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Persian-Period Metal Finds from Tel Mikhal (Tel Michal)

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More than 100 metal objects dated to the Persian period (fourth to fifth centuries BCE) were found during the 1996 IAA excavations at Tel Mikhal.[2] The assemblage includes: weapons (arrowheads); tools and implements (e.g., knives, needles, nails and tacks); weights (mainly for fishing); and jewelry (bracelets, fibulae, pins and spatulae). A collection of 340 metal objects dating to the Persian period, uncovered in the 1977–1980 excavations (Muhly and Muhly 1989), offers the nearest parallel. Together, both groups comprise one of the most important Persian-period assemblages of metalwork from Israel.

All the objects from the 1996 excavation were uncovered on the Northern Hill (Appendix 1). A representative collection of these objects was analyzed and compared to previous results from the 1977–1980 excavations (Lupu 1989). Typological parallels exist at Haifa, Tel Megadim, Tell Keisan, Nahariyya and Ashdod.

A select group of copper and copper-based objects have been analyzed and tested metallographically. All types of artifacts were analyzed and totalled approximately one-quarter of the metal objects found. The chemical and metallurgical analyses included:

(A) Chemical microanalysis by electron X-ray probe to determine the precise X-ray wavelengths and their intensity for qualitative analyses of specific elements' trace concentrations present in the sample (Appendix 2).

(B) To examine the metal microstructure, metallographic analysis by optical and electron microscopy was used to interpret the method and conditions of casting each object, in addition to discerning later thermo-mechanical treatment (Appendix 3).

Weapons

Arrowheads (Fig. 1).— This group includes five arrowheads, ranging in size from 24.0 to 39.2 mm long and 8.5–11.5 mm wide. The entire group belongs to the Irano-Scythic type. These are triangular in shape, with three fins that are wide at the base, and disappear toward the upper point. Similar arrowheads were found at Tel Megadim[3], Tell Keisan (Briend and Humbert 1980:323), Tel Shiqmona (Elgavish 1968: Pl. LXII), Nahariyya (Ovadia 1993:22; 27; Dothan and Porat 1982:171) and Ashdod (Porath 1974:54).

Both samples were made of tin bronze with lead inclusions, and show corrosion from the surface. The shape and size of the dendrite arms indicate a relatively rapid cooling for No. 3 and slow cooling for No. 4 (Fig. 2). The arrowheads were left as cast without any posterior mechanical or thermal treatment. The system

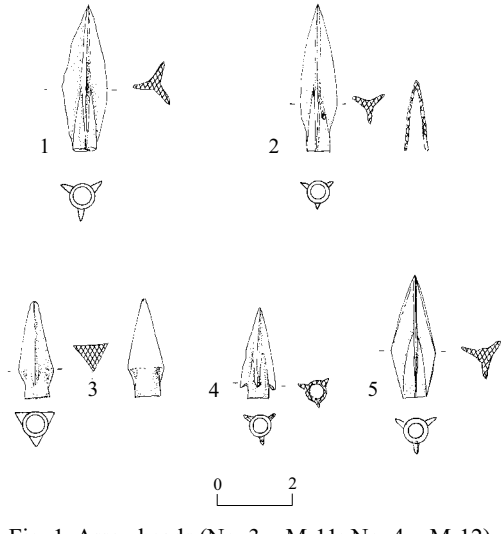

Fig. 1. Arrowheads (No. 3 = M-11; No. 4 = M-12).

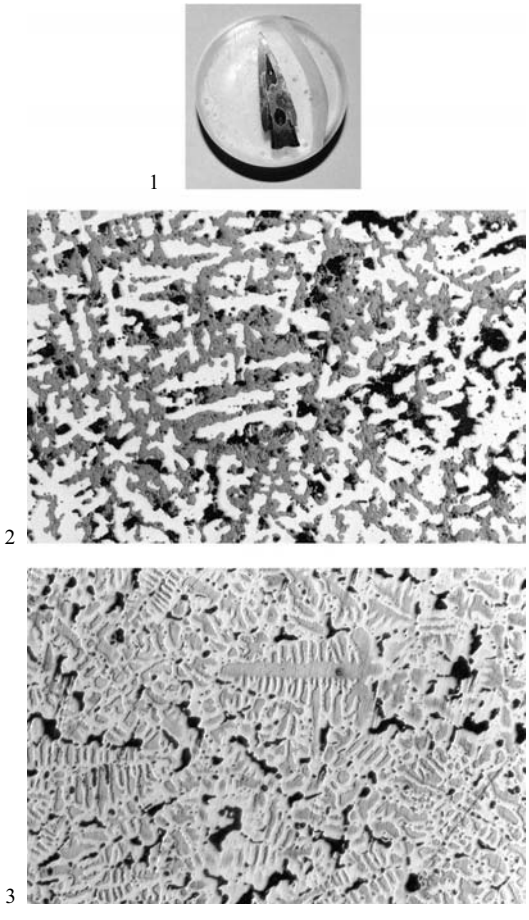

Fig. 2. (1) sample M-12 arrowhead; (2) unetched corrosion: interdentritic structure; (3) etched: the dentritic structure.

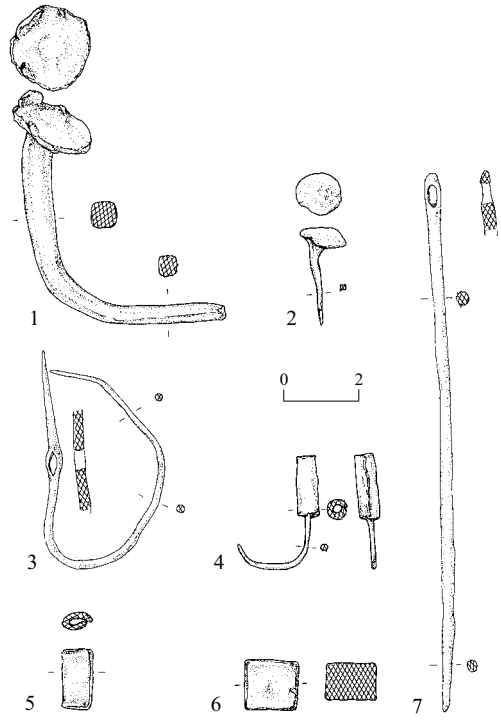

Fig. 3. (1) nail (M-18); (2) tacks; (3) needle (M-14); (4) fish hook (M-9); (5) net weight; (6) line weight; (7) needle (M-1).

used in the production of these arrowheads was probably 'lost-wax casting'.[4]

Tools and Implements

This group includes the implements used in daily life: nails, needles and pins, knives, an ax, spatulae, fish hooks, weights and a bucket handle.

Nails (Fig 3:1).— Both large and small nails were found. The long nails are 35.0–148.5 mm in length and 4.5–7.5 mm wide. Most have a square-sectioned shank and faceted head. In some examples the shank was bent at an angle. The small nails were classified as tacks and are of varying sizes, all with short, thin shanks and circular heads.

Each of the six analyzed samples was corroded to varying degrees. The shank structure showed equiaxed grains and twins, and most were hammered after casting (Figs. 4, 5).

Needles and Pins (Fig. 6).— The difference between needles and pins lies in their shape. Needles have a plain or hooked head, while pins are straight. Both are very thin. Six needles were found, measuring 23.6–148.5 mm long and 1.3–3.6 mm wide. All are made wholly from copper, except No. 3 which contains 2.82% arsenic (see Table 2). This needle was found in a pit (L172) and could belong to the Middle Bronze Age. Only one pin has been found complete, it is 64 mm long and 2.6 mm wide. Good parallels were discovered at the site on the tell (Muhly and Muhly 1989:289–291), Ashdod (Porath 1974:43–55) and Nahariyya (Ovadia 1993:22, 27).

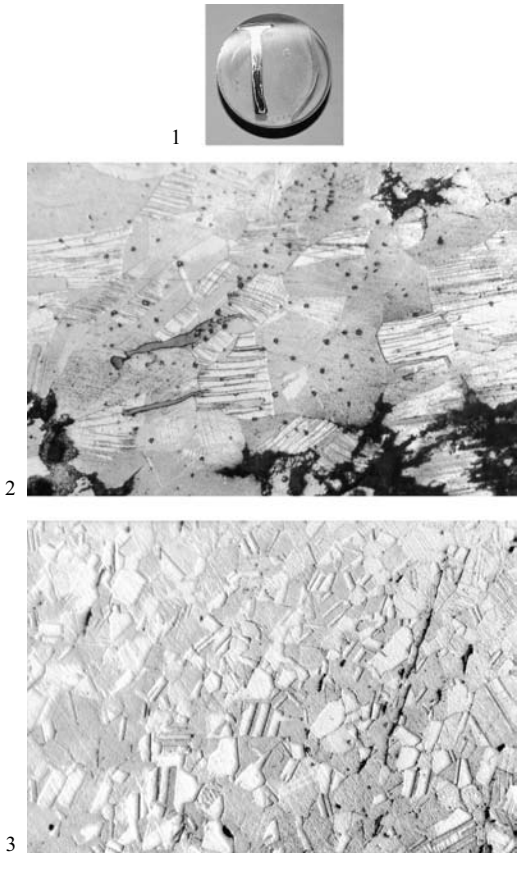

Fig. 4. (1) Sample M-19 nail; (2) Equiaxed grain structure with twins and slip lines; (3) Equiaxed grains with twins and elongated inclusions.

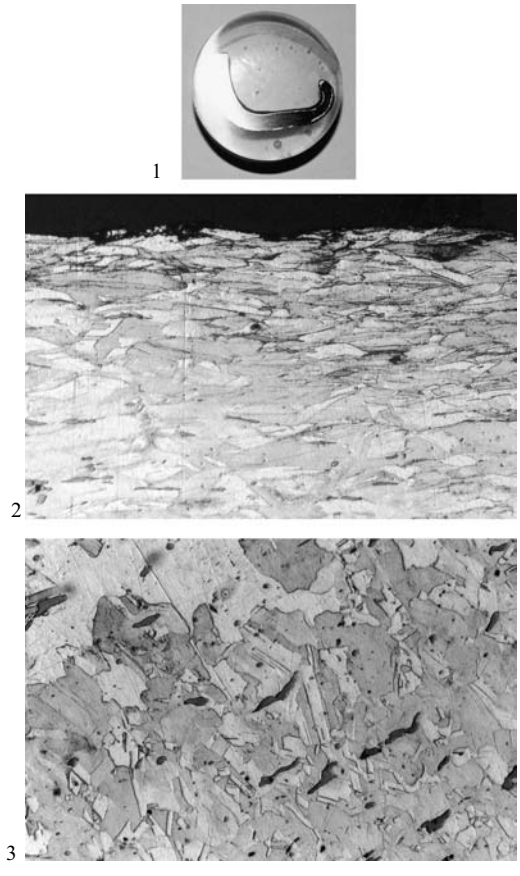

Fig. 5. (1) Sample M-23 nail bent to an angle; (2) Deformed grains with slip lines at the area where the nail was bent; (3) Equiaxed grains with twins indicating annealing in center.

The needles were worked after casting by cycles of hammering and annealing. The central parts of the needle remain annealed while hammering hardened the point in the final phase of manufacture.

Knives.— Two irons knives and two handles were found.[5] The knives belong to a small type (54.0–54.3 mm long and 12.0–21.4 mm wide). The handles seem to belong to a large type (80–117 mm long and 21–24 mm wide). Good parallels to these knives were also discovered on the tell (Muhly and Muhly 1989:272–273) and at Nahariyya (Ovadia 1993:22).

Ax.— One iron ax (170 mm long and 59.3 mm wide) was found, but has not been analyzed.

Fishhook (Fig. 3:4).— A complete fishhook is made of a bronze shank (18.2 mm long and 1.6 mm wide) and a lead weight (16.4 mm long and 6.4 mm wide). The general weight of this hook is 4.24 g. Two parallels were found at Tel Shiqmona (Elgavish 1968: Pl. 38), but this is the only complete example.

Weights (Fig. 3:5, 6).— Lead weights, including those used for fishing, were found: one net weight (No. 6) and four fishing weights (No. 5). Similar weights were uncovered in the 1977–1980 excavations at Tel Mikhal (Muhly and Muhly 1989:281–282), Tel Megadim and Ashdod (Dothan and Porat 1982:171). Twenty-seven weights were found at excavations along the Israel coastline, all made of lead except four of bronze.

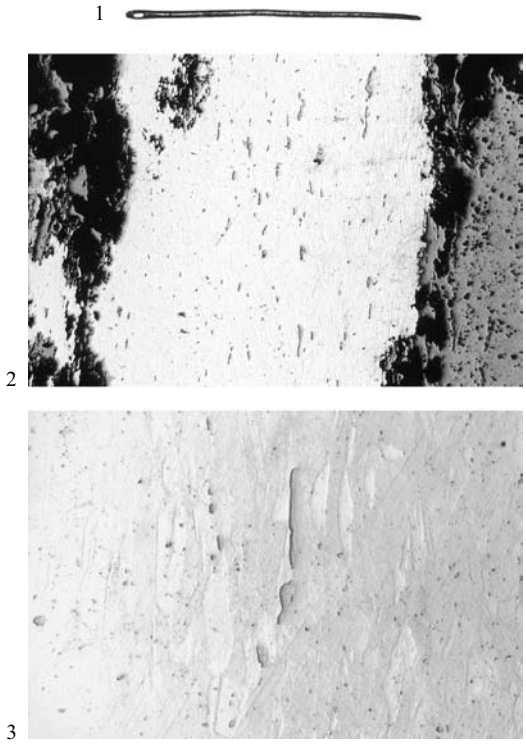

Fig. 6. (1) Sample M-1 needle; (2) Etching at the point edge: slip lines with distortion crystals; (3) Equiaxed grains, homogenized structure, twins and elongated inclusions.

Handle (Fig. 7).— One bronze handle was uncovered. The handle has a circular section and seems to have belonged to a large bronze bucket. Two nails connected the handle to the body. No similar handles have been found dated to the Persian period. A similar handle dated to the Hellenistic period, from a private collection, can be seen in the Hecht Museum in the University of Haifa.

Cosmetic Sticks (Spatulae).— All were found broken except for one, with a straight edge similar to those uncovered in the 1977–1980 excavations. All three are made of tin-bronze (7% tin). They measure 21.7–105.5 mm long and 2.2–2.8 mm thick.

Jewelry

The jewelry group includes rings, bracelets, earrings, a bead, fibulae and an amulet.

Rings (Fig. 8:1).— Two types of finger rings were found, with either a square or circular section: they measure 23.5–86.0 mm long, 3.2–9.0 mm wide and 0.6–3.8 mm thick. One

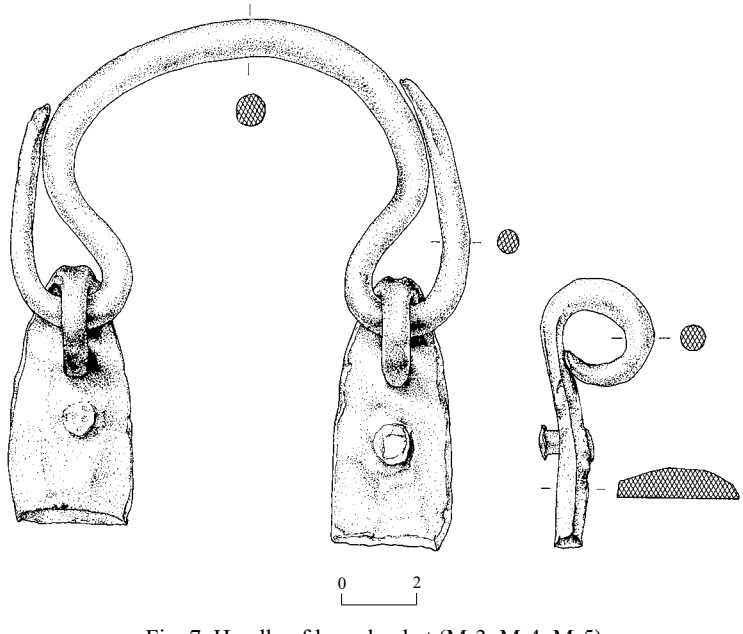

Fig. 7. Handle of large bucket (M-3, M-4, M-5).

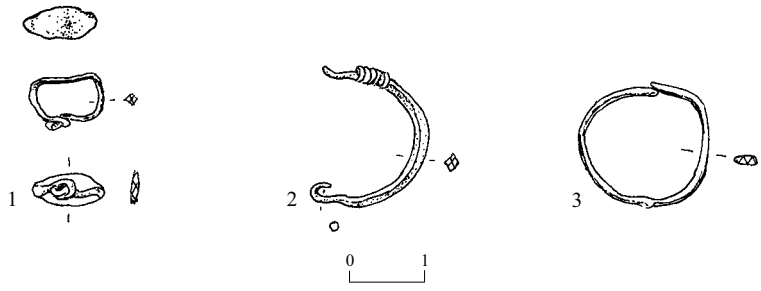

Fig. 8. Jewelry: (1) finger ring; (2, 3) earrings.

of the rings is very small (Fig. 9), and probably belonged to a child.

Bracelets.— All the bracelets have a circular section and are made of tin bronze (64–95 mm long and 2.5–7.5 mm wide). Similar bracelets were found in the 1977–1980 excavations at Tel Mikhal (Muhly and Muhly 1989:286–288; Herzog and Levy 1999:6–16).

Earrings (Figs. 8:2, 3).— Two earrings, one of bronze and the other of silver, measuring 39–50 mm long and 1.8–2.5 mm thick, were found. The silver earring (M-8) was analyzed.

Bead.— One silver bead was analyzed (M-6). Its size is 4–6 mm. A similar bead was found in the 1977–1980 excavations (Muhly and Muhly 1989:283) and in 1993 north of the cemetery (Herzog and Levy 1999:11, 16). This bead is made of silver mixed with copper (30% Cu). It has a cast dendritic structure: dendrites containing silver with 30% copper and an interdendrite phase almost completely made of silver and only 3% copper. After casting, it was left without any later thermo-mechanical treatment.

Fibulae (Figs. 10, 11, 12).— Most of the fibulae are semicircular in shape with decorated bows. All nine tin-bronze fibulae of the ribbed-bow type ranged in size between 51.0 and 104.5 mm long and 1.6–3.8 mm thick. Similar fibulae were found at Tel Megadim (as yet unpublished), Tel Mikhal (Muhly and Muhly 1989:288–291), Shiqmona (Elgavish 1968: Pl. 64), Nahariyya (Ovadia 1993:22; 27), Ashdod (Dothan and Porat 1982:171; Porath 1974:49–55) and Tell Keisan (Briend and Humbert 1980:324).

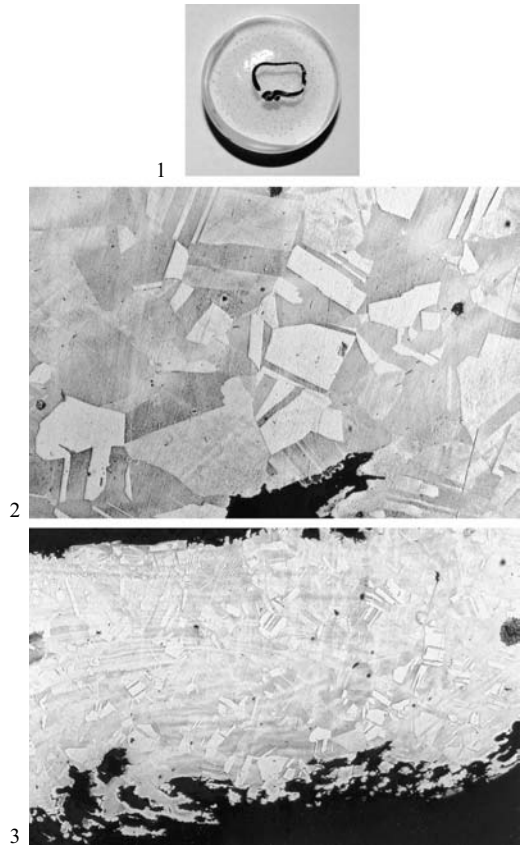

Fig. 9. (1) Sample M-7 finger ring; (2) Equiaxed grains with twins; (3) Deformed grains observed at the side of the object.

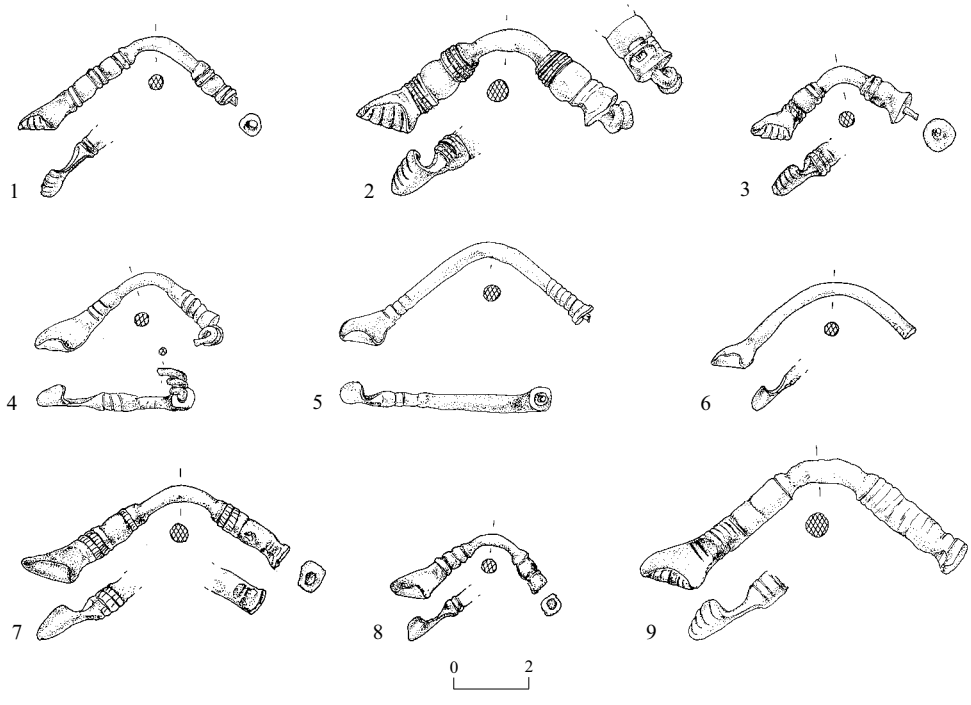

Fig. 10. Fibulae.

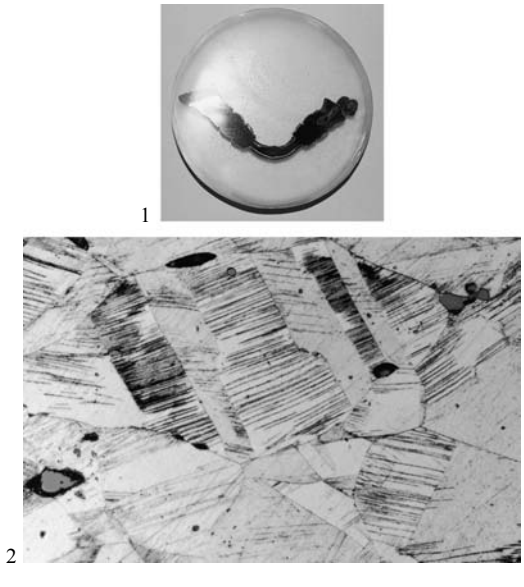

Fig. 11. (1) Sample M-17 fibula; (2) Equiaxed grain structure with slip lines.

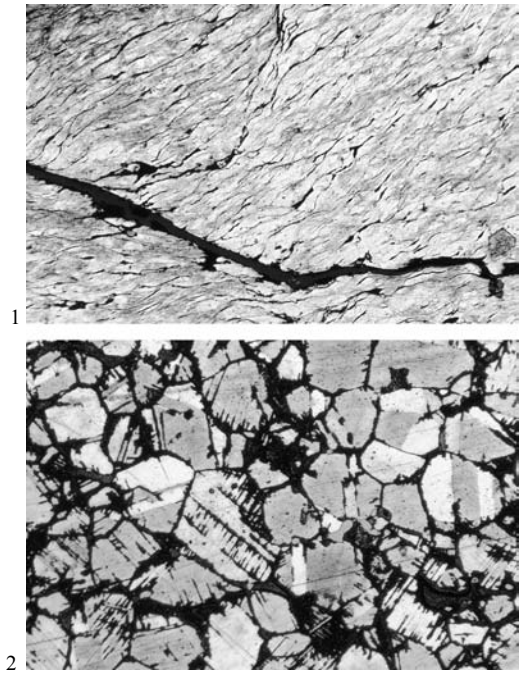

Fig. 12. Sample M-17 (cont.): (1) Equiaxed grains with inclusions at the inner part of the fibula; (2) Highly deformed grains and signs of chasing.

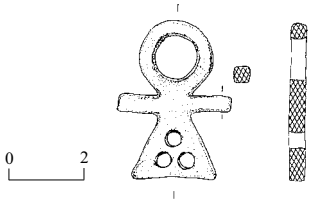

Fig. 13. Tanit figurine (M-26).

Tanit Figurine

A statuette of the Phoenician goddess *Tanit* was uncovered (Gorzalczany, this volume). Made of tin bronze, it measures 41 mm long, 29.7 mm wide and 4.8 mm thick (Fig. 13). In Israel three similar goddesses were found, all of them at Ashqelon, and are dated to the Iron and Persian periods.

Tanit, the moon goddess and goddess of fecundity, was considered the sky goddess of Carthage who ruled the sun, moon and stars. She created all life by giving birth to herself without the help of a male partner. She was considered bisexual and was also known as *Tanit Pnei Baal* (the face of Baal).

All the *Tanit* symbols discovered during the excavations are similar in shape with a circular face (representing the moon), triangular body and both arms extended to her sides or stretched up to the sky.

An Egyptian Amulet

A small pendant of an Egyptian god was found in the vicinity of the Persian-period cemetery in April 1996 (L706, No. 7029; see Gorzalczany, this volume: Fig. 1). After undergoing cleaning and preservation at the IAA laboratories, the archaeometallurgy of the amulet was examined in the Archaeological Sciences Laboratory at the Weizmann Institute.

Macro-surface examination with an Olympus ZS40 zoom stereoscope shows that the amulet was cast in a closed mold. The sprue, or top hole through which molten material is channelled was at the foot, while the head with its complex hat was at the bottom of the cast. Unfortunately, the thorough cleaning of the surface may have erased signs on the cast that might have indicated the use of a multi-sectioned mold. Therefore, we have no evidence whether the original mold, was made of a single piece or more. The relatively small dimensions of the amulet,[6] as well as the even ridge at the base, might indicate the use of a single closed mold possibly made of clay or sand. The amulet was cast face down. The small depression visible in the center of the base probably resulted from the shrinkage of the upper, open part of the cast during solidification. The ring at the back of the amulet's head, just below the base of the hat, was cast originally as a solid knob. The ring hole probably was drilled soon after casting. Signs of right to left drilling are visible. These show a smooth rim due to compression on the right side of the ring and slightly elevated edges due to pressing out material, on the opposite side.

The amulet's chemical composition was analyzed by Eugenia Klein with an ISIS 300 energy dispersive spectrometer (EDS) on a JEOL 6400 scanning electron microscope (SEM) in the Weizmann Institute of Science. Since the amulet is small, there was no need to cut or drill a sample for this test. Rather, we set the whole object inside the electron microscope's vacuum chamber. Several different areas of the amulet surface were analyzed and compared. Yet, due to the fact that the cleaned surface of the amulet is not smooth and even, quantitative analyses are less precise and therefore based partly on estimation and calculation.

All the visible, gray-metal regions on the surface were composed mainly of lead (Pb) with low percentage of tin (Sn). Even though the surface was partly oxidized, identical spectra were found in the head area, the lower part of the body and the base of the amulet as well. In some hidden parts, for example in the folds of the skirt, slight remains of the original corrosion were observed. Most of this corrosion had been mechanically removed during the earlier conservation treatment. The brown, rust-colored corrosion contained the same metals, but with a much higher ratio of tin to lead, probably owing to chemical reactions with its deposition environment.

Scanning the entire amulet surface did not detect traces of other metals such as silver (Ag) or gold (Au). Due to the fact that these elements resist corrosion much better than lead or tin, their total absence indicates that the amulet was never coated. The presence of tin traces in the lead indicates that the raw material for the cast was based on re-melting of scrap. The melting point of both metals is quite close (237°C for lead and 232°C for tin), much lower than the melting temperature for most of the metals found in this period (for example, the melting point of copper is 1160°C). The color of these two metals is also relatively similar.

DISCUSSION

Among the correlated results of the metallurgical and the typological analyses several facts stand out. First, arrowheads have been found in all excavated coastal sites. In the 1996 excavations at Tel Mikhal, the five arrowheads found belong to the Irano-Scythic type, whereas others from the 1977–1980 excavations were Greek types.[7] At other sites this type was discovered alongside local types as well. Tin bronze (3–4% tin) was the preferred alloy for the production of the Irano-Scythic arrowheads uncovered in the 1977–1980 excavations at Tel Mikhal. This alloy contains c. 30% lead. In some cases they contain more than 50% lead. According to Lupu, lead was popular as an alloying component for certain objects due to its good casting properties and its cheapness as opposed to copper (Lupu 1989:301). All the arrowheads were left as cast without any further mechanical treatment.

Among the tools and implements found, nails were the largest group. Typologically, those with a long, square-sectioned shank are defined as 'nails', while the smaller examples are called 'tacks'. Similar examples have been found at all coastal sites, except Tel Samarya. These nails were made of unalloyed copper and tin bronze. Usually nails are made of copper, while tacks are made of tin bronze. The reason for this could be related to their mechanical and decorative properties. Tacks are usually used for household objects, and therefore are gold-like and hard, while the unalloyed copper nails are elastic and therefore more suitable for uses such as ship building or for furniture. All the analyzed nails underwent treatment after casting that included beating, hammering and annealing in order to attain the desired shape, size and degree of hardness.

The needles and pins have good parallels in all coastal sites except Tel Shiqmona and Tell Keisan. They are made of unalloyed copper similar to the objects found in the 1977–1980 excavations. Only one sample (M-14) was made of arsenic copper (2.8% As). The addition of arsenic to a needle is unusual for the Persian period. After checking the locus in which it was found (L172; probably a later pit dug into an earlier strata), we suggest that this find belongs to the earlier MB II period. Pins and needles were worked mechanically after casting. This included hammering the pin area to achieve a suitable level of hardness, while leaving the central parts softer.

Of 55 fibulae found on the coast of Israel, 31 (56%) were found at Tel Mikhal. The ten found in the 1996 excavations have good parallels in all coastal sites. Most of the fibulae are more or less of a similar shape: semicircular with ribbed bows. Some were decorated while others left plain. Tin bronze was found to be the most suitable alloy for producing the fibulae (with 7–12% tin). The analyses of the 1977–1980 objects showed that some of the bronzes include c. 4% tin and 17% lead. All the fibulae underwent mechanical treatment after casting, including hammering and annealing. Specific metallographic analysis revealed the method of connecting and fastening the needle into the fibulae body.

The jewelry group includes four bracelets made of bronze, two earrings (one of bronze and the other of silver), one silver bead and the *Tanit* bronze figurine. All the jewelry was found at the settlement, no finds were uncovered in the cemetery. Tin bronze (with 7% tin) was the best alloy for bracelets. Only one bracelet (M-13) included a high concentration of lead at around 8%. One ring (M-25) was made of tin bronze,

while the other (M-7) was made of unalloyed copper. The silver objects contained silver with 30–40% copper. Jewelry was produced in different ways: objects of a thick circular section, such as the ring (M-25), bracelet (M-10) and silver bead, were not worked by any thermal or mechanical treatment after casting. The other objects including the silver earring and square-sectioned bracelets were worked thermally and mechanically after casting to achieve their final shape.

The tools and objects of daily use include three cosmetic sticks (spatulae) made of tin bronze. All were similar to those found in other sites, but broken. Only at Tel Megadim and Tel Samarya (in the coastal area) cosmetic sticks were not found. According to chemical analysis, one sample (M-24) included c. 6.5% tin. Analysis of objects found in 1977–1980 reveals that some of the cosmetic sticks are made of unalloyed copper, while others included c. 4.5% lead. After casting, these objects were worked thermally and mechanically by annealing and hammering in order to achieve their shape and hardness.

Only one fishhook of tin bronze was found. The only parallel comes from Tel Shiqmona, and was not analyzed.

From the results of the metallurgical analysis it is apparent that in the manufacturing of metal objects, considerable emphasis was placed upon the raw materials from which the objects were crafted. Technological innovation certainly took into account environmental conditions and their implications, such as corrosion. For example, boat nails were made from unalloyed copper rather than iron, probably for greater corrosion resistance. However, as copper is a malleable material, hammering was necessary in the final phase in order to attain the required strength.

Arrowheads were produced from tin bronze cast in a closed mold. They did not undergo thermal or mechanical treatment of any sort following casting. Small jewelry, such as earrings, bracelets and toggle pins, was also cast from tin bronze, but was then crafted mechanically in the last phase of production in order to acquire the desired final shape and decorative properties.

APPENDIX 1. THE OBJECTS

Object	Locus	Basket	Lab No.	Wt (g)	L (mm)	W (mm)	Th (mm)
Arrowhead	493	4426	M-1	3.46	39.2	8.7	
Arrowhead	485	4388	M-2	4.87	37.7	11.5	
Arrowhead	252	1497	M-3	4.04	32.4	10.8	
Arrowhead	418	4059	M-4	3.48	25.6	8.5	
Arrowhead	223	1371	M-5	1.91	24.0	8.8	
Ax	140	1078	M-55		170.0 +	59.3	22.5
Fish hook	229	1417	M-54	4.24	18.2	1.6	
Handle	107	1007	M-56		121.2	8.6	
Handle	709	7022A	M-57	51.92	117.5 +	24.7	8.3
Knife	761	7262	M-59	9.05	54.3 +	21.4	4.4
Knife	766	7318	M-60	4.10	54.0 +	12.0	2.8
Knife handle	766	7298	M-58	16.37	80.0 +	21.4	4.9
Nail	454	4227	M-06	7.19	96.5 +	4.5	
Nail	464	4308	M-07	30.14	94.5 +	7.4	
Nail	437	4143	M-08	17.79	94.4 +	5.6	

APPENDIX 1. THE OBJECTS (cont.)

Object	Locus	Basket	Lab No.	Wt (g)	L (mm)	W (mm)	Th (mm)
Nail	229	1382B	M-09	7.48	88.8 +	3.5	
Nail	450	4218	M-10	15.77	78.2	5.0	
Nail	459	4259	M-11	28.65	74.5 +	8.0	
Nail	182	1247	M-13	4.82	57.0 +	4.2	
Nail	Surface		M-14	3.09	52.0 +	3.7	
Nail	242	1426	M-15	5.55	48.5 +	4.5	
Nail	159	1137	M-16	5.27	46.0 +	4.8	
Nail	238	1422B	M-17	2.14	43.0 +	3.2	3.4
Nail	252	1487	M-18	0.89	42.2 +	2.3	2.7
Nail	999	7193	M-19	5.63	40.8	4.0	2.7
Nail	999	4199A	M-20	3.99	39.3 +	3.5	1.2
Nail	245	1464	M-21	10.80	37.7 +	6.2	
Nail	159	1137	M-22	1.63	34.4 +	2.8	6.3
Nail	180	1226	M-23	3.21	34.0 +	4.0	5.2
Nail	155	1335+6	M-24	2.28	33.6 +	5.0	
Nail	503	4497A	M-25	3.98	32.5 +	4.8	3.4
Nail	447	4184	M-26	7.84	31.1 +	6.5	1.8
Nail	229	1382A	M-27	1.84	30.2 +	3.6	2.2
Nail	150	1369	M-28	1.27	30.0 +	3.0	2.6
Nail	131	1084	M-29	1.89	30.0 +	2.9	1.1
Nail	503	4497B	M-30	1.54	29.0 +	3.3	5.5
Nail	503	4414	M-31	2.90	28.4 +	4.2	8.8
Nail	416	4057	M-32	2.87	26.0 +	5.8	4.1
Nail	227	1386	M-33	1.93	25.0 +	2.4	
Nail	448	4223	M-34	1.44	25.0	3.0	
Nail	436	4142	M-35	1.71	24.5 +	3.8	
Nail	246	1445	M-36	0.85	23.7 +	3.1	
Nail	503	4485	M-37	1.10	19.7 +	3.0	
Nail	999	7086	M-38	3.29	19.0 +	5.0	
Nail	418	4137	M-39	0.77	16.6 +	3.4	
Nail	734	7115	M-40	1.56	12.8	3.3	
Nail	492	4428	M-41	2.56	10.2 +	3.0	
Nail	228	1472	M-42	1.51	5.8 +	3.8	
Nail	999	9001	M-43	0.54	5.0 +	2.6	
Nail	417	4058	M-62	0.55	8.6 +	3.6	2.6
Needle	172	1276	M-44	3.52	148.5	2.6	
Needle	163	1171	M-45	7.70	143.0	3.6	
Needle	172	1212	M-46	2.18	116.0	2.0	
Needle	240	1485	M-48	1.10	82.0	1.7	
Needle	726	7170A	M-50	0.30	39.4 +	1.3	
Needle	726	7170B	M-51	0.18	23.6 +		1.3
Pin	229	1378	M-49	2.56	64.0 +	2.6	

APPENDIX 1. THE OBJECTS (cont.)

Object	Locus	Basket	Lab No.	Wt (g)	L (mm)	W (mm)	Th (mm)
Spatula	493	4463	M-47	4.12	115.5	2.8	
Spatula	455	4231	M-52	0.71	28.7 +	2.2	
Spatula	464	4280	M-53	0.74	21.7 +		2.6
Unid. Object	251	1496	M-61	3.51	27.4	8.5	1.4
Weight	226	1427	M-63	4.42	19.6	6.7	
Weight	229	1417	M-64	4.24	16.4	6.4	
Weight	732	7192	M-65	4.32	16.2	8.3	
Weight	457	4243	M-66	20.45	14.5	10.3	
Weight	231	1495	M-67	5.06	14.3	8.0	
Fibula	999	4298	M-68	33.07	104.5 +	5.5	
Fibula	747	7209	M-69	33.81	89.5 +	3.3	
Fibula	485	4394	M-70	15.73	81.0 +	3.8	
Fibula	999		M-71	7.79	78.0 +	2.0	
Fibula	999	9002	M-72	9.53	72.0 +	2.5	
Fibula	411	4063	M-73	4.49	65.0 +	3.4	
Fibula	485	4390	M-74	6.97	63.0 +	1.8	
Fibula	503	4495	M-75	9.51	53.5 +	1.6	
Fibula	733	7112	M-76	4.70	51.0 +	3.4	
Bracelet	709	7028	M-77	26.82	95.0 +		7.5
Bracelet	745	7178	M-78	4.78	87.0 +		3.2
Bracelet	485	4445	M-79	2.72	64.5 +	3.6	2.5
Bracelet	485	4427	M-80	2.59	64.0 +		2.9
Ring	503	4498	M-81	6.06	86.0	6.0	2.5
Ring	739	7155	M-82	5.27	76.0	15.0	3.8
Ring	139	1108	M-83	0.87	55.0	3.2	1.2
Earring	420	4061	M-84	1.37	50.0		2.5
Earring	485	4400	M-85	0.39	39.0		1.8
Ring	487	4387	M-86	0.64	36.0	4.5	1.4
Ring	118	1139	M-87	0.27	30.0	4.0	0.6
Ring	489	4409	M-88	1.15	23.5 +	9.0	1.8
Tanit	173	1268	M-89	19.76	41.2	29.7	4.8
Bead	464	4312	M-90	0.31	6.0		4.0

APPENDIX 2. CHEMICAL ANALYSIS (alphabetical by object)

Object	Lab No.	Basket	Cu% (Copper)	Sb% (Antimony)	Pb% (Lead)	Sn% (Tin)	Ag% (Silver)	As% (Arsenic)	Zn% (Zinc)	Fe% (Iron)	S% (Sulfur)
Arrow-head	M-11	4059	96.98		0.44	2.28		0.15	0.80	0.07	
Arrow-head	M-12	1371	81.25	0.16	14.85	3.82	0.31			0.05	0.04
Bead	M-6	4312	31.69				58.18	0.42	0.18		0.14
Bracelet	M-10	7028	91.16		0.45	8.54	0.18	0.07		0.30	
Bracelet	M-13	7178	83.68	0.67	11.27	3.45	0.86		0.08	0.24	
Earring	M-8	4400	38.78				61.57	0.21		0.11	
Fibula	M-16	4495	92.35	0.05	0.11	6.31	0.05	0.45		0.78	
Fibula	M-17	7209	Not analyzed								
Handle	M-3	1007	32.76				0.03		0.06	0.11	
Handle	M-4	1007	98.42	0.10	0.12	0.20		1.01	0.39	0.10	
Handle	M-5	1007	98.97	0.10	0.02	0.01	0.01	1.09		0.25	0.04
Nail	M-18	4308	Not analyzed								
Nail	M-19	1386	94.37		0.24	4.60	0.16	0.44	0.55		
Nail	M-20	4485	99.82			0.23		0.14		0.29	
Nail	M-21	7115	99.34	0.06	0.07	0.22		0.90			0.02
Nail	M-22	4184	99.52	0.30	0.01		0.03	0.13	0.12		0.04
Nail	M-23	1137	99.23				0.06		0.94	0.29	
Pin	M-1	1171	74.47		0.47		0.20	0.49		0.04	
Pin	M-14	1276	81.41	0.54	0.20	0.55	0.42	2.82		0.31	0.07
Pin	M-15	1485	97.59		0.13			0.56	0.30	0.40	1.59
Ring	M-25	7155	88.5		3.41	6.42	0.20	0.88	0.07	0.07	0.59
Ring	M-7	1139	94.77	0.33	0.35	0.42	0.10		0.70	0.34	0.07
Spatula	M-24	4231	91.67		0.16	6.95	0.49	0.30	0.37	0.10	
Tanit	M-26	1268	91.47		1.75	6.72		0.36		0.37	0.08
Unid.	M-2	4144	60.78			11.57	0.44	0.26		0.16	0.09
Weight	M-9	1417		0.12	99.46		0.57	0.21		0.36	0.09

* Since all elements are not listed in the table, the composition of some objects does not equal 100%.

APPENDIX 3. METALLOGRAPHIC ANALYSIS (alphabetical by object)

Object	Lab. No.	Composition	Corrosion	Homo-geneous	Structure	Annealed/ hammered
Arrow-head	M-11	Tin bronze (2% Sn) w/lead inclusions	Surface to interdentritic phase	Yes	Coring at the dendrite arms indicates rapid cooling	Closed mold ('lost-wax casting'), no later treatment
Arrow-head	M-12	Tin bronze (4% Sn) w/lead inclusions.	As M-11	Yes	Dendrite arms of diferent sizes due to the slow and varying process of casting	As M-11
Bead	M-6	Silver mixed with copper (32% Cu)	Surface	No	Dendrites containing silver with 30% copper and an interdendrite phase of silver and only 3% copper	Cast and left without any later thermo-mechanical treatment
Bracelet	M-10	Tin-bronze (8.5% tin) with 0.5% lead	Surface up to inter-dendrite phase, especially at segregated lead inclusions		Rich copper phase (α) with coring in dendrite arms, and an interdentritic phase richer in tin and with segregated lead inclusions	Cast in a closed mold without later treatment
Bracelet	M-13	Tin-bronze (3% tin) and 11% lead inclusions	Surface and intergranular	Yes	Equiaxed grains, twins and slip-lines outlined at surface	Hammered and left soft by annealing
Earring	M-8	Silver and 39% copper at the major part of the earring, < 20% Cu in the decorative cord	Surface and intergranioal	Yes		Hammered or pulled
Fibula	M-16	Tin bronze (6% Sn) fibula with few inclusions of lead and copper sulfide	Surface and intergranioal	Yes	Elip traces and deformed equiaxed grains together with twin lines are preserved in the inner structure	Cycles of hammering and annealing; engraving at the surface
Fibula	M-17		Surface and intergranioal	Yes	Equiaxed grain structure with annealing twins; deformed grains coupled with slip-lines, mainly near surface	After casting, the fibula was fully homogenized, then hammered and annealed; signs of chasing evident
Figurine	M-26	Tin bronze (6.7% Sn) with inclusions of lead and copper sulfide	Surface and interdendritic	No	Equiaxed grains, twins and slip-lines outlined at surface	Slightly hammered after casting
Fishing-Weight	M-9	Tin bronze (9% Sn) fishhook with lead weight (99% Pb)	Surface, intergranular inclusions of copper and iron	Yes	Equiaxed grains twins and slip-lines deformed near surface	Hammered and annealed
Handle	M-3	Unalloyed copper with inclusions of copper sulfide	Surface and intergranular	Yes	Equiaxed grains, twins and slip-lines	Hammered and annealed with very little final cold work
Handle	M-5	Copper mixed with 1% arsenic (As)	Surface penetrating to the intergranioal		Equiaxed grains twins	Annealed
Nail	M-18	Not analyzed	To intergranioal structure	No	60–70% thickness equiaxed grains and twins	Annealed
Nail	M-19	Tin bronze (5% Sn) with inclusions of lead and copper sulfide	Same as M-18	Yes	c. 70%	Same as M-18

APPENDIX 3. METALLOGRAPHIC ANALYSIS (alphabetical by object) (cont.)

Object	Lab. No.	Composition	Corrosion	Homo-geneous	Structure	Annealed/ hammered
Nail	M-20	Unalloyed copper with inclusions of copper sulfide	Mainly at surface	Yes	c. 70%	Same as M-18
Nail	M-21	Unalloyed copper	Surface	No	c. 90%	Hammered
Nail	M-22	Unalloyed copper	To intergraniol structure	Yes		Hammered
Nail	M-23	Unalloyed copper with some iron (c. 0.3% Fe), zinc (1%), inclusions of copper sulfide and lead	Surface to intergraniol structure			Hammered and annealed
Pin	M-1	Crystal structure, unalloyed copper, elongated inclusions of lead and copper sulfide	Yes	Slip-lines with distortion crystals	Equiaxed grains and twins	Hammered and annealed
Pin	M-14	Unalloyed copper with elongated inclusions of lead	No	Deformed grains and slip lines	Equiaxed grains and twins	Cold hammered and annealed, total reduction of 30–40%
Pin	M-15	Same as M-1	Yes, with slight segregation	Slip lines and elongated inclusions	Equiaxed grains and twins	Cold work followed by annealing, total reduction of 25–40%
Ring	M-7	Unalloyed copper	Surface and intergranioal	Yes	Equiaxed grains, twins and slip-lines	Hammered on surface and inner sections, annealed
Ring	M-25	Tin bronze with lead inclusions	Surface up to interdendrite phase, coring at the dendrite arms			Cast in a closed mould directly to shape without any later thermo-mechanical treatment
Rivet	M-4	Copper mixed with 1% arsenic (As)	Surface and very little intergranular	No	Equiaxed grains and coring	Hammered and annealed
Spatula	M-24	Tin bronze (7% Sn), with lead inclusions	Surface and intergranular	Yes	Equiaxed grains, twins and slip-lines	Hammered and annealed with little Final cold work in the spoon area
Unid.	M-2	Tin bronze (12% Sn) with inclusions of silver and copper sulfide	Surface and intergranular		Equiaxed grains, elongated inclusions	Hammered and annealed; reduction of c. 70–80%

NOTES

[1] Both authors delivered the report on the metal finds, while Sariel Shalev alone wrote the report on the Egyptian amulet.

[2] This article does not discuss the dating of the finds. The objects have been dated to the Persian period according to stratigraphy and coins by the excavators. For the dating of the metalwork see Muhly and Muhly 1989:267–268.

[3] IAA Excavations in 1995 by Sam Wolff (unpublished).

[4] For a detailed explanation of the 'lost wax casting' technique, see Hurst 1996:60–84.

[5] Iron artifacts were not analyzed in this research.

[6] Max. diam. of the body including hands: 9 mm; width from face to edge of ring attached to the back: 11 mm; max. base length, 13.6 mm.

[7] For more details about dating and typology of Irano-Scythic arrowheads, see Cleuziou 1977.

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