Reports

Stratiform Copper Deposit, Northern Anatolia, Turkey: Evidence for Early Bronze I (2800 B.C.) Mining Activity

Abstract. *A stratiform, massive copper sulfide deposit with possible gold, silver, and cobalt credits was discovered by a United Nations reconnaissance team in Paleozoic (?) metamorphic terrain of north central Turkey. The deposit, which is of possible volcanigenic exhalative origin, contains evidence of extensive prehistoric underground mining and smelting activity that, based on radiocarbon data, may date to 2800 B.C. (Early Bronze I Age).*

During the 1972 reconnaissance phase of a United Nations minerals resource program in Turkey, an apparent site of ancient mining activity was discovered near the village of Kozlu in the province of Tokat, north central Anatolia (Fig. 1). Follow-up exploratory work on the location in 1973 has indicated that the site, a prehistoric underground mine on a stratiform and probably massive copper sulfide deposit, is probably the oldest radiometrically (^{14}C) dated underground copper mine known at present, and is remarkable for the extent and sophistication of subsurface excavation that was carried out to obtain ore.

The Kozlu site, located in the western Pontic range at 40°36′N, 36°25′E, is approximately 80 km south of the Black Sea coastal city of Samsun, 30 km north-northwest of the provincial capital of Tokat (which is near the Bronze Age sites of Horoztepe and Mahmatlan), 300 km east-northeast of the Turkish capital of Ankara, and about 165 km northeast of the ruins of Hattusa, the ancient capital of the Hittite state (*1*). The site, which is named after the nearby village of Kozlu (Fig. 1), is at an elevation of about 1300 m, in a densely forested and sparsely populated upland area of moderate to strong relief. The climate is highland continental, with warm, dry summers and cold, snowy winters. The area is only 15 km south of the trace of the Great Anatolian fault, in one of the world's most seismically active fault zones. The province of Tokat has been cited in an excellent article by Wertime (*2*) as a possible source of Bronze Age copper.

The physiography of the immediate mine site area is distinctly anomalous relative to the surrounding terrain: a broad linear depression or "trough," extending east-west for about 300 m across a shallow southwest-facing slope, is geomorphologically inconsistent with the valley trends of the well-developed dendritic drainage pattern of the area. Adjacent to the south side of the deepest, widest, central part of the trough is an elevated, hummocky land area characterized by a complex of rounded to irregular knolls and shallow depressions that stands somewhat above the natural ground level. The entire area is overlain by thick soil, and apart from the hummocky area a dense, mature growth of beech trees covers the slopes. The above features, along with the tracing back of anomalous base metal values in nearby stream sediment samples to their source, were the key factors in the early recognition of the site as representing ancient mining activity.

Stripping the bottom of the widest part of the trough by bulldozer revealed that, underneath the thick soil, the trough is filled by rubble—a loose, unconsolidated overburden consisting of angular pieces of broken rock intermixed with small amounts of soil or earthy material. The rubble is predominantly brick-size material or smaller; consists mostly of barren, hydrothermally altered bedrock; but in significant instances contains pyrite- and copper sulfide–bearing rock. This rubble material is interpreted as wall rock and ore that was broken and excavated from the deposit. Considerable amounts of secondary copper oxide are present throughout the rubble zone, due to percolation of alkaline groundwater.

In an effort to examine bedrock beneath the rubble fill, hand pitting was undertaken, and during the course of sinking the pit numerous chunks of wood were encountered at several deeper horizons within the rubble. The logical explanation for this abundant wood is that it is probably the remnant of mine timber—the wooden props, posts, bars, beams, and so forth used to support the roof or face of mine workings during excavation. A carefully collected sample of this wood was dated by the ^{14}C method by the Geological Survey of Finland at about 2800 B.C. (*3*). The inference is that trees were being cut in the early third millennium B.C. in order to provide timber for an extensive and ongoing mining operation at the Kozlu site. We recognize, however, the degree of uncertainty in basing the above argument on a single ^{14}C date; the evidence is preliminary.

The 2800 B.C. radiocarbon date, insofar as it is valid, corresponds with the following archeological correlations in Asia Minor: Early Bronze I of Cilician peoples at Tarsus in southern Anatolia, Troy I in western Anatolia, levels 8 and 9 at Alaca and 12M to 14M at Alisar in central Anatolia, and Amuq G in Mesopotamia (*4, 5*). As stressed by Lloyd (*5*, pp. 28–29), evidence from the Pontic tombs of Horoztepe and Mahmatlan near Tokat suggests that these sites had an early pre-Hittite metallurgical tradition and style that was Anatolian in character, and not from Early Bronze Age Mesopotamian areas to the south. The availability of copper metal from nearby Kozlu could help confirm this thesis.

The hummocky area to the south of

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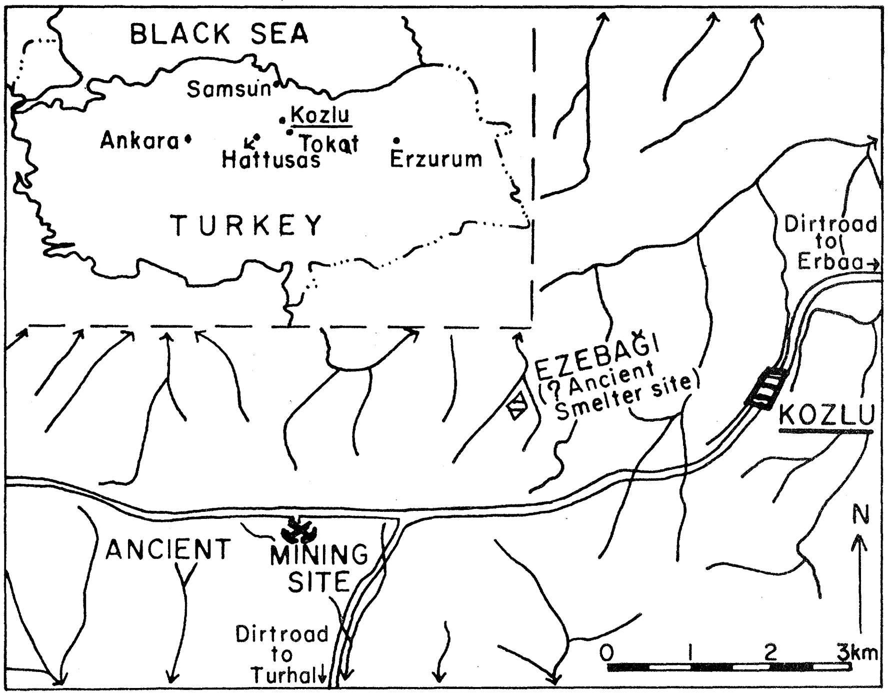

Fig. 1. Location map of the Kozlu site.

the trough, or indicated zone of most extensive ancient mining at Kozlu, is interpreted as the site of the waste dump where broken rock from the mining activity was piled. Erosion and subsequent soil cover have blended and smoothed the dump to its present topography. Shallow trenching of this dump area has turned up scattered pottery sherds, suggesting that the dump site served also as a temporary campsite. We are unable to provide any meaningful information on these sherds, and since the nature of this pottery could be very important, further detailed archeological work in the area seems warranted.

Piecing together the diverse geological clues obtained by the U.N. team, the mineral deposit at Kozlu appears to have been originally an outcropping, steeply dipping (~ 60°), and stratiform high-sulfide lens or layer of significant thickness (*6*). It may be of volcanigenic exhalative origin, has a high Cu/S ratio (dominately chalcopyrite, bornite, and so forth), and has possible recoverable gold, silver, and cobalt credits. The mineral horizon, and the probable primary ore control for sulfide mineralization, is within the contact zone between an albite-epidote-amphibolite schist sequence, which is the host rock, and quartz-sericite schist of probable early Paleozoic age. Chloritic alteration is widespread in the general area of the mineralized horizon, and hematitic quartzites (possibly former jasperoid or iron-rich chemical sediments) occur along the strike. Geophysical surveys have indicated that the top of a linear sulfide layer still exists at a vertical depth of about 40 to 80 m, slightly to the north of and parallel to the trough as projected vertically to surface.

In the original near-surface oxidation zone, the outcropping Kozlu deposit undoubtedly contained a significant amount of (or was wholly composed of) secondary copper minerals derived from the oxidation and partial leaching of sulfide minerals. Judging from the apparent low total sulfide (low pyrite) mineralogy of the deposit, this would almost certainly include native copper and copper carbonates, and possibly small amounts of cuprite, chalcocite, and copper sulfates. These minerals would have comprised the first ore mined, but in view of outcrops occurring laterally from the trough it is probable that primary sulfides became the principal ore component at a fairly shallow depth.

This deposit, interpreted as the ore body on which mining took place, was probably exploited along the mineral horizon at the surface for at least 300 m, which is the length of the trough. Diamond core drilling showed that the rubble of ancient mining, as occurs near the surface, exists for a minimum 45 m as measured downdip along the mineralized horizon. Evidently ancient miners excavated and exploited the ore body to at least that depth in this area, after which the cavity became filled with rubble debris. The lateral extent of deeper excavation along the mineral horizon is unknown at present, but may be as much as 50 to 80 m.

Mining along the steeply dipping ore horizon was probably accomplished by a primitive underhand stope or caving method—mining successively downward from the surface in a series of steps, with the resulting cavity (stope) being either left open or supported from roof to floor by pillars and timber. The width of the stope may have been 3 to 5 m or more, and judging from the altered and incompetent nature of the wall rock, cave-ins were a hazard and support by timbering was a necessity. Ore was almost certainly handpicked to obtain the richest pieces. Sub-ore and waste material was piled conveniently nearby, but apparently too near (in places) to prevent the broken rock from eventually coming back into the excavation. Perhaps a massive rockslide was triggered by one of the frequent earthquakes along the Great Anatolian fault.

Considering the then-existent technological ability and the scarcity of iron for use in tools, to physically break and extract ore from such depth required the allure of rich ore, probably significant native copper at higher levels and massive or nearly pure copper sulfides at depth. Even by modern standards, to hold and to cave an equivalent underground stope requires advanced mining methods and equipment.

Late in 1973, a large planoconvex copper casting about 40 cm in diameter was discovered by the U.N. exploration team in the small village of Ezebaği about 3 km northeast of the Kozlu mine site (Fig. 1). This object had been exhumed from a cut made by a diverted water channel and will soon be on display at the geological museum of the Geological Survey of Turkey (MTA) in Ankara. It consists of copper matte (a melted metallic sulfide mixture) containing numerous vugs or bubble cavities, and appears to represent partially refined molten ore that solidified before complete degasification in the bottom of a hearth during the smelting process. If this is the case, this matte most likely represents Kozlu ore, and so the ancient smelter for the ore may have been very near the modern village site of Ezebaği.

The discovery of the copper matte is of considerable importance if it represents Kozlu ore, and if that ore was in fact being smelted in the early third millennium B.C., as suggested by the radiocarbon date for mining activity. This would have direct bearing on the view held by many scholars that the smelting of sulfide ore did not become important before the end of the second millennium B.C. Spectrographic studies of the matte and of pieces of Kozlu ore may shed some light on the issue.

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References and Notes

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2. T. A. Wertime, *Science* **146**, 1257 (1964).
3. This is wood sample Su-295 collected at a depth of 6 m in a hand-dug pit on 24 May 1973. The actual date was calculated as 4750 ± 30 years before 1950. Calculations are based on 95 percent of the isotopically corrected activity of the National Bureau of Standards oxalic acid standard and on a half-life of 5568 years. The date will be referenced by the Geological Survey of Finland in a future issue of *Radiocarbon*.
4. M. J. Mellink, in *Chronologies in the Old World Archaeology*, R. W. Erich, Ed. (Univ. of Chicago Press, Chicago, 1965), pp. 101–131; J. Mellaart, in *The Cambridge Ancient History*, I. E. S. Edwards *et al.*, Eds. (Cambridge Univ. Press, Cambridge, ed. 3, 1971), vol. 1, part 2, pp. 363–410.
5. S. Lloyd, *Early Highland Peoples of Anatolia* (Thames & Hudson, London, 1967).
6. D. L. Giles, "Final project report" in the files of the U.N. Office of Technical Cooperation, New York (1973); E. P. Kuijpers, in *Technical Report No. 4: Mineral Exploration in Two Areas (TUR/72/004)* (United Nations, New York, 1974), pp. 72–79.
7. We stress that we are professional geologists and that the finer points of archeological interpretation (for example, interpretation of Pre-Hittite Pontic pottery) are outside our expertise. Our intent has been to present an interdisciplinary research report emphasizing a significant geologic discovery that contains important archeological evidence. We hope that our archeologist colleagues overlook what may appear to be errors of omission or incomplete research on our part, and that the report stimulates in-depth archeological studies of Kozlu on their part. We thank the United Nations Development Program and the Turkish government for permission to publish.

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Lunar Magnetic Field: Permanent and Induced Dipole Moments

Abstract. *Apollo 15 subsatellite magnetic field observations have been used to measure both the permanent and the induced lunar dipole moments. Although only an upper limit of 1.3 × 10*^{18} *gauss-cubic centimeters has been determined for the permanent dipole moment in the orbital plane, there is a significant induced dipole moment which opposes the applied field, indicating the existence of a weak lunar ionosphere.*

The lunar magnetic field has been studied indirectly via the natural remanent magnetization of the returned lunar samples, and directly with magnetometers carried to the surface and placed in orbit at low altitude above the surface on the Apollo 15 and Apollo 16 subsatellites (*1*). These measurements reveal widespread lunar magnetism with scale sizes ranging up to many tens of kilometers. The origin of these fields remains a puzzle. According to one model, there existed an ancient lunar dipole field either generated by an internal dynamo, induced by a strong external field, or acquired during accretion (*2*). If this were true, then some trace of this ancient global field might still be present, and it is of some interest to attempt to detect this field. It has also been reported that, when the moon is in the geomagnetic tail, it possesses a substantial induced dipole moment (*3*), which could interfere with the measurement of the permanent moment. Fortunately, it is possible to separate the permanent from the induced moment in the orbital measurements. In this report, we reevaluate earlier orbital measurements of the permanent moment which did not take this into account (*4*) and examine the induced moment observed in the orbital data.

Measurements of the lunar magnetic field are usually made during the 4- to 5-day period each month when the moon is shielded from the solar wind plasma by the geomagnetic tail. The tail consists of two bundles of oppositely directed magnetic flux, the north and south lobes, separated by a plasma sheet. In the north lobe the magnetic field induced in a ferromagnetic moon would be in the solar direction and in the south lobe the induced magnetic field would be in the antisolar direction, whereas a permanent field would be fixed in selenographic coordinates. Thus, we can separate permanent from induced effects by giving measurements from each lobe equal weight, even though there may be more data obtained from one of the lobes than the other. A total of 25 lunar orbits were used in the analysis reported here: 17 from the north lobe and 8 from the south lobe.

To measure the permanent dipole field, one separates the average field in inertial coordinates from the data and then rotates the residual fields into a coordinate system that has directions radially outward, parallel to the orbit plane (eastward) and perpendicular to the orbit plane (northward). Data from each lobe are averaged separately by azimuthal angle around the orbital plane from the 0° selenographic meridian and are Fourier-analyzed at the orbital period. This provides four estimates of the dipole moment: one from each of the radial and tangential components in each of the lobes. Table 1 lists the radial and tangential estimates of the moment after the data from both lobes have been averaged, as well as the resultant average moment and the two error estimates, that is, the difference vector and the equivalent moment from the perpendicular component. The magnitude of the expected error vector, 1.33×10^{18} gauss-cm^3, is comparable to the magnitude of the measured dipole moment. Thus, we have measured only an upper limit for the permanent dipole moment. Although the upper limit applies only to the components of the moments in the orbital plane, it is unlikely that the moon is principally magnetized along the orbital normal (116°E, 62°N).

To measure the induced field, we proceed as above except that we measure the azimuthal angle eastward from the direction of the orbital average field projected into the orbital plane. The orbital average magnetic field is taken to be the external field, and, since this analysis is insensitive to induced moments perpendicular to the orbital plane, we use the magnitude of the field projected on the orbital plane to normalize the induced field. Table 2 shows the radial and tangential measures of the induced dipole after the north and south lobe data have been averaged, as well as the average moment, the difference between the average and the radial estimates, and the equivalent moment deduced from the perpendicular component. The induced moment is $(6.3 \pm 2.4) \times 10^{22}$ gauss-cm^3 per gauss of applied field, and is opposite to the applied field.

If an ancient lunar dipole field were responsible for the magnetization of