Bulletin of the Peak District Mines Historical Society. Volume 12, Number 5. Summer 1995.

KESTEL TIN MINE, TURKEY
INTERIM REPORT 1995

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Abstract: An interim report of a further season (1992) of investigations at Kestel is presented, including an outline of the geology, possible amounts of ore mined, the full area-survey of the mine, and a model of possible beneficiation processes used to produce a concentrate suitable for smelting. In conjunction with other research carried out on samples and artifacts used in smelting the ore, the mine is confirmed asa producer of low grade tin ore in the Early Bronze Age, with a metal production of as much as 100 tons, in the two mines examined, over a millenium. Further substantial amounts were available nearby, but some later working is also indicated.

INTRODUCTION

Kestel has been the subject of two previous reports in this Bulletin (Willies 1990; 1992), and a further interim is presented here. It includes the completion in 1992 of the survey started in 1991, notably of the Mine 2 Mortuary Chamber area found at the end of the 1991 campaign. This was made accessible by sinking a new shaft through an infilled rift at the easternmost extent of the workings. Provision of electrical power assisted further excavation of the T5 trench in Mine 1, and examination of all parts of the mines, whilst a detailed plan was made of the Entrance and Mortuary Chambers of Mine 2 and the graves and pottery and bone scatters within them. The examination of these last areas will continue, probably in 1996, and are thus not described in detail here.

From the date of publication of the discovery and identification of the mine (Yener *et al* 1989), there has been international controversy over almost every aspect of the mine at Kestel and the associated processing site at Göltepe, conducted in articles, seminars and via the Internet. Parts of the debate were indicated in the writer's 1992 article. The tin processing at the Göltepe site has now been thoroughly described by Yener and Vandiver (1993) which drew an extremely critical response from J.D. Muhly (1993) and an equally robust rejoinder from the joint authors, which included a reponse in the form of an appendix on mining elements by the present writer, all published in the same issue of the *American Journal of Archaeology*. Since then a curiously naive article has been published by Sharp and Mittwede (1994), suggesting Kestel was mined for haematite to be used as a flux in smelting lead at Çamardi. This totally ignored the archaeology of the Early Bronze Age context of mining at Kestel, failed to mention the contemporary processing complex at Göltepe, and failed to note the post-Medieval age of the exposed Çamardi slag heaps.

At the conference on the Prehistory of Mining and Metallurgy recently held at the British Museum, papers on Göltepe and Kestel were presented by Yener; Willies; Earl and Özbal; Photos-Jones, Adriaens and Hendry (1995). In these the progress of the excavations and the scientific results were outlined by Yener, with particular stress on tracing the ore by mineralogical comparison using electron microscopy from Kestel to Göltepe, and on tracing the increasing percentage of tin in concentrates, from low grade at around 0.5% in the mine, to as much as 10% at Göltepe, with almost tin free haematite waste in middens there (a 5% sample of tin concentrate was placed on exhibition). The substance of the contribution of the present writer is found below, including an outline of the geology, the completed survey of the mine, and a model by which ore beneficiation could have been carried out. Earl demonstrated how the ore could be smelted, initially on a carbon block, later within a crucible, a possibility which had been denied by some commentators relying on modern theoretical metallurgical constraints (see also Earl and Yenner 1995). Özbal then demonstrated a series of experiments which took tin with different levels of iron within it, covering the range of possible results of smelting Kestel ores including that smelted by Earl. This showed that low grade cassiterite ore in a haematite matrix could be smelted and then alloyed with copper to yield bronze with very low iron content, comparable with that actually found in Early Bronze Age (EBA) artifacts. Photos-Jones *et al*, though their examinations had yet to include crucible bases, described the metallic tin in fine particles which adhered to crucible rims from the Göltepe site, but was absent in the sub-surface fabric. Thus, though the final steps in this progression of scientific evidence remain to be taken, few, if any, present remained to doubt that, indeed, Kestel and Göltepe were in the Early Bronze Age tin business. A composite paper will be published as part of the Conference Proceedings.

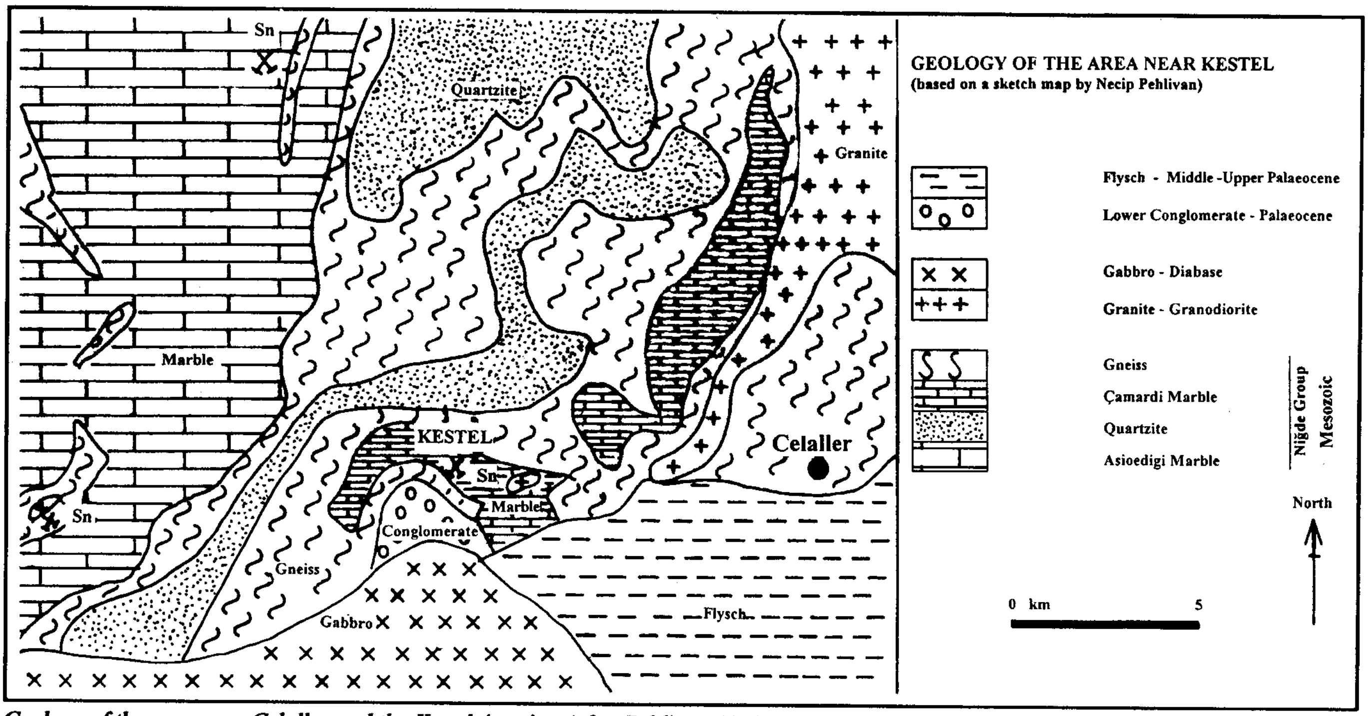
TOPOGRAPHY

Kestel is a hill within the geologically and mineralogically complex Niğde Massif, near Celaller and about 7 km from the small town of Çamardi in the Niğde Province of south west Turkey. At over 1800 metres high, it is part of the eastern foothills of the Taurus Mountains. It is located on the east side of one of the few significant gaps in the Taurus which links Tarsus (160 km away) on the Mediterranean coast with the medieval Silk Road which crosses Anatolia.

The hill has a steep convex slope facing southwards towards the junction of two ephemeral rivers, with remains of surface and underground mining in an area of about 600 metres by 300, with the main mines investigated some 400 metres from the valley floor. There are several, probably smaller, underground mines, and large areas of surface openworking, which, cumulatively, probably produced much more ore than the underground.The main host rock is marble, bordered on the west by quartzite, with the eastern margin obscured by eluvial deposits. In the area close-by there are also granitic and basic igneous rocks, and at the hilltop settlement and ore processing site of Göltepe, some 2 km away, there are the shales and greywacke of a flysche deposit.

GEOLOGY OF THE KESTEL AREA

The area between Niğde and Çamardi which are some 50 km apart, has been the subject of detailed regional reconnaisance by the MTA and by mining companies interested, particularly, in the gold mining possibilities of the area. Most of the literature is in

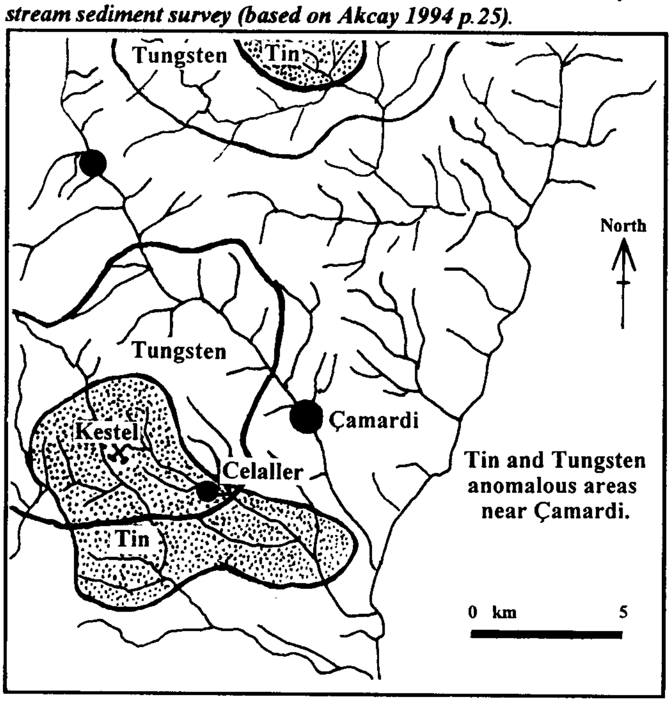


Geology of the area near Celaller and the Kestel tin mine (after Pehlivan 1988).

Turkish, but a convenient summary in English of work done there is available from a Leicester University PhD thesis by Migrac Akcay (1994), which particularly involves the area of Gümüsler some 20 km northwest of Kestel. The following account thus partially relies on Akcay for the wider picture and comparisons and on personal observation and on-site discussions with specialists at the Kestel site itself.

The Niğde Massif is a polymetallic province with mined or potentially economic deposits of antimony, mercury, tungsten, copper, lead, zinc and iron, many of which occur with gold. Around Çamardi tin occurs near Celaller, of which Kestel is a part, and in an area a few kilometres north. A copper/lead/zinc deposit with silver, quite distinct from Kestel, occurs near Çamardi itself, where it has been extensively mined during Ottoman (post-Medieval) times.

Anomolous areas for tin and tungsten near Kestel, derived from stream sediment survey (based on Akcay 1994 p.25).



A stream sediment survey of the Niğde Massif carried out by the MTA, (Mineral Research and Exploration Institute of Turkey) using panning and subsequent microscopic examination (Pehlivan 1988) showed that the area west of Celaller, including the streams below Kestel, to have anomalous cinnabar, tungsten and tin, whilst Kestel itself was marginal to an anomalous area for gold (Akcay 1994 p.23-25. This survey subsequently led to the discovery of the Kestel mine, as a tin deposit, by Pehlivan. The tin mineralisation extends westwardly, upstream of Kestel, where further mines have been located, and to a few kilometres further south where there has subsequently been investigation of terraces for placer-tin. The anomalous tungsten (scheelite) mineralisation partially coincides with the anomalous tin area, as it does with another anomalous area found further north in the river catchment draining to Çamardi.

The tin-mineralisation of Kestel and adjacent area is predominantly hosted within rocks of the Niğde Group, contact metamorphosed equivalents of pre-Cretaceous limestone, sandstone and mudstones, which today occur as marble, quartzite and gneiss. The metamorphism is related to a phase of crustal subduction, in which first gabbro or diabase was intruded, and later a granitoid known as the Üç Kapili granitoid mass. These wer intruded prior to the late Pliocene, in rocks of which granitic pebbles are found. An outcropping granitoid boss is found within half a kilometre north east of the Kestel deposit where mineralisation is found mainly in the Çamardi Marble, but with some within an underlying quartzite. Granitic pegmatites found on Kestel and in the mine as dykes are probably the fractionated end-members of the granitoid intrusion and are clearly related to mineralisation, though their tin content seems not to have been high enough for extraction in the known occurences at Kestel (see below for examples). This may possibly suggest the granitic body acted as a motor for circulating ground-waters and leaching minerals from country rock, rather than being the sole source itself. Fragments of quartz/tourmaline veinstuff are also found at surface, probably from a north-south trending vein in the marble, but this has not been worked, and was thus probably very low in tin or other worthwhile mineral.

The top of the marble seen in small exposures at surface, and underground in Area 2 of Mine 1, has a layer of dark coloured marble, possibly resulting from metamorphosis of a rather muddy limestone: this sits above a slight erosion unconformity, and from its relationship to the worked zones of marble below, may have acted as a cap-rock to mineralisation. It may have been used as an indicator by early miners, since mine entrances are commonly found adjacent to outcrops. Small fragments coloured green and brown of a possible calc-silicate marble are occasionally found on tips, which may indicate small proportions of sandy dolomitic material in the original marble, or, conceivably, may have been the result of penetration and alteration by circulating mineralising fluids.

The long period of erosion which led to the unroofing of the granitoid boss may have exposed much of the existing surface and led to the unconformable deposition of a late Palaeocene breccia-conglomerate found today as an eroded fragment at the south east part of the site just above the valley floor, and to the west along the sides of the valley bottom. Since its deposition, erosion has removed the greater part of the breccia-conglomerate at Kestel, as well as finally modifying the slopes to their present form.

Goltëpe, two kilometres away has steeply inclined shales and greywacke sandstones of a flysch deposit, marking a further, Middle/Upper Palaeocene, subductive phase, separated from the older Kestel rocks by a fault. There is no associated mineralisation, and the rock of the hill there appears free of tin other than that imported there from Kestel.

The gabbro or diabase, noted above, is found just south of Kestel. Following weathering this has provided hard stone-cores within boulders formed by exfoliation, which seem to have been the source of the many stone tools found at Kestel and Göltepe.

The two mines investigated at Kestel (which adjoin each other, and may have been worked as one) lie on either side of a NW/SE trending fault system which has both a near-vertical plane in which pegmatite is found at the bottom of the mine and, adjacent, a plane hading steeply north-east in and close to which, some, as yet unidentified, material has been worked within the quartzite. Subject to further intended investigation, the vertical fault appears to downthrow by several metres on the northeast. Working of the much weathered and easily worked pegmatite found at the bottom of the mine, seems only to have been to facilitate access. Narrow veinlets of clayey-limonitic material found either side of the pegmatite suggest further movement in the fault after the initial solidification of the pegmatite. It is possible the pegmatite has been worked for mineral in a collapsed section of working south east of the exposed section, but, for example, at an exposure of an east-west trending pegmatite dyke found low down on the slope of Kestel, working has extracted material from the adjacent marble, and probably also some quartzite, leaving the pegmatite in place, which seems to be the general case. Small workings some two kilometres westwardly upstream of the foot of Kestel also enter in pegmatite dykes, but to little result. Tin has been analysed in pegmatite at the Gümüsler area, but only at values between 3.2 and 15.2 ppm, (Akcay 1994 p.39), whilst Özbal (pers. comm.) has so far not detected economically significant levels in the pegmatite at Kestel. The occurrence of tin in quartzite and in pegmatite requires further investigation, since there are substantial areas of openworked mines on Kestel and in the adjacent area in quartzite which Pehlivan (pers. comm.) as a result of his extensive field survey in the area for the MTA. considers associated with pegmatite dykes. If this is so, pegmatite dykes are also found trending roughly NE/SW on the northwest flank of the mineralised (ie. mined) area, covered by mined overburden.

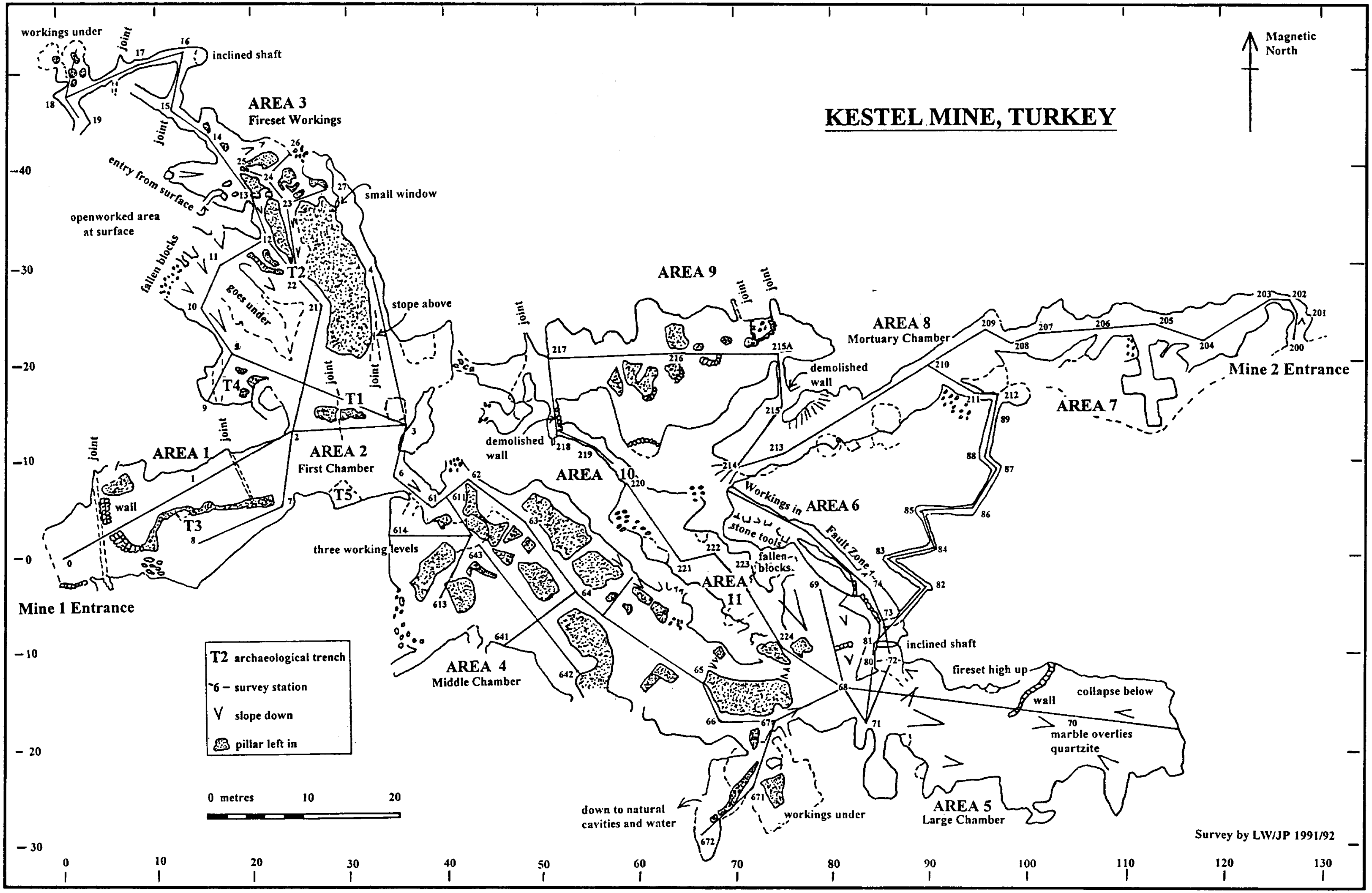
The major NW/SE fault direction roughly coincides with the SE dip of the marble and underlying quartzite. The mine workings (see survey of the mines below) suggest highest tin concentrations along and near the fault zone, especially on the upfaulted west side in which the largest chambers occur, with mineralisation spreading laterally into adjacent rock. The greatest lateral extent occurs in the central portion, almost along the strike, extending west to the Mine 1 entrance and east or slightly north of east towards the Mine 2 re-entry shaft sunk by ourselves. This widest lateral extent may coincide with a slight monoclinal flexure, just visible in the rocks above the Mine 1 entrance, which may have caused "ponding" beneath the "black marble" cap.

Several further faults are found with evidence of post-pegmatite and post-mineralisation movement. One, in the Upper Fireset Workings (Area 3 of Mine 1) downthrows some 5 metres to the south, and runs roughly NNE/SSW. It seems largely unmineralised (there is a little ochreous, probably secondary content) and displaces the mined (mineralised area of) workings an equivalent amount. Two other widened joints, or, possibly, faults, are found in the entrance area to Mine 1, Area 1, one of which has a strong rib of quartz within it. Both seem to have been subsequently either widened by solution or further movement, or both, and have had an infill of limonitic material. An apparently similar "joint" cuts throught the central pillar of the First Chamber, Area 2, where it has been worked by both first and later-phase workings, suggesting that whatever else was in the infill, it contained tin. This suggests some secondary deposition of tin-bearing material in karstic-derived cavities. Other karst derived, partially infilled, solutional features are seen in the narrow zig-zag connection between the two mines, but little more there appears to have been done by the miners except the minimum to provide access.

Both the workings themselves, and analyses of material by Özbal, suggest the tin was found in low concentration (mainly <10,000 ppm) as the oxide, cassiterite, within a haematite dominated phase of mineralisation. Two forms of haematite are found, a hard, blue-black, fine grained, very dense, specular form, which is discarded in substantial quantities on the hillside. It has been found to be very low in tin and, since this is the form found in an obvious 30 cm wide vein in a surface exposure a short distance above Mine 1, may have led to some of the mis-apprehensions about the mine which have circulated. The second form is a red, usually softer, form of haematite, found in large lenticular vugs, and as replacements in the marble, and as dense dendritic networks in the marble. There is some evidence, from the zoning in the vugs, that tin was either the first to be deposited, followed, or possibly accompanied, by the red-haematite phase, and then the black unstaniferous haematite (Pehlivan and Özbal, pers. comms.).

Two substantial vugs remain in the First Chamber (Area 2) of Mine 1, which contain substantial amounts of haematite. There are also several other domed cavities nearby which appear once to have had similar infill, and it is possible these are metasomatised structural features within a flexure in the marble. Substantial metasomatism of marble is also seen in the Middle Chamber (Area 4), where the red-rock still has substantial haematite within it. In other areas the haematite is seen, as what remains rather than necessarily what originally occurred in the mined cavities, as thin veinlets infilling joints, or as dendritic networks of haematite in rock adjacent to fault-induced fractures.

The presence of granitoid bodies and quartz and quartz/tourmaline vein infill, and tungsten in the form of scheelite, thus suggests the tin deposit at Kestel genetically has some parallels with the better known tin/wolfram mineralisation found in Cornwall, though the host is mainly marble rather than killas. The tin is intimately associated with a first phase of reddish haematite mineralisation which may have occurred some time later than the intrusion phase of the pegmatites which themselves generally seem to bear little tin. Both pegmatites and haematite


KESTEL MINE, TURKEY
Magnetic North
AREA 1
AREA 2
First Chamber
AREA 3
Fireset Workings
AREA 4
Middle Chamber
AREA 5
Large Chamber
AREA 6
Workings in Fault Zone
AREA 7
AREA 8
Mortuary Chamber
AREA 9
AREA 10
AREA 11
Mine 1 Entrance
Mine 2 Entrance
workings under
inclined shaft
entry from surface
openworked area
at surface
fallen blocks
goes under
small window
stope above
demolished wall
three working levels
stone tools
fallen blocks
fireset high up
collapse below
wall
marble overlies
quartzite
down to natural
cavities and water
joint
T1
T2
T3
T4
T5
T2 archaeological trench
6 – survey station
V slope down
pillar left in
0 metres 10 20
Survey by LW/JP 1991/92

are important in that they provide markers to where tin is found, and the original miners may also have been aware of the importance of the black-marble cap-rock in defining the deposit. Mining access to the deposit has been eased in some areas of the mine by weathering of the pegmatites, and by post-depositional movement of faults and by karstic development within faults and joints, notably, but far from exclusively, in the zig-zag connection between the two mines. Secondary deposition of limonite, presumably derived from the primary haematite, has taken place in such cavities, and may sometimes have born workable levels of tin. The grade of tin is very low, though it should be remembered that the sub-10,000 ppm. ore which remains might be regarded as a "cut-off grade" in modern mining practice, rather than being an average grade, let alone being the best grade which early, selective, mining might occasionally have found.

THE MINES

Mining has taken place both by underground mining, and by openworking. Some of the larger openworking is remote from the underground mines, and takes the form of large"scoops" or depressions, notably on the west and east sides of the hill, north of the mines, and below Mine 2 on the east side almost down to the valley floor. Openworks close to the Mine 1 have a different form, with vertical walls and some corners squared, and cut into and through the earlier underground workings. Openworking following underground mining is a normal sequence, since the earliest exploitation in ancient mines generally followed the richest ore and minimised the amount of waste worked. The openworkings have not yet been examined in detail though a radiocarbon date based on charcoal excavated from a trench outside the mine, in an openworking which cuts through the underground workings of Area 3 yielded a date of 1210 ± 50 BP (uncalibrated). This is still a lone date, but hints at a possible early-Medieval (Islamic) phase of openworking of the deposit. The following, however, refers mainly to the underground mineworkings.

There are several small mine-entries on the hillside, but following modern re-discovery by the MTA and Aslihan Yenner, all the known substantial underground workings were located from a single large and obvious entrance, that to Mine 1, which opens outwards into one of the smaller openworkings. Survey of Mine 1 led to the discovery of a very difficult and narrow connection to a further series of workings. Subsequently, in 1992, an inclined shaft was sunk some 10 metres by the PDMM team to this further series at its furthest extremity and, as it turned out, through infilled domestic and smelting debris on what must have been originally a quite separate entrance. Survey found another connection between the two systems (only emaciated persons managed to pass), and since the use of this second area as a mortuary led to its sealing-off as early as EB I, whilst the area of Mine 1 remained in production, the second area is considered as a separate, Mine 2, and includes all, or nearly all the known mine east of the central fault.

Mine 1.

As can be seen on the survey, this has several areas with different forms of workings visible within it. The earliest appear as small fireset passages, 70-80 cm diameter where only for access, and widening out into rounded chambers to the presumed form of the original orebody. These are seen in the upper, northern part of the workings (Area 3), and have been cut through by a surface openwork on the west side, and by a later much larger scale underground working - the northern end of the First Chamber (Area 2) on the south. Three more or less parallel passages in plan have been driven northwards, the easternmost is roughly horizontal, whilst the centre and west passage rise fairly steeply, until all three unite in a substantial chamber. Several of these small earlier passages are seen in both the Entrance (Area 1) and in Area 2. Pottery scatters included mostly EBII and EBIII, but a MBA vase was also found in the tiny entrance from surface to the Area 3 workings.

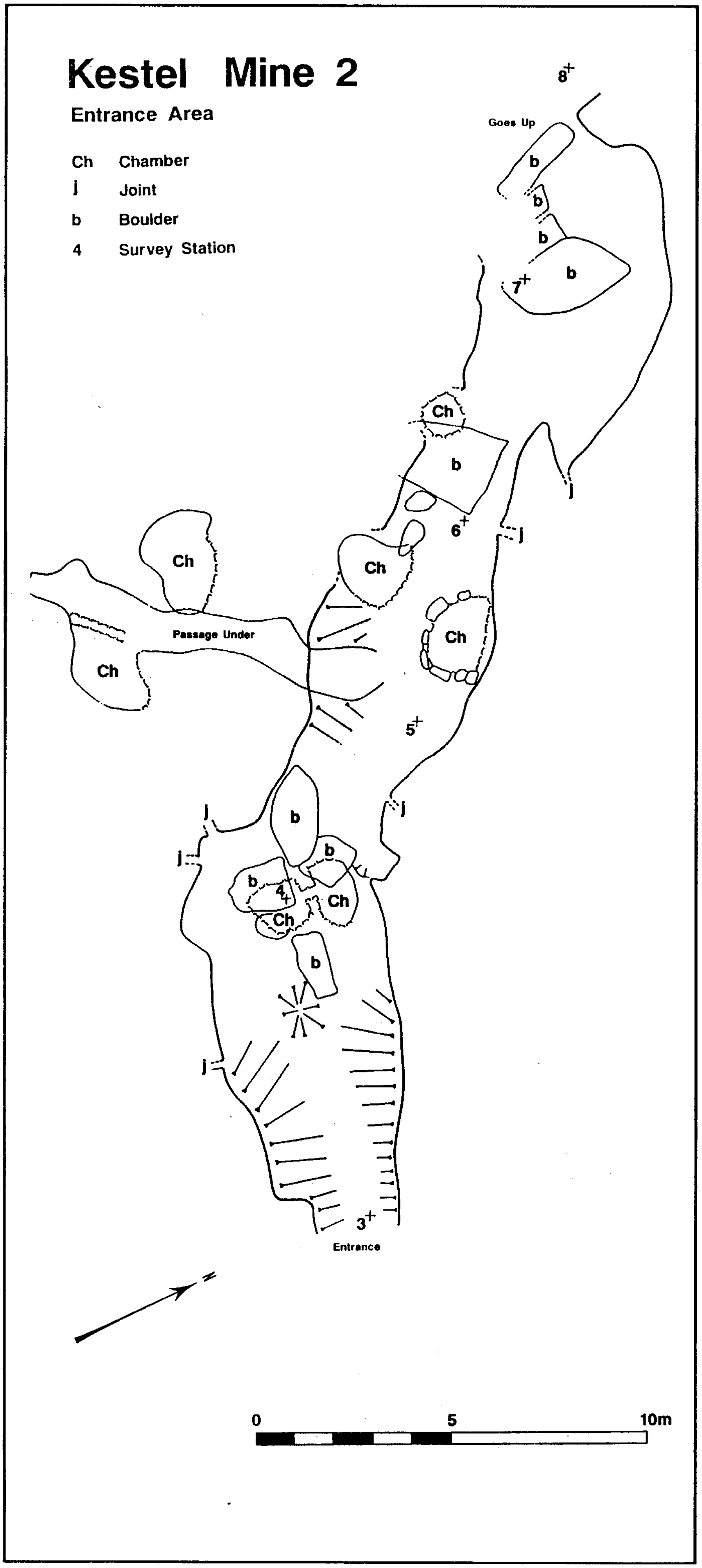
The floor of the Entrance and First Chamber (Areas 1 and 2) are level or is only slightly inclined for the most part, though sloping more steeply uphill to and at the north end. Firesetting has been extensively used, but in conjunction with much more mechanical breakage of the rock, so surfaces are sometimes angular as well as curved, and the maximum possible amount of material appears to have been excavated, leaving pillars to support the roof. An archaeological trench (T5) sunk in this first chamber by Phil Andrews showed a large quantity of evenly broken stone left in the floor to a depth of at least two metres, interpreted as ore-processing debris. Tentative dating using pottery sherds suggests mine-working in EB II and EB III, with use for domestic purposes in the Byzantine period by which time extensive mine-working had ended (see below also).A radiocarbon date from a charcoal layer within the beneficiation debris found in the T5 trench suggests the second phase working here to be around 4690 ± 100 years BP (uncalibrated).

South of Area 2, a small floor-level opening leads to a series of almost horizontal large passages and openings, known by us as the Middle Chamber, Area 4. In plan this forms a wide area supported by pillars, with workings on three interconnected levels. At the south end a small passage winds down, below the mine floor near Stn 672, into what appear to be natural passages with stalagmite formations and a pool of water (entrance only shown on the plan). Considerable amounts of fairly friable, red haematite are found on the walls of the east side, but whether this was the original condition is not known.

This area in turn leads by a further small crawl-size opening to the Large Chamber, Area 5. This is some 50 metres long, up to 15 m wide and up to over 5m high, and is calculated to have had as much as 5000 tonnes of material excavated. Both roof and floor steeply slope down to the south, and remains of firesetting at the sides, high on the walls, suggest the chamber-working cuts through an earlier phase. A radiocarbon date 220 ± 45 years BP (uncalibrated), but found in an area of a substantial scatter of EB pottery, indicates great care will be needed in determining the last phase of operations in this area, though it might simply relate to entry for exploration purposes.

The furthermost part of the chamber (southern end) is excavated in the underlying quartzite, and on the east side a narrow climbing way leads down into a faulted zone (Area 6), to the maximum depth in the mine of about 30 metres. This is, here, also bounded by the quartzite, with a partially decomposed pegmatite visible at the end of the working within the fault walls. A thin vertical layer of limonitic clay either side of the pegmatite, within the fault, has been worked with a (surviving) bone tool. At least two, differently hading, fault planes can be observed. The adjacent quartzite on the west side of the fault has been exploited using stone hammers and firesetting, but in general the rock is so fractured that curved firesetting faces are entirely absent. We have so far been unable to determine the type of ore worked in the quartzite, though the workings are reasonably extensive, certainly more so than need have been done for exploration only.

The northern end of the Large Chamber leads into an area of fallen blocks, in which a narrow connection to Mine 2 was only found in 1992. Just below this, on the highest part of the steeply sloping east wall, a narrow passage, utilising natural joints and fault planes leads, zig-zagging and tortuously, to Mine 2.



Mine 2.

A line survey using hand-held compass and tape enabled the extent of the Mine 2 workings to be established at surface, some 130 metres distance just north of east of the Mine 1 entrance. Examination underground revealed a strong joint at the eastern extremity of the workings, which, though entirely concealed, was confirmed at surface by simple geophysics. An inclined shaft was successfully sunk at this point through a metre or so of topsoil and slope-wash into the joint in marble-rock. Within the joint, the fill included a substantial amount of pottery sherds and some crucible fragments similar to those found at Göltepe, but of EB I date. Thus the absolute minimum was excavated for access to allow later proper examination, but the finds provisionally suggest a domestic site with some smelting activity close by the entrance, belonging to the earliest period of workings established.

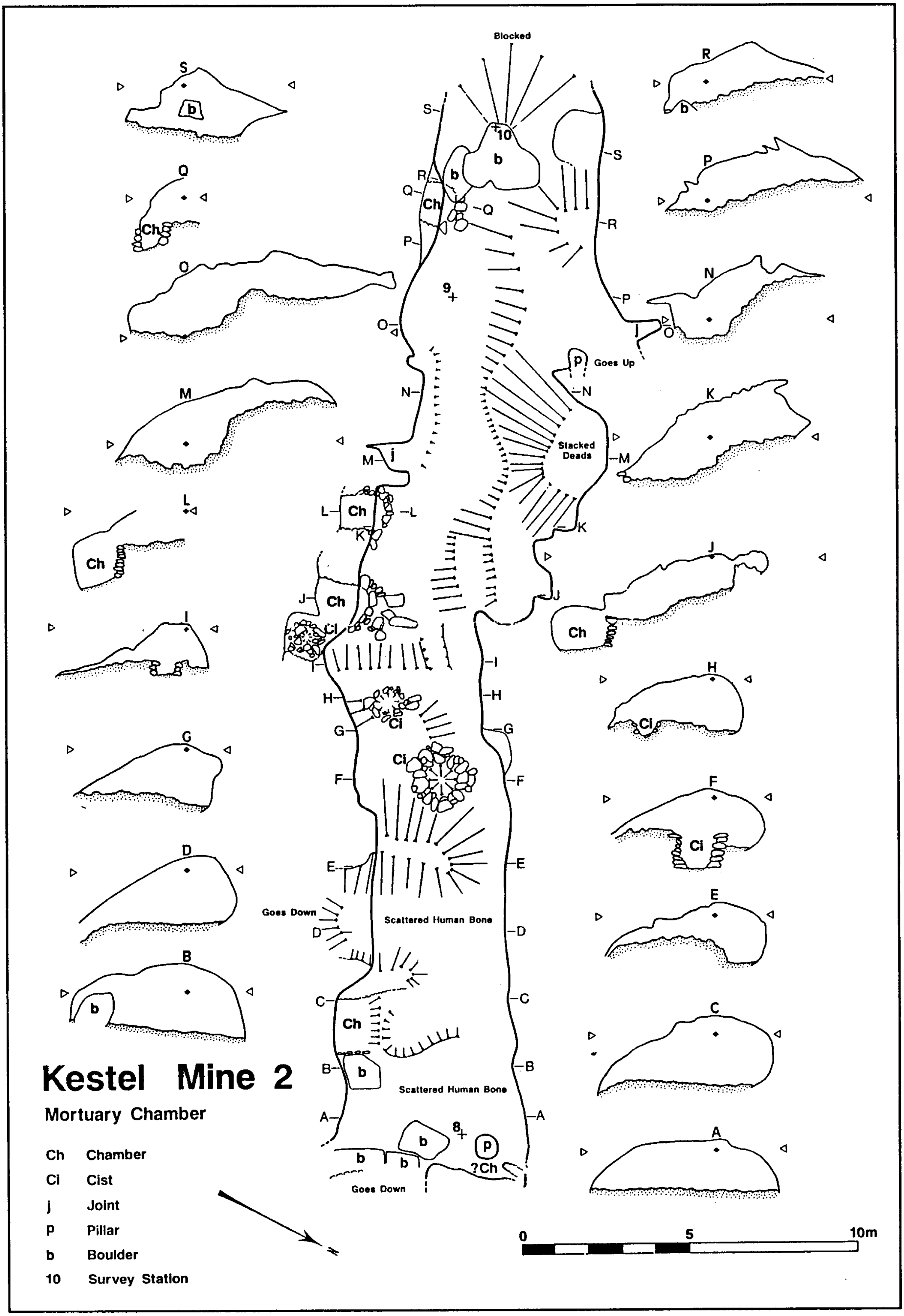
The new shaft (or re-opened entry) enters a long, and almost horizontal chamber (Area 7) which appears partly to be a collapse, possibly into workings below. This has been reused to provide burial places, by small excavations in the floor, or between fallen blocks. The original entry seems to have been via the rift in which our shaft was sunk, which implies sealing during the EB I period. Some blocks may have fallen subsequent to this use, since otherwise the route towards some burial places must have been extremely difficult.

Beyond the somewhat chaotic area of fallen blocks of Area 7, a further long mined chamber (Area 8 - the so-called Mortuary Chamber) had a number of human bones scattered, with a probable minimum of eight bodies represented. The chamber appears to have been mined by use of firesetting working along a "long-wall" in panels along the strike, working up the the dip. Much stone had been backfilled some five metres behind the workings in packs, which have disguised the full extent of the chamber. A way had been left open to the long zig-zag leading back to Mine 1, though this had been sealed overhead, and the workings would not have been found except for a collapse at the junction. Burials seem to have utilised small chambers in the down-dip side of the chamber, or were in pits or shallow inhumations. No complete skeleton has been found, and robbery has taken place at some time. A small amount of Byzantine ware may suggest the first occasion.

(Left) The Entrance Chamber (Area 7) to Mine 2, showing position of possible inhumations.

(Opposite page) The Mortuary Chamber (Area 8) of Mine 2, showing possible burial chambers and cists.

Both surveyed by Phil Andrews and Jen Jones, and redrawn by Brenda Craddock.


Kestel Mine 2
Mortuary Chamber
Ch Chamber
Ci Cist
j Joint
p Pillar
b Boulder
10 Survey Station
Blocked
Goes Up
Stacked Deads
Goes Down
Scattered Human Bone
Scattered Human Bone
?Ch
Goes Down
0
5
10m

At the further (west) end of the chamber, loose boulders appear to have been piled, and the rough pathway found earlier, and in most other parts of the mine, is no longer found. The piling of stones appears to have been from a non-mining activity. The west end of the chamber is blocked with what appears to be a collapse, and may have led originally to the faulted Area 10, where a further skeleton was located. Progress beyond the Mortuary Chamber was via a small crawl on the north side (station 215-215A), which had at sometime been sealed using stones and a limonitic clay, but was broken down long ago. This led into more "conventional" fireset workings with passages and chambers supported by pillars, and leading to a series of small fireset chambers (Area 9, west of station 217) which incline upwards, but were filled by stones from above - these may have been into the workings of Mine 1 at the eastern side of the Area 3. Area 9 connects to Area 10 via a widened joint or fault, turning back behind the end of the Mortuary Chamber (Area 8), with the remains of a broken-down, rubble-stone wall at Station 218 suggesting this way too was also originally sealed-off.

Beyond the rubble wall, a passage leads into a widened rift (Area 10), possibly part of the fault system, which has been excavated to some 5 metres depth below the original passage level. The remains of a skeleton was found at the north end at the deepest point. A fireset cavity in the roof close to Station 220 was remarkable in that it clearly showed the combination of firesetting and stone hammer work. The firesetting, remains of which were left *in situ*, was clearly followed by a very heavy hammering, using a remaining very large, but obviously hand-held, stone hammer, with some 50 mm and more of hammered rock removed, but leaving the work half-incompleted. Lack of fallen material below suggests the placing of the skeleton post-dated the excavation of this particular cavity. A radiocarbon date for the fireset cavity shows working continuing to about 4090 ± 60 years BP (uncalibrated). Both east and west margins at the level above the fault-rift were filled with fallen rubble or had been backfilled, suggesting a former connection with the Mortuary Chamber, and possibly with workings in Mine 1, Area 4.

Beyond the rift, several small entrances led into a chamber with small workings and fallen blocks (Area 11), from which the connection with the Large Chamber (Area 5) of Mine 1 was eventually located.

INTERPRETATION

It is clear from the pottery and from radiocarbon dates that the underground mine is predominantly Early Bronze Age, though some later working, both underground and at surface is not precluded. The earliest part to be worked, in EB I, so far as is presently known, is Mine 1, whose probable entry position might well have been discovered by simple prospection methods, ie. the following of weathered fragment from the vein or "shode ore" up the hillside by panning, from just downstream of where stream sediment lost the ore. The infill evidence of the Mine 2 entry suggests an early settlement near to it, at which ore processing and smelting probably took place. A possible mould-stone was found nearby on the surface. This might suggest the initial settlement was close by the ore-supply, with migration of this facility to Göltepe at a later date, possibly because of better water supply and more fuel.

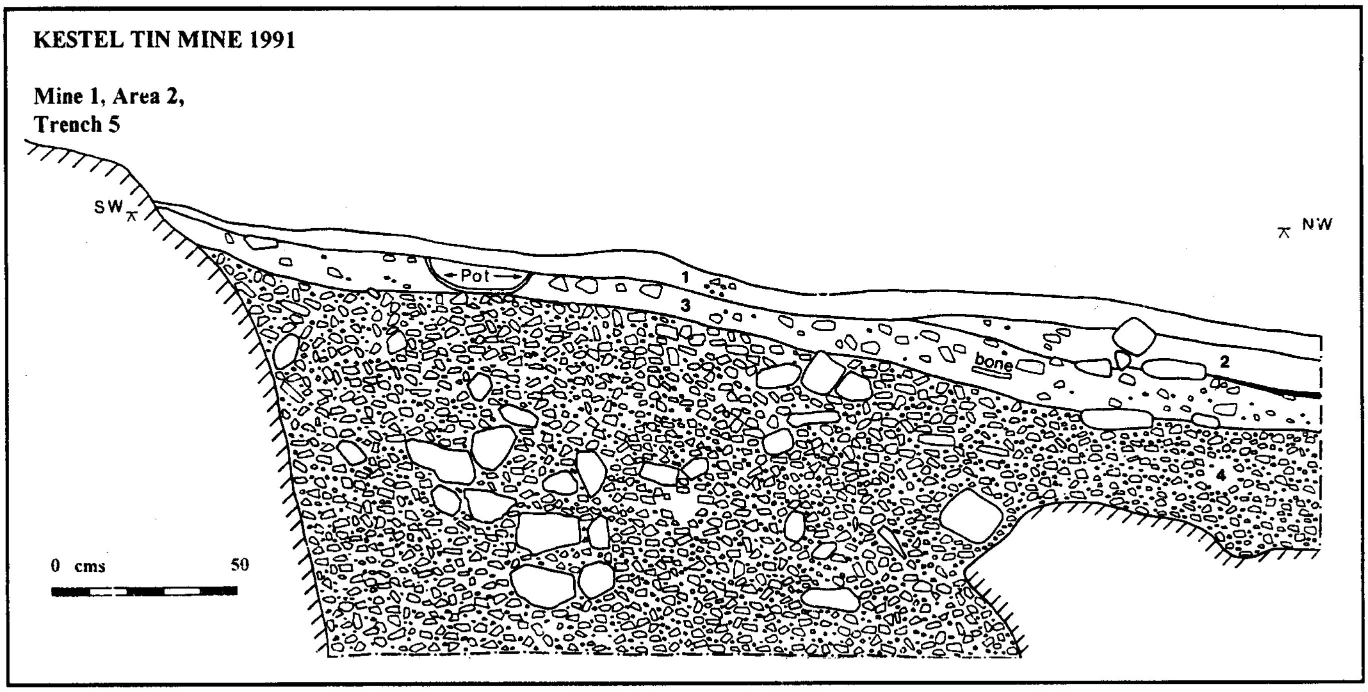
Abandonment of the main part of Mine 2 possibly took place before the end of EB I, based on pottery scatters,and probably prior to the inhumation of the skeleton in the fault-working of Area 11, though the radiocarbon date (above) suggests working later than this before this area was sealed-off and reused as a burial place. Mining, however, continued in Mine 1, and possibly some parts of Mine 2, where remains generally indicate EB II and EB III activity, whilst a small vase of Middle Bronze Age found in the upper part of Mine 1, Area 3, indicates some activity therein at that time too. The finding of Byzantine artifacts in a domestic rather than mining context in the Area 2 of Mine 1 (and lack of such artefacts in less approachable areas), suggests substantial underground mining activity had ceased by that time.

Firesetting was the dominant method of mining in the early phases of activity, in conjunction with stone hammers used for battering. A bone tool was used to extract soft limonitic material in one place in the mine, but bone as a tool was not very suitable in the mine generally for working the ore, and though an ox-scapula may have been useful as a shovel, no evidence for such a use has yet emerged. There are a large number of animal bones in Mine 1, but most appear to have been introduced by recent carnivores. A few marks found during the excavation T5 in Area 1 of Mine 1 suggest metal tools may have been used, but there is no general pattern of use, and it is just possble the marks resulted from a sharpened tool such as antler or bone. Antler was found in the Mine 2 entrance infill, but this could relate to dumping from surface. Several techniques of firesetting were employed, including shaft sinking on a steep incline, driving of small passages (c. 70-80 cm diameter), chambering using large fires, and longwall working using panels of fires advancing up-dip. The variety suggest sophistication of mining, even at the earliest phase, though there is a general lack of suitable settings for comparison of firesetting methods of this age. (see also Willies 1994 and Craddock 1994 for consideration of firesetting methodology).

In later phases of activity, in which large chambers were developed, cutting through earlier smaller passages, then hammering, still mainly with stone tools, resulted in surfaces being rough and angular, rather than smooth and curved from fires. In several places, however, there is evidence that the hammering followed firesetting, or at least that harder places were still so tackled. It may suggest that wood was less easily available, but, in fact, the combination was probably a more efficient system of mining made possible where there was more space in which to work. The mine is well ventilated today, and there is evidence of more openings to the outside - but it has not, so far, been possible to shown how ventilation systems were designed to operate.

WHAT WAS MINED?

It is frequently difficult to determine what was the object of mining in many old mines, since hand methods can be very effective in removing most traces of ore. Kestel was identified by the MTA, the Turkish Geological Survey, as a tin prospect, and cassiterite was soon after identified there by Yener and co-workers (1989). Proving that it was indeed worked for tin is more problematical, and has been particularly controversial. Conclusive evidence can only come from examination of metallurgical residues associates with material derived from the mine. As described in the introduction, the balance of archaeo-metallurgical evidence, from crucible material excavated at Göltepe now seems overwhelmingly to favour tin as the main product. Though gold has also been found in very small quantities, this would be relatively minor in quantity and, very likely, gross value, in contrast to tin which in the EBA must have been considered a rare commodity indeed. No archaeo-metallurgical evidence for gold working has yet been found, but since gold would be revealed by the same processing methods necessary to work tin (and vice versa), it is very likely any gold would also have been recovered. Gold was probably anciently worked within the Niğde Massif, and a gold prospect seems to have been located a few kilometres from Kestel by the MTA and has been investigated further by commercial interests. The ancient search for gold provides a possible discovery method for the tin which would be included in



Trench 5 in Area 2 of Mine 1: Section showing quantities of waste crushing debris in layer 4. Layer 3 with the domestic pot is Byzantine, and suggests mining activity had ended by then. Excavated by Phil Andrews and redrawn by Brenda Craddock.

substantial quantities in the "black sand" (which would also include magnetite especially) of the gold prospector's pan. The abundant haematite was probably also valuable as colour and would not have been neglected as a product, but a mine of this sophistication, and high cost of working, solely for such a generally easily available substance seems less than likely.

It is clear from examination of the workings that haematitic material was that which was mainly sought, but it seems more likely an associated mineral within it was the true object of this relatively sophisticated mining operation. The two likely materials found by microscopic examination, assay, and panning, are gold and tin, and it is clear from the remains of processing that a similar and suitable technology for separation of either was available on the site.

Whichever, it is possible to comment on the levels of tin as cassiterite which might have been found in the mine. It is clear that what is left in the mine will be marginal material, and given the very extensive, long period, multi-phase working of the mine, on average this can be considered the cut-off grade of the final working. In an earlier, very guarded comment, the present writer suggested the average grade of ore which had been worked, expressed as a fraction of the whole rock excavated was probably in the range of 0.1 to 1% tin (metal equivalent). This was based on the grades of samples taken by the writer and Özbal, at that time with little geological knowledge of the mine, and no knowledge of what was actually ore! This caused considerable adverse comment - first that the grade was impossibly low to have been worked in the EBA (assuming, some critics considered, if a mine could be worked at all at that period) especially, presumably, at the earliest part of that time, and secondly that the projections of the total tin metal which might have been worked at these grades was too much for that period to have absorbed. There has subsequently been an indicator that the openworked areas of the site may be from a later period.

The main useful contribution from sceptics in this respect has been by Budd, both in direct discussion with myself at a seminar at Bradford University, and in contributions circulated on the Internet. Budd has examined assay data produced and supplied by Özbal, which included tin (metal) grades of up to 7900 ppm. As a result, he appears to accept an average grade of some 600 ppm as reasonable for material recovered by Özbal and myself from the mine. This level is some hundreds of times higher than any postulated for gold (only one speck has so far been located from samples examined by Earl (pers. comm.). Low it may be, but this refers to what was left in the mine, not what was removed, and as such it is probably an acceptable minimum estimate until more data is available.

In modern terms, this would be termed the cut-off grade for actual mined material, and there is no reason to suspect that ancient miners were any less aware than modern of the useful grades at which a deposit could be worked. Few mining engineers today would be surprised at an average ore grade worked of perhaps ten times this level, say 6000 ppm, or 0.06%, and at least one example of this, in the writer's own experience, can be cited, of silver grades in the Rio Tinto Mines of Spain, which were determined by a major drilling and sampling programme. By differentiating between cut-off and average grades therefore, by this factor there seems very little in practice between Budd and the present writer's position. However Budd appears less inclined to accept that the cut-off grade would be different from the average mined, and is sceptical of both the ability of the ancient miner to recognise such lean ore, let alone have the ability to process and smelt it. By selective sampling in the mine, now that we have had the necessary experience based on many analyses, we are confident we could recognise an average grade of ore around 0.5%. Ancient miners probably did better.

Although we cannot know to what extent the material mined was in ore, and what proportion was excavated for communicating passages in unmineralised rock, it is possible to envisage large mined spaces as being in ore. Given that the miners would clearly favour getting orey ground, and that sometimes rich cassiterite mineralisation was very likely met with, the 0.1 - 1% range of tin ore/whole rock excavated probably remains a viable level for estimation purposes. Because of the extensive nature of the later phase of mining, and the large amounts of waste rock found within the mine, the writer would himself favour a level towards the lower end of this scale overall. However, it would be extra-ordinary if the earlier miners did not select the higher grades to follow in their narrow workings, thus achieving higher grades at the early phase of development.

Counting squares on the plan of the whole explored mine shows the mine occupies some 2300 square metres. This is a minimum estimate since we know there are areas of the mine we have not been able to enter due to backfilling. Taking an average height of two metres, which is suggested by the average of the long section, even without accounting for unknown, but substantial, amounts of backfill on the floors, then the total tonnage extracted would be about 11,500 tonnes - equivalent to 115 tonnes of tin at the 1% level (and of course 69 tonnes at the 0.6% grade and *pro rata*). This does not take account of the substantial amounts of tin which came from other underground sources on the site, and the much larger quantities which must have resulted from the extensive openworking, and the possibly substantial amounts which might result from tin-streaming or placer working on the rivers. On the debit side, we also do not know what percentage of the tin in the ore was lost in beneficiation procedures, or in smelting.

The point has been raised several times in articles and correspondence, that early miners would favour exploitation of river sediments (placer deposits) over underground mining. We can reasonably expect placer working did take place - it is an intrinsic part of the probable discovery mechanism of the Kestel deposit. Given sufficient reserves, placer working might well be favoured, but it is cautionary to remember two things: first how rich placers in gold rush days were very quickly exhausted, and secondly to remember that placer working often involved the removal of enormous amounts of sediment - sometimes many metres thick, to get at the mineral desired. It was not necessarily easy work, and probably much more capricious than the underground deposit. For instance, placer and underground mining survived for several centuries alongside each other in post-Medieval Cornwall.

Radiocarbon Dating - data provided by the British Museum.

BM-2879 Charcoal, ref. S46 (*Cupressus sempervirens*), from an *in situ* hearth in a cavity worked by firesetting in the roof of Area 11, Mine 2. The last stage of work, and pre-dating an inhumation of probable EB age in a mined fault some 6 m below.
4090 ± 60 years BP

BM-2880 Charcoal, ref S2 (*Pinus ?halepensis*) from the last phase of working within the large chamber of Mine 1 (Area 5).
220 ± 45 years BP

BM-2881 Charcoal, ref S33 (mostly *Pinus ?halepensis* with small amount of *Cupressus sempervirens*). From a charcoal layer in trench T5 in the First Chamber (Area 2), of Mine 1. Associated with large quantities of stone chippings resulting from beneficiation processes.
4690 ± 100 years BP

BM-2882 Charcoal, ref S24 (*Arbutus unedo*) from a layer deposited after colluvium had entered the mine adjacent to Area 3, where openworking had cut into earlier mine workings.
1210 ± 50 years BP

The dates given are all uncalibrated. Wood identifications were by Caroline Cartwright..

BENEFICIATION

This term describes the processes in which the ore is prepared so as to provide the most economic feedstock for smelting: This will not necessarily be the highest degree of concentration possible, since any improvement in this respect might be wiped out by losses of ore involved, and in some circumstances might involve mixing of ores of different grade of composition and, nowadays, might even involve dilution. It would improve both transport and fuel economics, and perhaps proportionate losses of tin by decrepitation and absorption in slags during smelting, if a more concentrated feedstock could be produced from the rather lean ores which appear to have been mined at Kestel. There is considerable evidence at Kestel and Göltepe that beneficiation processes were used.

The early phases of mining seem predominantly to have been by the use of firesetting, with the minimum use of stone hammers, leaving the characteristic smooth curves of firesetting. This would cause the material excavated to be in small pieces and very friable, and may even enhance the separation by inter-fracturing of cassiterite grains. Wherever possible the working would have been limited to reasonable grade ore, and further fine crushing and grinding would thus be relatively simple (see below).

In the later phases, where it can reasonably be assumed that ore of a lower cut-off grade was worked, then firesetting seems to have been accompanied by very heavy hammering, resulting in much larger fragments which would have required much more effort to reduce to a fine size. This is the type of material, "chatter", seen making up the bulk of waste material in the archaeological trench excavated by Phil Andrews in the first chamber (Area 2, Trench 5,of Mine 1). It suggests that reasonable grade material, haematite, was picked out, whilst less good was broken, and the finer product kept. Beneficiation using the relative friability of minerals, is a normal means of processing even today and, in particular, would tend to free haematitic material disseminated in closely spaced rock fractures. It leaves open the possiblity that the finer material was then burnt to assist in breaking.

There is plenty of evidence of the fine crushing stage of processing in the many thousands of stone tools found at surface at both Kestel and Göltepe used in crushing and fine grinding. These include stone hammers and a great many former rubbing stones utilised for crushing (indicated by dimpling of the former smooth surface), scores of mortars formed from cavities in the marble, and purpose made mortars in the gabbro or diabase for coarse crushing. Hand-held rubbing stones with resultant polished surfaces were used on substantial saddle querns. The point of this was to "liberate" (break apart) fine particles of cassiterite (or gold) from the haematite matrix.

In a point not previously emphasised enough, this fine grinding infers that a further ore-dressing process was used to separate the lighter haematite from heavier cassiterite, since such fine grinding was unnecessary for smelting if this was to be done directly with a low-grade ore-concentrate, and, indeed would be deleterious to the process. Panning with a wooden dish and using only a small quantity of water would do this very simply and well, but better working efficiency would be attained by using running water over some form of inclined table or planilla, of which the "golden fleece" is the best known example from antiquity. For the present, at least, the details of this aspect remain speculative, and the survival of such equipment is not too likely, especially since part of it would be located at springs or the river side where subsequent disturbance is almost certain.

There are suitable reasonably modern, but still primitive, parallels for this type of ore processing technology. Crushing and grinding using very similar stone tools to those at Kestel has been used in the 1980s for separating gold from quartz in Uganda (Terry Worthington, pers. comm) and iron hammers and stone blocks are still in use in the Kolar goldfield in India nowadays. Taggart (1947 p.2-228) describes separation in China of c.5% tin ore finely disseminated in a clayey mixture of limonite and porous haematite, which was largely hand milled and treated on planillas. The planilla is described by Taggart as having a curved surface, which for fine tin ore was sometimes formed of a grass sod with roots uppermost, but could be of wood or other material. The first of the planillas he described for Hunan was about 5 by 6 feet (1.5 by 1.8 metres) and was placed at an angle of 20° and worked with much water (in which the fine ore was suspended as a pulp). It yielded a concentrate of 50-55% tin, which could be raised by similar methods, but using less water, on slopes of different (steeper) angles to around 68.5% tin, with a 70% recovery rate.

The type of ore at Kestel is somewhat similar to that described for Hunan by Taggart where it was "probably an oxidised residue of a replacement deposit in limestone". Whether such methods were in fact used at Göltepe and Kestel is unlikely to be determined, but the level of understanding of the technology of mining and smelting suggests a good understanding of the simpler forms of ore processing was at least likely. The known early use of such methods and the simplicity of both the concepts and practice suggest it would not have been difficult to concentrate the very lean ores found at Kestel.

CONCLUSIONS

A further season, planned for 1996, and further scientific work will be required to finalise the Peak District Mining Museum contribution to the work at Kestel, but the main results are now clear and accepted by most workers in the field. Kestel was indeed an Early Bronze Age tin mine, and Göltepe its linked processing site, successfully beneficiating very low grade ore into a smeltable concentrate for a period in excess of a millenium. It was active at a very early date (well before 5000 years ago is likely), and though sophisticated techniques of mining were used, it was very likely amongst the first such underground tin mining operations undertaken. The mines probably produced around 100 tonnes of tin and with surrounding openworking and underground mines a total of probably several times as much. In the early phase after discovery, a small settlement probably grew up near Mine 2, which included smelting amongst its activities.

ACKNOWLEDGEMENTS

As an international and multi-disciplinary project the number of people to whom thanks are due is legion. Pre-eminent amongst them, however, are Aslihan Yener the Project Director, now of the School of Oriental Studies at Chicago University; Hadi Özbal of Boğaziçi University, Istanbul; Bryan Earl, best described as of Cornwall, and others in the team from Peak District Mining Museum - John and Rachel Peel, Brenda Craddock, Phil Andrews and Sheelagh Willies. Jen Jones joined the team from America as a specialist in bones for the preliminary work in the Mortuary Chamber. I received a basic field course in Kestel geology from Necip Pehlivan of the MTA, and also benefitted from discussion with Migrac Akcay and Charlie Moon of Leicester University, though all errors in geological interpretation are mine alone. We have developed very friendly relations with the local people in Celaller and Çamardi which eases life there immensely. We are all grateful to the British Academy which gave a grant towards our costs (much also was born by the participants), and to the American donors who helped us feed, and to the British Museum which has carried out radiocarbon dating for us.

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