4972846	44.563969
Himachal Pradesh	Chargaon	ore	Law 2011	HP4	2.6756	0.6801	16.678	24.52286428	44.6236568
Himachal Pradesh	Chargaon	ore	Law 2011	HP5	2.665	0.6812	16.702	24.51849677	44.51083
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 96	2.4891	0.8348	15.639	18.73382846	38.9270349
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 101/1	2.4935	0.8341	15.643	18.754346	39.0058205
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 137	2.4934	0.8336	15.631	18.75119962	38.9743354

Appendix 5.3
HARP Artifacts

Lead (Pb) Isotope Analyses for HARP Copper Artifacts Pilot Study

Sample #	Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206
#1UM	H2000	2102	1447	Copper Sheet/Blade	None	E	3B/C	No Comp.	38.33700	15.68090	18.20680	2.105641848	0.86126612
#2UM	H2000	2226	40	Copper Sheet/Blade	None	E	3B	No Comp.	38.38700	15.60870	18.44510	2.081148923	0.846224743
#3UM	H2000	2357	3	Copper Bead	Round	E	3B	No Comp.	38.70140	15.68240	18.50140	2.091809268	0.847633152
#4UM	H2001	2394	3	Copper Bead	Cylinder/Rolled Sheet	E	3B	No Comp.	38.97870	15.76820	18.59660	2.096012174	0.847907682
#5UM	H1996	6913	45	Copper Bangle	Flat Solid	E	3B/C	No Comp.	38.28610	15.61310	18.25300	2.097523695	0.85537172
#6UM	H1996	6958	61	Copper Rod/Wire/Pin	square tapered w/pointed tip	E		No Comp.	38.07140	15.50510	18.28900	2.08165564	0.84778282
#7UM	H1994	4353	3	Copper Sheet/Blade	None	E	3C	No Comp.	38.60770	15.63930	18.45730	2.091730643	0.847323281
#8UM	H1995	4638	1	Copper Bangle	Round Solid	ET	3	No Comp.	37.84140	15.45840	18.36140	2.060921281	0.841896587
#9UM	H1995	4968	12	Copper Bangle	Round Solid	ET	3C	No Comp.	38.33400	15.68950	18.40350	2.082973347	0.852528052
#10UM	H1996	7227	32	Copper Rod/Wire/Pin	square flat point tool	F		No Comp.	38.45320	15.67690	18.33050	2.097771474	0.855235809
#11UM	H1996	7248	1	Copper Rod/Wire/Pin	Wire or Pin	F	3C	No Comp.	38.87020	15.72210	18.56070	2.094220584	0.847063958
#12UM	H1998	8627	18	Copper Rod/Wire/Pin	Square point tool	F	3C	No Comp.	38.94160	15.80200	18.52430	2.102190096	0.85304168

Appendix 5.4
HARP Samples

Lead (Pb) Isotope Analyses of HARP Copper Artifacts
Comparison of Metal versus Oxide

UF LIA Sample #	Sample Material Designation	208/204	207/204	206/204	208/206	207/206
1	metal	37.97651	15.65405	17.90593	2.12087	0.8742487
1	oxide	37.95591	15.64838	17.90152	2.120248	0.8741363
7	metal	37.29144	15.62636	17.32427	2.15253	0.9019998
7	oxide	37.29365	15.62715	17.32785	2.152284	0.9018639
12	metal	38.68137	15.68429	18.52024	2.088605	0.8468636
12	oxide	38.67422	15.68178	18.51715	2.08862	0.8468859
16	metal	38.91048	15.68718	18.33856	2.121835	0.855444
16	metal	38.9137	15.68809	18.33938	2.121855	0.8554396
16	oxide	38.92005	15.68665	18.34297	2.121821	0.8552042
21	metal	38.61074	15.68548	18.42585	2.095458	0.8512712
21	oxide	38.59955	15.68171	18.42246	2.095264	0.8512263
32	metal	38.61669	15.67203	18.51948	2.085184	0.8462674
32	oxide	38.62065	15.67374	18.522	2.085215	0.8462631
41	metal	38.68161	15.682	18.51949	2.088815	0.8468035
41	oxide	38.68263	15.68171	18.51842	2.088879	0.8468135
44	metal	38.46545	15.67127	18.352	2.096038	0.8539516
44	oxide	38.46106	15.66998	18.35267	2.095671	0.8538168

Sample #	Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206	Notes
1	H1988	346	27	Copper Bead	Bead	E	3C	Cu-Pb-As	37.97651	15.65405	17.90593	2.120870	0.8742487	
2	H1988	413	A	Copper Ring	Ring	R37	3B	Cu	38.50036	15.63495	18.48714	2.082538	0.8457142	
3	H1988	413	B	Copper Misc. Fragment	None	R37	3B	Cu-Pb-As	38.66188	15.67998	18.50239	2.089549	0.8474527	
4	H1988	413	C	Copper Misc. Fragment	None	R37	3B	Cu-Pb	38.71079	15.69069	18.53023	2.089089	0.8467764	
5	H1988	754	2	Copper Misc. Fragment	None	E	3A	Cu-Pb	38.55048	15.68999	18.24014	2.113548	0.8601827	
6	H1988	758	16	Copper Misc. Fragment	None	E	3A	Cu-Ag-Au-Pb	38.19188	15.66223	18.09850	2.110218	0.8653848	
7	H1989	1054	24	Copper Misc. Fragment	None	E	2/3	Cu	37.29144	15.62636	17.32427	2.152530	0.9019998	
8	H1990	1171	22	Copper Sheet/Blade	None	E	2/3	Cu-Sn	37.30320	15.62946	17.33496	2.151868	0.9016032	
9	H1990	1185	1A	Copper Sheet/Blade	None	E	2	Cu	38.12841	15.70348	18.09513	2.107132	0.8678294	
10	H1990	1185	1C	Copper Rod/Wire/Pin	None	E	2	Cu	38.44740	15.79667	18.56786	2.070610	0.8507504	
11	H1990	3056	30	Copper Rod/Wire/Pin	square/flat	E	3B	Cu-Sn	38.55909	15.67933	18.41140	2.094317	0.8516094	
12	H1990	3072	4	Copper Bead	cylinder	E	3C	Cu-As	38.68137	15.68429	18.52024	2.088605	0.8468636	
13	H1990	3095	7	Copper Bangle	round hollow	E	3C	Cu-Sn	38.55071	15.67940	18.41961	2.092907	0.8512387	
14	H1990	3127	1	Copper Sheet/Blade	None	E	3B	Cu-Sn	38.63672	15.68132	18.48585	2.090110	0.8482997	
15	H1990	3135	14	Copper Ring	solid round single coil	E	3B/C	Cu	38.74939	15.70619	18.54956	2.088966	0.8467027	
16	H1990	3150	3	Copper Rod/Wire/Pin	round/curved	E	3C	Cu-Sn	38.91370	15.68809	18.33938	2.121855	0.8554396	
17	H1990	3153	19	Copper Bangle	round hollow	E	3B	Cu-Sn	38.45636	15.67542	18.32431	2.098659	0.8554395	
18	H1990	3189	24	Copper Bangle	round hollow	E	Mixed	Cu	38.32281	15.70520	18.08721	2.118842	0.8683185	
19	H1993	3650	1	Copper Arrow Point	None	E	3A/B	Cu-As	38.31006	15.69248	18.16622	2.108864	0.8638048	
20	H1993	3812	1	Copper Arrow Point	None	E	3C	Cu-Pb	38.65839	15.67999	18.51010	2.088484	0.8471072	
21	H1993	4074	10	Copper Rod/Wire/Pin	Round	ET	3B/C	Cu-Sn	38.61074	15.68548	18.42585	2.095458	0.8512712	
22	H1993	4098	20	Copper Arrow Point	None	ET	3B	Cu-Sn	39.24284	15.74085	19.00009	2.065373	0.8284560	
23	H1993	4099	5	Copper Prill	None	ET	3B	None	38.70940	15.68706	18.51925	2.090293	0.8470651	
24	H1994	3978	1	Copper Ring	solid flat single coil	ET	2/3A	Cu	38.09880	15.64216	18.51126	2.058114	0.8449966	
25	H1994	4297	1	Copper Prill	None	ET	3C	Cu or Cu-Pb	38.63101	15.67648	18.50631	2.087503	0.8470858	
26	H1994	4297	2	Copper Prill	None	ET	3C	Cu-Pb	38.17989	15.65140	18.51661	2.061929	0.8452649	
27	H1994	4353	2	Copper Prill	None	E	3C	Cu	38.45098	15.66657	18.51182	2.077110	0.8462875	
28	H1994	4544	13	Copper Bangle	round hollow	ET	3B	Cu-Sn-Pb	38.61266	15.68084	18.48884	2.088434	0.8481151	
29	H1994	5421	1	Copper Ring	solid round single coil	ET	3B	Cu-As	38.57391	15.68415	18.49453	2.085772	0.8480629	
30	H1995	4451	8	Copper Prill	None	E	3C	Cu-Pb-As	38.69396	15.68436	18.55652	2.085228	0.8452280	
31	H1995	4606	9	Copper Rod/Wire/Pin	flat with taper	ET	Mixed	Cu-As	38.63558	15.67950	18.51681	2.086520	0.8467744	
32	H1995	4623	17	Copper Misc. Fragment	None	ET	Mixed	Cu	38.61669	15.67203	18.51948	2.085184	0.8462674	
33	H1995	4661	2	Copper Sheet/Blade	None	ET	3B	Cu	38.68337	15.68613	18.52442	2.088266	0.8467841	
34	H1995	4989	75	Copper Prill	None	ET	3C	Cu-As	38.69154	15.68712	18.51581	2.089631	0.8472133	
35	H1995	5145	19	Copper Prill	None	E	3C	None	38.31029	15.68381	18.14482	2.111361	0.8643732	
36	H1995	5182	42	Copper Prill	None	E	3C	None	38.55248	15.68826	18.34240	2.101949	0.8553385	
37	H1995	5182	43	Copper Prill	None	E	3C	None	38.44131	15.68828	18.15245	2.117680	0.8642410	
38	H1995	5182	44	Copper Prill	None	E	3C	None	38.80815	15.66943	18.63611	2.082478	0.8408206	
39	H1995	5603	21	Copper Bangle	round hollow	ET	Mixed	Cu-Sn(Pb)	38.66359	15.68280	18.52363	2.087311	0.8466287	
40	H1995	5641	21	Copper Arrow Point	None	ET	Mixed	Cu-Sn	38.67797	15.68102	18.51469	2.089054	0.8469495	
41	H1995	5680	17	Copper Misc. Fragment	None	ET	3B	Cu-Pb-As	38.68161	15.68200	18.51949	2.088815	0.8468035	
42	H1995	5729	113	Copper Bead	cylinder	ET	Mixed	Cu or Cu-Sn	39.47833	16.18275	18.71369	2.087428	0.8570066	Low Accuracy
43	H1995	5789	1	Copper Bead	cylinder	ET	Mixed	Cu-Pb	27.56579	11.29238	13.29073	2.083155	0.8509949	Low Accuracy
44	H1995	6509	1	Copper Rod/Wire/Pin	None	E	Mixed	Cu-As	38.46545	15.67127	18.35200	2.096038	0.8539516	
45	H1996	6226	57	Copper Prill	None	ET	3C	Cu	39.33683	15.92888	19.37979	2.029665	0.8219408	
46	H1996	6237	56	Copper Prill	None	ET	3C	None	38.88301	15.69087	18.63564	2.086529	0.8419812	
47	H1996	6237	57	Copper Prill	None	ET	3C	None	38.13591	15.66072	18.05392	2.112302	0.8674404	
48	H1996	6237	58	Copper Prill	None	ET	3C	None	38.67298	15.68712	18.51481	2.088739	0.8472598	
49	H1996	6249	2	Copper Bead	Round	ET	Mixed	None	38.65600	15.67842	18.51371	2.087916	0.8468510	
50	H1996	6930	8	Copper Prill	None	E	3C	Cu-Sn-Pb-As	38.64815	15.67614	18.50922	2.088070	0.8469381	
51	H1996	7106	34	Copper Arrow Point	None	E	3C	Cu-Pb	38.71527	15.68905	18.55171	2.086860	0.8456864	
52	H1996	7126	1	Copper Prill	None	E	3C	Cu-Sn	38.65771	15.71049	18.54580	2.084458	0.8471207	
53	H1996	7210	11	Copper Bangle	Round Hollow	F	3C	Cu	38.63745	15.67734	18.51292	2.087059	0.8468362	
54	H1996	7232	65	Copper Misc. Fragment	bent arrow	F	Mixed	Cu	40.16051	15.80872	19.30683	2.080149	0.8188229	
55	H1996	7236	1	Copper Misc. Fragment	handle	F	Mixed	Cu	38.63990	15.68098	18.49401	2.089367	0.8478916	
56	H1996	7291	2	Copper Arrow Point	None	F	3B	Cu	38.65109	15.68022	18.50008	2.089287	0.8475891	
57	H1996	7293	1	Copper Arrow Point	None	F	3B	Cu	38.79270	15.71412	18.76747	2.067159	0.8374041	

Appendix 5.5
HARP Dataset

Lead (Pb) Isotope Analyses for HARP
Copper/Bronze Artifacts

All 125 Samples Analyzed at
University of Florida

Sample #	Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206	Notes
58	H1996	7400	47	Copper Ring	solid round single coil	AB	Mixed	Cu-Pb	38.40281	15.29746	20.62312	1.925376	0.7633685	Low Accuracy
59	H1996	7410	4	Copper Ring	None	AB	Mixed	Cu	44.59207	16.33889	24.26446	1.837746	0.6733876	Low Accuracy
60	H1996	7431	2	Copper Sheet/Blade	None	AB	2	Cu-As	36.62297	15.64012	17.10774	2.140764	0.9142157	
61	H1996	7457	1	Copper Rod/Wire/Pin	square tapered w/curve to point	AB	Mixed	None	37.30015	15.63362	17.32555	2.152929	0.9023574	
62	H1996	7467	962	Copper Ring	solid round single coil	AB	3A	Cu-Sn-Pb	38.58194	15.67752	18.43331	2.093069	0.8505266	
63	H1996	7467	963	Copper Rod/Wire/Pin	round	AB	Mixed	Cu	37.94267	15.76171	17.89024	2.120843	0.8810365	
64	H1996	7467	965	Copper Rod/Wire/Pin	square	AB	Mixed	Cu-As	37.61140	15.65910	17.60130	2.136860	0.8896580	
65	H1996	7490	32	Copper Arrow Point	fragment	AB	2	Cu-As	38.66646	15.68127	18.51193	2.088693	0.8470712	
66	H1996	7509	2	Copper Misc. Fragment	Bead	AB	1	Cu	37.46450	15.67523	17.88969	2.094140	0.8761595	
67	H1996	7512	9	Copper Misc. Fragment	None	AB	1	Cu	39.64100	15.94080	20.69140	1.915790	0.7703980	Low Accuracy
68	H1996	7513	59	Copper Bead	Round	AB	1	Cu	37.17560	15.64400	17.51850	2.122020	0.8929770	
69	H1996	7516	78	Copper Prill	None	AB	1	Cu	38.02180	15.69200	18.13640	2.096430	0.8652350	
70	H1997	6650	6	Copper Ring	solid round single coil	ET	3C	Cu-Pb	38.66195	15.67736	18.51225	2.088471	0.8468683	
71	H1997	6660	30	Copper Disc	Laminated Disc	ET	3B	Cu-Sn(Pb)	37.97475	15.65701	17.91046	2.120216	0.8741864	
72	H1997	6688	1	Copper Rod/Wire/Pin	round/curved	ET	3B	Cu	38.67438	15.68529	18.49942	2.090584	0.8478755	
73	H1997	8012	16	Copper Prill	None	E	3B	Cu-Pb-As	38.68735	15.68588	18.51723	2.089271	0.8470915	
74	H1997	8022	24	Copper Arrow Point	None	E	3C	Cu-Pb	38.38181	15.67630	18.24902	2.103339	0.8590387	
75	H1997	8026	13	Copper Arrow Point	None	E	3B	Cu-Pb	38.64077	15.67425	18.51551	2.086943	0.8465528	
76	H1997	8059	19	Copper Bead	Cylinder	E	3B	Cu	38.63206	15.67621	18.48032	2.090426	0.8482602	
77	H1997	8103	6	Copper Prill	None	E	3C	Cu-Sn-Pb	38.54534	15.68178	18.38143	2.097045	0.8531530	
78	H1998	8336	68	Copper Rod/Wire/Pin	square flat	AB	3C	Cu-Sn-Pb	38.61494	15.68237	18.44745	2.093224	0.8501198	
79	H1998	8407	36	Copper Rod/Wire/Pin	round/curved	AB	2	Cu	38.84694	15.71409	18.53035	2.096379	0.8479665	
80	H1998	8412	122	Copper Prill	None	AB	3	None	38.82965	15.74302	18.61212	2.086247	0.8458442	
81	H1998	8412	123	Copper Prill	None	AB	3	None	38.84708	15.71294	18.52821	2.096669	0.8480740	
82	H1998	8412	23	Copper Prill	None	AB	3	None	40.53925	15.85313	19.60178	2.068141	0.8087685	
83	H1998	8412	24	Copper Prill	None	AB	3	None	38.11680	15.68557	18.02906	2.114227	0.8700248	
84	H1998	8422	15	Copper Sheet/Blade	None	AB	2	None	37.33627	15.63542	17.35628	2.151174	0.9008448	
85	H1998	8432	8	Copper Prill	None	AB	2	Cu	37.76322	15.70285	17.82092	2.119045	0.8811158	
86	H1998	8433	37	Copper Rod/Wire/Pin	square	AB	2	Cu	38.10515	15.66193	18.02482	2.114040	0.8688774	
87	H1998	8439	58	Copper Arrow Point	None	AB	3	Cu	39.61280	16.09136	20.59949	1.923161	0.7811565	Low Accuracy
88	H1998	8455	1	Copper Sheet/Blade	None	AB	2	Cu-As	39.55290	16.07230	20.58990	1.920960	0.7805920	Low Accuracy
89	H1998	8483	1	Copper Misc. Fragment	None	AB	3A	Cu	38.41851	15.67166	18.30483	2.098809	0.8561419	
90	H1998	8486	5	Copper Misc. Fragment	None	AB	2	Cu-Sn-Pb	37.31692	15.62822	17.34572	2.151546	0.9010462	
91	H1998	8487	1	Copper Bangle	Round Hollow	AB	2	Cu-Sn-Pb	37.29511	15.62419	17.32884	2.152157	0.9016194	
92	H1998	8488	11	Copper Bangle	Round Hollow	AB	2	Cu-Sn	37.28877	15.62616	17.32558	2.152239	0.9019154	
93	H1998	8488	12	Copper Misc. Fragment	None	AB	2	None	37.28717	15.62497	17.33092	2.151469	0.9015435	
94	H1998	8488	13	Copper Misc. Fragment	None	AB	2	Cu-Sn(Pb)	37.31432	15.63131	17.34611	2.151346	0.9011909	
95	H1998	8506	3	Copper Rod/Wire/Pin	Round w/ spatula end	AB	1	Cu-As	37.89310	15.76240	18.03770	2.100750	0.8738510	
96	H1998	8522	1	Copper Sheet/Blade	None	AB	1	Cu-As	38.83800	15.70480	18.91310	2.053520	0.8303670	
97	H1998	8562	36	Copper Misc. Fragment	None	AB	1	Cu-Sn	38.41130	15.69600	18.22220	2.107940	0.8613710	
98	H1998	8604	12	Copper Prill	None	F	Mixed	None	38.46553	15.79402	18.60345	2.067614	0.8489565	
99	H1998	8604	13	Copper Prill	None	F	Mixed	None	38.48430	15.67680	18.32620	2.100000	0.8554250	
100	H1998	8657	4	Copper Rod/Wire/Pin	square flat	F	3C	Cu-As	38.28900	15.67870	18.17210	2.107010	0.8627860	
101	H1996	7241	16	Copper Sheet/Blade	None	F	3C	Cu-Pb	38.67324	15.67926	18.51221	2.089093	0.8469691	
102	H1999	8492	116	Copper Bangle	Flat Hollow	AB	2	Cu-Sn-Pb	37.28780	15.62520	17.32590	2.152060	0.9018080	
103	H1999	8754	43	Copper Rod/Wire/Pin	Round	F	3C	Cu	38.53550	15.68450	18.32330	2.103130	0.8560130	
104	H1999	8768	88	Copper Rod/Wire/Pin	square	F	3C	Cu	38.65810	15.68580	18.49490	2.090220	0.8481240	
105	H1999	8776	4	Copper Rod/Wire/Pin	round/curved	F	3C	Cu-As	38.45100	15.69870	18.27950	2.103530	0.8588730	
106	H1999	8950	12	Copper Rod/Wire/Pin	square long thin	AB	2	Cu	39.73180	15.95200	19.33670	2.054750	0.8249480	
107	H1999	8950	14	Copper Arrow Point	None	AB	2	Cu-As	37.46330	15.64270	17.52360	2.137880	0.8926630	
108	H2000	2226	55	Copper Bead	Cylinder	E	Mixed	Cu	38.35691	15.66719	18.24296	2.102546	0.8587991	
109	H1999	9702	2	Copper Sheet/Blade	None	F	3C	None	38.58481	15.78126	18.53108	2.082241	0.8516339	
110	H2000	11064	1	Copper Rod/Wire/Pin	None	AB	1	Cu	39.26496	15.81234	19.50268	2.013288	0.8107698	
111	H2000	2110	174	Copper Ring	solid round single coil	E	Mixed	Cu-As-Pb	38.67450	15.68050	18.51070	2.089310	0.8471280	
112	H2000	2110	175	Copper Ring	solid round single coil	E	Mixed	Cu-As	37.02460	15.63600	17.30470	2.139240	0.9035200	
113	H2000	2110	180	Copper Bangle	Round Solid	E	Mixed	Cu	38.65910	15.68020	18.50080	2.089580	0.8475480	
114	H2000	2128	22	Copper Bead	Round	E	3A	Cu	38.15730	15.66100	18.06210	2.112360	0.8669310	

Appendix 5.5
HARP Dataset

Lead (Pb) Isotope Analyses for HARP
Copper/Bronze Artifacts

All 125 Samples Analyzed at
University of Florida

Sample #	Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206	Notes
115	H2000	2137	11	Copper Arrow Point	None	E	3A	Cu-As	38.30910	15.67470	18.18910	2.106160	0.8617810	
116	H2000	2227	37	Copper Bangle	round hollow	E	Mixed	Cu-Pb-As	38.67710	15.68420	18.51030	2.089480	0.8473320	
117	H2000	8990	78	Copper Ring	solid flat double coil	AB	2	Cu	39.34560	15.81000	19.43320	2.024670	0.8135500	
118	H2000	8990	80	Copper Misc. Fragment	Copper Coil	AB	2	Cu-Sn	37.30340	15.62510	17.38240	2.146130	0.8989090	
119	H2000	9514	6	Copper Rod/Wire/Pin	square/flat	AB	2	Cu-Pb-As	38.71454	15.68659	18.56572	2.085287	0.8449184	
120	H2000	9845	54	Copper Sheet/Blade	None	F	3C	Cu-Sn	38.51700	15.67310	18.37165	2.096595	0.8531296	
121	H2000	9954	1	Copper Misc. Fragment	None	AB	2	Cu-As	39.00250	15.74050	18.77400	2.077630	0.8384690	
122	H2001	11905	1	Copper Arrow Point	None	E	3C	Cu-As	38.66580	15.67940	18.51530	2.088300	0.8468250	
123	H2001	2378	1	Copper Prill	None	E	3C	Cu-Pb-As	38.67455	15.68242	18.51705	2.088589	0.8468927	
124	H2001	2387	1	Copper Arrow Point	None	E	3B	Cu-Pb	38.66100	15.68090	18.51250	2.088370	0.8470400	
125	H2001	2394	4	Copper Rod/Wire/Pin	round	E	3B	Cu-Pb	38.67960	15.68420	18.52330	2.088170	0.8467270	

Appendix 5.6
HARP Lead Isotope Sample Set (130)

All Lead (Pb) Isotope Analyses for HARP
Copper/Bronze Artifacts

Total Compiled
Isotopic Data Set

Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206
H1988	346	27	Copper Bead	Bead	E	3C	Cu-Pb-As	37.97651	15.65405	17.90593	2.120870	0.8742487
H1988	413	A	Copper Ring	Ring	R37	3B	Cu	38.50036	15.63495	18.48714	2.082538	0.8457142
H1988	413	B	Copper Misc. Fragment	None	R37	3B	Cu-Pb-As	38.66188	15.67998	18.50239	2.089549	0.8474527
H1988	413	C	Copper Misc. Fragment	None	R37	3B	Cu-Pb	38.71079	15.69069	18.53023	2.089089	0.8467764
H1988	754	2	Copper Misc. Fragment	None	E	3A	Cu-Pb	38.55048	15.68999	18.24014	2.113548	0.8601827
H1988	758	16	Copper Misc. Fragment	None	E	3A	Cu-Ag-Au-Pb	38.19188	15.66223	18.09850	2.110218	0.8653848
H1989	1054	24	Copper Misc. Fragment	None	E	2/3	Cu	37.29144	15.62636	17.32427	2.152530	0.9019998
H1990	1171	22	Copper Sheet/Blade	None	E	2/3	Cu-Sn	37.30320	15.62946	17.33496	2.151868	0.9016032
H1990	1185	1A	Copper Sheet/Blade	None	E	2	Cu	38.12841	15.70348	18.09513	2.107132	0.8678294
H1990	1185	1C	Copper Rod/Wire/Pin	None	E	2	Cu	38.44740	15.79667	18.56786	2.070610	0.8507504
H1990	3056	30	Copper Rod/Wire/Pin	square/flat	E	3B	Cu-Sn	38.55909	15.67933	18.41140	2.094317	0.8516094
H1990	3072	4	Copper Bead	cylinder	E	3C	Cu-As	38.68137	15.68429	18.52024	2.088605	0.8468636
H1990	3095	7	Copper Bangle	round hollow	E	3C	Cu-Sn	38.55071	15.67940	18.41961	2.092907	0.8512387
H1990	3127	1	Copper Sheet/Blade	None	E	3B	Cu-Sn	38.63672	15.68132	18.48585	2.090110	0.8482997
H1990	3135	14	Copper Ring	solid round single coil	E	3B/C	Cu	38.74939	15.70619	18.54956	2.088966	0.8467027
H1990	3150	3	Copper Rod/Wire/Pin	round/curved	E	3C	Cu-Sn	38.91370	15.68809	18.33938	2.121855	0.8554396
H1990	3153	19	Copper Bangle	round hollow	E	3B	Cu-Sn	38.45636	15.67542	18.32431	2.098659	0.8554395
H1990	3189	24	Copper Bangle	round hollow	E	Mixed	Cu	38.32281	15.70520	18.08721	2.118842	0.8683185
H1993	3650	1	Copper Arrow Point	None	E	3A/B	Cu-As	38.31006	15.69248	18.16622	2.108864	0.8638048
H1993	3812	1	Copper Arrow Point	None	E	3C	Cu-Pb	38.65839	15.67999	18.51010	2.088484	0.8471072
H1993	4074	10	Copper Rod/Wire/Pin	Round	ET	3B/C	Cu-Sn	38.61074	15.68548	18.42585	2.095458	0.8512712
H1993	4098	20	Copper Arrow Point	None	ET	3B	Cu-Sn	39.24284	15.74085	19.00009	2.065373	0.8284560
H1993	4099	5	Copper Prill	None	ET	3B	None	38.70940	15.68706	18.51925	2.090293	0.8470651
H1994	3978	1	Copper Ring	solid flat single coil	ET	2/3A	Cu	38.09880	15.64216	18.51126	2.058114	0.8449966
H1994	4297	1	Copper Prill	None	ET	3C	Cu or Cu-Pb	38.63101	15.67648	18.50631	2.087503	0.8470858
H1994	4297	2	Copper Prill	None	ET	3C	Cu-Pb	38.17989	15.65140	18.51661	2.061929	0.8452649
H1994	4353	2	Copper Prill	None	E	3C	Cu	38.45098	15.66657	18.51182	2.077110	0.8462875
H1994	4544	13	Copper Bangle	round hollow	ET	3B	Cu-Sn-Pb	38.61266	15.68084	18.48884	2.088434	0.8481151
H1994	5421	1	Copper Ring	solid round single coil	ET	3B	Cu-As	38.57391	15.68415	18.49453	2.085772	0.8480629
H1995	4451	8	Copper Prill	None	E	3C	Cu-Pb-As	38.69396	15.68436	18.55652	2.085228	0.8452280
H1995	4606	9	Copper Rod/Wire/Pin	flat with taper	ET	Mixed	Cu-As	38.63558	15.67950	18.51681	2.086520	0.8467744
H1995	4623	17	Copper Misc. Fragment	None	ET	Mixed	Cu	38.61669	15.67203	18.51948	2.085184	0.8462674
H1995	4661	2	Copper Sheet/Blade	None	ET	3B	Cu	38.68337	15.68613	18.52442	2.088266	0.8467841
H1995	4989	75	Copper Prill	None	ET	3C	Cu-As	38.69154	15.68712	18.51581	2.089631	0.8472133
H1995	5145	19	Copper Prill	None	E	3C	None	38.31029	15.68381	18.14482	2.111361	0.8643732
H1995	5182	42	Copper Prill	None	E	3C	None	38.55248	15.68826	18.34240	2.101949	0.8553385
H1995	5182	43	Copper Prill	None	E	3C	None	38.44131	15.68828	18.15245	2.117680	0.8642410
H1995	5182	44	Copper Prill	None	E	3C	None	38.80815	15.66943	18.63611	2.082478	0.8408206
H1995	5603	21	Copper Bangle	round hollow	ET	Mixed	Cu-Sn(Pb)	38.66359	15.68280	18.52363	2.087311	0.8466287
H1995	5641	21	Copper Arrow Point	None	ET	Mixed	Cu-Sn	38.67797	15.68102	18.51469	2.089054	0.8469495
H1995	5680	17	Copper Misc. Fragment	None	ET	3B	Cu-Pb-As	38.68161	15.68200	18.51949	2.088815	0.8468035
H1995	6509	1	Copper Rod/Wire/Pin	None	E	Mixed	Cu-As	38.46545	15.67127	18.35200	2.096038	0.8539516
H1996	6226	57	Copper Prill	None	ET	3C	Cu	39.33683	15.92888	19.37979	2.029665	0.8219408

Appendix 5.6
HARP Lead Isotope Sample Set (130)

All Lead (Pb) Isotope Analyses for HARP
Copper/Bronze Artifacts

Total Compiled
Isotopic Data Set

Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206
H1996	6237	56	Copper Prill	None	ET	3C	None	38.88301	15.69087	18.63564	2.086529	0.8419812
H1996	6237	57	Copper Prill	None	ET	3C	None	38.13591	15.66072	18.05392	2.112302	0.8674404
H1996	6237	58	Copper Prill	None	ET	3C	None	38.67298	15.68712	18.51481	2.088739	0.8472598
H1996	6249	2	Copper Bead	Round	ET	Mixed		38.65600	15.67842	18.51371	2.087916	0.8468510
H1996	6930	8	Copper Prill	None	E	3C	Cu-Sn-Pb-As	38.64815	15.67614	18.50922	2.088070	0.8469381
H1996	7106	34	Copper Arrow Point	None	E	3C	Cu-Pb	38.71527	15.68905	18.55171	2.086860	0.8456864
H1996	7126	1	Copper Prill	None	E	3C	Cu-Sn	38.65771	15.71049	18.54580	2.084458	0.8471207
H1996	7210	11	Copper Bangle	Round Hollow	F	3C	Cu	38.63745	15.67734	18.51292	2.087059	0.8468362
H1996	7232	65	Copper Misc. Fragment	bent arrow	F	Mixed	Cu	40.16051	15.80872	19.30683	2.080149	0.8188229
H1996	7236	1	Copper Misc. Fragment	handle	F	Mixed	Cu	38.63990	15.68098	18.49401	2.089367	0.8478916
H1996	7291	2	Copper Arrow Point	None	F	3B	Cu	38.65109	15.68022	18.50008	2.089287	0.8475891
H1996	7293	1	Copper Arrow Point	None	F	3B	Cu	38.79270	15.71412	18.76747	2.067159	0.8374041
H1996	7431	2	Copper Sheet/Blade	None	AB	2	Cu-As	36.62297	15.64012	17.10774	2.140764	0.9142157
H1996	7457	1	Copper Rod/Wire/Pin	square tapered w/curve to point	AB	Mixed	None	37.30015	15.63362	17.32555	2.152929	0.9023574
H1996	7467	962	Copper Ring	solid round single coil	AB	3A	Cu-Sn-Pb	38.58194	15.67752	18.43331	2.093069	0.8505266
H1996	7467	963	Copper Rod/Wire/Pin	round	AB	Mixed	Cu	37.94267	15.76171	17.89024	2.120843	0.8810365
H1996	7467	965	Copper Rod/Wire/Pin	square	AB	Mixed	Cu-As	37.61140	15.65910	17.60130	2.136860	0.8896580
H1996	7490	32	Copper Arrow Point	fragment	AB	2	Cu-As	38.66646	15.68127	18.51193	2.088693	0.8470712
H1996	7509	2	Copper Misc. Fragment	Bead	AB	1	Cu	37.46450	15.67523	17.88969	2.094140	0.8761595
H1996	7513	59	Copper Bead	Round	AB	1	Cu	37.17560	15.64400	17.51850	2.122020	0.8929770
H1996	7516	78	Copper Prill	None	AB	1	Cu	38.02180	15.69200	18.13640	2.096430	0.8652350
H1997	6650	6	Copper Ring	solid round single coil	ET	3C	Cu-Pb	38.66195	15.67736	18.51225	2.088471	0.8468683
H1997	6660	30	Copper Disc	Laminated Disc	ET	3B	Cu-Sn(Pb)	37.97475	15.65701	17.91046	2.120216	0.8741864
H1997	6688	1	Copper Rod/Wire/Pin	round/curved	ET	3B	Cu	38.67438	15.68529	18.49942	2.090584	0.8478755
H1997	8012	16	Copper Prill	None	E	3B	Cu-Pb-As	38.68735	15.68588	18.51723	2.089271	0.8470915
H1997	8022	24	Copper Arrow Point	None	E	3C	Cu-Pb	38.38181	15.67630	18.24902	2.103339	0.8590387
H1997	8026	13	Copper Arrow Point	None	E	3B	Cu-Pb	38.64077	15.67425	18.51551	2.086943	0.8465528
H1997	8059	19	Copper Bead	Cylinder	E	3B	Cu	38.63206	15.67621	18.48032	2.090426	0.8482602
H1997	8103	6	Copper Prill	None	E	3C	Cu-Sn-Pb	38.54534	15.68178	18.38143	2.097045	0.8531530
H1998	8336	68	Copper Rod/Wire/Pin	square flat	AB	3C	Cu-Sn-Pb	38.61494	15.68237	18.44745	2.093224	0.8501198
H1998	8407	36	Copper Rod/Wire/Pin	round/curved	AB	2	Cu	38.84694	15.71409	18.53035	2.096379	0.8479665
H1998	8412	122	Copper Prill	None	AB	3	None	38.82965	15.74302	18.61212	2.086247	0.8458442
H1998	8412	123	Copper Prill	None	AB	3	None	38.84708	15.71294	18.52821	2.096669	0.8480740
H1998	8412	23	Copper Prill	None	AB	3	None	40.53925	15.85313	19.60178	2.068141	0.8087685
H1998	8412	24	Copper Prill	None	AB	3	None	38.11680	15.68557	18.02906	2.114227	0.8700248
H1998	8422	15	Copper Sheet/Blade	None	AB	2	None	37.33627	15.63542	17.35628	2.151174	0.9008448
H1998	8432	8	Copper Prill	None	AB	2	Cu	37.76322	15.70285	17.82092	2.119045	0.8811158
H1998	8433	37	Copper Rod/Wire/Pin	square	AB	2	Cu	38.10515	15.66193	18.02482	2.114040	0.8688774
H1998	8483	1	Copper Misc. Fragment	None	AB	3A	Cu	38.41851	15.67166	18.30483	2.098809	0.8561419
H1998	8486	5	Copper Misc. Fragment	None	AB	2	Cu-Sn-Pb	37.31692	15.62822	17.34572	2.151546	0.9010462
H1998	8487	1	Copper Bangle	Round Hollow	AB	2	Cu-Sn-Pb	37.29511	15.62419	17.32884	2.152157	0.9016194
H1998	8488	11	Copper Bangle	Round Hollow	AB	2	Cu-Sn	37.28877	15.62616	17.32558	2.152239	0.9019154
H1998	8488	12	Copper Misc. Fragment	None	AB	2	None	37.28717	15.62497	17.33092	2.151469	0.9015435

Appendix 5.6

HARP Lead Isotope Sample Set (130)

All Lead (Pb) Isotope Analyses for HARP
Copper/Bronze ArtifactsTotal Compiled
Isotopic Data Set

Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206
H1998	8488	13	Copper Misc. Fragment	None	AB	2	Cu-Sn(Pb)	37.31432	15.63131	17.34611	2.151346	0.9011909
H1998	8506	3	Copper Rod/Wire/Pin	Round w/ spatula end	AB	1	Cu-As	37.89310	15.76240	18.03770	2.100750	0.8738510
H1998	8522	1	Copper Sheet/Blade	None	AB	1	Cu-As	38.83800	15.70480	18.91310	2.053520	0.8303670
H1998	8562	36	Copper Misc. Fragment	None	AB	1	Cu-Sn	38.41130	15.69600	18.22220	2.107940	0.8613710
H1998	8604	12	Copper Prill	None	F	Mixed	None	38.46553	15.79402	18.60345	2.067614	0.8489565
H1998	8604	13	Copper Prill	None	F	Mixed	None	38.48430	15.67680	18.32620	2.100000	0.8554250
H1998	8657	4	Copper Rod/Wire/Pin	square flat	F	3C	Cu-As	38.28900	15.67870	18.17210	2.107010	0.8627860
H1996	7241	16	Copper Sheet/Blade	None	F	3C	Cu-Pb	38.67324	15.67926	18.51221	2.089093	0.8469691
H1999	8492	116	Copper Bangle	Flat Hollow	AB	2	Cu-Sn-Pb	37.28780	15.62520	17.32590	2.152060	0.9018080
H1999	8754	43	Copper Rod/Wire/Pin	Round	F	3C	Cu	38.53550	15.68450	18.32330	2.103130	0.8560130
H1999	8768	88	Copper Rod/Wire/Pin	square	F	3C	Cu	38.65810	15.68580	18.49490	2.090220	0.8481240
H1999	8776	4	Copper Rod/Wire/Pin	round/curved	F	3C	Cu-As	38.45100	15.69870	18.27950	2.103530	0.8588730
H1999	8950	12	Copper Rod/Wire/Pin	square long thin	AB	2	Cu	39.73180	15.95200	19.33670	2.054750	0.8249480
H1999	8950	14	Copper Arrow Point	None	AB	2	Cu-As	37.46330	15.64270	17.52360	2.137880	0.8926630
H2000	2226	55	Copper Bead	Cylinder	E	Mixed	Cu	38.35691	15.66719	18.24296	2.102546	0.8587991
H1999	9702	2	Copper Sheet/Blade	None	F	3C	None	38.58481	15.78126	18.53108	2.082241	0.8516339
H2000	11064	1	Copper Rod/Wire/Pin	WTF?	AB	1	Cu	39.26496	15.81234	19.50268	2.013288	0.8107698
H2000	2110	174	Copper Ring	solid round single coil	E	Mixed	Cu-As-Pb	38.67450	15.68050	18.51070	2.089310	0.8471280
H2000	2110	175	Copper Ring	solid round single coil	E	Mixed	Cu-As	37.02460	15.63600	17.30470	2.139240	0.9035200
H2000	2110	180	Copper Bangle	Round Solid	E	Mixed	Cu	38.65910	15.68020	18.50080	2.089580	0.8475480
H2000	2128	22	Copper Bead	Round	E	3A	Cu	38.15730	15.66100	18.06210	2.112360	0.8669310
H2000	2137	11	Copper Arrow Point	None	E	3A	Cu-As	38.30910	15.67470	18.18910	2.106160	0.8617810
H2000	2227	37	Copper Bangle	round hollow	E	Mixed	Cu-Pb-As	38.67710	15.68420	18.51030	2.089480	0.8473320
H2000	8990	78	Copper Ring	solid flat double coil	AB	2	Cu	39.34560	15.81000	19.43320	2.024670	0.8135500
H2000	8990	80	Copper Misc. Fragment	copper coil	AB	2	Cu-Sn	37.30340	15.62510	17.38240	2.146130	0.8989090
H2000	9514	6	Copper Rod/Wire/Pin	square/flat	AB	2	Cu-Pb-As	38.71454	15.68659	18.56572	2.085287	0.8449184
H2000	9845	54	Copper Sheet/Blade	None	F	3C	Cu-Sn	38.51700	15.67310	18.37165	2.096595	0.8531296
H2000	9954	1	Copper Misc. Fragment	None	AB	2	Cu-As	39.00250	15.74050	18.77400	2.077630	0.8384690
H2001	11905	1	Copper Arrow Point	None	E	3C	Cu-As	38.66580	15.67940	18.51530	2.088300	0.8468250
H2001	2378	1	Copper Prill	None	E	3C	Cu-Pb-As	38.67455	15.68242	18.51705	2.088589	0.8468927
H2001	2387	1	Copper Arrow Point	None	E	3B	Cu-Pb	38.66100	15.68090	18.51250	2.088370	0.8470400
H2001	2394	4	Copper Rod/Wire/Pin	round	E	3B	Cu-Pb	38.67960	15.68420	18.52330	2.088170	0.8467270
H1996	7227	32	Copper Rod/Wire/Pin	square flat point tool	F	Mixed	No Comp.	38.45320	15.67690	18.33050	2.097771474	0.855235809
H1996	7248	1	Copper Rod/Wire/Pin	Wire or Pin	F	3C	No Comp.	38.87020	15.72210	18.56070	2.094220584	0.847063958
H1998	8627	18	Copper Rod/Wire/Pin	Square point tool	F	3C	No Comp.	38.94160	15.80200	18.52430	2.102190096	0.85304168
H2000	2102	1447	Copper Sheet/Blade	None	E	3B/C	No Comp.	38.33700	15.68090	18.20680	2.105641848	0.86126612
H2000	2226	40	Copper Sheet/Blade	None	E	3B	No Comp.	38.38700	15.60870	18.44510	2.081148923	0.846224743
H2000	2357	3	Copper Bead	Round	E	3B	No Comp.	38.70140	15.68240	18.50140	2.091809268	0.847633152
H2001	2394	3	Copper Bead	Cylinder/Rolled Sheet	E	3B	No Comp.	38.97870	15.76820	18.59660	2.096012174	0.847907682
H1996	6913	45	Copper Bangle	Flat Solid	E	3B/C	No Comp.	38.28610	15.61310	18.25300	2.097523695	0.85537172
H1996	6958	61	Copper Rod/Wire/Pin	square tapered w/pointed tip	E	Mixed	No Comp.	38.07140	15.50510	18.28900	2.08165564	0.84778282
H1994	4353	3	Copper Sheet/Blade	None	E	3C	No Comp.	38.60770	15.63930	18.45730	2.091730643	0.847323281
H1995	4638	1	Copper Bangle	Round Solid	ET	3	No Comp.	37.84140	15.45840	18.36140	2.060921281	0.841896587

Appendix 5.6
HARP Lead Isotope Sample Set (130)

All Lead (Pb) Isotope Analyses for HARP
Copper/Bronze Artifacts

Total Compiled
Isotopic Data Set

Year	Lot	Rec #	Type	BCH Refined Type	Mound	Period	BCH Alloy Type	208/204	207/204	206/204	208/206	207/206
H1995	4968	12	Copper Bangle	Round Solid	ET	3C	No Comp.	38.33400	15.68950	18.40350	2.082973347	0.852528052

Appendices 6.1-6.10

The appendices in this section are the comparative geological and artifact lead isotope datasets for interpreting the lead isotope signatures of the HARP copper and bronze artifacts from Harappa. These appendices have been compiled from a combination of previously published data and fresh analyses provided by Dr. R.W. Law and Dr. J.M. Kenoyer. All appendices display the various ratios of the 4 isotopes of the element lead (Pb): ^{208}Pb , ^{207}Pb , ^{206}Pb , and ^{204}Pb .

Appendix 6.1 – Comparative lead isotope data for Greece, Turkey and Cyprus.

Appendix 6.2 – A compiled listing of lead isotope analyses on copper ores and artifacts from the Feinan and Timna regions.

Appendix 6.3 – Lead isotope analyses compiled from Saudi Arabia, Bahrain, and Yemen.

Appendix 6.4 – Lead isotope data from Oman.

Appendix 6.5 – Compiled listing of comparative lead isotope data from artifacts from Oman and United Arab Emirates (UAE).

Appendix 6.6 – A comparative lead isotope database of copper materials from Afghanistan.

Appendix 6.7 – A compilation of lead isotope data from two copper sources in the Himalayas. This has been previously published in Law 2011 and Hoffman and Miller 2014 and was part of the initial pilot study for this project.

Appendix 6.8 - A compilation of lead isotope data from a copper source in Waziristan. This has been previously published in Law 2011 and Hoffman and Miller 2014 and was part of the initial pilot study for this project.

Appendix 6.9 - A compilation of lead isotope data from copper sources in Baluchistan. Portions of this data has been previously published in Law 2011 and Hoffman and Miller 2014 and was part of the initial pilot study for this project. New analyses are also provided here courtesy of Dr. R.W. Law and Dr. J.M. Kenoyer.

Appendix 6.10 – A compiled database of lead isotope analyses on copper ore sources from across the Aravalli Range. This data is taken from previously published sources and new analyses are also provided courtesy of Dr. R.W. Law.

Appendix 6.1

- All lead isotope data points for Laviron, Greece were collated from the OXALID database of lead isotope analyses on lead and copper ores from the area. Data can be accessed at the Oxford Archaeological Lead Isotope Database (OXALID):
<http://oxalid.arch.ox.ac.uk/The%20Database/TheDatabase.htm>
- All lead isotope data points for the island of Cyprus were collated from the OXALID database of lead isotope analyses on iron and copper ores from the area. Data can be accessed at the Oxford Archaeological Lead Isotope Database (OXALID):
<http://oxalid.arch.ox.ac.uk/The%20Database/TheDatabase.htm>
- All lead isotope data points for Anatolia were collated from the OXALID database of lead isotope analysis on lead and copper ores from the area. Data can be accessed at the Oxford Archaeological Lead Isotope Database (OXALID):
<http://oxalid.arch.ox.ac.uk/The%20Database/TheDatabase.htm>

Region	Source	Material	reference	analysis #	207/206	208/206	206/204	208/204	207/204	Comments
Timna	Area T	Copper Ore	Hauptmann et al 1992	T1-1/1	0.8730	2.1260	17.901	38.058	15.628	
Timna	Mine T1	Copper Ore	Gale et al 1990	Mine	0.8649	2.1103	18.038	38.0655914	15.6010662	Table 2 p. 187 (iron and manganese ores not included)
Timna	Site 33b	Copper Ore	Gale et al 1990		0.8675	2.1099	18.011	38.0014089	15.6245425	Table 2 p. 187 (iron and manganese ores not included)
Timna	Site 88a	Copper Ore	Gale et al 1990	1329	0.8658	2.1136	18.066	38.1842976	15.6415428	Table 2 p. 187 (iron and manganese ores not included)
Timna	Site 87	Copper Ore	Gale et al 1990	1332	0.8610	2.1041	18.01	37.894841	15.50661	Table 2 p. 187 (iron and manganese ores not included)
Timna	Mines S28.2 and S28.3	Copper Ore	Gale et al 1990	1336	0.8678	2.1136	17.929	37.8947344	15.5587862	Table 2 p. 187 (iron and manganese ores not included)
Timna	Mines Area T	Copper Ore	Gale et al 1990	1337	0.8718	2.1218	17.943	38.0714574	15.6427074	Table 2 p. 187 (iron and manganese ores not included)
Timna	Avrona Formation	Copper Ore	Gale et al 1990	1500	0.8691	2.1125	17.961	37.9426125	15.6099051	Table 2 p. 187 (iron and manganese ores not included)
Timna	Amir Formation	Copper Ore	Gale et al 1990	1501	0.86656	2.11336	18.082	38.21377552	15.66913792	Table 2 p. 187 (iron and manganese ores not included)
Timna	Timna	Copper Ore	Hauptmann 2007	23054P D6	0.8628	2.1067	18.112	38.157	15.627	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area A	Copper Ore	Hauptmann 2007	23057U A1	0.8578	2.1041	18.273	38.449	15.674	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area D	Copper Ore	Hauptmann 2007	23060T D17	0.8552	2.0983	18.289	38.375	15.640	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area DI	Copper Ore	Hauptmann 2007	23061R D31	0.8605	2.1066	18.186	38.311	15.650	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area I	Copper Ore	Hauptmann 2007	23065U T1	0.8640	2.1106	18.091	38.183	15.630	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area M	Copper Ore	Hauptmann 2007	23069X N3	0.8640	2.1103	18.092	38.179	15.632	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area P	Copper Ore	Hauptmann 2007	23070P P1	0.8620	2.1106	18.176	38.363	15.667	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Site 2	Copper Ore	Hauptmann 2007	23071Y T2	0.8681	2.1172	17.980	38.068	15.608	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area T	Copper Ore	Hauptmann 2007	23072W T23	0.8726	2.1245	17.938	38.110	15.652	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area U	Copper Ore	Hauptmann 2007	23074S T18	0.8583	2.1017	18.215	38.283	15.634	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area T	Copper Ore	Hauptmann 2007	23708V U6	0.8728	2.1270	17.933	38.144	15.652	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area U	Copper Ore	Hauptmann 2007	23079T U8	0.8685	2.1183	18.003	38.136	15.635	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Wadi Amram Site 33A	Copper Ore	Hauptmann 2007	23082S D33A	0.8611	2.1057	18.185	38.293	15.658	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Site 18	Copper Ore	Hauptmann 2007	23088R D18	0.8618	2.1084	18.146	38.258	15.637	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Site 26A	Copper Ore	Hauptmann 2007	23089P 26A	0.8657	2.1157	18.075	38.242	15.648	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Site 9	Copper Ore	Hauptmann 2007	23090S ARB9	0.8726	2.1243	17.897	38.018	15.616	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23094 V T11	0.8731	2.1256	17.911	38.071	15.637	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23098 Y T5	0.8731	2.1225	17.907	38.007	15.634	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23101Q T8	0.8716	2.1228	17.933	38.068	15.630	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23102Z T9	0.8726	2.1243	17.897	38.018	15.616	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23107P T16	0.8666	2.1153	18.028	38.135	15.624	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23108Y W18	0.8583	2.1017	18.215	38.283	15.634	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23113T T23	0.8736	2.1264	17.898	38.059	15.636	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23114R T24	0.8737	2.1280	17.91	38.112	15.649	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23116Y T26	0.8657	2.1157	18.075	38.242	15.648	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area S/T	Copper Ore	Hauptmann 2007	23118U C3	0.8646	2.1145	18.124	38.323	15.671	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Timna	Copper Ore	Hauptmann 2007	6491	0.8739	2.1240	17.852	37.918	15.601	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Timna	Copper Ore	Hauptmann 2007	6597	0.8577	2.1038	18.226	38.343	15.632	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Near Site 25	Copper Ore	Hauptmann 2007	T1505	0.8691	2.1125	17.961	37.943	15.610	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Timna	Copper Ore	Hauptmann 2007	TIM C	0.8723	2.1231	17.885	37.971	15.602	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)
Timna	Area T	Copper Ore	Hauptmann 2007	T11/1	0.8730	2.1260	17.901	38.058	15.628	Table A.3 p. 346-347 (archaeological artifact and previously published items not included)

Appendix 6.2
Timma Copper Ores
Lead Isotope Analyses

Published Lead Isotope Data
Remaining Data Points taken from Oxalid Database:
<http://oxalid.arch.ox.ac.uk/The%20Database/TheDatabase.htm>

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>
Timna	Area T	Copper Ore	Hauptmann et al 1992	TI-1/1	0.8730	2.1260	17.901	38.058	15.628
Timna	Mine T1	Copper Ore	Gale et al 1990	Mine	0.8649	2.1103	18.038	38.0655914	15.6010662
Timna	Site 33b	Copper Ore	Gale et al 1990	1329	0.8675	2.1099	18.011	38.0014089	15.6245425
Timna	Site 88a	Copper Ore	Gale et al 1990	1330	0.8658	2.1136	18.066	38.1842976	15.6415428
Timna	Site 87	Copper Ore	Gale et al 1990	1332	0.8610	2.1041	18.01	37.894841	15.50661
Timna	Mines S28.2 and S28.3	Copper Ore	Gale et al 1990	1336	0.8678	2.1136	17.929	37.8947344	15.5587862
Timna	Mines Area T	Copper Ore	Gale et al 1990	1337	0.8718	2.1218	17.943	38.0714574	15.6427074
Timna	Avrona Formation	Copper Ore	Gale et al 1990	1500	0.8691	2.1125	17.961	37.9426125	15.6099051
Timna	Amir Formation	Copper Ore	Gale et al 1990	1501	0.86656	2.11336	18.082	38.21377552	15.66913792
Timna	Timna	Copper Ore	Hauptmann 2007	23054P D6	0.8628	2.1067	18.112	38.157	15.627
Timna	Area A	Copper Ore	Hauptmann 2007	23057U A1	0.8578	2.1041	18.273	38.449	15.674
Timna	Area D	Copper Ore	Hauptmann 2007	23060T D17	0.8552	2.0983	18.289	38.375	15.640
Timna	Area DI	Copper Ore	Hauptmann 2007	23061R D31	0.8605	2.1066	18.186	38.311	15.650
Timna	Area I	Copper Ore	Hauptmann 2007	23065U T1	0.8640	2.1106	18.091	38.183	15.630
Timna	Area M	Copper Ore	Hauptmann 2007	23069X N3	0.8640	2.1103	18.092	38.179	15.632
Timna	Area P	Copper Ore	Hauptmann 2007	23070P P1	0.8620	2.1106	18.176	38.363	15.667
Timna	Site 2	Copper Ore	Hauptmann 2007	23071Y T2	0.8681	2.1172	17.980	38.068	15.608
Timna	Area T	Copper Ore	Hauptmann 2007	23072W T23	0.8726	2.1245	17.938	38.110	15.652
Timna	Area T	Copper Ore	Hauptmann 2007	23074S T18	0.8583	2.1017	18.215	38.283	15.634
Timna	Area U	Copper Ore	Hauptmann 2007	23708V U6	0.8728	2.1270	17.933	38.144	15.652
Timna	Area U	Copper Ore	Hauptmann 2007	23079T U8	0.8685	2.1183	18.003	38.136	15.635
Timna	Wadi Amram Site 33A	Copper Ore	Hauptmann 2007	23082S D33A	0.8611	2.1057	18.185	38.293	15.658
Timna	Site 18	Copper Ore	Hauptmann 2007	23088R D18	0.8618	2.1084	18.146	38.258	15.637
Timna	Site 26A	Copper Ore	Hauptmann 2007	23089P 26A	0.8657	2.1157	18.075	38.242	15.648
Timna	Site 9	Copper Ore	Hauptmann 2007	23090S ARB9	0.8726	2.1243	17.897	38.018	15.616
Timna	Area S/T	Copper Ore	Hauptmann 2007	23094 V T11	0.8731	2.1256	17.911	38.071	15.637
Timna	Area S/T	Copper Ore	Hauptmann 2007	23098 Y T5	0.8731	2.1225	17.907	38.007	15.634
Timna	Area S/T	Copper Ore	Hauptmann 2007	23101Q T8	0.8716	2.1228	17.933	38.068	15.630
Timna	Area S/T	Copper Ore	Hauptmann 2007	23102Z T9	0.8726	2.1243	17.897	38.018	15.616
Timna	Area S/T	Copper Ore	Hauptmann 2007	23107P T16	0.8666	2.1153	18.028	38.135	15.624
Timna	Area S/T	Copper Ore	Hauptmann 2007	23108Y W18	0.8583	2.1017	18.215	38.283	15.634
Timna	Area S/T	Copper Ore	Hauptmann 2007	23113T T23	0.8736	2.1264	17.898	38.059	15.636
Timna	Area S/T	Copper Ore	Hauptmann 2007	23114R T24	0.8737	2.1280	17.91	38.112	15.649
Timna	Area S/T	Copper Ore	Hauptmann 2007	23116Y T26	0.8657	2.1157	18.075	38.242	15.648
Timna	Area S/T	Copper Ore	Hauptmann 2007	23118U C3	0.8646	2.1145	18.124	38.323	15.671

Appendix 6.2
Timna Copper and Bronze Artifacts
Lead Isotope Analyses

Published Lead Isotope Data
Remaining Data Points taken from Oxalid Database:
<http://oxalid.arch.ox.ac.uk/The%20Database/TheDatabase.htm>

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>
Timna	Site # 200	bronze ear ring	Gale et al 1990	721	0.8425	2.08116	18.574	38.65546584	15.648595
Timna	Site # 200	bronze pointed rod	Gale et al 1990	724	0.8656	2.11120	17.990	37.980488	15.572144
Timna	Site # 200	bronze awl	Gale et al 1990	735	0.8616	2.10281	18.190	38.2501139	15.672504
Timna	Site # 200	bronze ring	Gale et al 1990	916	0.8699	2.11622	17.916	37.91419752	15.5851284
Timna	Site # 200	bronze ring	Gale et al 1990	921	0.8695	2.11832	17.950	38.023844	15.607525
Timna	Site # 200	bronze ring	Gale et al 1990	924	0.8708	2.12138	17.949	38.07664962	15.6299892
Timna	Site T200	Male figurine	OXALID	T1	0.82225	2.016005	18.9653	38.23413963	15.59421793
Timna	Site T200	Wire, circular section	OXALID	T150	0.86537	2.11373	18.0738	38.20313327	15.64052431
Timna	Site T200	Rivet	OXALID	T180	0.87011	2.121053	17.9644	38.10344451	15.63105798
Timna	Site T200	Crook shaped wire	OXALID	T229	0.87006	2.12031	17.9698	38.10154664	15.63480419
Timna	Site T200	Crook shape wire	OXALID	T231	0.87005	2.12028	17.9704	38.10227971	15.6352184
Timna	Site T200	Crook shape wire	OXALID	T233	0.87053	2.1224	17.9846	38.17051504	15.65616981
Timna	Site T200	Crook shaped wire	OXALID	T235	0.87005	2.12053	17.9739	38.11419417	15.6381917
Timna	Site T200	Sistrum rod	OXALID	T240B	0.87003	2.12012	17.96814	38.09461298	15.63287475
	Site T200	Ring, rectangular section		T293	0.86570				
Timna			OXALID			2.11414	18.0767	38.21667454	15.64905342
Timna	Site T200	Boat shaped ear ring	OXALID	T38	0.86945	2.12043	17.9819	38.12936022	15.63436296
Timna	Site T200	Spatulated wire	OXALID	T476	0.87093	2.125269	18.0149	38.28650851	15.68971686
Timna	Site T200	Wire made implement	OXALID	T58	0.87016	2.12056	17.9685	38.10328236	15.63541605
Timna	Site T200	Ram figurine	OXALID	T6	0.82728	2.057024	18.97803	39.03826318	15.70008772
Timna	Site T200	Wire, circular section	OXALID	T77	0.86970	2.12015	17.9787	38.11754081	15.63607539
Timna	Site T200	Wire, circular section	OXALID	T84	0.87010	2.120355	17.9669	38.09620625	15.63307156
Timna	Site T200	Wire, circular section	OXALID	T89	0.86991	2.120202	17.9717	38.10363428	15.63376155

Appendix 6.3
Saudi Arabia Artifacts

Published Lead Isotope Data

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/206</u>	<u>206/204</u>	<u>207/204</u>	<u>208/204</u>
Saudi Arabia	Qurayyah	Crucible fragment	Liu et al 2015	Qu 08-12:	0.88247	2.1208	17.555	15.49176085	37.230644
Saudi Arabia	Qurayyah	Furnace slag	Liu et al 2015	Qu 08-16:1	0.85415	2.0931	18.237	15.57713355	38.1718647
Saudi Arabia	Tayma	Crucible fragment	Liu et al 2015	TA 5312	0.83427	2.0710	18.793	15.67843611	38.920303
Saudi Arabia	Tayma	Crucible fragment	Liu et al 2015	TA 5409	0.83597	2.0715	18.754	15.67778138	38.848911
Saudi Arabia	Tayma	Crucible fragment	Liu et al 2015	TA 5675	0.86929	2.1071	17.888	15.54985952	37.6918048
Saudi Arabia	Tayma	Furnace fragment	Liu et al 2015	TA 6329.1	0.83499	2.0671	18.753	15.65856747	38.7643263
Saudi Arabia	Tayma	metal dross	Liu et al 2015	TA 6335.1	0.83287	2.0639	18.829	15.68210923	38.8611731
Saudi Arabia	Tayma	Furnace fragment	Liu et al 2015	TA 6335.3	0.83253	2.0627	18.819	15.66738207	38.8179513
Saudi Arabia	Tayma	Crucible fragment	Liu et al 2015	TA 6337.1	0.83644	2.0704	18.719	15.65732036	38.7558176
Saudi Arabia	Tayma	Crucible fragment	Liu et al 2015	TA 6337.5	0.83222	2.0616	18.841	15.67985702	38.8426056

Appendix 6.3

Saudi Arabia Galena and Lead Ores

Published Lead Isotope Data

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/206</u>	<u>206/204</u>	<u>207/204</u>	<u>208/204</u>
Saudi Arabia	Wadi Tarib	K feldspar	Stacey et al 1980	112680	0.886264618	2.122334327	17.444	15.460	37.022
Saudi Arabia	Al Ar	K feldspar	Stacey et al 1980	111541	0.88240314	2.116060761	17.577	15.510	37.194
Saudi Arabia	Bishah	K feldspar	Stacey et al 1980	112671	0.870533956	2.087773589	17.773	15.472	37.106
Saudi Arabia	Jabal Ajah	Galena	Stacey et al 1980	112991	0.874009998	2.108352525	17.803	15.560	37.535
Saudi Arabia	Jabal Ajah	Galenas and Ore Leads	Stacey et al 1980	128590	0.874887184	2.106893051	17.728	15.510	37.351
Saudi Arabia	Muhaylot	Galenas and Ore Leads	Stacey et al 1980		0.881078314	2.112665643	17.583	15.492	37.147
Saudi Arabia	Fowakhir (Egypt)	Galenas and Ore Leads	Stacey et al 1980		0.870245709	2.096993156	17.826	15.513	37.381
Saudi Arabia	Tuwayrah	Galenas and Ore Leads	Stacey et al 1980	74878	0.876656473	2.105561219	17.658	15.480	37.180
Saudi Arabia	Nuqrah	Galenas and Ore Leads	Stacey et al 1980		0.905434908	2.127944387	17.406	15.760	37.039
Saudi Arabia	Jabal Hadb	Galenas and Ore Leads	Stacey et al 1980		0.87385153	2.09988163	17.741	15.503	37.254
Saudi Arabia	Mahd ahd Dhahab	Galenas and Ore Leads	Stacey et al 1980	87520	0.889380531	2.123721411	17.402	15.477	36.957
Saudi Arabia	Mahd ahd Dhahab	Galenas and Ore Leads	Stacey et al 1980	87223	0.907832209	2.169433852	17.045	15.474	36.978
Saudi Arabia	Mahd ahd Dhahab	Galenas and Ore Leads	Stacey et al 1980	DDB-11	0.889176146	2.123348271	17.406	15.477	36.959
Saudi Arabia	Mahd ahd Dhahab	Galenas and Ore Leads	Stacey et al 1980	69115	0.88958465	2.124145459	17.407	15.485	36.975
Saudi Arabia	Mahd ahd Dhahab	Galenas and Ore Leads	Stacey et al 1980	64026	0.88872932	2.120691636	17.408	15.471	36.917
Saudi Arabia	Jabal Sayid	Galenas and Ore Leads	Stacey et al 1980	107510	0.892764336	2.128197725	17.317	15.460	36.854
Saudi Arabia	Taif	Galenas and Ore Leads	Stacey et al 1980	MS-ORE	0.878521626	2.105662944	17.641	15.498	37.146
Saudi Arabia	Prospect	Galenas and Ore Leads	Stacey et al 1980	5731	0.882939334	2.113927656	17.555	15.500	37.110
Saudi Arabia	Mamilah	Galenas and Ore Leads	Stacey et al 1980	64132	0.881005174	2.109784524	17.589	15.496	37.109
Saudi Arabia	Jabal Dalfa	Galenas and Ore Leads	Stacey et al 1980	64115	0.874823396	2.103249506	17.695	15.480	37.217
Saudi Arabia	Garb Hadad	Galenas and Ore Leads	Stacey et al 1980	64117	0.883449617	2.116893515	17.486	15.448	37.016
Saudi Arabia	Mulhal	Galenas and Ore Leads	Stacey et al 1980	64683	0.883015007	2.108401546	17.592	15.534	37.091
Saudi Arabia	Mokhayat	Galenas and Ore Leads	Stacey et al 1980	64112	0.873578106	2.099898637	17.758	15.513	37.290
Saudi Arabia	Wadi Shwas	Galenas and Ore Leads	Stacey et al 1980	70050	0.888544892	2.121717693	17.442	15.498	37.007
Saudi Arabia	Abu Bir	Galenas and Ore Leads	Stacey et al 1980	DDB-4	0.868992943	2.09062395	17.854	15.515	37.326
Saudi Arabia	Suq Al Khamis	Galenas and Ore Leads	Stacey et al 1980	E-37214	0.87807784	2.108135709	17.626	15.477	37.158
Saudi Arabia	Al Muchahal	Galenas and Ore Leads	Stacey et al 1980	B-8	0.874393683	2.096672307	17.730	15.503	37.174
Saudi Arabia	Al Muchahal	Galenas and Ore Leads	Stacey et al 1980	B-7	0.873915004	2.100157818	17.742	15.505	37.261
Saudi Arabia	Kutam	Galenas and Ore Leads	Stacey et al 1980	107515	0.881102586	2.108780904	17.595	15.503	37.104
Saudi Arabia	Kutam	Galenas and Ore Leads	Stacey et al 1980	69-50	0.881536273	2.109928876	17.575	15.493	37.082
Saudi Arabia	Samrah	Galenas and Ore Leads	Stacey et al 1980	DDB-10	0.886055686	2.130409925	17.491	15.498	37.263
Saudi Arabia	Ardayat	Galenas and Ore Leads	Stacey et al 1980	DDB-7	0.875380282	2.111661972	17.750	15.538	37.482
Saudi Arabia	Ar Ridayniyah	Galenas and Ore Leads	Stacey et al 1980	126066A	0.87464131	2.111967591	17.773	15.545	37.536
Saudi Arabia	Ar Ridayniyah	Galenas and Ore Leads	Stacey et al 1980	ARP-13	0.873980768	2.110555024	17.783	15.542	37.532
Saudi Arabia	Al Amar	Galenas and Ore Leads	Stacey et al 1980	87300	0.896203999	2.151028687	17.255	15.464	37.116
Saudi Arabia	Bahfor	Galenas and Ore Leads	Stacey et al 1980	72401	0.876903983	2.113900485	17.726	15.544	37.471
Saudi Arabia	Wadi Aqarah	Galenas and Ore Leads	Stacey et al 1980	RR-14M	0.896210014	2.153511822	17.256	15.465	37.161
Saudi Arabia	Bosnum	Galenas and Ore Leads	Stacey et al 1980	82115	0.878912872	2.119900554	17.698	15.555	37.518
Saudi Arabia	Al Kushamiyah	Galenas and Ore Leads	Stacey et al 1980	72134	0.879605487	2.119204172	17.642	15.518	37.387
Saudi Arabia	Jabal Sitarah	Galenas and Ore Leads	Stacey et al 1980		0.892242369	2.150275419	17.428	15.550	37.475

Appendix 6.3
Bahrain Artifacts

Published Lead Isotope Data

<u>Region</u>	<u>Location</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>208/206</u>	<u>207/206</u>	<u>204/206</u>	<u>208/204</u>	<u>207/204</u>	<u>206/204</u>
Bahrain	Barbar Temple	axe	Begemann et al 2010	BAH-11	2.0824	0.8397	0.05388	38.648	15.584	18.560
Bahrain	Diraz Level II	axe	Begemann et al 2010	BAH-12	2.0895	0.8466	0.05418	38.565	15.625	18.457
Bahrain	Saar	bronze dagger	Begemann et al 2010	BAH-13	2.0957	0.8539	0.05457	38.403	15.647	<i>18.325</i>
Bahrain	Ali	spearhead	Begemann et al 2010	BAH-14	2.0923	0.8487	0.05449	38.397	15.575	18.352
Bahrain	Qala'at al Bahrain	rod	Begemann et al 2010	BAH-15	2.1035	0.8611	0.05493	38.294	15.676	<i>18.205</i>
Bahrain	al Nasaria	cuprite	Begemann et al 2010	BAH-18	2.0874	0.8452	0.05406	38.612	15.634	<i>18.498</i>
Bahrain	Hamad	axe	Begemann et al 2010	BAH-19	2.0891	0.8476	0.05420	38.544	15.638	<i>18.450</i>
Bahrain	Bahrain	chisel	Begemann et al 2010	BAH-21	2.1047	0.8590	0.05480	38.406	15.675	<i>18.248</i>
Bahrain	Bahrain	spearhead	Begemann et al 2010	BAH-22	2.0894	0.8462	0.05411	38.613	15.638	<i>18.481</i>
Bahrain	Bahrain	spearhead	Begemann et al 2010	BAH-23	2.0868	0.8420	0.05378	38.802	15.656	<i>18.594</i>
Bahrain	Barbar Temple Iia	bull's head	Begemann et al 2010	BAH-27	2.0851	0.8435	0.05393	38.663	15.640	<i>18.543</i>

Appendix 6.3
Bahrain Ores and Ingots

Published Lead Isotope Data

<u>Region</u>	<u>Location</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>208/206</u>	<u>207/206</u>	<u>204/206</u>	<u>208/204</u>	<u>207/204</u>	<u>206/204</u>
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-1	2.0956	0.8522	0.05443	38.500	15.656	18.372
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-2	2.0771	0.8396	0.05361	38.744	15.661	18.653
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-3	2.0808	0.8412	0.05379	38.683	15.638	18.591
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-4	2.0901	0.8463	0.05405	38.699	15.657	18.501
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-5	2.0797	0.8407	0.05376	38.684	15.638	18.601
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-6	2.0937	0.8500	0.05434	38.529	15.642	18.403
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-7	2.0846	0.8524	0.05552	37.546	15.353	18.012
Bahrain	al Nasaria	Cu lump	Begemann et al 2010	BAH-8	2.0651	0.8342	0.05334	38.715	15.639	18.748
Bahrain	al Nasaria	Cu lump	Begemann et al 2010	BAH-10	2.0828	0.8531	0.05613	37.106	15.198	17.816
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-16	2.0867	0.843	0.05395	38.678	15.625	18.536
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-17	2.0781	0.8376	0.05345	38.879	15.670	18.709
Bahrain	al Nasaria	cuprite	Begemann et al 2010	BAH-18	2.0874	0.8452	0.05406	38.612	15.634	18.498
Bahrain	al Nasaria	ingot	Begemann et al 2010	BAH-20	2.0834	0.8421	0.05390	38.653	15.623	18.553
Bahrain	Barbar Temple	ingot	Begemann et al 2010	BAH-9	2.0710	0.8434	0.05653	36.635	14.919	17.690

Appendix 6.3
Yemen Artifacts

Published Lead Isotope Data

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/207</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>
Yemen	al-Midamman	razor	Weeks et al 2009	zp97.110	0.87421	2.402626371	2.1004	17.736	37.2526944	15.50498856
Yemen	al-Midamman	spatula	Weeks et al 2009	zp97.111	0.87414	2.402475576	2.1001	17.732	37.2389732	15.50025048
Yemen	al-Midamman	razor	Weeks et al 2009	zp97.218	0.87425	2.40274521	2.1006	17.735	37.254141	15.50482375
Yemen	al-Midamman	adze	Weeks et al 2009	zp97.224	0.87375	2.403547926	2.1001	17.745	37.2662745	15.50469375
Yemen	al-Midamman	point	Weeks et al 2009	zp97.231a	0.87411	2.402672433	2.1002	17.736	37.2491472	15.50321496
Yemen	al-Midamman	dagger	Weeks et al 2009	zp97.232	0.87414	2.402704372	2.1003	17.733	37.2446199	15.50112462
Yemen	al-Midamman	spatula	Weeks et al 2009	zp97.236	0.88348	2.395413592	2.1163	17.589	37.2236007	15.53952972
Yemen	al-Midamman	point	Weeks et al 2009	zp97.237	0.88431	2.39395687	2.117	17.566	37.187222	15.53378946
Yemen	al-Midamman	dagger	Weeks et al 2009	zp97.244	0.88298	2.395977259	2.1156	17.602	37.2387912	15.54221396
Yemen	al-Midamman	dagger/knife	Weeks et al 2009	zp97.201a	0.87364	2.300146513	2.0095	17.744	35.656568	15.50186816
Yemen	al-Midamman	dagger/knife	Weeks et al 2009	zp97.201b	0.87259	2.407659955	2.1009	17.709	37.2048381	15.45269631
Yemen	al-Midamman	adze	Weeks et al 2009	zp97.219	0.87326	2.404438541	2.0997	17.759	37.2885723	15.50822434
Yemen	al-Midamman	lump	Weeks et al 2009	zp97.67	0.84395	2.418745186	2.0413	18.458	37.6783154	15.5776291
Yemen	al-Midamman	razor	Weeks et al 2009	zp97.71	0.87117	2.413191455	2.1023	17.833	37.4903159	15.53557461
Yemen	al-Midamman	dagger/knife	Weeks et al 2009	zp97.156	0.83896	2.442667112	2.0493	18.597	38.1108321	15.60213912
Yemen	al-Midamman	point	Weeks et al 2009	zp97.216a	0.84933	2.446045707	2.0775	18.356	38.13459	15.59030148
Yemen	al-Midamman	point	Weeks et al 2009	zp97.216b	0.85935	2.433699889	2.0914	18.124	37.9045336	15.5748594

Appendix 6.4
Oman Copper and Lead Ores

Published Lead Isotope Data

Region	Location	Material	reference	analysis #	208/206	207/206	208/204	207/204	206/204	
	Bibid	Nujum	Ore - Archaeology	Begemann et al 2010	OM 355	2.0778	0.8378	38.804	15.646	18.676
	Bibid	Nujum	Ore - Archaeology	Begemann et al 2010	OM Pb 1	2.0769	0.8377	38.800	15.650	18.681
	Bidbid	Mullaq	ore	Prange 2002	OM 482	2.083	0.8406	38.80629	15.660378	18.63
	Bidbid	Mullaq	ore	Prange 2002	OM 302	2.0985	0.8587	37.722636	15.4359912	17.976
	Bidbid	W. Andam	ore	Prange 2002	OM 358	2.0867	0.8465	38.3577194	15.560363	18.382
	Bidbid	Wadi Salh	ore	Prange 2002	OM 536	2.089	0.8499	38.308082	15.5854662	18.338
Masirah Island	Farukh	Ore - Bedrock	Begemann et al 2010	OM 1002 #	2.0082	0.8419	38.830	15.656	18.595	
Masirah Island	J16	Ore - Bedrock	Begemann et al 2010	OM 1000 #	2.0870	0.8409	38.854	15.655	18.617	
Masirah Island	P183	Ore - Bedrock	Begemann et al 2010	OM 1012 #	2.1058	0.8600	38.296	15.642	18.192	
Masirah Island	P183b	Ore - Bedrock	Begemann et al 2010	OM 1011 #	2.0948	0.8478	38.811	15.708	18.527	
Masirah Island	P57	Ore - Bedrock	Begemann et al 2010	OM 1010 #	2.0972	0.8531	38.622	15.708	18.420	
Masirah Island	Shinzi	Ore - Bedrock	Begemann et al 2010	OM 1008 #	2.0646	0.8372	38.536	15.639	18.662	
Masirah Island	Shinzi	Ore - Bedrock	Begemann et al 2010	OM 1013 #	2.0530	0.8302	38.493	15.582	18.750	
Masirah Island	Sur	Ore - Bedrock	Begemann et al 2010	OM 1009 #	2.0974	0.8516	38.734	15.729	18.468	
Masirah Island	Suwayr	Ore - Bedrock	Begemann et al 2010	OM 1004 #	2.0903	0.8426	38.861	15.664	18.590	
Masirah Island	Suwayr	Ore - Bedrock	Begemann et al 2010	OM 1006 #	2.0962	0.8512	38.446	15.627	18.339	
Masirah Island	Wadi Madi	Ore - Bedrock	Begemann et al 2010	OM 1003 #	2.0914	0.8438	38.837	15.669	18.570	
Masirah Island	Wadi Madi	Ore - Bedrock	Begemann et al 2010	OM 1005 #	2.0829	0.8451	38.274	15.546	18.375	
Masirah Island	X16	Ore - Bedrock	Begemann et al 2010	OM 1001 #	2.0899	0.8430	38.802	15.652	18.567	
Masirah Island	Gabal Khasun	Surface Ore Sample	Begemann et al 2010	OM 616	2.114	0.8323	39.656	15.613	18.759	
Nizwa	Assayab	ore	Prange 2002	OM 211	2.0898	0.8503	38.431422	15.637017	18.39	
Nizwa	Hawqayn	Ore - Bedrock	Begemann et al 2010	OM 547	2.0819	0.8426	38.645	15.640	18.562	
Nizwa	Miadin-2	Ore - Bedrock	Begemann et al 2010	OM 544	2.0898	0.8522	38.302	15.618	18.328	
Nizwa	Daris 2	sulphide	Calvez and Lescuyer 1991	PS1	2.086892649	0.845911094	38.355	15.547	18.379	
Nizwa	Daris 2	sulphide	Calvez and Lescuyer 1991	PS2	2.086169521	0.845436809	38.494	15.600	18.452	
Nizwa	Daris 1	sulphide	Calvez and Lescuyer 1991	PS4	2.09918546	0.85571009	37.884	15.443	18.047	
Nizwa	Daris 1	sulphide	Calvez and Lescuyer 1991	PS5	2.097651285	0.855927052	37.957	15.488	18.095	
Nizwa	Hayl as Safil	sulphide	Calvez and Lescuyer 1991	CJ55	2.083486835	0.845324521	38.457	15.603	18.458	
Nizwa	Hayl as Safil	sulphide	Calvez and Lescuyer 1991	PS16	2.095395826	0.853538699	37.956	15.461	18.114	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	CJ57	2.082508786	0.84379562	38.516	15.606	18.495	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	CJ58	2.083946742	0.84444685	38.503	15.602	18.476	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	PS10	2.088240074	0.845403824	38.551	15.607	18.461	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	PS6	2.080916113	0.843083239	38.524	15.608	18.513	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	PS7	2.083387446	0.843777056	38.501	15.593	18.48	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	PS8	2.082486486	0.843675676	38.526	15.608	18.5	
Nizwa	Rakah	sulphide	Calvez and Lescuyer 1991	PS9	2.086824562	0.846566582	38.504	15.620	18.451	
None	?	galena	Doe from Chen and Pallister 1981	OMG-15	2.077994875	0.837550715	38.925	15.689	18.732	
Oman/UAE Border	Buraimi	copper metal from smelt	Kenoyer CES 15 Project	5P-96	2.086119687	0.851784415	38.38296898	15.6721664	18.39921708	
Oman/UAE Border	Hatta	copper metal from smelt	Kenoyer CES 15 Project	5P-101	2.155299294	0.90260808	37.31144924	15.6254937	17.31149328	
Oman/UAE Border	Hatta	copper metal from smelt	Kenoyer CES 15 Project	5P-80	2.131920138	0.88473478	37.56154735	15.5878294	17.61864653	
Oman/UAE Border	Hatta	copper metal from smelt	Kenoyer CES 15 Project	5P-91	2.156159947	0.903132861	37.30932	15.6274459	17.30359571	
Oman/UAE Border	Buraimi	copper ore	Kenoyer CES 15 Project	5P-94	No Data	No Data	No Data	No Data	No Data	
Samad	Nujum	galena	Calvez and Lescuyer 1991	NUJUM	2.080213904	0.838502674	38.9	15.680	18.7	
Samad	Bilad al Maaidin	ore	Prange 2002	OM 565	2.0741	0.8499	38.1883292	15.6483588	18.412	
Samad	Maysar	ore	Prange 2002	OM 110	2.081	0.8444	38.329939	15.5530036	18.419	
Samad	Bilad al Maaidin	Ore - Archaeology	Begemann et al 2010	DA 5340	2.0857	0.8404	38.888	15.669	18.645	

Appendix 6.4
Oman Copper and Lead Ores

Published Lead Isotope Data

<u>Region</u>	<u>Location</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>208/206</u>	<u>207/206</u>	<u>208/204</u>	<u>207/204</u>	<u>206/204</u>
Samad	Mullaq	Ore - Bedrock	Begemann et al 2010	OM 482/3	2.0830	0.8406	38.808	15.660	18.63
Samad	Gabal Ghuraib	Surface Ore Sample	Begemann et al 2010	OM 1018	2.0781	0.8396	38.663	15.620	18.605
Samad	Gabal Ghuraib	Surface Ore Sample	Begemann et al 2010	OM 620/6	2.0363	0.8239	35.988	14.561	17.673
Samad	Maysar-49	Surface Ore Sample	Begemann et al 2010	OM 511	2.0977	0.8569	38.137	15.578	18.180
Samad	Nibal al Kara	Surface Ore Sample	Begemann et al 2010	OM 1022	2.0822	0.8414	38.665	15.624	18.569
Samad	Nibal al Kara	Surface Ore Sample	Begemann et al 2010	OM 1023	2.0776	0.8382	38.799	15.653	18.675
Samad	Wadi Majazeh/Mgasse	Surface Ore Sample	Begemann et al 2010	OM 620/1	2.0917	0.8507	38.483	15.650	18.398
Suhar	Aarja/Arja	copper ore	Kenoyer CES 15 Project	5P-84	2.133551712	0.885055136	37.51131852	15.5607126	17.58163081
Suhar	Wadi Jizi	Fe-Mn metall. seds.	Gale et al. 1981	OM 294	2.102720711	0.856191005	37.87	15.420	18.01
Suhar	Wadi Jizi	Fe-Mn metall. seds.	Gale et al. 1981	OM 329	2.096578366	0.854856512	37.99	15.490	18.12
Suhar	Zuha	gossan	Calvez and Lescuyer 1991	CU54	2.101556913	0.854541453	38.2	15.533	18.177
Suhar	Arja-18	Ore - Bedrock	Begemann et al 2010	OM 453	2.1040	0.8599	37.776	15.440	17.955
Suhar	Assayab	Ore - Bedrock	Begemann et al 2010	OM 491	2.1144	0.8693	37.514	15.423	17.742
Suhar	Lasail	Ore - Bedrock	Begemann et al 2010	OM 161	2.1041	0.8602	37.745	15.430	17.938
Suhar	Semdah	Ore - Bedrock	Begemann et al 2010	OM 481	2.1180	0.8710	37.473	15.410	17.693
Suhar	Aarja	pyrite	Stos-Gale et. al. 1997	AAR17	2.10791	0.8625	37.73369691	15.4396	17.901
Suhar	Aarja	pyrite	Stos-Gale et. al. 1997	AAR48	2.10653	0.86031	37.85013104	15.4581	17.968
Suhar	Aarja	pyrite	Stos-Gale et. al. 1997	AAR83	2.10583	0.8601	37.86492923	15.4655	17.981
Suhar	Aarja	pyrite	Stos-Gale et. al. 1997	AAR85	2.10709	0.8631	37.67266211	15.4314	17.879
Suhar	Aarja	pyrite	Chen and Pallister 1981	Aarja	2.161695972	0.860171378	38.85	15.459	17.972
Suhar	Bayda	pyrite	Stos-Gale et. al. 1997	BAY87	2.10411	0.85944	37.84241835	15.4570	17.985
Suhar	Lasail	pyrite	Stos-Gale et. al. 1997	LAS26a	2.10479	0.85999	37.81886672	15.4523	17.968
Suhar	Bayda	pyrite, chalcopryrite	Chen and Pallister 1981	Bayda	2.108031074	0.862795507	37.719	15.438	17.893
Suhar	Lasail	pyrite, chalcopryrite	Chen and Pallister 1981	Lasail	2.094255686	0.857754546	37.661	15.425	17.983
Suhar	Maqa'il	sulphide	Calvez and Lescuyer 1991	CU73	2.09943478	0.852987982	38.258	15.544	18.223
UNCLEAR	Wadi Khabiyat	Fe-Mn metall. seds.	Gale et al. 1981	OM 423	2.098676957	0.85446527	38.07	15.500	18.14
UNCLEAR	Wadi Khabiyat	Fe-Mn metall. seds.	Gale et al. 1981	OM 440	2.09789823	0.855641593	37.93	15.470	18.08
UNCLEAR	Wadi Khabiyat	Fe-Mn metall. seds.	Gale et al. 1981	OM 606	2.075997813	0.84691088	37.97	15.490	18.29
UNCLEAR	Wadi Khabiyat	Fe-Mn metall. seds.	Gale et al. 1981	OM 780	2.096969697	0.853443526	38.06	15.490	18.15
UNCLEAR	Qumayrah	galena	Calvez and Lescuyer 1991	JL90-35	2.082263586	0.840768079	38.93	15.719	18.696
UNCLEAR	Wadi May	galena	Calvez and Lescuyer 1991	C 533	2.115928524	0.862420522	38.603	15.734	18.244
UNCLEAR	Gaddamah W	gossan	Calvez and Lescuyer 1991	CU24	2.121437285	0.856770545	38.258	15.451	18.034
UNCLEAR	Al Ajal	sulphide	Calvez and Lescuyer 1991	PS12	2.120494104	0.868500842	37.766	15.468	17.81
UNCLEAR	Al Ajal	sulphide	Calvez and Lescuyer 1991	PS17	2.105941144	0.861465852	37.928	15.515	18.01
UNCLEAR	Al Ajal	sulphide	Calvez and Lescuyer 1991	PS18	2.125596274	0.869914137	37.876	15.501	17.819

Appendix 6.5

Oman Artifacts, Ingots, Slag

Published Lead Isotope Data

<u>Location</u>	<u>Region (BCH)</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>208/206</u>	<u>207/206</u>	<u>208/204</u>	<u>207/204</u>	<u>206/204</u>
al Aqir/Bahla	Nizwa	ingot	Begemann et al 2010	DA 7405/1	2.0766	0.8475	38.455	15.697	18.518
al Aqir/Bahla	Nizwa	ingot	Begemann et al 2010	DA 7407/A	2.0766	0.8482	38.415	15.691	18.499
al Aqir/Bahla	Nizwa	ingot	Begemann et al 2010	DA 7410	2.0809	0.8411	38.657	15.625	18.577
al Aqir/Bahla	Nizwa	ingot	Begemann et al 2010	DA 7412	2.0879	0.8560	38.280	15.694	18.334
Batin	Nizwa	slag	Prange 2002	om0146	2.0976	0.8527	38.8454544	15.7911513	18.519
Maysar-1	Samad	axe	Begemann et al 2010	DA 4305	2.0786	0.8380	38.885	15.676	18.708
Maysar-1	Samad	axe	Begemann et al 2010	DA 5168	2.0423	0.8296	38.570	15.667	18.886
Maysar-1	Samad	chisel	Begemann et al 2010	DA 4962	2.0810	0.8393	38.822	15.657	18.655
Maysar-1	Samad	Copper Prill	Begemann et al 2010	OM 437	2.0752	0.8439	38.511	15.661	18.558
Maysar-1	Samad	Copper Prill	Begemann et al 2010	OM 46	2.0829	0.8418	38.681	15.632	18.571
Maysar-1	Samad	Copper Slag	Begemann et al 2010	OM 114	2.0442	0.8388	38.221	15.683	18.697
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4028	2.0313	0.8330	38.294	15.703	18.852
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4040	2.0773	0.8376	38.842	15.661	18.698
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4259	2.0814	0.8406	38.704	15.632	18.595
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4840/F1	2.0566	0.8439	38.246	15.694	18.596
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4840/QA	2.0477	0.8386	38.403	15.694	18.755
Maysar-1	Samad	ingot	Begemann et al 2010	DA 4840/TB	2.0556	0.8331	38.626	15.655	18.791
Aarja	Suhar	slag	Prange 2002	om0203	2.1037	0.8596	37.677267	15.395436	17.91

Appendix 6.5

Published Lead Isotope Data

United Arab Emirates Artifacts

<u>Sample</u>	<u>Site</u>	<u>Material</u>	<u>206Pb/204Pb</u>	<u>207Pb/204Pb</u>	<u>208Pb/204Pb</u>	<u>207Pb/206Pb</u>	<u>208Pb/206Pb</u>	<u>Reference</u>
M10-41	Al Sufouh	Cu	18.525	15.683	38.737	0.84658	2.09109	Weeks 2004
ASI-5	Al Sufouh	Cu-As	18.205	15.728	38.471	0.86391	2.11318	Weeks 2004
ASI-2	Al Sufouh	Cu-Sn(low)-As	17.747	15.700	37.869	0.88469	2.13387	Weeks 2004
ASI-1d	Al Sufouh	Cu-Sn(low)-As-Ni	18.485	15.727	38.723	0.85079	2.09485	Weeks 2004
ASI-3	Al Sufouh	Cu-Sn(low)-As-Ni-Co	18.247	15.583	38.414	0.85397	2.10518	Weeks 2004
TA1227	Tell Abraq	Cu	18.671	15.694	38.885	0.841	2.083	Weeks 2004
TA1310	Tell Abraq	Cu	18.804	15.729	38.847	0.836	2.066	Weeks 2004
TA1461	Tell Abraq	Cu	18.699	15.724	38.966	0.841	2.084	Weeks 2004
TA1612	Tell Abraq	Cu-As-Ni-S	18.754	15.755	40.110	0.840	2.085	Weeks 2004
TA1389	Tell Abraq	Cu-Ni-S	18.520	15.696	38.734	0.848	2.092	Weeks 2004
TA1426	Tell Abraq	Cu-S	18.606	15.655	38.710	0.841	2.081	Weeks 2004
TA1467	Tell Abraq	Cu-S-Fe	18.501	15.669	38.704	0.847	2.092	Weeks 2004
TA699 Avg.	Tell Abraq	Cu-Sn	24.401	16.093	42.830	0.660	1.756	Weeks 2004
TA1217	Tell Abraq	Cu-Sn	18.831	15.708	39.026	0.834	2.072	Weeks 2004
TA1286	Tell Abraq	Cu-Sn	18.792	15.692	38.978	0.835	2.074	Weeks 2004
TA1306	Tell Abraq	Cu-Sn	18.807	15.712	39.046	0.835	2.076	Weeks 2004
TA1459	Tell Abraq	Cu-Sn	18.531	15.680	38.764	0.846	2.092	Weeks 2004
TA1648	Tell Abraq	Cu-Sn	17.919	15.665	38.017	0.874	2.122	Weeks 2004
TA107 Avg.	Tell Abraq	Cu-Sn-As-Ni	19.244	15.741	39.463	0.818	2.051	Weeks 2004
TA1614 Avg.	Tell Abraq	Cu-Sn-Fe	25.518	16.177	45.996	0.634	1.803	Weeks 2004
TA1231	Tell Abraq	Cu-Sn(low)	18.061	15.726	38.364	0.871	2.124	Weeks 2004
TA1428	Tell Abraq	Cu-Sn(low)-Fe	18.515	15.684	38.619	0.847	2.086	Weeks 2004
TA2918	Tell Abraq	Sn-As ring	18.454	15.668	38.650	0.8490	2.0944	Weeks 2004
M10-38	UNAR1	Cu	18.378	15.614	38.543	0.84959	2.09722	Weeks 2004
L14N-PIN	UNAR1	Cu-As-Ni-Fe	18.708	15.693	38.933	0.83885	2.08108	Weeks 2004
M10-12	UNAR1	Cu-As-Ni-Fe	18.403	15.684	38.579	0.85227	2.09637	Weeks 2004
M10-13v	UNAR1	Cu-Sn	18.461	15.668	38.672	0.84869	2.09475	Weeks 2004
M10-22r	UNAR1	Cu-Sn-Fe	18.330	15.626	38.520	0.85248	2.10149	Weeks 2004
M10-39	UNAR1	Cu-Sn-Fe	18.372	15.601	38.529	0.84915	2.09712	Weeks 2004
M10-17 Avg.	UNAR1	Cu-Sn(low)	19.392	15.772	38.733	0.813	1.997	Weeks 2004
M10-19	UNAR1	Cu-Sn(low)	18.299	15.654	38.491	0.85542	2.10341	Weeks 2004
M10-7	UNAR1	Cu-Sn(low)	18.451	15.686	38.670	0.85014	2.09589	Weeks 2004
19359	UNAR2	Cu	17.997	15.709	37.959	0.87285	2.10912	Weeks 2004
18393	UNAR2	Cu-As-Fe	18.723	15.723	38.982	0.83974	2.08203	Weeks 2004
194108	UNAR2	Cu-As-Ni	18.738	15.721	39.004	0.83897	2.08156	Weeks 2004
23410	UNAR2	Cu-Sn-(Fe)	18.404	15.722	38.547	0.85430	2.09452	Weeks 2004
1476	UNAR2	Cu-Sn-As	18.167	15.678	38.362	0.86300	2.11168	Weeks 2004
14158	UNAR2	Cu-Sn-As	18.055	15.677	38.209	0.86833	2.11632	Weeks 2004
19571	UNAR2	Cu-Sn-As	18.655	15.723	38.885	0.84283	2.08447	Weeks 2004
18399	UNAR2	Cu-Sn-As-(Ni)	18.615	15.711	38.916	0.84399	2.09053	Weeks 2004
193105	UNAR2	Cu-Sn-As-Fe	18.028	15.740	38.025	0.87306	2.10920	Weeks 2004
232110	UNAR2	Cu-Sn(low)-Fe	17.507	15.637	37.687	0.89320	2.15268	Weeks 2004

<u>Region</u>	<u>Locality</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/207</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>
Afghanistan	Logar Province SE Afghan	Mes Aynak	malachite?	Unpublished Data Set	ore1	0.320949	5.395535709	1.73171	57.4275	99.4435	18.4307
Afghanistan	Logar Province SE Afghan	Mes Aynak	malachite?	Unpublished Data Set	ore2	0.368871	4.733991005	1.74624	48.283	84.3138	17.8103
Afghanistan	Logar Province SE Afghan	Mes Aynak	slag	Unpublished Data Set	slag4	0.692378	2.929797416	2.02853	23.1491	46.9585	16.0279
Afghanistan	Logar Province SE Afghan	Mes Aynak	slag	Unpublished Data Set	slag7	0.804392	2.575921407	2.07212	19.6133	40.6416	15.7775
Afghanistan	Logar Province SE Afghan	Mes Aynak	slag	Unpublished Data Set	slag8	0.560728	3.27063179	1.83394	29.3849	53.8902	16.477
Afghanistan	Logar Province SE Afghan	Mes Aynak	Copper ore	Begemann & Schmitt-Strecker	202	0.5887	2.961610328	1.7435	27.71618625	48.32317073	16.31651885
Afghanistan	Hindu Kush	Bezarak	Copper ore	Begemann & Schmitt-Strecker	221	0.8338	2.487287119	2.0739	18.85014138	39.0933082	15.71724788
Afghanistan	Kabul	Maydan	Copper ore	Begemann & Schmitt-Strecker	201	0.8327	2.511108442	2.0910	18.9000189	39.51993952	15.73804574
Afghanistan	Herat Province W Afghan	Shaida	Copper ore	Begemann & Schmitt-Strecker	227	0.8477	2.464079273	2.0888	18.42638659	38.4890363	15.62004791
Afghanistan	Herat Province W Afghan	Shaida	Copper ore	Begemann & Schmitt-Strecker	228/230D	0.844	2.477132701	2.0907	18.53568119	38.75254866	15.64411492
Afghanistan	Herat Province W Afghan	Shaida	Copper ore	Begemann & Schmitt-Strecker	228/230G	0.8421	2.476427978	2.0854	18.57010214	38.72609099	15.63788301
Afghanistan	Unclear	Wostok	Copper ore	Begemann & Schmitt-Strecker	224	0.8442	2.47761194	2.0916	18.55631843	38.81239562	15.66524402
Afghanistan	Unclear	Wostok	Copper ore	Begemann & Schmitt-Strecker	226	0.8445	2.47696862	2.0918	18.53224611	38.76575241	15.65048184
Afghanistan	Unknown	Unknown	Copper ore	Begemann & Schmitt-Strecker	210	0.3115	2.252006421	0.7015	59.66587112	41.85560859	18.58591885
Afghanistan	Unknown	Unknown	Copper ore	Begemann & Schmitt-Strecker	216	0.6284	2.957192871	1.8583	24.98750625	46.43428286	15.70214893
Afghanistan	Unknown	Unknown	Copper ore	Begemann & Schmitt-Strecker	217	0.4030	3.537468983	1.4256	44.84304933	63.92825112	18.07174888
Afghanistan	Unknown	Unknown	Copper ore	Begemann & Schmitt-Strecker	239	0.8301	2.496205276	2.0721	18.82175795	39.00056465	15.62394128
Afghanistan	Farinjal	Unknown	Ore	Brill et al 1997	Pb-839	0.81933	2.523561935	2.06763	19.19385797	39.68579655	15.72610365
Afghanistan	Farinjal	Unknown	Ore	Brill et al 1997	Pb-838	0.81935	2.519985354	2.06475	19.14608463	39.53187823	15.68734444
Afghanistan	Farinjal	Unknown	vitreous slag	Brill et al 1997	Pb-840	0.8195	2.5233313	2.06787	19.1791331	39.65995397	15.71729958
Afghanistan	Farinjal	Unknown	ore	Brill et al 1997	Pb-837	0.8225	2.51424924	2.06797	19.08032818	39.45754627	15.69356993
Afghanistan	Herat	Unknown	galena/sormah	Brill et al 1997	Pb-867	0.8892	2.446131354	2.1751	17.35508504	37.74904547	15.43214162
Afghanistan	Herat	Unknown	galena/sormah	Brill et al 1997	Pb-1343	0.83588	2.488634732	2.0802	18.76876877	39.04279279	15.68843844

Appendix 6.7
Himalayan Copper Ore

Analytical Samples Provided by
Dr. R.W.Law

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/207</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>	<u>Coordinate 001</u>	<u>Coordinate 002</u>
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP1	0.6834	2.6692	1.82413128	24.34738074	44.4128188	16.639	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP1	0.6834	2.6692	1.82413128	24.34738074	44.4128188	16.639	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP2	0.6801	2.6706	1.81627506	24.49933833	44.4975372	16.662	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP2	0.6801	2.6706	1.81627506	24.49933833	44.4975372	16.662	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP3	0.6813	2.6701	1.81913913	24.4972846	44.563969	16.69	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP3	0.6813	2.6701	1.81913913	24.4972846	44.563969	16.69	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP4	0.6801	2.6756	1.81967556	24.52286428	44.6236568	16.678	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP4	0.6801	2.6756	1.81967556	24.52286428	44.6236568	16.678	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP5	0.6812	2.665	1.815398	24.51849677	44.51083	16.702	31° 31' 8.47" North	78° 7' 8.05" East
Himachal Pradesh	Chargaon	Copper Ore	Law 2011	HP5	0.6812	2.665	1.815398	24.51849677	44.51083	16.702	31° 31' 8.47" North	78° 7' 8.05" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT1	0.9547	2.3351	2.22931997	16.49313921	36.7684846	15.746	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT10	0.9755	2.3094	2.2528197	16.05228088	36.1628946	15.659	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT2	0.9813	2.3013	2.25826569	16.02669928	36.1925451	15.727	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT4	0.9823	2.3034	2.26262982	15.79761784	35.7441612	15.518	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT5	0.9841	2.3017	2.26510297	15.9617925	36.1551036	15.708	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT6	0.982	2.3001	2.2586982	15.97352342	36.0793686	15.686	29° 45' 43" North	80° 18' 45" East
Uttaranchal	Askot	Copper Ore	Law 2011	UT7	0.9799	2.3023	2.25602377	15.95979182	36.0056697	15.639	29° 45' 43" North	80° 18' 45" East

Appendix 6.8
Waziristan Copper Ores

Analytical Samples Provided by
Dr. R.W.Law

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/207</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>	<u>Coordinate 001</u>	<u>Coordinate 002</u>
Waziristan	Shinkai	Copper Ore	Law 2011	WAZ-1	0.8467	2.4671	2.08889357	18.50478328	38.6545228	15.668	32° 55' 53.32" North	69° 51' 43.57" East
Waziristan	Shinkai	Copper Ore	Law 2011	WAZ-2	0.8478	2.4674	2.09186172	18.47605567	38.6493536	15.664	32° 55' 53.32" North	69° 51' 43.57" East
Waziristan	Shinkai	Copper Ore	Law 2011	WAZ-3	0.8462	2.4768	2.09586816	18.48735524	38.7470592	15.644	32° 55' 53.32" North	69° 51' 43.57" East
Waziristan	Shinkai	Copper Ore	Law 2011	WAZ-4	0.8444	2.4812	2.09512528	18.44268119	38.6397276	15.573	32° 55' 53.32" North	69° 51' 43.57" East
Waziristan	Shinkai	Copper Ore	Law 2011	WAZ-5	0.8465	2.4799	2.09923535	18.43236858	38.6938797	15.603	32° 55' 53.32" North	69° 51' 43.57" East

Appendix 6.9
Baluchistan Copper and Lead Ores

Analytical Samples Provided by
Dr. R.W.Law and Dr. J.M. Kenoyer

<u>Region</u>	<u>Source</u>	<u>Material</u>	<u>reference</u>	<u>analysis #</u>	<u>207/206</u>	<u>208/207</u>	<u>208/206</u>	<u>206/204</u>	<u>208/204</u>	<u>207/204</u>	<u>Coordinate 001</u>	<u>Coordinate 002</u>
Baluchistan	Chagai-Koh-i-Sultan	Galena Ore	Unpublished (RW Law)	CH14_KIS	0.83539	2.486383605	2.0771	18.7197	38.88268887	15.63825018	None	None
Baluchistan	Chagai-Koh-i-Sultan	Galena Ore	Unpublished (RW Law)	CH2_KIS	0.83545	2.486205039	2.0771	18.7172	38.87749612	15.63728474	None	None
Baluchistan	Chagai-Koh-i-Sultan	Galena Ore	Unpublished (RW Law)	CH3_KS	0.83553	2.486086676	2.0772	18.7132	38.87105904	15.63544	None	None
Baluchistan	Chagai-Reko Diq	Copper Ore	Unpublished	5P-87	0.848	2.461523875	2.088571559	18.5771196911364	38.7996438393475	15.7624487158450	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch4	0.8362	2.4856	2.0783	18.73450886	38.93592976	15.6646	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch4.2	0.8366	2.4872	2.0807	18.7131109	38.93636984	15.6547	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch5	0.8374	2.4833	2.0796	18.69986039	38.88822967	15.6599	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch5.2	0.8375	2.4857	2.0817	18.76221692	39.05730696	15.7128	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch6	0.8367	2.4847	2.079	18.75082022	38.98295524	15.6892	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Law 2011	ch6.2	0.8355	2.4849	2.0762	18.71107439	38.84793264	15.6336	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Reko Diq	Galena Ore	Unpublished (RW Law)	CH7_REK	0.84093	2.484035532	2.0889	18.5607	38.77144623	15.60824945	29° 7" 18.17" North	62° 10" 16.43" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu1	0.8327	2.4878	2.07159106	18.95280413	39.2624596	15.782	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu2	0.8407	2.4802	2.08510414	18.82716784	39.2566056	15.828	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu3	0.8421	2.4763	2.08529223	18.67830424	38.9497227	15.729	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu4	0.8424	2.4697	2.08047528	18.70607787	38.9175326	15.758	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu5	0.8447	2.4728	2.08877416	18.70131408	39.0628216	15.797	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu6	0.8434	2.4838	2.09483692	18.61987195	39.0055952	15.704	29° 17" North	61° 34" East
Baluchistan	Chagai-Saindak	Copper Ore	Law 2011	ChCu7	0.8315	2.4911	2.07134965	19.01022249	39.3768177	15.807	29° 17" North	61° 34" East

Appendix 6.10

Lead Isotope Analyses

Aravalli Range Copper Sources

Published Data
Analytical Data from Dr. R.W. Law

Region	Source	Material	reference	analysis #	207/206	208/206	208/206	206/204	208/204	207/204	Coordinate 001	Coordinate 002	Grover 2004 Belt #
Rajasthan	Chirana	Malachite	Unpublished (RW Law)	UCSC-LAW-27	0.6521	2.605160342	1.6989	25.0129	42.4915	16.3115	27° 43' 24.77" North	75° 27' 34.17" East	1
Rajasthan	Chirana	Malachite	Unpublished (RW Law)	UCSC-LAW-28	0.7484	2.641418102	1.9769	21.5292	42.5609	16.1127	27° 48' North	75° 35' East	1
Rajasthan	Dariba	copper slag	Unpublished (RW Law)	UCSC-LAW-38	0.8538	2.313076472	1.9750	18.4294	36.3978	15.7356	27° 40' 33.19" North	75° 53' 57.32" East	1
Rajasthan	Dhanaota	Malachite-Hematite	Unpublished (RW Law)	UCSC-LAW-31	0.7821	2.460501246	1.9243	20.2132	38.8969	15.8085	27° 44' 45" North	75° 30' East	1
Rajasthan	Dhanaota	Malachite-Hematite	Unpublished (RW Law)	UCSC-LAW-32	0.7685	2.479114621	1.9053	20.6909	39.4250	15.9023	27° 58' 30" North	75° 45' 30" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG_13	0.8513	2.4613	2.09530469	18.50581464	38.7753202	15.754	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_10	0.8552	2.4534	2.09814768	18.37815716	38.5600878	15.717	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_11	0.8689	2.4304	2.11177456	18.12061227	38.266648	15.745	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2_12	0.8662	2.4392	2.11283504	18.15169707	38.3515416	15.723	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Unpublished (RW Law)	RNSG2.2	0.8645	2.444722098	2.1134	18.1926	38.4476	15.7269	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2.2_14	0.8682	2.4345	2.1136329	18.25501037	38.5843905	15.849	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG2.5	0.8674	2.4249	2.10335826	17.94673738	37.7484183	15.567	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Law 2011	RNSG6	0.8688	2.4304	2.11153152	18.04673112	38.1062416	15.679	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Unpublished (RW Law)	RNSG7	0.8609	2.454881303	2.1135	18.3136	38.7048	15.7667	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Unpublished (RW Law)	RNSG8	0.8628	2.443807173	2.1084	18.2019	38.3770	15.7038	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Ganeshwar	slag	Unpublished (RW Law)	RNSG9	0.8600	2.441367808	2.0997	18.2572	38.3344	15.7024	27° 39' 58.92" North	75° 49' 30.66" East	1
Rajasthan	Khetri	host rock	Ericson and Shirahata 1985	4-6	0.74702	2.731787636	2.0407	21.311	43.496	15.923	28° 3' 56.3" North	75° 47' 48.42" East	1
Rajasthan	Khetri	Chalcocopyrite Ore	Unpublished (RW Law)	UCSC-LAW-41	0.8023	2.503993119	2.0089	19.7274	39.6296	15.8278	28° 3' 56.3" North	75° 47' 48.42" East	1
Rajasthan	Khetri	Chalcocopyrite-Bornite Ore	Unpublished (RW Law)	UCSC-LAW-42	0.9298	2.347442356	2.1827	16.4464	35.8958	15.2912	28° 15' 59.22" North	75° 50' 31.20" East	1
Rajasthan	Nanagwas	Bornite-Malachite ore	Unpublished (RW Law)	UCSC-LAW-35	0.7418	2.621302938	1.9446	21.6304	42.0597	16.0458	27° 44' 54.45" North	75° 55' 12.45" East	1
Rajasthan	Papurna	Malachite-Dolomite	Unpublished (RW Law)	UCSC-LAW-23	0.5474	2.930259256	1.6040	30.5762	49.0427	16.7372	27° 58' 30" North	75° 45' 30" East	1
Rajasthan	Papurna	copper slag	Unpublished (RW Law)	UCSC-LAW-34	0.7301	2.504854919	1.8288	21.9745	40.1872	16.0441	27° 44' 54.45" North	75° 55' 12.45" East	1
Rajasthan	Saikui	Malachite	Unpublished (RW Law)	UCSC-LAW-29	0.8254	2.470450803	2.0390	19.0798	38.9046	15.7479	27° 48' North	75° 35' East	1
Rajasthan	Saikui	Malachite	Unpublished (RW Law)	UCSC-LAW-30	0.7973	2.527237666	2.0150	19.9410	40.1831	15.8989	27° 44' 45" North	75° 30' East	1
Rajasthan	Singhana	slag	Unpublished (RW Law)	RNSS11	0.8711	2.43068587	2.1173	18.0320	38.1813	15.7075	28° 06' North	75° 50' East	1
Rajasthan	Singhana	slag	Unpublished (RW Law)	RNSS12	0.9389	2.339575844	2.1966	16.5903	36.4437	15.5765	28° 06' North	75° 50' East	1
Rajasthan	Singhana	slag	Unpublished (RW Law)	RNSS4	0.8821	2.399699317	2.1168	17.7911	37.6604	15.6941	28° 06' North	75° 50' East	1
Rajasthan	Singhana	slag	Unpublished (RW Law)	RNSS5	0.8813	2.402615487	2.1173	17.7674	37.6196	15.6577	28° 06' North	75° 50' East	1
Rajasthan	Singhana	slag	Unpublished (RW Law)	RNSS7	0.8777	2.41384583	2.1183	17.8732	37.8595	15.6872	28° 06' North	75° 50' East	1
Rajasthan	Singhana	slag	Law 2011	RNSS8	0.8637	2.4354	2.10345498	18.80035197	38.0312064	15.616	28° 06' North	75° 50' East	1
Rajasthan	Bhukia	Sulfide	Unpublished (RW Law)	UCSC-LAW-19	0.8297	2.45690356	2.0384	19.0869	38.9072	15.8359	27° 25' 21.48" North	76° 27' 3.28" East	2
Rajasthan	Bhukia	Sulfide	Unpublished (RW Law)	UCSC-LAW-20	0.9015	2.386730945	2.1517	17.3455	37.3219	15.6373	27° 25' 21.48" North	76° 27' 3.28" East	2
Rajasthan	Jodhawas	Silver Slag	Unpublished (RW Law)	UCSC-LAW-23	0.8567	2.429878651	2.0817	18.3641	38.2288	15.7328	27° 21' 23.85" North	76° 18' 56.43" East	2
Rajasthan	Jodhawas	Malachite-Dolomite	Unpublished (RW Law)	UCSC-LAW-24	0.4431	3.539765488	1.5685	39.8049	62.4340	17.6377	27° 21' 24.44" North	76° 18' 29.88" East	2
Rajasthan	Kho Dariba	copper slag	Unpublished (RW Law)	UCSC-LAW-25	0.9618	2.312433708	2.2242	16.1347	35.8871	15.5187	27° 10' 00" North	76° 23' 30" East	2
Rajasthan	Kho Dariba	malachite-quartz	Unpublished (RW Law)	UCSC-LAW-26	0.7228	2.350762198	1.6992	22.1684	37.6690	16.0241	27° 10' 00" North	76° 23' 30" East	2
Rajasthan	Naldeshwar	copper slag	Unpublished (RW Law)	UCSC-LAW-21	0.8818	2.392141239	2.1095	17.8087	37.5683	15.7048	27° 25' 21.48" North	76° 27' 3.28" East	2
Rajasthan	Naldeshwar	copper slag	Unpublished (RW Law)	UCSC-LAW-22	0.8797	2.361398234	2.0772	17.8428	37.0643	15.6956	27° 21' 23.85" North	76° 18' 56.43" East	2
Rajasthan	Birantiya Khurd	Zn-Pb-Cu Ore	Deb et al 2001	TQ92-74	0.897692792	2.395153061	2.150111639	17.467	37.556	15.680	26° 07' North	74° 08' East	4
Rajasthan	Kankaria	host rock	Ericson and Shirahata 1985	11-6	0.9575	2.302872063	2.2050	16.269	35.887	15.581	26° 28' North	74° 38' East	4
Rajasthan	Kankaria	malachite stains	Ericson and Shirahata 1985	11-9	0.96301	2.313994663	2.2284	16.122	35.925	15.524	26° 28' North	74° 38' East	4
Rajasthan	Kayad	Galena	Unpublished (RW Law)	UCSC-LAW-43	0.9643	2.310426372	2.2279	16.1051	35.8804	15.5299	None	None	4
Rajasthan	Kayad	Galena	Unpublished (RW Law)	UCSC-LAW-44	0.9643	2.310483404	2.2279	16.1057	35.8828	15.5304	None	None	4
Rajasthan	Hanothia	malachite ore	Unpublished (RW Law)	UCSC-LAW-39	0.7861	2.563911455	2.0155	20.2798	40.8735	15.9440	24° 56' 29.30" North	74° 29' 21.80" East	5
Rajasthan	Hanothia	Slag with copper prill	Unpublished (RW Law)	UCSC-LAW-40	0.6961	2.951484329	2.0546	23.3427	47.9596	16.2496	24° 56' 29.30" North	74° 29' 21.80" East	5
Rajasthan	Nanagwas	Bornite-Malachite ore	Unpublished (RW Law)	UCSC-LAW-36	0.6999	2.752180472	1.9264	23.0530	44.3699	16.1218	25° 56' 29.30" North	74° 29' 21.80" East	5
Rajasthan	Rajpura-Dariba	host rock	Ericson and Shirahata 1985	16-10	0.92708	2.327738706	2.1580	16.800	36.237	15.571	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Galena ore	Ericson and Shirahata 1985	16-18 (A)	0.96543	2.314512704	2.2345	16.061	35.815	15.477	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Galena ore	Ericson and Shirahata 1985	16-18 (B)	0.96441	2.311983492	2.2297	16.056	35.892	15.485	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/208	0.965951609	2.311555842	2.232851085	16.036	35.806	15.490	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/224	0.965766665	2.311402376	2.232275363	16.037	35.799	15.488	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/231	0.965766665	2.307141011	2.22815988	16.037	35.733	15.488	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/263	0.966020325	2.31089454	2.232371095	16.039	35.805	15.494	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/28	0.965850315	2.309890961	2.231008911	16.047	35.801	15.499	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/305	0.965770933	2.310910265	2.231809963	16.039	35.796	15.490	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba	Polymetallic copper ore	Deb et al 1989	RD400/52	0.96582902	2.310865726	2.231901228	16.037	35.793	15.489	24° 57' 1" North	74° 8' 2" East	8
Rajasthan	Rajpura-Dariba (Dariba)	Ore	Srinivasan 1999	23	0.96200	2.299376299	2.21200	16.100	35.6132	15.4882	24° 57' North	74° 08' East	8
Rajasthan	Rajpura-Dariba (Dariba)	Ore	Srinivasan 1999	24	0.95900	2.299270073	2.20500	16.160	35.6328	15.49744	24° 57' North	74° 08' East	8
Rajasthan	Rajpura-Dariba (Dariba)	Pb slag	Srinivasan 1999	26	0.94961	2.325965396	2.20876	16.379	36.17728004	15.55366219	24° 57' North	74° 08' East	8
Rajasthan	Rajpura-Dariba (Dariba)	Pb slag	Srinivasan 1999	27	0.95271	2.324295956	2.21438	16.307	36.10989466	15.53584197	24° 57' North	74° 08' East	8
Rajasthan	Basantgarh	Cu-Zn	Deb 2000	TQ91-43	0.915143989	2.371866115	2.170599018	16.911	36.707	15.476	24° 43' 30" North	73° 01' 15" East	9
Rajasthan	Danva	Cu-Zn(Au)	Deb et al 2001	TQ92-75	0.926712949	2.361670249	2.188590401	16.565	36.254	15.351	24° 46' 10.35" North	73° 2' 10.51" East	9
Gujarat	Ambaji	slag	Srinivasan 1999	28	0.90079	2.3850509	2.14843	17.313	37.19576859	15.59537727	24° 20' North	72° 53" East	10
Gujarat	Ambaji	slag	Srinivasan 1999	29	0.90085	2.385336071	2.14883	17.318	37.21343794	15.6009203	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Ore	Srinivasan 1999	30	0.86951	2.403882647	2.09020	18.003	37.6298706	15.65378853	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Malachite in Quartzite	Ericson and Shirahata 1985	1-33	0.090247	23.854532256	2.1528	17.337	37.329	15.648	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Malachite in Chlorite Schist	Ericson and Shirahata 1985	1-31	0.89936	2.389921322	2.1494	17.127	36.81	15.411	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Copper Prills from smelt	Unpublished	5P-102	0.903	2.386642808	2.155921049	17.2945646332796	37.2857159203283	15.6226628421109	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Copper Prills from smelt	Unpublished	5P-103	0.903	2.386767318	2.156216489	17.296199780831	37.294351170627	15.625465831507	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Copper Prills from smelt	Unpublished	5P-78	0.903	2.38680093	2.156044759	17.299004816651	37.297428669411	15.626535169111	24° 20' North	72° 53" East	10
Gujarat	Ambaji	Copper Ore	Unpublished	5P-85	0.903	2.386723446	2.155676558	17.2979716170947	37.2888319102130	15.6234405709616	24° 20' North	72° 53" East	10

Appendix 6.10
Lead Isotope Analyses
Aravalli Range Copper Sources

Published Data
Analytical Data from Dr. R.W. Law

Region	Source	Material	reference	analysis #	207/206	208/207	208/206	206/204	208/204	207/204	Coordinate 001	Coordinate 002	Grover 2004 Belt #
Gujarat	Ambaji	Copper Prills from smelt	Unpublished	SP-92	0.903	2.386546975	2.155861457	17.294305220216	37.284126043419	15.622623998055	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Zn-Pb-Cu Ore	Deb et al 2001	Average	0.903175429	2.387512008	2.156342183	17.289	37.281	15.615	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-01	0.9111	2.395	2.1820845	17.44045659	38.05655	15.89	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-02	0.9106	2.4027	2.18789862	16.90753349	36.9919692	15.396	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-03	0.9079	2.4035	2.18213765	17.47108712	38.124317	15.862	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-04	0.8995	2.3916	2.1512442	17.53307393	37.7179236	15.771	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-05	0.8795	2.4041	2.11440595	17.85787379	37.7587946	15.706	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-06	0.8976	2.3977	2.15217552	17.47437611	37.6079245	15.685	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-07	0.8991	2.3889	2.14785999	17.45412079	37.4890077	15.693	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-08	0.8972	2.3861	2.14080892	17.43981275	37.3353067	15.647	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-09	0.897	2.3858	2.14006026	17.44370123	37.3306126	15.647	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Law 2011	GN-10	0.8991	2.3879	2.14696089	17.43632521	37.4351083	15.677	24° 20' North	72° 53' East	10
Gujarat	Ambaji	Copper Ore	Hegde 1991	Hegde 001	0.90405	2.389098345	2.159864359	17.3098833	37.387	15.649	24° 20' North	72° 53' East	10
Gujarat	Ambaji (Kumbariya)	Zn-Pb-Cu Ore	Deb et al 2001	4	0.901947229	2.385283597	2.151399931	17.358	37.344	15.656	24° 18' 36.84" North	72° 53' 48.36" East	10
Gujarat	Ambaji (Kumbariya)	talc-chlorite schist host rock	Ericson and Shirahata 1985	2-10	0.90165	2.385515444	2.1509	17.358	37.344	15.656	24° 18' 36.84" North	72° 53' 48.36" East	10
Rajasthan	Amli Mal	Cu-Zn	Deb 2000	TQ90-11	0.907041599	2.392838842	2.170404369	17.212	37.357	15.612	24° 21' 53.6" North	72° 48' 22.61" East	10
Rajasthan	Deri	host rock	Ericson and Shirahata 1985	3-3	0.90263	2.39223159	2.1593	17.292	37.336	15.614	24° 25' North	75° 50' East	10
Rajasthan	Deri	Galena ore	Ericson and Shirahata 1985	23-5	0.90343	2.38789945	2.1573	17.280	37.279	15.608	24° 25' North	75° 50' East	10
Rajasthan	Deri	Zn-Pb-Cu Ore	Deb et al 2001	Average	0.903701562	2.387648	2.157721226	17.290	37.307	15.625	24° 25' North	75° 50' East	10
Rajasthan	Deri	Cu-Pb ore from drill core	Deb et al 1989	DR 9/14	0.90353363	2.388145683	2.157769938	17.291	37.310	15.623	24° 25' North	75° 50' East	10
Rajasthan	Pipalwas	galena in chlorite schist	Ericson and Shirahata 1985	14-9 (A)	0.98443	2.279999594	2.2445	15.682	35.203	15.440	None	None	11
Rajasthan	Pipalwas	galena in chlorite schist	Ericson and Shirahata 1985	14-9 (B)	0.98449	2.281079544	2.2457	15.688	35.233	15.447	None	None	11
Rajasthan	Zawar	Pb slag	Srinivasan 1999	10	0.94290	2.32520946	2.19244	16.730	36.6795212	15.774717	24° 22' North	73° 30' East	11
Rajasthan	Zawar	Pb slag	Srinivasan 1999	13	0.94806	2.323260131	2.20259	16.575	36.50792925	15.7140945	24° 22' North	73° 30' East	11
Rajasthan	Zawar	Pb ore	Srinivasan 1999	16	0.94324	2.328654425	2.19648	16.661	36.59555328	15.71532164	24° 22' North	73° 30' East	11
Rajasthan	Zawar	Galena and Chalcopyrite in host rock	Ericson and Shirahata 1985	12-4	0.94778	2.31878706	2.1977	16.593	36.472	15.730	24° 22' North	73° 30' East	11
Rajasthan	Zawar	Galena ore	Ericson and Shirahata 1985	12-5	0.94671	2.327111787	2.2031	16.583	36.535	15.698	24° 22' North	73° 30' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	14	0.94685	2.324032318	2.20051	16.614	36.55927314	15.7309659	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	15	0.95244	2.32160556	2.21119	16.461	36.39839859	15.67811484	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	18	0.95200	2.319327731	2.20800	16.470	36.36576	15.67944	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	19	0.94600	2.316067653	2.19100	16.530	36.21723	15.63738	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	20	0.94600	2.321353066	2.19600	16.550	36.3438	15.6563	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	21	0.95100	2.318611987	2.20500	16.400	36.162	15.5964	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Balaria	Pb ore	Srinivasan 1999	22	0.95048	2.317039811	2.20230	16.397	36.1111131	15.58502056	24° 21' North	73° 44' East	11
Rajasthan	Zawar - Mala	Pb ore	Srinivasan 1999	17	0.94760	2.323712537	2.20195	16.604	36.5611778	15.7339504	24° 19' 30" North	73° 40' 00" East	11
Rajasthan	Zawar - Mochia	Pb ore	Srinivasan 1999	11	0.95004	2.320902278	2.20495	16.493	36.36624035	15.66900972	24° 21' 47" North	73° 43' 15" East	11
Rajasthan	Zawar - Mochia	Pb ore	Srinivasan 1999	12	0.94345	2.330902539	2.19909	16.640	36.5928576	15.699008	24° 21' 47" North	73° 43' 15" East	11
Haryana	Tosham	Sn-Cu stockwork	Deb et al 2001	TQ89-8	0.88329121	2.416544796	2.134512777	17.805	38.005	15.727	28° 52' 19.17" North	75° 54' 38.01" East	

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