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REPORT ON THE 1991 ARCHAEOLOGICAL SURVEY OF KESTEL TIN MINE, TURKEY

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Abstract: Survey and minor excavation took place in summer 1991 at the Early Bronze Age tin mine at Kestel, near Çamardi, Nigde, southeastern Turkey. Although minor finds indicate some later work underground, indications from pottery finds suggests the bulk of the underground mine to be Early Bronze Age, and possible output is tentatively computed. There is a possibility that substantial opencast workings belong to a later period. Part of the working were found to have been utilised to form a mortuary chamber, with at least five inhumations. Controversy over the mine and wider impact of firesetting technology is discussed. Work is due to continue in summer 1992.

INTRODUCTION

Brief details of the mine appeared in an earlier Bulletin (Willies 1990), and the present report is intended to up-date the earlier, though since a further season is envisaged, it will only carry a brief outline of the work done and results so far available. Scientific data, notably radiocarbon dating, are still awaited, and pottery identification is only partially completed. Comments here are thus subject to confirmation.

The project, which also involves the excavation of a related Early Bronze Age (EBA) habitation and tin-smelting site at Göltepe, about two kilometres away, is directed by Aslihan Yener of the Smithsonian Institution, jointly with the Nigde Museum, Turkey. They were able to provide experts in bones and pottery, etc. and we also had the practical assistance of Hadi Özbal, Necip Pehlivan, and Ergun Kaptan, co-authors of the original report (Yener 1989). All artefacts, excepting charcoal samples brought out under permit for radiocarbon dating, have been deposited with the Nigde Museum.

CONTROVERSY

Since the initial announcement of the discovery of the mine by Yener and Goodway of the Smithsonian, jointly with Pehlivan and Kaptan of the MTA, and Özbal of Boğaziçi University at Istanbul (Yener et al 1989), there has been considerable discussion of the results previously reported, with some skepticism that such extensive underground exploitation for tin took place in the Early Bronze Age (eg. Muhly, Begemann et al 1990; Hall and Steadman, with a *Comment* by Pernicka, Muhly, Oztunali and Wagner and *Replies* by Yener and Goodway, and the present writer, 1991).

Muhly et al relied predominantly on a single sample from "the richest part of the mineralisation", which was apparently a conspicuous haematite-rich surface exposure clearly left by ancient miners, and found only 26 ppm tin. In Pernicka et al, they conclude, that "it is very unlikely that one vein (ie. that sampled) contained much more tin than the others", and that "therefore the estimate made by Willies (1990)" (over the possible production of several hundred tons of concentrate in both surface and underground workings) "is certainly unrealistic". Muhly et al also cite an exploration company report which claimed gold was the objective of mining (there is a gold prospect just over a kilometre away), the company having also only found low levels of tin. In their summary they conclude that the area was not worked for tin, and that a distant source was used for local metalworking.

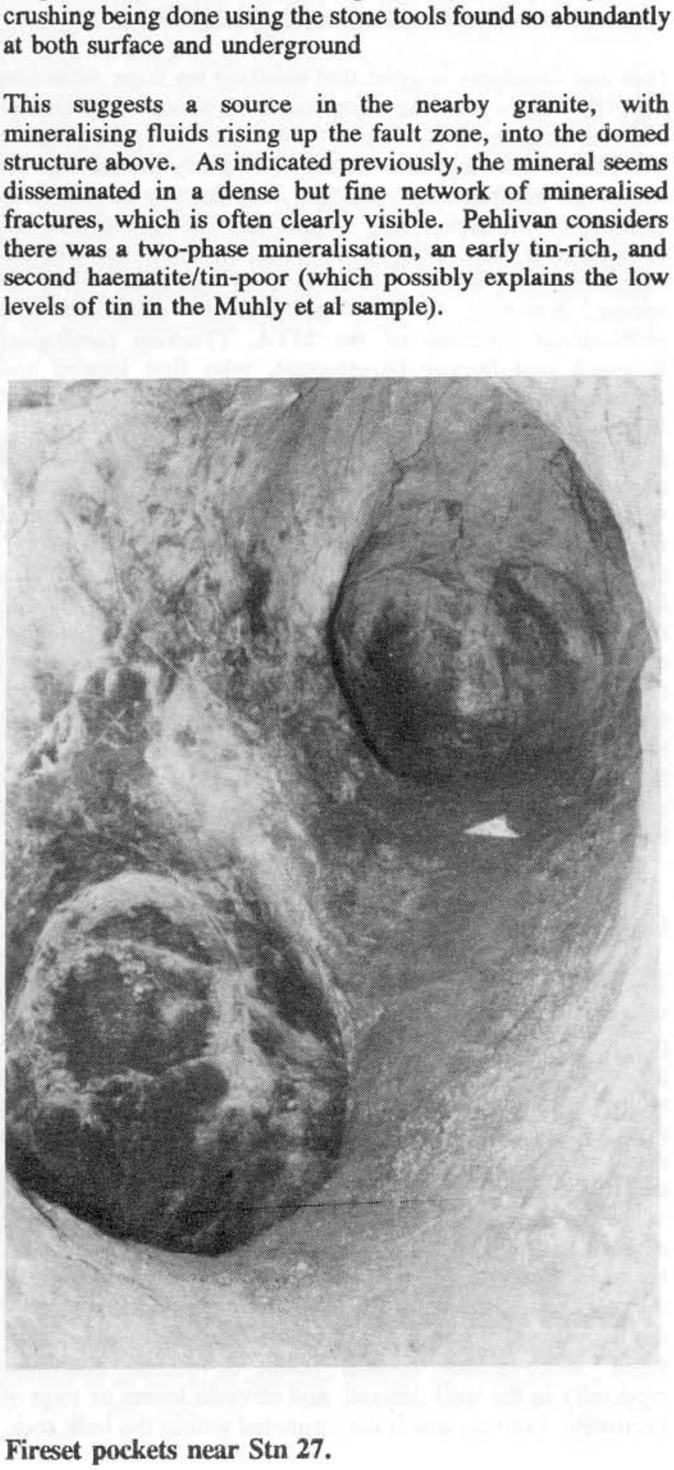
Hall and Steadman suggest that smelting tin from Anatolian deposits was beyond the competance of Bronze Age miners and smelters, and that, despite the work of Yener et al, there was little archaeological evidence of an Early Bronze Age tin source in southeastern Anatolia. In fairness to all three groups of writers, they were not in possession of metallurgical data, with up to 99% tin found on crucible fragments on a nearby site from 1989 onwards. They do appear, however, to have unreasonably discounted the professional opinions of the MTA. (Turkish Geological Research and Survey Directorate), who first located and confirmed the mine as a tin prospect (Pehlivan 1989), and it is perhaps unfortunate they found it necessary to comment prior to full publication of results, and with such slender (or no) association with the actual site. As Muhly has himself written, "the most attractive and convincing historical reconstruction can be disproven by a single new discovery" (1973). Discussion following a presentation by Yener at a Los Angeles conference last December appears to indicate that Early Bronze Age tin working is now close to being an acceptable hypothesis to him at least. Özbal has reported (verbally) tin levels up to 1.5% in whole rock samples taken from inside the mine. This was exceptional, though there were others around 1%, and, it seems to need pointing out, this is what was left behind. The question of "how much" is considered below, together with analyses of samples collected this time from possible ore-bearing locations at the mine.

GEOLOGY

The mine is about 7 km west of Çamardi, near the small village of Celaller (not, as shown in the map published previously in Willies 1990 p91, east of Çamardi). The geology, within an active tectonic region, is complex, with a wide range rocks within a short distance. The mine is primarily in marble and the underlying quartz-schist, the result of intrusion of granite, which outcrops not far away, and was responsible for the doming or arching of the rocks visible on the mine site. The granite appears to be the source of pegmatitic dykes, a small exposure of which has now been found in the mine. It seems necessary, on reading some of the misconceptions about the mine, to emphasise that most of the tin mineral was not found in the "conventional" quartz-filled, more-or-less vertical faults or joints, nor even especially in the well defined and obvious lenses or vugs of haematite, but was and is disseminated within the bulk rock.

It was found during the survey of previously inaccessible areas of the mine, that as well as the mineral being found disseminated in marble, as previously reported, the mineralisation continued in the underlying quartz-schist, which had been worked in the vicinity of two faults, one inclined into the other. This area seems to have been particularly rich, to judge by the amount of ore extracted, and there was found also the thin "leader" of a granitic pegmatite, similar to tin- bearing pegmatites found elsewhere in the general area (Pehlivan - see below). It remains however, that it is still very difficult for us to see in most of the mine how the miner selected and rejected economic ore and uneconomic rock respectively. It seems probable that in a continuation of the probable original discovery process, frequent trial samples were ground and tested by some method of concentration before extraction proceeded further. This would be analogous to long standing modern gold and tin working practice, and would not necessarily take very long. Some form of "vanning" seems most likely, with crushing being done using the stone tools found so abundantly at both surface and underground

This suggests a source in the nearby granite, with mineralising fluids rising up the fault zone, into the domed structure above. As indicated previously, the mineral seems disseminated in a dense but fine network of mineralised fractures, which is often clearly visible. Pehlivan considers there was a two-phase mineralisation, an early tin-rich, and second haematite/tin-poor (which possibly explains the low levels of tin in the Muhly et al sample).



Fireset pockets near Stn 27.

UNDERGROUND

Two main tasks were tackled. First, a thorough exploration (including removal of obstructions to likely passages), and a survey of the workings found, though the late discovery of the mortuary chamber prevented completion. Secondly an excavation of an area in the first chamber, near Stn 6, which had the objective of isolating the second phase of working from the earlier. These were accompanied by video and still photography, collection of samples etc.

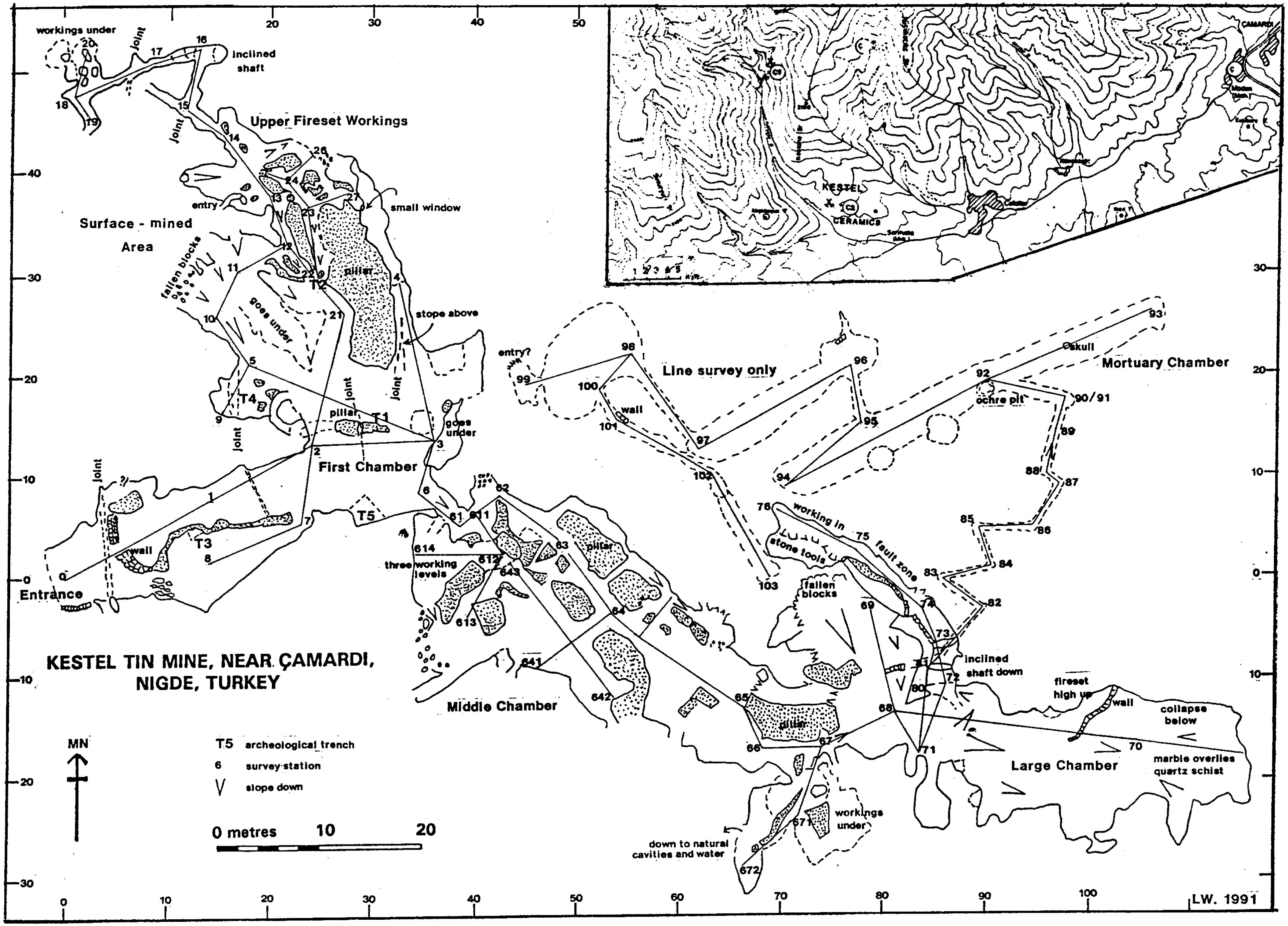
The first chamber area, which includes Stns 0-6 is clearly a second (at least) phase working, cutting through older much smaller work which seems to be at two horizons a few metres apart. The entrance is from a small openworked area, and superficially appears to have been cut through from it, probably replacing a small entrance on a cross-joint. It is wide, and in places over, sometimes well over, 3m high, with the widest part of the chamber supported by a pillar, which has been much cut into, to the point of endangering stability. Seen here are several domed hollows in the roof, a few metres across at most, probably structural features within the overall antiform. Two still have conspicuous linings of thick crystalline haematite remaining, though in others, if ever so present, it has been completely removed. The haematite left clearly was not considered tin-rich. Firesetting has been used in the area, but also mechanical breakage.

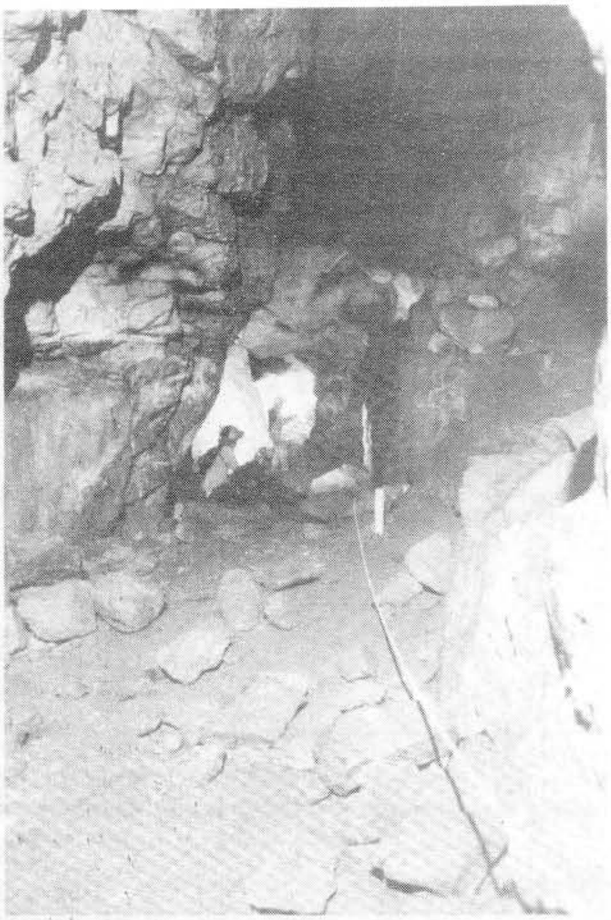
Updip of this area, three separate routes (via Stns 4, 21, 5 respectively) led, on roughly parallel bearings but different inclinations, into a substantial fireset chamber (Stns 12-13). It was from here that a small blocked hole in the roof was forced out to surface by John Peel (see Surface, below). A small vase, possibly a lamp, from the Middle Bronze Age was found in the inclined small passage above the hole, but other pottery scatters in all areas seem to have been virtually all Early Bronze Age.

Passages in this area were all fireset, with little sign of mechanical breakage, and thin pillars had been left for roof support. From and along the passages, there were inter-linking small rounded chambers and pockets, and sometimes the pillars had been fireset-through, in one case spiralling up through the pillar: overall it resulted in a small maze. Charcoal was recovered from a hearth in one such small pocket (between Stns 23-27).

Further up-dip, a single passage led to a cross-joint, and a shaft up to a higher level. This had been sunk, some 5 m from above, on a a steep inclination, by fire, and a trial excavation showed an infilled rounded cavity in the floor below it, almost a further metre deep. Again Early Bronze Age pottery was found, and at the shaft-foot, a fine piece of obsidian, possibly a crude scraper. From the top of the shaft, a further passage led to another small "maze" of workings, with many pieces of pottery bowls or necked jars, perhaps used for water.

The above was the area entered previously, in 1990. However, down-dip, removal of a few boulders, probably placed by modern shepherds (there was directional graffiti from a relatively recent entry), gave access to a much larger series of workings (Middle Chamber on the plan, Stns 61-67), made up of a substantial passage, with chambers off, and pillars left, fairly systematically, to support the roof. The maze of workings at the north end was on three levels, and over 4 m high.


KESTEL TIN MINE, NEAR ÇAMARDI, NIGDE, TURKEY
workings under
inclined shaft
Upper Fireset Workings
Surface - mined Area
entry
small window
fallen blocks
goes under
pillar
stope above
joint
First Chamber
goes under
T1
T2
T3
T4
T5
wall
Entrance
three working levels
Middle Chamber
pillar
entry?
Line survey only
wall
Mortuary Chamber
skull
ochre pit
working in fault zone
stone tools
fallen blocks
inclined shaft down
fireset high up
wall
collapse below
Large Chamber
marble overlies quartz schist
workings under
down to natural cavities and water
KESTEL
CERAMICS
MN
T5 archeological trench
6 survey station
V slope down
0 metres 10 20
LW. 1991



(Above) Larger workings near Stn 63.
(Below) Stone maul and broken rock near Stns 75-76.

This in turn led via a small low crawl to a large, steeply inclined, chamber (Stns 68-72), about 50 m long, and capable of having had originally, allowing for infill of the floor, some 4000-5000 tons of ore for extraction. This area also showed evidence of two phases of working, and charcoal was recovered from a fireset hearth-remnant high up the wall, almost certainly belonging to the earlier phase. At its lower end, the marble was underlain by quartz-schist, which had been extensively worked, leaving much angular debris. Some of this had slumped into workings below, and a climbing-shaft at the side near the mid-point of the chamber gave access to a faulted zone underneath which led into the slumped and collapsed area.

Here, (Stns 72-76), the fault had been worked, and stone tools, left "as if yesterday", showed these were certainly used for breaking ore out from the rock, aided by small fires (rather than just being used for crushing, which was possible, if not likely, elsewhere). The fault had several geological phases of movement, and the plane was infilled with a clayey-limonite. This had been removed by a small, unmodified bone tool, to leave a "free-face". The process of removal of rock using stone hammers was tested by experiment, and found efficaceous, probably much aided here by natural fractures of the fault zone, in what otherwise would have been a very tough and hard rock indeed. This was the deepest point found in the mine, about 30 m below the entrance, and it was here that a small leader of granite pegmatite was noted (so small in fact, it had not been noticed until floodlighting was brought in to aid video-photography and drawing). It is likely this was the last work done in this general area of the mine, otherwise dumping of waste into the shaft was likely to have commenced.

Above the cleft of the shaft in the large chamber above, a small passage was found high-up, leading off. It led (Stns 81-90), with difficulty, via widened but largely natural joints and a fault plane, to a further series of workings, entering the larger passages of the mortuary chamber and asssociated workings, down a precipitous (it precipitated us!) slope, probably where a blockage originally placed to seal the area had collapsed. Only a rapid hand-compass and tape survey was possible in the time available.

The mortuary chamber consists dominantly of a large gallery (Stns 92-94), up to two or three metres high, and as much as 5 m wide and over 50 m long. There are many sherds of pot on the floor, some apparently of good quality, but, on the evidence of samples taken out, still EBA. Passages off led to further modest chambers, again mainly fireset, and a possible, but blocked, further entry point (Stn 99), which the survey revealed is not far from the original main entrance. Part of these workings (Stns 100-103) seems likely to be in the fault seen earlier in the deepest part of the mine.

Many bones of a variety of animals were found strewn throughout the mine, but some in the chamber appeared to be human, which was soon confirmed by finding of skull and jawbones, so that some five human skeletons at least are represented (four jawbones, and a younger person's skull). Further investigation showed two shallow shaft-like walled pits, one of which contained ochreous clay. This may have been used to line cavities in the walls of the galleries, which appear to have been the original graves. Possibly these were later robbed, and the bones strewn by animals. A further broken-down wall was found (Stn 101), near the possible, but blocked, entrance, which may have originally sealed off the mortuary area.

A 3 m square excavation trench (T5 near Stn 6), was located in the first chamber where it was felt second or last phase working may have taken place, free of debris of earlier phases, and where safety considerations were acceptable. Floodlighting powered from a generator at surface proved invaluable for this. The report of Phil Andrews, the excavator, suggests that the area was mainly mined in EBA times, using stone battering hammers and fire, from which there was abundant charcoal to supplement the evidence of pottery dates. There was also what appeared to be a few pointed tool marks on the mined wall. The layer of mined debris was predominantly made up of "chatter" of broken rock, mainly roughly minus 6 cm, but with a scatter of larger pieces and occasion stone mauls. It was so consistent as to suggest systematic breaking as part of an ore separation process, but the criteria for selection or rejection is still not apparent to us. The layer was not bottomed, out of regard for the stability of the area.

It had subsequently been occupied for habitation, probably in conjunction with some mining, and possibly from EBA times onwards. Finds indicate occupation certainly through Roman, Byzantine and Islamic: the occupation layers were mixed, probably from leveling, but finds included a large vessel used for storage or cooking, and small objects including a coin, an ivory Byzantine cross, and small pieces of iron. There was abundant bone also, but it may have been introduced from a wide area within the mine by animals or humans.

SURFACE

At surface, the open-work mining found on the previous visit was found to extend over an even larger area than anticipated, partly since we gained experience in recognising features, and partly since it was possible with our better geological knowledge to explain certain puzzling features (large subsidence hollows?) away from the marble as likely to be mining. The stone hammering, mortar, and grinding tools noted in the previous report were also seen in the wider areas, but in addition what appears to be a (tin) mould was found, suggesting some smelting may have been carried out on the Kestel site as well as at Göltepe. The detailed surface survey however was limited to the immediate area of the main mine entrance because of time limitations imposed by the underground survey. This linked the main entrance with an open-worked area which had cut-through the underground workings, and also the entrance which was "forced" to surface from below. It also included an area of small mortar holes in the marble outcrop. This last was drawn up in some detail by Brenda Craddock to test an hypothesis put forward by Ergun Kaptan, well known for his studies of mining and smelting history in Turkey on behalf of the MTA: that the mortar hollows formed a pattern, with smaller holes surrounding and associated with a few larger; and also our own thoughts that orientations of radial inequalities and depths might indicate working positions of the operators. Results were inconclusive, and no pattern could discerned.

A small excavation was carried out at this second entrance (Trench 7) by David Gale in order to determine the relationship of the underground work with the open-work. Just inside, a complete small vase or lamp had been found from the Middle Bronze Age, which suggested the access to have been used after the main EBA phase of underground working, possibly when the open-work was carried out. The excavation made it clear underground was followed by open-working at a substantially later date, since charcoal from firesetting the open-work overlay an alluvial deposit on the floor of the entrance section. An absolute date should thus be possible for this area of open-working.

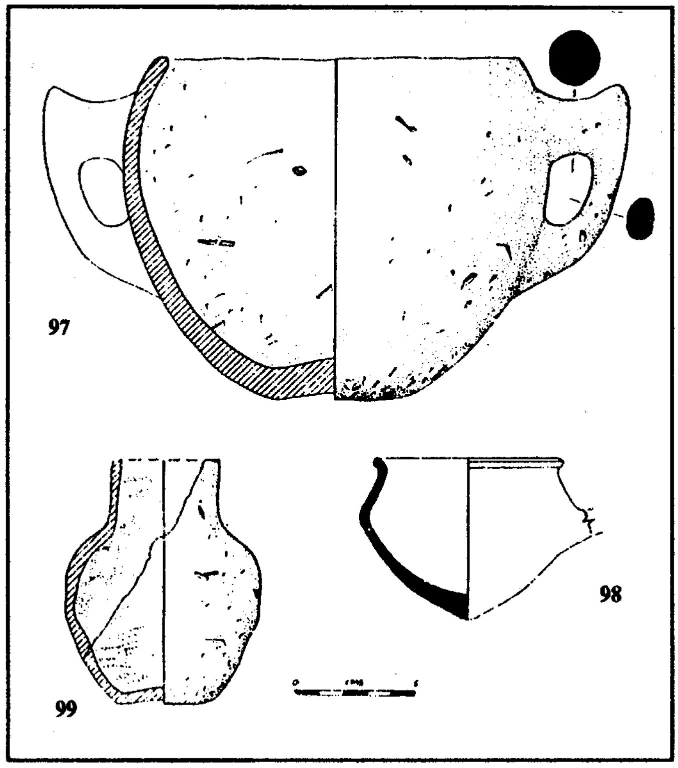
A further small trench on what appeared to be a strong joint or small fault crossing the site from just above the main mine entrance, and which was worked near and inside the main entrance, showed it to be a shallow infilled trench about 30 x 30 cm cross-section. It may just conceivably have been natural, since it was not possible to find tooling marks, but more likely is an original sampling trench across the site. It thus also emphasises that major joints across the site are not always mineralised.

A visit was also made to three other sites discovered, and shown to the writer, by Pehlivan, in an area about 3 km away from Kestel, following the ephemeral river upstream from below the Kestel site. Two of these were clearly in pegmatite dykes, but weathering had destroyed detail, and they were blocked close to the entrances. The third site appeared to be a drainage adit, driven through marble, but blocked about 20 metres in, but probably re-openable. Alluvial debris inside the adit, cut through by the subsequent lowering of the floor by water flow had abundant charcoal fragments within it, but it was considered too contextually insecure to warrant radio-carbon dating. The level, in which it is possible to almost walk upright were it not for infill is conjectured to be "Roman", and leads to speculation about deep drainage systems possibly connected with mines at a distance away. Local sources tell us of at least one deep shaft, at which relatively recent attemps to bottom using ropes failed. The pegmatite veins almost certainly were tried or exploited for tin, but there are of course other possibilities in the area.

FIRESETTING

The wide and clearly skilled use of firesetting at Kestel

Trench 7. Openwork cuts through older working in which an MBA vase was found. Front of trench is 3 m.



Pottery finds: (97) Devils Ear Pot, (99) Small pot used as lamp? (both EB III) and (98) pointed base vase (MBA).

Sn Analysis results from Kestel 1991 Survey, by Professor Hadi Özbal, Archaeometry Research Center, Boğaziçi University, Istanbul, Turkey.

LW. Sample No.

S3	Massive granular haematite Stns 12-13	710 ppm
S9	Marble from pillar between Stns 13-14	3 ppm
S11	Firesetting rock chips near Stn 27	228 ppm
S12	Marble from Trench 7 (top)	7 ppm
S13	Haematite exposed in openwork area	2315 ppm
S14	Gossan outcrop NE of mined area	14 ppm
S15	Trench 5, marble waste, layer 3	230 ppm
S17	Trench 5, marble fireset debris, layer 5	316 ppm
S18	Trench 5, soily fireset debris, layer 6	418 ppm
	Quartz schist, Stn 76 fault	29 ppm
	Quartz schist, Stn 76 fault	79 ppm
	6 samples from area of Stn 76 fault ranged between	16 - 195ppm
	Rock sample from burial pit, Stn 92-94	38 ppm
	Soil sample from burial pit Stn 92-94	152 ppm

Preliminary conclusions: drawn from analysis of material left behind in the mine and openworks

1. Association with haematite/limonite. Seen in other samples too.

2. Conspicuous ore of over 0.2% untouched - suggests higher grade mined.

3. Waste and rock left *in situ* - usually very low grade.

4. Higher Sn in soily material suggests ore is more friable than rock.

makes it necessary to consider the importance of firesetting in the EBA, and the ability of miners to exploit hard rocks. Hard rocks are sometimes considered (Muhly 1977 p.38), even by mining engineers, as making the minerals contained inaccessible to early miners. In Kestel the hard and tough quartz-schist rock proved susceptible to fire, just as did the softer marble, without the use of metal tools. The same is likely to be true for any quartz-rich rock, notably the granites in which cassiterite often occurs, and there are now plenty of known examples of the technique in early metal mines, though generally of Middle or Late rather than Early Bronze Age (see for instance Willies 1987, or Crew and Crew 1990). Quartz is pecularily susceptible to even modestly high temperatures, since it can exist in several different crystalline forms which invert to other forms when they are heated or cooled through a specific temperature: thus in the most dramatic example α/β cristobalite quartz will have a linear expansion (or contraction) of about 1% as it passes through 250°C, equal to about 3% of its volume. Another critical point for quartz is at 575°C. Experiment has shown that granite is indeed very susceptible at these temperature ranges (Sincock 1984).

Other rocks have different reasons for their specific susceptibilities, but it is clear that nearly all rocks will yield to fire, the most likely exceptions being basic or ultra-basic quartz-free rocks which have formed at high temperatures. It cannot therefore be assumed that tin or most other metal-bearing rocks of any likely type were inaccessible in the EBA: it is thus necessary to re-assess the possibility of EBA working of other tin deposits, such as Bohemia.

In the case of tin at Kestel, further effects may have been beneficial from firesetting. The first is that rock affected by fire is crumbly, and thus easily crushed, secondly that grain boundary disintegration as a result of differential effects of heating on the different minerals would tend to preserve the crystals whole, thus reducing the tendency, in hand crushing and rubbing, to overgrind the cassiterite: overgrinding would cause very high losses below about 50 microns size during washing (Binns 1984). Thirdly it would cause haematite and limonite to become porous, and thus easier to separate by washing. According to Taggart (1945 Sect. 2, p227-228) the separation of iron oxides does not appear to be especially difficult, and he describes a hand-treatment process in China, in southern Yunan, which would have coped readily with the iron oxide-bearing Kestel ores. This is in contradiction to the implication by Hall and Steadman (1991), citing the same reference, that iron oxides present at Kestel would make it impossible to separate the tin before magnetic separation or sulphuric acid leaching methods were available. The Cornish seem to have managed too with their haematite-rich ores long before mechanisation or acid leaching methods.

This analysis suggests some thought needs to be applied to the extent firesetting was used. The first phase of working seems to have dominantly been by fire, leaving the very smooth walls, and finely broken rock matrix, but the later work which cuts through the earlier has much mechanical breakage. Much of the debris in the excavation T5 clearly was mechanically broken, and thus so would be the richer material removed. This might possibly be due to a growing shortage of wood for fuel, thus providing the incentive for a combination of methods. If heat treatment of the ore was necessary for easy liberation of the cassiterite, then this could most economically be done, in terms of fuel, after the first waste fraction had been discarded.

CONCLUSIONS

With so much work yet to be done on the site, and whilst still awaiting most scientific results, conclusions have to be limited and guarded. It is however evident from pottery examination so far carried out that the main period of underground working was EBA (2800 to 2000 BC), largely EB II, but also EB I and EB III, and that that it took place in two phases at least. It is also clear that from the specialised tools, the pottery, and of course the usage of the Gőltepe site, reported elsewhere, that the two sites were associated in time and purpose. Although much remains to be done on the latter site, one clear omission from likely finds has been a burial ground, and the discovery in the mine has provided a possible solution. The discovery of the MBA vase just inside the mine near the openwork not only mildly suggests the possibility of the openwork being MBA, but is also the first MBA evidence on the two sites. This should have even further significance for the metalworking archaeology of southeast Anatolia (see Hall and Steadman and replies 1991).

It has been possible by use of the survey plan and long section to further refine the levels of tin output which may have been possible from the underground mine. The area surveyed underground amounts to some 2100 m^2, with an average height of 2.3 m, which at about 2.5 tonnes/m^3 yields a total of some 12075 tonnes of ore. Although it can never be possible to have total certainty, the results shown opposite of analyses by Hadi Özbal suggest a 1% level of tin metal from whole rock removed remains feasible, and is almost certainly within the correct order. Allowing a conservative 50% for parts of the mine infilled with waste or with access blocked by it, which is the equivalent of the modern mining concept of "proved ore" (space) plus "probable ore" (infilled), over 180 tons of tin is possible from the surveyed mine alone, perhaps a little less allowing for inefficiences in beneficiation and smelting. Further survey will be needed of the openwork areas to make an estimate of their product, though a lower grade is likely overall to have been gained from these. However they will certainly provide a much greater mass of ore than was worked underground as so far considered, so the originally suggested "several hundreds of tonnes" is certainly feasible, even if the 1% level is considered too high.

There are indications of substantial further underground mining almost adjacent that we have not yet examined and of course much of the openworked area was originally mined underground also. Yener and Goodway (in their reply to Hall and Steadman 1991) also suggest a number of other small tin sites in the rich metallogenic region of the Taurus Mountains, and Pehlivan showed the present writer three more probable sites in the immediate area. So although Hall and Steadman's comment that a "centralised tin source in the Ancient Near East postulated and sought by scholars for decades" has not yet been definitively realised, at least one substantial source has, with the possibility of more to come in the same general area.

Finally, the ability of EBA miners to exploit hard quartzose rocks is clearly demonstrated. This will require re-assessment of other tin-bearing locations which have previously been dismissed as unworkable. The probable beneficial effects of firesetting on subsequent dressing or washing processes may also be an important factor in any experimental processing of the Kestel ore, whilst reduction in firesetting noted in later phases of mining has implications for palaeo-environmental investigations of wood-fuel supply.

ACKNOWLEDGEMENTS

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