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Metal Technologies of the Indus Valley Tradition in Pakistan and Western India

Jonathan M. Kenoyer and

Heather M.-L. Miller

ABSTRACT In this paper we summarize the available literature and recent discoveries on the production and use of metals by peoples of the Indus Valley Tradition of Pakistan and western India. Our primary focus is on the Harappan Phase (2600–1900 B.C.), and includes a review of collections and technical analyses of metal artifacts, along with tables of the published analyses from the sites of Mohenjo-daro, Harappa, Lothal, and Rangpur. The potential ore sources for metals are discussed, with particular attention given to copper, arsenical copper, and tin bronzes but also including lead, gold, silver, and iron. We present an overview of evidence for Harappan Phase metal processing techniques, from smelting to finishing, and examine the use of metal in the context of an urban society that still uses stone tools. In conclusion we outline some future directions for archaeological and archaeometallurgical research in the subcontinent. [Final ms. received 10/96.]

INTRODUCTION

The Indus Valley Tradition of Pakistan and western India has been the focus of considerable research over the past two decades and scholars have begun to fill in many of the gaps in our understanding of regional geography, settlement patterns, subsistence, specific technological developments and the chronology of these changes (see Kenoyer 1991; Mughal 1990; Possehl 1990 for summaries). This paper provides an overview of the non-ferrous metal technologies in the northwestern regions of the subcontinent, and of the role of these technologies during the Harappan Phase of the Indus Valley Tradition (2600–1900 B.C.). As the first such overview since Agrawal's seminal work in 1971, we will focus on the presentation of often inaccessible data, summarizing the information available on metal sources, processing, and use.

The Indus Valley Tradition was centered in the greater Indus plain, which was formerly watered by two major river systems, the Indus and the Ghaggar-Hakra (now dry) (Fig. 5.1). Adjacent regions which were culturally integrated at various periods with this vast double river plain include the highlands and plateaus of Baluchistan to the west, and the mountainous regions of northern Pakistan, Afghanistan, and India to the northwest and north. The Thar Desert and the Aravalli Hills formed the eastern periphery. The coastal regions from Makran to Kutch and Gujarat formed the southern boundary and provided access by sea to the resource areas of the Arabian Peninsula (Besenval 1992).

We have chosen to use the chronology defined by Shaffer (1992), which is presented in Table 5.1 along with its correlations to other more widely used but less precisely defined chronologies. As defined by Shaffer

TABLE 5.1

GENERAL DATES AND ARCHAEOLOGICAL PERIODS

INDUS TRADITION	*Early Food Producing Era*	ca. 6500–5000 B.C.
	Aceramic Neolithic	
	Regionalization Era	ca. 5000–2600 B.C.
	Early Harappan	
	Early Chalcolithic	
	Ceramic Neolithic	
	Integration Era	2600–1900 B.C.
	Mature Harappan	
	Chalcolithic/Bronze Age	
	Localization Era	1900–1300 B.C.
	Late Harappan	
Iron Age		
	Painted Gray Ware	+1200–800 B.C.
	Northern Black Polished Ware	(?700) 500 to 300 B.C.

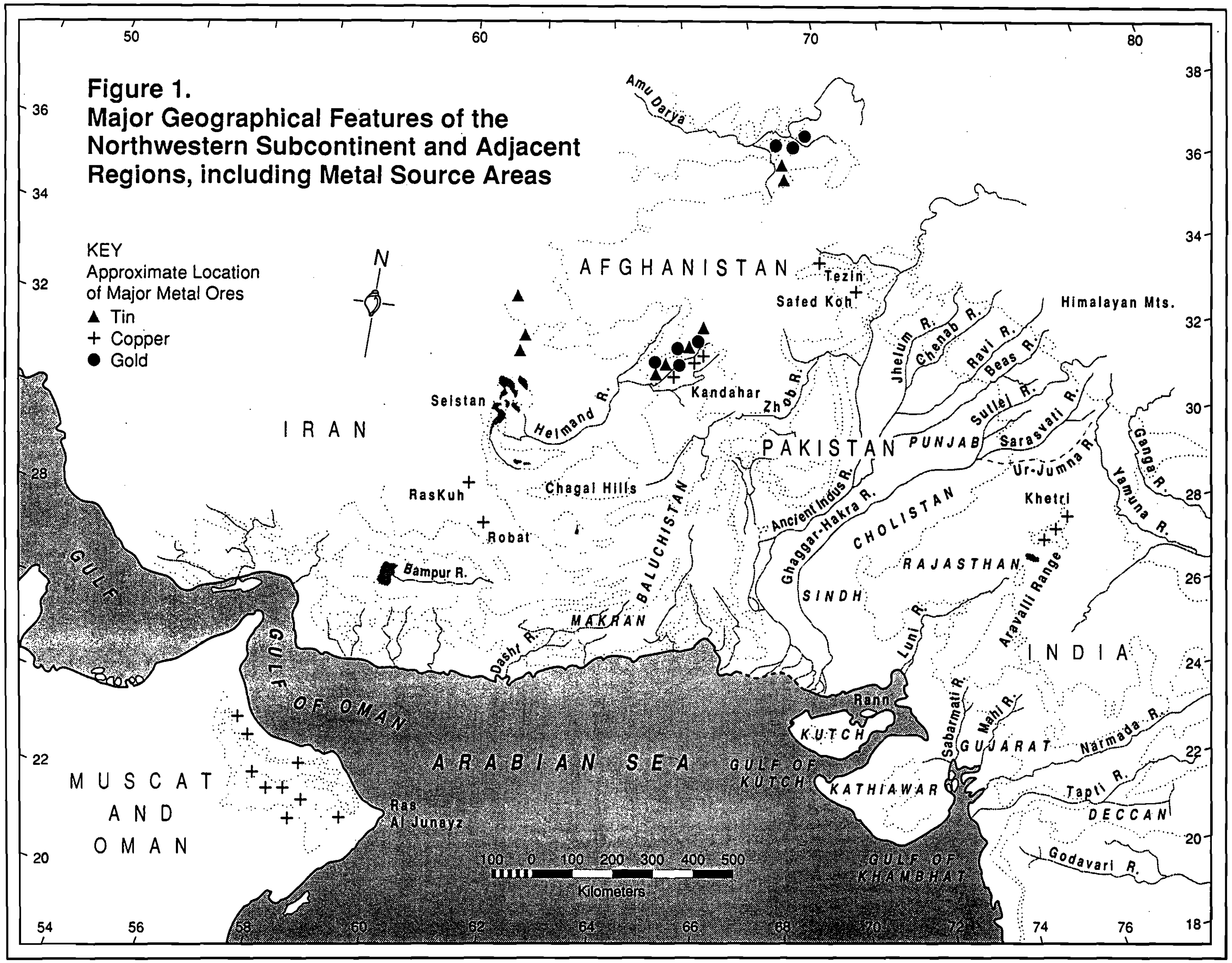

Figure 5.1 *Major geographical features of the northwestern subcontinent and adjacent regions, including metal source areas (composed by J. M. Kenoyer from various sources).*

TABLE 5.2
ARCHAEOLOGICAL TRADITIONS OF NORTHWESTERN SOUTH ASIA (AFTER SHAFFER 1992)

INDUS VALLEY TRADITION	BALUCHISTAN TRADITION	HELMAND TRADITION
Early Food Producing Era Mehrgarh Phase	*Early Food Producing Era* Mehrgarh Phase	*Early Food Producing Era* Ghar-i-mar Phase*
Regionalization Era Balakot Phase Amri Phase Hakra Phase Kot Diji Phase	*Regionalization Era* Kachi Phase Kili Gul Muhammad Phase Sheri Khan Tarakai Phase* Kechi Beg Phase Damb Sadaat Phase Nal Phase	*Regionalization Era* Mundigak Phase Helmand Phase
Integration Era Harappan Phase	*Integration Era* Kulli Phase Periano Phase	*Integration Era* Shahr-i Sokhta Phase
Localization Era Punjab Phase Jhukar Phase Rangpur Phase	*Localization Era* Bampur Phase Pirak Phase	*Localization Era* Seistan Phase

*The Ghar-i-Mar (Dupree 1972) and Sheri Khan Tarakai Phases (Khan et al. 1989) were not identified by Shaffer because the excavations are only recently published or not fully analyzed.

(1992), the Indus Valley Tradition includes all human adaptations in this greater Indus region from around 6500 B.C. until 1500 B.C. and later. This Tradition can be subdivided into four Eras and several Phases (Tables 5.1 and 5.2). The Early Food Producing Era (ca. 6500–5000 B.C.), as defined at the site of Mehrgarh, sees the beginning of domesticated plants and animals, as well as the first find of copper in the form of a bead (Jarrige 1983). The Regionalization Era (ca. 5000–2600 B.C.) follows, with the development of distinct agricultural and pastoral-based cultures associated with various specialized crafts, including the melting and working of copper. During the Integration Era, which is represented by the Harappan Phase (2600–1900 B.C.), we see the cultural, economic, and political integration of the vast region defined above. This paper focuses on the state of metal processing during the Harappan Phase.

The Harappan Phase of the Integration Era represents the first urban civilization in southern Asia and the earliest state-level society in the region (Jacobson 1986; Kenoyer 1991; Meadow 1991). Recent studies suggest that the Indus state was composed of several classes of elites who maintained different levels of control over the vast regions of the Indus and Ghaggar-Hakra Valley. The rulers or dominant members in the various cities would have included merchants, ritual specialists, and individuals who controlled resources such as land, livestock, and raw materials. Although these groups may have had different means of control, they shared a common ideology and economic system as represented by seals, ornaments, ceramics, and other artifacts. This ideology would have been shared by occupational specialists and service communities, who appear to have been organized in loosely stratified groups (Kenoyer 1991). Political and economic integration of the cities may have been achieved through the trade and exchange of important socio-ritual status items, many of which would have been produced by specialized artisans using complex pyrotechnologies to manufacture metal objects, agate beads, steatite seals, stoneware bangles, elaborately painted and specialized ceramics, and faience objects (Kenoyer 1992a).

PROBLEMS IN DEFINING THE ORIGINS AND DIFFUSION OF METAL TECHNOLOGIES

The extensive overlapping exchange networks that connected the greater Indus region to the metal resource areas of West Asia, eastern Iran, and Rajasthan make it difficult to determine the role of diffusion in the origins and dispersal of various metal technologies, especially copper metallurgy. The simplistic yet pervasive model that copper-working technology was developed somewhere in West Asia and diffused to adjacent regions such as the greater Indus region (see this volume and Agrawal 1971) is based on assumptions regarding human cultural interaction and the control of knowledge that are not supported by the archaeologi-

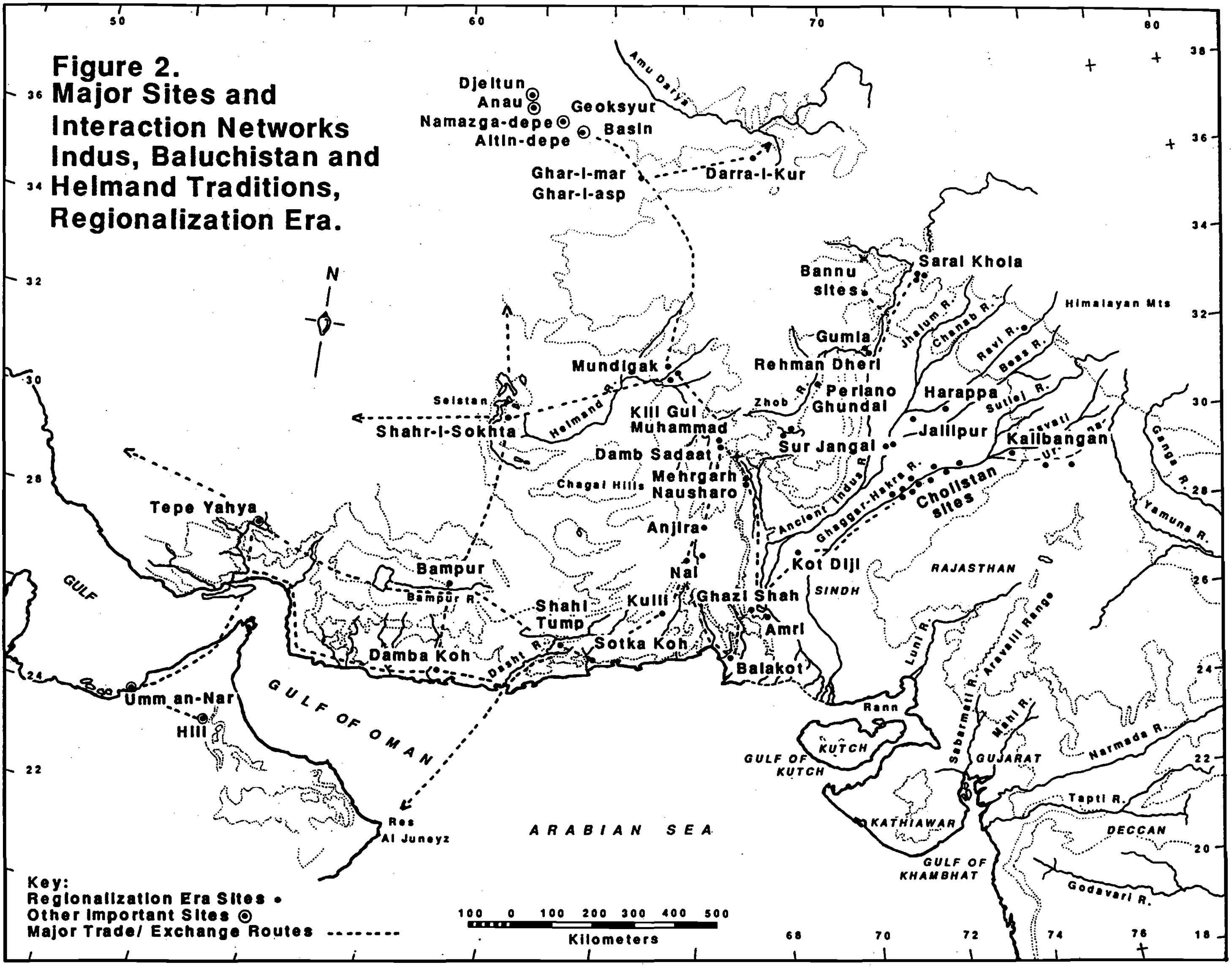

Figure 5.2 *Major sites and interaction networks of the Indus Valley, Baluchistan, and Helmand Traditions, Regionalization Era (drawn by J. M. Kenoyer).*

cal data currently available for study (Kenoyer 1989). Throughout West and South Asia, beginning in the Palaeolithic and continuing through the Neolithic, we find evidence for a familiarity with fire and its effect on various materials. In the Upper Palaeolithic, iron ores were routinely roasted to make pigments (Schmandt-Besserat 1980) and chert was heated to make it more flakable. During the Neolithic and early Chalcolithic, pyrotechnologies included the firing of different types of clays to make ceramics, and the heating of lithic materials to enhance color, workability, and/or hardness. Although we have no direct evidence for the earliest metal procurement techniques, it is not unlikely that fire setting was being used to extract native copper lumps and granules that could then be further processed by hammering and annealing. The many different pyrotechnologies in practice make it unreasonable to assume that the discovery of metal smelting and melting was simply an accident, and not the result of intentional experimentation and innovation.

For the greater Indus region, the evidence from Mehrgarh and other early sites demonstrates that the pyrotechnological and metallurgical innovations of the Neolithic and Chalcolithic set the technological background for the metallurgical traditions of the Harappan Phase (Jarrige 1985b; Jarrige and Lechevallier 1979). It is clear that the origin and development of copper metal technology occurred *in conjunction with* developments in other technologies. At the site of Mehrgarh during the fifth to fourth millennium B.C., changes were occurring simultaneously in metal production, ceramic production, the drilling of hard stone, production of fired and glazed steatite beads, and shell working. A decrease in the use of certain types of bone and stone tools is also seen at this time (Jarrige 1983). The transitions seen at Mehrgarh between the Neolithic and the Chalcolithic have numerous parallels with similar changes in the highlands of Baluchistan and other regions of the greater Indus region (Fig. 5.2). Sites such as Nausharo (Jarrige 1990), Balakot (Dales 1979), Ghazi Shah (Flam 1993), Rehman Dheri (Durrani 1988), and Kalibangan (Agrawala 1984a; Lal and Thapar 1967) all show evidence for the use of copper in the period prior to the Harappan Phase, along with changes in other technologies.

Throughout southern and northern Baluchistan, Afghanistan, and Rajasthan, the combined resources of metal ores and fuel were available to communities of sedentary agriculturalists and semi-nomadic pastoralists. Such communities were undoubtedly familiar with the properties of ores and how to extract the metal long before it became an important economic process. Furthermore, it is highly unlikely that the process for smelting ores and processing copper was discovered only in one isolated area, since there is increasing evidence that the highland communities of West and South Asia were connected by numerous overlapping networks, both economic and social (Kenoyer 1991).

Since there are many regions of West Asia and South Asia that are rich in both metal ores and fuel, it is quite likely that regional styles of pyrotechnologies evolved according to the physical characteristics of locally available ores. Over time, in adjacent regions such as northern and southern Baluchistan, the regional styles that were less effective and/or practiced by sociopolitically weaker communities would have been eliminated or absorbed through competition. More widely separated regions such as Baluchistan and Rajasthan, which are divided by the Indus Valley flood plains, may have retained their styles and continued to function parallel to each other for a longer period of time. Future studies of regional styles of metal processing and use may provide valuable information for understanding the development of a possible Indus "technological style" or multiple "technological styles" (see Lechtman and Steinberg 1979).

STUDIES OF HARAPPAN PHASE METAL OBJECTS: CATALOGUES AND TECHNICAL ANALYSES

The metal objects have been one of the most neglected of the Indus artifact classes, even though the first technological analyses were carried out in the 1920s and '30s. Although numerous metal objects have been recovered from Harappan Phase sites in Pakistan and western India, relatively few of these have been subjected to metallurgical or compositional analyses. In fact, few of the excavated collections have even been completely published.

CATALOGUES

The most extensive published collections of metal objects are those from the early excavations at the Harappan Phase sites of Mohenjo-daro (Mackay 1931, 1938; Marshall 1931), Harappa (Vats 1940), and Chanhu-daro (Mackay 1943), all in the Indus Valley (Fig. 5.3). The metals from excavations at Rangpur (Rao 1963) and Lothal (Rao 1979, 1985) provide information on the metals of Harappan Phase Gujarat. Information on metal use in the greater Indus region prior to the Harappan Phase comes primarily from the site of Mehrgarh (Jarrige and Lechevallier 1979).

For the Harappan Phase, the best references are the catalogues of metal objects compiled by Yule (Yule 1985a, 1985b), providing descriptions and illustrations of the copper objects from Mohenjo-daro,

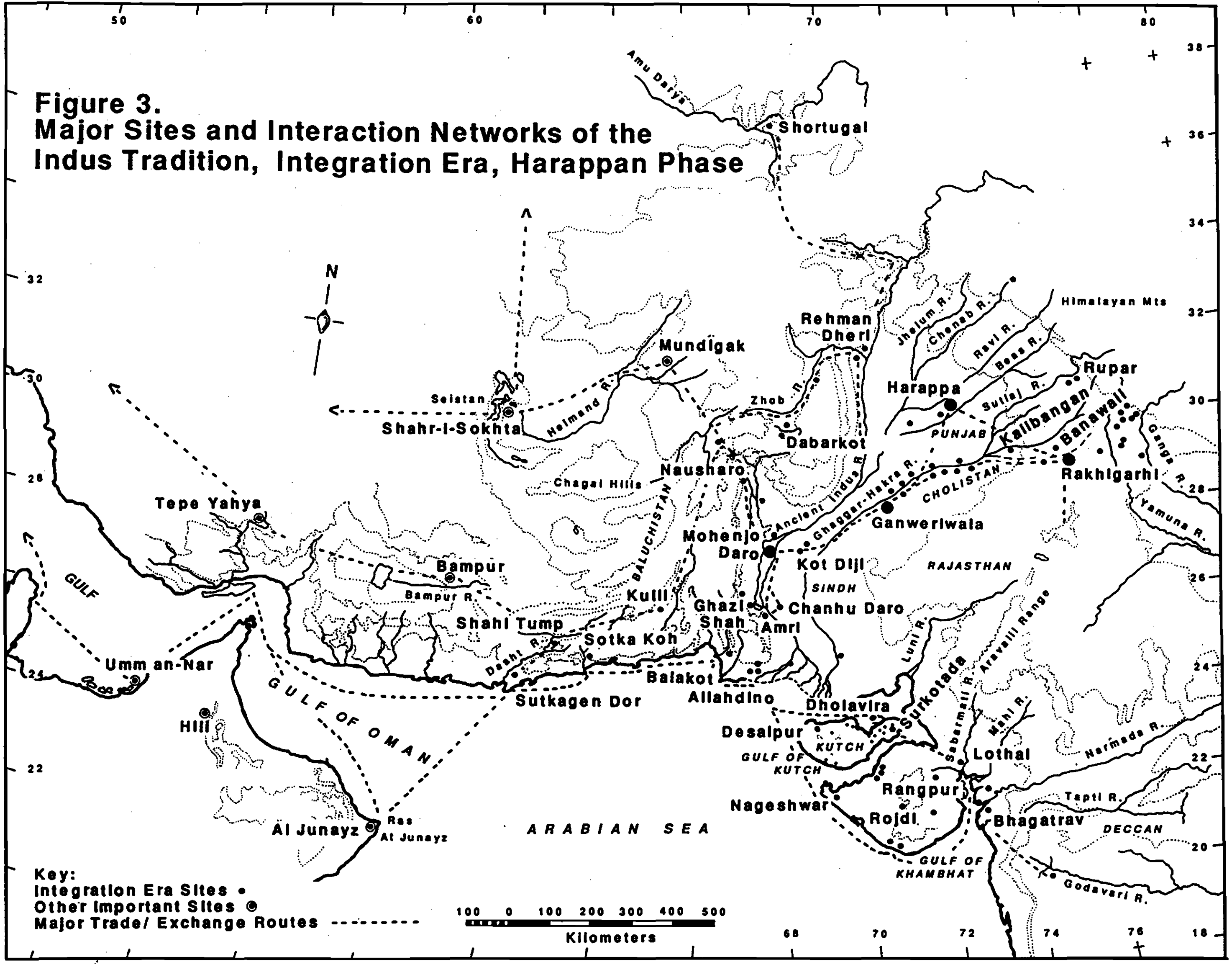

Figure 5.3 *Major sites and interaction networks of the Indus Valley Tradition, Integration Era, Harappan Phase (drawn by J. M. Kenoyer).*

Harappa, Lothal, and several other sites, including many objects previously unpublished. (Note, however, that these catalogues do not include the objects from Chanhu-daro in the Museum of Fine Arts, Boston.) Herman (1984) has also compiled a catalogue of metal objects from the published Harappan Phase sites, which is particularly useful for its assessment of the stratigraphic relationships of the objects. Haquet (1994) is currently preparing a data base and typology of metal objects from Mehrgarh, Nausharo, and Mundigak, which will be the first catalogue to present metal objects from well-defined stratigraphic contexts ranging from the Regionalization through the Integration Eras.

Full publication of the metal objects from a number of recently excavated sites are still needed, however, before we can confidently discuss changes in Indus Valley Tradition metals over time and in different regions. This includes the metals from recent excavations at Harappa by the Harappa Archaeological Research Project (originally the University of California-Berkeley Expedition), which we hope will be studied within the next year or two. Other important assemblages awaiting study are from the site of Kalibangan (Agrawala 1984a), a site key to our understanding of the northern regions of Rajasthan and Haryana; from Ganeshwar and related sites in Rajasthan, which are very near to the Rajasthani copper mines and extremely rich in copper metal objects (Agrawala 1984a, 1984b; Kumar 1986); and from Ahar and related sites in southeastern Rajastan, where evidence of copper processing has been found (summarized in Hooja 1988; Hooja and Kumar 1995).

We look forward to more detailed publications on the contexts, elemental compositions, and methods of production for the copper objects from Rajasthan. These materials are extremely important for a more complete understanding of the metallurgy of the greater Indus region, particularly its ore sources. They will also provide comparative information about the distinct metallurgical styles and approaches of the Rajasthani cultures that were apparently contemporaneous with the Harappan Phase of the Indus Valley Tradition. (It should be noted that the dating of most of these sites is problematical, as there are very few radiocarbon dates and the relations between the various ceramic types are still highly debated [Kenoyer 1991; Shaffer 1992]. The metal objects themselves have not cleared up the question of chronological affinities because many of the "type" markers are in fact distributed over wide regions and time periods, for example, the double spiral-headed pins, celts, and barbed arrowheads.)

Metal objects from the Localization Era (Late Harappan) are represented by the assemblage of objects from Daimabad (Sali 1986). Unfortunately, until further discoveries are made at the site, the dating and provenience of the metal objects will remain controversial. Consequently, we will not include them in this study. Yule (1985c) has compiled a catalogue of the Copper Hoard objects from India, thought to be roughly contemporaneous with or slightly later than the Harappan Phase. Finally, a summary discussion of metallurgy in the subcontinent has been presented by Kuppuram (1989) which focuses primarily on the historic rather than the prehistoric period.

CHEMICAL AND PHYSICAL ANALYSES

The vast majority of analyzed metal objects come from the major urban sites of Mohenjo-daro, Harappa, and Lothal, and date to the Harappan Phase, between 2600 and 1900 B.C. (Fig. 5.3). It has been impossible to ascertain the total number of chemical and physical analyses conducted to date. Since many of the published tables do not list the field or identification numbers of the object sampled, it has been impossible to determine if an object has been sampled and reported more than once (e.g., Agrawal 1971:tables 18 and 19). Consequently, in our summary tables of chemical analyses (Appendices A and B), we only include analyses reported with field or identification numbers for the object.

Chemical and some physical analyses were done on metal objects from the early excavations at Harappa and Mohenjo-daro (Desch 1931; SanaUllah 1931, 1940; Wraight 1940; Hamid, SanaUllah, Pascoe, and Desch and Carey reported in Mackay 1938). Agrawal's (1971) comprehensive treatise on South Asian metalworking is still of major importance for its critical summary of the earlier published material and many previously unpublished chemical analyses; however, many of his interpretations need to be revised due to the availability of new data from sites such as Mehrgarh (Jarrige and Lechevallier 1979) and Lothal (Rao 1979, 1985), particularly the chemical analyses done by Lal (1985) on material from Lothal.

The most common metal objects were made of copper or copper alloys. SanaUllah (1931:485) defined four categories of copper metal objects at the site of Mohenjo-daro: (1) "lumps" of crude copper directly derived from smelting and rich in sulfur (these are ingots, based on the size and shape description); (2) "refined" copper (i.e., specimens containing few non-copper elements—note that one such specimen is also a "lump" or ingot, however); (3) arsenical copper (SanaUllah's "copper-arsenic alloy"); and (4) tin bronze. At the present no object made from native copper has been reported from an Indus Valley Tradition site.

Other processed metals that have been reported include lead, gold, silver, and electrum. Although there are copper objects with iron components from contemporaneous sites in Baluchistan (Shaffer 1984), no confirmed iron objects have been reported from Harappan Phase sites in the greater Indus region. Finally, no true brass objects (copper-zinc alloy) have been identified from any Harappan sites (but see Other Metals section below).

A serious problem is that most of the published analytical studies of Indus Valley Tradition metals do not outline the specific methods of analysis, so we do not know if the results are really comparable. For example, the very large differences in percent oxygen and acid insoluble materials between metal objects from Harappa and Mohenjo-daro (tested by SanaUllah or Hamid) and from Lothal (tested by Lal) may be due to analytical techniques. Also, we can seldom tell if an element was truly absent from a collection of artifacts, or if no tests were done to determine its presence, such as zinc at Mohenjo-daro (Appendix A). An additional discrepancy factor is introduced by the great disparity in the preservation of metal in different objects and at different sites. For example, many of the objects analyzed from Lothal were less well preserved than those from Harappa and Mohenjo-daro.

Fortunately, additional analytical studies of archaeological materials are currently underway. The compositional and metallographic analysis of recently excavated copper metal objects from Harappa is being conducted at the University of Pennsylvania Museum, MASCA laboratories under the direction of Dr. V. Pigott (Pigott et al. 1989), and a large number of copper metal objects from Chanhu-daro are currently being studied at the Museum of Fine Arts, Boston, under the direction of Dr. Thomas Beale (pers. comm.).

POTENTIAL ORE SOURCES FOR HARAPPAN PHASE METALS

The studies which have been done in the various source areas are discussed by metal type in the sections below. Most of the objects analyzed from sites of the Indus Valley Tradition have been finished copper metal objects, and few analyses have been done of other metals, or of copper ores, slags, metal prills on crucibles, or ingots. The systematic comparison of Indus Valley Tradition copper with copper ores from the variety of sources available has been sorely neglected. This is due in part to the lack of archaeological samples of ores, and in part because many of the ore mineral deposits potentially used in the past are located in border areas or tribal regions that are not easily accessible to modern researchers (e.g., Baluchistan).

Only a small number of actual mineral fragments have been reported from Harappan Phase sites. At the site of Mohenjo-daro, "a quantity of copper ore" was found in a pit in DK area (Mackay 1938:54), and at Harappa, small fragments of chrysocolla and chalcopyrite have been recovered (Dales and Kenoyer 1990; Kenoyer, on-going research). In addition to these copper minerals, a few fragments of hematite, löllingite (arsenic and iron), antimony, cinnabar (sulfide of mercury), cerussite (carbonate of lead), galena, and an unidentified type of lead ore (recently recovered from excavations at Harappa) have been recovered from these two sites as well (Mackay 1938; Marshall 1931; SanaUllah 1931; Vats 1940). It is possible that some of these metallic minerals may have been used in melting and alloying processes, but it is just as likely that they were used for other purposes, e.g., as colorants, cosmetics, medicines, poisons, etc., since the great majority were not found in association with metal processing debris.

COPPER; ARSENICAL COPPER; TIN BRONZE

One of the earliest sourcing studies for Harappan Phase copper was the analysis of material from Mohenjo-daro by Desch (Desch 1931; Desch and Carey reported in Mackay 1938), but Agrawal's (1971) examination of the data and methodology clearly demonstrated the need for new analyses. Agrawal (1971, 1984) suggested that Indus peoples used native copper, oxide ores, and also sulfide ores, at least for the copper objects at Harappa and Mohenjo-daro. This interpretation is based on the percentage of elements found in finished objects, using a method presented by Freidmann et al. in 1966 (Agrawal 1971:tables 14 and 15; 1984). However, given the current debates about sourcing (see this volume and Tylecote 1980), Agrawal's suggestions based on this method may not be valid. As noted above, no native copper fragments or objects have been reported from any Indus Valley Tradition site.

Relatively pure copper objects have been found at all sites in the greater Indus region where copper metal objects have been analyzed, and they comprise the largest percentage of objects (Appendices A and B). (Note that these appendices do not include Desch's work, which only tested for a few elements, nor the analyzed objects without identification information in Agrawal 1971.) Depending on how one defines alloys, tin bronzes are the second largest category and arsenical coppers the third. Out of the 129 copper metal objects that we have tabulated, 36 objects have 1% or more tin, 20 objects have approximately 1% or more arsenic, and 6 of these objects have 1% or more of both tin and arsenic (Appendix B—objects with both tin and arsenic are listed in both tables). It should be emphasized that the analyses of these objects by different scholars are not always comparable, but in general terms the numbers can be useful.

It is important to note that different researchers have used different standards to define alloying (see Stech, this volume, for an excellent discussion of alloying). Agrawal (1971:150, 168) states that more than 1% arsenic or tin constitutes intentional alloying. However, SanaUllah (1931) defined an intentional alloy as containing from 2 to 4.5% arsenic or 4.5 to 13% tin. Some scholars favor the value of 5% tin to qualify as an intentional tin bronze used for functional purposes (Hall and Steadman 1991). This functional criterion ignores the changes in color that occur with the addition of less than 5% tin, and color or ability to resist oxidation may have been more important than hardness or strength for the early metalsmiths and consumers (Lal 1985:653).

Harappan Phase copper alloys are especially difficult to define at present, given the lack of information on copper ore composition and processing technology. In this paper we will follow Agrawal in defining metal objects with 1% or more tin or arsenic as being alloyed. In the lower percentages, however, it is not possible to determine if the tin or arsenic alloy is the result of intentional manufacture or simply a result of the natural ore compositions (e.g., see Tylecote 1980). Some scholars suggest that regardless of the arsenic content, arsenical copper was derived primarily from arsenical copper ores (Pigott 1989).

Morphologically similar objects found at Harappan Phase sites are made from relatively pure copper, arsenical copper, and tin bronze. Possible patterns of alloying are obscured by the lack of a large sample, the absence of any sampling methodology, and the inconsistent manner in which samples from different sites have been studied. It should be noted that most of the objects analyzed were excavated before the introduction of stratigraphic controls, and the variations may have some chronological significance. Another obvious factor contributing to the apparent lack of consistency in alloying is the re-melting of a mixture of metal objects. The recycling of copper/bronze objects is indicated by the numerous caches of broken tools and metal scraps recovered from all of the major sites.

Given these problems with our sample, we prefer to discuss the use of copper and copper alloys as a single group, rather than create artificial divisions based on elemental composition. At this point in our study it appears that Indus metalsmiths did not follow a rigid system of alloying related to specific artifact categories. Furthermore, the lack of patterning seems to be the norm during this period throughout West and South Asia. For example Pigott et al. (1982:231) note that no apparent correlations exist between artifact categories and elemental compositions during any period at Tepe Hissar.

We may be unable to define patterns of alloying because the Indus metalsmiths used alloying for a variety of purposes—functional, aesthetic, ritual, and/or simply expedient. For example, the addition of tin to copper may have been done to increase strength and hardness for some objects, but may have been used to produce particular colors or fulfill ritual requirements in other objects. Or a mixture of alloyed scrap metals may have been the material available for a smith's selection—expediency is difficult to model archaeologically, but too common ethnographically to ignore. (See Lahiri [1993] for an excellent discussion of the variety of reasons for alloying in modern and historic South Asia.) This multiplicity of choice is hinted at by the types of finished objects with high tin contents from Harappan Phase sites. Two categories of objects are high in tin: tools or weapons such as chisels, daggers, and some "celts"; and ornaments such as bangles (Appendix B). When faced with the choice of desired characteristics, including hardness, color, shape, etc., the Indus metalsmiths may have chosen between a number of alternative means of producing a given result. For example, in some instances they may have relied on physical modifications such as forging to harden metal, while in other situations they may have chosen to produce a harder metal by modifying the composition of the metal through alloying. These choices would depend in part on the manufacturing techniques used, and on the stage of metal production (smelting, melting, casting of blanks, etc.) at which the end product was first visualized.

While there is no distinct pattern of alloying relating to specific artifact categories, there does seem to be a pattern in metallurgical traditions on a regional scale. This will be discussed in the Arsenical Copper and Tin Bronze sections below, as these regional patterns are most evident in the varying amount of arsenic in copper metal objects from different parts of the greater Indus region. These compositional differences probably result from the use of more than one copper source by the Indus peoples, rather than from different traditions of alloy use. Therefore, before further discussing copper alloys, the potential source areas for copper are described below, along with any evidence for their exploitation during the Harappan Phase.

COPPER SOURCES

There are three, possibly four, major regions that could have supplied the copper ores or processed metal used by the Indus metalsmiths (Fig. 5.1). The first is the combined area of Baluchistan and Afghanistan, to the west of the Indus Valley, which extends from highland Badakhshan to coastal Makran. This extensive region contains numerous copper deposits and appears to have the earliest evidence for copper processing. A second potential source of copper is the inland mountain range of modern Oman on the other side of the Arabian Sea. A third region, to the east of the Indus and Ghaggar-Hakra Valley, comprises the north-south oriented Aravalli mountain range of Rajasthan. Numerous concentrations of copper ores are found in these ranges along with zinc, lead, and silver ores. A fourth potential source may have been eastern Iran, but so far there is no clear indication that the Indus metalsmiths used Iranian ores or metal, so this source is not discussed here.

BALUCHISTAN-AFGHANISTAN

In the highland plateau west of the Indus Valley flood plains, numerous copper-working areas have been reported over the years, but the most impressive is the region of southern Afghan Seistan, often referred to as Gardan-i-Reg (Dales and Flam 1969; Fairservis 1952, 1961). Here in the windswept wastes of the Helmand Basin there are vast areas of exposed copper slag mixed with pottery and other cultural debris. Dales (1992) mentions that some of this slag was analyzed and contained 14% copper, and that the gold assay was also quite high, but most of the samples have yet to be studied. The copper ores processed at Gardan-i-Reg are assumed to be from nearby deposits, but no detailed report has been published on the mining areas.

The ceramics and other cultural material associated with the copper smelting debris of Gardan-i-Reg correspond to the Helmand Tradition (Shaffer 1992) at the sites of Mundigak, Shahr-i Sokhta (Period III), and Tepe Rud-e Biyaban (Periods II and III). The dating of the ceramics is disputed and while some scholars feel that they fall between approximately 2500–2400 B.C. (M. Vidale, pers. comm.), others suggest that they date to the period prior to 2600 B.C. (J.-F. Jarrige, pers. comm.). The copper smelting activity would be basically contemporaneous with either the late Regionalization Era ("Early Harappan") or the Integration Era, Harappan Phase of the Indus Valley Tradition (Tables 5.1 and 5.2). The occasional discovery of Indus Valley Tradition artifacts at sites in Baluchistan and Afghanistan indicates that there was movement of people and goods between this important mineral resource area and the greater Indus region.

Copper and iron ores that are rich in arsenic are found in limited distributions in Baluchistan (Agrawal 1971; SanaUllah 1940) and the Iranian plateau (Pigott 1989), but it is not clear if these ores were being exploited continuously or only at specific chronological periods. For example, Pigott et al. (1982) note that the arsenic and lead components in copper objects increase in the later periods at Tepe Hissar in Iran (Periods II and III: ca. 3600 to 1700 B.C.; Dyson and Remsen 1989:108–109) and suggest that this increase is due to selection by the metalsmiths. On the other hand this pattern could be the result of changing access to copper ores due to political or trade alliances, and not an intentional act on the part of metalsmiths.

OMAN

Major connections between Oman and the greater Indus region may be inferred from the presence of Harappan Phase artifacts and possible short-term Harappan Phase settlements in Oman (Cleuziou 1984, 1989; Cleuziou and Tosi 1989; Tosi 1982; Potts 1990), combined with the presence of shells from Oman at Indus Valley Tradition sites (Kenoyer 1983). By taking advantage of the monsoon winds, Indus or other maritime traders may have been marketing Arabian copper in the Indus Valley, Baluchistan, and Gujarat.

Much research has been conducted in the important copper mining regions of Oman and Iranian Baluchistan (this volume and Berthoud and Cleuziou 1983; Frifelt 1991; Hauptmann 1985; Hauptmann and Weisgerber 1980a, 1980b; Weisgerber 1981, 1983, 1984; Weisgerber and Yule 1989). Omani copper ores are similar to those of the Aravalli region of Rajasthan (below) in that they have little or no arsenic and have relatively high quantities of nickel, cobalt, and vanadium (Agrawal 1971:152, table 20). They are different from Iranian ores in that they have higher quantities of nickel, cobalt, vanadium, and chromium (Berthoud and Cleuziou 1983). However, in light of the use of arsenic impurities as a sourcing marker by Indus researchers (see below), it is important to note that copper slags and objects containing arsenic *have* been reported from copper processing sites in Oman (Hauptmann and Weisgerber 1980b:135, 137). As is discussed in the section on Arsenical Copper below, the sites in the Indus Valley flood plains may have imported Omani copper, but probably drew on at least one other source as well.

RAJASTHAN

The copper deposits in Rajasthan and the Aravalli mountain ranges have been discussed by SanaUllah (1940), Hegde (1965, 1969), Agrawal (1971, 1984), Asthana (1982), Agrawala (1984a), Hegde and Ericson (1985), Rao (1985), and Hooja (1988:38), but only a few analyses of ore samples have actually been published. Hegde and Ericson (1985:61) also present results from lead isotope analyses of copper ores from eight sites in the Aravallis.

Samples of ores from mines in Rajasthan (Khetri and Alwar), Bihar (Singhbhum), and Afghanistan were examined by SanaUllah, and all contained both nickel and arsenic. SanaUllah (1940:379) proposed that the Rajasthan (Aravalli) mines were the source for most of the metal used in the greater Indus region, because of their relative proximity to Mohenjo-daro and Harappa. SanaUllah did not publish his analyses of Aravalli ores, but Hegde (1969:227) notes that his "sample of Chalco-pyrite obtained from Khetri showed 4.28% of arsenic." In contrast, copper ore impurities from the region of Khetri as reported by the Director, Indian Bureau of Mines, to Rao (1985) are as follows:

Lead	Generally occurs as traces, highest percentage noted is 0.18%
Zinc	Generally occurs in the second decimal, highest percentage noted is 0.18%
Arsenic	Generally occurs in the fourth decimal, highest percentage noted is 0.06%
Cobalt	Around 0.01%
Nickel	Around 0.05%
Iron	15 to 20%

and Agrawal's (1971:table 20, fac. p. 152) analyses of chalcopyrite ores from Khetri (in Rajasthan) and Singhbhum (in Bihar) yielded less than 0.05% arsenic. The question of arsenic in the Aravalli copper deposits is discussed further in the following section.

At this point there is no direct evidence for Harappan Phase mines or smelting sites in the Aravalli copper resource areas, even though these areas have been explored by numerous scholars. The earliest well-dated copper smelting slags are from levels of Ahar dated to the early second millennium B.C. (Sankalia et al. 1969:10; Allchin and Allchin 1982:262; Hegde and Ericson 1985:60). Although Hegde and Ericson (1985) assumed that the smelting furnaces they found in surface surveys in the Aravallis are from the third millennium B.C., these furnaces have not been dated, either by radiocarbon or by associated artifacts. (This is not meant to detract from this very important survey work, but to clarify the dating problems.) If these sources were actually being exploited as early as the third millennium B.C., it is possible that the Indus peoples themselves were not involved in the mining and smelting. These activities may have been undertaken by local communities of the Aravalli region. The Ganeshwar-Jodhpura Culture in northern Rajasthan or the Ahar Culture in southeastern Rajasthan may in fact be some of these groups (Agrawala 1984b; Hooja and Kumar 1995).

However, many Harappan Phase sites *have* been reported in the nearby desert region of modern Cholistan, Pakistan, along the now dry bed of the Ghaggar-Hakra River (Mughal 1980) (Figs. 5.1 and 5.3). This region is close to the copper sources of Rajasthan, and Sir Aurel Stein recovered a copper ingot from Siddhuwala Ther, near Derawar. Many of the sites discovered by Mughal have kilns that were apparently used for "firing pottery, clay objects, bricks and perhaps smelting of copper" (Mughal 1980:96). However, there is no report of ores, slag heaps, or smelting furnaces, which would be required before classifying any of these as copper smelting sites.

With the availability of at least three different major source areas in easy reach, it is not unlikely that the larger urban centers used copper from more than one source over the 700 years of the Harappan Phase. Only future systematic studies will provide the necessary data to elucidate these sources, and the analyses of copper ores, ingots, slags, and metal prills on crucibles are particularly needed. However, the regional patterns of arsenic presence/absence already provide some evidence for the exploitation of more than one source of copper metal.

ARSENICAL COPPER AND SOURCES

Most of the discussion of sourcing of Harappan Phase copper metal has revolved around the presence or absence of arsenic, since it is usually assumed to be an impurity rather than a deliberate alloy, and thus indicative of the source of the copper.

At the Indus Valley urban centers of Mohenjo-daro and Harappa, the great majority of the objects that were analyzed contain at least trace amounts of arsenic, usually less than 1% (Appendices A and B; as noted, these do not include work by Desch or Agrawal). The overall composition of the copper items from the smaller Gujarati sites of Lothal and Rangpur is very different (Appendices A and B). While all four sites contain artifacts with variable amounts of nickel and iron, arsenic is noticeably absent at Lothal and Rangpur (Lal 1985; Rao 1963).

Thus, it appears that the two major cities situated in the actual Indus Valley flood plains were using copper derived from sources containing significant amounts of arsenic, or possibly alloying to produce arsenical copper. These sites were part of the major trade and exchange networks connecting the western highlands, the central plains, the eastern riverine areas, and the coasts of the Indian Ocean. The most probable source areas for arsenical copper ores are the mines of Baluchistan and Afghanistan, or possibly even eastern Iran. The Indus Valley cities may also have used copper from the Aravalli or Oman sources, and mixed these with arsenical copper objects through remelting or recycling, as these sources are usually represented as containing little or no arsenic (but see discussion of source areas, above).

The absence of arsenic from the finished objects at Lothal and Rangpur could be taken as circumstantial evidence for the exploitation of the Aravalli copper ores by the Indus peoples in Gujarat. However, Rao (1985:524) insists that the traces of arsenic in the Aravalli ores show that the arsenic-free Rangpur and Lothal copper was not coming from Rajasthan, but rather from Oman. Such a fine distinction is hard to support, given the values of less than 0.06% arsenic in modern Aravalli ores that Rao himself quotes, as well as the evidence for traces of arsenic in some Omani ores (above, Hauptmann and Weisgerber 1980b).

Data from sites in Rajasthan itself complicate rather than clarify the issue. The site of Ganeshwar is close to the Aravalli ore sources, within 10 to 15 km of copper mining areas at Ahirwala and only 75 km from the Khetri mines, and we might assume that copper objects from the site were being made from local ores. A single copper celt and a number of copper arrowheads (exact quantity unknown) from the site of Ganeshwar have been analyzed by the Geological Survey of India, Jaipur, with the following compositions reported: (1) for the celt: Cu 97%; Ag 0.2; Pb 1.0; As 0.3; Sn 0.01; Ni 0.6; and (2) for the arrowhead(s) (it is unclear whether this is an average of several samples, or the result from a single arrowhead): Cu 96.5%; Ag 0.3; Pb 0.03; As 1.0; Sn 0.2; Ni 0.04; Zn 0.25; Fe 0.2 (Agrawala 1984a; Agrawala and Kumar 1982). At least in these objects, tin and arsenic are present. These figures match the higher arsenic levels in the copper used at Harappa and Mohenjo-daro, rather than the arsenic-free copper used at Lothal and Rangpur (Appendices A and B).

We considered the possibility that arsenic was deliberately added, although this seems unlikely. Actual arsenical ores may have been traded to the smelting areas or even to the major cities of the greater Indus region for use in copper metallurgy. However, the only evidence for such arsenical ores are a few fragments of löllingite or leucopyrite found at both Mohenjo-daro and Harappa. SanaUllah (1931:690) notes that the fragments from Mohenjo-daro were heated, a necessary step to release arsenic, although he suggests the arsenic was used for medicines or poisons rather than copper alloying. In addition, the presence/absence pattern of arsenic in arsenical copper objects holds for the tin bronze objects from Harappan Phase sites as well. That is, the tin bronzes from Harappa and Mohenjo-daro often have high percentages of arsenic, while those from Lothal and Rangpur do not (Appendix B). This further supports the idea that the arsenic is an impurity in the copper from one of several sources, and was *not* intentionally added as an alloy in some parts of the Indus region.

We have no definite conclusions about the source(s) for the arsenical copper at this point; the possibilities are varied, since the data base is small. However, we cannot rule out the possibility that arsenical copper deposits within the Aravalli copper ore beds have been mined out, and previously contained ores that could have supplied the arsenical copper used at Mohenjo-daro, Harappa, and Ganeshwar.

In contrast, it is clear that Lothal, Rangpur, and probably most of the other sites in Gujarat were using copper derived from sources with little or no arsenic. Perhaps after all Rao was correct (although not for the reasons he cites), and the Gujarati sites imported copper from Oman rather than Rajasthan. It is significant that the sites in Gujarat were not consumers of the arsenical copper used by the major cities in the Indus Valley itself, and it will be interesting to see what the copper objects from major Saurashtran urban sites such as Dholavira are like. Probably the Gujarati sites were participating in different trade networks, dealing with peoples in Rajasthan and/or Oman, but not Baluchistan. The Indus Valley Tradition peoples in Gujarat would thus have used other techniques for making hard tools or decorative ornaments without resorting to arsenical copper. One such alternative would be the use of tin bronzes, discussed below.

TIN BRONZE AND SOURCES

Unlike lead and even arsenic, there are no known tin objects or tin minerals from Harappan Phase sites. Tin bronzes were definitely used by the Indus peoples, however, as is seen in Appendices A and B. If tin was being added as a separate metal to form copper alloys, it was carefully conserved and has not yet been discovered in the archaeological record. However, it is also possible that previously alloyed tin bronze ingots and scrap were traded to Indus peoples, rather than tin being traded as a separate metal. Future analyses of ingots and slags at Harappan Phase sites may help answer this question; for example, one of the copper "lumps" (ingots) from Mohenjo-daro analyzed by SanaUllah (1931:485) contained 12.13% tin. This could, of course, be a secondary ingot; the other four "lumps" analyzed all contained little if any tin, and considerably more sulfur (Appendix A).

From the large site of Mohenjo-daro only 24 analyses of copper metal objects have been published, and of these, 12 objects have more than 1% tin (Appendices A and B). At the present time 9 out of 29 copper metal objects analyzed from Harappa contain more than 1% tin. At Lothal, 71 out of the total of 1500 (metal?) objects recovered were analyzed (Lal 1985); this is a relatively large sample for an Indus site. Of the 64 copper metal objects published, few are alloyed with tin, and only 8 have more than 1% tin. Twelve Harappan Phase copper metal objects from Rangpur were analyzed, out of a total of less than 25 recovered. However, all of these analyzed samples from Rangpur have some trace of tin, and 7 out of the 12 objects contain more than 1% tin (Agrawal 1971; Rao 1963).

As discussed above, the fact that the tin bronzes from Lothal and Rangpur contain little or no arsenic indicates that these tin bronzes were being made locally, or imported from sources that were different from those supplying Harappa and Mohenjo-daro (Appendices A and B).

The major sources of tin used during the Harappan Phase probably derive from what is now modern Afghanistan. Some alluvial deposits are reported in western Afghanistan in the Sarkar Valley south of Herat (Berthoud and Cleuziou 1983) and major deposits occur in the central regions north of Kandahar (Pigott 1989; Stech and Pigott 1986; see Pigott, this volume, for more discussion). Other tin deposits occur in northern Afghanistan near the ancient lapis lazuli mines. It is unclear who was controlling the access to the tin resources during the third millennium B.C., but the largest settlements of the Helmand Tradition, Mundigak and Shahr-i Sokhta, are located at strategic points along the trade routes that would have connected these resource areas to the consumers in Mesopotamia. The Harappan Phase site of Shortugai is located at a northern source and may reflect a competitive situation where the Indus peoples chose to develop their own mining and distribution rather than rely on alliances with the sites of Mundigak or Shahr-i Sokhta. However, it is not clear if Shortugai was indeed a trading settlement for *all* of the different available minerals (Francfort 1989). Lapis lazuli and gold working is evidenced from the excavated materials, but there is no clear evidence for the processing of either copper or tin.

It is not unlikely that there was some overland trade of tin to Mesopotamia from northern Afghanistan through northern Iran and from Seistan through southeastern Iran (Moorey 1994:298–299). However, Mesopotamian texts sometimes refer to Meluhha as being a supplier of tin (Berthoud and Cleuziou 1983; Sollberger 1970) and this may indicate that some of the trade was conducted via the Indus Valley or along the Makran coast.

To interject a final note of caution, although the differences in copper alloy compositions between the Indus Valley sites and the Gujarat region sites appear quite striking, more conclusive interpretations must await a larger archaeological sample, further analyses of a wider range of elements, and comparative studies of ores, ingots, and slags.

LEAD

Numerous lead objects have been found at Harappan Phase sites and it is clear that lead was used as a separate metal. Small masses of metallic lead were found in the excavations at Chanhu-daro and a number of lead objects have been reported from Mohenjo-daro and Harappa (Mackay 1938, 1943; Marshall 1931; Vats 1940). One object from Mohenjo-daro described as a "net-sinker" (Marshall 1931:464) has a rough convex surface that appears to have been cast in sand. This object has recently been examined by Kenoyer and appears to be a plano-convex disc-shaped lead ingot. There is a perforation in the center and a lateral perforation that extends across part of the flat surface. Other forms of lead objects include vessels, such as a lead dish (Mackay 1938:pl. CXXVIII, 21), lead cones, and so-called "plumb-bobs" (Marshall 1931). Another use for lead is seen in the form of a rivet used to fill a hole in the bottom of a shell ladle (Dales and Kenoyer 1990). Lead may have been deliberately added to a few copper objects (see Appendices A and B) and may have been important for casting, as the addition of lead causes molten copper to flow more easily.

One lump of lead from Mohenjo-daro analyzed by Desch (reported in Mackay 1938:600) was composed of 99.7% lead and 0.15% copper and had traces of silver. The ores used to make Indus Valley Tradition lead could have been cerussite (lead carbonate) or galena, which is found in many regions of Baluchistan and Rajasthan (e.g., Ajmer) (Pascoe 1931). Craddock et al. (1989) describe in detail the lead, silver, and zinc ores of the Aravallis, in Rajasthan. (See Silver section below.) Cerussite was found at Mohenjo-daro, and a footnote mentions that powdered cerussite was found in a faience vessel at Harappa (SanaUllah 1931:691). Several fragments of what appear to be galena have been recovered from recent excavations at Harappa, along with an unidentified variety of lead ore (possibly lead and arsenic combined) (Griffin and Fenn in Meadow and Kenoyer 1992). Finally, cerussite and lead slag have been reported from Area D at the site of Nal in Baluchistan (Hargreaves 1929; Agrawal 1971:15). This area also has evidence for burned structures and it will be important to determine if the slags represent intentional production or accidental burning of lead minerals used for cosmetic or other purposes.

However, neither of the lead objects analyzed by Lal (1985:656) from Lothal contained silver, copper, iron, tin, or zinc: (1) lead piece 4280 contained 91.42% Pb, traces of Ni, 2.2% acid insoluble residues, and 6.38% oxygen (by difference); and (2) object 10092 contained 99.54% Pb, and 0.46% oxygen (by difference).

SILVER

Silver objects are not uncommon at Harappan Phase sites and practically every major excavated site has objects made of this metal. Silver was used primarily to make vessels that were similar to copper metal or ceramic forms. Silver ornaments are also quite common and include beads, bangles, and rings, as well as fillets and perforated discs. Marshall (1931) claims that silver objects were more common than gold, in contrast to Mesopotamia or Egypt, where silver was rarer. Asthana (1982:276) also notes that silver was much more common at Mohenjo-daro and Harappa than at Lothal and Kalibangan.

Nevertheless, only five samples of silver have been analyzed, two from Mohenjo-daro and three from Lothal (Table 5.3). They all contain significant traces of copper, and three contain lead. The sources of Indus Valley Tradition silver are not known, but on the basis of copper and lead traces in their samples, SanaUllah (in Mackay 1938:599) suggested that most of the silver from Mohenjo-daro was extracted from argentiferous galena. Pascoe (1931) notes the presence of silver mines in Baluchistan and Afghanistan, but to date no Harappan Phase extraction sites have been reported. Silver deposits in the Aravallis are described in Craddock et al. (1989), but again there is no evidence for exploitation until after the Harappan Phase; the earliest dated mines are from the second millennium B.C.

GOLD AND ELECTRUM

Gold ornaments or flakes of gold leaf have been recovered from most excavated Harappan Phase sites. All of the relatively complete pieces of gold ornaments have been recovered from hoards where objects have been stored in copper or ceramic vessels and buried within a house. Fragments of gold leaf or tiny beads are not uncommon in the excavations of Harappan Phase sites; the gold leaf may be derived from beads or other objects that were covered with decorative gold, and the tiny beads undoubtedly derive from broken necklaces. Only a few small gold beads have been recovered from Harappan Phase burials (Dales and Kenoyer 1990).

Very little of the gold recovered from Indus Valley Tradition sites has been subjected to chemical analysis. The earlier excavators used visual criteria to discrimi-

TABLE 5.3

ANALYSES OF SILVER METAL SAMPLES (HAMID AND SANAULLAH IN MACKAY 1938:480, 599; LAL 1985:656, 658)

	MOHENJO-DARO			LOTHAL†		
	DK 5774*	**DK 11337,o****		**5034**	**4176**	**15114**
% Silver	94.52	95.52	% Silver	54.65	86.53	71.20
% Lead	0.42	1.40	% Lead	1.64	–	–
% Copper	3.68	3.08	% Copper	2.67	7.87	4.13
			% Iron	3.29	–	trace
			% Nickel	trace	–	–
% Insolubles	0.85	–	% Insolubles	3.06	2.32	16.29
			% Oxygen (by diff.)	34.69	3.28	8.38
TOTAL %	99.47	100.00	TOTAL %	100.00	100.00	100.00

*Also listed as DK 6129 (cf. Mackay 1938:480, 599); not clear which sample actually tested.

**Note that this is a derived estimate (see Mackay 1938:599).

†Tin and zinc were also tested for in the Lothal samples, but no traces were found.

nate between pure gold and a gold/silver alloy. The gold/silver alloy was thought to be either a natural electrum or an artificial alloy made by the Indus gold/silversmiths.

In the course of recent analyses of materials from Harappa by Kenoyer, one gold/silver object and four gold objects have been subjected to initial microprobe elemental analysis. One gold object from Allahdino has also been analyzed. All of the samples were examined with an electron microprobe (Kenoyer assisted by E. Glover, Department of Geology, University of Wisconsin-Madison) to determine the overall ratio of gold to silver, and one object was analyzed for copper as well. The proportion of gold to silver was between 91% and 94% in the five gold objects, but further analysis is necessary to determine if other elements are present. The gold/silver object from Harappa was a lump of partly melted and hammered metal visibly composed of gold and silver. The gold-colored portions had a high ratio of gold to silver and the silver-colored portions had a high ratio of silver to gold. This object was obviously in the process of manufacture, and may reflect a stage in the production of artificial gold/silver alloy.

Two "gold" objects from Lothal have been analyzed by Lal (1985:664–665) and contain 33.45% and 41.48% silver, but no copper, nickel, lead, or zinc. He concludes that the high percentage of silver and the absence of lead indicate that these items were made from electrum rather than an artificial mixture of silver (derived from galena) and gold. If the Indus peoples did use natural electrum, which has a relatively limited distribution in South Asia, it will be much easier to source this material. In contrast, gold has a wide distribution in alluvial deposits throughout South Asia, although mine deposits are more restricted.

There has been much discussion on the possible origin of Harappan Phase gold and, as with copper, there are several potential resource areas. While some earlier scholars considered the South Indian gold mines as a major source area, there is no conclusive evidence for trade between the Indus Valley Tradition cities and the Kollur gold-producing area of South India. The most obvious source of alluvial gold is the upper reaches of the Indus Valley itself and the streams of northern Afghanistan (Pascoe 1931; Stech and Pigott 1986). Significant quantities of gold are found in the tributaries of the Amu Darya, and the Kokcha river itself cuts through deposits that have gold ores. The most convincing indications to date of gold working at a Harappan Phase site have been found at Shortugai in Afghanistan, where the excavators found a fine globule (*gouttelette*) of gold imbedded in the cuprous vitrified internal surface of a crucible fragment (Francfort 1989:136).

IRON

No specific iron objects have been reported from Harappan Phase sites, but there are a few objects with iron components from sites in Afghanistan that were roughly contemporaneous with the Harappan Phase. While these few occurrences indicate that iron was known and used, Shaffer (1984:48–49) may be overstating the case when he concludes that in the late third millennium in Afghanistan, iron was being used to make luxury items and "iron ore was a culturally recognized and valued item, selected for its hardness and functional utility."

Three items incorporating manufactured iron were found at the site of Mundigak, an important urban center that probably controlled the trade from central Afghanistan of tin, copper, and possibly gold (Casal 1961). At Mundigak the iron was always combined with copper/bronze objects, and it appears to have served an ornamental or symbolic function. These objects include a small copper/bronze bell with an iron clapper, a copper/bronze rod with two iron decorative buttons, and a copper/bronze mirror handle with a decorative iron button (Shaffer 1984).

Two other sites in Afghanistan demonstrate the use of unprocessed iron. At Deh Morasi Ghundai a single utilized magnetite nodule was recovered in association with what Dupree (1963) referred to as a shrine complex. At the site of Said Qala Tepe, 28 specular hematite nodules were found that appear to have been used as hammerstones, but Shaffer (1984) suggests that they may also have had a socio-ritual function. (See Fabrication section below for the possible association of such objects with metalworking, at least in Iran.)

In the Indus region itself, ferruginous lumps or possible iron objects have been reported, but where analyses have been conducted (Lal 1985) there is no evidence for actual manufactured iron objects (see Slags section below). On the other hand, the Indus artisans were quite familiar with the properties of iron minerals (limonite, hematite, magnetite, etc.), using them in pigments and slips for ceramics and steatite, and perhaps for coloring faience glazes as well.

OTHER METALS

At this time there is only a little evidence for the use of other metals. Antimony is found in "appreciable proportions" in some copper metal objects at Mohenjo-daro and Harappa, almost always in copper objects containing greater than 1% tin (Appendix A) (SanaUllah 1931:485). Several pieces have also been found at Harappa as an unworked mineral, but mostly from surface contexts (and so are perhaps from the modern fair held at the site). Zinc is also found in traces within a few copper objects at Harappa, and is even present in greater than 1% in two cases (SanaUllah 1940, Pigott et al. 1989). Note that where modern techniques of analysis were used (Pigott et al. 1989), zinc was found in amounts greater than 0.5% in every artifact tested (Appendix A). It seems that the zinc was an impurity in the original copper ores at Harappa, in contrast to Lothal and Rangpur (Appendix A). Finally, cinnabar was found at Mohenjo-daro (SanaUllah 1931:691), but the context is not given. Cinnabar may be the deep red coloring that appears in some shell and steatite inlay (Kenoyer, on-going research).

HARAPPAN PHASE NON-FERROUS METAL PROCESSING

Overall, the Indus metalsmiths appear to have been familiar with the techniques used to process the major metals and alloys, except iron and brass, and we will briefly summarize the important metallurgical processes, techniques, and artifact types in this section.

Given the problems with identifying the uses of firing structures at Indus Valley Tradition sites, as described below, as well as the fact that metal processing is only one of the pyrotechnologies we investigate, we prefer the more general term "kiln" rather than using "furnace," a term specific to metal processing. A detailed discussion of the terms referring to "slags" is presented in Miller (1994b). Other specific terms used in this section will be defined as they are introduced.

Except for the site of Shortugai, where there is evidence for gold processing, most of the indicators for metal processing at Harappan Phase sites are associated with copper processing. These indicators are assessed below, grouped according to the various stages of metal processing (Fig. 5.4; see Miller 1994b).

The major indicators for metal processing at a site include: (1) fragments of ores; (2) kilns, or fragments of kilns, attributed to metal processing; (3) metallurgical slag, from the reduction of ore to metal; (4) tools used for metal processing, such as crucible fragments with metal prills, molds, anvils, stakes, hammers, chisels, etc.; and (5) metal objects, including smelting and melting ingots, semi-finished and finished objects.

Significant amounts of ores and/or metallurgical slag fragments are the most convincing evidence for smelting at a site. A variety of clay-based non-metallurgical slags, including fragments of kilns and crucibles, can represent either the smelting of ores or the melting of metal, depending on the exact nature of these indicators (Bayley 1989; Craddock 1989; Miller 1994b). Metalworking tools (other than crucibles with prills or molds) are usually difficult to attribute directly to metal processing, except when found in well-documented contexts in association with a number of other metalworking indicators. Metal objects, including metal ingots, must also be from such contexts to show their production at a site, as these objects may have been imported from other sites.

METAL PRODUCTION: SMELTING

No evidence for the processing of copper has been found during the Neolithic period in the greater Indus region. The initial stages of copper processing (extraction of native copper or smelting) were probably being carried out closer to the source areas (probably Baluchistan and Afghanistan). The question of how this technology evolved is still unclear and will not be fully understood until new surveys and excavations are carried out. Nevertheless, by the fourth and third millennia it is clear that mining and smelting of ores was being carried out in many localities throughout

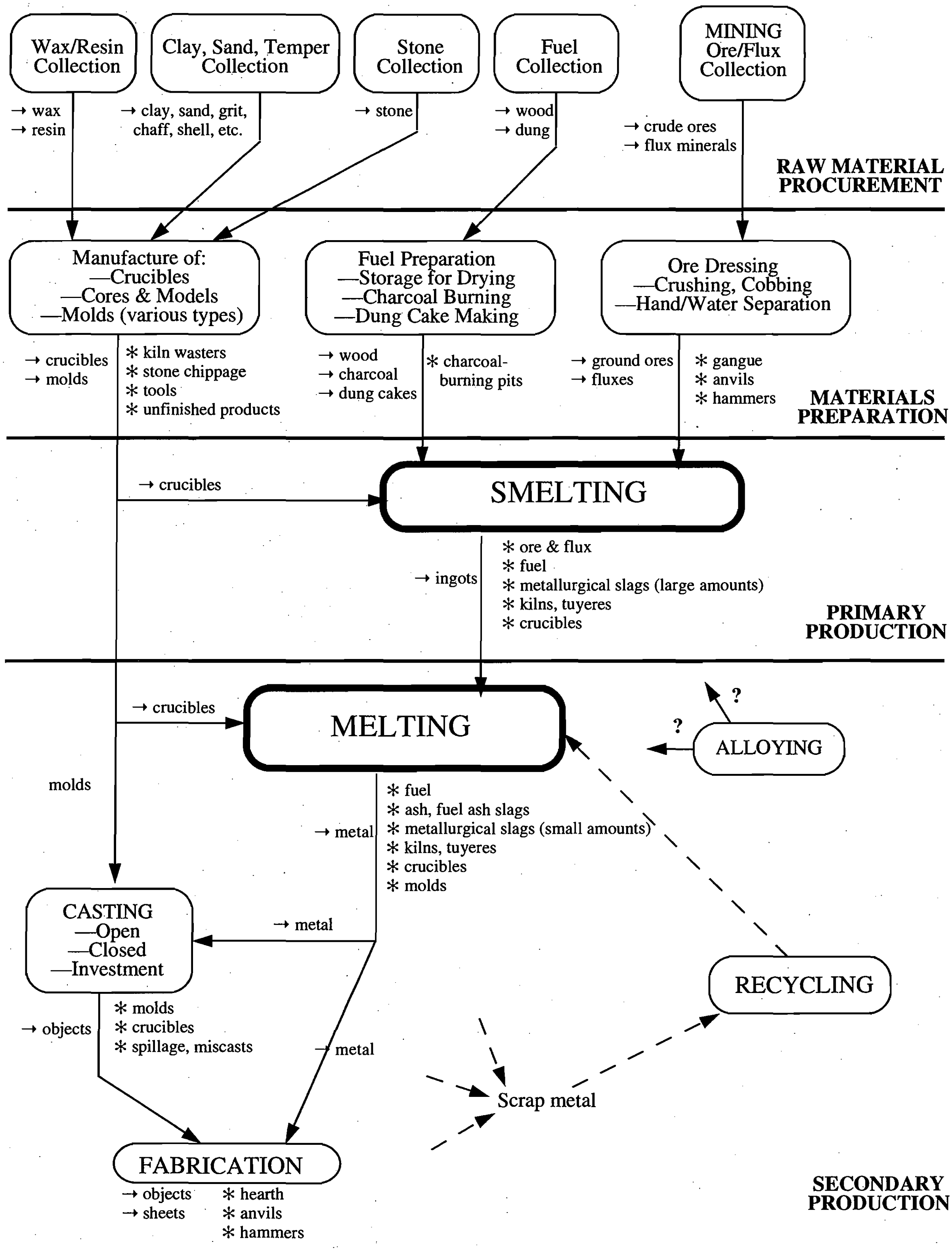

Figure 5.4 *Generalized reconstruction of non-ferrous metal processing, showing end-products (→) and by-products (*) (from Miller 1994b).*

Baluchistan and Afghanistan (Dales and Flam 1969; Fairservis 1952, 1961; Jarrige and Tosi 1981; Stech and Pigott 1986) (Figs. 5.1 and 5.2).

The paucity of metal ores from Indus Valley Tradition sites was noted above; there is a similar lack of metallurgical slags. Smelting of metal ore usually results in fairly conspicuous accumulations of manufacturing debris and broken furnaces. In particular, the smelting of most ores results in the production of weather-resistant metallurgical slags, vitrified masses of silica, and other fused minerals, which generally accumulate in conspicuous mounds near the smelting furnaces. On the basis of quantity and type of slag, the small amounts of copper metal slag found at Indus Valley Tradition sites seem to be more representative of melting rather than smelting (Miller 1994b). It is not clear if the gold processing at the site of Shortugai (above) involved gold smelting or simply gold working. The often cited copper smelting slags from Ahar are from levels dated to the second millennium B.C., after the end of the Harappan Phase (Sankalia et al. 1969:10; Allchin and Allchin 1982:262; Hegde and Ericson 1985:60).

The absence of slag heaps and smelting debris may be due to the fact that most excavated sites, particularly of the Harappan Phase, are located some distance from the primary sources of metal ores. Further collections and analyses are needed in the Aravallis, as well as in the regions of Gardan-i-Reg and Cholistan, to determine if there are Indus Valley Tradition or contemporaneous smelting sites in these regions. Archaeologists working in Rajasthan have made a laudable effort to look for copper slags, but specialist surveys are needed. The surveys done by Lowe in South India to locate and analyze iron-working sites, and the work done by Craddock and others on the silver and zinc mines of Zawar, Rajasthan, provide good models for future studies of third millennium copper smelting (Lowe 1989a, 1989b; Craddock 1989, 1991; Craddock et al. 1989).

In view of the present evidence, we must concur with SanaUllah's (1931:485) and Mackay's (1938:451) earlier interpretations that most of the copper used at the Harappan Phase sites was imported in ingot form, and little or no smelting was done at the major sites of the Indus Valley Tradition. Plano-convex disc-shaped ingots (almost all of copper) have been recovered from Chanhu-daro (Mackay 1943:188), Lothal (Rao 1979), Harappa (not reported but found in the reserve collections), and Mohenjo-daro (SanaUllah 1931:485; Mackay 1938:451). Although relatively few ingots were reported in these publications, recent examination by Kenoyer of the reserve collections for Harappa, Mohenjo-daro, and Chanhu-daro (Museum of Fine Arts, Boston) have revealed the presence of additional examples. Many of these ingots in the reserve collections at Harappa and Mohenjo-daro appear to have been smashed and broken in half or into smaller wedge-shaped fragments, apparently to facilitate further processing. Mackay (1938:450–453) also noted that several of the ingots and "castings" (secondary ingots) from Mohenjo-daro had chisel or saw marks partway into the ingot, which was then broken.

MELTING OF METAL

Melting of metal is a necessary stage in the production of cast objects, both semi-finished and finished. The remelting of original smelting ingots to produce secondary or refined ingots is also a common intermediary stage between the production of the original smelting ingot and the final fabricated or cast object. This secondary ingot production is undertaken for one or more reasons: to remove slaggy impurities left in the original smelting ingots; to break up large smelting ingots into more workable or transportable ingots; to form metal alloys; and/or to melt down metal scrap, which is usually varied in composition.

For example, SanaUllah (1931:484–485) remarked in the very first published analysis of Harappan Phase ingots (his "copper lumps"), that three of the four ingots were the "crude product of the smelting furnace" which were too rich in sulfur to be forged. He suggested that such ingots would be remelted for refining; otherwise this metal could only be used for casting "heavy or plain objects."

As noted above, much of the archaeological evidence for melting (and casting) resembles the evidence for smelting, i.e., the presence of crucibles, kilns, slag, and metal ingots. However, careful analysis of these objects, particularly identification of the types of slags present, usually allows differentiation of these processes (see Miller 1994b for a full explanation and references).

CRUCIBLES

Evidence for melting of copper in crucibles is first found during Period III at Mehrgarh, dated to 4000–3500 B.C. Crucibles with traces of melted copper have been found in rubble associated with a Period III firing structure made of brick (Jarrige 1983, 1985a). Jarrige (1985a:289) notes that the crucibles are comparable in interior size and shape to the ingot recovered from Lothal.

Only a few crucible fragments with copper prills have been reported from Harappan Phase sites, and although they could represent small-scale smelting of high-quality copper, copper melting seems more likely; further archaeometric tests may allow definite discrimination between the two processes (see Miller 1994b).

A crucible rim fragment was found during excavations at Mohenjo-daro, and SanaUllah (1931:485 and pl. CXLII, 9) gives the opinion that it represents the re-melting of crude metal for refining. No analyses were ever published, but the photograph of this rim shows slagging, and looks quite similar to fragments found by the Aachen/IsMEO surveys at Mohenjo-daro (below). A single crucible is also reported from the excavations at Harappa; Vats (1940:471) mentions in a footnote that "a fragmentary earthenware crucible whose contents show that it was used for melting bronze" was found near furnace "Fa" on Mound F at Harappa. Again, no analyses were ever published. Finally, the so-called "crucibles" reported from Lothal must be some other kind of container, as they had no traces of slagging and upon analysis contained no trace of copper (Lal 1985:661; see also section on Molds below).

The evidence from surface surveys and recent excavations at Harappa and Mohenjo-daro is much more encouraging. At Harappa, half a dozen crucible rim fragments with slagging and copper prills have been found in surface surveys of the southern slope of E Mound, and a number of both rim and base fragments of similarly slagged crucibles have been found in nearby excavations (Miller 1994a, 1994b). At least two crucible fragments with slagging and copper prills were also found in surface surveys at Mohenjo-daro, as well as an entire small ceramic cup (Pracchia et al. 1985; Tosi et al. 1984). This cup is similar to the crucibles used by modern goldsmiths in South Asia, but there are no visible traces of metal or slagging, and microprobe analyses found no traces of metal (M. Vidale, pers. comm.). All of the crucible fragments from Harappa, and one of the two from Mohenjo-daro, show a quite small diameter; the second fragment from Mohenjo-daro is much larger. Based on the associated types of slags, these seem to represent melting crucibles, not smelting crucibles, but archaeometric research still has to be done.

KILNS

Four kilns at Harappan Phase sites have been attributed to copper-processing: one at Harappa (Vats 1940:470–473, fig. d, pl. XVIIa and b), one at Lothal (Rao 1979:522), and two at Mohenjo-daro (Mackay 1938:49–50, 452). In all these kilns the interior is heavily vitrified, and the blackened melted surface indicates a reducing atmosphere. This evidence of high temperatures seems to have been the primary reason for attributing these kilns to metal processing. However, evidence of high heat alone is not sufficient to show that a kiln was used for metal processing. Many of the excavated Indus Valley Tradition pottery kilns show similar vitrification (e.g., Dales and Kenoyer 1990), as did experimental mudbrick pottery kilns fired at Harappa during the past seven seasons. Temperature data taken during the experimental firings show that the vitrification of the ceramics and the walls of the kiln occurred somewhere in the range of 1000 to 1100°C, in what was usually a heavily reducing atmosphere (Meadow and Kenoyer 1992; Kenoyer 1994).

Kiln "Fa" at Harappa was one of 16 pyrotechnological structures excavated by Vats in a relatively small area of Mound F. Contrary to much of the literature, this kiln was the only one of the 16 that Vats ever genuinely suggested might be related to metal processing. When first excavated, half of the original structure was present (split vertically), and the interior was well preserved due to heavy vitrification. The kiln is described by Vats as a pit 3 ft. 4 in. (1 m) in diameter and 3 ft. 8 in. (1.1 m) to 5 ft. 3 in. (1.6 m) deep. The interior was covered with a sand-tempered mud plaster (Vats 1940), and recent observations reveal that it was at least partly constructed with mudbrick (Miller in Meadow and Kenoyer 1992). Vats found evidence for a vaulted roof with four "flues" remaining, and a fifth "flue" entering at a slightly lower level. Using a modern Punjabi metal melting furnace as a parallel, Vats (1940:471) proposed that the latter flue was "used as an air channel worked by bellows from above," and further suggested that the roof flues were intended as outlets for smoke and/or inlets for fuel that could be closed during operation. No copper prills or copper slags were found in Vats' original excavations or in subsequent surface surveys by the present authors (Dales and Kenoyer 1990 and Miller in Meadow and Kenoyer 1992). Consequently, upon closer examination there is no evidence to support the implication that kiln "Fa" was used for metal processing.

The circular kiln at Lothal was 6 ft. (1.8 m) in diameter, 2 ft. 3 in. (0.7 m) deep, and made of mudbrick with mud plaster. The use of this kiln for melting copper ingots was attributed from its location near the so-called "coppersmith's workshop" (Rao 1979:522). However, the kiln itself showed no signs of copper melting. Indeed, most of the evidence for use of this area for copper melting has been refuted: the analyzed terra-cotta crucibles/molds show no signs of copper or other metals, the "slag" turned out to be corroded copper metal, and the "stone molds" for casting are more likely to be for grinding of stone beads or other materials (see discussions elsewhere in this section). At present there is no published evidence for copper melting at Lothal.

The two kilns at Mohenjo-daro were approximately the same depth and diameter at the top, but varied in size at the base: 4 ft. 3 in. (1.3 m) deep, 3 ft. 3 in. (1.0 m) in diameter at the top, and 2 ft. 10 in. and 3 ft. 2 in. (0.9 m and 1.0 m) in diameter at the base (Mackay 1938:49). They were paved with wedge-shaped brick and covered with mud plaster, with a 4 inch (10 cm) wide ledge on the inside (at different heights), perhaps to support a crucible or grating (Mackay 1938). The interior walls of these kilns were highly vitrified, but again there is no mention of metal slag, prills, or crucibles associated with these kilns. Mackay (1938:50) himself expresses the opinion that these kilns from Mohenjo-daro were used for "something more fusible than copper, owing to the lack of a draught or vent in their lower portions." Although in another section he contradicts himself, saying that the furnaces *were* for copper working, based on the find of three discarded copper/bronze castings in a nearby area (Mackay 1938:452), in later writings Mackay (1948:94) states firmly that there are no known copper smelting kilns from Mohenjo-daro.

Finally, we should mention the "circular furnace pit, 1.5 m in diameter and about 0.6 m deep, full of white ashes and metal-worker's slag (pl. IX, fig 3)" from Ahar, according to Misra (1969:300). Misra reports that this pit was found in the lowermost level of the site, just above virgin soil. However, we were unable to find any mention of such a pit in the Ahar site report (Sankalia et al. 1969), and the only slags mentioned in that report are from Phase Ib and Ic levels (second millennium B.C. levels)—no slags are reported from the Phase Ia levels, tentatively thought to be contemporaneous with the end of the Harappan Phase (see below, Slags section). In any case, such a pit is very large for a furnace, and as no signs of burning are noted, probably represents a dump.

In summary, based on the published data, there are no known metal processing kilns from any Harappan Phase sites, contrary to secondary sources claiming copper smelting furnaces at Harappa. However, new research is beginning to produce the types of data needed to define the presence of copper processing kilns. For example, many kiln wall fragments with embedded copper prills have been found on the southern slope of Mound E at Harappa (Miller 1994a, 1994b), and M. Vidale (pers. comm.) reports the discovery of a small circular kiln on the surface of Mohenjo-daro between VS and Moneer Areas. This kiln was approximately 0.8 to 1 m in diameter and was surrounded by hundreds of copper prills and overfired pieces of clay with copper traces.

SLAG

There is no mention of metal processing slag from any of the early excavations at Harappa or Mohenjo-daro. At the site of Lothal, several objects originally identified as copper slag have been analyzed and were found to be lumps of corroded copper metal (Lal 1985:659–661). On the other hand, two possible candidates for copper or iron processing by-products are listed in Lal's (1985:658) tables of analyses; namely, two unshaped objects composed primarily of iron and copper:

	15211 (Lump)	**15212 (Cu frag.)**
% Cu	43.1	9.3
% Fe	39.1	66.1
% Sn	–	–
% Pb	–	–
% Ni	1.5	tr
% Zn	–	–
% Ag	–	–
% Acid Insol.	11.5	17.2
% O by diff.	4.8	7.04
TOTAL %	100	100

No information is given about the archaeological contexts or phases of these objects, however, so it is not clear if they are even from the Harappan Phase. Similarly, as noted above, the only well-dated copper slags from Rajasthan were found at Ahar in levels dating to the second millennium B.C., after the Harappan Phase (Sankalia et al. 1969:10; Allchin and Allchin 1982:262; Hegde and Ericson 1985:60).

A few tantalizing statements have been made in preliminary reports on the site of Banawali, in Haryana (Bisht 1982, 1984). Bisht (1984:90–91) mentions "a few contiguous rooms" with reddened floors, "several hearths, ovens and fire-pits," and "pieces of copper and copper slags," and concluded that this area was probably used by metalsmiths. If subsequent analyses show that these are indeed copper slags, this information from Banawali will make a welcome addition to the scanty information on metal processing, especially as these rooms are attributed to the Sothi or pre-Harappan (Kalibangan I) levels of Banawali (Bisht 1984:90).

Also, as with the crucible fragments, several discrete scatters of metal processing slags have been found during surveys at Harappa (Miller 1994a, 1994b) and Mohenjo-daro (Pracchia et al. 1985; Tosi et al. 1984). These slags are primarily vitrified clay-based materials with copper prills; metallurgical slags are quite limited in number and do not appear to constitute the type or quantity of slag associated with smelting (Miller 1994a, 1994b). Based on both the characteristics of these slags and the relatively small amount of copper slag found at the excavated Harappan Phase sites, they are more likely to be by-products from the re-processing of copper ingots or scraps than from the original smelting of ores.

It is highly unlikely that copper processing was not being carried out in these large cities and in smaller settlements, but future research is needed to recover the types of indicators needed to define different stages of metal processing.

OBJECT PRODUCTION: CASTING AND FABRICATION

The production of metal objects can be divided into two categories, casting and fabrication, depending on the state of the metal during the actual working. Casting is done when the metal is molten and fabrication is undertaken when the metal is not molten. These two categories divide the methodologies of metalworking artisans as well as the states of the metal itself. Fabrication involves the direct shaping of metal, while casting begins with the shaping of other materials into which the molten metal is poured.

The tools and techniques of the two categories overlap to some degree, and ancient metalworking ateliers may have been involved in both fabrication and casting. Some objects, however, may have been cast by one group of artisans and finished or fabricated by another group in a separate workshop. The possible division of manufacturing stages into discrete and often exclusive activities practiced by different artisans is an important part of metalworking that has not been investigated for the Indus Valley Tradition primarily because metal production areas have not yet been conclusively identified. The implications of such separation of activities are touched on in the final section of this paper.

CASTING

By defining casting as the shaping of molten metal we include a wide range of metalworking activities, including the production of secondary ingots as well as the casting of semi-finished or finished objects. Evidence for casting thus includes all of the indicators discussed above in the section on Melting, as well as several types of indicators directly related to casting, such as molds, semi-finished objects, and finished objects. (Lahiri [1993] notes the importance of recognizing the presence of secondary ingot casting in South Asian metalworking.)

The best evidence for casting activities at a site is the presence of molds. Ancient mold types include open stone, terra-cotta, or sand molds; bivalve stone, terra-cotta, or sand molds; and terra-cotta-based "lost model" molds. Horne (1990) suggests the term "lost model" rather than "lost wax" since the technique employs other materials besides wax, such as tallow, resin, and tar. At present, no convincing examples of any type of mold for casting metal have been reported from Harappan Phase sites. (Note: we have been unable to find any reference to "open stone molds" reported from Chanhu-daro, contrary to Agrawal's [1984] statement.)

The only published stone "molds" from a Harappan Phase site are from Lothal, where Rao identifies two grooved stones as open molds for casting pins/rods (Rao 1979:557, 568, fig. 121, nos. 3 and 4, pl. CCLIIb). The first problem with Rao's identification is that the grooves are much larger than the metal pins found at Harappan Phase sites. Second, the grooves are not straight along their length or sides and taper off in depth at each end, which seems highly impractical and unlike known casting molds from other regions and periods. Third, there is no report of discoloring or spalling, which would occur if molten metal were repeatedly poured onto a stone surface. Similar stones (made of sandstone and quartzite) with long parallel grooves have been found at Harappa and Mohenjo-daro, and at Chanhu-daro they are clearly associated with agate bead manufacturing areas (Mackay 1943:213–214, pl. XCIII). Our opinion is that the grooved stones from Lothal probably do not represent open stone molds for metal casting.

The only published terra-cotta molds are also from Lothal, and might be fragments of open molds, although Rao calls them "crucibles" (Rao 1979:pl. CCXIIIa, b, c). Scrapings collected from the interiors of these "crucibles" gave negative tests for tin, lead, nickel, arsenic, and copper, even upon repetition of the copper test (Lal 1985:661). Future test results showing the presence of some metallic traces would be necessary to define these objects as molds for casting metal (but see Bayley 1989:298–299). Finally, there are no reports of sand molds of any kind nor of fragments of lost model molds.

Paradoxically, the few metallographic analyses that have been done on Harappan Phase copper/bronze objects indicate that some tools were definitely made by open or bivalve casting (Agrawal 1971; Pigott et al. 1989; SanaUllah 1940; Wraight 1940). In addition, the modeled forms of the famous metal figurines of animals and humans can be attributed to lost model casting. For example, two exquisite objects reported from Chanhu-daro that may have been made by lost model casting have often been overlooked: a covered cart with the wheels missing, and a complete cart with a driver holding a goad (Mackay 1943:39, 41, pl. LVII, 1 and 2). A similar model cart was also recovered in excavations at Harappa (Vats 1940:27). Some of the small vessels may also have been made by lost model casting (Mackay 1938:446; 1943:176).

Due to the low percentages of lead found in his analyses, SanaUllah (1940) did not think that the Indus peoples used lost model casting techniques. While unalloyed copper is difficult to cast, it should be pointed out that lead is not a prerequisite for lost model casting. Other alloys may be used (e.g., copper-tin), as most alloys are usually fluid enough to cast well. Furthermore, the types of objects tested by SanaUllah (see Appendix A) were unlikely to have been made by lost model casting in any case; no figurines or vessels were tested.

The presence of cast objects and no molds could be taken as an indicator of importation of finished metal objects, but this seems unlikely. Many of the cast Harappan Phase metal objects, particularly the figurines, are definitely Harappan in style, corresponding to the morphology and subject matter of objects in other materials such as faience, stone, and ceramic. There is no evidence for Harappan-style metal objects or molds from sites outside of the greater Indus region; indeed, Yule (1985b) notes that Harappan Phase metalware is very different in style from contemporaneous products in other regions.

It is more likely that this paradox is due to the lack of identified metal processing areas at Indus Valley Tradition sites and also perhaps a problem of the archaeological *identification* of molds. The Egyptians and Mesopotamians obligingly left molds of stone, clay, and even metal (Moorey 1985; Scheel 1989); the Indus peoples were not so helpful. Given the scarcity of stone in the Indus Valley flood plains, it is possible that stone molds were reused for other purposes. However, this seems extremely unlikely, as the detailed examination of every fragment of stone and fired ceramic recovered from five seasons of excavations at Harappa, as well as examination of the Mohenjo-daro reserve collections, has not revealed any fragments of stone or ceramic molds (Kenoyer, on-going research). Another explanation is that the Indus peoples used mold materials, such as sand or sandy clays, that leave little trace in the archaeological record.

Two techniques using sand or sandy clay molds are sand casting and lost model casting, both of which leave almost no archaeological traces. Sand-based molds are used for casting in modern South Asia and many other areas of the world (Untracht 1975), and employ a finely powdered sand, sometimes mixed with water and organics such as dissolved sugars. This mixture can be used to make an open mold or packed into a hinged wooden box to make a bivalve mold. A form made of wood or some other material is impressed into the sand mixture, which is cohesive enough to create a mold into which the molten metal is poured. It is well suited for flat objects, such as celts, axes, adzes, knives, or spears. It may even leave characteristic bivalve lines on the objects, often taken to be indicative of the use of stone or terra-cotta bivalve molds.

Since forms are used to impress the sand and create the mold, some degree of duplication of objects is possible, and creation of the sand molds is obviously quite rapid. Although these molds have a great resistance to heat, making them an excellent casting material, they break down quickly into sandy deposits when exposed to weathering from water and wind. In addition, modern sand molds are usually ground and reused, and ancient molds would probably have been similarly recycled.

The materials used to make lost model molds are also quite ephemeral. These materials form a continuum with the fine sticky sand used for sand casting, but employ a more cohesive sandy clay so as to better retain the complex three-dimensional features of the object to be cast. Lost model casting often employs several grades of material. First, the model of wax, resin, tar, etc., is coated with a fine sandy clay. This inner coat will form the details of the object to be cast, so the finer the detail desired, the finer the texture of the coat. Increasingly coarser sandy clay is used to form the bulk of the mold. The crucible containing the metal can be built into the mold, as is done in India and Africa, or metal can be poured into the mold from a separate crucible, as was done in the Americas and Egypt (see Emmerich 1965; Fox 1988; Fröhlich 1979; Horne 1990; Reeves 1962; Scheel 1989 for ethnographic and historic descriptions of lost model casting).

An essential component of the lost model process is the use of a sandy clay that will not sinter under high temperatures. Thus, in addition to the fact that the molds are broken to remove the cast object, such molds also break down very quickly when exposed to weathering. As with sand casting, the broken pieces of the mold are also often recycled, increasing their archaeological invisibility.

The ability to produce molds rapidly and to recycle the mold materials is one of the great advantages of sand and lost model casting over stone-mold casting. While this is beneficial for the artisan, it is a nightmare for the archaeologist. Perhaps with increasing awareness of these methods and their ephemeral remains, archaeologists will begin to look more closely at patches of sand for the tiny fragments that may still retain the contours of cast objects.

FABRICATION

Fabrication of metal objects includes all of the various types of modification of non-molten metal: shaping, via forging, turning, and drawing; cutting; cold and hot joining; and finishing via planishing, filing, polishing, coloring, engraving, and so forth. The metal can be worked while cold or hot, but at a heat below the molten state. Ingots (either secondary or smelting ingots) can be worked either into sheet form or directly into a finished object. Cast semi-finished objects, such as those found by Mackay (1943:175) at Chanhudaro, also would be subsequently worked to form the finished object.

SHAPING

In its broad sense, shaping is the controlled mechanical stretching of metal. This includes stretching by forging, including sinking and raising; by spinning or turning; and by drawing.

Forging. The most common form of shaping is forging, "the controlled shaping of metal by the force of a hammer," usually on an anvil or stake (McCreight 1982:36). Whereas the term "hammering" is sometimes used for non-ferrous metals, and "forging" reserved for ferrous metals, forging is the term most often used by coppersmiths themselves, and will be used here.

The hammer and the anvil or stake can be made of a variety of materials, such as metal, stone, wood, bone or horn, or even leather. Finds of such tools, or of the marks left on objects by such tools, comprise one type of archaeological evidence for forging. The other main source of evidence for forging comes from metallographic examination of artifacts. Forging can be done while the metal is hot or cold. Forging not only shapes the object, it also hardens it, and so forging is an important step in the manufacture of edged tools. Annealing is the re-heating of an object after working, and most metalworking involves cycles of annealing and hot or cold "hammering" (forging). Metallographic studies help to establish the use of such methods.

There is some evidence for forging during the Harappan Phase, both from finds of tool marks and from metallography (Agrawal 1971; Mackay 1938; Piggott et al. 1989; SanaUllah 1940; Wraight 1940). The Indus peoples forged objects both from castings, including bar or block ingots and semi-finished shapes, and from sheet metal. For example, chisels, which are one of the most numerous tool types, appear to have been forged from cast bars (e.g., Vats 1940:87–88). Metallographic analyses of other edged tools confirm that at least some of these tools were cast and then forged (Agrawal 1971; Pigott et al. 1989; SanaUllah 1940; Wraight 1940). Thin razors are thought to have been cut from copper sheets, then forged to a sharp edge (Mackay 1938, 1943).

Sheet manufacture is a type of forging, and fragments of copper, silver, and/or gold sheets have been found at Chanhu-daro (Mackay 1943), Harappa (Vats 1940), Lothal (Rao 1979, 1985), and Mohenjo-daro (Mackay 1931, 1938; Marshall 1931). The Indus method of sheet manufacture is unknown, and there are no published anvils or hammers. However, many of the noncubical "weights" from Harappan Phase sites are very smooth cylindrical or semi-hemispherical stones with highly polished surfaces. These types of objects might well have been used for metalworking, and the highly polished surface would be necessary to avoid marring the metal. The reports of hematite and magnetite "hammerstones" from Afghanistan (Dupree 1963; Shaffer 1984) are particularly interesting, given the use of these materials in copper metal sheet manufacture in western Iran (Pigott, this volume). Use-wear studies of these stone objects may help to clarify their function. It is also possible that wood or other perishable materials were used. At this time, the most hopeful method for elucidating the methods and materials used by the Indus peoples for forging is through the analysis of objects for tool marks, particularly on the better-preserved gold objects. Experimental studies aimed at discriminating marks left by various tool materials (e.g., stone, wood, metal) will also be useful.

Sinking and *raising* to form vessels from metal are also types of forging. As the names imply, sinking is the forming of metal by hammering from the interior of an object into a depression in an anvil, while raising employs hammering from the exterior of the object over a shaped stake or form. There are a number of ways to raise objects: both from sheets and from ingots directly, while the metal is cold and while it is hot, by an individual artisan or by a group working together. The Indus peoples are known to have raised vessels (Mackay 1938:chap. XIII; Vats 1940), and appear to have made some jewelry by similar forming techniques, particularly the gold "cones." Unfortunately, no studies have been done to show what techniques of raising or sinking were employed.

Hollow metal tubes of copper or copper alloys were also made. The method of production is not exactly known, but the tubes are seamed and were produced from sheets, and so were forged in some fashion (Mackay 1943). The edges do not overlap, but rather abut, and there is no mention of the use of solder in the published accounts. The handled pans (Mackay 1931, 1938, 1943) also show the production of tubes by raising, in that their handles are tubes made by lapping over the opposite sides of the metal. Two pieces of a long, one-inch diameter copper tube were also found at Mohenjo-daro, but no details of its construction are given. Marshall (1931:198) refers to this tube as a "coppersmith's blow pipe," but gives absolutely no support for such a conjecture.

Decorative uses of forging include the use of stamps or punches, hammering of thin metal sheet (often gold) into or over patterns, and chasing. Hammering into or over patterns is not noted so far, but simple circular punch marks were used in the decoration of gold objects and fillets (e.g., Mackay 1938:526, no. 4; Marshall 1931:527, pl. CXVIII, 14), and sheet metal was beaten out from one side to make designs in at least one piece (Vats 1940:64, [d] no. 8). There are no published reports of true chasing (the working of metal from both sides).

Spinning and turning. Spinning and turning are methods of mechanical stretching with results similar to sinking and raising but using a lathe rather than a hammer. While Mackay originally suggested that some of the vessels from Mohenjo-daro may have been made by turning (1931), no lathe marks or evidence for a lathe have yet been discovered to support this conjecture, and Mackay seems to discard it in later writings.

Drawing. Wire production has not been studied at all, although there are abundant examples of copper "wire" and silver "wire." This is probably due to the poor preservation of the metal, so that details of manufacture are not discernible. There is no evidence at present to indicate whether Harappan Phase wire was drawn or forged, although the latter is far more likely for the third millennium B.C. Wire was used to make rings, possibly for adorning the fingers, toes, and ears, as well as for other purposes. Some stone beads have pieces of copper wire inserted through the hole, possibly in imitation of the method seen with gold wire, so that the bead could be hung as a pendant from a larger composite necklace.

When corroded wire remains inside a bead it will often split the bead into two fragments, making the bead look as if it was broken in manufacture. Occasional reports of copper "drill bits" found stuck in beads may be such fragments of corroded wire. For example, Jarrige (1985b) mentions that a long barrel-shaped lapis lazuli bead from Mehrgarh, Period VII, with a "copper bit" still inserted in the hole, was broken in two during the drilling process. This may instead be a fragment of the copper wire used for stringing the bead. However, further investigation of these reports are needed, as the possible use of copper for drill bits is an important unanswered question for the Indus Valley Tradition (Kenoyer and Vidale 1992). Jarrige's (1985a:290) discussion of the helicoidal bronze rods from Lothal, Mundigak, and perhaps Mehrgarh are of great interest for this topic. These rods are exactly like modern auger drills, and the rods from

Lothal and Mundigak still retain their pointed tip. Jarrige (1985a:290) also notes that the helicoidal rod from Mundigak corresponds in diameter to the hafting holes in wooden handles found at Shahr-i Sokhta.

CUTTING

The Indus peoples are thought to have cut many of their thin objects out of sheet metal. Cutting was probably done for the most part with chisels (Mackay 1938:chap. XIII, and many other cases); the V-shaped or double-edged chisels, which are the most common type, can be used to cut metal. Most of the chisels analyzed to date are of tin bronze or arsenical copper, and therefore relatively hard. In addition, there are some saw marks in metal objects (Mackay 1938:368, 452, 475, 583), although Mackay was unable to distinguish if these were from an ordinary blade saw or a wire saw. From the evidence of both chisel and saw marks, the usual procedure seems to have been to cut a groove in the metal mass on one or more sides, then snap the piece in two. Similar methods are seen in Indus Valley Tradition stone working.

JOINING

The number of identified Harappan Phase methods of joining metal is limited. There are very few examples of cold joining, comprising primarily the use of rivets to attach metal handles to metal vessels (Marshall 1931). Hot joining is represented by evidence for soldering of gold and silver (SanaUllah 1940; Rao 1979), and by one example of pouring molten copper metal over a join to attach a copper handle securely to a copper vessel (Mackay 1931:489). (Hot joining is considered a fabrication technique even though the joining material is molten, because the body of the metal is not molten.) There are as yet no published examples of soldering of copper materials, but this is probably due to the generally poor state of preservation of the copper metal and the lack of analysis. For example, a large cooking vessel found at Chanhu-daro appears to have been joined at the carination. However, it is not yet clear if this join was cold or hot joined, due to the poor preservation of the object (Kenoyer, on-going research at the Museum of Fine Arts, Boston).

One possible example of hot joining without solder is seen in a gold tubular bead from Harappa, measuring 33.95 mm in length and between 2.14 and 2.41 mm in diameter. The thickness of the gold wall of the tube is between 0.34 and 0.39 mm and there is no visible longitudinal seam. Further studies of the bead are needed to confirm the precise techniques, but one possible method of manufacture was reproduced in silver by a skilled jeweler in Karachi (Kenoyer, on-going research). A long silver wire was wrapped around a solid rod, and the wire was fused into a tube by vigorous burnishing and annealing. If this were the manufacturing method of the ancient tubular bead, casts of the interior of the gold tube should reveal whorls along the circumference.

Another find from Harappa perhaps related to joining is the discovery of a tiny snippet of gold that is a swollen pillow shape (4.35 mm length, 1.39 width, 1.58 mm thickness). This type of object is often seen in the process of manufacturing granules of gold for use in granulated decoration. However, such granules are also a standard by-product of soldering, for the intentional or unintentional heating of a tiny gold, silver, or copper fragment often results in such a shape. The essential step defining granulation is not the *making* of the granules, but the *attachment* of the granules. At present no ornaments with gold granulation have been found from Indus Valley Tradition sites.

FINISHING

There have been few discussions of Harappan Phase metal finishing techniques (Mackay 1938). While this is understandable for the copper-based objects, which are generally heavily corroded, the silver and especially the gold objects should provide evidence for Indus methods of finishing. Finishing techniques which need to be investigated include the planishing of forged (especially raised) objects; filing and polishing to smooth surfaces; engraving; inlay and stone-setting; and surface coloration via plating or enrichment.

Mackay (1938) notes the presence of hammer marks on many of the vessels, but does not indicate if this represents *planishing.* (Planishing refers to fine, even hammering with a highly polished hammer, used particularly to create a smoother surface on forged objects.) Evidence for *polishing* comes from the gold objects from recent excavations at Harappa, such as the copper and gold beads described below, which show minute striae oriented in groups. Polishing materials could have included ground and polished stone objects, perhaps even magnetite nodules (Pigott, this volume), sand- or silt-sized powders, plants, or even leather. *Engraving* to produce designs or accentuate details is known from the figurines and the numerous inscriptions on copper tablets and other metal objects (Yule 1985a, 1985b). Stone burins or metal engravers may have been used for this technique, and could probably be identified through use-wear studies. Finally, a number of *inlaid* pieces are found among the Indus jewelry, although the techniques of setting have not yet been studied.

At present there is no evidence for *surface coloration* via plating or chemical enrichment. However, the mechanical wrapping of gold sheet over copper and paste beads is known from Mohenjo-daro (Mackay 1938) and Harappa (Dales and Kenoyer 1990), as well as from Allahdino (Fairservis, pers. comm.). At Harappa, the gold sheet used for wrapping the core ranges in thickness from 0.07 to 0.1 mm in thickness; it appears to have been only wrapped and hammered around the core without having been actually fused to it.

More precise information on finishing, and manufacturing techniques in general, would benefit greatly from the restudy of all objects in a standardized fashion, using xeroradiography of the objects and selected metallography. Methods of manufacture would give us more information on the diffusion and independent invention of metal processing techniques in the Indus Valley Tradition. It would also allow investigation of possible regional styles of production both within the Indus Valley Tradition (e.g., Indus Valley vs. Gujarati sites), and in contrast with other Traditions (e.g., Indus Valley vs. the Rajasthani cultures, or even Mesopotamian groups).

THE ROLE OF METAL DURING THE HARAPPAN PHASE

In order to better understand the role of metal objects in Indus society we need to have detailed information on the contexts in which metal objects have been found. The vast majority of metal objects available for study come from the earlier excavations and we have little information on the stratigraphic or chronological context of the artifacts within each site. Nevertheless, some generalizations can be made on the basis of the current evidence. Based on the published reports from sites in the greater Indus region (including parts of Afghanistan, Baluchistan, northwestern India, and Gujarat) and firsthand observations of some unpublished material, we have made a preliminary tabulation of the use of metal and non-metal materials to manufacture specific types of objects (Table 5.4). This table is preliminary and by no means comprehensive, but some of the patterns seen in these rough data are discussed below.

ORNAMENTS AND MIRRORS

The use of copper as a form of ornament has a long history in the greater Indus region and can be traced back to the early levels at the site of Mehrgarh, where there is evidence for a single copper bead from the Neolithic levels (Period IB), circa 6000 B.C. (Jarrige 1983, 1985b). Several copper ornaments have been reported from the subsequent layers (Jarrige 1983), but these objects have not yet been analyzed, so details of composition and manufacture are still unknown.

Deposits of Period III at Mehrgarh (4000–3500 B.C.) also contained corroded fragments of rods and pins. Two double spiral-headed pins show that the discovery of such pins in the later Harappan Phase sites no longer indicates connection with the much later Namazga III sites in the western and northern highlands. A fragmentary copper object from one grave of Mehrgarh Period III may be a compartmented seal, again indicating the presence of these objects in a context that pre-dates the Quetta-Namazga III complexes (Jarrige 1985b).

The excavations at Mehrgarh and other sites of the Regionalization Era provide clear evidence for the gradual increase in importance of metal between the Early Food Producing and the Regionalization Eras. During the Harappan Phase of the Integration Era, it is evident that metals supplement rather than replace the earlier materials used to manufacture ornaments (Table 5.4). In fact, many metal ornaments are copies of beads, pendants, or bangles made in non-metal materials. There are some unique new types of metal ornaments, however, specifically those that incorporate gold, silver, and electrum. Metal also comes to be used in composite ornaments with other valued or symbolic materials, such as faience, various colored stones, and shell.

At present, the best clue we have to the role of metal ornaments in Indus society is their archaeological context. Unlike contemporaneous sites in Mesopotamia, almost all of the complete ornaments (e.g., necklaces and belts) found at Harappan Phase sites have been recovered from hoards rather than from burials. Fentress (1977) tabulated the metal objects from Mohenjo-daro and Harappa that were found in hoards vs. those found in non-hoard contexts, including burials (Table 5.5).

Although Fentress' table needs to be updated and to include other sites, it presents some noteworthy patterns. Copper/bronze ornaments as well as copper/bronze tools have been recovered primarily from non-hoard contexts. In contrast, gold and silver ornaments and silver vessels have been found almost exclusively in hoards. It is interesting that copper/bronze *vessels* have been found almost equally in hoard and non-hoard contexts.

When considering the distribution of ornaments, it is thus necessary to discriminate between copper/bronze and metals such as gold and silver (Table 5.5). Gold and silver ornaments have been found stored in ceramic, copper, or silver vessels that appear to have been deliberately hidden away. Some of these hoards include broken ornaments and melted lumps of gold or silver that would undoubtedly have been remelted and made into new ornaments. The hoards often contain numerous stone beads made from agate, carnelian, jasper, turquoise, and other varieties of colored stones.

Copper beads and spacers are also included with some of the hoards (e.g., Allahdino; Fairservis, pers. comm.), but copper ornaments have primarily been recovered in non-hoard contexts, such as in the debris accumulating in the streets or habitation areas, or in some of the burials. Out of 168 total copper/bronze ornaments reported, 130 were found in non-hoard contexts and only 38 were found in hoards, generally in association with gold and silver ornaments. The

TABLE 5.4

METAL AND NON-METAL OBJECTS OF THE INDUS VALLEY TRADITION (COMPILED BY J. M. KENOYER)

	EARLY FOOD PRODUCING ERA NEOLITHIC		*REGIONALIZATION ERA** EARLY CHALCOLITHIC		*INTEGRATION ERA* HARAPPAN PHASE	
OBJECT CATEGORIES	**NON-METAL OBJECTS**	**METAL OBJECTS**	**NON-METAL OBJECTS**	**METAL OBJECTS**	**NON-METAL OBJECTS**	**METAL OBJECTS**
VESSELS	ceramic, stone	– none –	ceramic, stone	– none –	ceramic, stone	copper/bronze/silver/lead
MIRRORS	– none –	– none –	– none –	– none –	– none –	copper/bronze
ORNAMENTS						
beads, pendants	stone, shell, bone, ceramic	copper/gold	stone, shell, ceramic	copper/bronze/silver/gold	stone, shell, ceramic	copper/bronze/silver/gold
bangles	ceramic, shell	– none –	ceramic, shell	copper/bronze	ceramic, shell	copper/bronze/silver/gold
pins/awls	bone, antler	– none –	bone, antler	copper/bronze	bone	copper/bronze
finger/toe rings	– none –	– none –	? shell	copper/bronze	stone, shell, ceramic	copper/bronze/silver/gold
fillets/head bands	? beaded, fabric, leather	– none –	? beaded, fabric, leather	– none –	? beaded, fabric, leather	gold
composite/inlay	stone	– none –	shell, stone, faience	– none –	shell, stone, faience	gold, silver
TOOLS						
arrowheads	stone (microliths)	– none –	stone (microliths)	copper/bronze	– none –	copper/bronze
points	bone, antler	– none –	bone, antler	copper/bronze	bone, antler	copper/bronze
axes	stone	– none –	stone	copper/bronze	– none –	copper/bronze
adzes	stone	– none –	stone	copper/bronze	– none –	copper/bronze
chisels	stone	– none –	stone	copper/bronze	– none –	copper/bronze
drills	stone	– none –	stone	– none –	stone	copper/bronze
blades	stone	– none –	stone	copper/bronze	– none –	copper bronze
spear points	stone	– none –	stone	copper/bronze/silver	– none –	copper/bronze
small knives/razors	stone	– none –	stone	copper/bronze	stone	copper/bronze
fishhooks	– none –	– none –	- none -	– none –	– none –	copper/bronze
sickles	stone blades	– none –	stone blades	– none –	stone blades	– ? none –
saws	denticulated stone blades	– none –	denticulated stone blades	– none –	denticulated stone blades	copper/bronze
INSCRIBED/DESIGNS						
seals, tokens, plaques	stone, bone, ivory, ceramic	– none –	stone, shell, bone, ivory, ceramic	copper/bronze	stone, shell, bone, ivory, ceramic	copper/bronze
FIGURINES						
animal	ceramic, stone	– none –	ceramic, stone	– none –	ceramic, stone	copper/bronze
human	ceramic, stone	– none –	ceramic, stone	– none –	ceramic, stone	copper/bronze

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*Sites of the Nal Phase have copper and silver tools and weapons similar to those found in the Harappan Phase of the Integration Era. There are problems with the actual dating of Nal burials and settlements.

TABLE 5.5

MOHENJO-DARO AND HARAPPA: METAL OBJECTS FOUND IN HOARD AND NON-HOARD CONTEXTS (BASED ON FENTRESS 1977:243, TABLE 28)

Vessels	**Hoard**	**Non-Hoard**
copper/bronze	39	28
silver	3	0
lead	0	1
Ornaments		
copper/bronze	38	130
gold	2,133	5
silver	47	4
electrum	0	2
Tools		
copper/bronze	72	314

gold and silver ornaments found in non-hoard contexts are usually tiny beads or gold foil fragments that were probably lost in the muddy streets or courtyards.

Although very little metal was buried with the dead, burials, like hoards, provide a context in which metal ornaments were intentionally placed by the Indus peoples. Metal objects found in burials are almost all of copper/bronze, and include mirrors, finger rings, bangles, and occasional beads. In one instance three gold beads were found, strung together with three stone beads. While the mirrors are invariably placed with female burials, the other metal ornaments have been found with both male and female individuals (Dales and Kenoyer 1990). It should be noted that no utilitarian copper/bronze tools have been found in the burials.

The occasional pilfering of burials (see below) cannot be used to explain the low incidence of metal in undisturbed burials, especially the absence of elaborate gold and silver ornaments. Other ornaments that are noticeably absent are those made from exotic materials or involving complex production techniques, e.g., carnelian, faience, or stoneware. This pattern suggests that ornaments that represented wealth or status were passed on from generation to generation and recycled, much as is done today in the subcontinent (Kenoyer 1992b).

The presence of mirrors in the burials is intriguing, as they were made of a considerable amount of metal that could have been recycled. Metal mirrors are a new object during the Harappan Phase, as mirrors were not previously made in any material, either polished stone or metal (Table 5.4). Perhaps mirrors were needed by women in the afterlife, or the personal use of a mirror made it an object that could not be passed on to another individual at death. However, mirrors are not found in *all* female burials. One possibility is that such beliefs may have been important to certain groups within Harappan Phase communities, while others held different beliefs. However, another possibility is that this difference may reflect looting by grave diggers. Many of the burials recently excavated at Harappa were disturbed by Harappan grave diggers in the course of digging pits for later burials, and shell bangles and copper mirrors were generally missing from the disturbed female burials (Dales and Kenoyer 1990).

The fact that precious metal vessels and ornaments have been found primarily in hoards suggests that, unlike copper/bronze metal objects, they were used more overtly to define wealth, status, and power. The types of ornaments depicted on figurines may represent gold, silver, and stone ornaments that had symbolic as well as ornamental value. However it is curious that, unlike Mesopotamia or Egypt, the Indus terra-cotta or stone figures are never depicted holding metal tools or weapons as symbols of status or power. The only pictorial or glyptic representation of the use of weapons or tools is seen in the pictographic signs of the undeciphered Indus script, or in narrative scenes on seals or molded tablets.

TOOLS AND VESSELS

As noted above, the earliest use of metals by Indus peoples is for ornaments or amulets and not for functional tools. During the Regionalization Era at sites such as Mehrgarh, Nausharo, Balakot, Jalilpur, Rehman Dheri, etc. (Fig. 5.2), we see an increase in the use of copper to make tools as well as ornaments. These copper/bronze tools are used in conjunction with the stone or bone tools and supplement rather than replace them (Table 5.4).

During the final Phases of the Regionalization Era in both the Indus Valley and Baluchistan, there is evidence for the introduction of new forms of copper/bronze tools that anticipate the major surge in metal tool production during the subsequent Harappan Phase of the Integration Era (see Yule 1985a, 1985b; Herman 1984 for catalogues of Harappan Phase metal objects; Haquet 1994 for work in progress on a catalogue for Baluchi sites).

During the Harappan Phase, some types of tools that had previously been made of stone do become totally replaced by metal tools (Cleland 1977). The most important include the barbed arrowheads (probably originally made with geometric microliths—Agrawala 1984a), spearheads, axes, adzes, hoes, chisels, and large blade tools. Copper fishhooks may be a new type of tool, as so far no hooks have been identified in bone or shell, or they may replace earlier hooks made of bamboo or some other perishable material.

Interestingly enough, however, there are still some tool categories where non-metal materials are supplemented rather than replaced by metal versions (Table 5.4). These tool categories include stone drills used for perforating a variety of materials, stone blade engraving tools (burins and engravers), various denticulated blades used as saws or scrapers, unmodified stone blades used as knives or scrapers, and a range of stone and bone points or awls.

The first metal vessels, primarily in copper, also appear during this time, supplementing but not replacing previous materials. Many of the metal vessel forms are similar to terra-cotta prototypes, with the "cooking pot" being a predominant form. Yule (1985b:25) notes that of the examples available for his study, "about one half of the types/forms exist in pottery, but many are peculiar to metal." It is not clear how many of the unique shapes in metal are due to the variations that result from the techniques of manufacturing metal, rather than the desire to make new forms. However, the distinctive long-handled pan is a definite example of a new form, as even short handles are almost unknown for Indus Valley Tradition ceramics.

Finally, some uses of metal which might be expected do not occur. The primary example is the continuing use of chert blades to make sickles during the Harappan Phase; only one possible metal sickle (or dagger) has been found, a curved copper blade from Mohenjo-daro (Mackay 1938:471). Even if other more convincing examples of copper sickles do turn up, it is clear that this type of tool was made predominantly by hafting stone blades. A distinctive type of denticulated sickle blade continues to be used in the later Localization Era, e.g., at Pirak (Jarrige and Santoni 1979).

Many scholars specifically focusing on the replacement of some stone tools by metal have concluded that the role of metal (i.e., copper/bronze) during the Harappan Phase was primarily utilitarian (Cleland 1977, Shaffer 1982). However, this conclusion is based on the distribution of *all* metal objects at Harappan Phase sites; ornaments and tools are not separated.

For example, at the small rural site of Allahdino the apparently utilitarian nature of metal objects is further supported by their recovery in all areas of the excavations and not in just one area of the site (Shaffer 1982). In a comparison of artifact distributions at Mohenjo-daro and Harappa, Fentress (1977) notes that the highest frequency of metal objects at Mohenjo-daro was in the so-called "Lower Town" area and not in the so-called "citadel" mound. In contrast, she finds that metal objects are distributed evenly throughout the site of Harappa (Fentress 1977). Recent excavations at Harappa suggest that this type of approach to the presence or absence of metals in different sectors of the large urban centers is not appropriate for understanding the role of metal in the different areas. The main problem lies with site formation processes at Harappa and Mohenjo-daro, where garbage was being dumped in empty structures and platforms were raised by filling them with trash from other areas of the site. Eventually, this process could result in a fairly even distribution of metal objects regardless of where they were originally used or discarded.

Nevertheless, these general observations on the use and distribution of metal objects has led Shaffer to conclude that "metal artifacts were manufactured for use in daily activities and were available to a broad segment of Harappan Phase society, urban or rural" (Shaffer 1982:47). The widespread use of metal tools is thought to reflect a pattern that is distinct from Mesopotamia and Egypt, where metal was generally associated with elites (Hoffman and Cleland 1977). At this point no quantitative data have been given to support this conclusion, and given the current investigations of non-elite contexts in Mesopotamia, it is not unlikely that our understanding of metal use in West Asia will change.

The fact that metal tools are found throughout most sites does not necessarily mean that all segments of the population had access to metal tools. It is possible that the use of metal tools was limited to specific groups or individuals who themselves may have been distributed throughout the settlements (Kenoyer 1989). Given the lack of more precise distributional or chronological data, we can only say that some types of copper/bronze tools and other utilitarian objects appear to have been generally available both at the large urban sites and at smaller rural settlements.

It is clear that metal objects were not simply utilitarian or symbolic, but that they played a variety of roles in the economy, technology, and socio-ritual/ornamental aspects of the Harappan Phase. As we continue to study the role of metal in early urban societies, it is important to remember that a piece of metal in itself does not indicate status or power. It is the context in which metal is used that is most important for understanding its role in a specific society. One clue to such contextual uses may be gleaned from the inscriptions on metal objects.

HARAPPAN PHASE INSCRIPTIONS ON METAL OBJECTS

Although it has not been possible to make an exhaustive study of the types of metal objects on which inscriptions occur, the recent publications of inscribed objects from the Indus Valley Tradition sites (Shah and Parpola 1991; Joshi and Parpola 1987; Parpola 1994a, 1994b; Yule 1985a, 1985b) reveal some interesting patterns. Large axes, adzes, spears, chisels, and sheets of copper often have one or more signs chiseled into one or both sides. The inscriptions are usually in a vertical line down the center but in the case of some celts, they are located at the butt edge. In most instances the script would be obscured by hafting or damaged during use, and this suggests that these metal tools may have had some specific ritual or symbolic function.

One category of metal object that was used almost exclusively for inscriptions is flat, square to rectangular copper tablets. At Mohenjo-daro hundreds of these inscribed tablets have been recovered (Marshall 1931; Mackay 1938; Yule 1985a). The inscriptions consist of Indus script and animal motifs, usually on both faces of the tablet. The engraving may have been done with either a stone burin or a bronze graver. So far this type of engraved tablet is unique to Mohenjo-daro, but copper tablets with raised script were found at Harappa by Vats (Vats 1940) and also by the Harappa Archaeological Research Project (Meadow and Kenoyer 1994). Due to heavy corrosion, the techniques of manufacture have not yet been determined. The script on both types of tablets was not written in reverse and therefore these tablets were not intended to be used as seals, but represent some sort of ritual or economic token (Parpola 1992).

Usually, Harappan Phase seals are made from fired steatite, but there are two examples from Mohenjo-daro of silver seals made in the standard square shape with a boss (Mackay 1938:348, pls. XC, 1, XCVI, 520). Mackay suggests that they were first cast with the animal motif, script, and boss, and later touched up using a graver. The edges have been scraped and pared, but the rest of the surfaces are too corroded to determine the exact nature of manufacture (Kenoyer, on-going research).

Careful examination of some gold ornaments from a jewelry hoard in DK-E area at Mohenjo-daro by Kenoyer has revealed the almost invisible traces of inscriptions that have been overlooked by previous scholars. Of particular interest are gold pendants that have often been referred to as "needles" (Marshall 1931:251–253, 521, pl. CLI, B 3, 4, 5). Two of three pendants are inscribed. The third pendant is currently on display at the National Museum in Delhi and it has not been examined, but it too may be inscribed. On one pendant the five signs encircle the entire object, while on the second example a sequence of five different signs is inscribed along the length of the pendant. From this same hoard came two pairs of gold caps or terminals that would have been affixed to the ends of beads. One of each pair of gold caps has an identical inscription consisting of a single sign.

All of the inscriptions appear to have been made by the same sharp and very pointed tool, and give the impression of being written in the same "handwriting." These inscriptions are extremely important because they are clearly different from the types of inscriptions found on the large copper celts and chisels. These inscribed gold objects were found inside a copper cooking pot that had been covered by a copper plate. Other items in this hoard include a massive belt made of carnelian and bronze beads, gold ear studs, stone beads, and some copper vessels. It is possible that before this wealth was hidden away, the names of specific owners were incised on some of the gold jewelry (Kenoyer, on-going research).

CONCLUSION

We will conclude this long summary of data relating to Indus Valley Tradition metal processing with a brief outline of selected future challenges for work on Indus Valley Tradition metals. High archaeological and analytical priorities include the search for metal processing areas, both at Indus Valley Tradition sites and in the resource areas, and the investigation of production techniques through systematic analyses of objects, slags, and ores. Among the highest theoretical and comparative priorities are understanding the organization and control of metal craft production, and the relationships between Harappan Phase peoples and the copper-using, apparently contemporaneous cultures in Rajasthan.

ARCHAEOLOGICAL AND ANALYTICAL CHALLENGES

As noted above, recent surface surveys have located a few metal processing areas at Harappa and Mohenjo-daro (Miller 1994a, 1994b; Pracchia et al. 1985). But given the fumes, smoke, and fire associated with metal processing, the most likely location of melting and casting areas would be on the periphery of settlements. Very few metalworking areas have been found on the high, mounded portions of the Harappan Phase settlements, and therefore the majority may be buried beneath the alluvium or at the edges of the site. It is also possible that the infrastructure of Harappan Phase craft production encouraged the establishment of "villages" of specialized producers, such as the site of Chanhu-daro, which seems to be a specialized lapidary production site. The currently unexcavated sites in Cholistan and on the Pakistan-Indian border may well supply evidence for a great deal of metalworking, as hinted at by large-scale surface surveys (Mughal 1982). The implications of these sorts of spatial distributions form part of on-going dissertation research by Miller (1994a) on the organization of high-temperature manufacturing areas in relation to both the physical structure and the socioeconomic structure of the Harappan Phase cities.

Systematic compositional and physical analyses of objects, slags, and ores are needed for the determination of Indus Valley Tradition metal sources, and of production techniques. The study of Indus Valley Tradition ore procurement would be greatly enhanced if further detailed investigations of copper ore deposits could be conducted in the Aravalli and Baluchistan regions, as has been done in Oman and for non-copper ores in the Aravallis (see section on Ore Sources above). Some work is in progress on the investigation of production techniques, via examination of finished objects (Pigott et al. 1989 and on-going research) and examination of by-products and manufacturing sites (Miller 1994b and on-going research). However, a great deal remains to be done on all stages of processing.

THEORETICAL AND COMPARATIVE CHALLENGES

The Indus Valley Tradition peoples were talented craftspeople and technological innovators, and the study of craft production is producing important data on many aspects of their economy, society, beliefs, and political structures. Metal production has been one of the least studied industries, and further work on metals will be a welcome addition to on-going discussions about craft production, particularly examinations of control of various crafts.

It is difficult to discuss control for the Indus Valley Tradition, due to the still elusive nature both of Indus elites and of their power base(s). The majority of Indus craft production studies have so far focused on segregation/aggregation of craft production stages, and their use in defining control of craft industries (Bondioli and Vidale 1986; Kenoyer 1989, 1992a; Pracchia et al. 1985; Tosi 1984; Vidale et al. 1992; Wright 1991; summarized in Miller 1994a). These discussions suggest that some Harappan Phase crafts were apparently structured on the basis of social networks and were decentralized in terms of state control. Other crafts may have involved long-distance social networks and alliances that could be decentralized in terms of direct political control, but required some centralized support to maintain long-distance trade relations. It has also been suggested that crafts that were difficult to control directly may have been less important for state economy, while easily controlled crafts could have been important for state economy (Kenoyer 1991, 1992a). The location of the various metal processing stages will form an important new data set for these segregation/aggregation-based discussions.

Other aspects of craft production used to indicate control of production have received less attention for the Indus Valley Tradition (summarized in Miller 1994a). This is in part due to inherent difficulties with the data, including the lack of written texts as well as past methods of excavation and record-keeping, and geomorphological transformations of deposits. Nevertheless, some information about degrees of control can be gleaned from considering such aspects of craft production as the distribution and association of various craft production areas, and the degree of restriction of access to such areas. Standardization of products, although not simply indicative of "attached" vs. "independent" production (Costin 1991), also provides information about the producers and the structure of production. Costin's discussion of different types and degrees of control will be helpful in the continuing process of developing more appropriate interpretive models for the complex Indus Valley Tradition situation.

Finally, some of the more intriguing results of Indus Valley Tradition metal studies will be the opportunities for comparison of metal use and production both within the Indus Valley Tradition (regional variants) and with contemporaneous groups to the west and to the east.

The comparison of production techniques and uses of metals within the Indus Valley Tradition itself will be extremely important. Through such approaches we can begin more meaningful discussions of independent and derived invention, shared and restricted knowledge, the adoption of technological innovations, and technological style, including the deliberate choice of methodologies as a component of ethnic identity (cf. Lechtman and Steinberg 1979).

On an inter-regional level, while many of the diffusion models that were proposed in the past have been refuted, there is still an underlying assumption that the Indus artisans were the recipients of knowledge from the highlands to the west, which they then passed on eastwards. Current investigations of information exchange and control of knowledge are gradually breaking away from the bounds of directionality that dominated the diffusion models of the past. In addition, the use and production of copper objects by groups in Rajasthan, some of which may still have been heavily dependent on hunting and/or shifting agriculture, reminds us that technological "stages" like the working of metal cannot be equated with other levels of social complexity, such as urban/non-urban. The comparison of metal processing techniques between culturally very distinct regions known to have communicated to some degree will add considerably to our knowledge of technological change and information exchange.

ACKNOWLEDGMENTS

As much of our experience and understanding of Indus Valley Tradition metallurgy derives from our recent firsthand experience at the site of Harappa, we would both like to dedicate this paper to the memory of Dr. George F. Dales who made it possible for us to work at Harappa and was always encouraging and supportive in our metallurgical research. We would also like to thank the Department of Archaeology and Museums, Pakistan for allowing us to work at Harappa and allowing Kenoyer to study the reserve collections in Harappa, Mohenjo-daro, and Karachi.

Other aspects of this paper are the result of considerable cooperation from colleagues and experimentation by both authors. We would especially like to thank colleagues who have allowed us to examine their unpublished materials and papers, including the late W. A. Fairservis, R. Hooja, J. Haquet, J.-F. Jarrige, M. Jansen, M. Tosi, M. Vidale, and the Museum of Fine Arts, Boston, where the Chanhu-daro collection is presently being curated and restudied. Special thanks are due M. Vidale for his comments and new information.

In terms of our own expertise it is important to note that Kenoyer has only recently begun to delve into the details of metallurgical research with the study of the metal objects from Harappa and through experimental research in smelting, melting, casting, and forging.

Miller acquired much of her practical knowledge of metalworking as the result of a year of part-time apprenticeship with Eleanor Moty and Fred Fenster of the Department of Art, University of Wisconsin-Madison, and at Max and Ruth Frōlich's seminar on Ashante lost-wax casting at the Haystack Mountain School of Crafts; many thanks to the many metalsmiths associated with these programs for their enthusiasm and advice.

Please contact us with any suggestions or comments about our presentation of the data or our interpretations, especially if we have overlooked data (both authors are at: Dept. of Anthropology; 1180 Observatory Drive, No. 5240; Madison, WI 53706-1393; Email: kenoyer@macc.wisc.edu, heatherm@macc.wisc.edu). Finally, we would both like to thank Dr. Vince Pigott for inviting us to prepare this paper, R. Meadow and R. Wright for their comments on earlier drafts, and an anonymous reviewer for his/her painstaking reading and thoughtful suggestions, which significantly improved the clarity of this paper.

Note: We regret that we only received a copy of Chakrabarti and Lahiri's book after this article was in production. We highly recommend this seminal volume for more information on sites and ore sources in India, the use of copper after the Indus Tradition period, textual evidence for copper working, and ethnographic work on Indian coppersmiths.

Chakrabarti, D. K., and Lahiri, N.
1996 *Copper and its Alloys in Ancient India.* New Delhi: Munshiram Manoharlal Publ. Pvt. Ltd.

APPENDIX A

Dashes (–), "tr," "0.00" recorded exactly as in original published tables. Blanks indicate that these elements were not reported.

MOHENJO-DARO: COPPER AND COPPER ALLOYS (SANAULLAH 1931:484)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
	slab	82.71	13.21	1.17	0.11	0.42	0.56	0.33		0.00				1.49		100.00
	lump	83.92	12.13	0.00	0.17	0.00	0.17	tr		0.00				3.61		100.00
	chisel	85.37	11.09	0.07	tr	0.18	0.16	tr		0.11				3.02		100.00
	chisel	86.22	12.38	–	0.70	0.35	0.00	0.35		–				–		100.00
	buttons	88.05	8.22	tr	0.00	0.29	tr	2.60		0.84				–		100.00
	rod	91.90	4.51	1.96	0.17	0.15	–	1.15		0.16				–		100.00
	chisel (?)	92.41	0.00	3.42	3.28	0.59	0.15	0.10		0.05				–		100.00
	copper lump	92.49	0.37	1.30	tr	1.51	1.06	tr		2.26				1.01		100.00
	celt	94.76	0.09	4.42	0.26	0.15	0.14	–		–				–		99.82
	frag. of implement	95.80	0.00	0.74	1.58	0.12	0.25	0.72		0.61				0.18		100.00
	copper lump	96.42	0.00	0.00	0.09	0.00	0.35	–		0.36				2.78		100.00
	copper lump	96.67	0.00	0.15	0.02	0.03	1.27	0.88		0.98				–		100.00
	copper lump	97.07	0.00	0.98	tr	0.49	0.31	tr		1.15				–		100.00

MOHENJO-DARO: COPPER AND COPPER ALLOYS (HAMID IN MACKAY 1938:479–480 EXCEPT AS NOTED)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
Dk 7856	chisel	75.25	7.84	0.00	0.39	0.51	0.61	1.25		0.00						85.85
Dk 5486	axe	80.56	1.76	2.10	0.20	0.34	0.58	tr		0.00						85.54
Dk 5360	pan with handle	81.94	0.37	0.80	0.05	0.33	0.21	0.18		0.14						84.02
Dk 6043	chisel	86.92	8.56	1.58	tr	0.02	0.68	0.54		0.07						98.37*
Dk 7861	portion of axe	88.49	9.88	0.00	0.22	0.10	0.30	0.14		0.06						99.19
Dk 7854	axe/celt	90.18	7.66	0.00	0.95	0.50	0.20	0.43		0.07						99.99
Dk 7535	axe/celt	91.01	6.14	0.66	0.59	0.33	0.48	0.25		0.12						99.58
Dk 7853	axe/celt	94.64	0.31	0.40	0.71	0.28	0.33	0.06		0.69						97.42
Dk 7859	spear/knife	95.23	0.00	0.24	0.82	0.56	0.41	0.00		0.48						97.74
Dk 7343	chisel/square rod	97.23	0.00	0.24	0.81	0.29	0.89	0.00		0.10						99.56
Pit-Dk 5316?**	copper ore	76.15		0.37	tr		0.23			1.12					4.8	77.87

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*Addition error in original.

**Published in Pascoe in Mackay 1938:600.

APPENDIX A (CONTINUED)

HARAPPA: COPPER AND COPPER ALLOYS (SANAULLAH 1940:378)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
X	chisel	87.42	10.45	1.10	0.52	0.34	0.17	–	–	*						100.00
Af150	awl	88.38	9.16	0.40	0.10	1.37	0.17	0.42	–	*						100.00
—	dagger	90.05	0.00	6.58	2.80	0.39	0.18	–	–	*						100.00
1208	dagger	91.00	6.76	0.04	0.88	0.74	0.14	0.44	–	*						100.00
Lot 277a/21	celt	91.10	7.85	0.42	tr	0.41	0.22	tr	–	*						100.00
4255	dagger	91.87	6.42	0.26	0.98	0.47	tr	–	–	*						100.00
11859	needle	92.55	0.29	2.96	3.72	0.20	0.21	–	0.07	*						100.00
B1754	chisel	92.61	6.43	0.36	tr	0.09	0.20	0.31	–	*						100.00
Lot 277k/3	chisel	94.92	3.60	0.60	0.20	0.39	0.29	–	–	*						100.00
5133	rectangular rod	97.20	0.84	0.70	0.00	0.98	0.09	0.19	–	*						100.00
J125	spearhead	97.66	0.33	0.06	0.70	1.11	0.14	–	–	*						100.00
Lot 277	folded sheet	97.69	0.15	1.19	0.85	0.07	0.05	tr	–	*						100.00
Lot 277g/2	saw	98.12	0.33	0.65	0.10	0.41	0.39	–	–	*						100.00
Lot 277a/19	celt	98.37	0.00	1.40	0.11	0.02	0.10	–	–	*						100.00
Lot 277	fragment	98.60	0.07	0.66	tr	0.41	0.26	–	–	*						100.00
Lot 277e/2	lancehead	98.69	0.10	0.68	tr	0.13	0.40	–	–	*						100.00

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*SanaUllah notes that for the items from Harappa, "Sulphur is frequently present in minute quantities," but gives no particulars.

HARAPPA: COPPER AND COPPER ALLOYS (PIGOTT ET AL. 1989)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
H88/444-1	mirror	77.20	<.038	0.93	0.5	0.051	0.25	<.057	<1.1	0.38	<.029	<.022	18.9			98.21
H88/346-27	spherical bead	85.30	12.7	0.59	0.27	0.11	0.38	0.042	<.84	0.041	0.035	0.028	0.05			99.55
H88/751-21	spear point	93.40	2.6	1.91	0.17	0.15	0.3	<.053	<1.2	0.18	<.028	<.033	1.08			99.79
H88/529-120	blade/rod frags	93.70	<.015	4.71	0.051	0.13	0.15	<.022	<.052	0.074	<.012	<.046	<.95			98.82
H86.a	rod fragment	96.40	<.018	2.26	0.39	0.34	0.24	<.019	<.63	0.096	<.015	<.039	0.008			99.73
H86.c	rod fragment	96.50	<.014	2.08	0.32	0.34	0.23	<.018	<.72	0.12	0.02	<.02	0.052			99.66
H87/515	sheet metal/scoop	96.70	<.014	1.17	0.65	0.31	0.52	<.015	<.53	0.29	<.012	0.039	0.022			99.70
H88/325-08E	rod fragment	97.00	<.021	1.95	0.19	0.2	0.27	<.029	<.74	0.074	<.016	<.039	0.019			99.70
H88/325-08D	rod fragment	97.00	<.024	1.86	0.17	0.26	0.26	<.032	<.78	0.094	<.018	<.038	<.011			99.64
H88/761-1B	needle (point)	97.20	<.013	1.95	<.015	0.14	0.23	<.016	<.52	0.018	<.011	0.034	0.14			99.71
H88/761-1A	needle (eye end)	97.40	<.011	1.91	<.017	0.1	<.23	<.015	<.56	0.014	<.013	0.036	0.037			99.50
H88/374-1	large hook/handle	98.60	<.013	10.57	0.032	0.3	0.11	<.017	<.81	0.035	0.036	<.032	0.036			99.72
H88/413-A	finger ring	99.40	<.015	<.01	<.016	0.05	0.091	<.017	<.67	0.01	<.012	<.029	0.016			99.57

APPENDIX A (CONTINUED)

LOTHAL: COPPER AND COPPER ALLOYS (LAL 1985)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
15217	spear/knife	39.07	2.27	*	–	tr	tr		–		–			36.08	12.58	90.00
—	revetted jar	43.00	–	*	–	1.00	–		–					53.77	2.23	100.00
14211	spear head	43.38	–	*	–	0.99	–		–		–			51.18	1.28/3.17 **	100.00
15176	knife handle	46.57	–	*	–	–	–		–		–			49.23	4.20	100.00
15139	ear ornament	48.24	tr	*	tr	0.70	tr		–		–			34.70	16.36	100.00
8480	spear head	48.26	–	*	–	tr	tr		–		–			38.09	13.65	100.00
15079	engraver	49.64	3.96	*	–	tr	tr		–		–			35.68	10.72	100.00
15155	pin	51.89	13.80	*	–	tr	–		–		–			28.91	5.40	100.00
15030	mirror	54.78	5.47	*	–	tr	–		–					31.58	8.17	100.00
15209	bangle	55.32	11.82	*	–	–	–		–		–			28.97	3.89	100.00
15251	lump	57.68	–	*	–	–	–		–		–			35.38	6.94	100.00
13886	rod with grooves	57.75	9.02	*	–	tr	tr		–					29.92	3.31	100.00
13134	pin	57.76	–	*	–	–	–		–		–			28.92	13.32	100.00
14855	ring from burial	58.36	–	*	–	tr	tr		–		–			28.60	13.04	100.00
15073	fragment	59.00	–	*	0.95	1.56	tr		–		–			25.38	13.11	100.00
10842	dagger/chisel	59.64	–	*	–	0.85	1.62		–		–			37.89	–	100.00
15137	rod	60.30	tr	*	–	tr	tr		–		–			26.26	13.44	100.00
5578	fish hook	60.65	–	*	1.30	tr	tr		–		–			32.16	5.99	100.10
14841	ornament	63.58	–	*	–	tr	–		–		–			21.18	15.24	100.00
15085	fragment	66.60	–	*	–	0.80	tr		–		–			32.60	tr	100.00
12378	axe	70.00	–	*	–	–	–		–		–			7.00	23.00	100.00
3872	arrow head	70.30	–	*	–	tr	1.50		–					27.70	0.50	100.00
15210	engraver	70.45	–	*	–	tr	tr		–		–			12.45	17.10	100.00
4189	object	70.69	–	*	–	0.90	tr		–**					22.37	6.04	100.00
12264	bangle	72.26	–	*	–	–	tr		–		–			19.85	7.89	100.00
12432	fragment	72.50	–	*	–	0.95	2.48		–		–			16.65	7.42	100.00
15196	lump	72.83	–	*	–	0.55	tr		–		–			24.09	2.53	100.00
5971	bangle/ring	72.95	–	*	–	–	–		–		–			17.09	9.96	100.00
11893	chisel	74.28	9.62	*	–	tr	tr		–					13.02	3.06	99.98
12143	bangle	74.34	11.20	*	–	tr	tr		–					11.24	3.22	100.00
4148	fragment	74.84	–	*	–	0.61	tr		–					20.10	4.43	100.00
15169	fragment	75.60	–	*	–	tr	tr		–		–			23.90	0.50	100.00
15208	pin	77.40	–	*	–	0.50	tr		–		–			5.90	16.20	100.00
14302	hook	77.44	–	*	–	–	–		–		–			22.56	–	100.00
4759	fragment	79.89	–	*	3.60	tr	tr		–					16.31	0.20	100.00
15194	lump	81.07	–	*	–	0.64	tr		–		–			15.74	2.55	100.00
15063	fish hook	82.90	–	*	–	tr	tr		–		–			15.90	1.20	100.00
11971	figurine	83.31	–	*	–	tr	–		–		–			13.58	–	96.89
15036	lump	83.90	–	*	–	0.32	tr		–		–			12.46	3.32	100.00

APPENDIX A (CONTINUED)

LOTHAL: COPPER AND COPPER ALLOYS (LAL 1985) (CONTINUED)

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	% Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
5590	object	87.08	–	*	–	tr	tr		–					2.92	–	100.00
13140	hook	87.34	–	*	–	0.40	tr		–		–			11.48	0.78	100.00
5373	spear head	87.34	–	*	–	–	–		–		–			12.66	–	100.00
3091	shaft hole axe	88.27	–	*	–	tr	0.19		–					10.75	0.79	100.00
8110	chisel	88.53	–	*	–	tr	tr		–					10.99	0.48	100.00
5501	rod	88.60	–	*	–	tr	tr		–					11.10	0.30	100.00
14087	piece	88.76	–	*	–	tr	tr		–		–			10.66	0.58	100.00
12455	pin	89.95	–	*	–	tr	–		–		–			1.04	9.01	100.00
7700	chisel	90.44	–	*	–	tr	tr		–		–			9.56	–	100.00
12125	lump	90.68	–	*	–	4.02	–		–		–			5.03	0.28	100.00
6030	nail/pin	90.79	–	*	–	tr	0.63		–		–			8.58	–	100.00
SRG-324	fish hook	91.60	–	*	–	–	tr		–					8.40	–	100.00
SRG-B (20)	hand axe/celt	91.87	–	*	–	tr	0.80		–					7.11	0.20	100.00
4813	lump	93.65	–	*	1.51	tr	1.55		–					2.80	0.49	100.00
3091	hand axe/celt	94.33	–	*	–	–	tr		–					5.30	0.37	100.00
1344	bangle	94.90	–	*	–	2.14	0.45		–					2.51	–	100.00
4744	ring	95.31	–	*	–	–	–		–		–			4.69	–	100.00
10918	axe with sleeves†	96.27	–	*	2.51	tr	tr		–					1.22	–	100.00
15295	pin	96.76	0.57	*	–	tr	1.92		–		–			0.75	–	100.00
5957	celt	97.18	tr	*	–	tr	0.31		–					1.17	1.34	100.00
10918	axe/celt†	97.20	–	*	0.91	–	–		–		–			1.89	–	100.00
12147	arrow head	97.21	–	*	–	tr	tr		–					2.79	–	100.00
625	arrow head	97.70	–	*	–	–	tr		–					2.3	–	100.00
6040	fish hook	99.01	–	*	–	tr	0.28		–					0.71	–	100.00
14535	ingot	99.81	–	*	–	tr	tr		–					0.19	–	100.00

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*As was tested for, but no traces were found in any object.

**Typographical error in original.

†Two different analyses published.

APPENDIX A (CONTINUED)

RANGPUR: COPPER AND COPPER ALLOYS (RAO 1963:153; REPRINTED IN AGRAWAL 1971:167, TABLE 28).*

Object no.	Description	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb*	% Zn*	% S	% Ag*	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
RP 169	bangle	57.70	6.94	–	–	tr	tr		–					35.46		100.10**
RP 526	knife	59.00	5.28	–	–	tr	tr		–					35.72		100.00
RP 525	knife	59.60	2.69	–	–	1.08	–		–					36.63		100.00
RP 141	pin, needle	65.40	6.78	–	–	0.24	0.51		–					27.08		100.01**
RP 170	amulet	77.60	tr	–	–	0.57	0.1		–					21.73		100.00
RP 437	bangle	86.40	11.07	tr	tr	–	1.8		–					0.73		100.00
RP 324	celt	91.20	2.6	–	tr	–	2.1		–					4.1		100.00
RP 663	celt	91.35	4.09	tr	tr	–	tr		–					4.6		100.04**
RP 417	knife	94.80	0.7	–	–	tr	0.4		–					4.1		100.00
RP 635	ring, finger	96.10	tr	–	–	0.45	0.2		–					3.25		100.00
RP 442	pin, rolled head	96.60	tr	–	–	1.86	0.8		–					0.74		100.00
RP 260	bead	96.66	tr	–	–	1.4	0.38		–					1.56		100.00

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*Zn tests, with no traces found, were only reported by Rao. Agrawal seems to indicate that Ag, Bi, and Sb were all tested for, with no traces found, but there is no indication of this in Rao's original report.

**Addition error in original (Rao 1963:153).

Note: A thirteenth object, RP 330, was reported by both Rao and Agrawal, but is not included here since it is from Period III, dating to after the Harappan Phase. This object had a high nickel content, 5.88%.

APPENDIX B

Dashes (–), "tr," "0.00" recorded exactly as in original published tables. Blanks indicate that these elements were not reported.

TIN BRONZE OBJECTS: MOHENJO-DARO, HARAPPA, LOTHAL, RANGPUR

Object no.	Description	Reference	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	%Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
Mirrors																	
Lothal 15030	mirror	Lal 1985	54.78	5.47	–	–	tr	–		–					31.58	8.17	100.00
Ornaments																	
Lothal 15155	pin	Lal 1985	51.89	13.80	–	–	tr	–		–		–			28.91	5.40	100.00
H88/346-27	bead	Pigott et al. 1989	85.30	12.70	0.59	0.27	0.11	0.38	0.042	<.84	0.041	0.035	0.028	0.05			99.55
Lothal 15209	bangle	Lal 1985	55.32	11.82	–	–	–	–		–		–			28.97	3.89	100.00
Lothal 12143	bangle	Lal 1985	74.34	11.20	–	–	tr	tr		–					11.24	3.22	100.00
RP 437	bangle	Agrawal 1971; Rao 1963	86.40	11.07	tr	tr	–	1.8		–					0.73		100.00
MD	buttons	SanaUllah 1931	88.05	8.22	tr	0.00	0.29	tr	2.60		0.84				–		100.00
RP 169	bangle	Agrawal 1971; Rao 1963	57.70	6.94	–	–	tr	tr		–					35.46		100.10
RP 141	pin, needle	Agrawal 1971; Rao 1963	65.40	6.78	–	–	0.24	0.51		–					27.08		100.01
Tools																	
MD Dk 7861	axe	Hamid in Mackay 1938	88.49	9.88	0.00	0.22	0.10	0.30	0.14		0.06						99.19
H Lot 277a/21	celt	SanaUllah 1940	91.10	7.85	0.42	tr	0.41	0.22	tr	–	*						100.00
MD Dk 7854	axe/celt	Hamid in Mackay 1938	90.18	7.66	0.00	0.95	0.50	0.20	0.43		0.07						99.99
MD Dk 7535	axe/celt	Hamid in Mackay 1938	91.01	6.14	0.66	0.59	0.33	0.48	0.25		0.12						99.58
RP 663	celt	Agrawal 1971; Rao 1963	91.35	4.09	tr	tr	–	tr		–					4.6		100.04
RP 324	celt	Agrawal 1971; Rao 1963	91.20	2.60	–	tr	–	2.1		–					4.1		100.00
MD Dk 5486	axe	Hamid in Mackay 1938	80.56	1.76	2.10	0.20	0.34	0.58	tr		0.00						85.54
H 1208	dagger	SanaUllah 1940	91.00	6.76	0.04	0.88	0.74	0.14	0.44	–	*						100.00
H 4255	dagger	SanaUllah 1940	91.87	6.42	0.26	0.98	0.47	tr	–	–	*						100.00
RP 526	knife	Agrawal 1971; Rao 1963	59.00	5.28	–	–	tr	tr		–					35.72		100.00
RP 525	knife	Agrawal 1971; Rao 1963	59.60	2.69	–	–	1.08	–		–					36.63		100.00
H88/751-21	spear point	Pigott et al. 1989	93.40	2.60	1.91	0.17	0.15	0.3	<.053	<1.2	0.18	<.028	<.033	1.08			99.79
Lothal 15217	spear/knife	Lal 1985	39.07	2.27	–	–	tr	tr		–		–			36.08	12.58	90.00
MD	chisel	SanaUllah 1931	86.22	12.38	–	0.70	0.35	0.00	0.35		–				–		100.00
MD	chisel	SanaUllah 1931	85.37	11.09	0.07	tr	0.18	0.16	tr		0.11				3.02		100.00
H X	chisel	SanaUllah 1940	87.42	10.45	1.10	0.52	0.34	0.17	–	–	*						100.00
Lothal 11893	chisel	Lal 1985	74.28	9.62	–	–	tr	tr		–					13.02	3.06	99.98
MD Dk 6043	chisel	Hamid in Mackay 1938	86.92	8.56	1.58	tr	0.02	0.68	0.54		0.07						98.37
MD Dk 7856	chisel	Hamid in Mackay 1938	75.25	7.84	0.00	0.39	0.51	0.61	1.25		0.00						85.85
H B1754	chisel	SanaUllah 1940	92.61	6.43	0.36	tr	0.09	0.20	0.31	–	*						100.00
Lothal 15079	engraver	Lal 1985	49.64	3.96	–	–	tr	tr		–		–			35.68	10.72	100.00
H Lot 277k/3	chisel	SanaUllah 1940	94.92	3.60	0.60	0.20	0.39	0.29	–	–	*						100.00
MD	rod	SanaUllah 1931	91.90	4.51	1.96	0.17	0.15	–	1.15		0.16				–		100.00
Lothal 13886	rod with grooves	Lal 1985	57.75	9.02	–	–	tr	tr		–					29.92	3.31	100.00
H Af150	awl	SanaUllah 1940	88.38	9.16	0.40	0.10	1.37	0.17	0.42	–	*						100.00
Miscellaneous																	
MD	slab	SanaUllah 1931	82.71	13.21	1.17	0.11	0.42	0.56	0.33		0.00				1.49		100.00
MD	lump	SanaUllah 1931	83.92	12.13	0.00	0.17	0.00	0.17	tr		0.00				3.61		100.00

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*SanaUllah notes that for the items from Harappa, "Sulphur is frequently present in minute quantities," but gives no particulars.

APPENDIX B (CONTINUED)

ARSENICAL BRONZE: MOHENJO-DARO, HARAPPA

Object no.	Description	Reference	% Cu	% Sn	% As	% Pb	% Fe	% Ni	% Sb	% Zn	% S	%Ag	% Co	% Cl	% Oxygen by difference	% Acid-insoluble residue	TOTAL %
Mirrors																	
H88/444-1	mirror	Pigott et al. 1989	77.20	<.038	0.93	0.5	0.051	0.25	<.057	<1.1	0.38	<.029	<.022	18.9			98.21
Tools																	
MD	celt	SanaUllah 1931	94.76	0.09	4.42	0.26	0.15	0.14	–		–				–		99.82
MD Dk 5486	axe	Hamid in Mackay 1938	80.56	1.76	2.10	0.20	0.34	0.58	tr		0.00						85.54
H Lot 277a/19	celt	SanaUllah 1940	98.37	0.00	1.40	0.11	0.02	0.10	–	–	*						100.00
H	dagger	SanaUllah 1940	90.05	0.00	6.58	2.80	0.39	0.18	–	–	*						100.00
H88/529-120	blade/rod frags	Pigott et al. 1989	93.70	<.015	4.71	0.051	0.13	0.15	<.022	<.052	0.074	<.012	<.046	<.95			98.82
H88/751-21	spear point	Pigott et al. 1989	93.40	2.6	1.91	0.17	0.15	0.3	<.053	<1.2	0.18	<.028	<.033	1.08			99.79
MD	chisel (?)	SanaUllah 1931	92.41	0.00	3.42	3.28	0.59	0.15	0.10		0.05				–		100.00
MD Dk 6043	chisel	Hamid in Mackay 1938	86.92	8.56	1.58	tr	0.02	0.68	0.54		0.07						98.37
H X	chisel	SanaUllah 1940	87.42	10.45	1.10	0.52	0.34	0.17	–	–	*						100.00
H86.a	rod	Pigott et al. 1989	96.40	<.018	2.26	0.39	0.34	0.24	<.019	<.63	0.096	<.015	<.039	0.008			99.73
MD	rod	SanaUllah 1931	91.90	4.51	1.96	0.17	0.15	–	1.15		0.16				–		100.00
H88/325-08E	rod	Pigott et al. 1989	97.00	<.021	1.95	0.19	0.2	0.27	<.029	<.74	0.074	<.016	<.039	0.019			99.70
H 11859	needle	SanaUllah 1940	92.55	0.29	2.96	3.72	0.20	0.21	–	0.07	*						100.00
H88/761-1	needle	Pigott et al. 1989	97.20	<.013	1.95	<.015	0.14	0.23	<.016	<.52	0.018	<.011	0.034	0.14			99.71
Miscellaneous																	
MD	copper lump	SanaUllah 1931	92.49	0.37	1.30	tr	1.51	1.06	tr		2.26				1.01		100.00
H Lot 277	folded sheet	SanaUllah 1940	97.69	0.15	1.19	0.85	0.07	0.05	tr	–	*						100.00
H87/515	sheet metal/scoop	Pigott et al. 1989	96.70	<.014	1.17	0.65	0.31	0.52	<.015	<.53	0.29	<.012	0.039	0.022			99.70
MD	slab	SanaUllah 1931	82.71	13.21	1.17	0.11	0.42	0.56	0.33		0.00				1.49		100.00
MD	copper lump	SanaUllah 1931	97.07	0.00	0.98	tr	0.49	0.31	tr		1.15				–		100.00

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*SanaUllah notes that for the items from Harappa, "Sulphur is frequently present in minute quantities," but gives no particulars.

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