THE COMPOSITION AND TECHNOLOGY OF COPPER
ARTEFACTS FROM JERICHO AND SOME RELATED SITES

BY

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To My Parents, My Land

And The People Of Palestine
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ABSTRACT

One hundred and thirty nine objects from Jericho, the Amman Airport site, and Sahab were sampled. These artefacts are weapons, tools, ornaments and miscellaneous items, dating from the Bronze Age (EB, EB-MB, MB and LB). Atomic absorption spectroscopy was adopted for the analysis.

Fifty artefacts were sectioned for metallogographical examination, the study of different objects shows the development of the metallurgical technique in ancient Palestine - based on Jericho - during the different periods of the Bronze Age. Important metal ingots, runners and scraps indicate that secondary metallurgical processes were carried out on the tell of Jericho.

The chemical composition of the artefacts illustrates the different stages of alloying during the Bronze Age:

EB = Either copper or arsenical copper.
EB-MB = Mainly arsenic-copper alloy, sometimes tin-copper.
MB = Both alloys appear together, sometimes a mixture of high arsenic and tin is present in the same artefact.
LB = The age of high tin bronze, but copper or arsenical copper appear rarely.

Also, four artefacts proved to be silver, and one to be silver-plated.
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I. INTRODUCTION

I.1. Metallurgical background

Metals have been of importance to mankind from ancient times to the present. The transition from stone to metal ages has been described as the major break-through in man's technological progress. This transition seems to have happened gradually at various dates in different regions of the world. The rise of metallurgy following the spread of farming encouraged the introduction of specialization in prehistoric societies. Childe (1942, 61) believes that metallurgists were always specialists, whereas Rowlands (1971, 212) considers that metalworking could not be a full time occupation. However, it is difficult to resolve this aspect precisely using ethnographic evidence only, as other important factors such as economic and social factors must be taken into account.

Gold and copper are considered to be the earliest metals known to man. Coghlan (1975, 18) classified the prehistoric metallurgy of copper into three stages: native, smelted, and alloyed copper.

I.1.1. Native copper:

No doubt, in the early stages of using copper, man dealt with it as a sort of a malleable stone, but he would have noticed that it is heavier and tougher than stone. Unlike stone, however, native copper can be fashioned into different and useful artefacts such as awls, pins, and wires, with a reasonable amount of hammering. Copper has advantages over stone in making tools and weapons, such as its mechanical properties, and the ability to be cast. Native copper has been found in many parts of the world, and it can occur in nature as a primary mineral or in the oxidation zone, as small grains or pellets.

Probably the dawn of metallurgy was somewhere within the "Fertile Crescent", where it took place by an accident or a series of accidents. References differ in mentioning
and considering the earliest archaeological sites that may first have used copper. Moorey (in Coghlan, 1975, 40) mentions a double-perforated pendant or bead from Shanidar in Iraqi Kurdistan dating back to the 9th millennium B.C., whereas he later mentions that a reamer and wire pins hammered from native copper and dating from about the 8th millennium, were found in Cayönü Tepesi near Ergani in Anatolia. Also, copper objects which may well have been hammered from native copper and dating back to the 6th millennium have been found in Catal Hüyük in Anatolia (Wertime, 1964, 1258). Tylecote (1976, 1) mentions that various small objects were found in Ali Kosh in western Iran dating from between the 9th – 7th millennium, whilst the earliest metal hoard dating to c. 5000 B.C. was discovered in Tepe Sialk in Iran (Braidwood et al., 1951, 87). Wertime (1964, 1259) made a chronological chart for the development of metallurgy for different sites in the Near East, in comparison with pottery, glaze, and glass techniques. Meanwhile, Forbes (1972, 30) dates the stages of metallurgy such as the hammering of native copper to 5000 B.C., and the annealing to between 5000–4500 B.C.

Actually, nobody can be sure of giving a precise date for the beginning of the use of native copper, or any date for the early metallurgical stages, because the attribution for such early periods correlated with archaeology may well be changed according to new discoveries. Therefore dates should be approximate and be regarded as flexible.

Forbes (ibid., 30) himself is not precise, when he mentions that objects of native copper have been found in Palestine. It seems to be that he refers to the four objects from Kfar Monash, which have been analysed by Key (1963, 289). However, it is difficult to distinguish between native copper and high purity smelted copper, nevertheless, a fully metallurgical and analytical study can be helpful.

I.1.2. Metal extracted from ores:

There are two types of copper ores in nature; oxide-
carbonate ores and sulphide ores. The first type is formed by the natural oxidation or weathering of the sulphide ores, and usually occurs near the surface. The colour of these ores attracted the attention of ancient man, and as has been mentioned above, they are near the surface and easy to handle. The discovery that these coloured rocks contain copper, probably happened accidentally. It is certain that oxide and carbonate ores were first used in this early stage of metallurgy.

The ores of this first type have the advantage that they can be easily reduced to metal by direct smelting after mixing them with charcoal; they include ores such as: Cuprite (red copper oxide: \(\text{Cu}_2\text{O}\)), malacoite (black copper oxide: \(\text{CuO}\)), malachite (green copper carbonate: \(\text{CuCO}_3\cdot\text{Cu(OH)}_2\)), azurite (blue copper carbonate: \(2\text{CuCO}_3\cdot\text{Cu(OH)}_2\)), and the hydrated silicate of copper which is chrysocolla (\(\text{CuSiO}_3\cdot2\text{H}_2\text{O}\)).

Due to man's demand for copper, the supply of oxide-carbonate ores became exhausted, and this made him turn to an alternative source; sulphide ores. The second type of ore used by ancient man were the sulphide ores; chalcocite (\(\text{Cu}_2\text{S}\)), and chalcopyrite (\(\text{CuFeS}_2\)), after he had realized that they contain copper. There are two good reasons to make us believe that the stage of using sulphide ores happened later than the stage of using oxide-carbonate ores. Firstly, the sulphide ores are difficult to reduce by the simple smelting process because of their complex composition. In this case, roasting is usually the first step necessary before smelting the ores. Heating the crushed ore in a wood fire to a relatively low temperature is essential to break up the lumps of ore, and in order to convert the sulphide to oxide, and to eliminate many of the impurities. The second step is to smelt the mixture of roasted minerals with charcoal and flux at about 1100°C, to obtain slag, which is a black, glassy substance, and almost pure copper. Secondly, these sulphide ores need mining to be extracted, they usually occur deep beneath the surface.

The question of how the discovery of the smelting
process was first made, still has not been properly explained. The experimental work carried out by Coghlan (1975, 28) proves that it is unlikely that the camp-fire was the first metallurgical hearth, because a camp-fire gives a temperature of 600-700°C only, while the reducing atmosphere essential for this process to take place is absent. Tylecote (1976, 5) supports this conclusion, saying that smelting first started, either accidentally or intentionally, in a pottery kiln. Meanwhile, Coghlan (1975, 30) evades this issue altogether when explaining that the pottery kiln influenced the introduction of smelting (ibid., 31), "Upon present evidence it would seem that the earliest copper smelting was carried out in very simple 'bowl' hearths or furnaces."

The other question which should be raised is that of the "birth place" of this process. Aitchison (1960, 36) has good reasons to believe that there are two possibilities; the first is the area east of the Caspian Sea, in the north-east of Iran; and the second is the mountainous area including the south Caucasus; the eastern part of the Taurus, and part of Armenia.

By the time of the Chalcolithic period, which was correctly so called because of the use of copper and stone, smelting had spread from its birth place to other parts of Western Asia, and by about 3800 B.C. it was widely practised in that area, and the number of artefacts produced increased, copper quickly becoming the dominant metal.

Immigration and trade played a major role in spreading this knowledge from Western Asia to other parts of the world along different routes and at different times, but as is already known in the history of metal, copper objects spread more rapidly than the technical skill, and that trade carried the different objects great distances before the skill of smelting arrived there (ibid., 40).

Since most of the metallurgical processes are more likely to be carried on outside the boundaries of ancient settlements, and most of our information is derived from these settlements, it is therefore sometimes difficult to trace the metallurgical processes and their remains. But we
may be fortunate, since some of these remains have been found, and it is possible to demonstrate these metallurgical processes by finds such as the objects themselves, furnaces, slags, crucibles, moulds, and mining debris. Coghlan (1975, Fig. 14) illustrates paintings from different Egyptian tombs to show some of these ancient metallurgical processes.

Concerning early archaeological sites with metallurgical remains, Moorey in Coghlan (ibid., 40-44) mentions a list of sites in the Near East. Palestine has a long history of metallurgy, where metal started to appear in the Chalcolithic period. Four axes of simple form were found at Teleilat Ghassul (Mallon et al., 1934, Pl.34,2).

In view of the excavations at Timna, where mines, workshops, and smelting installations were found, this seems to be one of the earliest sites for the copper industry in the area. Different primitive tools for mining were found at Site 42. As well as this, many crushing tools and copper ore nodules were discovered at Site 39A, which was probably a place for preparing the actual smelting mixture, while finds, e.g. slags and hearth furnaces, from Site 39B indicate that it was used for primitive smelting. Thirty-eight other sites had been explored by Rothenberg (1962, 29) at the edge of Wadi Arabah in 1960, where slags and Chalcolithic flints were found. No evidence of refining or casting was found at Timna, but such practices in the Chalcolithic period were discovered at Tell Abu Matar. This is another site in the Negev where the complete process of copper production was carried out. Numerous fragments from specially constructed furnaces with small crucibles for refining the metal were excavated in House 244 (Perrot, 1955, 17-40, 73-84, 167-189).

However, communities had to enter into new specializations, with miners, smiths, traders, etc. These people were dependent on the farmers for their food. Also, trade relationships were established among different areas of the ancient world such as Palestine, Syria, and Egypt. Both factors are indicators of an important development in the Early Bronze Age (EB)(2900-2300 B.C.).
Palestine was still regarded as a source of copper in the EB age because of its rich deposits, but there is no evidence of any copper industry (Muhly, 1973, 216). Meanwhile, copper objects have been found; a hoard of thirty-five tools and weapons were found at Kfar Monash, the hoard has been dated to EBIII by Watkins (1975, 53-63). Toward the end of this period, the use of copper became more common in Palestine. A group of objects was found at Tell el-Hesi, consisting of six flat axes, two spearheads, and a crescentic axehead. Other finds were discovered at Tell el-Faraḥ, Gezer, Lachish, and Megiddo (de Vaux, 1971, 229). The metal finds from Jericho were a crescentic axehead, a dagger, axes, chisels, and remains of metallurgical activities.

I.1.3. Alloyed copper:

Copper objects, either native or smelted, always have a small percentage of impurities, the major impurities are arsenic, antimony, lead, iron, zinc, tin, nickel, cobalt, gold, silver, sulphur, etc. The presence or absence of these impurities with their differentiation in percentage depends upon two factors; the ore body they are derived from, and the metallurgical processes which have been carried out to produce them.

Copper alloying is considered to be the intentional mixing of copper with other elements to improve some of its properties. The discovery of alloying might have happened by the knowledge of the ancient smiths that by using a certain ore, or by mixing certain minerals with the copper ore, the quality of the product was improved.

Both arsenic and tin have the advantage of introducing a deoxidizing agent into copper, which greatly influences the mechanical properties and the ability to cast the copper. It is known that the first step in alloying started with arsenic, and that by the third millennium B.C. the copper-arsenic alloy was dominant.

In Palestine, copper objects with high arsenic were found in the EB age, but in the Intermediate Early-Middle
The Bronze period (EB-MB), which is dated between 2300-1900 B.C., arsenic was then routine. This period is marked by a break in the culture which was caused by the nomadic newcomers, believed to be Amorites. Kenyon (1970, 136) dating this period almost includes Albright's (1949, 80) Middle Bronze Age I, who believes that this culture came to Palestine from Syria. Numerous metal objects, mostly daggers, were found at Jericho and other sites, but there is no evidence yet for any metallurgy in Palestine during this period.

As tin has no superior advantages in properties over arsenic, then why did it replace the use of arsenic? Many references explain that this was due to the volatility and toxicity of the arsenic compounds, thus, tin is a more practical and safe metal to deal with. However, this replacement did not occur rapidly. Therefore, one finds that both elements were in use at the same period. This is well represented in Palestine during the Middle Bronze Age (MB) (1900-1550 B.C.), where tin and arsenic appear together in many objects analysed from this period.

However, it is known that in MBII towns were founded, and by the seventeenth century B.C., Palestine was in the heart of the Hyksos Empire. All the archaeological evidence indicates that there was great local prosperity at that time. This prosperity was caused by commerce flourishing, and this was because of the geographical situation of Palestine on the main routes between Asia and Africa. This wealth was reflected in the use of metals, tin was not the only metal which appeared in this period. Keynon (1965, 315) excavated many gold artefacts. The analyses in this thesis show that silver objects were also found in Jericho. Besides this, the metal objects from this period indicate a high technical skill in metal working. However, it is more likely that this development in the use of metal was caused by the connection between the major metallurgical centres in Syria and Lebanon and Palestine.

The second step in alloying was the use of tin, one of the most important inventions in the history of metal-
lurgy. Tin, unlike copper, does not occur in the metallic state in nature. The mineral cassiterite (SnO$_2$) or tin-stone is the only ore of importance, and this mineral can be found in alluvial deposits, because of its high specific gravity.

Bronze first appeared in Mesopotamia between 3000 - 2500 B.C., but it is apparent that there is no source of tin in Mesopotamia. So, how did tin reach Mesopotamia and other areas, where it does not occur naturally? In fact, there is no agreement among scholars about the sources and distribution of ancient tin. However, there are important Assyrian, Babylonian, Ugaritic and Aegean documents, which mention the trading of tin in the Near East. Unfortunately, these documents do not refer to any of the sources of this tin (Muhly, 1976, 97). Nevertheless, it is obvious that strong international trade routes were established between the tin sources and the centres of the bronze production.

There are many explanations for the occurrence of tin in copper, Coghlan (1975, 35) mentions four methods to make an intentional copper-tin alloy; melting a mixture of metallic copper and metallic tin, adding a tin-mineral to a molten copper in a crucible, smelting a naturally occurring copper-tin ore, and smelting a mixture of copper ore with a tin-mineral.

Casting is one advantage of the discovery of the melting process. Again, nobody knows how this invention happened in the history of metal. However, there are three main steps in using moulds for casting; open mould, closed mould or bi-valve, and the cire-perdue method. It is interesting to note that objects as early as 2800 - 2500 B.C. from the Royal Tombs at Ur, were cast by the last method (Aitchison, 1960, 30). The material of the mould was stone and clay.

By the last stage of the Bronze Age, more bronze products and more accurate and detailed casting were achieved, and this was due to the developed technique of alloying and casting. Thompson (1958, 6) refers to copper refining and the possibility of mixing pure copper with tin under
reducing conditions to produce an almost pure alloy, with the required composition. Crucibles have been found made from pottery, and of various shapes, and easy to handle with tongs.

As has been mentioned above, tin appeared first in Mesopotamia, and it was introduced to Palestine via Syria. However, during the Late Bronze Age (LB) (1550 – 1200 B.C.) high tin bronze was used, and alloying with tin was dominant.

Timna copper ores were exploited again at the end of this period and the beginning of the Iron Age (Ramesside period). In Site 2 sophisticated smelting installations were found, also, casting remains were found at this site (Rothenberg, 1972, 114), but the production of copper was to supply the demand of the Egyptian market. In this period, there were strong trade connections between Palestine and other eastern Mediterranean countries. Between the 14th – 12th centuries B.C., the area was unstable because of different invasions such as Egyptian and Israelite. Finally, the Sea People invaded the area, and they introduced a new metal. Iron weapons appeared with the newcomers, but bronze continued to be used. However, the new metal gave its name to the Iron Age.

I.2. Archaeological sites

One of the main aims of this thesis is to follow the development of metallurgy in Palestine during the Bronze Age. This study is based on Jericho material, because the site had been well excavated from the stratigraphic point of view. Because there is a lack of LB material at Jericho, the Amman Airport site and Sahab were chosen to fill this gap.

I.2.1. Jericho:

The ancient city of Jericho lies to the west of the modern oasis, on the west side of the Jordan Valley, and about 10 Km north of the Dead Sea. Its position is a very
Fig. 2
strategic one controlling one of the main ancient routes into Palestine. Apart from the Old Testament stories about its capture by Joshua, this has made it attractive to archaeologists from the beginning of archaeological activities in the area.

As early as 1867 Lord Kitchener, along with other Britains explored the site, and later in 1873 Sir Charles Warren led another campaign on behalf of the Palestine Exploration Fund. It was at this time that some sounding trenches were excavated at the site, but then of course archaeological technique in Palestine was in its infancy. Between 1908 and 1911, an Austro-German expedition took place under the direction of Sellin and Watzinger. Their work "Die Ergebnisse der Ausgrabungen" was published in Leipzig in 1913. Again it must be remembered that then the basis for dating Palestinian pottery was not yet well established. Further excavations undertaken by Garstang of Liverpool University occurred between 1930 and 1936. His work appeared in the Liverpool Annals of Archaeology and Anthropology (1932-36).

Since 1936, many other Palestinian sites have been excavated, and these shed more light on the history, chronological basis, and archaeological technique. Thus new excavations at Jericho became essential, and to quote Kenyon (1952, 64) "The excavations had three main aims, to obtain additional evidence on the date of the fall of the latest Bronze Age city, presumably to be associated with the Israelite invasion under Joshua, to clear a further area of the very important Neolithic remains discovered by Professor Garstang, and to excavate more of the rich tombs known to lie in the vicinity of the city." The late Dame Kathleen Kenyon, on behalf of the British School of Archaeology in Jerusalem, had excavated the tell and tombs between 1952 and 1958. Her preliminary reports were published in the Palestine Exploration Quarterly (1952-57, 1960). She also published "Digging up Jericho", 1957. The final archaeological report of the tombs is to be found in Excavations at Jericho; volume one: the tombs excavated in
1952-4, and volume two: the tombs excavated in 1955-8. Unfortunately, the excavator died before the final report about the tell was complete, but it is hoped that it will appear in the near future. As a result of the Jericho excavations, a new school of technique in the Palestinian field of Archaeology has been established. This method is called the "Wheeler-Keynon" method.

According to carbon-14 dating, it has been established that the site was occupied as early as 9000 B.C., and continued to be so more or less up until the time of its destruction c. 1580 B.C.. Of the LB age town, there are few remains to be found, as was established by the latest expedition to the tell. During the last seven Kenyon seasons, the excavations revealed many artefacts from different ages. These have been distributed amongst the various contributors, museums and institutions in the United Kingdom and abroad (for the present location of the objects which have been sampled in this project, refer to the Catalogue). The most important and unique objects are however kept in Jordan. The only source of information about their present location is from the excavator's Register-Book, which is out of date in the location of many objects. Actually, this is one of the major problems concerning any research project dealing with material found at Jericho, although, there are some metal objects here from the 1930-36 excavation, and the latter can be found in the Birmingham City Museum.

I.2.2. Amman Airport Temple:

The site was discovered by chance in 1955 during the bulldozing operation on the civil airport at Amman. Rescue excavations by the Department of Antiquities took place in the same year. The first announcement of the discovery of the stone walls was published by Harding (1956, 80 and 1958, 10-12). It was found in the middle of the aerodrome beside the runway. Also, there were other objects found such as Aegean ware and Mycenaean pottery. Among the other finds were fragments of alabaster, small gold leaves, scarabs, cylinder seals, a bronze sword "Khepesh", arrowheads, spear-
heads, and axes.

Hennessy (1966, 155-162) excavated the temple and he showed that there had been three stages of use. A number of arrowheads were found in the foundation trench of the temple. The 1966 preliminary reports of the temple, including pottery, architecture, and some of the artefacts, were published by Hennessy (ibid.) and Wright (1966, 351-357 and the supplementary note, 357-359). That was followed by Hankey (1974, 131-160) where she classified and dated the Aegean and Mycenaean pottery, and in the following pages (160-178) in the same volume of Levant she published the vases and objects made of stone which she described as imported objects from Egypt. Then she discussed (ibid., 142) the different theories about the function of the temple, which made her believe that East Jordan was occupied between the end of the MBII Age, and the Iron Age I, which had not been generally accepted before. This temple was a place of worship for the nomads who were settling in the surrounding areas e.g. Sahab. However, it is difficult to identify the deity to whom the temple was consecrated. Herr's (1976, 109-111) work outside the structure of the temple established that there is no connection between the outside and the temple itself.

The temple was very rich in finds, these artefacts made it possible to date its foundation to about the fourteenth century B.C., the latest use of it dates back to the thirteenth century B.C. Nevertheless it is difficult to tell how the imported objects reached the site, but it is obvious that there were strong international trade routes during this period. Most of the objects are available in the Jordanian Archaeological Museum, and the Ashmolean Museum, Oxford.

I.2.3. Sahab:

Sahab lies 12 Kms south-east of Amman with the new village built almost on the top of the ancient site. Two tombs of Iron Age II have been discovered; the first in 1929, published by Albright (1936, 295-306), and the second in 1948 by Harding (1948, 92-102). In 1968, two other tombs
were reported to the Department of Antiquities, only one of them has been published, by Dajani (1970, 29-35), and this is the tomb which is included in this thesis. Most of the finds which were found in this tomb have been lent to University of Jordan Archaeological Museum by the Department of Antiquities. Although the tomb has been dated between the 14th - 9th centuries B.C., it seems that it was used in the LBII Age, and then reused in the Iron Age I.
II. TYPOLOGY AND FUNCTION

Metal objects are not like other archaeological artefacts, they can be dated by their typology only with considerable risk. This is due to the fact that metal objects could be used over more than one period of time. However, a typological basis can be established by the general form of the metal objects, and the evidence associated with them can be used for dating purposes. Many of the metal types such as arrowheads, pins, etc. have their ancestors in stone or bone in earlier periods.

The function of the objects can be deduced according to their forms, we may also be lucky and find ancient illustrations showing the object in use (Pritchard, 1954, Figs. 159-181). Sometimes, the form of a weapon or a tool might serve more than one purpose. For example, it is difficult to discriminate in practice between an adze and an axe, or between a dagger and a knife.

The metal artefacts in this thesis are grouped in the following typological categories; weapons, tools, personal ornaments, and miscellaneous.

**Weapon types**: daggers, crescentic axehead, battle-axe heads, spearheads, javelins, arrowheads, sword, and armour; belt.

**Tools**: axes, chisels, awls, tweezers, and knives.

**Ornaments**: bracelet, rings, and toggle-pins.

**Miscellaneous**: metal fittings including; plates, bands, nails, etc.

I will not attempt to establish a new typology because this is not the main aim of the thesis. Instead, Kenyon's (1960, 187-198, and 1965, 46-50, 200) typology for the daggers, and (ibid., 1960, 297) for the toggle-pins, will be followed. For the javelins and arrowheads, Milik and Cross's (1956, 15-23) study will be used. Meanwhile, this typology will be compared with the other available studies on metal objects in the area such as; Maxwell-Hyslop (1946, 1-65 and 1949, 90-129), Stronach (1957, 89-
175), Henschel-Simon (1937, 169-210), and sometimes Deshayes (1960, Pl.XXIII) and Schaeffer (1948, Fig. 45).

II.1. Weapons

II.1.1. Daggers: (Fig. 11 - 13)

Generally, the required shape and effectiveness of the weapon depends on whether the enemy was wearing skin, or another kind of armour, or nothing at all. The dagger was one of the earliest copper weapons. It is a straight, double-edged, sharp weapon. It is mainly designed as a short range or hand-to-hand piece of war equipment, for stabbing and cutting. It was worn at the waist, and kept in place by using a belt. The centre of the dagger was thickened to overcome the possibility of break or bending by a heavy blow. Rivets were normally used to secure the hilt and to make it easy to handle, although early types of daggers from Anatolia were found rivetless, or with a single rivet (Stronach, 1957, 89).

Daggers can be divided into types on the basis of general form, and each main type can then be subdivided according to the variation in the method of attachment of the hilt, and the number of rivets. Also, the shape of the shoulder, and the midrib are other characteristics which must be considered for each type. It should be emphasized that a moderate variation in length or thickness is not important in establishing a typology.

Types during EB and EB-MB:

Type A1 (Cat. Nos. 1-8): Medium length (20-30 cm), the section of the blade is rhombic or sometimes slightly elliptical, without a true midrib. Four rivets in horizontal pairs secure the hilt. (Cat. No. 1) is an early example and has been dated to EBIII. This type is parallel to Maxwell-Hyslop's (1946) type 18, and similar to Stronach's (1957) type 7.

A2 (Cat. No. 9): Six rivets in horizontal pairs.

A3 (Cat. No. 10): Four rivets, but the blade is triangular in section.
Type B (Cat. No. 11): A short and wide blade, very slight shoulder at the head of the blade, which narrows slightly toward the end. It is thick in the centre, but without a true midrib.

Type C (Cat. No. 12): A long blade, the shoulder at the head of the blade is more noticeable than in type B. It has six rivets, and the hilt is slightly concave-sided with a square end, and it has a slight midrib.

Type D (Cat. Nos. 13-16): Medium to long blade (23-38 cm), square butt, and a slight midrib, three, four, or six rivets.

Actually, there are more types than those mentioned here, such as E, F and G. These are not included here, because no examples were available for sampling.

Types during MB age:

The general shape of the dagger in this period is different from that of the previous period, and there is no clear typological relation between them. An advanced improvement took place in the form of the dagger to make it a more efficient weapon. Generally, it is short, broad shouldered, with a real midrib to improve the rigidity. The hafting system is more advanced; alabaster pommels were found with most of the daggers. This indicates that the pommel was attached to the dagger with a wooden handle. The handle was fixed through a hole in the pommel, and a rivet penetrated the pommel and the handle. As far as the material of the handle is concerned, many fragments of wood are associated with the daggers of this era.

Type A1 (Cat. Nos. 17, 18): This has a short, square shoulder blade. It has a flat tang, and it is convex in section. (Cat. No. 18) has two rivet holes at the shoulder. While (Cat. No. 17) has a broken tang, pommels were associated with them.

A1a (Cat. No. 19): Short, square shoulder, wide flat tang. Slightly convex in section, three rivets in triangular position.
Alb (Cat. Nos. 20-23): Short, square shoulder, flat tang, wide and flat midrib tapers to a sharp point at the end. Usually with one, two, or three rivets positioned vertically on a narrow tang. Again, this type of dagger was associated with an alabaster pommel. It is parallel to Maxwell-Hyslop's (1946) type 26.

A2a (Cat. No. 24): Small, blunt blade, well marked square shoulder, no recognizable midrib. Short, narrow tang, and without rivets. Sometimes, this type had been described as a spearhead by mistake, but perhaps it could have been used as a knife. It compares with Maxwell-Hyslop's (1946) type 27a, and also with the important inscribed Tell Duweir (Lachish) dagger (Tufnell, 1958, Pl. 22:15).

A2b (Cat. No. 25): Medium blade, square shoulder, short tang with no rivets, pointed midrib. Again this type may have been used as a knife.

Type Bla (Cat. No. 26): It has a narrow blade, tapering gradually to a sharp point. The blade of this type is similar to the blade of type Alb. However, this dagger is characterized by a flanged hilt on both sides to hold the handle. Also rivets and metal bands were used in fixing the handle which was attached to the alabaster pommel. This flanged hilt was cast with the blade, and slightly hammered (see below, page 98). Maxwell-Hyslop (1970, 165) refers to a fresco from the Palace of Zimri-Lim at Mari, where this flanged-tang dagger was illustrated with a horned shoulder. But this flange technique is more likely to be imported from Crete (Sandars, 1961, Pl. 18: 1,3-5). This dagger has a pointed shoulder called "horns" caused by the flanges of the tang and the shoulder being projected upwards. These horns may have been used as guards for the handle of the dagger (Maxwell-Hyslop, 1946, 34). It is similar to her type 31, but the blade is shorter and with fewer rivets.

There are other types of dagger from the MB age, such as types C and D, but these are not included here because they were unavailable for sampling.
II.1.2. Axeheads: (Fig. 14)

EB - Crescentic axehead (Cat. No. 27): A thin, curved blade, with a sharp cutting edge. Kenyon (1955, 18) dates it between 2400-2200 B.C., it has been given different names such as; scolloped, ε-shape, and halberd. It was an important weapon of war designed for hand-to-hand fighting. Hillen (1953, 211) thinks that it developed as an "elaboration of the curved blades", Stronach (1957, 122, Fig. 13) illustrates the evolution of this axe. Petrie (1917, 9) considers this axe as a foreign importation into Egypt, and he accepts Syria-Palestine as its birthplace.

The axe has three tangs, one at each end and one in the centre, these tangs were used for hafting, by being hammered to fold around the handle, in order to secure the blade, or were fixed by rivets driven through the wooden handle. A relief discovered at Ur shows the axe in use. The example from Jericho has a broken tang, and there are knobs at the junction of the centre tang and the blade on both sides. This knob was probably derived from a rivet in the prototype (Kenyon, 1960, 179) which was used for some hafting attachment. A similar axehead was found at Tell el-Hesi (Bliss, 1894, Fig. 69). The Kfar Monash axehead is slightly different from the Jericho one (Gophna, 1968, 48). The third parallel example comes from Bab edh-Dhra' in Jordan (Lapp, 1966, 104-112). Other examples were found abroad in Syria, Mesopotamia, and Southern Anatolia, but in Egypt it was dated to about the end of the third, and the beginning of the second, millennium (Yadin, 1963, 43).

MB - Battleaxe head (Cat. Nos. 28-30): There is a general agreement that the crescent axehead further developed in the MB age, by improving the hafting system and the shape and length of the blade to achieve a more effective piercing weapon. Hillen (1953, 212) believes that there is no doubt that the eye axe developed from the former one, and the eye axe is earlier than the duckbill axe from a typological point of view. However, the chronological
evidence is not clear in this matter; as both axes have been found alongside each other. Maxwell-Hyslop (1949, 116) demonstrates this development from the crescent axe; type 24.B.1 to show type 24.B.2, and then she considers the two socketed axes (eye and duckbill) as types 24.B.3 and 24.B.4, but she classifies the battleaxe head as a separate type, 23, without indicating any relation to the other types.

This series is not completely represented in Jericho. The crescent axe was found in tomb A114, also, the eye axe is dated by Sellin (1913, Fig. 105:16) between 2000-1600 B.C. Other axes of this type were found in Palestine at Shechem, Megiddo and Ma'abarot (Gophna, 1969, 175). The third stage in the development, the duckbill, has not yet been found in Jericho. However, the duckbill and the last stage battleaxe head overlapped for a short period in the MB age. Thereafter the duckbill gives way to the battleaxe head.

It is a short range, hand-to-hand weapon, for piercing and penetrating. This axe is thin, light and almost like a chisel. The length is about 15 cm, and it is oval in section. The socket is decorated with ribs around the edge. There are knobs at the top of the socket on each side, and another two knobs where the socket joins the blade, these were to ensure proper hafting. This improvement in the technique of making axes is probably due to the advanced development of armour. It compares with Maxwell-Hyslop's (1949) type 23, and Deshayes's (1960, Pl.XXIII: 4 and 8). Four of these axes were found during Kenyon's excavations in Jericho, another one was found in tomb 9 by Garstang (1932, Fig. XXXVII:3). There are other examples of this type which were found in warrior tombs in Palestine and Syria; at Tell 'Ajjul, Tell el Farâh, Jerusalem, Ascalon and Ras Shamra.
II.1.3. Belt and Belt fasteners: (Fig. 15)

MB

Cat. Nos. 31-34): Jericho tomb J3 is one of the typical warrior tombs of the MB age. In this tomb three daggers and a battleaxe head were found. Another important piece of armour which was found in this tomb is a belt, with two belt fasteners. Unfortunately, the belt is in fragments (Kenyon, 1960, 308). A similar belt was found in another tomb at Tell el Farāh. This tomb is similar in finds to Jericho J3, this suggests that the belt was part of the equipment of the MB age warrior. Other fasteners were in further tombs at Jericho, but Moorey (1969, 98) argues that they were originally attached to clothes, and not part of the belt.

II.1.4. Spearheads: (Fig. 16)

LB

The spearhead is quite similar in appearance to the javelin, but it is larger in size, heavier than the javelin, and is different in function as an army weapon. It is used as a thrusting weapon which has a similar advantage to a long dagger since the enemy is kept at least the distance of the weapon away from the holder. It is similar to the dagger in the general shape, and this is why it had been described as a dagger, but it is not difficult to differentiate them, because the spearhead has a long thin tang which is not riveted. This long tang was to provide rigidity in hafting by inserting it in a wooden hilt. Some of the spearheads used to have hooks, this hook was fitted into a lateral niche near the end of the shaft, and this fixed hafting used to help to keep the blade firmly in position when the weapon was withdrawn from the enemy.

The spearhead was a common weapon as early as the third millennium B.C. in Anatolia. In the MB age, most of the spearheads in Palestine were socketed (Dajani, 1962,
Those included here were dated to the LB age, but they are less developed than the MB age spearheads and almost similar to the Anatolian EB Age spearheads. They can be classified according to their shape, length, straight or concave edge, and the tang. In this thesis, they are dealt with individually.

(Cat. No. 35): Long blade with rhombic section. The tang is long, hooked and squared in section. It has a sloping shoulder. It compares with Stronach (1957, Fig. 4:1) type 1, but the Anatolian example had been dated to the middle of the third millennium B.C. Also, it is similar to Catling's (1964, Fig. 2:10) type D which has been dated between 1900-1850 B.C., but another spearhead (ibid., Fig. 13:2) which is dated between 1550-1450 B.C. is close to our example.

(Cat. No. 36): Broken into two pieces, similar to the previous one but without a hook, and the section of the blade is slightly elliptical.

(Cat. No. 37): Medium blade with rhombic section, sloping shoulder. The tang is short, and rounded in section.

(Cat. No. 38): Broken, with a midrib blade. The tang is long, hooked, with a rhombic section. The edges of the blade tend to be parallel rather than tapering from the shoulder. It compares with Catling (1964, Fig. 12:5) type A.

(Cat. No. 39): Broken blade, slightly elliptical in section. The tang is long, and square in section.

(Cat. Nos. 40, 41): They have broken tangs, and are rhombic in section.

II.1.5. Javelins (Fig. 17 - 18)

The javelin is like a large arrowhead in appearance, but it is different in size and in the manner of use. It served as a medium range weapon, which was hurled by hand. Generally, the Shihan stele from Transjordan, which may date to EB-MB, shows a warrior carrying a javelin (Tufnell,
This is similar to other javelins found in Jericho (Kenyon, 1965, Fig. 4:11 and 13). Also, the javelin has been illustrated in Hittite sculpture as an important piece of army equipment.

The javelin was made of wood or reed with a head of metal, provided either with a socket or a tang (Yadin, 1963, 10-13). A cord was wound around the javelin, with a loop retained by the fingers of the warrior, and when it was hurled the swift unwinding of the cord would give it a spin, which increased the range of the throw. Also, the shape and weight of the javelin affects the range and the balance of the javelin flight.

**EB-MB (Fig. 17)**

Kenyon (1965, 49) divides the tanged javelins of this period into two groups; Type A (Cat. No. 43): Poker-head; which is almost square in section and the base is flattened.
Type B: Blade-headed, not included here, because it was not available.

**LB (Fig. 18)**

Milik and Cross (1956, 19) made the first attempt to distinguish between javelins and arrowheads according to their size and shape in the LB age and Iron Age. A typology is not going to be established, but javelins are dealt with individually.

(Cat. No. 44): Long blade with a short tang which is square in section. It has a wide and flat midrib, this type of midrib first appeared in the MB Age in Palestine (dagger type Alb).

(Cat. No. 45): Medium blade, wide and flat midrib, broken tang.

(Cat. No. 46): Short blade, wide and flat midrib, broken tang.
(Cat. No. 47): Broken blade, the tang is rhomboidal joining the blade in a rhomboidal stem. This development from a square to a rhomboidal tang creates the stem between the tang and the blade in the end of the LBI age (ibid, 18).

(Cat. No. 48): Medium blade, wide and flat midrib, rhomboidal tang, and the stem is also rhomboidal. Both (Cat. Nos. 117, 118) are parallel to their type J.I.

(Cat. No. 49): Thin blade, with a very wide and flat midrib. The end of the blade is elliptical in section.

(Cat. No. 50): Thin blade with a midrib, the end of the blade is elliptical in section.

II.1.6. Arrowheads: (Fig. 19)

LB

They are small, designed to give enough power to penetrate clothing or pierce armour. Reed was used for hafting, which was fixed with a thread to prevent splitting. It was necessary to fasten the heads by a tang. The arrowhead was a medium range weapon, launched by a bow and could be used as a war-head or for hunting. Evidence for the use of the bow comes from Tarkham Grave 22 in Egypt, and it is possible that the illustration is of an Assyrian invader during the 25th dynasty (Petrie, 1917, 36). An early example was represented on a scarab found by Garstang (1934, Pl. XXVI:SF) at Jericho tomb 5.

Arrowheads were rare before this period, but they became very common in the LB age. They have been found in many Palestinian sites such as Tell 'Ajul, Lachish, El-Khadr etc. Catling (1964, 131) considers the origin of the arrowheads as in the Near East.

On the one hand it is difficult to date them according to their typology; this is due to the fact that sometimes there is no basic change during different periods within one type. On the other hand, the arrowheads of LB age are more or less differentiated, which makes their typological study significant but difficult. In many cases
the slight variations within one type of arrowhead are a result simply of the method of manufacture. From their metallographic study, it is clear that they were roughly cast, and then heavily hammered and annealed more than once. This hammering caused the variations in their final shape. However, Milik and Cross' (1956) study of the El-Khadr hoard (south Jerusalem) is a systematic topological study in which they recommend that the most important factors to be considered are blade, stem, tang, midrib, and the blade point. Different arrowheads are dealt with individually.

(Cat. No. 51): A long tang which is square in section. The blade is leaf-shaped and elliptical in section.

Inscribed arrowheads:

Inscribed bronze weapons are known before this period such as the adze of Ras Shamra, the Tell Duweir (Lachish) dagger, and the sword of Adad-Nirari I. Also, inscribed javelins from El-Khadr are dated back to the 11th century B.C. A later arrowhead, 11th-10th century B.C., with a Phoenician inscription, was found in Biga in Lebanon (Milik, 1956, 3).

The two arrowheads from the Amman Airport Temple are inscribed with symbols, these do not have any palaeographic meaning. And so, the explanation of their purpose was as maker's marks or personal ownership (Tubb, 1977, 194). These marks are still in use by the Beduin to identify the different tribal properties such as sheep, camels etc. A sharp edge of a tool, e.g. chisel, could be used in engraving these marks. The best parallel to these arrowheads are the ones from Tell 'Ajjul (ibid., Fig. 1: b and c).

(Cat. No. 52): Inscribed, with a square tang, An oblan-ceolate blade shape, with wide flat midrib. Having a rib on an arrowhead or a dagger reduces the surface area of the weapon in contact with the flesh during penetration. Thus the frictional resistance is reduced and the weapon
enters more easily. The space between the ribs and the edges of the weapon serve as flesh spacers. The larger the spread the greater the bleeding. This arrowhead compares in type with Catling's (1964, Fig. 16:6) which is not inscribed.

(Cat. No. 53): This arrowhead has not been sampled but has been included here because it is inscribed, and at the same time it has four notches in each side of the tang. These V-shaped notches were worked by the sharp edge of a tool. There is no evidence for their function, but it is probably to ensure hafting or to fix the thread around the tang. The blade is oblanceolate in shape, with a wide and flat midrib.

(Cat. No. 54): Elliptical tang ending with a rhomboidal stem, this stem has the advantage of increasing the spinning and the speed of the arrowhead. The blade seems to be lanceolate in shape but it was corroded and had been chemically stripped so the shape is not very obvious.

(Cat. No. 55): Rhomboidal tang and stem, the blade is lanceolate in shape and elliptical in section.

(Cat. No. 56): Rhomboidal tang and stem, the blade is lanceolate in shape, and slightly elliptical in section.

(Cat. No. 57): Square tang, and without stem. The blade is lanceolate in shape and elliptical in section.

(Cat. Nos. 58, 59): They are similar, but the latter is smaller in size. Both are comparable with Catling's (1964, Fig. 16:5) which is dated between 1275-1200 B.C.

(Cat. No. 60): Short tang, the blade is elliptical in section. But this arrowhead had been chemically stripped.

Barbed arrowhead (Fig. 17):

This was found unstratified at the tell of Jericho, it is not dated, but its chemical analysis shows a very high lead content which makes it more likely to be dated to a late period, e.g. Roman.
II.1.7. **Sword**: (Fig. 20)

LB

(Cat. No. 61): The sword was an important military weapon. It appears in many reliefs, it was kept in a sheath with a strap for suspension at the waist of the carrier. Also, the sword could be used for ceremonial and ritual purposes.

According to Prof. Hennessy (personal communication), the sword was broken into three pieces during the bulldozing operation. It measures about 55 cm and consists of a curved blade which is sharpened on the outer edge for use in slashing. The straight part between the edge and the handle was to give length to the sword and therefore to protect the handler from the enemy. Three ribs are running from the end of the handle through the straight part of the sword, in parallel with the blade, joining at the sharp pointed end of the blade. The flange-horn hafting system of the sword developed from the MBII age, when it appeared in dagger type Bla. The handle is modified from a bird's head and it was inlaid probably with horn or ivory. The horn or ivory was held by the flanged hilts, and it was fixed with two rivets, the two horns could be considered as guards for the handle and for support in the sheath.

Maxwell-Hyslop (1946, 42) dates the early types of curved sword between 2400-1600 B.C. Petrie (1917, 26) dates an Egyptian example (ibid., Pl.XXVII:2) to Thutmose III period, and he believes that this type of weapon was introduced to Egypt from Mesopotamia. From the distribution of this kind of sword, it is more likely that Syria or Palestine was it's birthplace. The best parallel example is the inscribed sword of Adad-Nirari I, King of Assyria (Smith, 1928, 28), who ruled between 1310-1280 B.C. Another two swords which are similar to the Amman Airport sword come from Gezer (Macalister, 1912, Pl.LXXV:16) and Ras Shamra (Galling, 1937, 477:10), which are dated almost to the same period.
II.2. Tools

II.2.1. Axes: (Fig. 21)

As has been mentioned, it is difficult to distinguish between the function of an axe and an adze. Petrie (1917, 5) describes the differences between the two tools. However, both can be used more or less for the same purpose. The heavy weight of the axe is suitable for the use of cleaving or wood cutting. All the axes from Jericho come from the tell, others are published in Sellin (1913, Figs. 104, 105).

EB

(Cat. No. 62): Large, thick axe, elongated in section, with a slight swelling in the middle, rounded butt, and a straight V-shaped cutting edge.

(Cat. No. 63): Small, broken, flat axe, elongated in section, widening towards the rounded cutting edge, which is curved outwards.

(Cat. No. 64): The lower part of a small broken axe.

MB

(Cat. No. 65): Medium, flat, and thick axe. Elongated in section, and the cutting edge is swept slightly outwards, and straight cutting edge. It has been described as a "hatchet" by Garstang (1934, Pl.XXVI:18) because of the hole near the butt.

LB

(Cat. No. 66): It is medium in size, and flat. It has two lugs for hafting. The edges narrow towards the sharp, rounded cutting edge. It has no symmetry. Similar to Petrie (1917, Pl.V:135), and was used for ceremonial purposes in Egypt.

II.2.2. Chisels: (Fig. 22)

The flint chisel was a common tool in early times.
Metal chisels were also used for woodwork such as cutting, levering, chipping and fine work. Besides this, the chisel was useful for grooving or for piercing holes in metal. Chisels made of metal were also used for dressing stones or sculpture. Kenyon (1960, 200) observed actual traces of metal in the tool marks from the artefacts which were used in cutting tomb H22. Besides these chisels represented here, there are others which have been discovered in Jericho from previous excavations (Sellin, 1913, Fig. 105:10, 11). The chisel can be hafted in a wooden handle and used by pushing, or they could be hammered at the bottom. Chisels could also have two working ends for different functions. The use of the chisel is shown in ancient Egypt pictures (Pritchard, 1954, Fig. 123, 364). Chisels are different in size and shape and in the shape of the working end, the differences deriving from the main function of the chisel.

**EB**

(Cat. No. 67): Large, square in section, with a V-shape working end.

(Cat. No. 68): Medium, square in section, with a pointed working end.

(Cat. No. 69): Short, oval in section, the working end swept out (curved outwards). This may be a small axe, or a wide-short chisel.

(Cat. No. 70): Short, square in section, bent.

**MB**

(Cat. No. 71): Small, square in section, could be used as a small chisel, or as a rivet.

II.2.3. **Awls: (Fig. 22)**

The awl was used by hand or with a drill for piercing, some of the examples listed here could be pins.
EB-MB

(Cat. No. 72): Rounded in section with a pointed end.

MB

(Cat. No. 73): Broken, the head has a rectangular section with a pointed end.

(Cat. No. 74): Broken, square in section, possibly a pin.

II.2.4. Tweezers: (Fig. 22)

MB

(Cat. No. 75): Among the outstanding objects discovered at Jericho are two pairs of tweezers (Garstang, 1933, Fig. 10: 5.g.25, 5.f.46). In this thesis, a part of the arms of the tweezers 5.g.25 is included, which has a sharp end.

II.2.5. Knives: (Fig. 23)

It is difficult to discriminate in practice between the function of the dagger and the knife. Nevertheless, there are differences in shape. For example, the knife has fewer rivets than the dagger and this is due to the fact that the handle does not need to be strongly attached to the blade. Also, the knife has only one sharp edge without a midrib, while the dagger has two sharp edges with a midrib. The main use of the knife was for cutting, slashing and kitchen purposes. It was hafted with a wooden handle. Some of this wood is still well preserved within the corrosion. An alabaster pommel was used at the top of the wooden handle for better holding.

EB-MB

(Cat. No. 76): It is a long blade, with straight edges. It is elongated in section with two rivets and a pointed tip. It could be used as a dagger.
(Cat. Nos. 77-79): These are hollow-backed blades each with three rivets. The sharp side of the blade is convex so as to act as a razor. The two edges of the blade are joined together to make the crescent and sharp point of the knife. This distinguishing feature is obvious in the first two knives, but the tip of the third knife is broken. This shape is to make the knife a more useful tool for a sweeping cut (Petrie, 1917, 24). Another knife of this type was discovered by Garstang (1932, Pl.XXXVII:7).

II.3. Ornaments

II.3.1. Bracelet: (Fig. 23)

MB

(Cat. No. 80): A bracelet of child's size, the ends overlapped.

II.3.2. Rings: (Fig. 23)

MB

(Cat. No. 81): A finger ring, it has overlapping ends.

(Cat. No. 82): A small silver ring, could be used as an earring.

II.3.3. Toggle-pins: (Figs. 24 - 26)

MB

The toggle-pin is a decorative item and was used to fasten garments. Kenyon (1960, 266) found many bodies clothed with textiles, and the cloth was usually secured with a toggle-pin positioned on the left shoulder or on the ribs, with the point of the pin down (Fig. 26). Sometimes, it was used on the right shoulder, and occasionally with the point of the pin up. Sometimes a scarab was suspended from
the toggle-pin. The material for the manufacture of pins was mostly metal, and rarely bone.

Henschel-Simon (1937, 172) classifies the toggle-pins into three groups according to their date; Group I: the pre-Hyksos. Group II: includes toggle-pins from MB and LB ages. Group III: The Iron Age toggle-pins. Each group can be divided into types according to their shape and decoration, but it seems that there is no proper development in the sequence of these divisions, and the classification is based on types more than chronology.

The earliest example of a toggle-pin comes from Mesopotamia, but there is no certainty that this can be identified as the place of origin. The pre-Hyksos toggle-pin is simple in shape, either in the form of a nail with a semi-globular head, or with a club-head, this type is not included here because the material was not available for sampling, but the second group only is dealt with. A large number and various types of toggle-pins were introduced into Palestine with the Hyksos. There is no immediate typological connection between the previous types and these types, though some relationship is not out of the question. However, many interesting questions need to be answered, such as did the Hyksos invent the new type of toggle-pin, or did they improve the pre-Hyksos one? As has been mentioned earlier, Kenyon's (1960, 297) typology for the toggle-pins will be followed. Meanwhile, each type will be compared with Henschel-Simon (1937) wherever possible.

Type A1 (Cat. Nos. 83-88): In this type the part above the eyelet of the pin (shaft) is plain, a slight thickening towards the head, which is rounded. It is similar to Henschel-Simon's type 3 (Pl.LXVIII:Tp.14).

A2 (Cat. No. 89): The upper shaft does not thicken towards the flat head.

Type B1 (Cat. Nos. 90-93): The upper shaft of the pin is plain, but it has a disc-like head.

B2 (Cat. Nos. 94-96): The disc-like head is well defined. It compares with Henschel-Simon's type 8a (Pl.LXIX:Tp.63).
Types C and D are not included, because they were not available.

Type E (Cat. Nos. 97-100): The upper shaft is plain, but the head is like a ball on a disc, or a multi-disc.

Type F (Cat. Nos. 101-103): The whole upper shaft is grooved regularly, and the head is disc-like. It is parallel to Henschel-Simon's type 8Cγ (Pl. LXIX:Tp.86).

Type G1 (Cat. Nos. 104,105): The whole upper shaft is decorated with rounded moulding, and sometimes a small part of the upper shaft is decorated.

G2 (Cat. Nos. 106-108): About half of the upper part is decorated with rounded moulding.

There were no toggle-pins of type G3 available for sampling.

G4 (Cat. No. 109): It is a sub-type not included in Kenyon's classification, it is different from other sub-types due to the fact that the whole upper shaft and part of the shaft below the eyelet is decorated with rounded moulding decoration.

Miscellaneous:

(Cat. Nos. 110,111): These are small toggle-pins with decoration on the upper shaft.

(Cat. No. 112): A fragment of a silver toggle-pin.

(Cat. No. 113): The lower part of a toggle-pin.

(Cat. No. 114): This is a unique toggle-pin with a segmented sphere head, the head was cast separately and added to the top of the pin. A loop was inserted through the upper shaft. This loop is likely to have been used to hold a scarab. It compares with Henschel-Simon's type 9a (Pl.LXXTp.99) which is without a loop. Another example without a loop was found in Jericho by Garstang (1939, Fig. 19.C:16). Several similar examples from the MB age were found at Ras Shamra (Schaeffer, 1948, Fig. 49:1), and another LB age example was discovered in Cyprus (Catling, 1964, Fig. 6:6,8).
II.4. Miscellaneous

II.4.1. **Metal fittings:** (Figs. 27-28)

**EB-MB**

(Cat. Nos. 115, 117-130): A great number of fragments of plates and bands were found in many tombs from this period at Jericho. They were used with nails, rivets, studs, and staples for fitting purposes. Some of them are still attached to wooden fragments.

**MB**

(Cat. Nos. 116, 131): The chemical analysis indicates that both are silver in content, the first one is not well stratified.
III. METALLOGRAPHIC EXAMINATION

Metallography is the branch of science which deals with the investigation of the structure of metals and alloys. The investigation can be made by means of the observation of a cross-section of a sample as seen through a reflecting optical microscope. The cross-section is prepared by polishing and etching. The mechanical characteristics of metals are strongly related to their structure. The determination of physical and mechanical properties with the chemical composition of the metal helps to draw a picture of the kind of technology which has been applied to the metal during manufacture.

The basic structural properties of metals and alloys are governed by the orientation and the shape of the crystals. There are three types of metallic crystals:

1. Pure metal crystals, which usually occur in elemental metal.
2. Solid solution crystals.
3. Intermetallic compound crystals.

The last two types of crystals occur in alloys. Alloying is the result of the dissolution of one or more elements in another in the liquid or solid state. One reason for alloying is to enhance desirable mechanical and physical properties, which cannot occur in the pure metal. For example, hardness, strength, and ductility depend to a large extent on the type and amount of alloying and working and heat treatment applied to the alloy. When one metal is completely soluble in another, the atoms of the solute metal can accommodate themselves in the lattice of the solvent or the parent metal. In this case, the alloy will solidify as if it is a pure metal, forming a single type of crystal or "phase", where each crystal contains both types of atom (Cottrell, 1976), but in most cases, the accommodation of the solute metal in the solvent metal occurs to a limited extent only, and when this limit is exceeded, the excess "solute" metal (with probably some solvent metal
Fig. 3
dissolved in it) precipitates out as a second phase during solidification.

The relation between the composition of the two or more constituents of the alloy and the different solidification temperature ranges of the alloy phases can be illustrated on a graph, and this is called a phase diagram or equilibrium diagram.

In the copper-tin system (fig. 3), the α, β, γ and δ solid solutions appear as different phases. In any bronze containing less than 14% tin, as is the case in most of the bronzes examined in this study, only the alpha phase normally occurs at room temperature. This alpha phase is soft, ductile, and can be easily cold-worked. An excessive amount of cold-working results in an alloy which is hard and brittle, but by annealing it i.e. heating to an elevated temperature, elimination of the brittleness and recovery of the original ductile state of the metal occurs.

III.1. Experimental

III.1.1. Metallographic technique:

Metallographic investigation requires the removal of a small section of the artefact to be examined. Coghlan (1975, 86) recommends taking two V-shaped sections from an object to make such a study. If it is not possible to cut two sections, one can obtain sufficient information from a single representative section.

The method of cutting is important when removing the sample, any heating of the sample during this process must be avoided, otherwise the true microstructure may be altered, and lead to erroneous conclusions. This factor must be borne in mind during all the metallographic processes.

Where permission was given to remove the object from the museum, a Buehler 11-1180 Isomet low speed saw was employed, using a diamond wafering blade, which gave good results. Fragile and brittle metal artefacts can be cut using this saw, which leaves a very smooth surface. Isocut fluid lubricates the cutting blade during the process to avoid
overheating the sample. Where this was not possible, a small hacksaw was used to cut the section on the museum premises.

It is necessary to mount the sample for convenience in handling, and for protecting and preserving the sample during the metallographic processes. Scandiplast 9101 and Catalyzer 9102 were used successfully for embedding copper and its alloys. The whole mounting process must be completed within 6 minutes, and then left to set for an average of 2-4 hours.

The first stage in the preparation of the metallographic specimen is grinding in order to remove the marks caused by cutting. The Metaserv hand-grinder with grades: 220, 320, 400 and 600 silicon carbide papers was used. Excessive pressure on the specimen was avoided, and any heat generated was prevented by a series of jets providing a stream of water flowing down each strip. Grinding should be always in a direction across the scratches. The sample was cleaned in an ultrasonic cleaner and dried after each different grade of the grinding process.

The next stage in the preparation of the specimen is polishing, and it is important to provide a highly polished surface capable of reflecting the light from the microscope. This is a semi-manual process. The Metaserv Universal Polisher using two polishing discs with Metron polishing cloths attached was used and gave good results. Different discs must be used for different grades with diamond particle sizes of 6, 1, and ½ microns. A small amount of 6M3 Dialap Paste (Diamond Lapping Compound) was added to the cloth for 6 μ polishing, and Dialap Fluid Spray was used as a lubricant. The same fluid can be used on the disc with 1M1 Dialap Paste for 1 μ polishing. Hypez Spray with Hypez Fluid Spray was used on the ½ μ disc to achieve very fine polishing.

In fact, it is sometimes difficult to obtain a scratch-free finish on an ancient metal sample, due to external and internal corrosion, the large amount of inclusions, and the porosity. So, careful polishing and thorough washing
and cleaning in an ultrasonic cleaner between each polishing on different micron discs is essential to obtain an acceptably scratch-free surface.

Sometimes, the clean, dry specimen reveals certain structural features such as inclusions or physical imperfections. However, etching dissolves the film on the polished surface, and then attacks the grains themselves, to delineate and identify the structure and phases present in the metal. Etching is due to a difference in the rate of attack of the various phases present, together with the differences within a phase caused by the orientation of the grains. By etching the surface of the metal, the grains and the grain boundaries are attacked differently forming crystallographic terraces. These reflect the light in various directions, according to their orientation; some of them appear black, others white. The specimen can be immersed in the etching solution for seconds or minutes, depending on the etchant and the metal itself, until the polished surface becomes slightly coloured. The sample is then thoroughly washed, first in water, then in alcohol, and dried in warm air. The reagents used for etching copper and its alloys have an oxidizing action. Many different etchants are listed in metallurgical books: ferric chloride (in water), ammonium persulphate, and ammonia (0.880 S.G.) gave good results. Sometimes, the combination of more than one reagent gives successful results. It was found, for example, that by immersing the specimen for a few seconds in ammonium persulphate solution followed by rinsing and immersing in ferric chloride, that the structure of the metal was clearly revealed. Adding several drops of fresh ammonia to ammonium persulphate solution gave a good result when used to etch copper-arsenic alloys.

The etched sample can then be viewed under a microscope by reflected light. An Olympus BHB microscope (Olympus Optical Co. Ltd., Japan) was used. Photomicrographs were taken using the camera (C-35) attached to the microscope.
III.1.2. **Hardness test:**

After the metallographical study was completed, the hardness was examined using the McCrone low load hardness tester with diamond pyramid attached to the Vickers Projection Microscope (Cooke Troughton and Simms Ltd., England). Different weights were used with the indenter to achieve the diamond impression. The impression diagonal was measured in eyepiece scale divisions and converted to microns (\( \mu \)), using the factor: \( D \times 2.63 = D(\mu) \). The Vickers hardness was then calculated according to the formula:

\[
H_v = \frac{1854 \times P}{D^2}
\]

where:
- \( D \) = The reading of the diagonals (\( \mu \))
- \( P \) = The weight used in gramms.
- \( H_v \) = Vickers hardness

III.2. **Interpretation of metallurgical structure**

As has been mentioned before, the microstructure of an artefact is a preserved record of the technology that was used in the manufacture of the artefact. However, a metal object can be shaped either by casting or mechanical working, or by both means.

III.2.1. **Casting:**

In casting, the molten metal or alloy is poured into a mould, where solidification takes place. The structure of a cast artefact is either dendritic (tree-like), or equi-axed, depending on the composition, pouring temperature, cooling rate, the material and temperature of the mould, and the solidification conditions of the metal.

Dendrites can often be seen in the microstructure of alloys during solidification, because the crystals of the solid solution seem to be uneven in composition. The initial branches of the dendrites consist of the first solid phase to be rejected by the metal. The composition of these small
crystals has a different chemical composition from the average composition of the liquid from which they have solidified; the remaining liquid solidifies between the branches.

When a molten metal is cast in an unheated mould, the layer next to the walls of the mould cools rapidly, giving a columnar grain structure. The temperature gradient from the liquid to the mould, causes slow cooling of the crystals behind the columnar grains. The result is the formation of dendrites which continue to grow until their arms almost meet, and the remaining liquid metal solidifies between the dendrites (Cottrell, 1976, 177), but if the composition of the crystals of the solid solution is even, when solidification is complete, equi-axed grains will occur, and no traces of the original dendrites remain. The grains are varied in size, due to different factors, and the boundaries between them are known as grain boundaries.

III.2.2. Mechanical working:

Mechanical working means the use of a force in order to shape or alter the shape of a metal artefact in the solid state. Cast alloys are mostly heterogeneous in composition, and porous because of shrinkage and gas evolution during solidification. Also, oxide and sulphide inclusions may be present. Mechanical working is essential to improve the cast product by making the metal more uniform in composition, to eliminate porosity, and to enhance the mechanical properties e.g. hardness.

If a single phase of a cast copper-tin alloy is cold-worked below its crystallisation temperature (i.e. worked at room temperature), the dendrites will be distorted, and the alloy will become work-hardened, but if this is followed by annealing above its recrystallisation temperature, twins are formed as a result of recrystallisation after cold-working. Under microscopic examination, the twins show as parallel sided bands within a single crystal. Additional cold-work on a cold-worked and annealed metal, causes the distortion of the twins, while extreme cold-
work can result in slip bands, which appear to run across each grain. Slip bands may often be seen as a result of plastic deformation. Annealing twins appear in the recrystallisation structure of previously cold-worked and annealed metals or alloys, or in the structure of a hot worked alloy.

III.2.3. Inclusions:

Inclusions are foreign particles, which on microscopic examination may appear to be distributed throughout the structure of a metal. They can be originated during melting and casting. Inclusions may be classified as either metallic or non-metallic, whilst their origin is related to ores, fluxes, incompletely dissolved metallic alloy, or impurities introduced during the casting process (Rostoker and Dvorak, 1965, 48ff). They can be examined by scanning electron microscopy (SEM) and identified as oxides, sulphides, metallic particles, etc.

Oxide-type inclusions are segregated during the solidification process, these are mostly distributed along the grain boundaries as hyper-eutectic, or they can be as particles occurring in an eutectic shape (Cat. No. 136) (Atlas of Microstructures of Industrial Alloys, 274).

Inclusions may occur in different sizes, shapes, and colours. If they are relatively plastic, they can be elongated in the direction of working as stringers. Further working can break them down to a smaller size, but hard inclusions remain angular in shape.

Identification of inclusions by the examination of their colour under the microscope in reflected light might be misleading. The electron microscope unit of the Metallurgy Department in Imperial College, London University, kindly helped to examine seven samples using:

1. 100CX Temscan attached to a Link System X-ray energy dispersive analyser (Japanese Electron Optical Laboratories).
SEM analyses carried out on ancient samples showed that some of the light blue inclusions found by optical microscopy are composed of copper oxide (cuprite). However, other light blue inclusions in another sample (Pl. 40) gave 70% arsenic and 30% copper. Light grey inclusions (Pl. 43) from an object dated to LB age, were analysed as sulphides with small traces of copper and iron. Shapeless, blue inclusions (Pl. 47) from an ingot (Cat. No. 132) were found to be very high in lead. An apparent white inclusion was shown to be an α + δ eutectoid area of very high tin content as the line analyser illustrates (Pl. 45). It was difficult to detect the very bright inclusions in the ingot (Cat. No. 132) by the 100CX Temscan, instead, the Microscan 5 without photographic equipment was used, and a pure silver analysis was confirmed. The small black dots resulting from segregation during solidification appear to be copper oxide (Pl. 41).

As a result, it appears difficult to identify the inclusions by their colour, SEM analysis is essential to determine the true composition of the inclusions.

III.2.4. Examples from antiquities:

The study of the microstructure of ancient metals is important if one is to understand the development of metal working and fabrication techniques during different periods. For this purpose, about fifty sections from different types of object dated to the Bronze Age have been subjected to metallographic examination. This study is summarised here, while full microstructural data for individual samples will be represented later in the Catalogue.

Casting was an important technique in ancient times, it requires care and skill to control the operation for a good quality product. The material of the mould could be stone, clay, or metal, but it is important to bear in mind that this material must withstand the high temperature of the molten metal, and strong enough to hold its weight. Also, it is known that it was important to heat the mould before each cast, in order to avoid
cracking caused by thermal shock. There are three types of moulds:

1. The open mould is the earliest and simplest in shape, the desired shape was cut in stone, or a pattern was pressed into a block of clay. More likely, a capstone was used to prevent the oxidation of the surface of cast metal, in this case the term open is not correctly used. This type of mould was used to cast simple shapes, such a mould did not fulfil all the requirements of the ancient smith.

2. The bi-valve mould is more sophisticated and consists of two or more fitting pieces, a pouring cup and a runner serve to allow the run of metal in the mould during pouring. The air and gases must be free to escape, otherwise the product will fail or will be very porous. Tylecote (1973, 1ff) proves that if the contact between the pieces is not perfect, venting could happen easily, and the product is a sound metal casting.

   The bi-valve mould can be attached to a false-core to produce a hollow part in the casting e.g. a socketed battleaxe head; clay can be used as a material to make the false-core.

3. The cire perdue or lost-wax method was used to cast very complicated objects such as statues. Elliott (1974, 273) believes that this method was used to manufacture at least some of the objects of Nahar Mishmar, which are dated to the Chalcolithic period.

   A model of the shape required was formed from bees-wax, and covered with clay to form the mould. Both model and mould have to be supported, for example sand can be used, and the whole is then heated to melt or burn out the wax, and to replace it with the molten metal. This method produces a solid casting, but to save metal and wax, a core of clay covered with a layer of wax was used for the model, and the same procedure can be carried out to produce a hollow cast, also the thickness of metal can be easily controlled using this process.

   In the case of axes and chisels, it is more likely that they were cast in an open mould. Many of these moulds
were discovered in Palestine; Sellin (1927, 210, Pl.21) found at Shechem a very interesting block of clay with moulds on different sides of the block. These moulds were used to cast different implements. At Beit Mirsim (stratum D of the MB age), Albright (1938), 53, Pl. 43) reports the finding of moulds for axes or chisels and others for knives, made of limestone. Also, at Megiddo (stratum XVI) pottery and limestone moulds were discovered (Loud, 1948, Pl. 269). Bearing in mind that the mould must withstand the heat of the molten metal, it is difficult to believe that limestone was a suitable material for making the moulds. It is possible that such moulds were to cast moulds of clay, which were then used to cast metal objects. Additional evidence for this is that the excavators found no traces of any metal in these limestone moulds.

The structure of axes and chisels shows that they were cold-worked and annealed after having been cast. The structure of a small chisel (Cat. No. 69) appears as dendrites under small magnification, meanwhile, under higher magnification it shows twinning superimposed on the dendrites. Also, the twin structure is well preserved within the corrosion layers.

It is accepted that daggers were cast in bi-valve moulds, and ribs were also cast in (Branigan et al., 1976, 18). Some of the dagger sections show ghost dendrites. This has been caused by the segregation of the inclusions e.g. copper oxides, within the dendrites during solidification. When the dendrites become transformed by the effects of annealing, the inclusions remain in the structure. The edge of the cast dagger must be trimmed into shape, also, the cutting edge could be hardened and shaped by hammering. This causes the twins, and sometimes the slip bands, found in the structure of the daggers. The structure of some of these daggers has become distorted because of the cold-work and the heterogeneous nature of the metal.

The daggers of the MB age are more advanced than the EB-MB period daggers in their shape, haft attachment, and their technology. Also, the composition is different. The structure of the knives is similar to that of the daggers,
except that the twins are without slip bands.

Rivets were made separately from metal of different composition to the daggers before they were attached, rivets were used for other fitting and joining purposes. From their distorted structure, it can be deduced that they were heavily cold-worked.

The crescentic axe and the battleaxe heads are weapons of interest, it is more likely that they were cast in a bi-valve mould and then cold-worked and annealed into shape. Tin and lead are present in the battleaxe heads and together with their shape indicate an advanced casting technology. An unique discovery was made at Byblos in Lebanon by Dunand (1939, vol. I, 198, Pl. 108, No. 3069). He found that a fragment of a green steatite mould was used for casting a duckbill axe; and this mould was dated to the MB age. The duckbill axe represents a stage in the series of the development from crescent axehead to battleaxe head.

Henschel-Simon (1937, Pl. LXX) illustrates a mould for a toggle-pin from 'Ain Shems, which makes it clear that toggle-pins were cast in Palestine during the MB age. Some of these are tin-bronze in composition, whilst others contain tin as well as arsenic. But the structure of different toggle-pins is very similar consisting of a re-crystallised twinned grain structure.

As far as LB age weapons are concerned, various types were examined. Some of those which were studied from a metallographic point of view, contain as high as 10.5% tin in their composition, which enables a good casting to be obtained. Some α + δ eutectoid would be expected after casting such an alloy. It is known that this eutectoid causes brittleness and difficulties in cold-working. Hot-working, or annealing after cold-working, is likely to remove the δ phase by diffusion. The further cold-working or annealing was important to give the object its final shape, and this explains why it is sometimes hard to find two objects of the same type, e.g. arrowheads, similar in shape. This thermal and mechanical procedure is obvious from their structure, twins with slip bands, and their high
hardness (approximately 100 Hv). These objects are also similar in their chemical composition and structure to some bronze artefacts found in LBII tombs near the "Persian Garden", north of Akko (Brewer, 1977, 75ff). In the structure of the sword (Cat. No. 61) interesting inclusion-like white features are located between the grains. From their shape and the SEM analysis, these are most likely to be $\alpha + \delta$ eutectoid, with a very high proportion of $\delta$ phase.

III.3. Other aspects of ancient technology

A large number of fragments of metal fitting was found at Jericho from the EB-MB period. These include metal plates and bands, which were secured by rivets or spikes. Such techniques were known as early as the fourth millennium B.C. (Coghlan, 1975, 106); the Egyptians used to cast metal sheets in open sand moulds, the product then being hammered and annealed to smooth the surface, and to achieve a certain desired thickness.

A spike (Cat. No. 123) and a stud (Cat. No. 121) were very corroded and fragile, which made their handling and cutting impossible without mounting them in resin. Cutting through them was necessary to understand their technology. The spike was attached to a metal plate by piercing a hole in the plate, the spike was then driven through the hole facing the rough side. This has the advantage of covering and folding the rough side of the plate caused by piercing the hole (Pl. 50).

The dome-headed stud (Pl. 52) was made of a rivet fixed into a thin metal disc, the inside of the disc was then gradually hammered to the desired shape in a shallow concave depression. This is called hollowing, but the same effect can occur by doing the opposite – raising – by hammering the outside of the metal disc, over a small dome-headed anvil (Hodges, 1976, 74). The distorted structure is a good indication that the object had been heavily worked.

A rare skill was shown in the square section of the
awl (Cat. No. 73), between the corrosion layers, a shiny layer was shown. When this layer was examined by the electron probe microanalyser, a high concentration of arsenic was illustrated as is shown by the white dots (Pl. 55). A similar technique was confirmed when a dagger from Carnoët in France was examined by Hundt in 1971 (Briad and Mohen, 1974). Another example comes from a bull from Horoztepe in northeastern Anatolia. The layer of arsenic enrichment contains over 10% arsenic, meanwhile, the presence of arsenic in the underlying bronze is less than .001% (Smith, 1973, 96).

Generally, the technique of coating the cast bronze figurines with silver or electrum is known in Anatolia, but it is uncertain which method was employed in this arsenic enrichment.

Smith (ibid., 99) assumes that the arsenic was applied by a process involving arsenic vapour, or possibly a paste containing arsenic could have been applied. However, it is unlikely that metallic arsenic would have been available at that time. So, stable arsenate of the alkali metals which is available in plant ash can be easily reduced with charcoal. If a mixture of white arsenic, an alkali carbonate, and charcoal is heated, arsenic vapour will occur and react with the metallic copper to give a coating rich in arsenic.

McKerrell and Tylecote's (1972) experimental work on arsenical copper shows that when it is cast, the arsenic segregates near the surface which is known as inverse segregation. Actually, the technology of arsenic enrichment is not completely understood, and much work needs to be done before coming to any conclusions.

Cutting through the centre of the head of the toggle-pin (Cat. No. 114) was the only way to find out how it was made. Most surprisingly, the head was cast separately from the pin. A small space was left behind the pin when it was driven through the head. The ancient smith did not ignore that, therefore, a copper rivet was wedged in to fill the gap (Pl. 57).
It proved vital that to examine the section of the belt fastener (Cat. No. 34) when two analyses from the ends of this object showed silver, while another drilling from the core of the metal confirmed it to be arsenical copper. The section is severely corroded, but it is obvious that it had been silver-plated (Pl. 58).

Charles (1968, 282) believes that it is improbable that such silver coating was applied by a dipping technique, he thinks that it is more likely that a diffusion bonding technique was used which is known as "Sheffield plate". This process is obtained by adding a clean bar of silver on a thicker bar of copper, brushing with paste flux around the edges and then heating the whole above 780°C with pressure. In this case, hot pressing or rolling can be used, and a tough joint occurs. This silver-plating appeared in the cap of a rivet of a Minoan dagger dated to about 1500 B.C., also, there are other Mycenaean examples.

These technological aspects illustrate the degree of skill which the ancient smith reached in Palestine between the EB-MB period and the MB age.

III.4. Metallurgy from the tell of Jericho

Two pairs of tweezers are illustrated by Garstang (1933, Fig. 10:5.g.25, 5.f.46) and dated to the MB age. Apart from this, nothing has been mentioned about any remains of metallurgical activities from the tell of Jericho. However, this would be expected with the large amount of artefacts which were discovered on the site.

The preliminary investigation of these materials was carried out using a binocular microscope together with XRF analysis. According to this first examination, and following the general metallic appearance, the materials were divided into two groups:

A. Minerals (with no metal, or mineralised products).

These are either shapeless, crusty lumps of corroded metal, or decomposed copper ores. Also, nodules of very
rich copper ores could be included under this category.

B. Metal

They were subjected to a metallographic and analytical examination. According to this investigation and their general shape, they can be classified as follows:

1. Metal scrap (Cat. Nos. 134, 135, 140): Metal scrap can be found as a result of previously used and failed artefacts or failed castings, the structure of the first one is twinning with slip bands.

2. Ingots (Cat. Nos. 132, 136): They represent the raw material after smelting and are mostly pure copper without any alloying additions, but impurities can be expected to occur. The composition of the ingot (Cat. No. 132) is very interesting due to the high nickel content, 1.5%, and its structure in some areas equi-axed, while in the others it shows twinning with some slip bands. The second ingot looks like a bar, and its analysis confirmed almost pure copper. The structure is equi-axed, with large grains, twins also were shown. This means that it had been cooled slowly in its mould, and then compacted into shape by slight hammering, and then annealed.

Ingots were found in different shapes e.g. bun or plano-convex were common in the Near East. Meanwhile, oxhide ingots were used in the Mediterranean (Wheeler et al., 1975, 32). Also, secondary, small forms of ingots such as bars were found; this is to make it easy for shipment and to facilitate production of certain objects.

Three ingots from Har Yeruḥam in the north-east of the Negev, and another four from the Hebron Hills were examined by Maddin and Wheeler (1976, 170ff). The analyses of these ingots show copper with about 1% lead, and the presence of iron in some of them was confirmed. Meanwhile, their structure is either equi-axed or dendritic.

3. Metal drops (Cat. Nos. 133, 137-139): The metal drops or runners illustrate the practical evidence of metallur-
gical activities, some of these drops still cohere to either stone or textile. Their chemical analysis is very important because they can give an idea about the raw copper before alloying, and therefore will be discussed later. Their structure is either dendritic or equi-axed.

Apart from (Cat. No. 133) the metal drops were excavated from trench H:square II, III, VI. In this trench phases (XLiva-Li) belong to the MB age. Also, houses and other architectural evidence were found; rooms facing a street running east-west in both squares II and III. In the same strata a fire place was found.

All these metallurgical remains positively indicate that a secondary melting and casting processes took place on the tell of Jericho between the EB and MB ages. However, Jericho is not the only place in Palestine where metallurgical processes were carried out. For example, Rothenberg (1975, 74) in "Investigation at Lachish; the sanctuary and residency, vol. V" mentions that such activities took place in stratum VI. Also, Albright (1938, 54) found limestone moulds and crucibles, and ingots which were dated to the MB age at Beit Mirsim.
IV. ELEMENTAL ANALYSIS

The elemental analysis of ancient metal is very important for both archaeologists and museologists. By knowing the composition of the artefacts of a certain era in one area, the archaeologist can often give a relative date to unstratified finds, or he can adjudge the authenticity of purchased objects. Also, the study of trace elements analysis might be helpful to locate the provenance of an artefact, whether local or imported. Nevertheless, the analytical characteristics of metal artefacts of a certain period indicate the level of the technical skill in that culture.

Generally, the analysis is important to the museologist in order to guide him in classifying and recording the material in the museum. Besides this, it is important to know the chemical composition of an artefact to decide the optimum method of conservation.

In Europe, this interest was started about the end of the last century, but in the Near East, the archaeologists were aware of the importance of metallurgical investigations about the beginning of this century, thus they allowed metallurgists to sample metal artefacts. Prof. Rathgen and Dr. Büttnner of the Kgl. Museen, Berlin, analysed an axe from Jericho (Sellin, 1913, 116). Desch (1929) reported the examination of some metal artefacts, slags and ores to the Sumerian Committee of the British Association. This was followed by a detailed metallurgical examination of metal from the Royal Graves at Ur by Elam (1932). Four axes from Teleilat Ghassul were analysed (Mallon et al., 1934, 75-77) also, Kelso (1943) examined two artefacts from Tell Beit Mirmim.

In the second half of the twentieth century, more research concerning the area took place. In Palestine, metallurgical results appeared with the archaeological reports, e.g., Thompson's metallurgical report in Lachish IV (Tufnell, 1958, 328-331). Also, different types of
metallurgical research took place; Timna has been explored between 1959-64.

In the last decade, analytical methods in general were improved, and different projects were published in various journals. However, large metallurgical programmes are still needed in the area, and this is one of the main aims of this thesis.

There are different analytical methods with various characteristics which can be used in the determination of ancient metal. The method to be used depends on many factors such as the information required from the analysis, the condition of the object, the quantity of the sample, and the cost of the analysis. However, there is no method at present which can fulfil all the requirements for a complete analysis.

In the case of those samples which were found to be severely corroded, quantitative analysis would not give meaningful results, and therefore semi-quantitative X-ray fluorescence (XRF) can be used to determine the major components of the metal. The samples were mounted in resin, and ground smooth to remove the heavily corroded surface. Two hours were needed to complete the analysis using a Siemens dispersive spectrometer with 50 KV and 23 mA excitation. One of the disadvantages of this method is that it is not able to detect all the trace elements in the metal. Also, it can be considered as a non-representative analysis, due to two factors. First, the corrosion changes the concentration of elements at various rates e.g. tin enrichment, so that the composition of one section of a surface is different from another section, and so the expected error could be $\pm 20\%$ (Moorey and Schweizer, 1972, 180). Besides this, it is known that ancient metal is not homogeneous due to the segregation of different elements during the manufacture of the artefact, therefore the results of XRF analysis could be misleading. Ten samples from different periods were analysed by XRF, before they were drilled for Atomic Absorption Spectroscopy (AAS), in order to use them as a guide for the calculation of results.
of the subsequent samples which were analysed by XRF only.

Twenty-five different specimens were analysed by emission spectrometry (Plasma excitation), model: Philips PV8490 ICP in the Geology Department of King's College, University of London, and these results were compared with the results from AAS. Apart from gold which showed a higher content by plasma, both sets of analyses were similar. However, there is no place here to discuss the differences between the analytical methods, but Chase's (1974, 174) work on the variation between different methods of analysis has shown that AAS is usually the best method, followed by mass spectrometry and then XRF.

IV.1. Atomic absorption spectroscopy

Drilling:

The museum curators and keepers have been helpful and cooperative in many ways, but it is sometimes still difficult to obtain permission for sampling due to a general suspicion about the disfigurement of the objects. Coghlan (1960, 3) lists the factors which control the quantity of the sample to be taken from the artefact, the first being the information required from the analysis, and the second, the limitations imposed by the curator of the museum concerned. In fact, there are other factors to be taken into account, e.g. the method of analysis to be used and the condition of the object.

A small drill-bit (No. 60: 1mm) operated by a 12 volt motor via a transformer was used to obtain about 20 mg of metal, enough for the AAS analysis. It is important that the sample should be representative, otherwise the results would be misleading. And thus, the location of the sample must be carefully selected. Multi-position drilling is more advisable in order to avoid the heterogeneity of the metal. Charles (1973, 105ff) gives the reasons behind this heterogeneity which occurs during the manufacturing of the artefact. The hole left by drilling can be gap-filled with a suitable resin mixed with pigments so that
the object can be exhibited.

In general, ancient metal objects are corroded, and this corrosion must be avoided in sampling, due to the resultant change in the concentration of the elements in the metal. This can be done by drilling the corrosion away down to the shiny metal surface. Once having exposed the metal, the drill-bit is changed and the metal collected separately on a piece of clean glossy paper. Hardened steel bits do not cause contamination of the sample. Scraping the corrosion to obtain the surface of the metal is not advisable, because the disfigured area is larger than that caused by the first method. Contamination must be strictly avoided during the operation, because the amount of the sample is small, and the result would be misleading. Samples then can be kept in small gelatine sample capsules preserved in a dessicator containing silica-gel.

Sample preparation:

The sample was weighed and transferred to a 20 ml beaker, 1 ml of aqua regia (1 vol. conc. HNO₃: 3 vols. conc. HCl) was added. The beaker was covered with a small funnel to eliminate spitting during heating on the hotplate (c. 60°C). After the metal was dissolved in the acid it was left to cool, and then another 1 ml of the aqua regia was added. The solution was transferred to a 25 ml graduated flask, the beaker and the funnel were carefully washed off with distilled water which was transferred to the graduated flask. More distilled water was added to bring the solution up to the volume calibration.

Finally, the whole solution was placed in a polythene bottle to be ready for analysis (Hughes et al., 1976, 24). This amount of solution was enough for the determination of thirteen elements with flame, and the three elements with flameless AAS. The Perkin Elmer model 460, attached to the graphite furnace Perkin Elmer Programmers model HGA 76B, were used for the analysis by kind permission of the keeper of Conservation of the Victoria and Albert Museum.
The same procedure of sample preparation etc. was carried out on two samples of British Chemical Standards, Gunmetal No. 207/2, which is prepared and issued by the Bureau of Analysed Samples, Ltd., Middlesbrough, Teeside, England, in order to compare the results obtained with their known values.

Standard solution:

For each element to be determined, five standards from the Standard Solution for AAS (BDH Ltd., Poole, England), were prepared, which cover the range of values expected in the samples. Each 100 ml of these standards was enriched with 40 ml of copper nitrate solution (1g/l). During the analysis, between every ten samples, the standards were run.

A calibration curve was prepared for every individual element, showing the relationship between the reading given by the AAS and the concentration of that standard in parts per million (ppm). The percentage of the element in the sample was worked out according to this formula:

\[
\frac{C \times V}{W \times 10}
\]

Where:

- \( C \) = concentration of the element in the solution of the sample (in ppm).
- \( V \) = volume of the solution (25 ml).
- \( W \) = weight of the sample (in mg).

IV. 2. Interpretation of analyses

IV.2.1. Alloying in ancient Palestine during the Bronze Age:

It has been mentioned in the introduction that the first stage of metallurgy was the exploitation of native copper. Smelting was developed later, and evidence for the early methods of extracting copper from its ores comes from
the Chalcolithic sites in the Negev. Ores from Timna are very rich in copper, malachite, azurite, chalcocite, and some cuprite and chrysocolla. After mining, the rich nodules, containing 25-37% copper, were collected for dressing, and then removed for smelting. A small bowl-hearth, which looks like a pit in the ground, was found at Site 39. The crushed ores were added to the charcoal fire in the furnace and were then reduced to metallic globules. These were removed by breaking up the slag into pieces.

Tell Abu Matar is another Chalcolithic site where ores, slags, and crucibles were found. The analysis of some slags shows that they are similar in composition to some slags from Timna (Tylecote et al., 1974, 33). All the evidence indicates that there was an active copper industry (i.e. melting and casting) at the site.

Wadi Feinan, north-west of Petra in Jordan was explored by Kind (1965, 56 ff), where different metallurgical processes were practised during the Nabataean and Roman periods. However, further investigation is required to find out if these rich ores were used in earlier periods.

Little analysis of artefacts from the Chalcolithic period has taken place. An axehead from Safadi, about four miles south of Abu Matar, contains 0.2 - 0.3% arsenic (ibid., 34). The Nahal Mishmar hoard was found in a cave near the Dead Sea; the C-14 dates indicate that the hoard dates from the end of the fourth millennium B.C. (Bar-Adon, 1963), thirty mace-heads, staff-heads, and tools were analysed by Key (1964, 1578), where some of them show high arsenic content; also, significant traces of silver and nickel were detected. An unexpectedly high tin content of about 7% was found in an axe discovered at Teleilat Ghassul (Mallon et al., 1934, 77). Thirteen artefacts from Kfar Monash which dated to EBIII were analysed by Key (1963, 289); their analysis indicates either impure copper or arsenical copper. Another four objects of the EB age from Lachish show copper with impurities, or with traces of arsenic (Tufnell, 1958, 328).
Early Bronze Age

An early analysis (Sellin, 1913, 116) shows that an axe from Jericho contained 2.18% arsenic, also, as we have seen, arsenical copper appeared at an early period at certain sites.

However, eleven items found at the tell and tombs of Jericho were analysed here. These include seven artefacts, two metal scraps, a lump of metal, and an ingot-like piece. It is known that metal artefacts from Palestine and neighbouring countries dating to EB age are either impure copper or arsenical copper. Also, the technique of alloying during the first quarter of the third millennium is well represented in 'Amouq in central Syria, where about that time metal artefacts appeared to be arsenical, and a metal industry was well established (Braidwood et al., 1951). A dagger and a chisel (Cat. Nos. 1, 67) are almost pure copper with faint traces of impurities. Their structure indicates that they were cast and then cold-worked and annealed or hot-worked. They are similar in their chemical composition to a lump of metal from the tell (Cat. No. 133). Also, two un-stratified chisels (Cat. Nos. 62, 63) are more likely to be dated to EB age were shown unalloyed copper in their composition. Nevertheless, it is more likely that a fairly pure copper oxide ore was used to manufacture them.

Arsenic is present in the other artefacts in variable ranges i.e. 0.0-3.6%. The crescent axehead (Cat. No. 27) shows a high arsenic content and traces of nickel. The elemental analysis of the ingot (Cat. No. 132) is very interesting since it has 2% arsenic, 1.5% nickel, 0.45% lead, and traces of silver. Apart from this ingot, computing indicates that the chisels (Cat. Nos. 64, 69) are outliers, as a result of their high content of either nickel or silver. The trace elements, i.e. zinc, silver, gold, antimony, and bismuth, occur in various ranges. The lead range is between 0.0 and 0.45%, meanwhile the iron varies from not detected to 1%.

Nickel was not added intentionally to the metal, but
is an impurity occurring in the copper ore. Interest is aroused by objects containing an amount above 1%, but it seems strange that an occasional or few objects found together with other contemporary artefacts contain traces of nickel or no nickel at all. Desch (1929) analysed metal artefacts from the sites of Ur, Kish and Tell al-Ubaid, as a result of his analysis, he suggested Oman as a source for the Sumerian copper. Recent analyses carried out on ores from Oman showed that the ratio of nickel to copper in the ores is approximately 1:26 (Goettler et al., 1976, 43-57), but these ores are free of arsenic which is current in the artefacts, and there are no recognizable quantities of any arsenical mineral in Oman. Thus, Desch's theory about Oman is not acceptable now. Cheng and Schwitter (1957, 351-359) include a table for ancient bronze containing more than 1% nickel, which were reported in different publications. But when they tabulated the various ore bodies which contain nickel in China, India, and the Middle East, they did not include any Anatolian deposits of nickel-containing ores. Nevertheless, when Agrawal (1971, 124) refutes Desch about the source of the Sumerian copper, he mentions that there are other copper ores which contain nickel e.g. Armenia south of lake Van, and Anatolia at Yenekoi south of the Sea of Marmora; also, Kastamonn's copper deposits are known to contain nickel.

It has been shown that the use of arsenic alloying with copper was widespread, and strong trade relations were well established among different parts of the ancient world. Mellaart (1971, 369) relates the new prosperity of Anatolia in the EB age to the exploitation of its rich metal deposits. The rich Ergani copper ores are located to the north of Diyarbakir in the eastern part of modern Turkey, these deposits were mined as early as the Neolithic period (Muhly, 1973, 199-207). A slag analysed by Buchholz (1967, table 2:15) contains traces of silver and arsenic. de Jesus (1977, 229) says that there is no information available on these ores in antiquity, and at the same time he described them from an analytical point of view as they have
a wide range of impurities. Esin's (1969) analysis is an important study for the different copper artefacts from various sites and periods, but no illustration is associated with the analysis. However, she shows that some of the artefacts have a high nickel content. For example, two objects from Tilmen dated to EB age (Esin analyses, 17602, 17603) are arsenical copper with high lead and about 2% tin, in addition to the nickel which is higher than 1%, also, another object of the same date from Tarsus (Esin analysis 17944) contains arsenic and nickel.

It is not surprising that Anatolia played a significant role in the early metallurgy and metal trade in the ancient world. About the second half of the third millennium B.C., arsenical copper was used in many sites in Anatolia and Transcaucasia, where strong metallurgical relations were established between the two areas. Furthermore, Muhly (1973, 204) explains this connection in the light of the smoked-blackened burnished pottery (Khirbet Kerak ware: EBIII). Even the shape and the decoration of this pottery is strongly reminiscent of metallic appearance in many archaeologists' view. This type of pottery also spread to 'Amouq in the plain of Syria, and to Palestine. However, it is more likely that Khirbet Kerak people came from the Anatolian Plateau, east of the Euphrates, and that they settled in restricted areas. As far as Jericho is concerned, only a few pottery objects of this type have been found, which indicates that there was a commercial relationship between Palestine and north-eastern Anatolia (Keynon, 1970, 127).

These facts raise an important question: Was the spread of the arsenic metallurgy associated with these commercial relations? According to the present archaeological data, it seems that there is no evidence for any relation between the two, and such a question remains unanswered. Nevertheless, there was a metallurgical connection between Anatolia and Palestine via Syria, and copper could be imported from there, but until more archaeological information and analytical data for objects and ores
from different regions are available this theory must remain a hypothesis.

Intermediate Early-Middle Bronze period:

It is known that pure copper has a tendency to absorb gases during solidification which causes undesirable effects on the product e.g. (Cat. No. 136). Arsenic and tin work as de-oxidizing agents, and this facilitates the casting process. Also, both elements have the ability to enhance the mechanical properties and the workability of copper. However, it is generally agreed that arsenical copper was used before the discovery of tin.

Arsenic can be found in the native state, having a dull-grey colour, but it is often associated with native antimony or silver. Other arsenic is found as a component of mixed ores with sulphides of copper, iron and lead.

There are different views as to whether alloying with arsenic was made intentionally or whether it was accidentally included as an impurity in the copper ores. Nevertheless, it has been considered in this study that tin of above 2% and arsenic of above 1% (Figs. 4 and 5) are counted as intentional alloying.

Charles (1967, 24) has good reasons to believe that the high arsenical copper was an intentionally produced alloy; either by careful selection of raw materials, or by the addition of minerals containing arsenic which are associated with sulphide ores. It is known that these sulphide ores need roasting, and this causes them to lose arsenic. However, the sulphide ores still can withstand this loss because of their high content of arsenic. In any case, it is to be understood that arsenic was not added in the metallic state.

In the Near East, the second half of the third millennium B.C. was dominated by the use of arsenic, for example at Tell Inghana (Kish: cemetery A), the alloy appeared regularly about 2400 B.C.. In view of the analyses from Palestine, it has been established that this alloy was widely used in the EB-MB period.
Fig. 5
Thirty-five objects from Jericho tombs were analysed in this project. They are mostly daggers and fragments of metal fittings; bands, plates, nails etc. If we consider that any arsenic above 1%, or 2% for tin, is an alloy, thus 83% of the analysed artefacts from this period are arsenical copper, and 25% of them are a tin alloy (see fig. 31). Three objects including one dagger and two metal fittings (Cat. Nos. 13, 120 and 124) contain high tin with traces of arsenic. A combination of high tin and arsenic appeared in the analysis of a dagger, a knife, and two metal fittings (Cat. Nos. 10, 16, 115 and 122). Tin about 3% with around 3% of arsenic is indicated in the examination of a rivet and a fragment of a band (Cat. Nos. 125, and 117). Only three objects, metal fittings, (Cat. Nos. 118, 123, and 127) show copper with impurities, but with no sign of any alloying.

All daggers contained arsenic in the range between 1.2% and 4.7%, except for two (Cat. Nos. 10 and 13) which have tin instead. The first one has 3.6% of arsenic and about 8.5% tin, meanwhile the second has traces of arsenic only. Dagger (Cat. No. 10) contains a high iron content of 2.3%, while this element is present in other artefacts only as traces. A trace quantity of lead was found in all objects analysed, apart from the dagger (Cat. No. 4) which contains 1.4% lead; also, it has 1.5% nickel. It is interesting to note that the chemical composition of this dagger is almost similar to the EB age ingot piece (Cat. No. 132). Excluding this dagger, nickel continues to appear on the average to less than 1%. Concerning the two metal fittings (Cat. Nos. 117 and 120) which contain 1% nickel, it is worth mentioning that the XRF method was used. In computing, the daggers (Cat. Nos. 14 and 8) show as outliers, due to the high traces of cobalt in the first and of antimony in the second. Other trace elements are present in different amounts. As far as the small metal fittings are concerned, they are heterogeneous in composition, and here there is no correlation between the type of object and the composition.
It is obvious that the practice of alloying was well established, and there was control over the percentage of arsenic in this period. But the question is from where did this arsenic come?

Eaton and Mc Kerrell (1976) present useful analytical charts for the use of arsenic in the Near East between 3000 - 1600 B.C. A comparative study of these results for different regions shows that arsenic was widespread in Syria between 3000 - 2200 B.C. Also, the north west of Iran had a long tradition in using this alloy. Concerning Syria, there were flourishing centres of copper industry such as 'Amouq, Byblos, and Ras Shamra. At the same time, no ancient mines have been discovered, so it has been assumed that this copper was imported. Cyprus and Anatolia were suggested as sources for this copper. The archaeological evidence from Cyprus indicates that mining native copper was started in the EB age. However, it is known that there was an active copper trade between many parts of the Aegean, Anatolia, and the Near East at that time. So far, it has been assumed that Palestine had links with Anatolia in the EB age, from a metallurgical point of view. This raises the question of whether this connection continued in the EB-MB period? The archaeological evidence indicates that the "Amorites", who are the newcomers of this period, brought a new culture to Palestine from the north. The North Syria culture known as Syro-Cilica has a long tradition in metal-working and the use of arsenic. Therefore, Palestinian metallurgy might have been influenced by this northern culture.

Middle Bronze Age:

Adding tin to copper enhances the casting ability of the metal, and gives a product with good malleable properties, greater hardness, and also enables work-hardening. Coghlan (1975, 81-83) reports the relation between the percentage of tin in bronze artefacts and the improvement of the workability and the hardness of the bronze.

The discovery of how to use tin should be counted
as a very important invention in the history of metallurgy. There have been some discussions and arguments about the transition from alloying with arsenic to tin. However, this transition happened gradually, and no line can be drawn between the use of both elements in this period. It has been argued that the earliest use of tin was accidental, and that when the ancient smith used tin and copper ores which were found mixed together, he then discovered that it gave good results and went on using it again. However, tin and copper ores do not usually occur together. Many scholars believe that it was an accidental discovery and might have taken place in an area where the two ores occur side by side, and tin could have been used in the beginning to improve the colour of copper.

Stannite (\(\text{Cu}_2\text{S} \cdot \text{FeS} \cdot \text{SnS}_2\)) is a compound of tin, copper, iron and sulphur, containing about 25% tin. Nevertheless, it is unlikely that "tin-pyrite" was used in ancient times because of the complicated method of refining needed due to the presence of sulphur in stannite.

Cassiterite, "tin-stone", is the one which is more likely to have been used to manufacture bronze. This mineral occurs in nature as tin oxide - \(\text{SnO}_2\) -, pure cassiterite which contains about 87% of tin. Its colour varies from deep brown to black but sometimes it can be red, or even colourless, depending on the minor impurities such as copper, iron, lead, arsenic, and antimony. Because of its specific gravity (6.8 - 7.1), it can be found in alluvial deposits. Alluvial tin deposits in stream beds were the most important tin sources in ancient time. It is known that in such a stream deposit gold and tin are associated because of their high density. This is one of the reasons that make Muhly (1977, 76) believe that there is a chronological relation between the discovery of the two metals. When a stream flows through the tin sources, it washes out the tin ore, which could then be prospected for by ancient people in the stream bed as nuggets or pebbles in a range of sizes up to 30 mm.

Cassiterite is not available in plentiful quantity in nature, compared with copper ores. A number of people
(Coghlan, 1975; Dayton, 1971; Forbes, 1972 and Muhly, 1973) have listed the sources of tin in the world in order to explain the distribution of ancient bronze. Britain, France, Bohemia, Spain, Zimbabwe, Burma, and Thailand have been reported as the major producers of tin. Coghlan (1975, 24) mentions that tin is found in Russia on the southern slopes of the Caucasus and in the Ural and Altai region. As far as Anatolia is concerned, Muhly (1973, 257) is inclined to disagree with Forbes (1972, 24) when the latter claims that there are sources of tin there. Also, different places in Iran have been claimed as sources of tin: Khorasan, Astarabad, and Tabriz.

In spite of the fact that in the Near East deposits of cassiterite are scarce, trade played a major role in transporting the tin from its sources to the centres of bronze production. From very early times, Mesopotamia developed a high level of skill in tin metallurgy without the advantage of any tin deposits. An early analysis by Desch (1929, 438 ff) shows that samples from Ur and Kish which were dated between 3500 - 3000 B.C. contained a high percentage of tin. Also, two axeheads from the Royal Graves at Ur from the same period show more than 8% tin (Elam, 1932, 100). Levey (1959, 209) lists analyses of metal objects from Tepe Gawra in northern Mesopotamia, where he shows that two objects of high tin (about 6%) were dated to c. 2250 B.C. Artefacts from Geoy Tepe (Burton Brown, 1951, 179-197) in Azerbaijan - northwestern Iran - show that they are tin-free, and that alloying with tin started about 2000 B.C. The Anatolian highlands do not have an early stage of bronze metallurgy.

The analysis of artefacts from Brak dated between 2600 - 2500 B.C. shows that they are either arsenical copper, or low tin bronzes. In some cases, high tin was present (Moorey and Schweizer, 1972, 186-187). Holland (1976, 63) found at Tell Sweyhat, about 3 Km from the east bank of the Euphrates remains of metal-working dated to the end of the third millennium B.C., Hedges (ibid, 66) analysed some of the metal objects from the site to show
that they contain about 8% of tin. As much as 15% tin appeared in the analyses of figurines from 'Amouq phase G which is dated between 3100 - 2800 B.C., at the period arsenical copper was still in use, but by later phases H, I and J dating before 2000 B.C., bronze appeared more regularly, and arsenic disappeared (Braidwood et al., 1951). More than this, fragments of clay crucible were found in 'Amouq dating to 3000 B.C. These fragments contained charcoal, copper, and tin, a good indication that the production of bronze by reducing tin and copper was already practised by that time. Analysis of objects from Ras Shamra and Byblos demonstrates that bronze appeared between 2200 - 2000 B.C., and some of this bronze contains as much as 18% tin (Schaeffer, 1945, 95 and 1949, 64). Both sites show that they were very active metallurgical centres for bronze production.

It is now well understood that about the middle of the third millennium B.C., tin was widely used in Mesopotamia and many parts of Syria. The question is, where did this tin come from? Without repeating all the discussions and arguments which have been carried out between different scholars about the sources and the routes of ancient tin, a brief summary is useful here.

It is known that in the classical period, Aegean tin was brought from Cornwall, by trade, but did this trade occur in earlier periods? And did the Aegean merchants work as intermediaries bringing this tin from the West to the East? There is no evidence for such a trade, all we know is that about the end of the third millennium B.C. alloying with tin was practised in Cyprus, Crete, and Troy. Dayton (1971) gives no convincing evidence to support his belief that the tin of the Near East came from Bohemia.

The tin trade flourished between 2500 - 1900 B.C. An Assyrian text of about the early second millennium B.C. mentions that tin brought to Anatolia from Assur. Another Babylonian text from the time of Hammurabi describes the route of tin from Mesopotamia to Mari and then to Syria and Palestine. Both texts mention nothing about the original
sources of this tin, but it has been assumed that it came from northwestern Iran across the Zagros mountains into Mesopotamia. The fact is that no convincing evidence that has been published about this source. Even the translation of the word "tin" from different texts does not help identify its sources.

Philology is another important source for ancient matellurgy in the Near East. The Pre-Sargonic Sumerian text mentions tin as AN.NA (Akkadian = anāku), when it describes the recipes involved in producing bronze - Zabar (Akk. = Siparru). The ratio of copper to tin in this recipe is 6:1 and sometimes 7:1, which means that bronze artefacts from this period should contain about 17% tin, which is rarely the case in most of the objects analysed; only two objects from "A" cemetery at Kish were high tin (an axe has 15.5%, and a bowl contains 11.6%). This rarity of high tin bronzes is one of the reasons that made Eaton and McKeerrell (1976) suggest that the Sumerian word AN.NA cannot be accepted for tin, and can only be a high arsenic content (and thus silver-coloured) copper-arsenic alloy. However, the question about source of tin of the Near East is still not answered, and remains a mystery.

Palestine was not a part of the EB age world of bronze metallurgy, and Macalister's analysis (1912, 265) for some artefacts from Gezer is doubtful. In the EB-MB period, nine artefacts show higher than 2% of tin, this suggests that tin was used deliberately at this period in Palestine. Other analyses illustrate the use of tin e.g. Moorey and Schweizer (1972) and Branigan et al. (1976).

In this thesis, the two phases of MB age (I and II) are combined under the term MB, due to the lack of metal artefacts from the first phase, and because the MBI was a short period at Jericho. However, Oren (1971, 128 ff) includes analyses of different duckbill axeheads dated to MBI from Beth-Shan and Ascalon which do contain high tin in their composition. The results indicated from the analysis of twenty-three artefacts dating to MBII from the "500" cemetery at Tell Fara-South (Williams, 1977, 153), are very
similar to the results of MB analyses in this project. This similarity is obvious from the percentage using both arsenic and tin together, and at the same time the ranges of some traces i.e. lead, iron, nickel which are similar to those from Jericho.

Sixty-one different items are analysed here. Although high tin was found, alloying with arsenic did not disappear, and the combination of high arsenic and tin in one artefact was shown at this time (See Fig. 8). Also, there are a few unalloyed items. Previous analysis confirms that it is not strange to have unalloyed artefacts in the MB age e.g. Birmingham (1977, 118) and Kelso (1943, 28 ff).

From a statistical viewpoint, there is no interrelation between the chemical analysis of the artefacts and their typology. In this period, the presence of lead increased, but this does not correlate with other known factors. A dagger and its rivet (Cat. No. 26) are interesting because of their high lead content, but their chemical composition differs in other respects. Similar accidental lead appeared in Iranian artefacts analysed by Moorey (1964, 77) and Birmingham (1963, 76) and this lead could be considered as an isolated result. According to the traces of silver in the rivet (Cat. No. 22) and the toggle-pins (Cat. Nos. 99, 101, and 105) they show as outliers in the computer analysis. Apart from this, the other trace elements occur differently in varying ranges.

All facts indicate that tin metallurgy was established during this period, and the presence of the arsenical copper could be explained because of the shortage of tin supply due to interruption of trade routes. The interpretation of the occurrence of a high percentage of both tin and arsenic in the same artefact is probably due to the addition of tin to remelted scrap metal from previous periods. The analysis of the metal scrap and metal droplets (Cat. Nos. 138-140) shows arsenic, which could be in the process of alloying.

As far as we know, tin has never occurred in Palestine, but from where did the ancient smiths obtain their
Fig. 7
tin? Kesrwan east of Byblos in the Lebanon mountains has been suggested as a source of ancient tin. Wainwright (1934, 29) mentions that tin deposits were examined by Australian engineers in this area, where the rivers Feldar and Adonis flow through the ore bearing region, and could have brought down the tin into alluvial deposits. Nevertheless this Lebanese tin was never investigated, but as was pointed out earlier it is known that tin was imported from Mesopotamia to Palestine - Hazor - via Tell Mari, and this connects Palestine with Syria as far as tin is concerned. At this period, the "Hyksos" invaded Palestine, and their Empire extended as far as Egypt. But, did the increase in using tin with copper relate to the arrival of the Hyksos? The problem here is that the origin of these tribes remains uncertain.

**Late Bronze Age:**

This is the last era of the Bronze Age, according to a terminology entirely based on changes in pottery, without taking metallurgy into consideration. Because of the widespread distribution of metallurgy in general, and the increase of alloying with tin in particular, Tylecote (1976, 29) prefers to call LB age the "Full Bronze Age".

When the weathered copper ores (oxides and carbonates) were exhausted, the ancient miners had to go deeper to exploit the sulphide ores. These ores require a roasting process to oxidize them before the smelting takes place, and then copper can be supplied as ingots for the centres of production. The SEM analysis of the light grey inclusions in the sections of (Cat. Nos. 49 and 61) show a high sulphur content (Pl. 43).

The presence of copper artefacts with faint traces of impurities associated with other artefacts which contain high tin at the same period is an indicator that the alloyed artefacts were obtained by the purposeful addition of tin. As has been mentioned in the introduction, there are four possible methods which could be followed in
ancient times. The first to melt copper and then to add the tin. The second and more probable method is to put tin ore and copper ore in a crucible under a charcoal cover, and to heat both together, tin would be reduced and melted first at 232°C, and lower the melting point of copper to about 950°C.

Many copper ingots have been discovered, a wreck found near the Coast of Cape Gelidonia, in southern Turkey dating to 1200 B.C., was carrying copper ingots and a white powdery material containing 14% SnO and 71% CaCO3. This white material is believed to be corroded tin (ibid.,15). It has been suggested that the ship was Syrian, carrying copper from Cyprus to Crete or Greece, and also the tin in it must have been brought from somewhere else as we know there is no tin in Cyprus.

More recently, another wreck of a ship was found at the ancient port of Dor near Haifa, where ingots of tin and copper were found together. This ancient ship is dated between 700 and 600 B.C. The result of the investigation of the ingots which is not published yet may be useful in indicating some of the ancient routes for tin (Institute of Archaeo-metallurgical Studies, Newsletter No. 1, 1980).

Many oxhide and plano-convex copper ingots have been found in the Mediterranean. Ancient trade routes were established between different parts of the world, where overland and maritime transportation were well organized.

The Temple at Amman Airport was very rich in finds. Beside the metal objects, there were a large number of potsherds classified as either Aegean or Mycenaean. Stone objects were imported from Egypt. Among other finds were scarabs and cylinder seals with Mesopotamian influence. Aegean and Mycenaean pottery was also associated with the metal objects found in Sahab tomb. This archaeological evidence reflects the commercial situation in the LB age, when the area was a part of a strong international trade network.

Twenty-five weapons from Amman Airport Temple and Sahab tomb are represented here to replace the lack of LB
age metallurgy at Jericho. High tin bronze, as much as 11.9% (Cat. No. 66), is shown in this period, but this does not mean that tin replaced arsenic completely, nor that all the analysed artefacts are high tin (see Fig. 9). However, apart from (Cat. No. 59), all the objects containing arsenic, also have tin. This may well be due to the remelting of metal scrap from previous periods with the addition of tin. In any case, the arsenic percentage is not higher than 1.6%. The unalloyed artefacts analysed from this period are only three arrowheads from Amman Airport (Cat. Nos. 52, 56, and 57).

Because sulphide ores were used to manufacture bronzes in this period, a high impurity content would be expected, but the elemental analysis indicates that these impurities are much lower than they were in previous periods; small traces of lead and iron, and nickel were shown. This suggests that the copper was refined before alloying with tin. As a matter of fact this low level of impurities in the metal does not help as far as the study of trace elements is concerned.

There is evidence of copper smelting in Cyprus from this period, Buchholz (1967, 192) suggests that the earliest raw copper was either imported to Cyprus, or that the ores that were used by ancient people were exhausted and therefore no evidence of it remains now. However, he emphasizes that Cypriot copper can be characterized by the presence of high zinc. From the table represented (ibid., 218), it is clear that high zinc content is current in a lot of Cypriot artefacts from different periods. The analysis of various artefacts from Vounous, reveals high zinc (Stewart, 1950, 371). This high percentage of zinc is absent from the specimens in this thesis, nevertheless, on the one hand this cannot discount Cyprus as one of the copper sources for the objects. On the other hand some Cypriot ingots, e.g. the Enkomi ingot, shows 0.05% zinc (Buchholz, 1967, 235).

Ancient mines have not been discovered in Crete, though evidence suggests that copper was exploited in the
EB age (Branigan, 1968, 52). The analysis of various ingots from different sites reveals very faint traces of nickel and lead (Wheeler et al., 1975). A complex mixture of antimony and zinc is present in the analysis of ancient artefacts from the Greek mainland. It is known that the first appearance of bronze in Cyprus and Crete is dated to 2000 B.C., Cornwall was suggested as the source of this tin, but no satisfactory evidence is given.

The texts from Mari and Alalakh refer many times to metal-working, and metal trade. Ugaritic texts dated between 14th - 13th century B.C. mention tin "brr" at least six times, but indicate nothing about the source of this tin (Heltzer, 1977, 203). However, with the complicated trade routes, and the mystery of tin sources, it is impossible to locate the direction from which copper and tin came to the Amman Airport site and Sahab, and by the end of the 13th century B.C., the Sea People entered Palestine to put an end to this period, and they introduced iron as the new metal for the next age.

IV.2.2. The relation between the ores and the trace elements of the artefacts:

Trace elements means that those elements present in the composition of the metal are accidental rather than intentional. Metal analysis is not only important to tell if the artefacts are alloyed or not. Another important aim is to establish an interrelation between the artefacts and the copper sources. If the latter aim can be obtained, a map of the ancient copper trade routes can be easily established. Trace element analysis is important in this aspect, scholars differ in their choice of the number of elements to be detected. Apart from copper, arsenic and tin, other elements such as lead, iron, nickel, silver, gold, zinc, cobalt, antimony, bismuth and manganese are estimated in this project. For convenience, four percentage ranges have been established for the presence of each element (see Table 1). The latter element is not included in the table
of the analyses, because it was never detected in any sample.

In Europe, metallurgists who are interested in relating the artefacts to their origin carried out a lot of research, but the picture is still not definite. Desch (1929) adopted nickel to follow when he tried to locate the sources of Sumerian copper, but his theory about Oman is not accepted any more. Tylecote et al. (1977) investigated the behaviour of forty-nine elements when they did their experimental work on seven different types of mining areas. Ores, fuels, and fluxes were analysed to compare with the result of the analyses of the products, metallic copper and the slags.

From ore to artefact, there are many stages involving the production of the metal. The factors which have an effect on the final production are: the ore itself, smelting or roasting and smelting, alloying with other metals, and the conditions of casting and metal-working. These different factors must be considered in order to arrive at an approximate evaluation of the metal composition (Clayton, 1974, 75).

Generally, copper ores contain impurities, which vary from one ore to another. The concentration of the different elements within one ore varies over distances as small as a few feet. Besides this, it is possible that the deposits which had been used in ancient times, may have been worked out, so it must be borne in mind that the study of modern geological maps for this purpose could be misleading.

The method of smelting is an important factor, due to its effect on transferring the trace elements. Under normal smelting conditions, elements like silver, nickel, lead, and bismuth will transfer to the product without excessive loss. During roasting further changes could occur to the volatile elements, and we do not know to what limit the major constituents and trace elements will withstand the roasting and smelting processes. (Coghlan, 1960, 7). Also, it must be borne in mind that adding
fluxes to lower the melting point of the slag could be reflected in the final composition. Remelting scrap metal is another point to be remembered, because various metal scraps could be melted together to manufacture one object.

The addition of arsenic or tin to the copper led to the presence of their impurities in the metal. The sources of these agents and the way in which they were added also leads to variation in composition.

Moreover, casting and any subsequent hot working or annealing can cause the loss of volatile elements, i.e. arsenic and phosphorus.

In spite of the facts mentioned, the problem is so complicated and difficult, that it is very risky to draw any precise conclusions from the study of trace elements relating them to specific ores. Nevertheless, in the case of some of the high quantity impurities, they could be regarded as helpful indicators.

**Lead:**

It has been shown that the presence of lead in the range above 1% is increased in the MB age, this can be considered as an isolated result (see Fig. 10). It is possible that high lead is retained from the copper ore which is rich in it, or it might be that due to the use of alloying agents which contained a high percentage of lead.

However, the presence of lead has the advantage of enhancing the fluidity of the metal, and this made some scholars assume that it was deliberately added because of the temporary shortage of tin, but it has been shown that some of the high lead artefacts contain tin as well.

The range of the presence of lead decreased in the LB age, which might well be because of the improvement in metallurgical skill especially refining. Always, there is something to remember about lead that it is one of the elements which segregate during the casting operation (Charles, 1973). A barbed arrowhead (Cat. No. 42), not stratified, was found at Jericho, which contains very
Fig. 10

○ EB
△ EB-MB
+ MB
× LB
◇ NKD: Not known date
high lead 33.3%, which makes it more likely to be dated to a period later than LB age when alloying with lead was started.

Iron:

It occurs as traces in most of the objects which were analysed here, but sometimes, above 1%, or even as much as 2.3% (Cat. No. 10) is revealed. Cooke and Aschenbrenner (1975, 253) reported a number of artefacts from different parts of the world which showed high iron in their composition. However, a few percent of iron has neither any significant effect on the mechanical properties of copper nor upon its casting properties.

The presence of iron in the copper is due either to the ores, oxides and sulphides, or the fluxes. Sulphide ores contain high iron, which need a high melting point - above copper's melting point - to make the iron move to the slag, but under certain circumstances some iron could be reduced to the metallic form.

Nickel:

It is agreed that nickel was an accidental impurity in ancient metal; its high percentage seems to coincide with the deliberate alloying with arsenic. It has a higher melting point than copper, and its separation from copper was beyond the capabilities of the ancient smith.

Other elements:

Silver and zinc are probably the most useful traces in the composition of ancient metal (Biek, 1957, 72). Bismuth is useless because it segregates badly and it is extremely volatile during the smelting process (Slater and Charles, 1970). Another important factor is the relative proportion of different elements which behave similarly under the same conditions, e.g. arsenic and antimony. Examples from Irish artefacts show that the
ratio of arsenic to antimony is 3:1, which suggests that the same ratio should be indicated in the ores (Tylecote, 1962, 24), but we should always remember that arsenic can be an additive agent. Nevertheless, the general absence of certain elements may have some significance.

Friedman et al. (1966) include different tables to calculate the relative probabilities for a given analysis of an artefact to relate it to its type of ore; native, oxidized or sulphide.

In computing, statistical package for the social sciences (SPSS) was employed, differences in trace element composition among different groups of types of varying ages, i.e. daggers, arrowheads, spearheads, and toggle-pins show no significance. Also, the principal components plot did not indicate any obvious clustering. Correlation among all the elements in the four periods have been computed, neither positive nor negative interrelations have been shown among the elements from the EB age, this could be due to the small number of samples. In EB-MB age, a positive correlation is revealed between silver and antimony. This kind of relation did not appear in the MB age. On the one hand, silver correlates positively with arsenic in the LB age, on the other hand a negative correlation occurs between silver on one side and tin and bismuth on the other side.

IV.2.3. Silver artefacts:

Five artefacts (Cat. Nos. 34, 82, 112, 116, and 131) dating to MB age were described by Kenyon (1960 and 1965) as copper or bronze objects, they proved to be silver when they were analysed by XRF. Traces of copper were shown in their composition. As only copper alloy artefacts are included in this project, this is not the place to discuss them. Nevertheless, it is worth mentioning that the belt fastener is only to be plated with silver.
CATALOGUE OF ARTEFACTS EXAMINED
### KEY TO CATALOGUE

<table>
<thead>
<tr>
<th>Cat. No.</th>
<th>Site</th>
<th>Area</th>
<th>Registration No.</th>
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<tr>
<th>Site</th>
<th>Description</th>
<th>Type</th>
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<thead>
<tr>
<th>Publication</th>
<th>Method of analysis (Analysis No.), Analysis Microstructure</th>
<th>Illustration</th>
<th>Hardness test</th>
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<tbody>
<tr>
<td></td>
<td>Scanning Electron Microscope analysis</td>
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Present locations of artefacts

- **Amman** = The Jordanian Museum of Antiquities, Department of Antiquities. P.O. Box 88. Amman - Jordan
- **Amman (U.M.)** = The University Archaeological Museum, University of Jordan, Faculty of Arts. Amman - Jordan
- **Birmingham** = Department of Archaeology, City Museum and Art Gallery, Congreve Street, Birmingham, B3 3DH.
- **Cambridge** = University Museum of Archaeology and Ethnology, Downing Street, Cambridge, CB2 3DZ.
- **Inst. of Archaeology** = Institute of Archaeology, University of London, 31-34 Gordon Square, London WC1H 0PY.
- **Leeds** = Department of Semitic Studies, University of Leeds, Leeds, LS2 9JT.
- **Liverpool** = School of Archaeology and Oriental Studies, University of Liverpool, P.O. Box 147, Liverpool, L69 3BX.
- **Manchester** = The Manchester Museum, University of Manchester, Manchester, M13 9PL.
- **Oxford** = Department of Antiquities, Ashmolean Museum, Oxford OX1 2PH.
- **St. Andrews** = Department of Archaeology, University of St. Andrews, St. Andrews, Fife, Scotland, KY16 9AL.
1
Jericho tomb F5 1
Dagger, three rivets remaining, one missing A1 EBIII Inst. of Archaeology -
Jericho I, 174, fig. 66:3
AAS(1), Cu: 98.5; Sn:ND; AS:.784; Pb:ND; Zn:.0196; Ag:.0493;
Au:.0078; Fe:.453; Ni:.0231; Co:ND; Sb:.0529; Bi:.0051.
The section showed porosity and inclusions, a lot of twins
were revealed after etching with \( \text{H}_2\text{O}_2 + \text{H}_2\text{SO}_4 \) for about
three minutes. Some of the twinned grains near the edge of
the blade have slip bands, the grains are small. The
structure indicates that the dagger had been hammered and
annealed or hot worked, but the few slip bands indicate
that further hammering occurred on the edge of the blade to
sharpen and harden it. Under the optical microscope, light
blue inclusions flattened in the direction of hammering were
shown, also, small light blue inclusions were seen.
Pls. 1, 23
H\text{v} : 111

2
Jericho tomb A86 1
Dagger, three rivets in position, one missing A1 EB-MB Liverpool J.53.23
Jericho I, 189, fig. 70:1
AAS(14), Cu:88.5; Sn:ND; AS:3.82; Pb:.0621; Zn:.0111; Ag:.0429;
Au:ND; Fe:.497; Ni:.0643; Co:ND; Sb:.1202; Bi:.0027.

3
Jericho tomb A82 1
Dagger with three rivets, one missing A1 EB-MB St. Andrews 1976.1
Jericho I, 190, fig. 70:3
AAS(15), Cu:96.3; Sn:ND; AS:1.9; Pb:ND; Zn:.158; Ag:.0201;
Au:ND; Fe:.274; Ni:.497; Co:ND; Sb:.0222; Bi:.0028.
Metallographical examination showed corrosion along the grain
boundaries. Two types of grains were shown; small towards the
inside, large towards the outside, after etching with
\((\text{NH}_4)_2\text{S}_2\text{O}_8\) in water, also, twinning structure was revealed.
The cutting edge of the blade is severely corroded. Light blue inclusions lined up in the direction of working were confirmed.

Pl. 24

$H_v$: 116

4
Jericho tomb A95 1
Dagger, four rivets in position A1 EB-MB
Amman J.4125
Jericho I, 191, fig. 70:4
AAS(16), Cu:93.5; Sn:ND; AS:3.31; Pb:1.41; Zn:ND; Ag:.0612; Au:ND; Fe:ND; Ni:.1.59; Co:ND; Sb:.0095; Bi:ND.

5
Jericho tomb A26 1
Dagger with four rivets A1 EB-MB
Birmingham Jericho I, 196, fig. 70:8
AAS(17), Cu:94.2; Sn:ND; AS:4.76; Pb:ND; Zn:.1607; Ag:.0326; Au:ND; Fe:ND; Ni:.056; Co:ND; Sb:.135; Bi:.0038.
The section showed porosity and inclusions before etching. After it had been etched with FeCl$_3$ in water, a ghost dendritic was revealed. The structure shows twins with some slip bands. The inclusions are lined up as a result of working. The SEM analysis showed that the black dot inclusions are of copper oxide, while the light blue ones contain high arsenic.

Pl. 40

$H_v$: 49

6
Jericho tomb L6 1
Dagger, four rivets in position A1 EB-MB
Cambridge 56.296
Jericho II, 54, fig. 24:6
AAS(18), Cu:94.8; Sn:ND; AS:3.96; Pb:ND; Zn:.0029; Ag:.0162; Au:ND; Fe:.9; Ni:.0111; Co:ND; Sb:.0358; Bi:.0056.
Fig. 11
7
Jericho tomb  A100  1
Dagger, four rivets missing  A1  EB-MB
Amman  J.4124
Jericho I, 18
AAS(19), Cu:94.4; Sn:ND; AS:3.89; Pb:.053; Zn:.0219;
Ag:.03; Au:.0175; Fe:.518; Ni:.0617; Co:.0233; Sb:.0278;
Bi:ND.

8
Jericho tomb  A111  1
Dagger, no rivets in position  A1  EB-MB
Oxford  1953.724a
Jericho I, 189, fig. 70:2
AAS(20), Cu:93.7; Sn:ND; AS:2.54; Pb:ND; Zn:ND; Ag:.122;
Au:ND; Fe:.857; Ni:.161; Co:ND; Sb:.218; Bi:.0091.
The rivet only was analysed.

9
Jericho tomb  A28  1
Dagger, six rivets, sloping shoulder  A2  EB-MB
Inst. of Archaeology  -
Jericho I, 198, fig. 70:11
AAS(21), Cu:92.7; Sn:ND; AS:1.49; Pb:ND; Zn:.1048; Ag:.0409;
Au:ND; Fe:.555; Ni:.3607; Co:ND; Sb:.163; Bi:ND.
One of the rivets was analysed.

10
Jericho tomb  L4  1
Dagger, three rivets in position, one missing  A3  EB-MB
St. Andrews  1976.356
Jericho II, 57, fig. 24:10
AAS(22) the dagger, Cu:84.9; Sn:8.45; AS:3.6; Pb:ND;
Zn:.0071; Ag:.0424; Au:ND; Fe:2.28; Ni:.0336; Co:ND; Sb:.126;
Bi:ND.
AAS(23) Upper rivet of the dagger, Cu:95.5; Sn:ND; AS:4.28;
Pb:ND; Zn:.0079; Ag:.0317; Au:ND; Fe:.0398; Ni:ND; Co:ND;
Sb:.1108; Bi:.0032.
The polished section of the dagger showed internal corrosion and porosity. After etching with \((\text{NH}_4)\text{S}_2\text{O}_8\) in water mixed with a few drops of ammonium hydroxide solution, ghost dendrites were shown, which under higher magnification were revealed as small black dot-like inclusions. This ghost dendrite structure was caused by the segregation of these inclusions during solidification. When the dagger had been cold worked and annealed, or hot worked, as the twinning in its structure shows, the atoms of the metal diffused but the inclusions remained in place. Slip bands are also present. Apart from the black inclusions, a few light blue and small transparent dot-like inclusions were shown. Also, the very few large white inclusions appear to be iron.

The SEM analysis for the small black and transparent inclusions indicates that they are copper oxide. The light blue inclusions were found to be copper with very high arsenic, and traces of antimony and iron.

A section for the rivet was examined under the microscope and showed corrosion and porosity. It was etched with the previous agents and indicated a very distorted structure; this deformation in the structure may well have occurred during manufacture when the rivet was punched into the rivet's hole of the dagger.

Pls. 21-22, 41-42

Dagger \(H_v\) : 161

Rivet \(H_v\) : 125

11

Jericho tomb D1 6

Dagger, three rivets in position, one missing B EB-MB

Amman J.5659

Jericho II, 89, fig. 41:3

AAS(24), Cu:9; Sn:ND; AS:2.71; Pb:.615; Zn:.0109; Ag:.011; Au:ND; Fe:.966; Ni:.0341; Co:ND; Sb:.0445; Bi:.0034.

12

Jericho tomb A26 2

Dagger, six rivets, large C EB-MB

Birmingham -
Jericho I, 196, fig. 70:9
AAS(25), Cu: 91.6; Sn: ND; As: 4.33; Pb: 0.0886; Zn: 0.0913;
Ag: 0.0278; Au: ND; Fe: 0.955; Ni: ND; Co: ND; Sb: 0.127; Bi: 0.0039.

13
Jericho tomb L2
Dagger, six rivets in position
Amman J.5703
Jericho II, 146, fig. 41:6
AAS(26), Cu: 89.2; Sn: 5.28; As: 6.17; Pb: ND; Zn: 0.0096; Ag: 0.002
Au: ND; Fe: 0.256; Ni: 0.363; Co: ND; Sb: 0.0177; Bi: 0.0031.

14
Jericho tomb A131
Dagger, three rivets in position, one missing
Birmingham
Jericho II, 53, fig. 24:4
AAS(27), Cu: 92.7; Sn: ND; As: 2.1; Pb: ND; Zn: 0.137; Ag: 0.0129;
Au: ND; Fe: 0.722; Ni: 0.436; Co: 0.136; Sb: 0.0393; Bi: 0.0027.

15
Jericho tomb A131
Dagger, two rivets in position and two missing
Birmingham
Jericho II, 53, fig. 24:5
AAS(28), Cu: 93.9; Sn: ND; As: 1.28; Pb: ND; Zn: ND; Ag: 0.0438;
Au: ND; Fe: 0.347; Ni: 0.226; Co: 0.0204; Sb: 0.12; Bi: ND.

16
Jericho tomb L2
Dagger, three rivets in position, one missing
Amman J.5704
Jericho II, 148, fig. 41:7
XRF(29), Cu: (94.9); Sn: ND; As: 5; Pb: ND; Zn: ND; Ag: ND;
Au: ND; Fe: 0.1; Ni: ND; Co: 0.02; Sb: ND; Bi: ND.

17
Jericho tomb J3
Dagger, with pommel of alabaster
A1 MB
When the section was examined it showed that the corrosion followed the grain boundaries, with the result that it is attacked by heavy corrosion. Etching with FeCl$_3$ revealed small grains and twins with some slip bands as an indication of cold working and annealing or hot working, the few light blue inclusions were flattened by the working process. $H_v$: 67

18

Jericho tomb J3 37
Dagger, with alabaster pommel A1 MB

Amman J.5450b
Jericho I, 313
AAS(50), Cu: 91; Sn: 6.36; AS: .218; Pb: 1.026; Zn: .0982; Ag: .0345; Au: ND; Fe: .0425; Ni: ND; Co: ND; Sb: .0121; Bi: .0362.
It is very similar to Cat. No. 17 from microstructure point of view.
$H_v$: 89

19

Jericho tomb 9.d. 8
Dagger with pommel A1a MB

Birmingham 921
Annals of Archaeology and Anthropology, 1932, vol. 19, P1.27: 2
AAS(51) the dagger, Cu: 93.04; Sn: 1.68; AS: 1.7; Pb: .87; Zn: .004; Ag: .0547; Au: .0213; Fe: 1.015; Ni: .0625; Co: ND; Sb: .0829; Bi: .0059.
XRF(52) the rivet, Cu: (90); Sn: 4; AS: 4; Pb: ND; Zn: ND; Ag: ND; Au: ND; Fe: 1; Ni: ND; Co: ND; Sb: ND; Bi: ND.
A section of the dagger had been examined after polishing to show corrosion and porosity. After it was etched with $H_2SO_4 + H_2O_2$ twins were very clear, also light blue inclusions were revealed. The structure shows that the
dagger was cold worked and annealed or hot worked.

H_v: 97

20
Jericho tomb D22 111
Dagger, with alabaster pommel A1b  MB
Amman J. 7073
Jericho II, 259, fig. 111:4

AAS(53), Cu: 87.3; Sn: 9.74; AS: 1.48; Pb: .654; Zn: ND; Ag: .044; Au: ND; Fe: .232; Ni: .254; Co: ND; Sb: .0108; Bi: .0031.

The metallographic study of the dagger showed that corrosion lined the grain boundaries. Etching with FeCl_3 revealed clear twinning and few light blue inclusions.

Pls. 2, 25

H_v: 76

21
Jericho tomb D9 64
Dagger, with alabaster pommel A1b  MB
St. Andrews 1976.84
Jericho II, 284, fig. 111:11

AAS(54), Cu: 90.8; Sn: 4.24; AS: 1.92; Pb: 1.21; Zn: .0072; Ag: .0428; Au: ND; Fe: .249; Ni: .0677; Co: ND; Sb: .0259; Bi: .0035

The section showed corrosion and porosity. It was etched with FeCl_3 and showed ghost dendrites as remains of coring which means that the working did not diffuse the inclusions. The structure is twinning.

H_v: 89

22
Jericho tomb D9 84
Dagger, three rivets in position A1b  MB
St. Andrews 1976.100
Jericho II, 284, fig. 111:10

AAS(55) dagger, Cu: 90.1; Sn: 6; AS: 1.81; Pb: .148; Zn: .0061; Ag: .0419; Au: ND; Fe: .266; Ni: .431; Co: ND; Sb: .0301; Bi: .0041.

AAS(56) rivet of the dagger, Cu: 85.8; Sn: 6.61; AS: 1.76; Pb: 1.63; Zn: .0094; Ag: .133; Au: ND; Fe: .1073; Ni: .118;
A section from the lower rivet was examined and showed that corrosion attacked the grain boundaries, also it is porous. The section was etched with (NH$_4$)$_2$S$_2$O$_8$ mixed with a few drops of ammonium hydroxide solution. In the structure, there are a lot of twins with slip bands, these twins are either straight or bent, this means that it had been worked twice, once before annealing, and another after annealing, and the latter working could be explained as a result of punching the rivet through its hole. There are two different sizes of light blue inclusions.

$H_v$:141

23
Jericho tomb D22 91
Dagger, with alabaster pommel Alb MB
Amman J.7072
Jericho II, 258, fig. 111:3
AAS(57), Cu:86.8; Sn:7.22; AS:1.14; Pb:.554; Zn:.0171; Ag:.0457; Au:ND; Fe:.0919; Ni:.0538; Co:ND; Sb:.0457; Bi:.0046.

24
Jericho tomb J12 36
Dagger, with tang A2a MB
Cambridge 54.267
Jericho I, 424, fig. 146:2
AAS(58), Cu:89.4; Sn:2.68; AS:2.21; Pb:.18; Zn:.0239; Ag:.0388; Au:ND; Fe:.363; Ni:.055; Co:ND; Sb:.0424; Bi:.0025.

25
Jericho tomb D13 18
Dagger, tanged A2b MB
Liverpool J.56.18
Jericho I, 428, fig. 111:18
AAS(59), Cu:94; Sn:1.057; AS:3.82; Pb:.3044; Zn:.0126; Ag:.0258; Au:ND; Fe:.152; Ni:.0649; Co:ND; Sb:.0432; Bi:.0025.
Fig. 13
26
Jericho tomb D22
Dagger, four rivets in position, with
alabaster pommel
Amman J.7082
Jericho II, 259, fig. 111:5
AAS(60) the dagger, Cu:85.4; Sn:6.404; AS:.443; Pb:3.45;
Zn:.0138; Ag:.0759; Au:ND; Fe:ND; Ni:.117; Co:ND; Sb:.12;
Bi:ND.
AAS(61) the rivet, Cu:88.3; Sn:2.88; AS:2.28; Pb:3.12;
Zn:.0043; Ag:.0587; Au:ND; Fe:.117; Ni:.113; Co:ND; Sb:.074;
Bi:.0013.
A section was obtained from the flanged hilt of the dagger, it showed porosity and corrosion lining the grain boundaries. It was etched with FeCl₃ and twins with some slip bands were seen; the grains are small. A few light blue inclusions were revealed.
Another section was taken, but from the upper rivet, which showed a lot of porosity and severe interior corrosion. Etching was repeated with FeCl₃, the grains are very small, and the structure was distorted as a result of much working.
Hᵥ of the dagger: 95
Hᵥ of the rivet: 125

27
Jericho tomb A114(B)
Crescentic axehead
Amman J.5747
Jericho I, 179, fig. 66:1
AAS(2), Cu:91.3; Sn:ND; AS:3.68; Pb:.234; Zn:.011; Ag:.0252;
Au:ND; Fe:1.087; Ni:.26; Co:ND; Sb:.0221; Bi:ND.
A section was taken from the axehead near the broken tang, it showed very corroded and porous metal. In etching, a mixture of (NH₄)₂S₂O₈ and ammonium hydroxide solution (1:1) gave good results. There are two different sizes of grains, small near the edges, and large in the core of the metal. This could well be due to the rate of cooling during solidification. The structure shows twinning, some-
times with slip bands; this means that the axehead was cold
worked and annealed or hot worked. There are light blue
inclusions, also large inclusions of metallic appearance
were seen.
Pls. 26-27
Hv: 138

28
Jericho tomb A134 72
Battleaxe head - MB
Amman J.5815
Jericho II, 372, fig. 111:15
AAS(62), Cu: 86.3; Sn: 6.72; As: 1.63; Pb: 1018; Zn: .0053;
Ag: .0144; Au: ND; Fe: 158; Ni: .0247; Co: .0112; Sb: .0172;
Bi: .0029.

29
Jericho tomb J3 43
Battleaxe head - MB
Amman J.5451
Jericho I, 313, fig. 117:6
AAS(63), Cu: 86.07; Sn: 6.68; As: .452; Pb: 1.23; Zn: .0064;
Ag: .044; Au: ND; Fe: .0155; Ni: .0484; Co: ND; Sb: .0355; Bi: .0031.

30
Jericho tomb J3 36
Battleaxe head - MB
Amman J.5452
Jericho I, 313
Neither a hardness test nor chemical analysis were possible
due to the corroded nature of the sample. The section showed
that the corrosion attacked the grain boundaries. After
etching with FeCl₃, remains of coring - ghost dendrites
and twins were revealed. A few light blue inclusions were
seen.

31
Jericho tomb J3 44
Belt in fragmentary condition - MB
Amman J.5634
Jericho I, 311, fig. 117:2,3,4
XRF(64), Cu:(92.2), Sn:6; AS:7; Pb:1; Zn:ND; Ag:ND; Au:ND;
Fe:.1; Ni:ND; Co:ND; Sb:ND; Bi:ND.

32
Jericho tomb D9 100
Belt fastener - MB
St. Andrews 1976.113
Jericho II, 285, fig. 103:7
AAS(65), Cu:89.2; Sn:6.77; AS:.762; Pb:.346; Zn:ND; Ag:.0507;
Au:ND; Fe:.1021; Ni:.0299; Co:ND; Sb:.0339; Bi:.0042.
The section showed that the metal was mostly corroded and porous. Etching with FeCl₃ revealed the structure, which is twinning with some slip bands; small and medium grains were seen. Also, a few light blue inclusions appeared. Hᵥ: 108.

33
Jericho tomb D9 101
Belt fastener - MB
St. Andrews 1976.114
Jericho II, 285, fig. 103:6
AAS(66), Cu:91; Sn:6.207; AS:1.69; Pb:.383; Zn:.0053;
Ag:.0433; Au:ND; Fe:.127; Ni:.0396; Co:ND; Sb:.0497; Bi:.0034

34
Jericho tomb J14 118
Belt fastener - MB
Amman J.5635
Jericho II, 332, fig. 103:11
AAS(67), Cu:88.4; Sn:ND; AS:3.23; Pb:.123; Zn:ND; Ag:.0185;
Au:ND; Fe:1.42; Ni:.228; Co:.0377; Sb:.0146; Bi:ND
Other samples from both ends of the belt fastener show that they are mainly silver with traces of copper. This sample was obtained from the core of the metal; this means that the belt fastener was silver plated.
Pls. 58-59
The polished section showed that the corrosion lined the grain boundaries. Etching with FeCl₃ revealed a lot of twins with slip bands; light grey inclusions were shown. Hᵥ: 94
Fig. 16
Under the optical microscope, the section indicated that the corrosion attacked the grain boundaries, and it is very porous metal. After etching with FeCl₃, the structure appeared to be twinning with slip bands. Also, a lot of light blue to grey inclusions were shown, and they are lined up according to the direction of working.
Jericho tell
Barbed arrowhead
Amman

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AAS(142), Cu:58.6; Sn:4.74; AS:1.002; Pb:33.4; Zn:ND;
Ag:.0721; Au:ND; Fe:ND; Ni:.0424; Co:.0601; Sb:.1208;
Bi:.0027.
This is an unstratified find, its lead content makes it more likely to be dated to a later period.

Jericho tomb D1
Javelin Amman (U.M.)

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AAS(30), Cu:92.6; Sn:ND; AS:4.35; Pb:.29; Zn:ND; Ag:.0199;
Au:ND; Fe:.358; Ni:ND; Co:.0174; Sb:.139; Bi:ND.
Inclusions were shown before etching with (NH₄)₂S₂O₈ in water and FeCl₃ took place. Etching revealed twinning with slip bands, an indication of working. Also, after etching, the light blue inclusions were more clear.

Amman Airport
Javelin Amman

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AAS(124), Cu:85.9; Sn:11.7; AS:.7022; Pb:.1108; Zn:.0046;
Ag:ND; Au:ND; Fe:.25; Ni:.0344; Co:ND; Sb:.0139; Bi:.0058.

Amman Airport
Javelin Amman

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AAS(125), Cu:89.6; Sn:8.7; AS:.87; Pb:ND; Zn:.0087; Ag:ND;
Au:ND; Fe:.157; Ni:ND; Co:ND; Sb:.02; Bi:.0043.
Amman Airport  
Javelin  
Amman  

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AAS(126), Cu:90.65; Sn:7.61; AS:.62; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.177; Ni:ND; Co:ND; Sb:.0083; Bi:.0021.
The polished section showed that corrosion lined the grain boundaries. The specimen was etched with FeCl₃ to reveal a lot of obvious twins. These twins with slip bands show that the javelin was either cold worked and annealed or hot worked. A few light blue to grey inclusions were shown, also white inclusions similar to the one appearing in Cat. No. 61 were indicated. These white inclusions appeared to be an α + δ eutectoid area of very high tin as will be mentioned below.

Hᵥ: 106

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XRF(127), Cu:(90.4); Sn:.9; AS:.5; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.1; Ni:ND; Co:ND; Sb:ND; Bi:ND.
The section of the javelin was severely corroded, with a lot of porosity. Etching was carried out using FeCl₃ to show a mixture of small and medium grains. Twins with slip bands occur regularly, and few light blue inclusions were seen.

Hᵥ: 111

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AAS(128), Cu:89.2; Sn:6.05; AS:.658; Pb:ND; Zn:ND; Ag:.0431; Au:ND; Fe:.214; Ni:.0242; Co:ND; Sb:.0432; Bi:.0027.
The section showed no porosity. The specimen was etched with FeCl₃ to show two grain sizes; small and medium. Also, twins with a lot of slip bands were revealed. Besides this, a few light grey inclusions were indicated.

Pls. 28-29

Hᵥ: 125
53
Amman Airport  -  -
Arrowhead, with a sign and the tang  -  LB
has notches
Amman J.5898
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It is corroded, and sampling could disfigure it, so, no
sample was taken.

54
Sahab  -  299
Arrowhead  -  LB
Amman (U.M.) J.12057
Annual of the Department of Antiquities of Jordan, 1970,
vol. 15, 304, P1.18
AAS(133), Cu:92.3; Sn:5.41; AS:1.33; Pb:.234; Zn:.0161;
Ag:.044; Au:ND; Fe:.155; Ni:.0604; Co:ND; Sb:.036; Bi:ND.

55
Amman Airport  -  -
Arrowhead  -  LB
Amman J.5889
---
AAS(134), Cu:89.8; Sn:8.067; AS:.852; Pb:.116; Zn:.0048;
Ag:.0526; Au:ND; Fe:.462; Ni:.0451; Co:.0255; Sb:.0468;
Bi:.0046.

56
Amman Airport  -  -
Arrowhead  -  LB
Amman J.5895
---
AAS(135), Cu:97.6; Sn:ND; AS:.84; Pb:ND; Zn:.0053; Ag:ND;
Au:ND; Fe:.524; Ni:.0247; Co:.0112; Sb:.016; Bi:.0008.

57
Amman Airport  -  -
Arrowhead  -  LB
Amman J.6714(d)
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AAS(136), Cu: 93.3; Sn: ND; AS: .654; Pb: .0169; Zn: .0851; Ag: .0272; Au: ND; Fe: .5; Ni: ND; Co: ND; Sb: .0654; Bi: .0048.

58
Amman Airport
Arrowhead
Amman J. 5901(16)

AAS(137), Cu: 98.3; Sn: 2.034; AS: 1.39; Pb: .164; Zn: .0502; Ag: ND; Au: ND; Fe: .3029; Ni: ND; Co: ND; Sb: .0155; Bi: .0002.

59
Amman Airport
Arrowhead
Amman J. 5903

AAS(138), Cu: 96.5; Sn: ND; AS: 1.68; Pb: .122; Zn: .0075; Ag: ND; Au: ND; Fe: .727; Ni: ND; Co: ND; Sb: .0231; Bi: .002

60
Sahab 302
Arrowhead
Amman (U. M.) J. 12060
AAS(139), Cu: 91.2; Sn: 6.001; AS: 1.055; Pb: .346; Zn: .0214; Ag: .0489; Au: ND; Fe: .143; Ni: .1006; Co: ND; Sb: .0485; Bi: .0143.

61
Amman Airport
Sword, broken into four pieces
Amman J. 5912

AAS(140), Cu: 86.6; Sn: 10.6; AS: .424; Pb: ND; Zn: .0066; Ag: .0242; Au: ND; Fe: .0746; Ni: ND; Co: ND; Sb: .0488; Bi: .0106.
The polished section of the sword showed the growth of corrosion towards the metal core, along the grain boundaries. Also, there are few but large pores. It was etched with FeCl₃ and showed two sizes of grains, small
Fig. 20

Reconstruction
and medium. There are a lot of twins with slip bands in the structure. These twins are either straight or curved. It is very clear that the sword was cold worked and annealed or hot worked. However, the presence of slip bands within the crystals indicates that some final cold working - hammering - was carried out. The purpose of this final hammering was probably to harden and sharpen the edges of the sword. There are two types of inclusions: light grey inclusions which are elongated in the direction of working; and another type of large white inclusion. The SEM analysis of more than one of these elongated light grey inclusions shows that they contain mainly sulphide of copper and iron. When the large white inclusions were analysed, they indicated a very high tin content with copper. However, they seem to be an \( \alpha + \delta \) eutectoid area of high tin content which did not diffuse within the metal when it was worked. The very high magnification of the SEM also shows an area high in tin in a crack. According to the line scan analyser this could be tin oxide.

Pls. 30-31, 43-46

H:\(_v\): 137

62

Jericcho tell

Axe, big

Amman

J.6785

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XRF(12), Cu:(98.9); Sn:ND; AS:.5; Pb:.4; Zn:ND; Ag:ND; Au:ND; Fe:ND; Ni:.2; Co:.01; Sb:ND; Bi:ND.

The section showed that the metal is very porous. Etching with \( \text{H}_2\text{SO}_4 + \text{H}_2\text{O}_2 \) revealed large grains and very clear twins. Also, a few light blue inclusions appeared.

H:\(_v\): 97

63

Jericcho tell

Axe, two pieces

Amman

J.4090

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AAS(13), Cu: 96; Sn: .744; AS: 1.83; Pb: .414; Zn: .0029;
Ag: .0108; Au: ND; Fe: .829; Ni: .0166; Co: ND; Sb: .0283;
Bi: .0037.

64
Jericho tell - (stratum: viii)
Axe, small - EB
Inst. of Archaeology -
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AAS(3), Cu: 96.3; Sn: ND; AS: 1.62; Pb: .266; Zn: ND; Ag: .096;
Au: ND; Fe: .2018; Ni: .412; Co: ND; Sb: .0183; Bi: ND.
The polished section showed a lot of porosity; after etching
with $\text{H}_2\text{SO}_4 + \text{H}_2\text{O}_2$ many twins were seen. Also, light blue
inclusions were revealed.
$H_v$: 52

65
Jericho tell M.II/3:c/d 73.30
Axe, with a hole - MB
Birmingham -
Annals of Archaeology and Anthropology, 1934, vol. 21,
Pl. 26:18
AAS(68), Cu: 94.9; Sn: .647; AS: 2.55; Pb: .3087; Zn: .0069;
Ag: .0339; Au: .0085; Fe: .235; Ni: .0599; Co: .0141; Sb: .0722;
Bi: ND.

66
Amman Airport - -
Axe, flat - LB
Amman J.5911(G)
---
AAS(141), Cu: 86.7; Sn: 11.9; AS: .261; Pb: ND; Zn: ND; Ag: .0112;
Au: ND; Fe: .1805; Ni: .0154; Co: ND; Sb: .0131; Bi: .0052.

67
Jericho tell - (stratum: XLviiia)
Chisel, big - EB
Inst. of Archaeology -
---
Fig. 21
AAS(4), Cu: 99.7; Sn: ND; As: 0.031; Pb: ND; Zn: ND; Ag: 0.0118; Au: ND; Fe: ND; Ni: 0.0334; Co: ND; Sb: 0.0207; Bi: 0.001.
The equi-axed structure was obvious before etching with diluted FeCl₃. Etching revealed twins and two different sizes of grains: medium and large. This means that the chisel had been worked and annealed. Examining the specimen with high magnification showed that the small black dot-like inclusions lined the grain boundaries. A similar example, (Cat. No. 108), analysed as copper. This can be explained as a hyper-eutectic formed during solidification. Also, a few light blue inclusions were seen.

Pis. 16-18
Hᵥ: 70

68
Jericho tell - (stratum: L)
Chisel - EB
Inst. of Archaeology -
---
AAS(5), Cu: 96.7; Sn: ND; As: 2.84; Pb: ND; Zn: ND; Ag: 0.0292; Au: 0.0255; Fe: 0.0428; Ni: 1.703; Co: ND; Sb: 0.017; Bi: ND.
Porosity was seen before the section was etched. After etching with (NH₄)₂S₂O₈, small grains were revealed. The structure shows twinning. Also, light blue inclusions were observed.
Hᵥ: 101

69
Jericho tomb H1 1
Chisel - EB
Inst. of Archaeology -
Jericho II, 715
AAS(6), Cu: 90.4; Sn: ND; As: 2.18; Pb: 0.159; Zn: ND; Ag: 0.243; Au: ND; Fe: 0.447; Ni: ND; Co: ND; Sb: 0.017; Bi: 0.0039.
The section showed the progress of the corrosion, and the porosity of the metal. Etching with FeCl₃ revealed dendrites with light blue inclusions, but under higher magnification, twins were confirmed within the dendritic structure. Also, this twinned structure was preserved in a
layer sandwiched between other layers of corrosion. This could be explained by the object having been worked but not sufficiently annealed.

Pls. 9-12

$H_v$: 89

---

Jericho tell - (stratum:XL)
Chisel, small - EB
Inst. of Archaeology -

AAS(7), Cu:92.5; Sn:ND; AS:3.6; Pb:.0605; Zn:ND; Ag:.019; Au:ND; Fe:.0335; Ni:.047; Co:ND; Sb:.016; Bi:.0013.

---

Jericho tell - (stratum:xxxii-xxxiii)
Chisel, small - EB
Inst. of Archaeology -

AAS(69), Cu:91.8; Sn:1.18; AS:.893; Pb:.0676; Zn:ND; Ag:.0893; Au:.0223; Fe:.494; Ni:.0263; Co:ND; Sb:.0357; Bi:.003.

The section was severely corroded. After etching with diluted FeCl$_3$, twins with some slip bands were revealed. The inclusions are light blue.

$H_v$: 57

---

Jericho tomb G27 1
Awl - EB-MB
Jericho I, 251, fig. 84:3

AAS(31), Cu:95.9; Sn:ND; AS:2.24; Pb:.957; Zn:ND; Ag:.0167; Au:ND; Fe:.0952; Ni:.0406; Co:ND; Sb:.0165; Bi:.0024.

The polished section showed a lot of porosity. Etching with FeCl$_3$ revealed twins. The grain sizes and shapes vary, with very few light blue inclusions.

$H_v$: 102
Fig. 22
The polished section of the awl showed that it is severely corroded so that neither etching nor metallographic study could be obtained. However, when it was examined under the optical microscope, a layer with a shiny silvery colour was seen. When this layer was analysed by the electron probe microanalyser, a high arsenic content was confirmed. This arsenic enrichment appeared in a blade of a dagger from Carnoët in Finistère, France (Briad and Mohen, 1974). An analysis of different sections of the blade confirmed that the shiny layer consists of up to 29% arsenic, while the core of the metal contains only 7.1%. This enrichment in arsenic has been explained as an intentional decorative aspect, but its technological procedure is uncertain. (See page 49).

Pls. 53-55

---
<table>
<thead>
<tr>
<th>Jericho tomb</th>
<th>Knife, three rivet holes, alabaster pommel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amman</td>
<td>J.7086</td>
<td>MB</td>
</tr>
</tbody>
</table>

Jericho II, 259, fig. 111:8

AAS(72), Cu: 88.2; Sn: 2.24; AS: 2.84; Pb: 258; Zn: ND; Ag: 0.0244; Au: 0.0171; Fe: 3.085; Ni: 0.8025; Co: ND; Sb: 0.0256; Bi: 0.0051.

The section showed corrosion lining the grain boundaries, and porosity. After etching with FeCl$_3$, two sizes of grains were indicated, also, twins were shown. Also, a few light blue inclusions were seen. It is clear that the knife had been cold worked and annealed or hot worked.

\[ H_v: 81 \]

---

<table>
<thead>
<tr>
<th>Jericho tomb</th>
<th>Knife, three rivets in position</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amman</td>
<td>J.7083</td>
<td>MB</td>
</tr>
</tbody>
</table>

Jericho II, 259, fig. 111:9

AAS(72), Cu: 88.2; Sn: 2.24; AS: 2.84; Pb: 258; Zn: ND; Ag: 0.0244; Au: 0.0171; Fe: 3.085; Ni: 0.8025; Co: ND; Sb: 0.0256; Bi: 0.0051.

The section is severely corroded, with little metal left. After etching with FeCl$_3$, the structure was seen to be distorted, which means that the knife was hammered and annealed more than once. Also, light blue inclusions were revealed.
The unetched section of the bracelet showed corrosion following the grain boundaries; porosity was also shown. Etching with FeCl$_3$ revealed twins with some slip bands, as an indication of further hammering after it had been cold worked and annealed or hot worked. The grain size varies from small to medium. Besides this, small light blue inclusions were observed.

The bracelet was dated to EBIII, but it is mentioned that it was found unstratified. The presence of high tin in its composition makes it more likely to be dated to a period later than EBIII.

A section cut through the pin showed that the corrosion
attacked the grain boundaries and made them appear thick. Also, the metal is very porous, mainly in the centre of the pin. Etching with FeCl₃ showed a mixture of small and large grains. The structure shows twinning with few slip bands. Light blue inclusions were also seen.

Pls. 3, 34

Hᵥ: 99

84
Jericho tomb B51 122
Toggle-pin, many parts A1 MB
Birmingham
Jericho II, 357, fig. 174:3
XRF(76), Cu:(86.9); Sn:8; AS:4.5; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.2; Ni:.3; Co:.02; Sb:ND; Bi:ND.

85
Jericho tomb J12 55
Toggle-pin A1 MB
Cambridge 54.266
Jericho I, 424, fig. 177:5
AAS(77), Cu:88.7; Sn:5.52; AS:2.69; Pb:.2; Zn:.0081; Ag:.023; Au:ND; Fe:.426; Ni:.0569; Co:ND; Sb:.0516; Bi:.0048.

86
Jericho tomb B3 27
Toggle-pin A1 MB
Amman J.4915
Jericho I, 405, fig. 165:1
AAS(78), Cu:83.8; Sn:11.5; AS:.357; Pb:.459; Zn:.0053; Ag:.0385; Au:ND; Fe:ND; Ni:.0495; Co:ND; Sb:.0027; Bi:.0067

87
Jericho tomb D9 74
Toggle-pin, point missing A1 MB
St. Andrews 1976.93
Jericho II, 285, fig. 114:8
AAS(79), Cu:95; Sn:1.32; AS:1.12; Pb:.214; Zn:.0075; Ag:.0661; Au:ND; Fe:.273; Ni:.0651; Co:ND; Sb:.0423; Bi:.004.
88
Jericho -
Toggle-pin -
Birmingham -
---
AAS(80), Cu: 94; Sn: ND; AS: 1.98; Pb: 0.162; Zn: ND; Ag: 0.0254; Au: ND; Fe: 0.322; Ni: 0.0267; Co: ND; Sb: 0.0347; Bi: 0.0053.
It is from Garstang's excavations, but not registered.

89
Jericho tomb B51 94
Toggle-pin A2 MB
Birmingham -
Jericho II, 357, fig. 174:4
AAS(81), Cu: 90; Sn: 4.8; AS: 1.27; Pb: 1.104; Zn: ND; Ag: 0.0364; Au: ND; Fe: 0.0206; Ni: 113; Co: ND; Sb: 0.0346; Bi: 0.0046.
The section showed that interior corrosion penetrated within the metal, and made it appear spongy and porous. Etching with FeCl₃ revealed twinning and a few light blue inclusions. Hᵥ: 60

90
Jericho tomb B3 11
Toggle-pin, lower part missing B1 MB
Amman J.4917
Jericho I, 405, fig. 165:2
AAS(82), Cu: 88.9; Sn: 4.49; AS: 1.78; Pb: 0.226; Zn: ND; Ag: 0.0548; Au: ND; Fe: ND; Ni: 0.0753; Co: ND; Sb: 0.0757; Bi: ND.

91
Jericho tomb G1 54
Toggle-pin B1 MB
Birmingham -
Jericho I, 451, fig. 207:2
XRF(83), Cu: (99.8); Sn: ND; AS: ND; Pb: ND; Zn: ND; Ag: ND; Au: ND; Fe: 0.05; Ni: 0.05; Co: 0.01; Sb: ND; Bi: ND

92
Jericho tomb G1 33
Toggle-pin B1 MB
Birmingham
Jericho I, 451, fig. 207:3
AAS(84), Cu: 87.5; Sn: 2.606; AS: 4.13; Pb:. 425; Zn:. 0309; Ag:. 0283; Au:ND; Fe:1.003; Ni:.0971; Co:ND; Sb:.1039; Bi:ND.

<table>
<thead>
<tr>
<th>Jericho tomb</th>
<th>J39</th>
<th>46</th>
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<tbody>
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<td>Toggle-pin</td>
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<td>MB</td>
</tr>
<tr>
<td>St. Andrews</td>
<td>1976.343</td>
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</tr>
</tbody>
</table>

Jericho II, 478, fig. 245:6
AAS(85), Cu: 92.6; Sn: 5.204; AS: .6505; Pb:. 16; Zn:. 0319; Ag:. 0315; Au:ND; Fe:.2012; Ni:.0559; Co:ND; Sb:.042; Bi:.002

<table>
<thead>
<tr>
<th>Jericho tomb</th>
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<th>97</th>
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<tbody>
<tr>
<td>Toggle-pin</td>
<td>B2</td>
<td>MB</td>
</tr>
<tr>
<td>St. Andrews</td>
<td>1976.110</td>
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</tbody>
</table>

Jericho II, 285, fig. 114:9
AAS(86), Cu: 86.7; Sn: 6.055; AS: 1.6; Pb: 1.68; Zn:.1402; Ag:.0263; Au:ND; Fe:1.133; Ni:.0271; Co:ND; Sb:.1035; Bi:.0046.

<table>
<thead>
<tr>
<th>Jericho tomb</th>
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<th>53</th>
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<td>MB</td>
</tr>
<tr>
<td>Amman</td>
<td>J.6993</td>
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</tbody>
</table>

Jericho II, 366, fig. 174:8
AAS(87), Cu: 91.1; Sn:ND; AS: 3.63; Pb:.0991; Zn:.0818; Ag:.0327; Au:ND; Fe:1.18; Ni:.0289; Co:ND; Sb:.0164; Bi:ND.

<table>
<thead>
<tr>
<th>Jericho tomb</th>
<th>B51</th>
<th>164</th>
</tr>
</thead>
<tbody>
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<td>Toggle-pin, tip missing</td>
<td>B2</td>
<td>MB</td>
</tr>
<tr>
<td>Birmingham</td>
<td>629.58</td>
<td></td>
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</tbody>
</table>

Jericho II, 357, 174:5
AAS(88), Cu: 88.2; Sn: 3.15; AS: 1.903; Pb:.311; Zn:ND; Ag:.044; Au:.0086; Fe:.443; Ni:.1309; Co:ND; Sb:.0334; Bi:.0026.
97
Jericho tomb B51 183
Toggle-pin, broken E MB
Birmingham 583.58
Jericho II, 357, fig. 174:6
XRF(89), Cu:(93.9); Sn:2.5; AS:3; Pb:ND; Zn:ND; Ag:ND;
Au:ND; Fe:.5; Ni:ND; Co:.01; Sb:ND; Bi:ND.

98
Jericho tomb J12 44
Toggle-pin E MB
Cambridge 54.266
Jericho I, 424, fig.177:8
- AAS(90), Cu:82.9; Sn:8.8; AS:1.109; Pb:.231; Zn:.0043;
Ag:.0198; Au:ND; Fe:.0975; Ni:.0856; Co:.0277; Sb:.0159;
Bi:ND.

99
Jericho tomb J14 145
Toggle-pin, point missing E MB
Amman J.5638
Jericho II, 322, fig. 114:12
AAS(91), Cu:84.2; Sn:8.99; AS:.325; Pb:.466; Zn:.0427;
Ag:.1205; Au:ND; Fe:.112; Ni:.0653; Co:ND; Sb:.0119; Bi:ND.

100
Jericho tomb 22.C.27 -
Toggle-pin, broken E MB
Birmingham -
---
AAS(92), Cu:84; Sn:8.52; AS:.4204; Pb:.218; Zn:ND; Ag:.0348;
Au:ND; Fe:.133; Ni:.1074; Co:.0147; Sb:.016; Bi:.0033.
The polished section showed that the corrosion lined the
grain boundaries and thickened them, with a red colour
indicating redeposited copper. The metal is also porous.
The structure shows twinning, and a very few light blue
slag-like inclusions were revealed.
P1. 35
H_V: 85
101
Jericho tomb
Toggle-pin
Birmingham
Jericho II, 357, fig. 174:7
AAS(93), Cu: 83.8; Sn: 7.3; AS: 431; Pb: .753; Zn: .0049;
Ag: .166; Au: ND; Fe: .2301; Ni: .0183; Co: .0103; Sb: .0113;
Bi: .0027.

102
Jericho tomb
Toggle-pin
Amman
Jericho II, 366, fig. 174:9
AAS(94), Cu: 90.4; Sn: 1.22; AS: 3.43; Pb: .117; Zn: .0241;
Ag: .0265; Au: ND; Fe: .799; Ni: .0363; Co: ND; Sb: .0162;
Bi: .0043.

103
Jericho tomb
Toggle-pin
Amman
Jericho II, 366, fig. 174:10
AAS(95), Cu: 89.4; Sn: ND; AS: 3.8; Pb: .9506; Zn: ND; Ag: .0655;
Au: ND; Fe: 1.3; Ni: ND; Co: ND; Sb: .0314; Bi: .003

104
Jericho tomb
Toggle-pin
Cambridge
Jericho I, 424, fig. 177:10
AAS(96), Cu: 83; Sn: 9.57; AS: 1.49; Pb: .058; Zn: .0024;
Ag: .0569; Au: ND; Fe: .0654; Ni: .018; Co: ND; Sb: .013;
Bi: .0026.

105
Jericho tomb
Toggle-pin
Leeds
Jericho II, 472, fig. 245:4
AAS(97), Cu:.82.6; Sn:10.2; AS:.947; Pb:.985; Zn:.0106; Ag:.23; Au:.0237; Fe:.167; Ni:.134; Co:ND; Sb:.0757; Bi:.0133.

106
Jericho tomb
Toggle-pin
St. Andrews
1976.66
Jericho II, 285, fig. 114:10
AAS(98), Cu:94.8; Sn:ND; AS:3.29; Pb:.64; Zn:.0106; Ag:.0483; Au:.0169; Fe:.535; Ni:.0397; Co:ND; Sb:.0709; Bi:.003.

107
Jericho tomb
Toggle-pin, broken
Leeds
Jericho II, 472
AAS(99), Cu:86; Sn:3.75; AS:.855; Pb:.331; Zn:.0071; Ag:.0977; Au:ND; Fe:.322; Ni:.0503; Co:ND; Sb:.0665; Bi:.0038.

108
Jericho tomb
Toggle-pin
Inst. of Archaeology
Jericho II, 715
AAS(100), Cu:89.8; Sn:4.038; AS:1.62; Pb:2.18; Zn:.0044; Ag:.0201; Au:.007; Fe:.265; Ni:.161; Co:.0117; Sb:.0365; Bi:.0035.
The section showed that the metal is porous, but after etching with FeCl₃ the structure was revealed as twinned; medium grains and many light blue inclusions were confirmed.
Hᵥ: 84

109
Jericho tomb
Toggle-pin
Leeds
Jericho tomb A136 38
Toggle-pin G4 MB
Leeds
Jericho II, 472, fig. 245:5
AAS(101), Cu:.86.6; Sn:.9.37; AS:.163; Pb:.1.33; Zn:.0102;
Ag:.0139; Au:ND; Fe:.344; Ni:.0671; Co:.0163; Sb:.0033;
Bi:.0049.

110
Jericho - -
Toggle-pin, short - MB
Birmingham -
---
AAS(102), Cu:.88.3; Sn:.6.4; AS:.95; Pb:.0485; Zn:.005;
Ag:.0297; Au:ND; Fe:.129; Ni:.0565; Co:ND; Sb:.0268;
Bi:.0022.
After the section was polished, a metallic zone appeared
between two corroded areas: the centre and the outside. In
both areas corrosion lined the grain boundaries. However,
etching with FeCl₃ revealed many twins, and few light blue
inclusions.
Pls. 4, 36
H_v: 87
This was found by Garstang, but not registered.

111
Jericho - -
Toggle-pin, short - MB
Birmingham -
---
AAS(103), Cu:.83; Sn:.8.65; AS:.879; Pb:ND; Zn:.0277; Ag:.0241;
Au:ND; Fe:.138; Ni:.0248; Co:ND; Sb:.0132; Bi:.0026.

113
Jericho tomb A136 47
Toggle-pin, fragment - MB
Leeds -
Jericho II, 472
AAS(104), Cu:.97.1; Sn:ND; AS:1.4; Pb:ND; Zn:.1307; Ag:.0239;
Au:.0167; Fe:.0967; Ni:.1083; Co:ND; Sb:.005; Bi:.0067.
Illustration of the use of the toggle-pin.

Fig. 26
Jericho tomb A34 61
Toggle-pin, head segmented sphere, loop MB
Birmingham
Jericho I, 368, fig. 128:12
XRF(105) Pin, Cu:(91); Sn:7.5; As:ND; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.2; Ni:ND; Co:ND; Sb:ND; Bi:ND.
XRF(106) Head, Cu:(88); Sn:9; As:ND; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:ND; Ni:ND; Co:ND; Sb:ND; Bi:ND.
XRF(107) Rivet, Cu:(98); Sn:ND; As:ND; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:ND; Ni:ND; Co:ND; Sb:ND; Bi:ND.

In order to understand the technique of manufacture of the toggle-pin, whether the head was cast with or added to the pin, it was sectioned longitudinally, with a precision diamond saw (Buehler Isomet). After cutting, it was clear that the head was cast separately and slipped onto the pin, and locked on with a small piece of copper wedged in between. Because this toggle-pin is important to the museum from a display point of view, no mounting for metallographic investigation was done, but careful polishing was sufficient. The polished section showed different layers of corrosion of the pin and the head. Also, interior corrosion was obvious. It was difficult to etch the three different parts of the toggle-pin together, but short etching with FeCl₃ was enough to reveal the small grains of the pin. Also, the structure of the head was seen to include twinning. This indicates that cold-working and annealing or hot working was used. However, hammering or pressure must have been used to push the pin into the head. Also, hammering was important to wedge the piece of copper into the gap. It was not possible to measure the hardness of the component parts of the pin.

Pls. 56-57

Jericho tomb P6 2
Fragment of a curved band - EB-MB
Leeds
Jericho II, 109, fig. 45:17
XRF(33), Cu:(87.9); Sn:9; AS:2.5; Pb:.5; Zn:ND; Ag:ND; Au:ND; Fe:.02; Ni:ND; Co:ND; Sb:ND; Bi:ND.

117
Jericho tomb L2 13
Part of a band
Amman J.5708
Jericho II, 148, fig. 81:1
XRF(34), Cu:(92.1); Sn:3; AS:3.3; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.5; Ni:.1; Co:.01; Sb:ND; Bi:ND.

118
Jericho tomb L2 10a
Part of a band
Amman J.5708
Jericho II, 148, fig. 81:2
XRF(35), Cu:(98.8); Sn:ND; AS:.8; Pb:ND; Zn:ND; Ag:.05; Au:ND; Fe:.1; Ni:.2; Co:.01; Sb:ND; Bi:ND.

119
Jericho tomb D10 5
A: Fragment of a rivet
B: Oval plate
Birmingham 293.55
Jericho II, 92, fig. 45:1
A: AAS(36), Cu:93.6; Sn:ND; AS:3.901; Pb:.284; Zn:ND; Ag:.0334; Au:ND; Fe:.3058; Ni:ND; Co:ND; Sb:.183; Bi:ND.
B: XRF(37), Cu:(95.7); Sn:ND; AS:4; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.3; Ni:ND; Co:ND; Sb:ND; Bi:ND.
The polished section of the nail showed that the metal is porous. Etching with \((\text{NH}_4)_2\text{S}_2\text{O}_8\) revealed the small grains, and twins with slip bands. Also, a few small light blue inclusions were observed. 
HV:104.

120
Jericho tomb L2 11
Small oval plate with spikes
Amman J.5708
Jericho II, 148, fig. 81:10
XRF(38), Cu:(87.9), Sn:10; AS:.5; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.5; Ni:1; Co:.01; Sb:ND; Bi:ND.

121
Jericho tomb L2 7a, 7b
Dome-headed studs Amman J.5708
Jericho II, 148, fig. 81:8,7
A: XRF(39), Cu:(95.3); Sn:ND; AS:4.3; Pb:.2; Zn:ND; Ag:ND; Au:ND; Fe:.1; Ni:ND; Co:.02; Sb:ND; Bi:ND.
B: AAS(40), Cu:92; Sn:ND; AS:4.67; Pb:ND; Zn:ND; Ag:.0571; Au:ND; Fe:.335; Ni:ND; Co:ND; Sb:.193; Bi:ND.
The technological aspects of stud B were discussed earlier. Also, the section was etched with FeCl₃ and showed that the slip bands were distorted. Also, a few light blue inclusions were seen. This structure occurs as a result of extreme cold working.
Pls. 51-52
Hv: The shape and size of the specimen was not suitable for the hardness test.

122
Jericho tomb P6 7
Fragments of metal fitting Leeds
Jericho II, 108, fig. 45:14
XRF(41), Cu:(89); Sn:9; AS:1.5; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.5; Ni:ND; Co:ND; Sb:ND; Bi:ND.

123
Jericho tomb P6 5
Spike, fragment Leeds
Jericho II, 109, fig. 45:16
AAS(42), Cu:90.7; Sn:ND; AS:.795; Pb:.1095; Zn:ND; Ag:.0248; Au:ND; Fe:.545; Ni:.0255; Co:ND; Sb:.0397; Bi:.0029.
The spike was cut in the middle in order to study its technology. The structure was clear after etching with
FeCl$_3$ : it is distorted and similar to Cat. No. 121. PIs. 49-50
H$_v$: 116.

124
Jericho tomb P21
Nail in a wooden piece - EB-MB
Amman J.7093
Jericho II, 438, fig. 103:17
XRF(43), Cu: (92.4); Sn: 7.5; AS: ND; Pb: ND; Zn: ND; Ag: ND; Au: ND; Fe: ND; Ni: ND; Co: .01; Sb: ND; Bi: ND.
The polished section showed that the metal is corroded. After a light etch with FeCl$_3$, twins and a few light blue inclusions were revealed. H$_v$: 180

125
Jericho tomb P12
Rivet - EB-MB
Oxford 1958.638
Jericho II, 137, fig. 74:11
AAS(44), Cu: 91.87; Sn: 3.29; AS: 3.33; Pb: .126; Zn: .247; Ag: .0357; Au: ND; Fe: .0209; Ni: ND; Co: ND; Sb: .0104; Bi: ND.

126
Jericho tomb L2
Staple - EB-MB
Amman J.5708
Jericho II, 148, fig. 81:5
XRF(45), Cu: (98.3); Sn: ND; AS: 1.5; Pb: ND; Zn: ND; Ag: ND; Au: ND; Fe: .5; Ni: ND; Co: ND; Sb: ND; Bi: ND.

127
Jericho tomb G31
Rivet or nail - EB-MB
Inst. of Archaeology -
AAS(46), Cu: 92.3; Sn: ND; AS: .677; Pb: ND; Zn: .0061; Ag: ND; Au: ND; Fe: .392; Ni: .0358; Co: .0108; Sb: .0231; Bi: ND.
The section showed that the metal is very corroded, with a
lot of porosity and inclusions. Also there is a crack which could have been caused by working. After etching with a mixture of \( \text{FeCl}_3 \) and ammonium hydroxide solution, a distorted structure was revealed; also, many light blue inclusions were indicated.

Pls. 6, 37

\[ H_v: 108 \]

**128**

jericho tomb J.32.5

Nail or rivet - EB-MB(?)

Birmingham -

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AAS(116), Cu:88.6; Sn:6.76; AS:1.4; Pb:.0873; Zn:.0472; Ag:.0205; Au:.0107; Fe:.19; Ni:.0528; Co:.0144; Sb:.202; Bi:.0029.

The polished section showed some porosity and interior corrosion. Etching with \( \text{FeCl}_3 \) revealed twins with a lot of slip bands; also, a few light blue inclusions were confirmed.

\[ H_v: 145 \]

**129**

Jericho tell - (stratum: Li)

Nail or rivet - EB-MB

St. Andrews 1976.477

---

AAS(47), Cu:94.03; Sn:ND; AS:4.45; Pb:.135; Zn:.0863; Ag:.0318; Au:ND; Fe:.235; Ni:ND; Co:ND; Sb:.0267; Bi:.0156.

**130**

Jericho tomb P6 4

Rivet - EB-MB

Leeds -

Jericho II, 109

XRF(48), Cu:(97.3); Sn:ND; AS:2.5; Pb:ND; Zn:ND; Ag:ND; Au:ND; Fe:.2; Ni:ND; Co:ND; Sb:ND; Bi:ND.

The rivet consists of two parts. Before etching a black area like a wavy line was shown, which probably occurred because of corrosion. It was etched with \( (\text{NH}_4)_2\text{S}_2\text{O}_8 \) and showed
small grains with a lot of deformation lines caused by extreme cold working. Also, a lot of light blue inclusions perpendicular to the direction of working appeared. Pls. 5, 38-39
Hv: 186.

132
Jericho tell Trench III (stratum: Li)
A piece of metal which could be an ingot EB
Inst. of Archaeology
---
AAS(8), Cu: 92.5; Sn: ND; AS: 1.97; Pb: 0.4505; Zn: ND; Ag: 0.166; Au: ND; Fe: 0.0325; Ni: 1.46; Co: ND; Sb: 0.0129; Bi: ND.
The polished section showed some porosity. Etching with a mixture of (NH$_4$)$_2$S$_2$O$_8$ and ammonium hydroxide solution revealed twins with slip bands in some areas, and an equiaxed structure in others. Also, three types of inclusions were confirmed: light blue, blue, and white. The SEM analysis for the light blue and the shapeless blue inclusions indicated high lead as shown by the scan line analyser. The bright white inclusions could not be detected with a 100x Temscan microscope, so the section was carbon coated and mounted in the holder, and colloidal graphite used to ensure the conductivity. The Microscan 5 was used, and more than one of these white inclusions positively showed almost pure silver. As this was in a corroded area, it is not necessarily a feature of the original alloy. Pls. 19-20, 47-48
Hv: 93

133
Jericho tell Trench II (stratum: LviII)
A lump of copper, covered with dark green corrosion, textile still sticking to the corrosion EB
Inst. of Archaeology
---
AAS(9), Cu: 98.5; Sn: ND; AS: 0.2303; Pb: 0.0097; Zn: ND; Ag: 0.0376; Au: ND; Fe: 0.0496; Ni: 0.0484; Co: ND; Sb: 0.0247; Bi: ND.
The metal showed large pores. Etching with FeCl$_3$ revealed very large grains in an equi-axed structure.

Pl. 13

$H_v$: 44

134

Jericho tell Trench EIII-IV (stratum: C)

A scrap of metal

Inst. of Archaeology

---

AAS(10), Cu: 96.5; Sn: ND; AS: 1.14; Pb: .457; Zn: .0043; Ag: ND; Au: ND; Fe: ND; Ni: .0201; Co: ND; Sb: .0185; Bi: ND.

The polished section showed porosity. FeCl$_3$ etched the metal well and revealed twins and a very few light blue inclusions.

$H_v$: 49

135

Jericho tell Trench EIII-IV (stratum: Cii)

Piece of scrap metal

Inst. of Archaeology

---

AAS(11), Cu: 97.6; Sn: ND; AS: 1.32; Pb: .0902; Zn: ND; Ag: .017; Au: ND; Fe: .0179; Ni: .0281; Co: ND; Sb: .0119; Bi: .0012.

136

Jericho tell Trench H (stratum: XLV)

An ingot, like a bar, square in section

Inst. of Archaeology

---

AAS(108), Cu: 97.4; Sn: ND; AS: ND; Pb: ND; Zn: .0069; Ag: ND; Au: ND; Fe: ND; Ni: .0259; Co: ND; Sb: .0165; Bi: ND.

The polished but unetched section showed large pores, and an equi-axed structure. Also, the grain boundaries were outlined by small inclusions. After etching with FeCl$_3$, the equi-axed grains were heavily outlined and some twins were revealed as a result of light hammering, possibly to compact the final shape.
The SEM analysis of the small inclusions along the grain boundaries confirmed them as copper, and this could be explained as a hyper-eutectic occurring during the solidification of the metal.

Pls. 14, 15

H_{v}: 40

---

137
Jericho tell Trench H (stratum: XXXViiia)
A drop of metal adhering to a stone - MB
Inst. of Archaeology -

AAS(109), Cu:87.09; Sn:4.005; AS:2.12; Pb:.192; Zn:.0137; Ag:.0435; Au:ND; Fe:.659; Ni:.0398; Co:ND; Sb:.049; Bi:.0021.
The polished section showed the dendrites in the shape of pores, the alpha phase preferentially corroded in the shape of dendrites. Also, the dendritic structure was revealed in the metallic parts after etching with FeCl_3 for a short time. A very few light blue inclusions were shown.

Pls. 7-8
H_{v}: 60.

---

138
Jericho tell Trench H (stratum: XXXiii-XXXiii)
Metal runner - MB
Inst. of Archaeology -

AAS(110), Cu:94.1; Sn:ND; AS:1.86; Pb:.0563; Zn:ND; Ag:.0212; Au:ND; Fe:ND; Ni:.0364; Co:ND; Sb:.0167; Bi:ND.
The metal was very porous, and again the alpha phase corroded revealing the shape of the dendrites.
H_{v}: 43 .

---

139
Jericho tell Trench H (stratum: XLiv)
Drop of metal - MB
Inst. of Archaeology -
The section showed that the alpha phase corroded to make the metal very porous in the shape of a dendritic structure.

140
Jericho tell Trench III (stratum:LXXXVi)
Metal scrap - MB
Inst. of Archaeology -
---
AAS(112), Cu:94.6; Sn:ND; AS:2.32; Pb:.0439; Zn:.0045; 
Ag:.245; Au:ND; Fe:ND; Ni:.4604; Co:ND; Sb:.5072; Bi:.239.

SILVER ARTEFACTS

82
Jericho tomb G1 32
Ring, fragments - MB
Birmingham -
Jericho I, 451, fig. 207:4

112
Jericho tomb B3 122
Toggle-pin, broken - MB
Amman J.4916
Jericho I, 405, fig. 165:5

116
Jericho tomb P21 49
Amman J.7089 - MB
Jericho II, 438, fig. 103:16

131
Jericho tomb J14 102
Binding, fragmented - MB
Amman J.4640
Jericho II, 323, fig. 103:12
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V. CONCLUSIONS

It has been interesting to investigate the various artefacts from Jericho from the different periods of pre-history, as far as they are supposed to represent a single industry which was continued throughout the Bronze Age. The LB age metallurgy is represented here by the many weapons which were found in Amman Airport and at Sahab. A number of conclusions can be drawn from this study.

V.1. The development of the metallurgy of copper and its alloys during the Bronze Age in Palestine:

Unalloyed copper was used to manufacture different tools and weapons, which could either be derived from native or smelted copper.

In a site like Jericho which has no copper deposit, we do not expect to find any remains of furnaces for smelting. Thus the metal would be received by trade, either in the form of objects or as ingots. However, from the Neolithic period, Jericho had good trade connections with other parts of the ancient world as far away as Anatolia (Kenyon, 1970, 50). This was because of its location and wealth from the Dead Sea salts. Unfortunately, there is no clear evidence yet if copper played any significant role in this trade.

The ancient smith first used the oxide-carbonate copper ores. It is known that by the beginning of the second millennium B.C., he explored the sulphide ores. Sulphide inclusions were confirmed by the SEM analysis and the metallographical study of artefacts dated to the LB age from Amman Airport and Sahab.

V.1.1. Alloying:

Copper

However, in the EB age, arsenical copper was manu-
factured, although copper artefacts were still in use e.g. (Cat. Nos. 1, 62, 63, 67, and 133). In the EB-MB period, the ratio between the unalloyed objects and the ones with arsenic or tin is less than in the period before. Only three items out of thirty-five artefacts analysed were shown to be copper with traces of impurities (Cat. Nos. 118, 123, and 127). Even in the MB age, when alloying was well known, copper artefacts can be found such as Cat. Nos. 71, 74, 91, and 136. The last one, the ingot, is interesting since it is almost pure copper, thus it represents the raw material for fabricating objects. As far as the LB age is concerned, alloying with tin was widespread, although three arrowheads (Cat. Nos. 52, 56, 57) were shown to be of unalloyed copper. This could correlate with the type of object, in that it is not economic to add tin to a weapon which may not be used more than once, and at the same time does not need to be uniformly hardened.

Arsenical-copper

The ancient smith discovered either accidentally or intentionally the advantage of alloying copper with arsenic in the early stages of the history of metallurgy. The outstanding artefacts from Nahal Mishmar are reported to have as much as 12% arsenic. It is worth mentioning that surface analysis was used in determining their composition (Key, 1964, 1578). Also, it must be borne in mind that when a copper-arsenic alloy is cast, arsenic tends to segregate near the surface; this is known as inverse segregation (McKerrell and Tylecote, 1972, 211). However, this hoard stands out from other Palestinian metalwork and it is clearly an intrusive group. It is difficult to believe that these isolated metal objects were a result of the existence of a local metalworking centre in Palestine.

The analyses in this project showed that arsenic was routinely used in the EB and EB-MB periods (see fig. 31). The range of arsenic in the EB age varies between 0.03-3.6% (Cat. No. 27), with an average of 1.66%, while in the EB-MB period, where more objects were analysed, the range lies
between undetected and 5% (Cat. No. 16), with an average of 2.78%. In the MB age, when the use of tin was practised, arsenic was still in use. This could be due to an occasional short supply of the tin. However, the arsenic range varies between undetected and 4.5% (Cat. No. 84) with an average of 1.73%. In the LB age the situation is different, the range is low, up to 1.6% (Cat. No. 59), and the average is 0.85%. All the objects contain above 1% arsenic, and at the same time they contain tin. The only object which can be considered as an arsenical copper is the arrowhead (Cat. No. 59).

**Arsenic-tin-copper**

There are many objects which contain both arsenic and tin. This combination is represented as early as the EB-MB period (Cat. Nos. 10, 76, 115, and 122), also, high arsenic with about 3% tin is shown in the analyses of Cat. Nos. 117 and 125. This type of alloying increased in the MB age, where we found twenty-three items out of sixty-one with arsenic and tin (see fig. 8), while in the LB age eight objects out of twenty-five which were analysed contain both elements. This is a good indicator that in later periods some scrap arsenical copper artefacts were used in manufacturing the tin bronze objects.

**Tin-copper**

In view of the analyses, it is obvious that intentional alloying with tin began to appear in the EB-MB period, which can be considered as an introductory stage to the use of tin bronze, while the MB age metallurgy can be interpreted as a transition period from arsenical copper to tin bronze, where both alloys appeared almost equally in contemporary artefacts. The range of tin in the MB age varies between undetected and 11.5% (Cat. No. 86) and the average is 4.5%. Meanwhile, in the LB age when tin metallurgy was widespread, the range lies between 0.0-11.9% with an average of 6.76%.
The analyses have resolved much confusion concerning the true composition of many artefacts which had just been described as copper or bronze. Not only this, but several objects thought to be copper or copper alloy have proved to be silver (Cat. Nos. 82, 112, 116, 131) and one (Cat. No. 34) was found to be silver-plated.

V.1.2. Fabrication techniques:

Smelting is one of the main processes in the procedure of manufacturing an artefact, casting and mechanical working are the methods used to shape a metal object. The metal has to be melted in order to cast it in a mould.

Excavations at Jericho failed to discover either metal workshops or moulds. Instead, tweezers, ingots, and metal runners were found as an indicator that secondary melting and casting processes could have occurred on the tell of Jericho.

However, casting is a primary stage of metal production, the structure of such a cast artefact is either dendritic or equi-axed. The chisel (Cat. No. 69) is the only artefact which represents such a structure, but other objects showed ghost dendrites which is another indicator of casting. When the ancient smith discovered that copper could be shaped by hammering, he also found out that it could be softened by heating in a fire; this operation is called annealing, the softening being due to recrystallisation. Also, he discovered that hammering the metal gave harder metal; this is known as cold-working. Both examples were practised as early as the EB age in Jericho.

The technology of manufacturing the dagger did not change through the different periods, but in the MB age improvement of the shape and the attachment was achieved. Further cold working or annealing have occurred to cast javelins and arrowheads of the LB age to give them their final shape. Generally, most of the artefacts examined here
have twins either with or without slip bands in their structure. Rivets showed that their structure was distorted due to the excessive cold work.

Individual technological aspects illustrate the level of the skill which the ancient smith achieved. The fabrication of both the stud and the spike (Cat. Nos. 121, 123) showed that the ancient smith of the EB-MB period was aware of the hollowing or raising technique (Pl. 51). Also, arsenic enrichment appeared during this period. A section of the awl (Cat. No. 73) showed a silvery layer of arsenic. An example of arsenic enrichment appeared in a bull from Horoztepe in north-east Anatolia dated to about 2100 B.C.

All the archaeological, technological, and analytical data support the argument that Palestine had a strong metallurgical connection with the north during the EB and EB-MB periods.

In the MB age the fabrication of the toggle-pin was well known in Palestine. An unique decorated head of the toggle-pin (Cat. No. 114) is a good example of the degree of skill in the metallurgy of that time. Besides this, another development took place, which is silver-plating (Cat. No. 34) where the silver coated the arsenical copper metal of the belt fastener (Pl. 58). Such a technique of silver-plating by diffusion bonding was known in Crete at the same time.

V.2. Hardness

The hardness of the metal depends on its mechanical properties which of course are affected by two factors, alloying and work-hardening. One of the main advantages of alloying with arsenic or tin is to strengthen and harden the copper. The hardness of pure copper is about 40HV, and when it is cold-worked this figure is raised to between 85-115 HV (Brewer, 1979, 4). When examples of ancient copper (Cat. Nos. 133 and 136) are tested, they showed 44 HV and 40 HV, but when this type of copper is worked as in
the case of axe (Cat. No. 62) and chisel (Cat. No. 67) this hardness was found to be 97 $H_v$ and 70 $H_v$. The EB age dagger (Cat. No. 1) showed a high figure, 111 $H_v$, due to the work-hardening.

The metal runners, which had not been work-hardened contained arsenic (Cat. Nos. 138, 139), and arsenic and tin (Cat. No. 137). These were tested for their hardness and they showed 43 $H_v$, 72 $H_v$, and 60 $H_v$. Meanwhile, it is known that annealed copper with 3% arsenic gives about 42 $H_v$, and with 10% tin gives 80 $H_v$.

It is understood that mechanical working, e.g. hammering, changes the structure of metal. Besides this, it makes the metal more uniform and has a remarkable effect on its hardness. In the case of a weapon, for example a dagger, the ancient smith used to hammer-harden the cutting edges. An EB-MB age dagger (Cat. No. 10) with 4.3% arsenic, cold-worked and annealed or hot-worked and finally work-hardened, showed a very high hardness, 161 $H_v$. Also, the crescentic axehead (Cat. No. 27) containing 3.7% arsenic gave 137 $H_v$. The relation between the hardness and the percentage of arsenic in all the artefacts measured is illustrated in fig. (32).

It is known that copper with 3% arsenic measures 42 $H_v$, but when it is cold-worked it can measure as much as 206 $H_v$; this depends on the amount of working (Bass, 1976, 13). Possibly the hardness of the examples from antiquity is less than it should be, this depends on the condition of the artefact, and includes the internal oxidation. Also, it is interesting to mention that oxidation attacks more where metal is most worked (Charles, 1968, 280).

Tin gradually replaced the arsenic in alloying with copper. As far as the hardness is concerned, tin has a positive effect on hardening the copper. Daggers (Cat. Nos. 17-21) were examined for hardness, the average of their tin content is 6% and they gave a hardness of an average of 84 $H_v$. A copper with 10% tin which had been annealed would give 90 $H_v$, but if it had been cold-worked then its hardness would be raised between 200-250 $H_v$ (Brewer, 1979, 4).
Fig. 33
As has been mentioned, corrosion in ancient examples has a considerable effect on the measurement of their hardness. However, the javelins (Cat. Nos. 46, 47, and 49) of the LB age have tin in their composition of an average 8.6%, and when they were measured they showed a hardness of an average 114 Hv. This could well be due to the high percentage of tin as well as the excessive cold-work which is illustrated in their structure. The relation between the percentage of tin and the hardness is shown in fig. (33). The decorative items do not need to be hardened, however, the toggle-pins (Cat. Nos. 83, 89, 100, 108 and 110) have an average of 6.7% tin in their content, and they showed an average of 83 Hv when they were examined for the hardness.

V.3. Trace elements

The question of trace elements has always been very important in any analytical programme of ancient metal, but as has been mentioned earlier, the problem of the correlation of ore and metal is not at all easy. However, as far as the trace element study is concerned, some elements are more helpful than others.

Arsenic is not useful in this aspect because it could be an additive or from the source of copper. Also, it is a volatile element which could suffer a considerable amount of loss during the roasting or smelting process.

Antimony and bismuth are usually associated with the arsenic. The scrap metal (Cat. No. 140) of the MB age stands as an isolated result as far as the antimony and bismuth are concerned, due to the high percentage of both elements, 0.5% antimony and 0.2% bismuth in its composition, but always it should be borne in mind, that bismuth is an element which could be segregated during the solidification process.

The presence of high iron suggests that iron oxide (haematite: Fe$_2$O$_3$) was used as a fluxing agent in the smelting process. It is not obvious whether this iron is present in copper as metal, oxide, matte, or part of en-
trapped smelting slag. If there is excess of haematite during the smelting process, this can be reduced, under certain conditions some iron may be reduced to the metallic form, and appeared in the smelted copper (Cooke and Aschembrenner, 1975, 253). However, iron could be highly segregated in the copper matrix, besides this, the solubility of iron in copper is extremely low. In Cat. No. 10 the iron content is 2.3%, this sample proved to be magnetic.

Nickel in ancient metal as an accidental impurity is found more in periods earlier than the LB age. It is often thought that nickel correlates with cobalt, but the occurrence of cobalt here is occasional and low. The highest cobalt is found in Cat. No. 14.

The absence of some elements is sometimes more useful, e.g. tin, this means that a tin-free copper deposit must have been used.

It is also interesting to note that the percentage of lead increased during the MB age, but this has no correlation with other factors.

The silver occurs in variable ranges during the different ages, the highest silver percentage of 0.2% showed in the analysis of the chisel (Cat. No. 69) of the EB age. All the objects that have gold traces in their composition also contain silver, but the opposite is not so.

The zinc content is represented in various ranges, the highest is 0.2% which was shown in the analysis of the rivet (Cat. No. 125), but the presence of zinc traces increases in the LB age. However, this range of traces is still low compared with zinc traces in Cypriot copper.

Nevertheless, it is very dangerous to attempt to relate composition of the artefacts to the copper sources. Besides this, it is obvious that in later periods when scrap metal from different objects was melted together in order to manufacture an artefact, the result of the trace elements analysis for such an artefact would be misleading. So, as far as the problem of the determination of ancient ores which the copper objects were derived from is concerned, there is no solution, it is necessary to treat what can be obtained from the analyses with caution.
V.4. Future requirements

To understand the metallurgy of Palestine, we should consolidate our metallurgical knowledge about the region containing Cyprus, Crete, Anatolia, Mesopotamia, and the Levant where much more work remains to be done. This is because of the movement of metal in ancient times through a wide international trade network. Analyses of ores, slags, and artefacts are still incomplete, apart from which many sites which could help in the reconstruction of the history of metallurgy in the Near East are either still unexplored or unpublished.

This projects is one of the earliest programmes to examine the development of ancient metallurgy of Palestine during the Bronze Age from metallurgical and analytical points of views. Additional analyses are essential, and it is recommended to carry out the sampling of the artefacts before they are distributed among the different contributors.

Feinan in the south of Jordan is a source of copper which was used in ancient time. This site needs further excavation, and the area requires more exploration, which will be intended in the near future.
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