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RESEARCHES IN THE SOUTHERN ARABAH 1959–1990
Summary of Thirty Years of Archaeo-Metallurgical Field Work in the Timna Valley, the Wadi Amram and the Southern Arabah (Israel)

Beno Rothenberg

Director of the Institute for Archaeo-Metallurgical Studies, Institute of Archaeology, University College London, United Kingdom

Thirty years of field work and laboratory studies in the Southern Arabah, the Timna Valley and the W. Amram (Israel) led to a comprehensive picture of ancient copper mining technology and copper smelting from Late Neolithic times to the Early Islamic period. This is the only region were such comprehensive research by an international team, under the directorship of the author, lasting a whole generation, has been carried out. This work represents today the 'textbook' of ancient Near Eastern archaeo-metallurgy. This review is concluded by the description of the Egyptian/ Midianite Mining Temple in the Timna Valley.

1. INTRODUCTION: HISTORY OF RESEARCH AND ITS METHODOLOGY

1.1 During thirty years, beginning in 1959, the 'Arabah Expedition', founded and directed by the present author, undertook extensive archaeological surveys and excavations in the Western Arabah,[1] with special emphasise on archaeo-metallurgical sites (fig. 1). The area investigated extended from the Dead Sea to the Red Sea and from the border of Egypt (Sinai) to the border of Jordan, comprising most of the wadi systems and mountain range west of the Southern Arabah Valley. The results of these surveys changed fundamentally the historical picture of this region and of the southernmost part of the Land of Israel.[2]

Previous to our systematic field research in the Arabah, several explorers and archaeologists had visited the region and undertaken partial surveys, especially of the southernmost part of the Arabah, and also excavated at Tell el-Kheleifeh, a site on the shore of the Red Sea. In 1845, the British explorer J. Petherick (1861:37) identified copper-smelting slag in Timna (Wadi el-Mahait). In 1907, A. Musil (1908:185–187) found there 'remains of dwellings'. In 1934, F. Frank (1934: 233–234) recorded seven copper-smelting sites at Timna (W. Mene'iyeh),[3] which N. Glueck again visited in 1935. Glueck first dated the pottery found at sites of Timna to the Iron Age I and II; in 1940 he attributed the copper working sites of Timna to King Solomon, calling the area 'King Solomon's Mines'

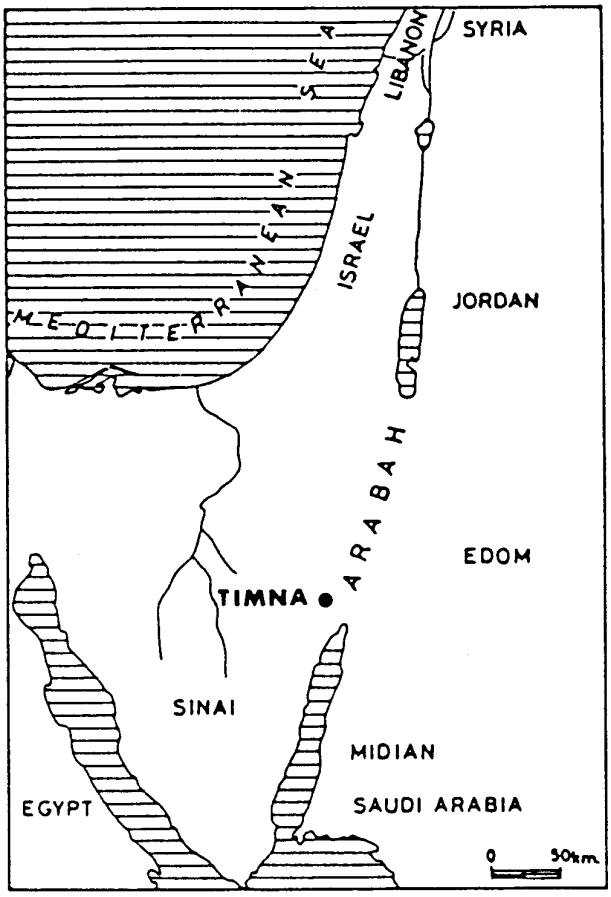

Fig. 1. Map showing location of the Arabah Rift Valley and Timna.

(Glueck 1935, 1940, 1959). Following Glueck's publications, a historical picture was generally accepted which saw the Arabah under the rule of King Solomon and the Judean kingdom and as the location of a huge copper industry, founded by King Solomon on both sides of the Arabah. The main focal point was a 'huge copper smelter' at Tell el-Kheleifeh, on the coast of the Red Sea, which Glueck had also identified as the Biblical port of Ezion-geber in the Gulf of Eilat-Aqabah.

1.2 The surveys of the 'Arabah Expedition' showed that the Arabah is indeed a distinct geographical unit, but not so from the historical point of view. Whilst during the prehistoric and protohistoric periods, a line of settlements and camping sites run all along the Arabah – with occupational clusters in the vicinity of the mining areas – during the later, historical periods (Late Bronze-Iron Age) the Southern Arabah faced towards Egypt and the Northern Arabah was under the rule of the United Monarchy and the kingdom of Judea or Edom. In both parts of the rather inhospitable Arabah Valley were only very few permanent settlements, located at the rare sources of drinking water. However, the picture changed drastically in the vicinity of the copper ore deposits on both sides of the Arabah, where clusters of settlements and camps of miners and copper smelters from the Late Neolithic Period to Medieval times were located.

The major mining centre of the Northern Arabah was in the region of Feinan, in ancient Edom (Hauptmann *et al.*1985; Hauptmann 1989). The main mining areas of the Southern Arabah were located in the Timna Valley (W. Mene'ijeh) and Wadi Amram (W. Amrani) (Rothenberg 1962, 1972, 1988, 1990). Near all of the copper ore deposits of the Arabah, remains of mining and copper smelting of identical prehistoric periods were discovered, but during historical times the two parts of the Arabah had a quite different history (Rothenberg 1971).

1.3 As mentioned above, our investigations of the Southwestern Arabah begun more than thirty years ago and were initially aimed at finding remains of ancient mines and smelters and, especially, their dating. This seemed to us imperative because before our investigations, no ancient mining relics had ever been recorded in the Timna region, and also because during my preliminary inspection of the smelting sites at Timna, pottery sherds of different kinds and periods were found, which had not been reported before from the Southern Arabah. The results of this initial phase of our work in the Arabah arose difficult problems concerning the identity and date of this pottery and caused fundamental disagreements with Israeli and USA 'Biblical archaeologists'. Already in 1964, as a result of our first excavation in a smelting camp (Site 2) in Timna, we doubted the Solomonic date and the Israelite identity of the pottery[4] – and as consequence also of the copper industry of the region as 'King Solomon's Mines' – and this view was hotly contested (see detailed review in Rothenberg 1988:1–18). These arguments came only to an end some years later, when, in 1969, we discovered in the midst of the large smelting camps of Timna an Egyptian New Kingdom mining temple (Site 200) and in its strata, dated by hieroglyphic inscriptions and cartouches, we uncovered *in situ* the same kind of pottery as found in the smelting camps. This discovery proved beyond any doubt that the major mine workings of the Southern Arabah were developed and operated by the Pharaohs of the Egyptian New Kingdom (Rothenberg 1990, 1988, 1972).

1.4 Parallel to the archaeological field work, we undertook systematic research of the smelting installations and production debris uncovered in the smelting camps, like different types of ore, slag, furnace fragments, tuyeres, and other metallurgical remains, in order to understand the extractive processes, which at the beginning of our work were rather difficult to explain.

Already at the beginning of my work in the Arabah did it become clear to me that in order to overcome the many scientific problems presented by the metallurgical remains, it will be necessary to enlist the cooperation of various experts. The main problems were caused by the fact that very little archaeological and archaeometallurgical research had ever been done at mining and smelting sites. Starting in 1964, the 'Arabah Expedition' excavated smelting camps in the region of Timna with the participation of A. Lupu, R.F. Tylecote and H.G. Bachmann. In the years 1974–1976 the first systematic excavations in the ancient mines of Timna were undertaken in collaboration with the German Mining Museum Bochum. At the same time a very detailed geomorphological survey was made in the mining region ('Model Survey Area') by the geologists A. Horowitz, Tel Aviv University and A. Hauptmann, Bochum. We also greatly benefited from the professional assistance of J. Bartura and M. Preis, geologists of the modern Timna Mines, and later on by A. Segev and M. Beyt, of the Israel Geological Institute, Jerusalem. The metallurgical research demanded of course a specialized group of scientists and, besides Lupu, Tylecote and Bachmann, who joined the 'Arabah Expedition' already in its early days, we also had the important research partnership of Peter Wincierz, Menahem Bamberger and John Merkel, who substantially advanced archaeo-metallurgy by their seminal experimental research on copper smelting in Timna furnaces and producing a mathematical model of the processes (in Rothenberg 1990).

1.5 During the years of field work, our research methods gradually improved. At the beginning our surveys extended over limited areas with the aim to find ancient remains. Each day additional sites were found, which added more details to the complex picture of a huge industrial set up in the Timna Valley. After several years of work we published a first summary of our results (Rothenberg 1962). Already at this stage of our

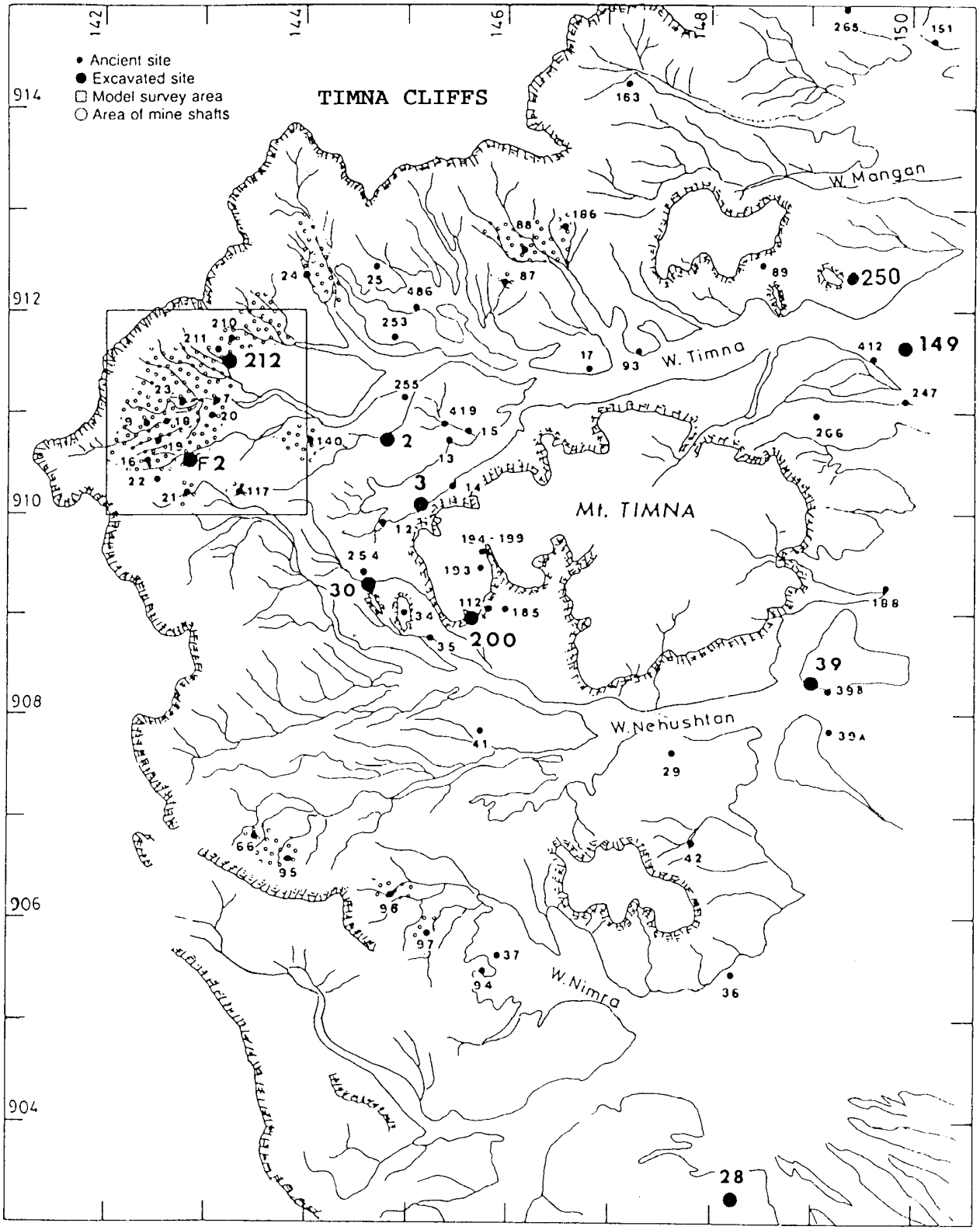

Fig. 2. Survey map of the Timna Valley and its sites.

investigations in Timna, many questions arose concerning the archaeological and metallurgical concepts of N. Glueck, which had been accepted by the archaeological world as unquestionable facts of history and technology (f.i. Albright 1956:126–128). According to Glueck, 'King Solomon's Mines' in the Arabah provided 'roasted ore' as raw material for the huge copper smelting works at Ezion Geber=Eilat (Tell el-Kheleifeh). Our first doubts arose when we found quite a lot of metallic copper pellets in the slags of Timna, which meant that copper was indeed produced there, and when the investigation of the ores of Timna made it clear that such ores would not need any roasting in preparation for their reduction to copper. In my first

Timna publication (Rothenberg 1962), I therefore had also to deal with the interpretation by Glueck of his excavations at Tell el-Kheleifeh, which for numerous reasons I found very difficult to accept. Following this publication, Glueck withdrew his metallurgical interpretations and accepted my suggestion that Tell el-Kheleifeh was not at all connected with copper production, but was a fortified settlement (Glueck 1965). According to a recent study of the pottery from Tell el-Kheleifeh, it was indeed an Edomite settlement of the 8th to 6th century BC (Pratico 1983).

1.6 Continuing our systematic field work, we constantly extended the borders of our survey area and because of this change of scale, and the increasing number of sites and features recorded by us, we had to revise several of our previous concepts and interpretations. For instance, at the beginning of our survey we discovered many open shafts whith rope-marks on their rim, similar to the marks often found on the rims of water cisterns. We therefore interpreted these shafts as cisterns for the collection of rain water. However, since during our later surveys we recorded a considerable number of such shafts, part of same at locations which would have been highly unsuitable for the collection of rain water – like on top of hills or high up in the wadi walls – we had to look for an alternative explanation of these features. A convincing explanation was only found in 1974, when our excavations provided the evidence that these features were in fact mining shafts.

1.7 After the conclusion of the major series of systematic excavations of sites in the Timna region, and the consequential, decisive changes in our understanding of the cultural history and archaeo-metallurgy of the Arabah sites, we undertook in 1982 an additional detailed survey of the whole of the Timna region, including the area of Beer Ora (Site 28) and the W. Amram (Sites 33 and 38), south of Timna. This survey was based on an aerial survey and low level aerial photography. This new survey method enabled us to map the whole region and its sites on the scale of 1:2000. In fact, the new survey was recorded on enlarged aerial photographs, which made it possible to identify even very small features and take into account also the geomorphological aspects of the sites. During this final survey we prepared new plans of all the archaeological features and mapped all traces of ancient roads and tracks.

1.8 Based on the results of our surveys we drew up a detailed, long-range plan for systematic excavations at the smelting sites of the region. Our objectives were the clarification of the copper smelting processes, the technological lay-out of the copper smelting camps, and, of course, the archaeological stratigraphy as the base for dating these sites. These systematic excavations laid the foundations for the metallurgy of copper in the Arabah (Rothenberg 1990) and established the chronology of the Arabah mining and smelting sites. In fact, the Timna research project of the 60th and 70th was seminal for the establishment of a new branch of techno-historical and archaeological research: archaeo-metallurgy, i.e. the investigation of the ancient processes of the production and working of metal and the impact of metal-related developments on human history. In other words: How man made metal and how metal contributed to the shaping of Man and his history.

The excavation of a smelting site requires special excavation techniques, the main aim of which would be the reconstruction of metallurgical 'production units' in their respective chronological frame. Through gaining experience in Timna we developed criteria for the identification of the function of the different kinds of process remains, like smelting slag or melting-casting slag, furnace fragments and lining materials, pits and areas for the preparation of raw materials and fuel. Parallel to this archaeological work, we undertook systematic analytical and metallurgical studies of finds and installations, which led to the experimental reconstruction and simulation of the processes in Timna type furnaces, using ores from the Timna mines (Rothenberg, Tylecote and Boydell 1978; Merkel and Bamberger-Wincierz, in Rothenberg 1990).

1.9 The first seasons of excavations in the Timna mines, discovered by us in 1959–60, were carried out in 1974–76 by the 'Arabah Expedition' with the German Mining Museum Bochum. (Conrad and Rothenberg 1980). Ivan Ordentlich, staff member of the 'Arabah Expedition', was in charge of the archaeological aspects of the excavations in the mines. In 1990 a thorough reinvestigation of the Timna mines, and new excavations in Timna and the Wadi Amram, were undertaken in collaboration with the Royal School of Mines, Imperial College London and the Peak District Mining Museum, Derbyshire, England (Rothenberg and Shaw 1990a; Rothenberg and Shaw forthcoming; Willies 1990). The investigations of the mines used up-to-date survey methods as employed in modern mining, including detailed surveying of the underground galleries and mine-shafts. The different mining tool marks left by the ancient miners on the walls of the underground workings, as well as actual mining tools of different periods found in the mines, were of decisive significance for the understanding of the mining technology and, especially, for the dating of the mine workings.

In 1976 we made an intensive, detailed survey of a 'Model Area' in the mining region at the foot of the Timna Cliffs, where most of our mining excavation were undertaken. This 'Model Area' extended over 4 km^2 and contained numerous mining remains of different ages. However, many of these remains were very difficult to understand in the present landscape. It appeared that there is a close connection between the mining relics and topographical features of different ages. According to these findings and their location in the present landscape it was obvious that since the

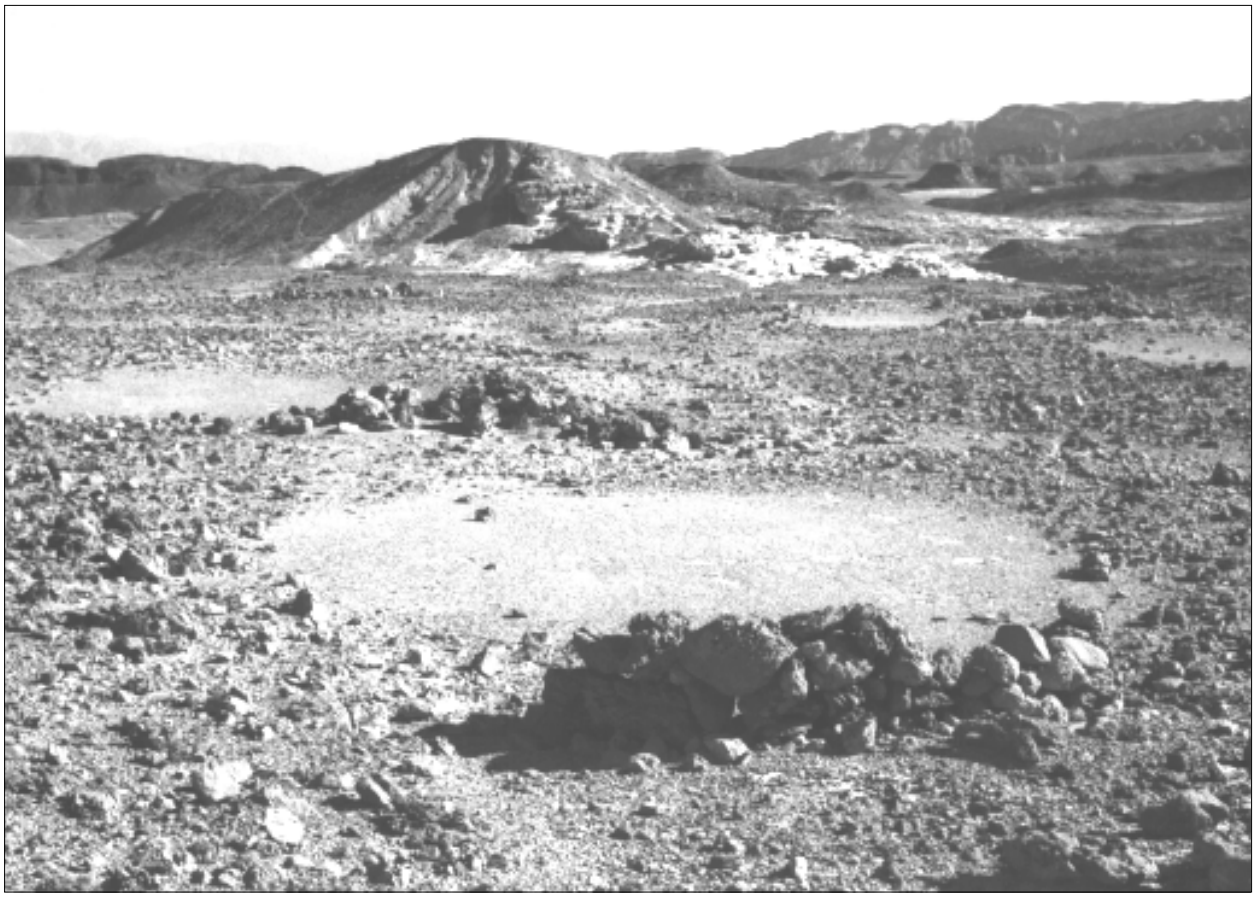

Fig. 3. 'Plates' (silted-up mining shafts).

ancient mining activities drastic changes of the topography had occurred. In order to understand the latter a detailed geomorphological survey of the 'Model Area' was made by A. Horowitz and A. Hauptmann, which explained the formation of the wadis and their destruction, the building by floods and wind erosion of terraces and other features of the landscape – geomorphological changes accompanied by the destruction, partly or even almost completely, of ancient mine workings. By this method, used for the first time in Timna for the investigation of ancient mining relics, it became possible to establish a relative chronology of the mines on the background of the development of the landscape. With the help of this new methodology we succeeded, during the continuation of our work in the mining area, to identify mining remains of most of the periods represented by the smelting and habitation sites in the Southern Arabah (Conrad and Rothenberg 1980).

1.10 We also had to develop new research methods in connection with the ceramic finds from the mines and smelting sites of the area, obviously of critical importance for the dating and identification of these sites, which had been the main subject of the prolonged arguments about 'King Solomon's Mines'. Several groups of pottery, different from each other in character, potters techniques and raw materials, created a difficult problem, mainly because no similar pottery had been found at any of the well-dated sites of the Southern Levant. For some of the pottery types we could not find any comparisons outside the Arabah region and the search for really comparative pottery in Palestine on both sides of the Jordan was not successful. For this reason we turned to the petrographic investigation of the pottery, i.e. the mineralogical-geological study of the paste and temper, the potters techniques and firing methods, in comparison with pottery from near as well as farer regions and their geology.

In the excavations of the smelting camps of Timna three completely different kinds of pottery were found together in the same archaeological strata: roughly hand-made 'Negevite' vessels of the kind found in the settlements of the Central Negev, ordinary, plain wheel-made vessels, and vessels of simple shapes, mainly small bowls and jars with a flat base, but with complex bichrome decorations on the inside and outside. Petrographic investigations provided the evidence for a very close relation between Timna of the Egyptian New Kingdom and the region of Biblical Midian, Northwest Arabia (Rothenberg and Glass 1983), and with the Late Bronze Age-Iron Age settlements of the Negev mountains (Glass, in Rothenberg 1988). The dating of these three contemporary kinds of pottery was based on the finds of Egyptian hieroglyphic inscriptions and Pharaonic cartouches along with the pottery

in the Timna Mining Temple, dating from the late 14th to the middle of the 12th centuries BC (Rothenberg 1988).

1.11 The pottery and flint implements of the prehistoric and protohistoric periods found in the sites of the Arabah, presented far more difficult problems of identification and dating than the finds in the New Kingdom sites of Timna. The petrographic study of all the sherds found by us in the Negev, the Arabah and Sinai, in comparison with the pottery from adjacent regions, like Egypt, Jordan, Northwest Arabia and Palestine, showed the existence of an indigenous population, with its own culture, in the arid regions of the Arabah, the Southern Negev and the Sinai, and wide areas of the Arabian Peninsula (Hejaz). This autochthonous culture developed parallel to the cultural development of the neighbouring fertile territories and at its own speed and direction, most of the time without significant contacts with the surrounding cultures. At some stage, apparently in the Late Neolithic Period, metallurgy appeared in this region, either as an indigenous development or by way of intrusion of metallurgical know-how or of people with, at least, incipient metallurgy. Meticulous studies of the ceramic and metallurgical finds from the region showed that it is possible to distinguish between three discrete phases in the material and technological development of the region, which are of decisive chronological significance. Consequently, it became clear why the use of the chronological terminology of the Southern Levant or Egypt for the characterisation of the developments in these isolated, arid territories, had led to distortions, misunderstandings and futile arguments (Muhly 1976, 1984; Rothenberg 1990b). For this reason we proposed lately (Rothenberg and Glass 1992; Rothenberg and Merkel 1995) to use a different, local chronological terminology: Sinai-Arabah Copper Age – Early, Middle and Late Phase, approximately parallel to Late Neolithic to Early Bronze I (6th–5th and 4th millennium BC), Early Bronze II–III (*c.* 3000 BC to 2200 BC), Early Bronze IV (2200 BC to 2000 BC), in the Archaeology of the Southern Levant.

1.12 The field work of the 'Arabah Expedition' was concluded in 1990. In 1988 and 1990, the first two volumes of the final publication *Researches in the Arabah* were published, two more volumes are now in preparation. In the following we present the first comprehensive, up-to-date review of our work in the Arabah in the years 1959–1990.

2. THE TIMNA VALLEY AND ITS SURROUNDINGS: COPPER ORES, MINES AND SMELTING SITES (FIG. 2)

2.1 The Timna Valley (previously Wadi Mene'ijeh) is located about 30 km north of the shores of the Gulf of Aqabah-Eilat. It is a large, semi-circular morphological formation, created by erosion. It is about 70 km^2 and is open at the east, facing the Arabah Rift Valley. It contains four wadis, running from the Timna Cliffs (approx. 300 m high) into the Wadi Arabah. At the foot of the Timna Cliffs, the whitish sandstone strata ('Avrona-Amir') of the Lower Cretaceous 'Kurnub Group' (Segev *et al.* 1992:11–12, fig. 3) contains nodules of copper ore consisting of up to 55% chalcocite and malachite. Another type of copper ore, belonging to the 'Timna Group' of the Lower Cambrian, consists mainly of chrysocolla, malachite and plancheite. These copper ore deposits were mined at Timna in ancient times.

In this region of Timna many relics of ancient mining were discovered, which could be grouped into three discrete but functionally interconnected major groups: 1) deep, vertical mining shafts leading down to the mineralized formations; 2) horizontal galleries, spreading out in the copper ore bearing whitish sandstone formation; 3) round, flat depressions in the ground, which we called 'Plates' (fig. 3), their diameter 2–6 m, which for many years were the subject of professional discussions between geologists and archaeologists – coming to an end only after our excavations of several 'plates' in 1976. As mentioned above, these 'plates', most of which were located on the conglomerate slopes overlaying the copper-bearing sandstone strata, were in fact mining shafts, filled in with windblown and water-carried sand.

By systematic excavations of mining remains we succeeded to reconstruct the technology of the ancient mines according to their chronology – a research project which contributed a great deal of new information to mining history, since such sophisticated techniques had previously be known only from Roman mines in Europe.

2.2 In 11 camp sites in the Timna Valley, located outside the actual mining region and mainly at the west side of Mt.Timna, large slag heaps provided the evidence for intensive copper smelting. These sites date mainly to the times of the Egyptian New Kingdom (the Late Bronze Age-Early Iron Age of the Southern Levant). In the actual mining region of Timna, one small smelting site, Site F2, was discovered, dated by its pottery to the Late Pottery 'Qatifian' Neolithic Period.[5] A later, Chalcolithic copper smelting installation, Site 39, and a smelting site, Site 149, of the Sinai-Arabah Copper Age – Late Phase (approx. Early Bronze Age IV), were excavated at the eastern fringes of the Timna Valley. Further north, in the estuary of the Wadi Timna, at the edge of the Arabah, we excavated a copper smelting site of the Sinai-Arabah Copper Age – Middle Phase (approx. Early Bronze Age II–III). South of the Timna Valley, at Beer Ora (Site 28), a copper smelting centre of the Roman to Early Islamic periods was excavated. In the Wadi Amram, about 9 km north of Eilat, copper mines were discovered which operated during the same periods as the Timna mines and we excavated there a large mining enterprise of the Roman

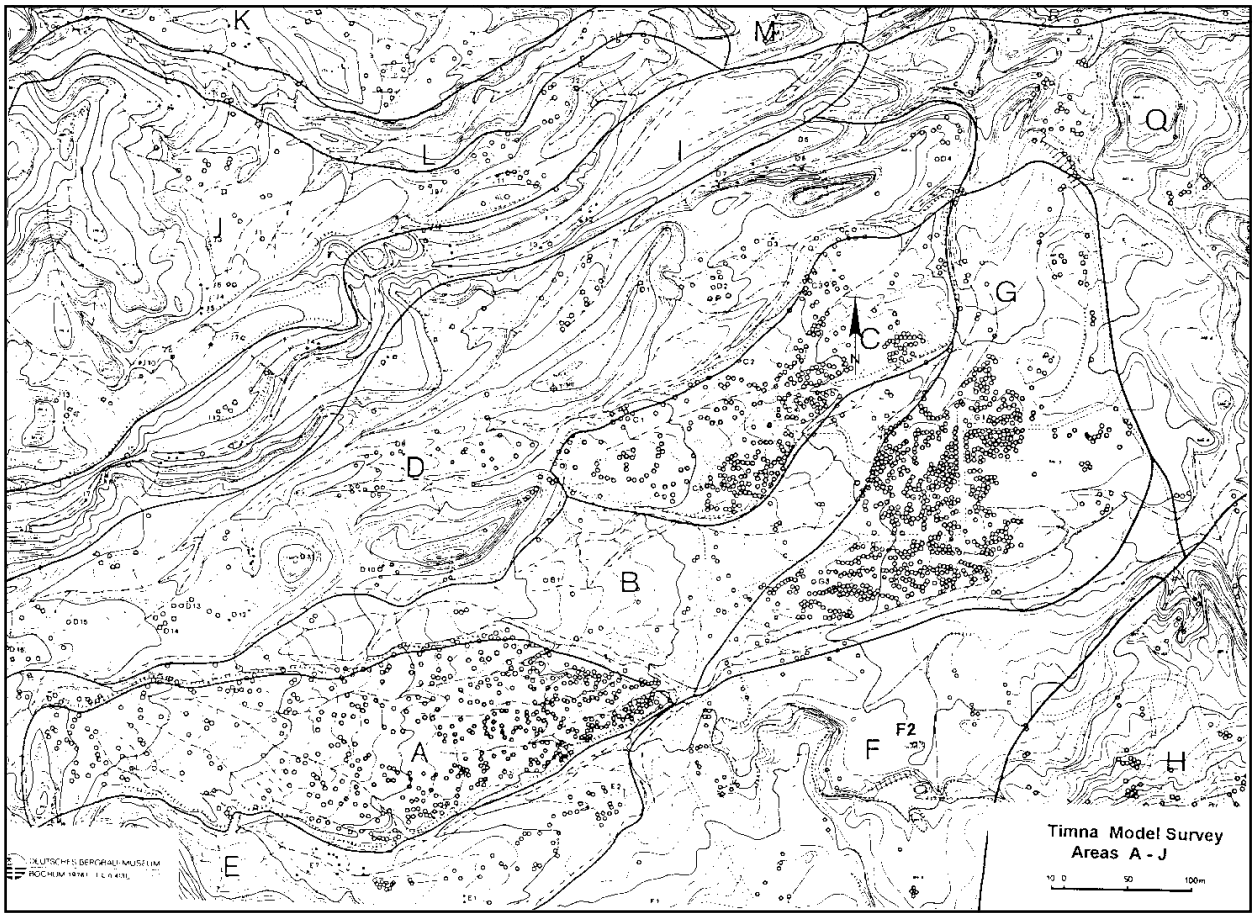

Fig. 4. Map of Timna Model Survey, Areas A-J.

and the Early Islamic periods. In the Wadi Amram we also discovered a large copper smelting and habitation site of the Egyptian New Kingdom, where also some Early Islamic copper smelting took place.

3. THE BEGINNINGS OF METALLURGY IN THE ARABAH

In the survey of the 'Arabah Expedition', habitation sites, camping sites, and burials of the Pre-Pottery Neolithic B Period were discovered, mostly related to roads and water sources (Rothenberg 1967). Remains of this period were also found inside the Timna Valley and we assume that during this period people visited Timna to look for beautiful minerals, like malachite and plancheite, widely used at that time for pigments and jewellery. At least one similar site, Site 560 on our Sinai Survey map (Rothenberg 1979:112), is known in the Wadi Ahmar in Southern Sinai (Currely, in Petrie 1906:239–140), where in the lowest stratum of our excavations a substantial occupation layer was uncovered, with evidence for working copper ores (malachite and azurite) from the nearby copper ore deposit, and, together with the latter, PPNB flint implements. In the layer above, copper smelting had taken place during the Sinai-Arabah Copper Age – Middle Phase (approx. Early Bronze Age II). Here remains of a stone-built smelting furnace (Kingery and Gourdin 1976) were uncovered and around it the earliest tapped slag ever found in the Sinai.

The beginnings of copper mining and smelting in Timna left only very few traces. It appears that at first, copper ore nodules were collected at the surface. Superficial pit-mining took place where copper ores could be seen stuck in the conglomerate. Some areas in the mining region at the foot of the Timna Cliffs were found covered with very dense clusters of irregular 'plates' (fig. 4), quite different from the filled-in mining shafts of the New Kingdom, mentioned above. Trial excavations proved that these areas of 'plates' were remains of pit-mining in the conglomerate containing copper ore nodules. There were also shallow, roundish hammer-marks on whitish sandstone outcrops, which probably relate to this earliest stage of mining. Next to one of such early mining sites, a grooved mining-pick (fig. 5) was found, the like of which has been found at many of the earliest metal mining sites of the Old World. This is the earliest mining tool known so far. All over the ancient mining region of Timna and the Wadi Amram, flint objects, fragments of prehistoric mace-heads and some pottery sherds, were found, which seem to belong to the early stages of the Sinai-Arabah Copper Age – Early Phase (Late Pottery Neolithic-Chalcolithic period, 6th-5th millennium BC).

Fig. 5. Grooved mining-pick, the earliest mining tool from Timna.

In Area F, next to the pit-mining in Area G, a unique smelting location was found, called 'Site F2' (fig. 6), which represented the beginnings of metallurgy in the region. It is the only smelting site with metallurgical debris, working tools, flints and pottery, ever found in the mining area of Timna. In fact, it is the only prehistoric smelting site found inside the Timna Valley, since all other early copper smelting sites were located in the Arabah, outside of Timna, near sources of water and firewood. Site F2 was in fact only a concentration of nut-sized, crushed slag lumps, covering an area of about 20 m^2, in the middle of which stood two large, oval-shaped stone mortars (fig. 7), reminiscent of similar stone tools at Neolithic sites. Among the slag were also hammers made of local gabbro.

The slag of Site F2, which showed numerous inclusions of unmolten or half-molten ores, as well as lumps of solid quartz, was highly viscous. For this reason, much of the metallic copper, which had been reduced

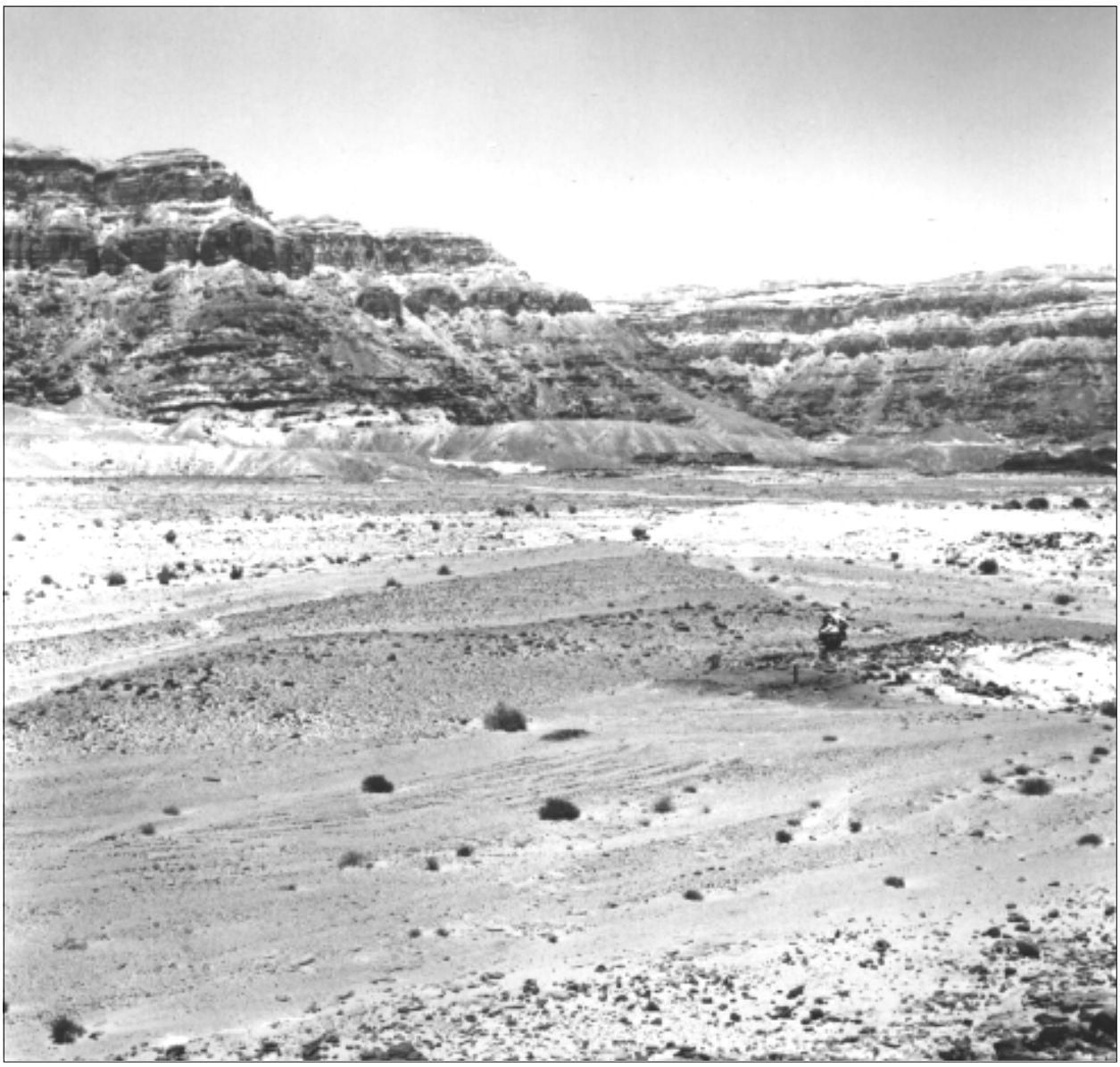

Fig. 6. Site F2 (the black spot indicates the major slag concentration).

Fig. 7. Neolithic stone mortars at Site F2.

already at a relative low temperature (700– 800°C), did not become separated from the slag and had to be manually extracted by crushing the slag. The slag at Site F2 was indeed not yet a 'slag' in the true sense of this term, i.e. a molten mixture of silicates (with or without oxides, etc.), but a kind of 'furnace conglomerate' representing a very primitive attempt to produce copper (Bachmann 1980:108).[6] Fluxing was unknown in this period, though the ore samples, found among the slag of Site F2, showed that not very common, iron-containing copper ore nodules, easily identified by their reddish, black and green colours, were intentionally selected and used in the smelting charge. This find at Site F of partly self-fluxing ores, strongly suggested that the Neolithic metallurgists did indeed realize the importance of the presence of the red-black-green ingredients in the ore – and smelting charge – for a more efficient smelting process (Rothenberg and Merkel 1995:1–7). The 'slag' at Site F2 was the most primitive slag found in the Arabah and represents the earliest stage of metallurgical know-how found anywhere.

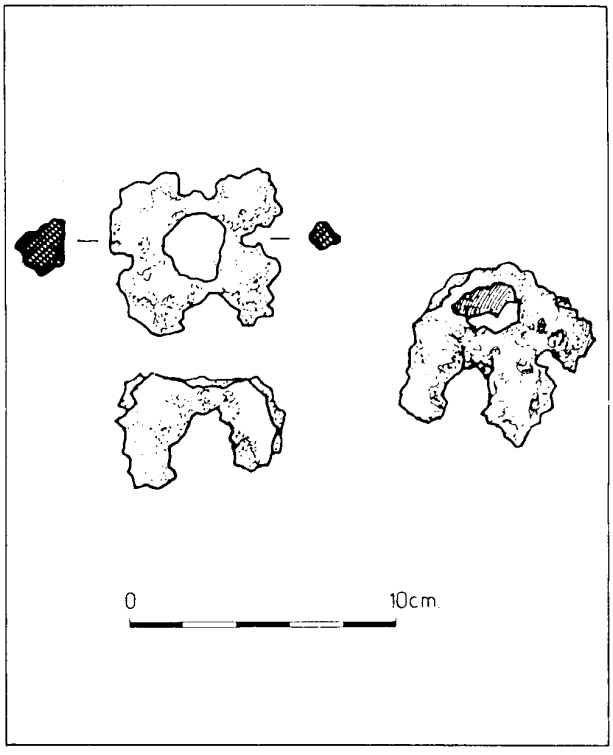

Fig. 8. Restored tuyere from Site F2.

In spite of the fact that the site was excavated to bedrock, we did not find any smelting installation *in situ.* However, we found slagged sand lumps, which provided the evidence that smelting took place in a shallow depression in the sandy soil, with the use of simple bellows. We assumed that the bellows of this period were made of goat skin, similar to the skin-bellows still used by the bedouins in many parts of the Near East. At Site F2, fragments of clay tuyeres were found, which could be reconstructed (fig. 8). This is the earliest tuyere ever found anywhere.

Among the finds at Site F2 were sherds of poorly fired, black and gritty, apparently coil-made pottery which contained a large quantity of vegetal temper and coarse grits, indicative for the 'Qatifian' Late Pottery Neolithic period (Goren 1990:101, 103; Gilead 1990; Gilead and Alon 1988) .

The metallurgical finds at Site F2 indicated a primitive smelting technology, typical for the very first steps in metal production from ore. These steps took place not in the Chalcolithic period, as believed so far, but already in Neolithic times, in the 6th–5th millennium BC.

4. THE EARLIEST UNDERGROUND MINING AND CHALCOLITHIC COPPER SMELTING

4.1 The copper ore nodules were mostly found as narrow veins of about 5–15 cm, but occasionally they were found filling a much larger space. Since this mineralization was mainly underground, the ancient miner had to find ways, fitting his technological facilities, knowledge and experience, to locate and extract the ore.

At Site 212, the copper ore bearing whitish sandstone outcropped on the surface. No wonder, therefore, that numerous ancient mine workings were found in this area: open, vertical mine shafts and a large number of 'plates' on hills, slopes, terraces and also in wadi-beds, and openings to horizontal galleries in the sides of narrow wadis. Our excavations of 1974– 1976 were also mainly carried out at and near Site 212.

Since there were obvious geomorphological differences in the location of these mining relics, we chose mine workings for excavation according to their geomorphological location, established by our geomorphological survey, mentioned above. We took in consideration the clearly recognisable, drastic erosional changes of the topography, including the recent formation of wadis, which often had cut through underground galleries and exposed same in pairs on opposite sides of the same wadi or canyon, sometimes at several levels, one above the other. This enabled us to identify and excavate workings of different mining technologies and of different periods.

Fig. 9. Chalcolithic, ring-shaped, shafted mining-hammer.

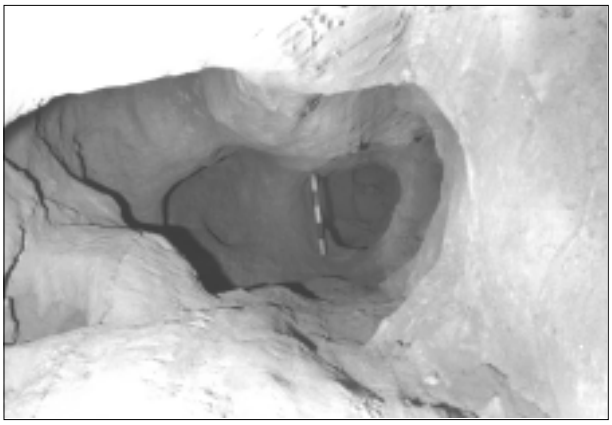

Fig. 10. Chalcolithic underground mine workings.

4.2 In the centre of Site 212, on a flat hilltop in the whitish sandstone formation, a shallow 'plate' was located and around it several roundish or square, shafted mining-hammers, i.e. hammers with a bi-conic perforation for a shaft (fig. 9),[7] made of local pebbles. Such stone implements had not been found previously in the Timna Valley.[8] Excavating this 'plate', a roughly hammered out vertical opening was found, with irregular steps in its wall. At its lower end it took the shape of a roundish 'shaft' of about 1 m diameter, leading into a large, irregular cavity (fig.10), partly filled by wind-carried sand. This was the most primitive underground copper mine, Mine T on our map, ever discovered in the Arabah.

The workings spread out in the shape of very rough, irregular galleries and it was obvious that the ancient miners had just followed the veins of copper mineralization, creating thereby an underground mine on two different levels. We excavated most of Mine T (fig. 11) and found three more openings to the surface, apparently for hauling out the ore and/or for ventilation. On the walls of the galleries were numerous roundish, shallow tool-marks. Shafted hammers, found in the same galleries, were obviously the mining tools which left behind these typical tool-marks.

In Mine T a number of pottery sherds and flint implements were found, datable to the later part of the Sinai-Arabah Copper Age – Early Phase (Chalcolithic-Early Bronze I) (Conrad and Rothenberg 1980: Abb. 195–196; Rothenberg and Glass 1992). This was the earliest copper mine in the Timna Valley representing the beginnings of underground 'shaft-and-gallery' mining, with 'shafts' as mine entrance, for ore transport, ventilation and, probably, also for light, a technology which in later times gradually developed to sophisticated shaft-and-gallery mining, still the principle of mining today.

4.3 The era of the earliest copper production in the Southern Arabah, i.e. the Sinai-Arabah Copper Age – Early Phase, extended over more than two thousand years, from the 6th to the later 4th millennium BC. During this time span, metallurgy developed from its most primitive beginnings, like at Site F2, to a much better developed technology, based on a better understanding of the nature of the copper ores, generations of experience with the preparation of a well-balanced smelting charge, and the development of the smelting installation from a hole-in-the-ground and a pair of skin-bellows to a partly stone-built furnace with efficient bellows ventilation. However, the copper production of this period still remained at the level of a simple 'cottage industry', producing copper at the scale of kilograms and not of tons, as in later, historical times.

Site 39, a copper smelting site of the later Sinai-Arabah Copper Age – Early Phase (Chalcolithic-Early Bronze I), was discovered at the eastern fringe of the Timna Valley, and excavated in 1965[9] (Rothenberg, Tylecote and Boydell 1978). The site consists of a habitation and workshop area (Site 39a) at the foot of a hill, east of the modern Timna Mine, and a smelting furnace surrounded by slag, Site 39b, on top of this hill.

At Site 39a (fig. 12) was an enclosure-like, circular string of small workshops, its diameter about 25 m,

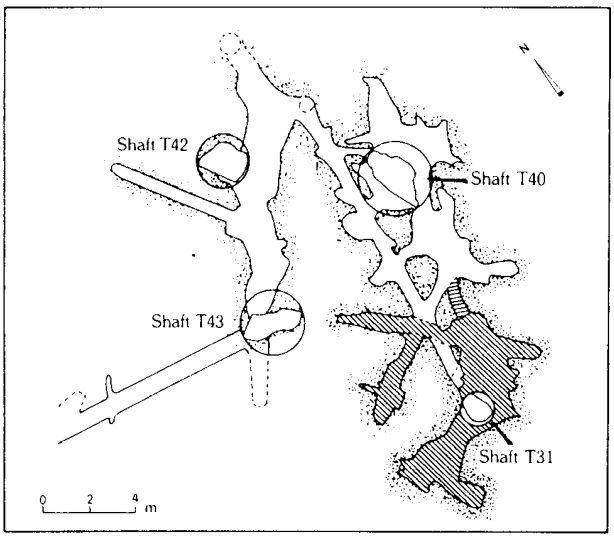

Fig. 11. Chalcolithic-EB I mine (T). The shaded section is the upper level. Access was initially through shaft T31.

Fig. 12. Chalcolithic workshop and habitation, Site 39a.

Fig. 13. Chalcolithic copper smelting furnace – Site 39b.

where different stone tools and lumps of copper ore indicated that a copper smelting charge was prepared here. Next to this workshop area we excavated a circular dwelling, built of rough fieldstones. There were two additional habitation structures, which could not be excavated.

A concentration of broken slag lumps on top of the hill, Site 39b, right above the workshop at Site 39a, indicated a smelting location and during its excavation a smelting furnace was uncovered (fig. 13). It was a simple hole-in-the-ground, reinforced by a low superstructure of small stones around its rim. Around this furnace, on a hard working surface and right up to the furnace, lay furnace fragments – slagged stones and slagged lumps of soil, flint implements and sherds of the same type as found below, in the habitation and workshop of Site 39a.

The flint implements and pottery sherds uncovered in the excavation of Site 39a and b, dated the site to the later Sinai-Arabah Copper Age – Early Phase (Chalcolithic–Early Bronze I), contemporary with the Mine Site 212 T (Bercovici 1978:16–20, see also Rothenberg 1990b: 9–12).

The slag found dispersed around the smelting furnace at Site 39b was more solid and dense than the primitive slags ('furnace conglomerate') of Site F2, but was still rather inhomogeneous and highly viscous. It was defined (Bachmann 1978:21–23) as 'furnace slag', contrary to 'tapping slag', i.e. due to insufficient retention time of the smelting charge inside the furnace and the temperatures achieved with the simple bellows, no free-flowing slag was formed in the furnace. However, the chemistry and phase composition of the slag (Bachmann *ibid.*: table 1) proved that the smelters of Site 39 already had a better control over the smelting process and understood that fluxing with iron ore was necessary in the production of copper. Yet, their metallurgical knowledge was still at a stage of 'trial-and-error', not yet sufficient to put together a well-balanced smelting charge, which gave rise to slags of widely different compositions. Apparently, they also did not have efficient enough bellows to reach the smelting conditions in the furnace, necessary for the separation by gravitation of the copper from the semi-liquid slag and the formation of some kind of ingot at the furnace bot-

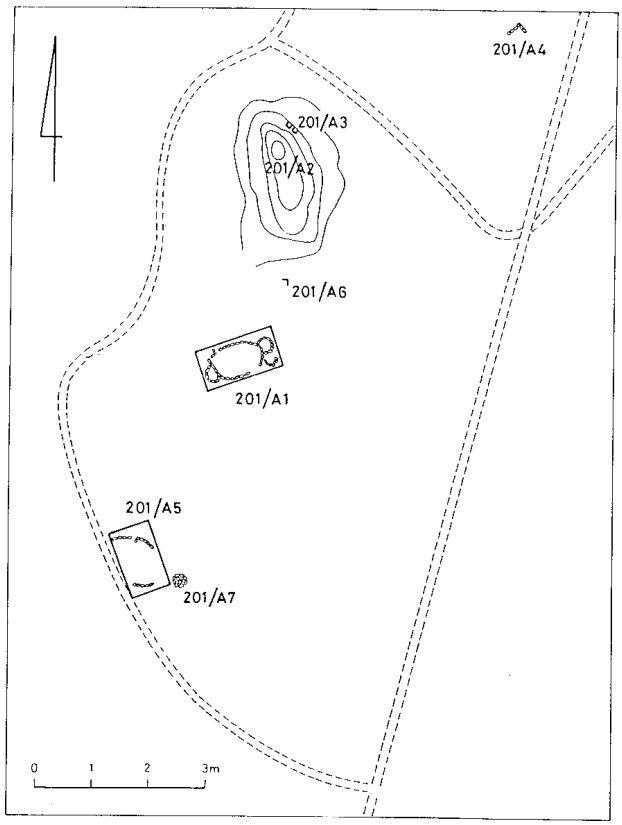

Fig.14. Site 201A – site plan of excavations.

Fig. 15. Entrance to mining 'cave' Site 250A. To the right, the ore dressing platform, partly covered by rock fall, with a large mineralized boulder.

tom. The copper prills remained, therefore, entrapped in the slag and it was necessary to let the furnace cool down, to rake out its contents and to crush it all in order to extract the copper (Rothenberg 1990:5–8). The furnace slag of spinel type[10] (Rothenberg 1990:69; Bachmann 1980:108– 110) from Site 39, was typical for the slags of all the Chalcolithic sites found in the Arabah (Rothenberg and Merkel forthcoming).

Following the initial investigation of the smelting debris from Site 39, Tylecote and Boydell (1978) undertook a series of smelting experiments based on Timna smelting furnaces and their slags. These experiments showed that already at this early stage of the development of metallurgy, when the 'furnace' was a simple hole in the ground and a pair of bellows, a great deal of experience was required to achieve even the quality of the slag and the metallic copper produced at Site 39 in the Chalcolithic Period.

The smelting installation at Site 39b is the earliest, Chalcolithic copper smelting furnace found *in situ* (Tylecote 1962:26; Raymond 1984).[11] Together with the metallurgical workshop of Site 39a and, especially, the Chalcolithic Mine T at Site 212, it represents the first complete picture of an already relatively advanced phase of prehistoric extractive metallurgy.

5. COPPER PRODUCTION IN THE SINAI-ARABAH COPPER AGE – MIDDLE PHASE (APPROX. EARLY BRONZE AGE II–III)

We could, of course, only excavate a limited number of the thousands of 'plates' of Timna and in spite of the fact that we chose the workings for excavation according to their geomorphological location, we could not identify any mine of the Sinai-Arabah Copper Age – Middle Phase. However, we discovered a smelting site of this period in the Arabah Valley, about 3 km north of Timna – Site 201 (fig. 14).

On both sides of a shallow wadibed we found several dwellings of the oblong 'broadhouse' type, common in Early Bronze Age II settlements of Palestine and Sinai (Ben-Tor in Kempinski and Reich, eds. 1992: 62–66). Two of these dwellings, Site 201/A1 and 201/A7, were excavated by the 'Arabah Expedition'.[12]

The pottery[13] uncovered in the excavation was of a type used widely in the region during the Sinai-Arabah Copper Age – Middle Phase. It is important to point out, that at Site 201A – as indeed at all the other sites of this period in the Southern Arabah – there was not even one sherd of the so-called 'Canaanite' pottery of

Fig.16. Site 249, the workshop for preparation of the furnace charge and for casting.

the Aradian EB II type, a fact which testifies to the culture-historical isolation of the Southern Arabah from the settled territories to the north and north-east during this period. Most of the pottery at the site was of local made; others, mainly cooking-pots of globular shape, a rounded base and thickened rim, originated from South Sinai (Rothenberg and Glass 1992). There was also pottery originating from Central Sinai, probably from the area of Themed, a pottery manufacturing area on the Tih Plateau. Very significant was the presence at Site 201A of pottery made along the Nile, which was the earliest Egyptian pottery found in the Arabah.

In the settlement itself, only a few small lumps of slag were found. More slag was found outside and to the north of the dwelling area, and, especially, on the slope of the hill nearby (Site 201/A2). All the slag was broken up to small lumps, apparently in order to extract metallic copper prills entrapped in the slag, like at the earlier, prehistoric smelting sites. However, some of the slag at Site 201A was more homogeneous, solid and dense and had a platy shape and the ropy surface of a suddenly 'frozen' liquid, typical for tapped slag. This shape of the slag indicated that at the end of the smelting process at least part of the slag in the furnace was made to run out through some kind of 'tapping hole' in the furnace wall, probably leaving some kind of 'ingot' of metallic copper at the furnace bottom. However, the fact that the tapped slag at Site 201A was found broken into small lumps, indicated that the conditions in the furnace – perhaps its ventilation by still inefficient bellows – were not yet suitable for a complete separation of the metallic copper from the slag. Some of the slag, which appeared to be highly viscous, had to be removed from the furnace as 'furnace slag' and crushed to extract the metal.

The Chemistry and mineralogy of the slag of Site 201A[14] was different from that of the Early Phase (Site 39). It was mainly fayalite and much of it was more homogeneous, due to a better control of fluxing (more iron in the slag relative to the gangue) and the more efficient use of fuel (less calcium in the slag). Many of the slag lumps showed an almost complete smelting of the ore and, therefore, a lower viscosity, which was a precondition for tapping.

Tapping, the chemistry and the phase composition of the slag of Site 201A, strongly suggested a considerable progress of its extractive metallurgy. Evidently, the Sinai-Arabah Copper Age – Middle Phase saw the first appearance of a slag tapping technology, also found by our Sinai Survey at Site 590 in Southwest Sinai, at a smelting location of the same period (Rothenberg 1979:138; Kingery and Gourdin 1976). The introduction of tapping was one of the major steps towards a fully developed, industrial metallurgy, because tapping made the continuous use of the smelting furnace possible, saving thereby large quantities of fuel and labour.

At Site 201A no smelting furnace was found *in situ*, but at the north side of the adjacent hill, two small stone settings (Site 201/A3), unfortunately found badly disturbed, appeared to be remains of furnaces. The slagged stones found in this area suggested that at least the upper part of the furnace, built above ground, was a stone structure. The location of the furnaces on the slope of the hill would be very convenient for the tapping of the slag.

The scale of working at Site 201A was still that of a 'cottage industry', although considerably more copper was produced in the Sinai-Arabah Copper Age – Middle Phase smelters than in the previous periods. The metallurgical remains also indicated a more advanced metallurgical know-how than seen in the smelters of the previous, earlier periods. The fact that Egyptian pottery was found at the site, and the discovery of a very similar smelting site, Site 590, of the same period, in Southern Sinai, may indicate the Egyptian origin of this more advanced metallurgy.

6. MINING, SMELTING AND CASTING DURING THE SINAI-ARABAH COPPER AGE – LATE PHASE (APPROX. EARLY BRONZE AGE IV)

6.1 No Sinai-Arabah Copper Age – Late Phase (approx. Early Bronze IV) mining remains were identified in the main mining area below the Timna Cliffs. However, in 1989, following up our previous excavations at a smelting site of this period, Site 149, on a hill in the estuary of Wadi Timna, where many tiny bits of a blue, platy ore, quite different from the green ore nodules of Timna, were found dispersed all over the site, we surveyed the area for a possible mining site of this ore. Several sites of mineralization of this kind were indeed found in the vicinity of the smelting site 149,

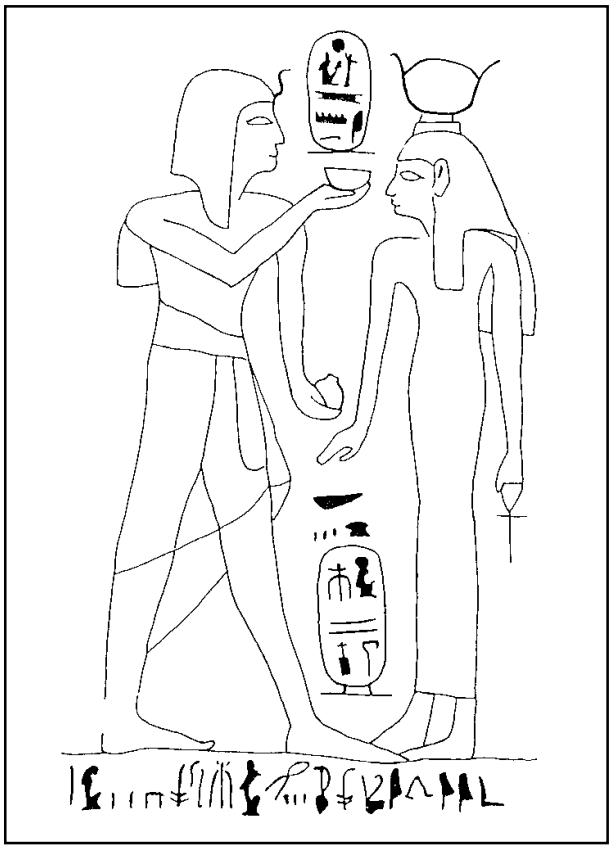

Fig.17. Rock-drawing above the Hathor Temple, Ramesses III. The inscription below reads 'Coming by the royal butler, the justified Ramesses-empere' (Shulman).

mainly on the slopes of Mt. Sasgon, Site 250, which were evidently ancient mining sites (Rothenberg and Shaw 1990). The mineralization consisted mainly of hydrated copper silicates, i.e. ores of the chrysocolla group, plancheite, atacamite and also malachite, located in the shaly facies of the Timna Formation of the Lower Cambrian, which was also the main target of the modern mining operations in Timna.

At Site 250 two mine workings were excavated, Mine 250 and Mine 250A, which from far appeared to be cave-like rock shelters (fig. 15), in the inside of which we found a thick vein of blue-green and grey mineralization. Mine 250 was a small, cave-like mine, where already in the Sinai-Arabah Copper Age – Early Phase platy beads were produced from the light blue plancheite, mined there. The evidence was found in the mine itself and on the slope in front of it in the shape of fine flint borers and pottery sherds.

Mine 250A was a much bigger mine and its cave-like shape was formed by the miners following the horizontal vein of ores. The mine suffered heavy damage by a huge collapse of rocks from its ceiling. In front of the mine was a flat working area, where ore dressing had taken place. When we discovered the site, a large boulder and many small ones showing heavy mineralization of plancheite, were still laying there, accompanied by round flint hammers and numerous tiny bits of ore.

One of the important aspects of the discovery of the mines at Site 250 is the fact that this was the first evidence of ancient mining in the Southern Arabah of ores of the chrysocolla group. During subsequent work in the area we found additional mining of this mineralization in the northwestern parts of the Timna Valley, continuing until Early Islamic times.

6.2 Site 149, the smelting site of the Sinai-Arabah Copper Age – Late Phase, was located on a solitary hill in the wide estuary of W. Timna. It was first excavated in 1984 and further investigated in 1989 (Rothenberg and Shaw 1990). On the flat slope of the hill we found an unique workshop (fig. 16), with a low wall running through its centre, perhaps erected as a shield against the often strong prevailing winds of the Arabah. Large stone mortars with deep 'cup-marks' clearly indicated the use of these implements for the crushing of hard materials. Other crushing implements, mortars and hammerstones, were found in small groups *in situ*, as

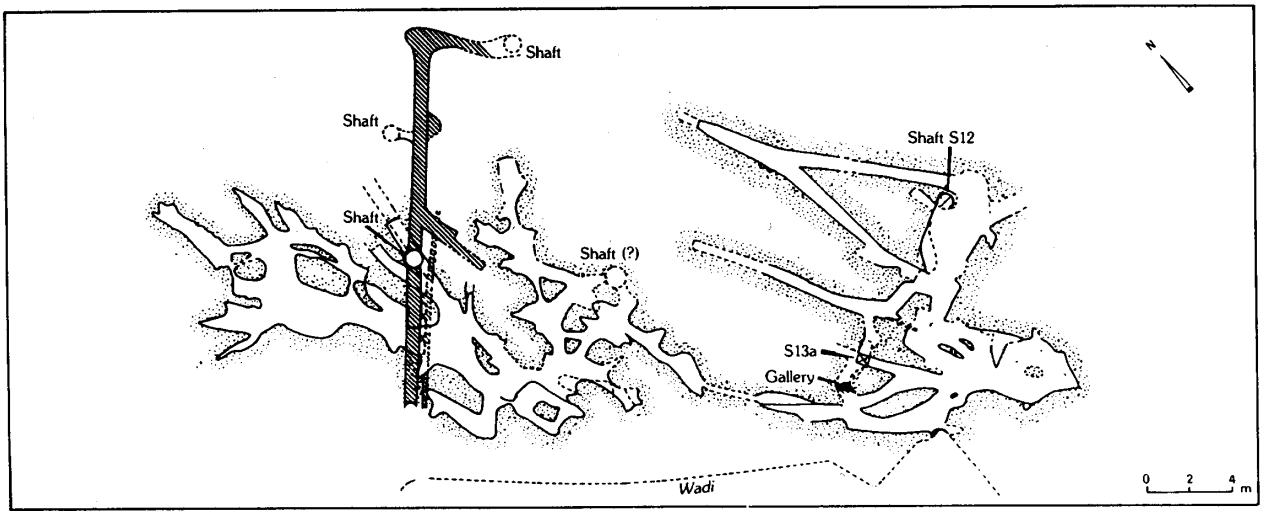

Fig.18. Mining area Site 212 – mine workings S. Shaded gallery at the left is the upper level. Note the narrow parallel gallery for ventilation of the main workings.

if the workers had just gone off for a short break. In some of the mortars we still found bits of blue copper ore and malachite, as was the case all over the workshop area excavated. Obviously, this was the workshop for the preparation of the smelting charge for the smelting furnaces on top of the hill.

In the workshop there were also small lumps of slag, which appeared to be, by their shape and consistency, typical crucible melting slag (Krawczyk and Rothenberg forthcoming: 7.2.1–3; Tylecote 1987:321 –324). There were also fragments of crucibles with slag encrustation on their rim (Rothenberg and Shaw 1990: 6–8). Evidently, besides smelting of copper on top of the hill, copper was refined and cast at this workshop.

Metallurgical and Lead Isotope studies of 'bar-shaped' ingots found at sites of this period in the Negev and the Judean Mountains, indicate that these could well have been cast in the workshop of Site 149 in Timna[15] (Segal *et al.* 1996–97; Stos-Gale 1991:5–6; Rothenberg 1991:3–4, 7).

The actual copper smelting at Site 149 took place on top of the hill, where heaps of tapped slag were located. This slag was very similar to the mainly fayalitic slag of the previous (EB II–III) period, but it was more homogeneous, of lower viscosity, denser and more solid (less gas-holes). Dispersed among the slag heaps were charred and slagged, often 'brick-like' stones, evidently fragments of stone-built smelting furnaces.

The slag and furnace remains of Site 149 represented a further important step in the development of extractive metallurgy from primitive, very small scale copper smelting in a hole in the ground with a pair of bellows, to copper production in a properly planned plant, with stone-built furnaces, apparently improved furnace ventilation and a better controlled furnace charge. Due to this improved smelting technology, the production of copper was on a much larger scale – estimated, according to the quantity of slag, to hundreds of kilograms.

Site 149 represented a new principle of 'industrial' work organisation, with the plant set up where technologically most convenient – in case of Site 149 very near the mine – quite far from any habitation site of this period, which were located nearer to rich sources of water and grazing land. This site was in fact the earliest industrial plant properly organized for a continuous and efficient production on a scale so far unknown from any other prehistoric smelting site in the region. We assume it was a plant set up as a common enterprise by the inhabitants of this period in the Southern Arabah.

The working installations of Site 149 and its pyrotechnological advancement indicated the immigration into the region of people with advanced metallurgical knowledge and experience, or, alternatively, the influx of metal-technological know-how from the north, through Western or Eastern Palestine.

Convincing evidence for the arrival in the region of a 'foreign element' can also be seen in the pottery found at Site 149 and at the habitation sites of the same

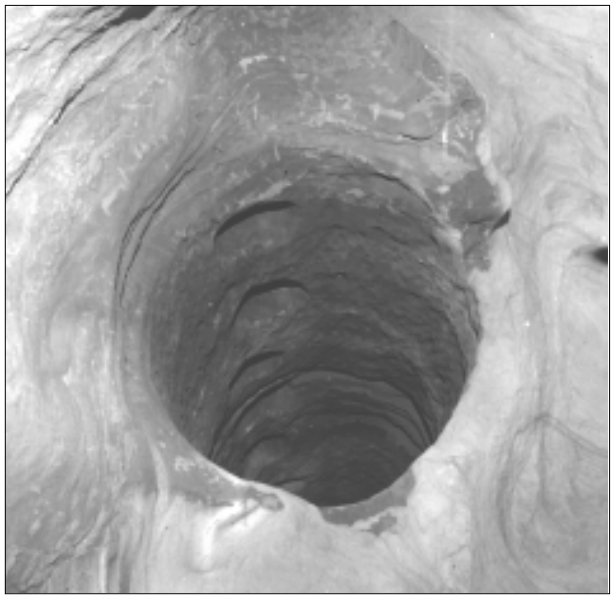

Fig.19. Main entrance shaft to New Kingdom mine.

period, located in the Southern Arabah adjacent to the Timna Valley. The pottery from these sites was generally typical for the settlements of this period in the whole region. It was, partly, locally made or originated from the Tih Plateau of Central Sinai. However, the high quality of much of the pottery, i.e. the treatments of its clay matrix, the shapes, the finishing and high-temperature firing, was very conspicuous compared to the pottery of the earlier Phases of the Sinai-Arabah

Fig. 20. Bronze chisel found inside New Kingdom mine.

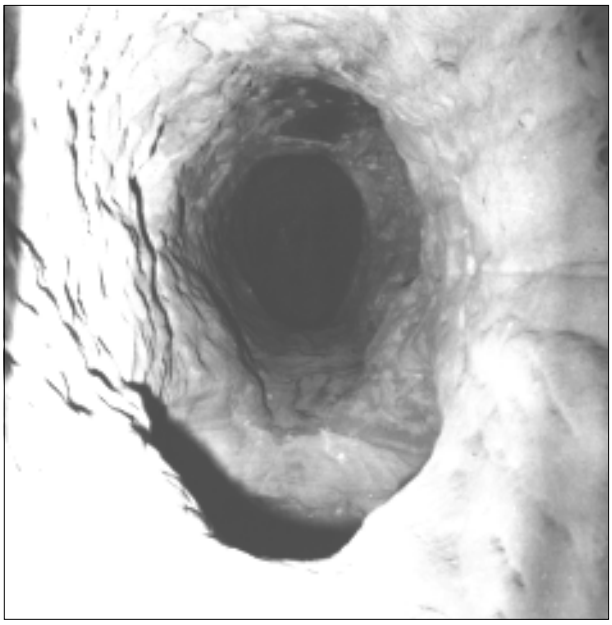

Fig. 21. New Kingdom main gallery. In foreground, the 'blind-shaft', leading to workings at a lower level.

Copper Age. At the sites of the Sinai-Arabah Copper Age – Late Phase of the Arabah, no Egyptian pottery was found. Of obvious intrusive character was well-fired pottery with 'combed' decorations, characteristic for the pottery of the Early Bronze Age IV all over the Southern Levant. This pottery can be seen as additional evidence for a connection in this period between the mining region in the Southern Arabah and the fertile regions to the north – and perhaps from somewhere in this northern region originated the so much improved metallurgical process technology of Site 149.

At the present stage of the archaeological research of the Arabah, we can not date the end of the Sinai-Arabah Copper Age – Late Phase. It is possible, even likely, that the local population and its specific culture continued the exist in the region for an additional, extensive period – which is not yet datable by archaeological evidence. However, it is quite certain that in the Arabah no settlements or mines can be related to the Middle Bronze Age (2000–1550), i.e. the Canaanites never reached the Southern Arabah and its mines.

Fig. 22. Large mining 'cavity' with branching out galleries.

The Timna mines were deserted at some time during the Sinai-Arabah Copper Age – Late Phase, became filled and covered by wind-blown sand, and greatly changed their appearance due to the continuous, drastic and fast geomorphological changes of the landscape. Only towards the end of the 2nd millennium BC, when the Pharaohs of the New Kingdom extended their control and activities to the eastern regions of the Sinai, was mining in the Timna Valley renewed, and at this time as large-scale sophisticated mining enterprises.

7. 'ATIKA' – LARGE SCALE COPPER INDUSTRIES OF THE EGYPTIAN NEW KINGDOM, FROM THE END OF THE 14TH TO THE MIDDLE OF THE 12TH CENTURIES BC

7.1 Our excavations in the mines of Timna and W. Amram, and the very characteristic features of the New kingdom mines, showed that probably most of the mining in the Timna Valley, and the W. Amram, belonged to the huge mining enterprise of the New Kingdom, during the times of the Ramesside Pharaohs of the 19th and 20th Dynasties.

In Papyrus Harris I:408 (in the British Museum) from the times of Ramesses III, we have the detailed description of huge copper production in a country called 'Atika' (Breasted 1907:204; Levene 1995). According to this description, the mines of the Southern Arabah, and in particular of the Timna Valley, may best be identified with 'Atika'. Further evidence for the importance of Ramesses III in Timna may be seen in a monumental rock-drawing above the Egyptian Mining Temple of Timna, which shows an Egyptian Pharaoh worshipping the goddess Hathor. The Pharaoh is identified as Ramesses III by a double cartouche bearing his name (fig. 17). A second inscription bearing the name of Ramesses III was found at the site of an ancient well on the ancient path from the Sinai to the copper region of the Arabah, which passes through the W. Roded (Radadi), south of Timna, and is the only Egyptian rock-inscription ever found alongside this path. At the time (Rothenberg 1972:201), I proposed the identification of Ramesside 'Atika' with the mines of Timna and this proposal has been widely accepted.

7.2 Our archaeological investigations proved that the Pharaonic New Kingdom activities in the Southern Arabah started at the time of Seti I, at the end of the 14th century BC, and by the time of Ramesses II, these had already developed into a huge copper industry. The

Fig. 23. Aerial view of Site 2.

major mining activities were prepared by a 'geological survey' covering the whole belt of mineralization along the Timna Cliffs. For this purpose, vertical shafts were dug through the layers of eluvial conglomerate into the copper ore bearing sandstone horizon underneath. Since the ore bearing formation, which outcropped at some points onto the surface, tilted down sharply in the direction to and underneath the Cliffs, the exploratory shafts of the Egyptian miners often had to reach considerable depth. One of these shafts, excavated by us, reached the mineralized zone only at the depth of 35 m. This shaft must have located a promising ore deposit, because the miners continued their work in horizontal galleries. However, not in all of the shafts copper ores were found and it was therefore necessary to dig a large number and a very dense 'net' of exploratory shafts, in order to produce a detailed picture of the mineralization underground. On aerial photographs it was possible to discern long series of solitary shafts along the slopes rising towards the Cliffs, covering thereby the whole area of mineralization. Apparently, this 'net' of exploratory shafts was begun from the whitish sandstone outcrops at the inner edge of the semi-circular 'copper belt', where prehistoric mines (Area T) would have been a clear indication of earlier copper mining, and from there run radially towards the Cliffs. Most of these shafts had the shape of 'plates', others were open almost to their bottom. The aerial photographs also showed that in several areas of the narrow belt of mineralization along the foot of the Timna Cliffs, are clusters of 'plates', indicating areas of intensive mining. According to the technological

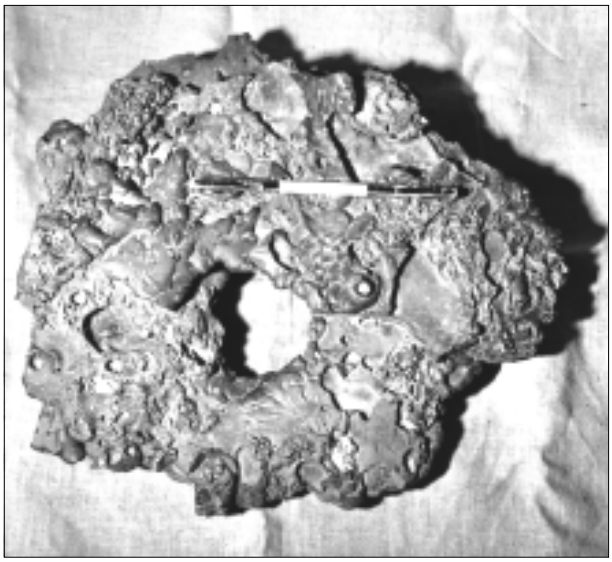

Fig. 24. Slag 'cake' with cast-in centre hole. Site 2.

characteristics, like mining tool marks, the majority of the approx. 8000 'plates' were Egyptian mining shafts. Evidently, 'Atika' was a huge Egyptian mining enterprise, one of the largest of the ancient world.

The 'survey methods' to search for underground concentrations of copper ore by systematic excavations of vertical shafts, is in principle very similar to the modern practice of systematic exploration by the drilling of bore-holes. As far as we know, the Egyptian miners in the Timna Valley were the first to develop this method, seemingly the first of its kind in mining history.

Once the Egyptian miners had obtained the 'geological information' and located promising ore deposits, they invested their efforts accordingly and developed extensive shaft-and-gallery mining systems. Our expedition excavated two such systems in Area S (fig. 18). The entrance to the mine was by means of vertical shafts of about 80 cm diameter (fig. 19), with footholds cut into their, opposite, walls. Chisel (fig. 20) and hammer were the mining tools and their working marks on the walls of the shafts and galleries served as hallmark for the mining technology of the New Kingdom. From the bottom of the vertical entrance-shaft, a horizontal main gallery was dug (fig. 21), with galleries branching off according to the course of the ore veins. In some of the mine systems there were several levels, one above the other, and 'blind shafts' would connect the different levels. Often, when the Egyptian miners would find a large pocket of ore nodules, they mined it out completely, thereby creating large mining cavities from which further galleries branched out in all directions (fig. 22). Whenever needed, ventilation shafts were dug – often from the gallery upwards – and there were also special shafts for hauling out the ore to the surface. It was obvious that the Egyptian miners had full control over underground mining technology. They had a well-established and uniform method of planning the mining systems, utilising in a sophisticated way the local geological conditions. Among these sophisticated features was the digging of horizontal, narrow ventilation tubes, connected to the parallel main gallery by short and narrow openings (see fig. 18). Especially impressive was the discovery by our team of a narrow and long ventilation 'gallery', dug between two mining systems in order to create an airflow between these neighbouring mines. In our excavations inside the mines we found mining tools made of tin-bronze (see fig. 20) and numerous round stone ham-

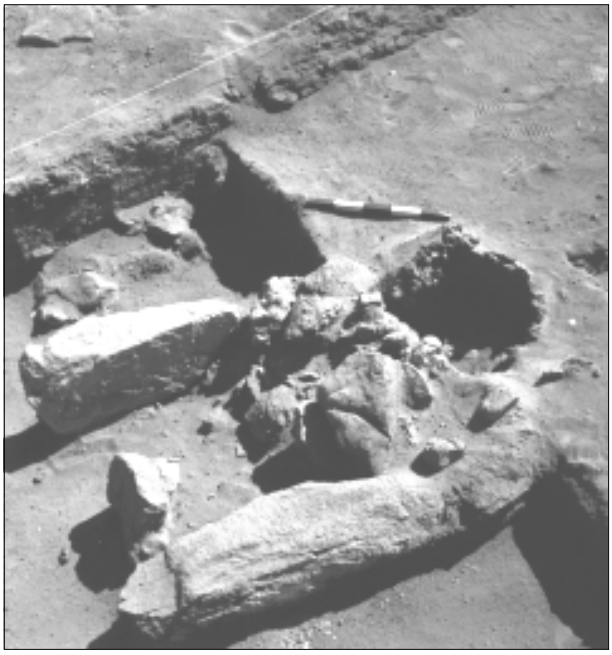

Fig. 25. Cupola-type smelting furnace, FIV, Site 2. This furnace was found refettled for further use.

Fig. 26. The same furnace, fully excavated, showing slag pit in front of the smelting hearth.

Fig. 27. Tubular-shaped, partly stone-built, smelting furnace, FI.

mers. We also found some pottery sherds underground, which provided the archaeological evidence for the dating of these mines to the Egyptian New Kingdom.

7.3 The smelting of copper took place in 11 camps, part of which also served as habitations of the workers, and for storage. Our expedition excavated two of these smelting camps, Site 2 and Site 30.

7.3.1 Site 2 (Rothenberg 1972:71–111; 1990: 13–44), excavated in 1964–66 (fig. 23), is located in one of the small, tributaries of W. Timna. It is an unwalled site, approx. 180 x 150 m, with building ruins and slag heaps. The objective of these excavations – the first excavations of a smelting site undertaken by our expedition – was the discovery of smelting installations *in situ* and also the collection of raw materials and process debris for subsequent analytical studies, aimed at the reconstruction of the ancient metallurgical processes. We also had to establish the archaeological stratigraphy of the site, which was obviously of vital importance for the chronology of the copper industries at Timna. We chose Site 2 for excavation because it was one of the largest smelting camps in the Timna Valley and because we had noticed there several large heaps of rather unusual, ring-shaped slags. We also found next to one of the slag heaps a smelting furnace in excellent conditions – at that time the first ancient copper smelting furnace found *in situ* anywhere. Furthermore, Site 2 was discovered in 1959 by my team and had not yet been ransacked by tourists, like most of the other sites of 'King Solomon's Mines' in Timna.

At Site 2 several squares were excavated and smelting furnaces, workshops, storage pits and even cult places were discovered. Area C was in fact only a big heap of large, heavy, round slag 'cakes', of a diameter of 35–50 cm (fig. 24), piled on the slope of a shallow wadibed. Each of these slag 'cakes' had a round hole in its centre, obviously intentionally 'cast in' during the tapping of the slag out of a nearby furnace. This unique cast-in hole would have made it much easier to lift the heavy slag 'cake' out of a tapping pit, prior to it being thrown down the slope. Since this downwards movement of the slags was noticeable in the slag heap, we assumed that the smelting furnaces must have been located further up on the slope, and there we excavated

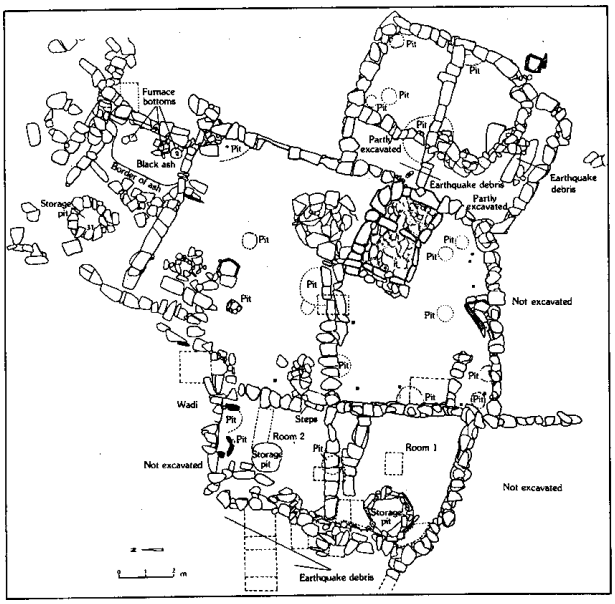

Fig. 28. Plan of workshop and casting site (L.1038) at Site 2.

a trench along the slag heap – and found indeed a series of smelting furnaces *in situ* (Rothenberg 1990:13–16).

One of these furnaces, FIV, was very well preserved (fig. 25). Its smelting hearth, where the actual extractive processes had taken place, was a hole dug into the ground, about 40 cm deep and of about the same diameter, lined with a thick layer of clay-like mortar. The upper part of the furnace, which protruded above the surface – found in the excavation only partly preserved – formed a dome-shaped, cupola-type cover for the hearth. In its centre was an opening for charging the furnace and the escape of the fumes. A thick layer of slag was found adhering to the upper part of the smelting hearth. Some slagging was also visible further down on the walls of the hearth, but here the slag must have been removed – at the end of the process and after the tapping of most of the liquid slag – together with the 'ingot' of metallic copper on the furnace bottom. A ceramic tube, its diameter about 10 cm, penetrated diagonally through the back wall of the furnace (opposite the tap-hole), directed at the furnace bottom. This ceramic tube served as tuyere for the tube of the bellows, which had to be protected against the great heat inside the smelting hearth. We assume that this type of furnace had at least two tuyeres/bellows, one also at the front, above the tap-hole.

Fig. 29. Ore crushing platform in the centre of the workshop.

In front of the smelting hearth was a shallow depression, protected by two long stones on edge (*c.* 80 cm), which served as tapping-pit for the slag. The front of the hearth was found broken open, apparently in order to remove all of its contents, before its refettling for further use (fig. 26).

Furnace IV was found in Layer 1, the uppermost occupation layer of Site 2. In Layer 2 below, the slag was of a different type. Instead of the ring-shaped tap-slag, which was just discarded onto the slag heap, the slag of Layer 2 was broken into small lumps. By its texture and rope-like surface, as well as small slag runners (round rod of slag that 'froze' inside the tap-hole and took its shape) found among the slag, the slag of Layer 2 was definitely also a tapped slag, but it was broken into small pieces to recover any copper pellets that were entrapped in the slag.

We did not find a complete smelting furnace in Layer 2. However, in our excavations at Site 30 (see below), we located in its Layers 2 and 3, which were contemporary with Layer 2 of Site 2, a well-preserved smelting furnace. Characteristic for this layer (in Site 2 and Site 30) were its ceramic tuyeres, which are the most sophisticated tuyeres known from ancient times. They measured about 8 cm in outer diameter, their inner tube about 2 cm (see fig. 30 below). These tuyeres were mass-produced in a special ceramic workshop at Site 30, and probably also at the other New Kingdom smelting sites in Timna.[16] Alternate layers of clay and reeds were wound around a wooded stick (2 cm diameter), with more refractory clay on its tip. Similar tuyeres are shown on several well-known Egyptian wall-paintings of metallurgical workshops.

Further along the slope of Furnace IV were two more heaps of the same ring-shaped slags and our excavation revealed several more smelting furnaces, partly well-preserved. Especially interesting was Furnace I (fig. 27), also in Layer 1. Its dimensions were very similar to those of Furnace IV, but it represented a different furnace technology: a wall, 40 cm high, was built in a semi-circle into a pit, dug into the ground, to form the smelting hearth. Below its open front, a tapping-pit was located. Here the furnace had been closed by a thick layer of mortar lining, strengthened by a pile of stones on the outside (see above fig. 25). The rest of the furnace wall and its bottom were also lined with

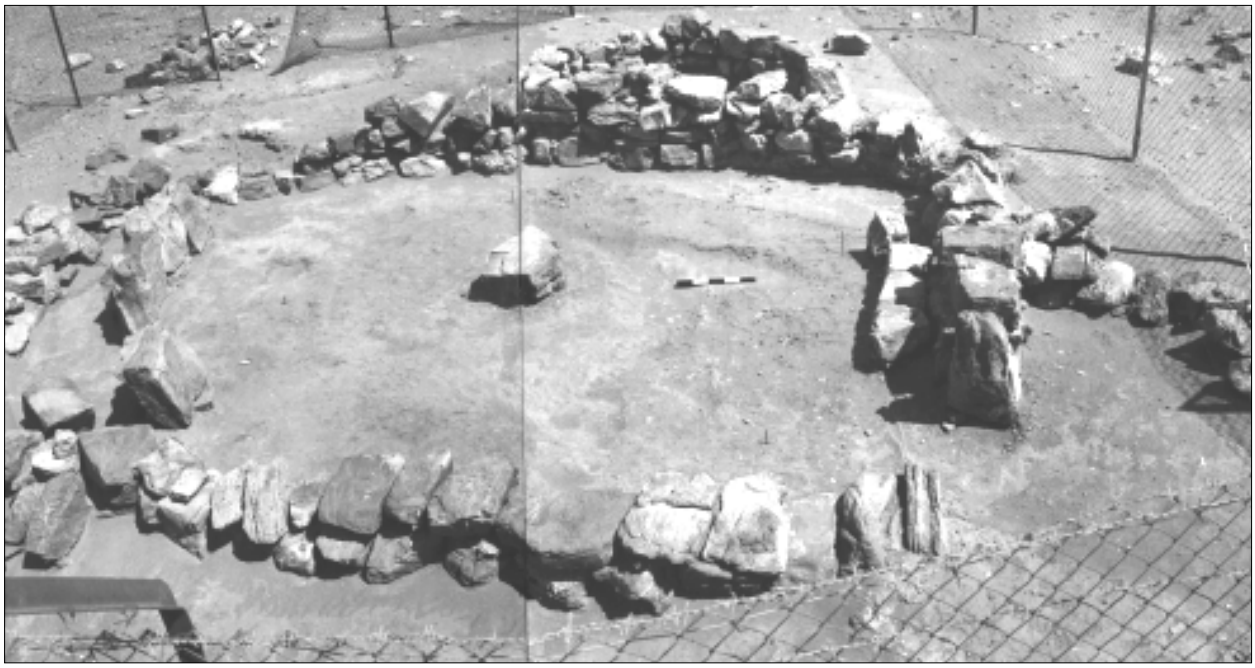

Fig. 30. Small 'semitic' shrine at Site 2.

clay mortar. However, contrary to Furnace IV, this furnace was not dome-shaped, but had straight walls, i.e. a tubular shape, open on top.

The other furnaces uncovered at Site 2 were of the same two types: dome-shaped or tubular furnaces. According to the findings at Site 30, Furnace IV was the continuation of the furnace technology related to the layer of the broken slags (Layer 2 at Site 2 and Layers 2 and 3 at Site 30). However, one of the furnaces at Site 2 (Area Z) had been cut into solid bedrock (Rothenberg 1990:20–25; 1983:116–119) and was therefore very well preserved. It clearly showed the characteristics of both types of furnaces found in Layer 1 of Site 2. Since these two types of furnaces stood next to each other and were operated at the same time, we have to assume that they were built by people of different origin; one apparently by Egyptians, the other by the 'Midianites' from Northwest Arabia. We must remember, that in all layers of the Egyptian copper smelting camps, nilotic Egyptian pottery was found together with 'Midianite' pottery from Arabia. Furnace Z indicated that the Egyptian and Midianite metallurgists learned to appreciate the advantage of each of the two types of furnace construction and built an improved furnace(s), combining both types.

Fig. 31. Midianite juglet with ostrich, bi-chrome, decoration.

The slags of Site 2 were mainly tapped slag of fayalite type (iron oxide flux), but in the same layers was also slag of knebelite type (manganese oxide flux) (Rothenberg 1990: tables 2–3; Bachmann 1980:110–113). There was very little copper left in these solid, tapped slags of very low viscosity, the copper having been separated by gravity from the liquid slag while still in the hot furnace. The obvious homogeneity of the slag pointed to a very advanced furnace technology and, especially, a good control of the consistency of a well-balanced smelting charge and of the problems of furnace ventilation. The smelters of Site 2 used iron oxide as well as manganese oxide as flux, sometimes both together in the same smelt. This seems to be the earliest occurrence of the intentional use of manganese as flux in copper smelting.

Near the furnaces and heaps of ring-shaped slag of Site 2 we excavated a group of ruined buildings of approx. 400 m^2, which turned out to have been a very well-organised working and storage complex (fig. 28). In its central courtyard (11 x 8 m) stood a stone-paved platform (fig. 29) and on it several crushing tools, mortars, pestles and hammerstones. Numerous crushed ore fragments were dispersed all around it. Evidently,

Fig. 32. Hand-made 'Negevite' cooking pot.

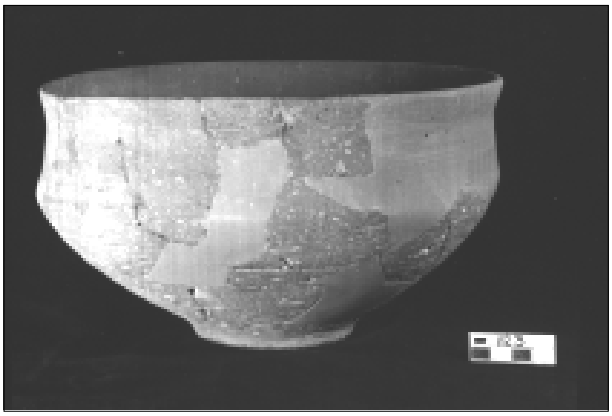

Fig. 33. Local, wheel-made crater.

this installation served as crushing floor for the preparation of the smelting charge. Right next to it was a large, stone-lined pit, which was found still to contain some crushed ores. Attached to all four sides of the courtyard were rooms, each containing a large storage-pit, also stone-lined. In some of these pit we found a store of clay, which was of course a very essential raw-material for the smelting installations. One of these rooms (upper left corner of fig. 29) was a small casting workshop with two melting-casting furnaces, accompanied by a considerable quantity of ash and charcoal, some copper spills and slagged crucible fragments.

At the southern edge of the camp, outside the working area, stood a solitary, oblong building, 9 x 8 m, its entrance towards the east (fig. 30). On both sides of the entrance. inside the building, stood a low bench, presumably a bench of offerings. A solitary monolith with a flat top in the centre of the building, seemed to have been an altar. Around it were animal bone fragments, ashes and pottery sherds. Along the west side of the building stood a row of big, roughly hewn, stele-like standing stones. A libation bowl stood before them, carefully carved from a sandstone block. Next to the entrance, on the outside, a small semi-circular structure was attached to the wall, another similar annex was at the outside of the northern wall of the building. Inside these annexes, woodash and bones of goats was found. This building 'complex' must have been a small semitic cult shrine, built for the use of the non-Egyptian workers.

On top of a nearby hill, west of the smelting camp, a High Place was discovered. On its meticulously laid stone pavement we found several goat horns, copper rings, two small iron (!) armlets and many beads. Next to this structure was a small (4 x 4 m) area of intensive metallurgical activities, which left behind fragments of small, slagged crucibles, charcoal, tuyeres and lumps of furnace lining, i.e. remains typical for casting operations. The whole area was littered with pottery sherds, especially of the bichrome decorated 'Midianite' type, but also with beads, perforated Red Sea shells and ostrich eggshells, small metal objects and metallurgical waste. This unusual site, Area F of Site 2, was interpreted as a High Place, where small votive copper implements, of the kind found also in the nearby Egyptian Mining Temple, were cast. Some simple faience beads were also manufactured here.It seemed likely that the metallurgical operations, which undoubtably took place here, were an integral part of the actual ritual and, according to the archaeological evidence, the Midianite were the worshippers at this High Place (Rothenberg 1972:114–117).

In the excavations of Site 2 were found together Egyptian pottery brought from the Nile Valley, handmade 'Negevite' ware of the Negev settlements, 'Midianite' pottery from Northwest Arabia and locally made vessels (figs. 31–33). There was also one scarab from the time of Ramesses II. At the time of the excavation, we dated Site 2 to the Egyptian New Kingdom (Late Bronze-Iron Age I), a date finally confirmed by the excavation in 1969 of the Egyptian Mining Temple at Timna (see below).

In the earliest layer of Site 2, i.e. in the Late Bronze Age Layer 2, we had found several iron bracelets, a fact which arose considerable interest. Microscopic investigations showed that the origin of this iron was from a copper smelting process, as a byproduct of using iron ore as flux. The investigation of several copper ingots, found on the slag heaps of Timna, revealed in some cases the presence of a layer of metallic iron at the upper surface of the copper ingot. Separating this iron from the copper, either manually or by melting it in a crucible, the iron turned out to be workable wrought iron (Tylecote and Boydell 1990: 45–48). Furthermore, lead isotope determinations established that the iron from which jewellery found at Site 2, and later also in the Timna Mining Temple, was manufactured, originated in the copper smelting furnaces of Timna (Gale *et al.* 1990:182–191). These unique results indicated the way of discovering the technique of iron smelting – first as adventitious production of iron during copper smelting – already in the Bronze Age.

7.3.2 Site 30 is one of the two walled smelting camps in the Timna Valley (fig. 34), the second is Site 35 – called on the new official map the 'slave hill' – a fortified smelter on top of a flat, hight plateau right next

Fig. 34. Site 30 under excavation, seen from top of hill behind it. Dark area at the left is the smelting and slag section of the site.

to Site 30. Site 30, 80 x 40 m, is located at the foot of a very steep hill and is surrounded on three sides by a solid wall, with two towers flanking its entrance. Both ends of this wall climbed the steep slope up to an unsurmountable cliff – a type of architecture which we also noticed at the Egyptian miners camps in the Sinai. Before the excavation, we noticed in the centre of this site a particular large heap of big and heavy slag 'cakes', surrounded by a group of ruins. We excavated most of this site in 1974–1976 (Rothenberg 1980; Bachmann and Rothenberg 1980). These excavations provided the first picture of the industrial-technological lay-out of an ancient copper smelting camp and of its extractive metallurgy. They also provided the stratigraphic foundations for the dating of the Egyptian mining and smelting activities in the Arabah.

In Site 30, three archaeological strata were distinguished. At the beginning of the metallurgical activities at the site, in Layer 3, the site was not fortified and was somewhat more spread out than the walled smelting camp of Layer 2, built on top of it. The occupation layer of Stratum 3 was indeed very shallow (5–10 cm), and had no buildings of any kind, except storage pits dug into virgin ground, without any lining. The metallurgical debris – slags, fragments of furnace lining, tuyeres – from this layer were very similar to the remains found in Layer 2 of the excavations of Site 2 and also of Layer 2 above Layer 3 of Site 30. It was clearly apparent that the Egyptians of the New Kingdom arrived in Timna with a well-established extractive metallurgy. Already at this stage of the Egyptian activities at Site 30, 'Negevite' as well as 'Midianite' pottery was found together with Egyptian vessels, evidence for the collaboration of these three neighbouring people already from the beginning of the Egyptian enterprise in this region. In the lowest stratum of Site 30 some Egyptian red-burnished pottery was found, which did not appear in the layers above, or at Site 2 and the Hathor Mining Temple. All other types and kinds of pottery of Layers 3 and 2 at Site 30 were identical with the

Fig. 35. Bowl-shaped smelting furnace, Site 30, Layer 2.

pottery at Site 2 as well as the other, unexcavated, Egyptian camps of Timna and the W. Amram, and, especially, the Hathor Temple. This fact was of course of decisive significance for the chronology of the Egyptian activities in the Southern Arabah, Timna and W. Amram.

Some times later, in the times of Seti, and parallel to the building of the Hathor Temple and probably also the adjacent large smelter Site 35, the defensive wall of Site 30 was built on the remains of Layer 3. This was the beginning of very intensive mining and metal production, which lasted, perhaps with one lengthy interruption, for about 150 years – Layer 2. This layer represents the major phase of Egyptian activities in the Timna Valley and of the parallel workings in the W. Amram.

At this time, several smelting workshops were established in the centre of the site, in each of which one or two smelting furnaces. Each of these production units were enclosed by a rough retaining wall, to separate the working area from the gradually piling up slag heaps covering the whole area. Lined up in a semi-circle, along the edge of this smelting centre and the slag build up, was a series of stone-lined pits of different sizes, which served for the storage of ores and charcoal, clay for the smelting furnaces and tuyeres, and perhaps also for pottery. In some of these pits we also found remains of foodstuffs, like bones of goats, camels and fruits. The rest of the camp was taken up by workshop buildings, perhaps also habitations, and a stable for pack animals, donkeys and camels.

In Layers 3 and 2, a number of smelting furnaces was discovered, most of which badly preserved. One of the furnaces in Layer 2 (fig. 35) was bowl-shaped, somewhat like a pear, open on top, and was build of clayish mortar strengthened by stones. There was no pre-prepared tapping pit and it seemed that at the end of the smelting pit, a hole was made in the furnace wall to let the fluid slag run out. The 'tapped slag' had, therefore, a platy shape, which was convenient for braking it up to extract copper entrapped in the slag. The slag of Layers 3–2 of Site 30 was very similar to the slag

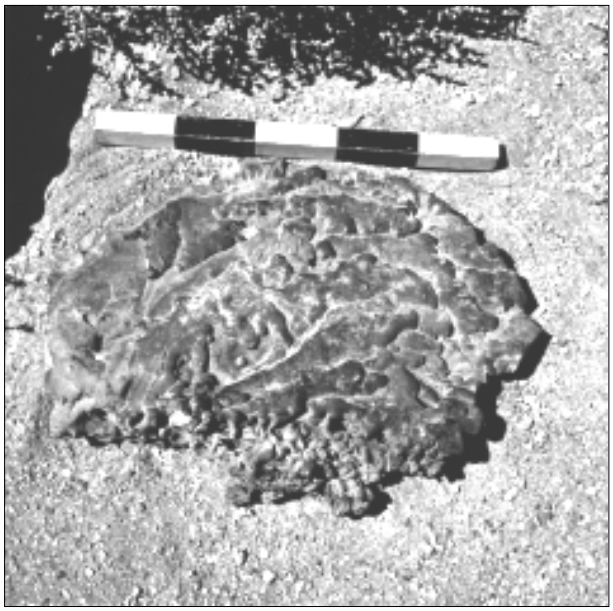

Fig. 36. Complete slag 'cake', Site 30, Layer 1.

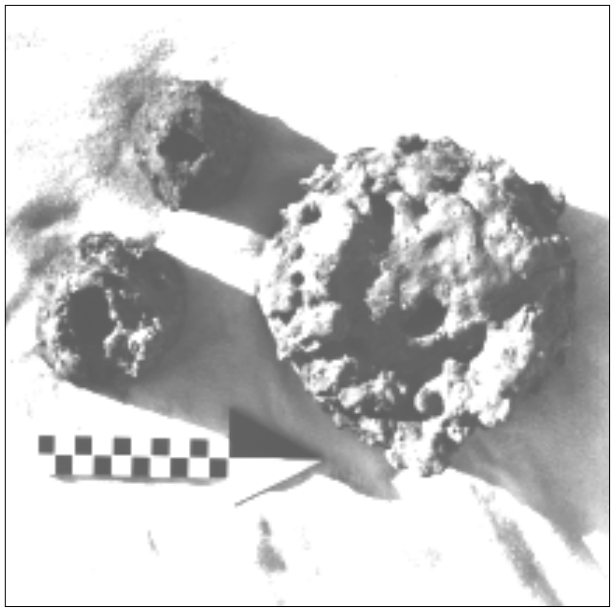

Fig. 38. Tuyeres from Site 30. At left, the small type of Layers 3–2; the large tuyere at the right is from Layer 1.

of Layer 2 of Site 2, except that at Site 30 only iron oxides were used as flux (and not iron as well as manganese as used in Layer 1 of Site 2). It seems certain that these two smelting sites were contemporary – and used the same technology. The discovery of a smelting furnace in Layer 2 of Site 30, the like of which was not found at Site 2 in reconstructible state, added an important link in the chain of the technological development of the smelting furnace in the Arabah during the Egyptian New Kingdom (Rothenberg 1990).

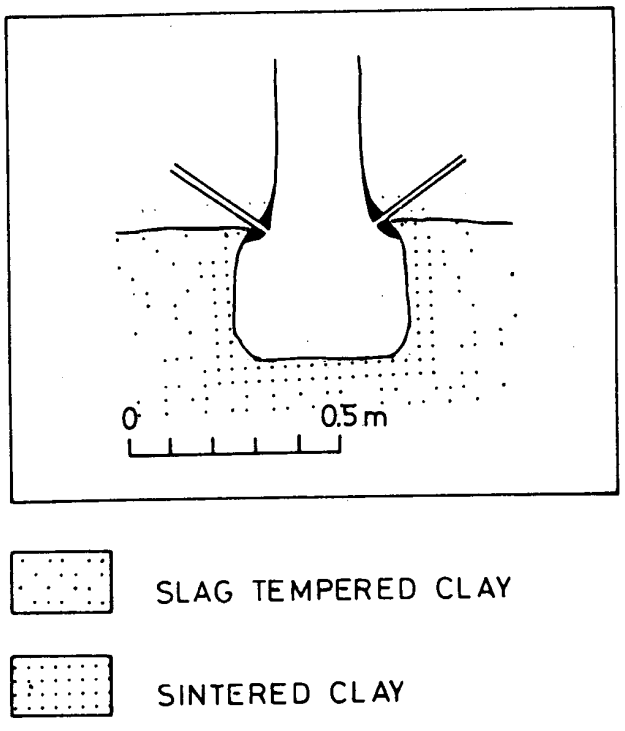

Fig. 37. Proposed reconstruction of Late New Kingdom smelting furnace, Site 30, Layer 1.

When the Egyptians abandoned Site 30, together with all the other smelters and mining sites of the region, in the middle of the 12th century BC, the site became covered by a yellowish layer of wind-blown loess. A layer of large and very heavy, roundish and oval-shaped slag 'cakes' (fig. 36) was found on top of this loess cover, and had been visible on top of the slag heap before excavation. This was Layer 1 of Site 30. This type of slag was only found on a limited area of the slag heap and it was obvious that it represents a different technology, used for only a limited period at Site 30. Besides a fragmentary, low enclosure wall, there were no building remains in Layer 1. However, there was evidence for a secondary use in Layer 1 of structures of Layer 2 as storage pits and working places. One of the buildings of Layer 2 was used again in Layer 1 for the storage of ores. Separated by a low partition of stones set on edge, there was a store of green-grey copper ore and a store of black manganese ore, both crushed to pea-size lumps, as required for the smelting charge.

In Layer 1 no smelting furnace was found *in situ*. However, based on numerous finds of typical furnace fragments, made of clayish mortar mixed with crushed slag lumps as temper, we were able to construct a model of a smelting furnace of Layer 1 (fig. 37). The furnace was pear-shaped, similar to the furnace of Layer 2, but its upper part bent sharply inside, and through this bend, or shoulder, penetrated the tuyere into the smelting hearth. Above this level of the tuyere, the furnace wall straightened up again and formed a vertical, low, chimney-like shaft (Rothenberg 1990:46).

The tuyere of Layer 1 had a diameter of 13–16.5 cm, much larger than the tuyeres of the other layers of Site 30, or of all the other smelting camps of the Arabah (fig. 38). Its inner tube was 2 cm, the same as all other tuyeres. They were made of the same mixture of clayish

Fig. 39. Main slag section at Site 30: The slag built-up, Layer 3, started on top of the light-yellow loess layer, about 25 cm from bottom of section, and was *c*. 30 cm deep. Layer 2, above it, was a homogeneous layer of crushed tapped slag. Layer 1, the uppermost layer, was characterised by complete, large, tapped slag 'cakes'.The stone structure in the foreground was a retaining wall around a smelting workshop.

mortar and crushed slag lumps as the building material of the furnace itself. The use of crushed slag as nonplastic temper for the construction material of metallurgical installations suggested an advanced knowledge about refractory materials, far more advanced than found in the earlier layers.

Such advanced technology was also especially evident in the high quality of the slag of this layer. This slag was a tapped slag of knebelite type (Bachmann 1980:110–114), i.e. with exclusive use of manganese oxide flux – locally available – its smelting temperature above 1300° C. In contrast to the slag of Layers 3–2, which had been broken up in order to extract entrapped copper pellets, the slag of Layer 1 contained only negligible copper inclusions and was simply discarded on the slag heap (fig. 39).

The metallurgy of Layer 1 represented the peak of ancient extractive technology of copper, which was only occasionally surpassed in Medieval times due to the availability of richer and cheaper sources of energy, and the operation of huge bellows by fast flowing water which led to the construction of larger and more efficient furnaces.

The pottery in Layer 1 was very similar to the Egyptian New Kingdom pottery of Layers 3–2, but there were also two groups of vessels which could be identified as pottery of the 22nd Dynasty (946–800 BC). We assume that this appearance of the Egyptians in Timna in the Late New Kingdom is related to the campaign in Palestine, *c*. 920 BC, by Sheshonk I, the founder of the 22nd Dynasty. In this connection we should mention the proposal by Albright (Glueck 1959:105) to interpret the name 'nekeb' on the Karnak list with 'mine' and identify this with the mines of Timna. In Layer 1 also 'Negevite' pottery was found, but not a single sherd of Midianite pottery.

Summing up the review of the copper industries of the Timna Valley, it has become evident that the major industries were founded and operated by mining expeditions of the Egyptian New Kingdom. No evidence was found of the presence in the mines of smelters of any of the kings of Israel or Judea. In the light of our thirty years of field work in the Western Arabah, and especially in its mining regions, and also in the light of current research in the copper mines of the Feinan region of the Northeastern Arabah (Hauptmann *et al.* 1985), it is now evident, that 'King Solomon's Mines' were only the product of romantic speculations, a beautiful and exciting story which had nothing to do with historical reality. It should be mentioned in this context, that there is no mentioning of any such mines in the Biblical sources.

8. ROMAN AND EARLY ISLAM COPPER MINES AND SMELTERS IN THE W. AMRAM AND AT BEER ORA

According to the finds of camping sites and temporary structures accompanied by Roman as well as Early Islamic pottery, there were some activities during these periods in the Timna Valley. However, the Egyptian miners had been there before them and exploited most of the copper mineralization of the Avrona-Amir Formation. Although the 'latecomers' did find some copper ores at the fringes of the Timna Valley, like Sites 87, 88, 186 in the north and Site 95 in the south, and also seemed to have crushed slags of some of the Egyptian smelting camps in order to extract the last of the entrapped copper pellets, the main mining site of these periods was located in the W. Amram, and the main smelting site near the ancient well of Beer Ora (Site 28), both south of the Timna Valley. In the following we review in some detail the sites of these periods in the W. Amram and at Beer Ora, because such sites have sofar not been investigated elsewhere in the Levant and they complete, for the first time, the history of mining and metallurgy of this region.

8.1 In the W. Amram, one of the southern tributaries of the Wadi Arabah, about 11 km from the shore of the Red Sea, two separate mining areas had been discovered in our first Arabah survey in 1959–61 (Rothenberg 1962, 1972). One of these mines, Site 33, is located on the slopes of a mountain range, and on its peak, about 1km from the head of the wadi and its history and technology is very similar to the Timna Mines, i.e. its earliest beginnings in the Sinai-Arabah Copper

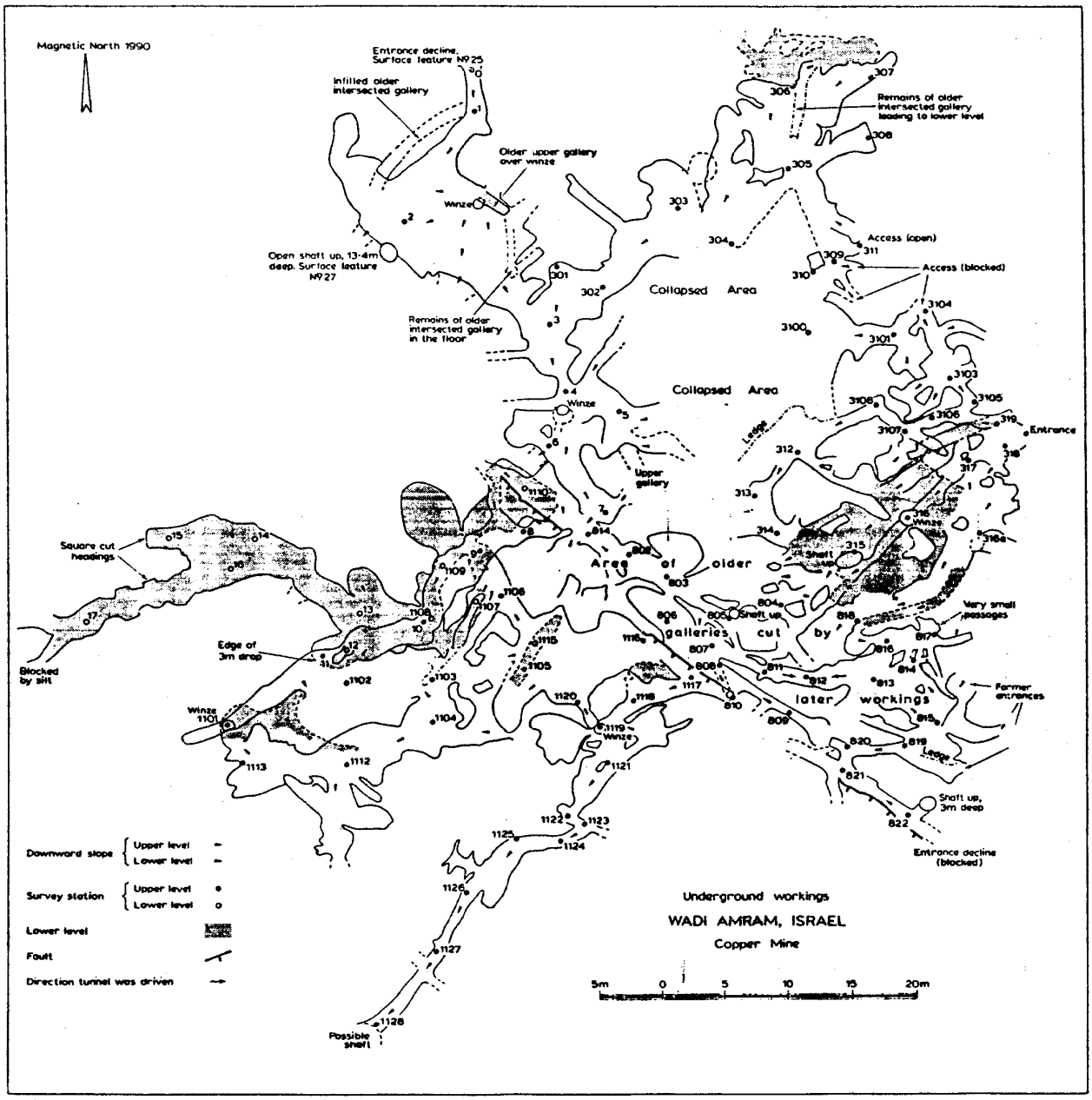

Fig. 40. Map of underground Roman-Early Islamic mines in W. Amram, Site 38. (Willies-Shaw).

Age – Early Phase (Chalcolithic Period) and its major period of exploitation during the Egyptian New Kingdom. At this latter stage it was a shaft-and-gallery mine, excavated with chisel-and-hammer tools. In the wide valley below this mine we found a large smelting enterprise with numerous workshops, slag concentrations and habitations, dated by archaeological finds, and its metallurgy, to the same Ramesside Period as Timna. We surveyed this area thoroughly in 1959–61, and the mine was again investigated in 1989–90, but this part of the mining and smelting complex in the W. Amram remained sofar unexcavated.

The second mining area, Site 38, is located at the head of the wadi, next to a beautiful erosional sandstone formation, a major tourist attraction called 'Amram Pillars'. This area was systematically investigated in 1989[17] (Willies 1990:12–15). Site 38 is a large mine in the depth of the mountain range which encloses a small valley, branching off from the W. Amram. This mine was worked by sloping galleries and vertical shafts and at a later stage also by open cast mining. Large dumps of finely crushed mining waste were particularly conspicuous on the slopes and at the bottom of the valley, the like of which were never seen at the earlier, Egyptian mines in the Arabah. Evidently, this mining technology was typical for the workings where Roman, Byzantine and Early Islam pottery was found. These mining dumps served during our subsequent surveys as reliable characteristics for the identification of mines of the later periods.

The mines of Site 38 (fig. 40) were completely underground and in our excavations we succeeded to distinguish between Roman, Byzantine and Early Islam as well as Mameluke mining technologies. Numerous

Fig. 41. Underground Islamic mine, W. Amram, Site 38; gallery at upper right corner was Roman.

pottery sherds found in the mine workings as well as on the mining dumps were of great help in dating the mines.

The main entrance to the workings was at the top of a steep slope, near the peak of the mountain on the south side of the valley. It was a sloping gallery, which led to a very complex mining system, descending to a depth below the level of the wadi at the bottom of the mining valley. From here several mining galleries run in a south-eastern direction underneath the mountain range and reached an ore deposit in the neighbouring wadi. In the mining wall were niches for small oil lamps, which were the only source of light in these complex, dark workings. During the earliest phase of mining at Site 38, dated to the Roman period, most of the mining was a simple following of the veins of copper nodules. At some points, shafts were dug upwards (or the opposite) to the surface, for ventilation or for ore transport. The Roman galleries had a diameter of about 70 cm but at places where large pockets of ore were encountered, large mining chambers were mined out. The diameter of the shafts was about 1 m, but connecting-shafts or exploration-shafts were often narrower. According to the tool-marks, various mining tools were used, like chisel and hammer, pickaxe and hatchet. Horizontal, very narrow drill holes indicated a long tool, probably a long wooden handle with a metal tip. A most interesting find was a reed-and-rope made basket for ore hauling, with a handle made of leather. It had the size of a modern shopping basket. It was found *in situ* at the lowest level of the Roman mine workings. Other fragments of baskets were also found in various parts of this mine. Obviously, the reed basket was the common means of ore transport in the Roman mine.

Most of the Roman workings were found deformed by later mining, often with a secondary use of the earlier galleries. Contrary to the early, Roman galleries, which were quite regular and narrow – just wide enough to follow the rich veins of copper concretions – the later workings often had a hight of about 3 m and extracted any available kind of mineralization. According to the pottery found in the workings,[18] identified as Roman, Byzantine, Early Islam (7th–10th centuries AD), Mameluke and Ottoman, there were at least 3 phases of mining after the Roman period. Most of these activities took place in the Byzantine period, when wide and sloping passages were opened until the lower levels. The entrance to the lowest level of mining was by shafts.

During the later, Islamic period, the mining technology was essentially different. Very wide sloping galleries formed large spaces, with pillars and irregular cavities (fig. 41). At the latest phase of mining, many of the supporting pillars were partly removed in order to extract any still available copper minerals to the very last. This mining technique caused frequent collapses of the mine. In fact, the removal of the support-pillars was the final, systematic and well-planned act of working the mine to exhaustion in the Late Arabic period.

Fig. 42. The Roman-Early Islamic smelting site, Site 28, at Beer Ora.

8.2 The large, central smelting site of the Roman-Early Islamic period, Site 28, was discovered by our first survey in 1960 (Rothenberg 1962:62–63). It is located in a small valley at the fringe of the Arabah, near the ancient well of Beer Ora (Bir Hendis; Frank: 'en handes). We excavated at Beer Ora in 1969 (Rothenberg 1972: 212–223).

Before the excavation, only slag heaps were visible at the site (fig. 42), but no building remains. There were 3 large heaps and some smaller slag piles, totalling about 5000 tons of slag. Most of these slags were large, roundish 'cakes' with a hole cast in the centre, but there were also slag 'plates' without the cast-in hole. There was a great similarity between the shape of these slag 'cakes' and the slags of the Egyptian Site 2, though the shapes were not identical. It seems that the casting-in of the central hole in the slag 'cakes' was an invention by the Egyptian New Kingdom smelters of Site 2 in Timna. According to ceramic finds at Timna, Roman and Early Islamic 'visitors' had been rummaging some of the Egyptian smelting camps, often even crushed some of the old slag in order to extract copper pellets, and must have adopted this cast-in hole as a useful innovation for their own smelters. However, this situation made it imperative to find additional support for our dating of these slags at Timna as well as at Beer Ora by C14 determination. The date received for the slags of Beer Ora was 7th century AD, and for Site 2 the 13th–12th century BC.[19]

In the excavation of Site 28 we uncovered two smelting furnaces right next to the large heap of plate and ring-shaped slag and one melting-casting furnace (Rothenberg 1990:54–63). These furnaces were C14-dated, calibrated date AD 640 (Vogel CSIR Pretoria Pta4117), the Early Islamic period (Rothenberg 1990: n. 52).

Smelting Furnace BOI (fig. 43) was a bowl=shaped pit dug into the slightly sloping virgin surface. A packing of small-sized rocks in clay-like mortar was placed around the dug-out pit to strengthen the upper rim of the hearth. The upper part of the hearth, which had protruded above the level of the working floor, had curved inside and formed a copula. This could be clearly seen in the shape of a large section of the up-

Fig. 43. Dome-shaped smelting furnace BOI of the Early Islamic period at Beer Ora.

per furnace, found *in situ* at the refettled front of the furnace. The Beer Ora smelting furnaces were definitely domed bowl-furnaces and, even compared to the advanced tapping furnaces of the New Kingdom, showed a more sophisticated furnace construction technology.

The smelting hearth itself had slightly tapering walls, a diameter of *c*. 55 cm and was *c*. 30 cm deep (up to the present surface), with a clayish mortar lining of 1–3 cm, found heavily sintered and slagged on its upper parts, especially the back wall. The latter indicated the location of the tuyere(s). As in all smelting furnaces of all periods in Timna, the bottom of the hearth showed no slagging and the lowermost lining of the hearth seemed to have been forcibly removed, together with the furnace contents, at the end of the smelting operation. The bottom of the hearth was also made of clayish mortar and this was found covered with a very fine, thin, light-grey cover of 'dusty' charred clay, typical for smelting installations.

In front of the smelting hearth a shallow tapping pit had been prepared, its unlined bottom was found to be grey-burned and covered with the same fine 'dusty' charred clay as the bottom of the hearth. The sandcore for the casting-in of the centre-hole in the slag 'cakes' was not preserved in Furnace BOI, but was found *in situ* in Furnace BOIV (Rothenberg 1990:57, fig. 88). Tuyere fragments were found on the slag heaps, but their too fragmentary state did not allow any detailed investigation.

The slag of Site 28 was of outstanding high quality. It was tapped slag of pyroxene type (Bachmann 1980: 114–116), i.e. it had a high contents of calcium oxides as well as iron oxides. Its main flux was iron oxides.[20] The slag was very homogeneous and contained only negligible traces of metallic copper. For this reason it had not been crushed but just discarded onto the slag heap. Many slag 'cakes' were very thick and showed several tap layers, one on top of the other, i.e. the smelters of Beer Ora operated as a continuous process and with repeated tapping. This fact, as well as the low viscosity and high density of the slag, indicated a very high standard of metallurgical knowledge and experience of the Early Islamic metallurgists in the Arabah. To reach such high efficiency and improved economy, involving reduced manpower and time and, especially, in order to save on the very sparse firewood in this arid region, a continuous furnace operation would have been necessary, involving repeated charging of ores and charcoal and tapping. This technique would have conserved for a considerable span of time the high temperature of the furnace and make any repeated, fuel-absorbing, pre-heating unnecessary.

Around the large slag heaps were several smaller piles of slag, which, on excavation, turned out to be ruins of slag-built workshops, a workers kitchen and, perhaps also some habitations. Near the furnace site, slag 'cakes' were found stuck into the ground side by side, forming a very low, rectangular, fence-like structure, with an apsidal niche facing south. Apparently, this 'structure' was intended as a demarcation of cultic significance, similar to the early mosques in the Negev mountains and in the Sinai. At the conclusion of the investigation of the pottery from Beer Ora and identification of most of its pottery as Early Islamic, it became obvious that this 'structure' was indeed one of the earliest 'open mosques' with its *mihrab* pointing towards Mecca (Rothenberg 1988b).

The pottery of Site 28, and several sites in the vicinity of Beer Ora, was dated to the Roman period, mainly the 2nd century AD, and to the Early Islamic period, the 7th–8th centuries AD. Site 28 was one of several smelting sites of the Romans in the Southern Arabah, but was the centre of copper smelting in Early Islamic times in the region. The mines of the southern part of the Timna Valley (Site 95 and, probably, Sites 96 and 97) and, especially, the large mines of the W. Amram were the sources of ores for these industries.

9. METALLURGY AND WORSHIP IN THE TIMNA VALLEY

The concluding overview of the ancient sites in the Timna region discloses an impressive interrelation between sites of ancient worship and the mining and smelting activities. Each period had its own style, and location, of worship. We know of such interrelation of metallurgy and cult, in the widest sense of these terms, also from other regions of the Ancient World and also from many written documents of different people of different periods. Apparently there were close links between the dangerous work in the dark underground, the manipulation of fire and sulphur and the 'alchemic' interference with the nature of materials – and the urge for support from supernatural powers. It would need a

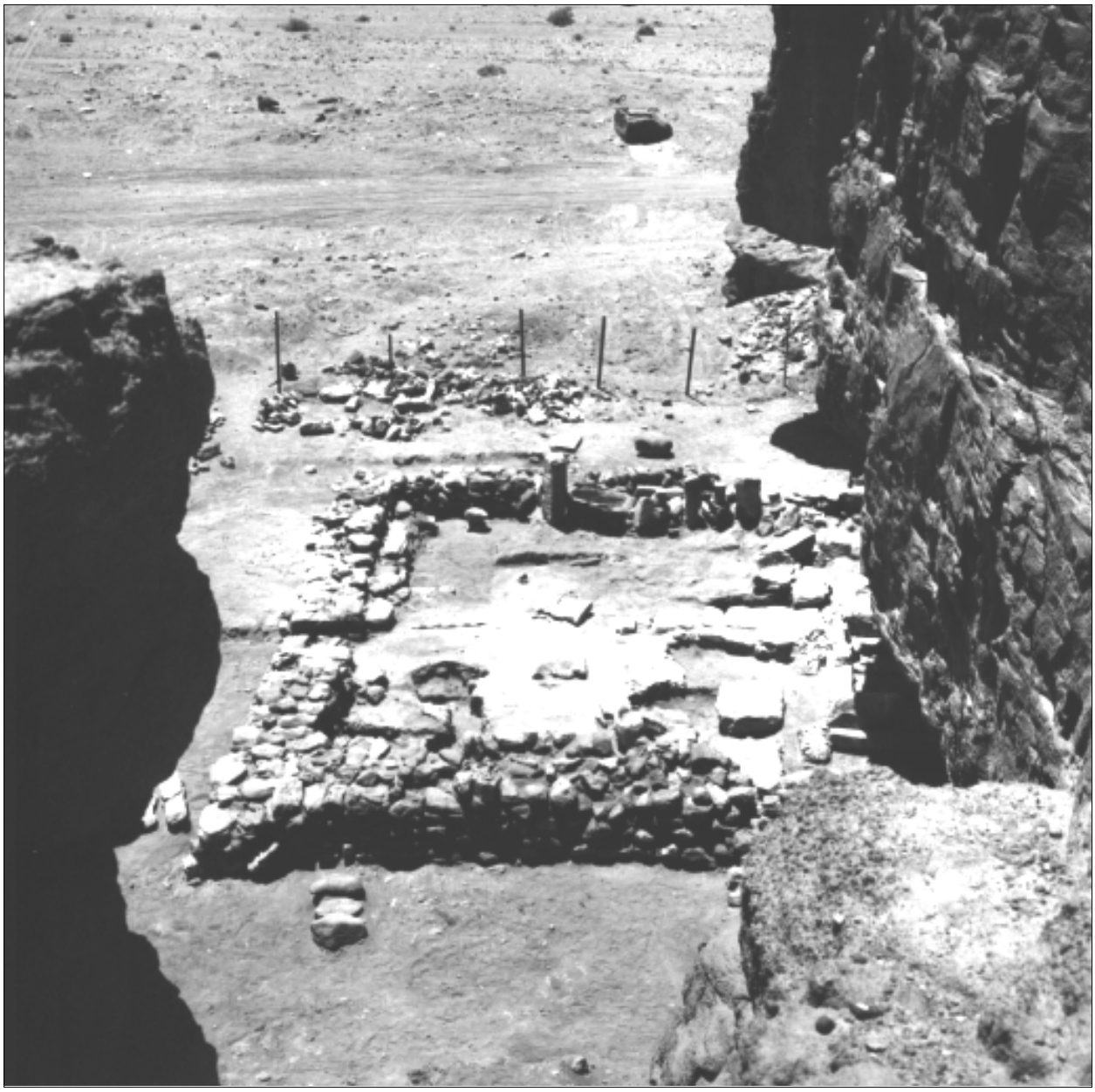

Fig. 44. The Hathor Mining Temple at Timna (at end of excavation 1969).

substantial separate paper to describe the many different cultic features in the Timna Valley, beginning with prehistoric cultic High Places with rock-altars and impressive rock-drawings, their peak the Hathor Mining Temple in the centre of the Egyptian New Kingdom copper industry, and their latest feature the 'open mosque' of Early Islamic times next to the smelters of Beer Ora. However, because of the importance of the Egyptian industries in the Arabah and the chronology of the sites of Timna, we shall conclude the present review with the description of the Mining Temple in the centre of the Timna Valley.

9.1 Site 200 (fig. 44), the site of the Hathor Mining Temple, was discovered at the foot of one of 'King Solomon's Pillars', a huge, picturesque, palaeozoic sandstone formations at the south-western end of Mt. Timna. Our attention was drawn to it already before its excavation by our expedition in 1969 and 1974 (Rothenberg 1972 and, especially, 1988), because of an unusual group of three rock-cut niches (Rothenberg 1988: pl. 86) under the rock-shelter, formed by the huge overhanging wall of this 'Pillar', and an adjacent low sand hillock which seemed to contain building debris of white sandstone. Since white sandstone was not locally available, we had assumed that a special kind of building must have stood here, now in ruins.

9.1.1 The earliest ancient remains at the site, Layer V, were datable by archaeological finds to the Sinai-Arabah Copper Age – Early Phase (Chalcolithic). This was a temporary, prehistoric habitation or camping site, like a number of similar sites we found all along the southern and western side of Mt. Timna. There were no architectural remains in this bottom layer (V), but several round, cup-shaped pits had been cut into bedrock

Fig. 45. Square Hathor Pillar.

and on a large boulder that had fallen down from above, apparently in an earthquake. Around these pits we uncovered occupation midden, like broken animal bones, ostrich eggshells, stone tools, pottery sherds and flint implements (Rothenberg 1972: pl. 42). It was of considerable interest to find here also copper ore nodules and lumps of crushed slag – evidence for primitive copper smelting in Layer V.

We did not consider the remains in Layer V as evidence for the existence of a prehistoric cult site, because further along the 'Pillars' we had discovered a huge rock with sun-like carvings on its upper surface – dated by Chalcolithic pottery found in a small stone enclosure attached to it – which we interpreted as a shrine of this period.

9.1.2 During the reign of Seti I (1318–1304 BC), a small Temple, 9 x 6 m, dedicated to the goddess Hathor, was built at the site, partly in the shadow of the huge overhanging wall of the 'Pillar' (Layer IV). The 'Midianite' pottery, found in this layer together with many objects of obvious Egyptian origin, suggested the partnership between Egyptian mining expeditions and the 'Midianites' from Northwest Arabia not only in the metallurgical activities, but also in the Hathor cult, from the beginning of the Egyptian presence at Timna. According to the finds also of Negevite pottery in Layer IV, it was evident that the workers in the Egyptian mines, originating from the Negev settlements of this period – which we proposed to identify with the Biblical Amalekites (Rothenberg 1967:86–100; 1972:153–154; 1979:122–123) – also took part in the Hathor worship from the time of the first Timna Mining Temple.

From this early phase of the Temple only a few features were found *in situ*. The excavation showed, that prior to the rebuilding of the Temple during the reign of Ramesses II (Layer III), the first Temple had been almost completely devastated. When the Temple was re-erected, a thick floor of crushed white sandstone (the 'white floor') was laid, probably taken from the debris of the Seti I Temple. On this white floor, which was laid over the area of the whole site, a larger courtyard was built, 10 x 9 m, including a *naos*, 2.70 x 1.70 m, built of well-dressed white sandstones and a *pronaos*, built of large and flat white sandstones. The front wall of the courtyard was also built of white sandstones. Obviously, the builders of the second Temple intentionally brought to the site white sandstones from the copper-bearing white sandstone formation of the mining region. No doubt, at sunrise, when the first rays of light across the Mountains of Arabia hit the white Temple, it must have been an amazing sight. It appears likely that this intentional connection between the white Hathor Temple and the white Timna mines also had ritual, cultic significance.

The function of the three rock-niches in the wall of the 'Pillar' became clear during the excavation of the site. At each of the two east corners of the *naos*, a very well dressed square stone was found, which had served as the base of a square pillar (fig. 45) with a head of Hathor on two sides, carved in high relief – similar to the famous 'Hathor pillars' at the Egyptian Hathor Temple Serabit el Khadim in Sinai. These two Hathor

Fig. 46. Faience plaque of Hathor.

Fig. 47. Faience ring-stand with cartouche of Ramesses III.

pillars, found in the excavation not *in situ*, must have carried one end of the beautifully decorated architraves (Rothenberg 1988: pl.110/1) of the roof of the *naos*, whilst two of the niches in the rockface behind the *naos* served as sockets for their other ends. The third, central, about man-high niche may have housed a statuette or a stele, several of which, related to the cult of Hathor, were found in the excavation (not *in situ*).

More than ten thousand votive gifts were uncovered by our excavations in the courtyard of the Temple, many of which had been brought there from Egypt, like pottery, stone and alabaster objects, faience beads, various stands, decorated faience bowls, glass vessels and jewellery, gold adornments, faience figurines of animals, ushabtis, amuletic wands, seals, plaques, scarabs and amulets. There was a number of Hathor plaques (fig. 46) and faience bracelets, amulets, jar stands and one glass amulet, and various other faience object, bearing hieroglyphic inscriptions, some with cartouches of the 19th–20th Dynasties, from Seti I to Ramesses V (fig. 47). These Pharaonic cartouches, found in Layers III–IV, provided the solid archaeological evidence for the dating of the Temple.[21]

Besides the Egyptian votive gifts, very many offerings had been brought to the Hathor Temple by the Midianites, like f.i. a phallic figurine made of tin-bronze, cast locally (found partly still with its mould), a ram figurine made of bronze and many bronze finger rings, amulets, earrings and armlets. There were also thousands of beads made of Red Sea shells.

Some of the pottery vessels found in the Temple had particular beautiful shapes, but belonged to the same types of pottery – Egyptian, Midianite, Negevite and ordinary, wheel-made local vessels. This fact was of fundamental importance for the dating of the mines and smelting camps of Timna and the Southern Arabah.

In the courtyard of the Temple, a small casting workshop had been operating, where copper and bronze votive offerings were made. In this part of the Temple was a considerable accumulation of fine woodash, but also crucible fragments and small bits of slag. According to the metallurgical evidence, especially copper-rich lumps of smelting slag was sent to the casting workshop of the Temple for the separation in crucibles of the copper from the slag – and for its casting into votive offerings for Hathor. It is of particular interest that among the finds in this workshop also metallic tin was found, obviously for alloying with the local copper for tin-bronze and/or to facilitate a better cast by the addition of some tin.

9.1.3 In the middle of the 12th century BC, the Egyptians withdrew from the Levant and also abandoned their copper industries in the Southern Arabah – and the Hathor Temple at Timna. The Midianites were left behind and took over the Temple. We could not estab-

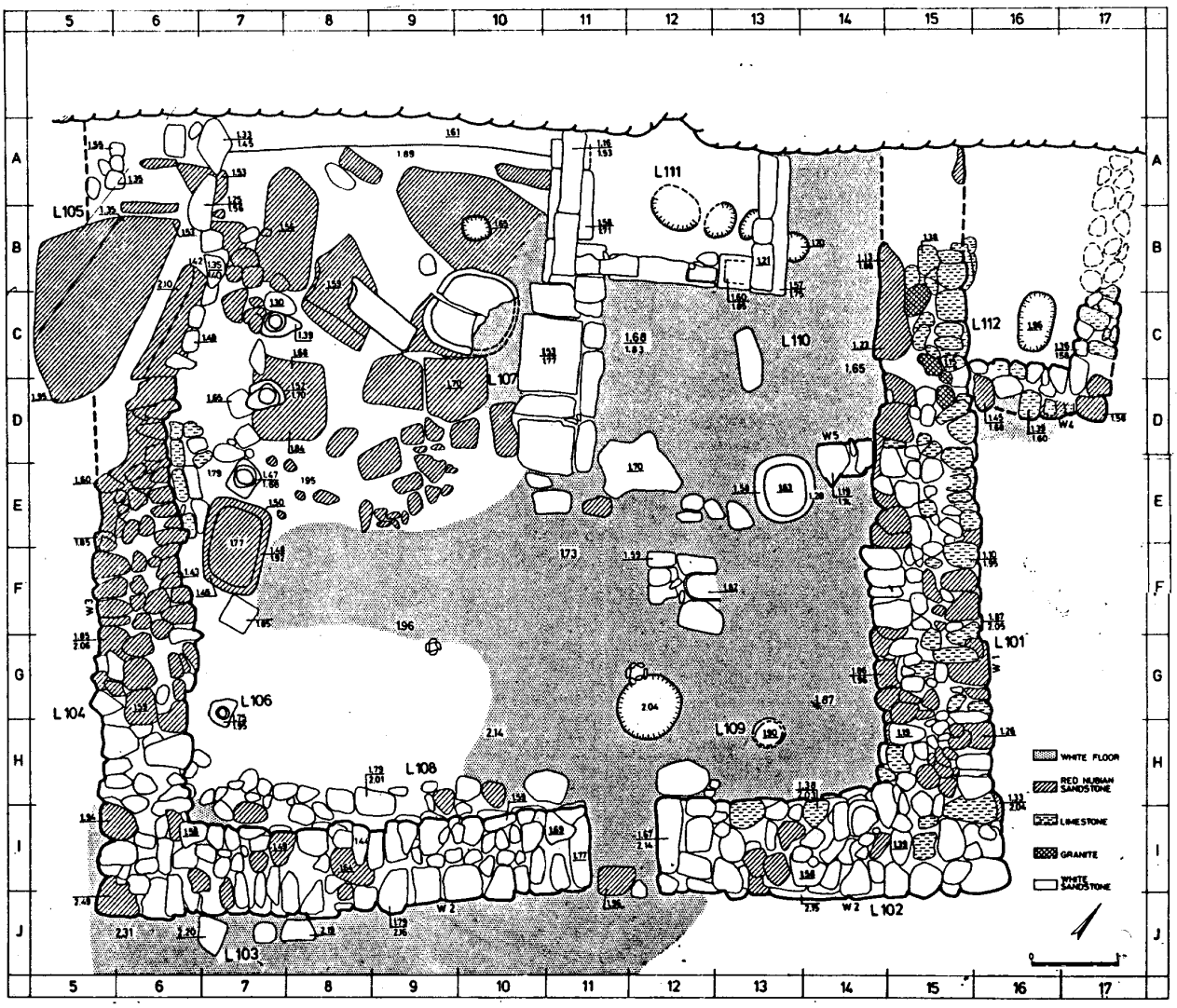

Fig. 48. Plan of the Timna Mining Temple at the end of excavations 1969, showing, mainly, its Midianite phase. The 'White Floor' was the floor of the Ramesses II Hathor Temple.

lish in the excavation, what had caused the destruction of the Hathor Temple – an earthquake or a huge rock-fall from the top of the mountain above – but it became clear that the Temple had been at least partly destroyed when the Midianites turned it into a typical, local, semitic shrine – Layer II of Site 200 (fig. 48). The Midianites dumped most of the Egyptians remains into the northwest corner of the courtyard. A line of stones was laid on top of the partly demolished east wall as demarcation of the new Temple area. Alongside this wall, a line of stelae, 'mazoboth', was erected from monoliths and Egyptian architectural fragments from the previous Temple, among which was a Hathor pillar, several incense altars and other square pillars, some of the latter showing traces of hieroglyphs. It is important to point out, that all of the Egyptian stone sculptures were dumped onto the heap of debris pilled up in the corner of the courtyard, and that the Hathor images on the Hathor pillars were obviously intentionally almost completely defaced.

A 'bench of offerings' was built along the inside of the wall on both sides of the entrance to the courtyard, and a small annex was attached to the outside of the east wall of the courtyard, apparently for the use of the priests. All along the western and eastern walls of the courtyard, bundles of thick woollen cloth were found. Some of these were red and yellowish, and small beads had been woven into the cloth. This was tent cloth, parts of a tent that covered the Midianite shrine. There were socket-like postholes in the floor of the courtyard in its Midianite phase – additional evidence for a tent-cover of the shrine of Layer II. The central niche of the *naos* remained empty, but closeby a copper serpent with a gilded head (fig. 49) was discovered. It was the only votive object inside the Midianite *naos* – a find that brought to mind the Biblical narrative of the 'Nehushtan', the 'brazen serpent' (*Numbers* 21:9) of the *Exodus* story. It is the first time that Midianite culture and worship has come to light as temple architecture and votive objects. The last, Midianite, phase of the Temple as a tented shrine also suggested a connection with the desert tradition of the Tabernacle. Timna may thus provide a factual background to the early part of the Exodus narrative.

Fig. 49. Copper serpent with gilded head from the Midianite tented shrine – the last phase of the Mining Temple at Timna.

In the Midianite Layer II, remains of metal working were discernible, with the use of Egyptian metal votive objects as raw material. Stratigraphically, the metallurgical workshop of the Midianite shrine was a continuation of the casting workshop of the previous layer and it seemed probable that Midianite metallurgists had actually worked there together with, or for, the Egyptians.

The excavations did not provide evidence for the end of the Midianite presence at Site 200. However, according to the data from the smelting camps, where the Midianites apparently continued work after the Egyptians failed to return, the Midianites did not stay for long. The Midianite shrine was soon abandoned and sometimes later, an additional huge rockfall covered most of the site. This natural disaster marked the final end of the Timna Temple.

Site 200 became slowly covered by driftsand. During the Roman period, sometimes between the end of the 1st and the 3rd centuries AD, the site was used as a camping site which left nothing behind besides a handful of pottery sherds. It appears that the Roman campers noticed the ruins underneath and dug a hole near the former *naos*, to look for 'treasures'. During these activities several white building stones were brought to the surface and left there – to draw our attention to Site 200 almost two thousand years later.

Acknowledgments

During the more than 30 years of research, numerous institutions and persons have assisted the author in many ways – and it would need a very long list to acknowledge and thank them all. However, besides the scientists referred to above as my research associates – whose contribution to my work was manyfold and of fundamental significance – I would like to express my deep gratitude to the trustees of IAMS London during more than twenty years, and especially Nigel Lion, Dr. Felix Posen, Sir Sigmund Sternberg and Milton H. Ward, as well as to my research assistant for many years, Judith Gavish, who has been in charge documentation, mapping, editing, personnel, for her absolute reliability and loyal friendship.

Without the generous support of the Volkswagen Foundation – our main supporter for many years, Rio Tinto Zinc London, and Cyprus Amax Minerals Company, our long-range field work in the Arabah, the laboratory research and our publication programme would not have been possible.

The present paper was submitted 15.10.1995 by Prof. Beno Rothenberg, Director of the Institute for Archaeo-Metallurgical Studies (IAMS), Institute of Archaeology, University College London, 31–34 Gordon Square, London WC1H 0PY, England. It was sent in final form 14.4.1997.

NOTES

1. The Jordanian side of the Arabah was closed to Israeli archaeologists and we had to stop work at the international border between Jordan and Israel, along the middle of the Wadi Arabah.

2. It is somewhat difficult to find the right geographical term for the part of ancient Palestine within the present international borders and in the literature we often find 'Holy Land', 'Land of the Bible', the 'West Bank', 'Land of Israel' and others. We adopt here the latter term, meaning thereby the area of the State of Israel.

3. 'Timna' is a new name given in the early 50th to the geographical unit contained by the semi-circular 'Timna Cliffs'. The main wadi of this area appears on the old maps and in the literature as Wadi Mene'ijeh.

4. I wish to express here the extremely important contribution by the late Yohanan Aharoni, head of the Institute of Archaeology Tel Aviv University, especially to the ceramic aspects of my work in the Arabah. It was Aharoni who first recognized that the sherds of Site 2 ,the first site excavated by my group, must be dated to the Late Bronze Age, and not, as previously assumed by us, to the time of King Solomon.

5. Sites F2 and 39, described here, belong to the Sinai-Arabah Copper Age – Early Phase. Since this 'Phase' covers a very extensive period of time, a closer dating of sites is of course commendable, wherever possible by archaeological context and comparisons (Rothenberg and Merkel 1995).

6. Bachmann in his excellent paper on the Sinai and Timna slag (1980:103–119), used a large lump of 'furnace conglomerate' found on a slag heap in W. Amram as representing a very primitive, incipient smelting process. As Bachmann rightly assumed, this was in fact 'an extinguished bowl-furnace charge' containing still a lot of unburned charcoal, decomposed ore nodules, fragments of gangue and globules of copper, and actually represents an interrupted smelting process. Since it was dated by C14 to the Early Islamic period, when extractive metallurgy was already at its peak (Rothenberg 1988a:1–4; 1988b:54–63), and it was found in a heap of tapped slag of the same date, we may assume that it was the product of an interrupted smelting process. This sample should now be replaced by slag from Site F2 as representing incipient copper smelting at an early, prehistoric copper smelting site.

7. For further documentation of the hammer types from Mine T see Conrad and Rothenberg 1980: Abb. 196–198.

8. The first shafted hammers were already found during our 1959–1962 surveys. Since the (unexcavated) mine workings of Site 212 known in 1972 indicated wide-spread Ramesside New Kingdom activities, and no prehistoric underground workings had been identified at that time, we believed these tools to belong to the New Kingdom (Rothenberg 1972:pl. 20). However, in 1974 the same tools were found in the excavations of the Chalcolithic underground workings Mine T (see below), accompanied by typical hammer tool-marks on the walls of the mine (contrary to Craddock 1995:64–69, who simply got all details of the Timna mines totally wrong, perhaps because he could not understand the German report Conrad and Rothenberg 1980), there can be no doubt about the early date of these tools, none of which were ever found in the extensively excavated New Kingdom workings.

9. In the 80th we returned to Site 39 for further excavations. During this work further finds of flint implements and pottery sherds were recorded, especially around the smelting furnace at Site 39b.

10. According to Bachmann, the 'furnace slag' of Site F2 contained as dominant phase oxides of spinel type, but also fayalite, pyroxenes and others. Recent investigations of the whole range of slag from the prehistoric sites of the Southern Arabah and related sites in the Negev and Sinai, by J. Merkel and others, will be published in the monograph Rothenberg and Merkel, *The Prehistory of Copper*, in preparation.

11. Fragments of a slagged Ghassulian-Beersheba culture Chalcolithic smelting furnace was recently found at Tell Abu Matar, near Beersheba (Gilead, Rosen and Rothenberg 1992), together with smelting slag. The metallurgical finds from Abu Mater are now being investigated by Dr. J. Merkel, IAMS London.

12. The excavation of Site 201A was supervised by Dr. Ivan Ordentlich, staff member of the 'Arabah Expedition'.

13. All the pottery from the surveys and excavations in the Arabah – and Sinai – was petrographically investigated by J. Glass. The final report of this work will be published in the forthcoming volumes of Rothenberg and Shaw (eds.), *Researches in the Arabah*, Vol. III, 1–2, and in Rothenberg and Merkel, *The Prehistory of Copper, IAMS Monograph Two*, also forthcoming.

14. The slag from Site 201A was investigated by Evelyn Krawczyk in 1986/7 as part of a comprehensive chemical and mineralogical study of slags from all smelting sites in the Southern Arabah. The final report (Krawczyk and Rothenberg forthcoming),will be published in the IAMS series *Researches in the Arabah*.

15. Since the ores of the Northern Arabah mining region of Feinan were very similar to the ores of the Timna Valley, it seems possible that 'bar-shaped' ingots were also made there. Further work on this problem is needed.

16. Very similar tuyeres were also found at the New Kingdom smelting site of Bir Nasib in Southern Sinai, a site which had very much in common with the Egyptian New Kingdom sites in the Arabah. The Bir Nasib smelter was, however, also in operation during the Egyptian Middle Kingdom (Rothenberg 1987:1–7).

17. In 1989–1990, IAMS returned to the Arabah for further excavations. L. Willies, Peak District Mining Museum, Derbyshire, England and C.T. Shaw, Royal School of Mines,

Imperial College London, directed the survey of the underground workings at Site 38, C.T. Shaw also undertook a detailed survey of Site 33 and of the mines of Timna, including the mine workings investigated in 1974–66 by the Arabah Expedition in collaboration with the German Mining Museum Bochum, in connection with the final publication Rothenberg and Shaw (eds.) forthcoming.

18. The pottery from W. Amram was first identified by M. Gichon, Tel Aviv University, and subsequently prepared for publication by Z. Shaham (in Rothenberg and Shaw forthcoming).

19. As far as is known to us, this type of slag 'cake' is unique to the Southern Arabah and its earliest appearance is in the New Kingdom smelter Site 2, Layer 1. It is a relative 'newcomer' also in the Ramesside copper industries of Timna and may have been invented at this site. For the dates of these slags see Rothenberg 1990: Endnote 23.

20. From the analyses of the slag, Bachmann (1980:114–116) inferred the use of lime as a major fluxing constituent of the smelting charge. However, experimental studies by Merkel (1990) showed that fuel ash can be identified as the source for most of the calcium in the slag. Since CaO occurs in the copper ore of the Avrona formation, exploited in Roman and Early Islamic times, it seems rather likely that the calcite was part of the gangue, which, in addition to the fuel ash and high calcareous furnace lining, produced the high calcium contents of the Beer Ora slag, the reason for the need at Site 28 of a furnace temperature above 1300°C. In this connection we should remember the obviously unintentional high calcium contents of the early, Chalcolithic slag – which had caused great problems to the ancient smelters (see above).

21. All the finds of the Temple were published in Rothenberg 1988. In the final report of the Temple excavations (Rothenberg 1988) the archaeologists dated the strata of the Temple according to strictly stratigraphic criteria, which from the methodological point of view should of course be decisive. Shulman (1988), based on purely egyptological considerations, proposed a varied chronological scheme of the Temple, and Pinch (1993), based on her analytical comparisons of the small finds, suggested a slightly earlier date for the erection of the first Temple at Timna.

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