THE ARCHAEOMETALLURGY OF COPPER AT FEINAN, JORDAN: FIELD RESEARCH AND ANALYTICAL WORK OF AN ANCIENT ORE DISTRICT

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1. AIMS AND METHODS OF ARCHAEOMETALLURGY

Research work in archaeometallurg is focussed basically on the development and diffusion of ancient extraction and treatment of metals, and there are two fundamental questions which may be traced back even to the beginnings of archaeology itself. The first is addressed to the technology of metal production. The second deals with provenance studies to reconstruct ancient trade ways.

The technology of metal production comprises the investigation of mining and smelting techniques, and the further treatment of metals such as refining, alloying, and smithing. Studies on these topics were performed as early as the beginning of this century, among others by Gowland [1] or Zschocke and Preuschen [2]. They quickly recognised the benefit of comparing the archaeological with ethnographic evidences of primitive mining and smelting techniques in countries such as Japan, Africa or the Far East. Such observations are as important as experimental work, because it has been shown repeatedly that one of the jeopardises of reconstructing ancient metallurgical processes is an intellectual overload by methods of modern metal technology.

Investigations on metal production, based upon research of ancient production centres, were neglected in archaeology for a long time. This is due to its research theory which up until today is mainly focussed on art-related archaeology, and, hence, directed by aesthetic aspects. In addition, materials like slag –ancient waste– are hardly to understand by conventional methods of archaeology. To unlock informations from slags and ores, not only the instrumental application of chemical, mineralogical and physical methods is necessary. An interpretation to response archaeological questions in a qualified matter is essentially based upon the dialogue between archaeologists and scientists, which also presupposes a proper "adjustment" of methods and scientific problems to archaeology. In this sense, pioneering work on mining archaeological and archaeometallurgical remains of prehistoric metal production was published [3, 4 and 5].

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It was not before the last twenty years, that a closer and serious cooperation between archaeologists and scientists -ARCHAEOMETRY- resulted in considerable scientific progress which on its side led to new directions in archaeology. Examples are the dating, isotope analyses in archaeometallurgy and other fields, DNA analyses in biochemistry, and others. But even today, archaeometry only rarely is fully established at Universities in Europe.

On the other hand, metal artefacts were investigated more intensively than ancient production sites. The purpose of these studies, even since the beginning of archaeology, was to trace back the origin of metals to sources, to find the ore they were smelted from. These provenance studies were the basis to reconstruct ancient trade ways and to gain informations on the spread of metallurgy. The so far largest research project on chemical and statistical analyses of metal objects was carried out in the sixties by Junghans *et al.* [6, 7 and 8] in "Studien zu den Anfängen der Metallurgie". Later, lead isotope analysis became one of the most powerfull tool in provenance studies, and most important research work was carried out by the Gales/Oxford and by the Heidelberg/Mainz research group. During all this work it became obvious that provenance studies are intimately connected with questions of the ore deposit, and the technology of early metallurgical processes. Hence, there is a considerable demand on field work especially on ancient production sites to investigate ores, ancient mines, and smelting sites.

2. THE SITE

The copper ore deposit of Feinan is located at the eastern margin of the Wadi Arabah (figure 1) which is part of a transform strike-slip fault from the Red Sea to the Zagros-Taurus subduction zone. By a lateral movement of the Arabian and the African Plates, the rift divided the originally coherent copper ore districts of Timna and Feinan. Other mineralizations, to a lesser content, emerge at the Wadis Abu Kusheiba/Abu Qurdiya farther south.

The outcrops of copper ore in the Feinan district comprise an area of ca. 20 x 25 km (figure 2). Field work carried out in a joint project between the Department of Antiquities, Amman (Jordan) and the Deutsches Bergbau-Museum, Bochum (Germany) has revealed that at Feinan early copper production took place on a large industrial scale. Smelting sites with 150.000 to 200.000 t of slag and more than 150 copper mines exceeded by far any activity at Timna or at the smelter of Bir Nasib, Sinai. Indeed, in this region no other smelting site of similar size is known. Feinan, therefore, must have played an important role in the early copper supply of the southern Levant.

3. THE EXPLOITATION OF THE ORE DEPOSIT

Feinan is part of an ore district which is exposed at several localities along the margins of the Wadi Arabah. It is a strataform, sedimentary deposit of a multistage origin. The ores monotonously consist of secondary copper ores such as atacamite, mala-

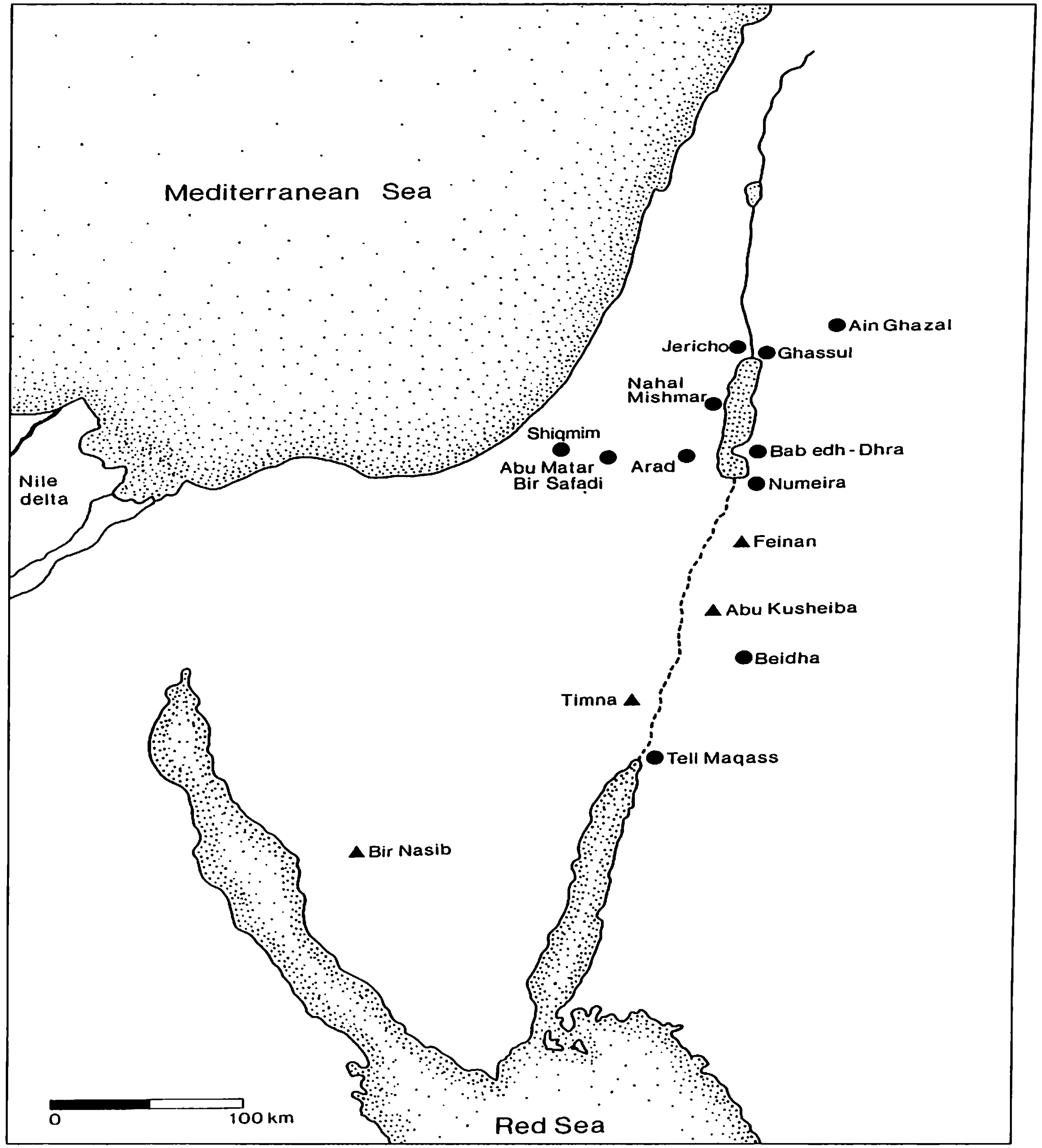

Figure 1. Geographic map of the southern Levant and Sinai with copper deposits (▲) and archaeological sites (•) mentioned in the text.

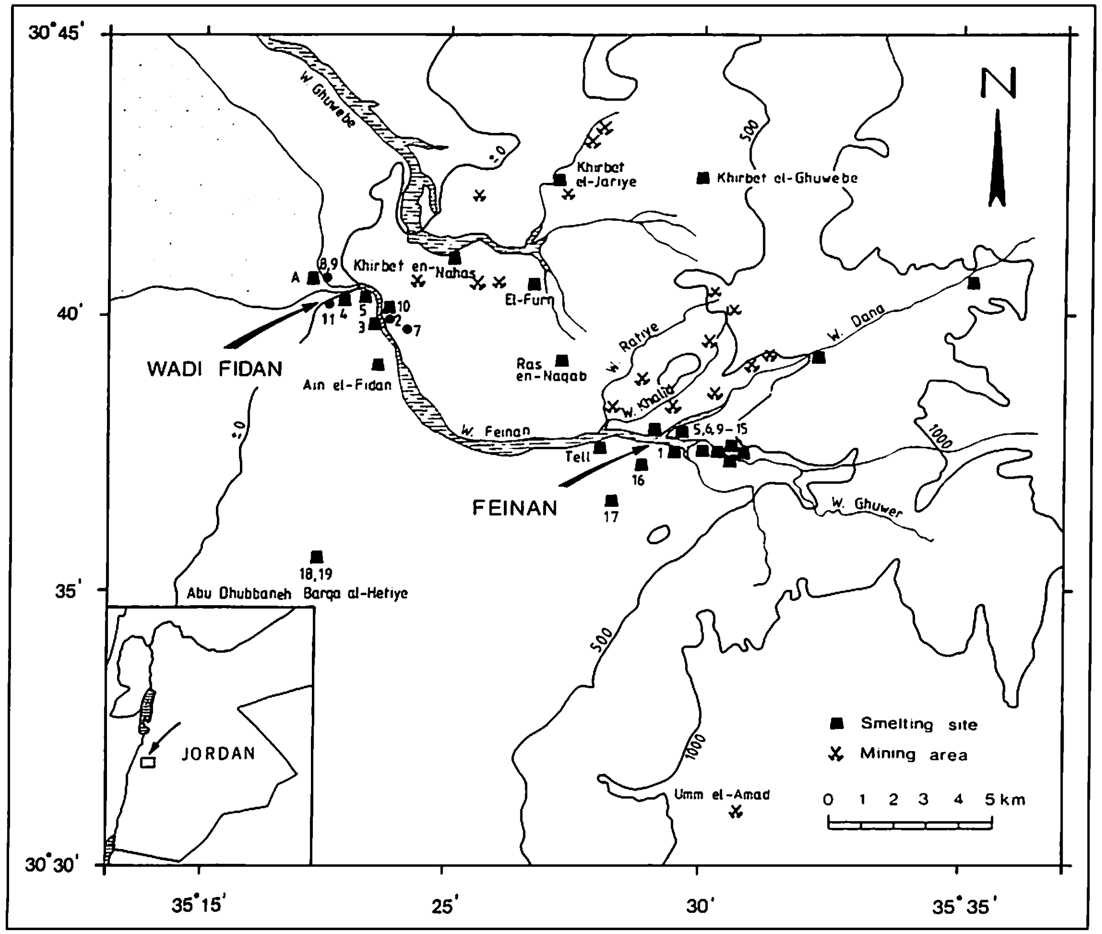

Figure 2. The ancient ore district in the area of Feinan at the foothills of the Jordanian Plateau. Indicated are smelting sites and mining areas. Each mining symbol represents a locality where sometimes up to fifty individual mines have been discovered. The location of mines on the map are primarily associated with outcrops of copper ores. Settlements mentioned in the text are also shown.

chite, and various copper silicates (chrysocolla, dioptas) which are embedded in flat dipping shales and sandstones [9]. Different to many other prehistoric ore districts which are more or less destroyed by modern mining activities, at Feinan it is possible still today to collect high grade ores with a copper concentration of > 50%.

This type of ore deposit is rather rare in the Near East, it has just one parallel in Late Precambrian sediments in the southwest of the Sinai peninsula [10]. Otherwise, and this is of major importance to better understand the development of metallurgy in the Old World, sulfidic ore deposits are prevailing. These are mostly of hydrothermal origin, and the iron hut or gossan of such deposits is exposed to the surface. With increasing depth, a zone of oxidized ores is below the outcrop; it covers a secondary enrichment zone and finally the primary ore deposit. This sequence of changing compositions served as a simplified model to explain the stepwise development of metallurgy:

the earliest use of native copper, then the smelting of oxidic copper ores, followed by the extractive metallurgy of (complex) sulfidic Cu/Fe-sulfides.

Due to their origin, Feinan and Timna are hardly to distinguish in their mineral content, geochemistry, and in the isotopic composition of their lead [11 and 12]. For instance, the chemical composition of more than 100 samples of ores from Timna, and the same number from Feinan showed that the concentrations of those elements are similar in both deposits which should be more or less enriched during smelting in the metal (Ag, Pb, Zn, As, Sb, Co, Ni). This implicates that also metal objects made from Timna or Feinan copper ores, respectively, are hardly to distinguish.

There is a possibility, however, to separate at least the copper ores from the two localities. This is due to their different geological setting. At Feinan, the major ore horizon in the Dolomite-Limestone-Shale Unit (DLS) is widely exposed to the surface especially in the Wadi Dana and Khalid (figure 3). The upper part of this formation, in a thickness of ca. 1-1.5 m, provides plentiful greenish copper silicates, malachite, and atacamite, embedded in a series of Cambrian shales which contain considerable concentrations of carbonates, manganese ores and phosphorite (figure 4). The corresponding formation in the west, the Timna-Formation, is buried under a thick sequence of sediments and, with but a few small outcrops [12], was only exploited by modern mining activities. At Feinan, ores from the DLS were easily to exploit in ancient times, because of the friability of the shales. In a stratigraphic higher formation, the Massive Brown Sandstone (MBS) thin vein fillings occur which were formed by a remobi-

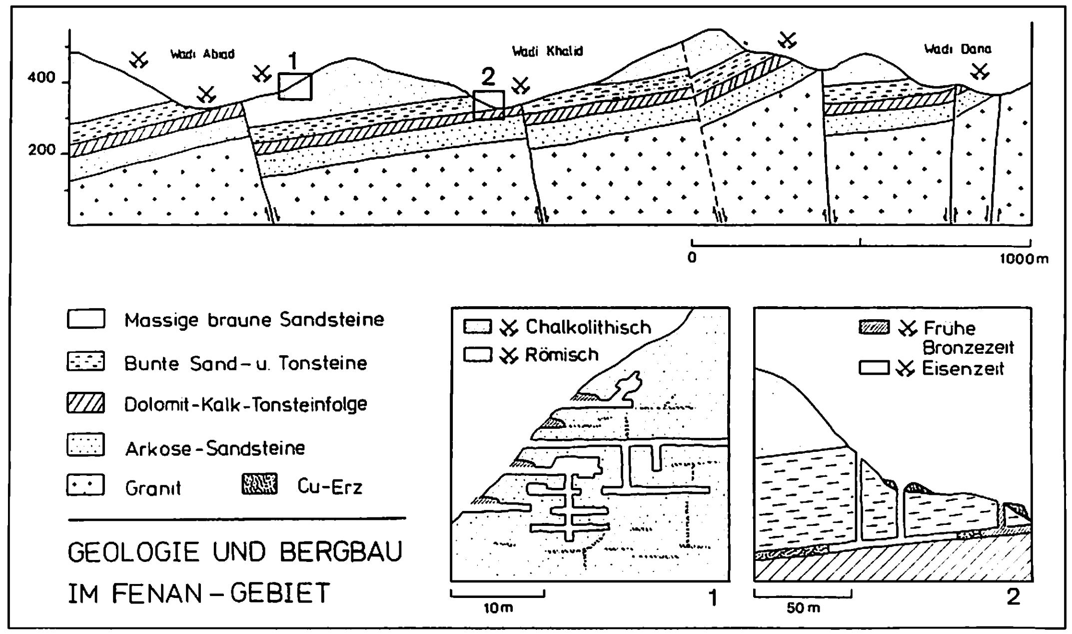

Figure 3. Simplified development of mining activities in the Feinan district. The geological section Wadi Khalid-Wadi Dana shows two ore-bearing formations (Massive Brown Sandstone, MBS, and Dolomite-Limestone-Shale Unit, DLS). They were exploited in different periods by specific techniques.

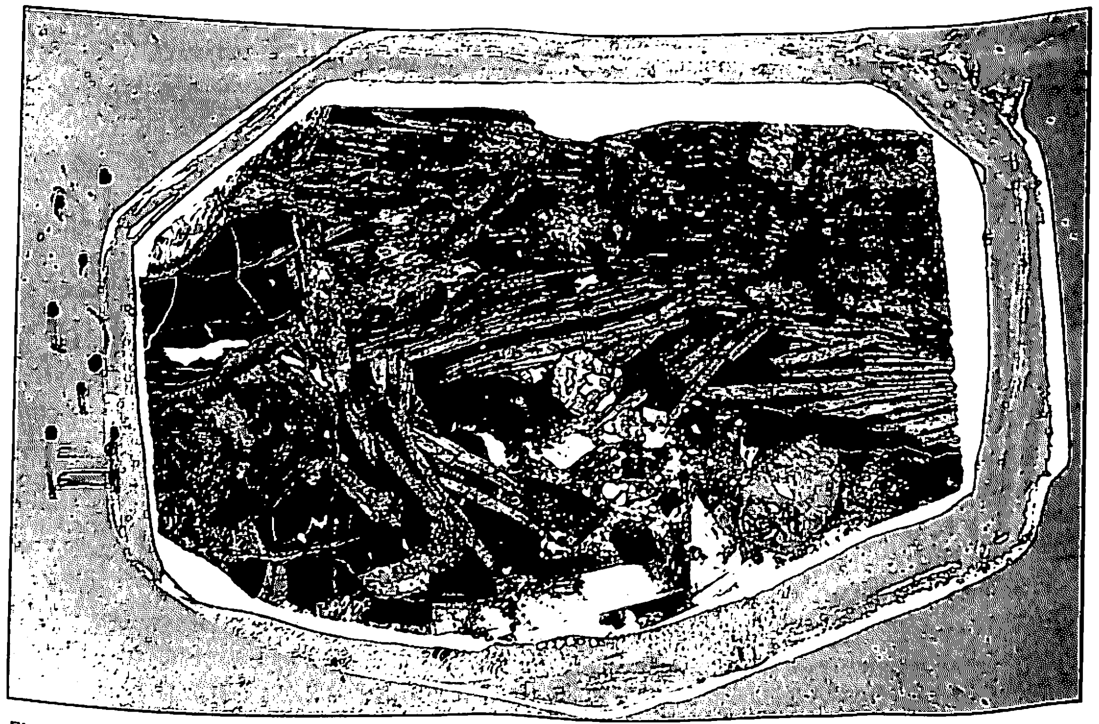

Figure 4. Micrograph of copper-manganese ore with stems of copper silicates, embedded in black manganese oxides. The copper content of this samples is 44 wt.%! Scale: 0.25 cm.

lization of copper. Due to their spatial distribution, this mineralization had to be exploited by different mining techniques (figure 3). However, it is this formation that contains exclusively at Timna cuprified plant relics.

Neither at Timna, nor at Feinan native copper was found. This is worth mentioning, because this was perhaps the main reason why metallurgy in the southern Levant started with a chronological delay in comparison with Anatolia and Iran. Here, native copper frequently occurs in ore deposits, and it was utilized even since the Pre-Pottery Neolithic period for making beads and small tools by hot and cold working.

Altogether, the ancient metallurgists at Feinan had benefit from the ores available in many respects:

1. They were smelted by a one-stage process. No roasting was necessary as it is the case with sulfidic ores, e.g. from those at Rio Tinto or Cyprus.

2. The high percentage of finegrained clay minerals in the host rock especially in the DLS considerably improved the reaction rate of the components.

3. The association with manganese-(hydr-)oxides provided a "self-fluxing" ore which quickly led to the formation of a liquid slag inside the furnace. In addition, the metallurgists had not to control the gas-atmosphere of the furnace in such a severe way as it is necessary during smelting iron-rich composition of ores.

4. THE CHRONOLOGY OF THE USE OF ORES AT FEINAN

One of the major goals of the project was to establish a chronological frame of the use of ores and the major activities of copper production in the Feinan district. For several reasons, we almost exclusively collected charcoal samples from inside the mines, and from slag heaps cut by erosion for dating by ^{14}C-measurements. Altogether 51 radiocarbon-measurements were carried out at the University of Heidelberg. As our main field activities were based upon surveys, pottery could be collected just from the surface and, hence, was of limited value. In addition, while pottery only rarely is found in ancient mines and slag heaps, they abound in charcoal relics from the use of wood e.g. for light or timbering and from smelting activities. The results obtained are not complete, and they will be completed by further excavations.

Ores from the copper deposit of Feinan were utilized for a period of roughly 10.000 years (figure 5). They were used for making beads and cosmetics during the Pre-Pottery Neolithic in the 8th millennium. The first evidence for smelting dates to the 5th millennium. It does not come from Feinan itself, but from chalcolithic settlements in the Beer Sheva basin, in a distance of 100 km and more, where ores from Feinan were exported to and were smelted inside the villages. During the Early Bronze Age (EBA) II-IV, there is the first evidence of a mass production at Feinan. Little activities were proven from the Middle Bronze Age, but at the Late Bronze and the Iron Age there is evidence for

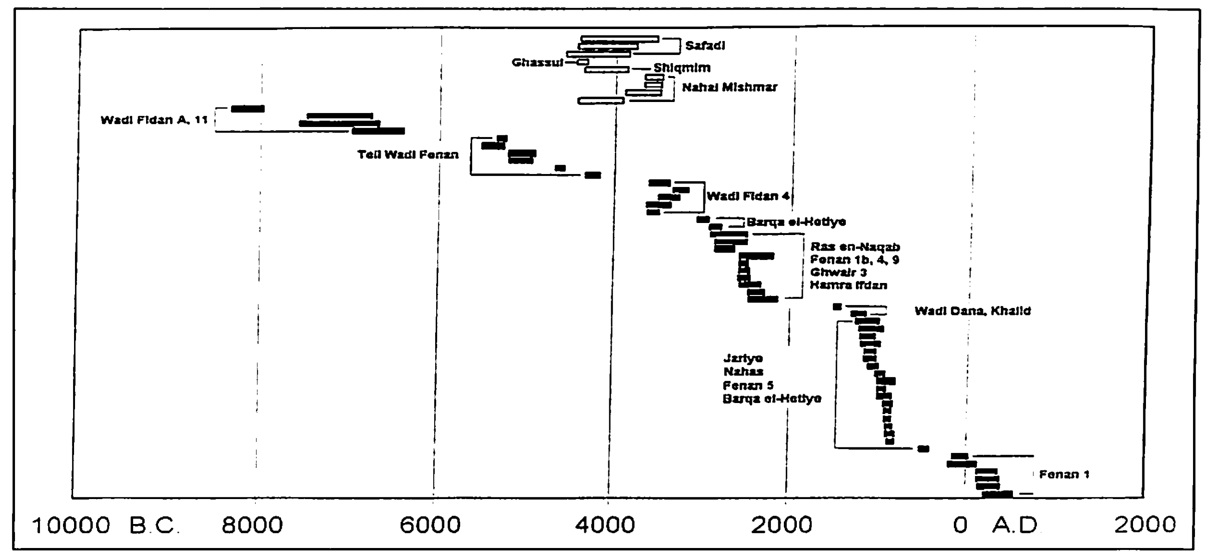

Figure 5. Overview of radiocarbon-data from the Feinan area. It shows that the ore deposit was utilized since the Pre-Pottery Neolithic up until the Roman-Byzantine period. Not shown are activities in the Mamluck period.

copper smelting in an industrial scale. Major slag heaps date to the Roman period, and some echos of metal production were found at the Mamluck period.

5. EXTRACTIVE METALLURGY OF COPPER

Most of the (scientific) studies on ancient slags were focussed on the formation and solidification of such samples that were not older than the LBA. As a rule, slags were investigated from even younger smelting sites such as Cyprus, Rio Tinto, Laurion, the Morvan in France or from Tuscany [13, 14, 15, 16, 17, 18 and 19]. All these materials have in common that they were produced after the inception and development of the slagging process – as it was named by Craddock [20]. Also most of the slag heaps at Feinan date to the Late Bronze and Iron Ages and to the Roman period.

It has to be pointed out especially, however, that the field evidence at Feinan provides the by far largest copper production of the EBA in the Near East. There are several copper mines, 13 smelting sites with an estimated tonnage of 2800 t of slag which corresponds to the production of several hundred tons of metal within a period of 1000 years. There is no ore district in the Near East where EBA copper production exists to a similar extent, perhaps with the exception of the island of Kythnos [21]. In addition, extensive copper processing was excavated with more than 600 casting moulds and fragments of them, over 100 metal objects, numerous crucible fragments, and a cache of 15 crescent shaped bar ingots [22]. This metal factory was located in a water-bearing gorge where the Wadi Fidan opens a natural transit from the Feinan area to the Wadi Arabah and, herewith, an access to the western cities and settlements in Canaan.

Without doubt, the investigation of slags unlocks most important informations to reconstruct smelting processes. By means of mineralogical texture and phase content and chemical bulk analyses informations on smelting parameters can be obtained such as smelting temperature (or interval of solidification, from which temperatures in the furnace may be reconstructed), composition of the gasatmosphere (redox-conditions), viscosity, and the composition of the charge. However, the last mentioned point only provides acceptable results if slag analyses were compared with the actual ores which were used for smelting. Otherwise, it is hard to argue whether self-fluxing ores were smelted or fluxes were added to improve the formation of slag. The last point would implicate a technological development, similar to deliberate alloying processes. Probably the use of fluxes was overestimated in archaeometallurgy, as a result of a hasty transference to prehistoric metallurgy of modern technologies and practices. After my opinion, there is no hard evidence yet for the deliberate use of fluxes before the Late Bronze Age.

The chemical bulk compositions of slags produced at Feinan since the Early Bronze Age show that SiO_2, CaO, MnO, and FeO are the predominant components (figure 6): this means that mainly silicate slags very rich in manganese were produced during copper smelting. The phase content comprises tephroite (Mn_2SiO_4), various modifications of Ca/Mn-pyroxenoids, (Bustamit and Rhodonit) and high amounts of glass. Slags of

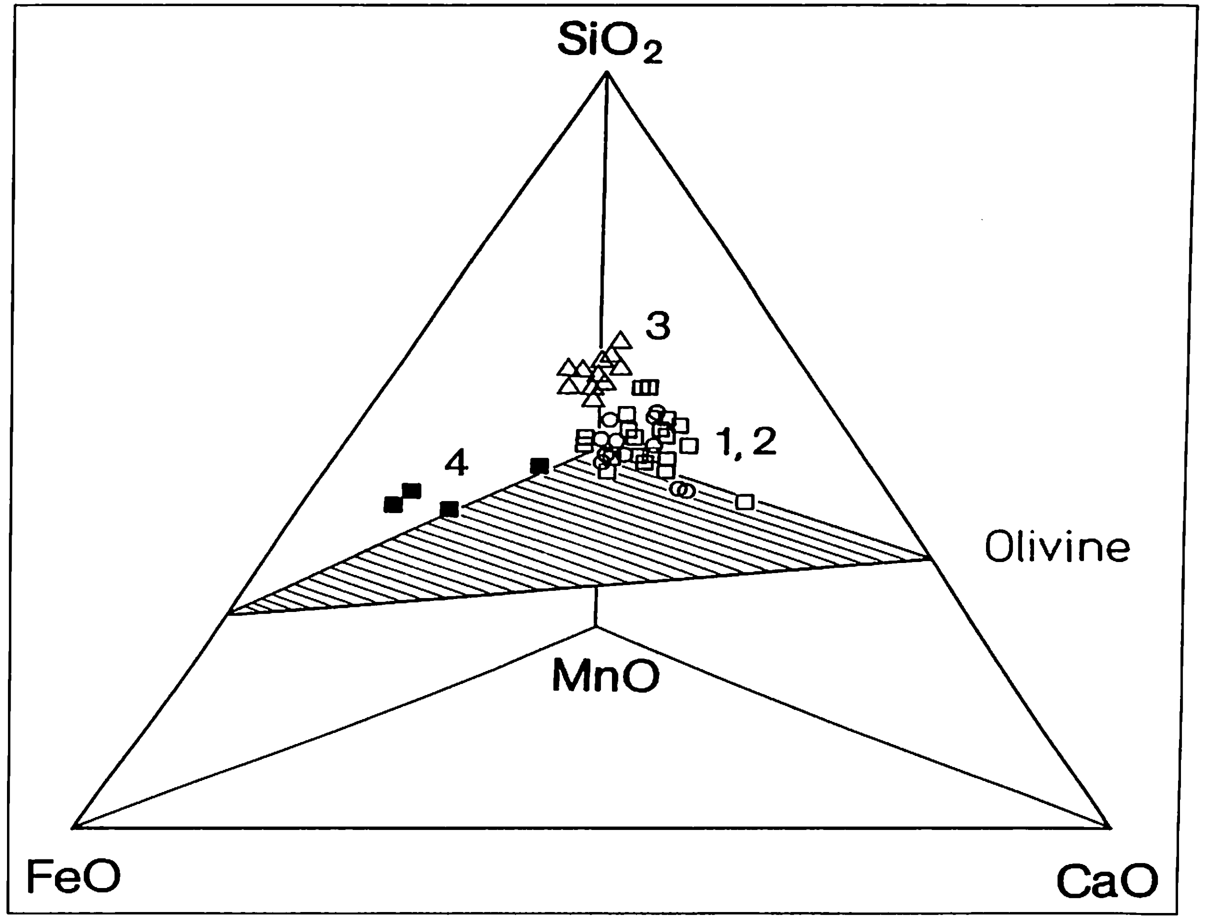

Figure 6. Chemical composition of copper slags from different periods in the Feinan district. All but those from the Mamluck period are extremely rich in manganese. Roman slags are surprisingly high in SiO_2. 1 = Early Bronze Age II/III. 2 = Iron Age. 3 = Roman period. 4 = Mamluck period.

such compositions are rather rare in Old World archaeometallurgy. They were observed just in ore districts where manganese ores are intergrown with copper ores, e.g. Timna, Cyprus, and Oman. Otherwise, the most common compositions are iron-rich silicate slags with the well known fayalite. The projection of reduced bulk analyses of slags from Feinan into suitable phase diagrams (e.g. into the ternary system $CaO\text{-}MnO\text{-}SiO_2$) points to liquidus temperatures between 1190 and 1300 °C. Even a large range of CaO- and MnO- concentrations would not affect these rather low temperatures, i.e. the metallurgists had not to take care about varying contents of dolomite or manganese in the charge and in almost every case it was possible to produce a liquid slag. In the Roman period smelting was carried out at higher temperatures. We conclude this from higher SiO_2 concentrations which indicate temperatures of > 1400 °C. These temperatures probably were hardly reached in reality, and it should be considered that, in general, alkali-concentrations would lower the melting range of a silicate liquid. Experimental measurements of the melting range of Bronze and Iron Ages slags in the laboratory indeed showed that they would be liquified between 1170 and 1210 °C.

What we can learn additionally from the plots is that Early Bronze Age slags contain much higher CaO-contents than later slags. This might be due to a poor beneficiation of ores before charging into the smelting furnace, i.e. a high proportion of host rock in the ore. This as more as the ore obviously had a self fluxing composition. Alternatively, the CaO may have its origin from a heavy resorption of furnace lining during smelting. This possibility came up during experimental work to reconstruct the EBA wind-driven furnaces at Feinan: we observed that the Ca-rich clay used for furnace construction reacted with the ore/hostrock to a large extent at temperatures around 1200-1400 °C [23].

In contrast, the Iron Age slags show a narrow range of compositions which probably resulted from the deliberate use of Mn-rich fluxes. This is confirmed by archaeological evidence e.g. from Timna, where next to an Iron Age smelting furnace a pit was found filled with manganese ores [24].

Manganese silicate slags in their chemo-physical properties provide a decisive advantage for the ancient smelters. As a function of the oxygen pressure or the CO/CO_2 ratio inside the furnace and the temperature, manganese oxide and also manganese silicates have a much larger range of stability during smelting than iron silicate slags which are well known in archaeometallurgy. They are not affected by a changing gas atmosphere as caused, for example, by rhythmic addition of charcoal into the furnace. There will be no precipitation of iron or manganese, respectively, under strong reducing conditions. On the other hand, manganese silicates are even liquid under a surplus of oxygen. Fe- rich slags, in such a case, would solodify due to the precipitation of iron oxides. These two points considerably affect the separation of metal from the slag, and, hence, the quality of smelting operations in general.

The assessment of smelting- or solidification temperatures of slags using plots in phase diagrams is based upon material which definitively was formed from a homogeneous liquid. In most cases, this is true for slags from the Late Bronze and Iron Ages. In case there are undecomposed relics of the charged material, the method is useless. Very often, this is to observe in slags from the incipient stages of extractive metallurgy, i.e. from the 4th and 3rd millennium. They often did not reach the fully liquid state and exhibit inclusions of the ores charged, and are extremely high in copper or copper-oxide. They show all features of a short-terminated smelting in small reaction vessels.

Such slags, for example, were recovered from the 4th millennium BC settlement of Wadi Fidan 4. They are representativ for copper smelting slags of this period in the eastern Mediterranean [25]. A macrograph (figure 7) indicates that only parts of the charged ore were liquified. They consist of clinopyroxene, magnetite, and glass, and the chemical composition points to a smelting temperature of approximately 1150 °C. Large parts consist of mm-sized fragments of sandstone where the original mineral content and texture is preserved. There is no evidence for the use of any fluxes. In ge-

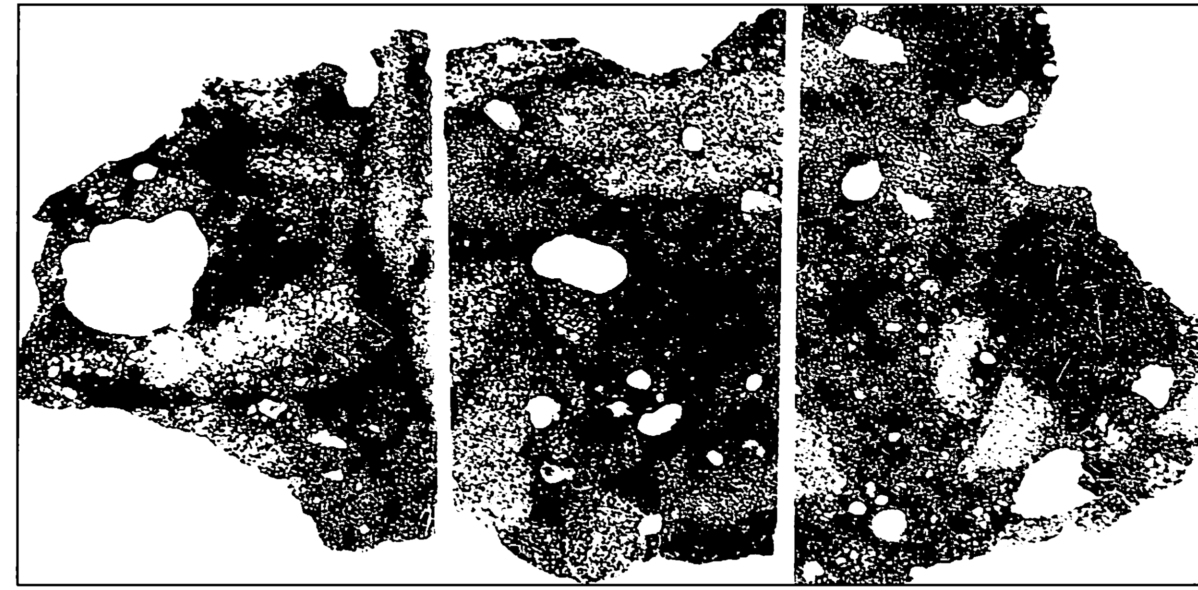

Figure 7. Macrograph of a slag from the 4th millennium BC settlement of Wadi Fidan 4 (Feinan area). The slag did not reach the fully liquid state and contains large fragments of undecomposed sandstone (white and grey inclusions) and droplets of cuprite and copper (not visible on the foto). Width of the slag: 5,5 cm.

neral, fayalite, a common phase in slags from later periods, is missing. Instead, Cu- and Cu/Fe-oxides like cuprite, tenorite and delafossite are typical predominant constituents and are reason for major losses of copper in the slag. They indicate a firing under low reducing conditions. This is typical for smelting processes in small crucibles.

We conclude from the texture and the phase content of these early slags that it never was the primary goal of smelting processes to produce a liquid slag. Regarding the high copper content of the ores available it was probably much more the intention, to reduce ore, to liquify the metal and to separate it from the hostrock, which by chance might or might not have reached the liquid state [26]. A mechanical separation of copper by crushing and grinding the slag was a common practice for metal recovery.

6. THE COPPER: VARYING QUALITY OF METAL IN DIFFERENT PERIODS

Slags use to contain inclusions of copper which we selected out for metallography and chemical analyses (electron microprobe analysis and ICP-OES) to characterize the metal produced. We investigated this aspect in order to better distinguish between natural impurities and deliberately alloying practices in later studies of metal artefacts. Excellent field conditions enabled us to differentiate between smelting sites from different periods, and, therefore, between copper produced e.g. during the EBA and the Iron Age (figure 8).

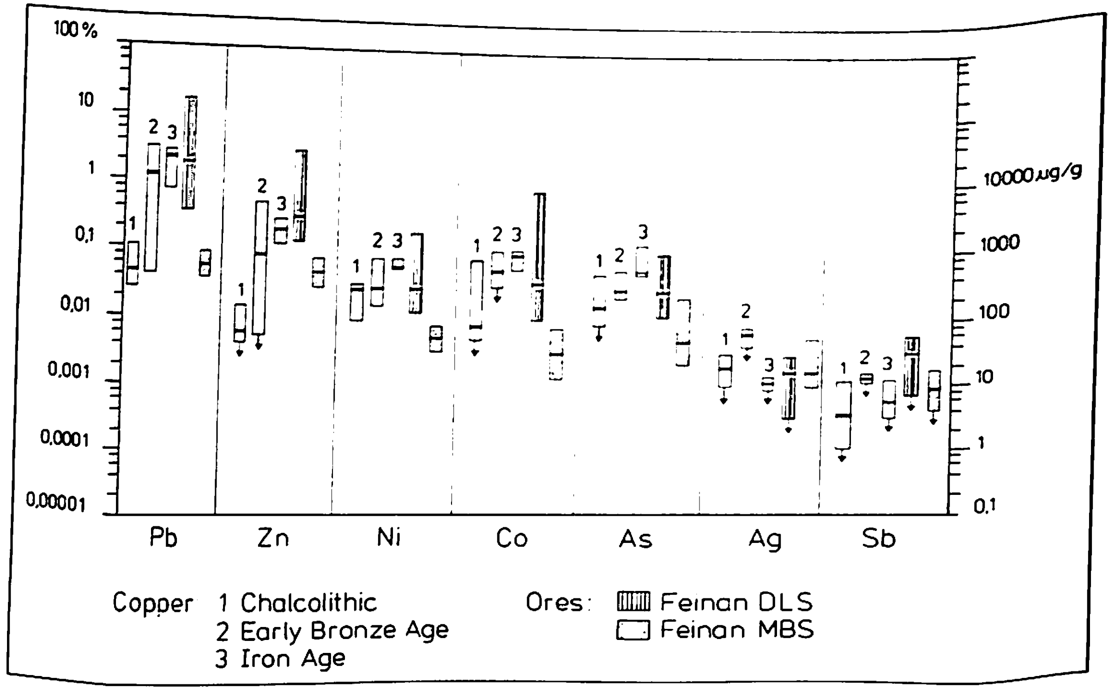

Figure 8. Interquartile ranges and medians of several trace elements in ores and copper prills from slags from the Feinan area (normalized to Cu = 100). Note the varying concentrations of elements in the copper from different periods.

Basically, copper ores and copper from Feinan are remarkably pure in comparison with other ores and metals in the eastern Mediterranean. Inclusions of cuprite or Cu-sulfides are very low in the metal, but occasionally we observe inclusions of iron-phosphides which are not uncommon in copper produced from sedimentary ore deposits. Looking more into details, we observed varying concentrations of minor- and trace elements in the metal. This is caused by the exploitation of various parts of the ore deposit, and by the technological development of furnaces. Due to the use of ores from the MBS, the lead concentrations are rather low in EBAI copper; we observe an increase up to a few percent of this element (i.e. an enrichment by a factor of 1000) in copper from the 3rd and 1st millennium, when ores from the DLS were mined.

On the other hand, concentrations in copper of iron and zinc are primarily influenced by technological aspects. Their distribution in slag or metal is a function of the redox-conditions, i.e. the oxygen concentration in the gas atmosphere of the furnace. High iron- and zinc-contents in the Iron Age copper, therefore, may be explained by strong reducing firing conditions caused by a new construction of smelting furnaces. While EBA I crucibles and natural draught furnaces of the EBA II-IV operated under erratic, but rather low reducing conditions [27], better controlled strong reducing conditions were achieved in later periods by the use of bellows and tuyeres. They caused the precipitation of a few percent of metallic iron. High amounts of iron in copper, in a few cases even iron objects were reported from Iron Age Timna. In contrast to Feinan,

where manganese ore constitutes the prevailing hostrock, iron-(hyd-)oxides are associated with copper ore there. Gale *et al.* [28] convincingly demonstrated by lead isotope analyses on ores, copper- and iron-artefacts how iron production was developed from the metallurgy of copper.

7. LEAD ISOTOPE ABUNDANCE RATIOS OF COPPER FROM FEINAN

To trace the distribution of exported Feinan copper and to reconstruct ancient trade-ways, a series of ores and metal inclusions from slags were analyzed for their lead isotope abundance ratios at the Max-Planck-Institute for Chemistry at Mainz. Herewith, any problems related to trace element variations in the ore deposit and on the way from ore to metal can be avoided. It was a major advantage to analyze copper prills in slags from well dated smelting sites, because they are better representative than single ore samples.

We made two observations which are characteristic. The first is a large range of compositions of lead isotope abundance ratios in copper ores as a result of the multi-stage origin of the deposit. This variation is identical with Timna, but the "Timna/Feinanfield" can easily be separated from other ore district in the eastern Mediterranean (figure 9). Second, and this is a useful tool to distinguish between copper from the two deposits, is a cluster of lead isotopes in all different abundance ratios of ores from the DLS. This is identical with all copper prills analyzed from the EBA and Iron Ages. It fully supports the field evidence: mining activities during these periods focussed exclusively on this ore horizon which was widely exposed to the surface in the whole Feinan area. At Timna, the corresponding Timna formation is exposed to the surface by one very small outcrop at Givat Sasgon [29]. Any compositions of metal objects, therefore, that match the DLS and the copper derived from this formation, with a high degree of probability has its origin in Feinan rather than in Timna.

8. EXPORT OF COPPER ORES AND COPPER

The brilliant green and blueish coloured copper ores from Feinan were utilized and traded since the Pre-Pottery Neolithic Period at the 8th millennium BC. At that time a new fashion emerged in the eastern Mediterranean. The coulour red, utilized since the Paleolithic, changed to green, and abundant finds of green beads, figures, and cosmetics were made in settlements. Among these "greenstones" were minerals such as amazonite, turquois, Cr-apatite, Cr-calcite, and in the Levant also secondary copper ores. They were identified easily by X-ray diffraction and petrographic analyses. In case of Cu-silicates, their origin from Feinan could be determined with a high degree of probability, because they are widespread exposed to the surface. At other deposits, these minerals are either very rare or do not occur.

Beads and other materials made of Cu-silicates were found, for instance, at Basta, Beidha, and at Ain Ghazal, at Jericho (figure 1), and even at Yiftahel in Galilee. They

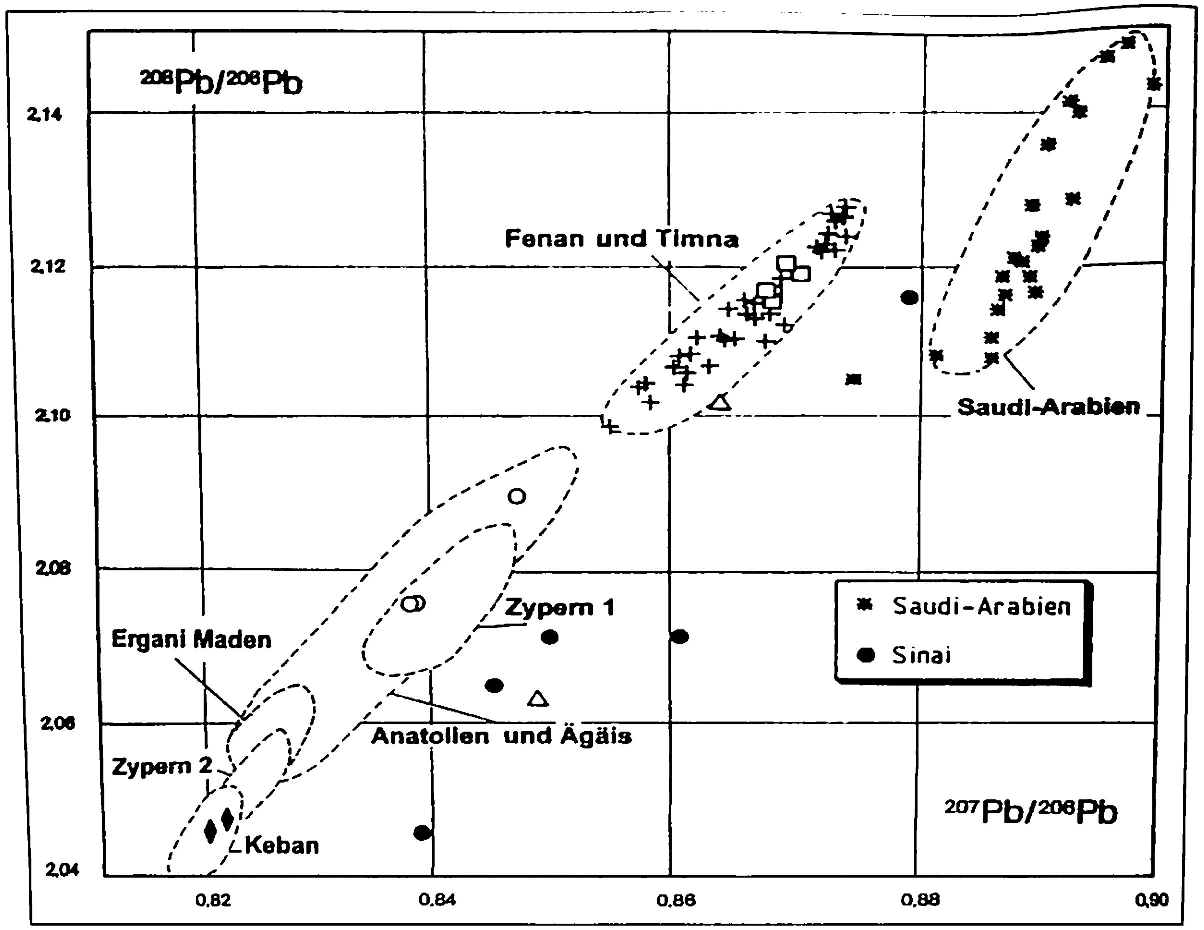

Figure 9. Lead isotope abundance ratios of copper ores from the Wadi Araba (all symbols except filled circles and asterisks). They define the "Feinan-Timna-field" which is different from all other compositions known from Saudi-Arabia and ore deposits in the Near East.

are evidence that the Feinan district was embedded in a far reaching trading network. The tradition of trading ores from Feinan continued until the 5th and 4th millennium BC when the earliest remains of extractive metallurgy appear in chalcolithic settlements of the Beer Sheva basin. This indicates that the monopol for copper was in this region, in a considerable distance to the source, and it points to a domestic mode production of copper. On the other hand, the distribution of Feinan copper ores was limited to the southern Levant. As yet, there is no evidence of a further reaching trade of ores from there.

Copper from Feinan is probably also among the 400 metal objects of the famous Judean Desert Hoard from Nahal Mishmar. It is dated to the first half of the 4th millennium BC. The artefacts of this hoard are basically divided in two groups of objects (Tadmor *et al.* 1995). One consists of "prestige items" such as crowns, scepters and maceheads; the second consists of "tools" such as axes, adzes and chisels. While the

"prestige items" are made of an exotic copper-arsenic-antimony- alloy, the "tools" were cast from pure copper with a low concentration of trace elements. This seems surprising, and one would expect the "tools" to be made of harder alloys instead of relatively soft copper. However, the main reasons to manufacture the "prestige items" probably were the extremely low melting point of the alloys which considerably improved the casting qualities, and aesthetic reasons. We can definitely exclude that the metal of the "prestige items" results from local sources. The analyses of hundreds of ores and copper prills from slags in Timna, Feinan, and the Sinai peninsula demonstrate that such alloys were not smelted from local ores. However, the chemical signature of the "tools" matches the one of the copper ores from the Wadi Arabah –Timna and Feinan–, and the analyses of lead isotope abundance ratios point to a possible origin from Feinan. This observation is supported by indirect evidence of 5th millennium BC mining activities and the metal production around 3500 BC at Wadi Fidan 4. The "tools" may principally also result from Timna-ores which, even to a lesser extent, were traded during the 4th millennium BC to Tell Abu Matar in the Beer Sheba basin, but mainly to Tell Maqass near Aqaba [30]. The evidence of chalcolithic copper smelting at Timna itself, however, is still heavily debated.

Copper itself was exported from Feinan not before the Early Bronze Age II at the beginning of the 3rd millennium BC. During this period, copper was produced in large amounts and reached an *"Industrial Stage"*. It took place in the vicinity of the ore deposits, as evidenced by numerous mines and smelting sites. Tin bronzes were traded. Metallurgy inside habitation sites was, as a rule, limited to manufacturing processes [30]. The market for Feinan-copper again was in the west. Recent excavations by Levy *et al.* [22] brought to light perhaps the largest EBA copper factory of the Near East at Hamra Ifdan. This site seemed to have been not only the center of copper processing and casting of the entire Feinan area. In addition, it was probably the controlling point, a checkpoint for the export of copper to the west. This discovery is most interesting, because it completes the field evidence as mentioned before: The EBA copper mining and smelting activities at Feinan, i.e. the primary production, is the largest known so far in the Near East.

We can demonstrate that Feinan copper was exported in large quantities again to settlements and to the EBA II/III cities in the west and in the north. In contrast to problems of provenancing which exist for chalcolithic copper by the variaty of lead isotope abundance ratios, we now are able to follow more comfortable the distribution of Feinan copper. The reason is the cluster of isotope compositions of ores from the DLS which was exclusively exploited during this period. I mentioned before arguments of the field evidence.

An excellent example are the copper objects from Arad, an EBII city near the southwestern edge of the Dead Sea. We analyzed 21 awls, axes, and chisels. With but a few exceptions, the chemical and lead isotopic composition of these objects were identical with copper smelted during the EBA in the Feinan area (figure 10, [10]). We observe a much better conformity of these data than it was the case with Nahal Mishmar. This

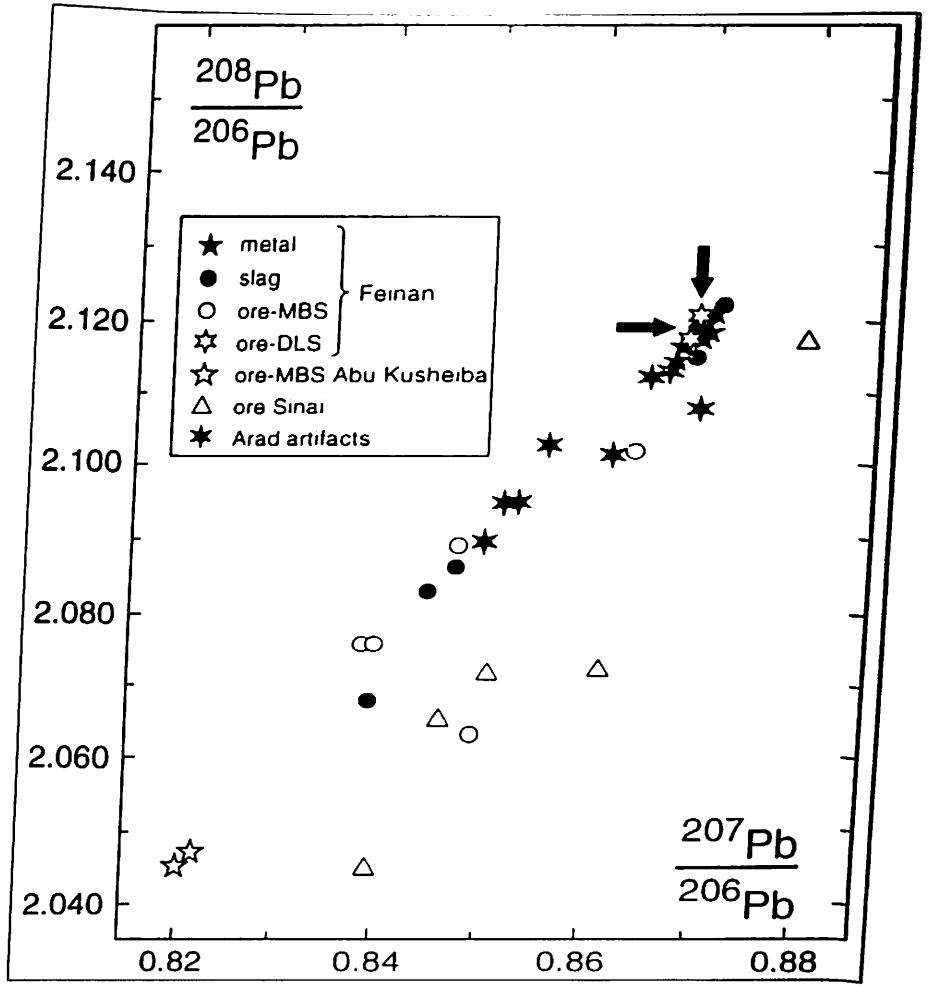

Figure 10. Lead isotope abundance ratios of copper artefacts from Arad and the Sinai. The lead isotope composition in all but two copper artefacts from Arad and the Sinai is compatible with an origin from Feinan, while all copper ores from Sinai analyzed can be ruled out (from [10]).

is caused by the exclusive exploitation of the DLS ore formation which is characterized by a pronounced homogeneity in its chemical and isotopic composition. We can not definitely exclude that the objects from Arad may have their origin in Timna. This, however, is unlikely for two reasons. First, the ore district of Feinan is closer to Arad, only about 70 km away. Timna, in the southwestern part of the Arabah, is nearly 130 km from Arad. Second, the ore formation of the dolomite-limestone-shale unit is extensively exposed to the surface at Feinan; at Timna, in contrast, there are only a few very small outcrops of this formation. Obviously, copper was produced here only in small quantities. Rothenberg and Shaw [29] described just a small mine, Timna 250, and a smelting site, Timna 149 at Givat Sasgon, which is dated to the EBA IV, i.e. later than the flourishing period of Arad. In any case, it can be excluded that the Arad was a trading center of copper from the Sinai peninsula, as suggested by Amiran [31] and by Beith-Arieh [32].

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