CENTENAIRE DE LA SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE
GISEMENTS STRATIFORMES ET PROVINCES CUPRIFÈRES, LIÈGE, 1974, 277-285

THE TIMNA COPPER DEPOSIT

Y. BARTURA and U. WÜRZBURGER (*)

ABSTRACT

The Timna copper deposit is a stratiform ore body of lowermost Cambrian age. The copper bearing strata consist of fine grained, bedded sandstones, shales, clays and lenses and layers of sandy dolomite indicating a shallow sea. They overly a Precambrian basement complex which contains minor amounts of pyrite and copper sulphides.

The deposit lies on the fringe of the Dead Sea Rift Valley. It is highly faulted but no connection exists between faulting and mineralization.

Main copper minerals are chrysocolla, malachite, pseudomalachite, bisbeite and plancheite distributed in cracks, veinlets, lenses, joints, bedding planes and disseminated throughout the sediments.

Very extensive diagenetic processes resulted in migration of the copper.

No evidence was found for the existence of a primary copper ore body and no sulphides are known.

INTRODUCTION

The Timna copper deposit is located about 25 km north of Elat in the southern part of Israel (fig. 1).

The climate is arid with temperatures ranging from 10-40 °C and with an annual rainfall of about 30 mm/annum.

Copper has been exploited in the area from ancient times. The present deposit was discovered during the geological mapping of southern Israel in the early 1950's. Open pit and underground mining began in 1958. Present annual mine and plant production is approximately 16 000 tons of cement copper averaging 80 % copper (Vered-Weiss *et al.*, 1971).

The deposit was first described by Bentor (1952), and various aspects were discussed in several unpublished reports. Syngenetic, epigenetic and volcanic origins have been proposed to explain the assemblage of copper silicates and carbonates. New stratigraphical and mineralogical data now permit a more unique interpretation.

(*) Timna Copper Mines, Elat, Israel.

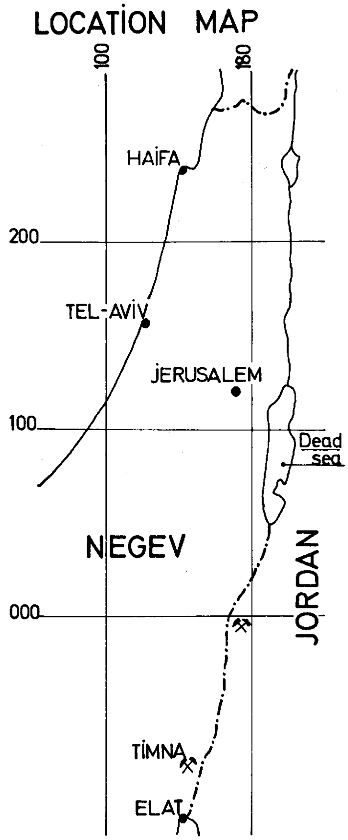

FIG. 1

GEOLOGICAL SETTING

Structure (fig. 2)

The Timna area consists of a small central Precambrian massif surrounded by a gently outward dipping (5-10°) clastic and carbonate sequence. The area is situated on the western flank of the Dead Sea Rift Valley and is cut in the east by post-Cretaceous step faults of the rift. A network of faults related to the rift, with throws of up to 100 m, criss-cross the ore body.

According to Freund *et al.* (1968, 1970), the horizontal displacement along the rift is 100 km, with the eastern side relatively shifted toward the north. Thus, a copper deposit similar to that at Timna is located approximately 100 km to the north, on the east side of the rift valley (Bender, 1965).

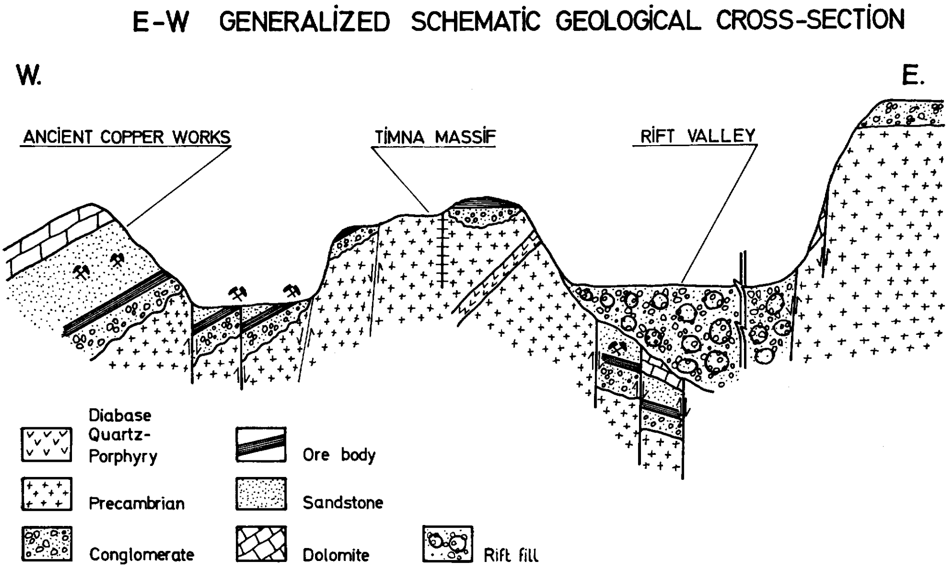

FIG. 2

Stratigraphy (fig. 3)

The stratigraphic section consists, from bottom to top of:
— Precambrian basement;
— Paleozoic Nubian Sandstone;
— Cambrian marine sequence;
— Paleo-Mesozoic Nubian Sandstone;
— Cretaceous-Tertiary marine transgression;
— Young sedimentary fill of the rift valley.

Copper mineralization appears in four zones: in the Precambrian, in the Cambrian marine sequence and in two horizons of the Paleo-Mesozoic Nubian Sandstones.

1. The Precambrian is composed of granite, grano-diorite, syenite and gabbro (Zlatkine and Würzburger, 1957 ; Bentor, 1961), intersected by quartz porphyry and diabase dykes. Small amounts of disseminated sulphide (pyrite, chalcopyrite, chalcocite) are found in the country rocks, in the quartz porphyry dykes and along fault and joint planes (Würzburger, 1969). Volcanic activity of post-Precambrian age known from Jordan (Bender, 1965; Lenz *et al.*, 1972) is not known in Timna.

2. Paleozoic Nubian Sandstone; a 0-90 m thick sequence of fluviatile red conglomeratic sandstones, arkoses and sandy shales unconformably overlies the Precambrian on a dissected surface (Karcz and Key, 1966). No traces of copper are found in this formation.

3. Cambrian marine sequence; the Cambrian (40 m) unconformably overlies the Paleozoic Nubian Sandstone. It consists of sandstone, silt, clay, dolomite and contains the main copper bearing strata.

4. Paleo-Mesozoic Nubian Sandstone; a 300 m thick sequence of Lower Cambrian to Upper Cretaceous age (Weissbrod, 1969) overlies the Cambrian marine

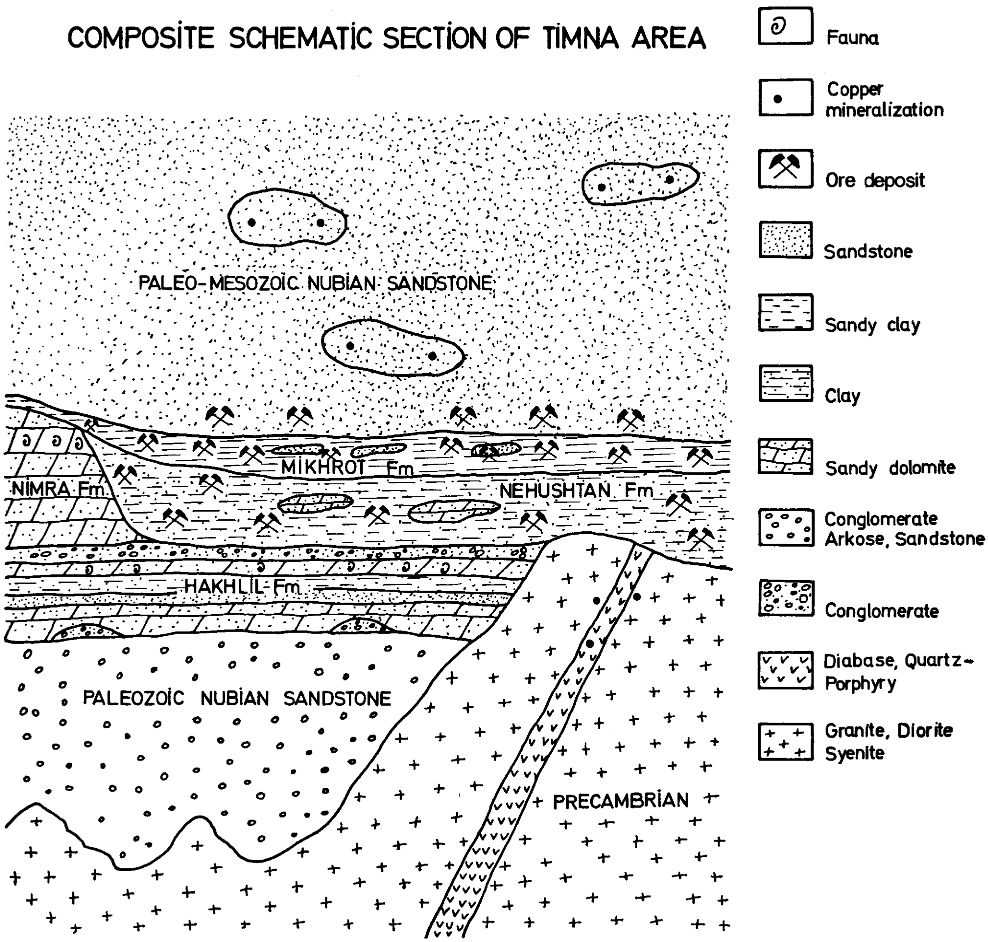

FIG. 3

sequence. Copper mineralization occurs in two horizons; the first one lies 5-20 m above the main copper horizon, where lenses of copper minerals (carbonates, silicates) impregnating sandstone appear. The second copper bearing horizon (sulphides, carbonates and silicates) occurs some 130 m higher in white fine grained, Lower Cretaceous sandstone.

5. Cretaceous-Tertiary marine transgression; several hundred meters of carbonates and marls, Cretaceous to Tertiary in age, overlies the Mesozoic Nubian Sandstone.

6. Young sedimentary fill of the rift valley; this is composed of several thousand meters of conglomerates, sandstones and clays of Tertiary to Recent age. No copper mineralization has been encountered in this sedimentary fill.

The Cambrian marine sequence — the main copper horizon

The Cambrian marine sequence in Timna is divided into four formations (Bartura, 1966). The lowermost Hakhlil and Nimra Fms. are only slightly mineralized, while the uppermost Nehushtan and Mikhrot Fms. contain the main copper horizon presently exploited.

1. The Hakhlil Formation; this is composed of 12-20 m of finely bedded sandstone, which is locally calcitic or dolomitic and alternates with variegated shaly silt and clay. The upper part contains trilobites and bilobites (cruziana), indicating an uppermost Georgian (Lower Cambrian) age (Parnes, 1971). Their occurrence enables correlation with the Lower Cambrian in Jordan (Picard, 1942; Seilacher, 1965). Ripple marks, cross bedding and dolomitic sandstones pseudomorphs after large halite crystals suggest a shallow, evaporitic sea. Weak copper mineralization is rarely found along cracks and joints in the upper part of this formation.

2. The Nimra Formation; the Nimra Fm. consists of an up to 25 m thick sequence of dolomitic and calcitic sandstones. The sandstones are grey to pink, well bedded and in places crossbedded. Red and grey interbeds of clay are numerous. Reefs of sandy dolomite several meters thick, are occasionally found at the top. These features, together with the presence of oolitic limestones apparently indicate a shallow sea. Diagenetic phenomena are developed in this formation. The quartz grains are extensively etched, and partly or fully replaced by dolomite which in turn is intersected and partly replaced by calcite. Silification is noted locally.

Druses of black and white calcite or dolomite, cavities filled with copper-montmorillonite and barite concretions, are typical. The entire section contains manganese oxides impregnations. Copper minerals are disseminated in the lower part and occur as veins and concretions in the upper part.

The Nimra Fm. is locally fully preserved whereas in other locations, it is totally missing. No intermediate stages occur. It is suspected that penecontemporaneous erosion carried away the yet unconsolidated sediments from between the reefs.

3. The Nehushtan Formation; unconformably overlying the Nimra Fm. is a sequence of predominantly soft, in places contorted, fine grained slightly phosphatic sandstones with grit horizons and thin layers of shaly silt. Its thickness varies considerably from 0-14 m, but most frequently is 6 m. Intraformational breccias are common. Very fine black and white banding is typical. The black bands contain manganese oxides which coat and cement quartz grains. In other areas, limonite is found in place of manganese oxide and the banding is red and white or yellow and white. Sandy dolomite lenses, 0.5-5 m in thickness appear within this formation and may represent stromatolitic reefs.

A shallow sea, with alternating conditions of quiet and turbulence, possibly with periodic changes in the reduction-oxidation environment, may mark this formation. Strong copper mineralization occurs throughout the Nehushtan Fm., the overlying Mikhrot Fm. and 1-2 m into the base of the overlying Paleo-Mesozoic Nubian Sandstone.

4. The Mikhrot Formation; this consists of a few centimeters to 3 meters thick sequence of finely banded red, buff and black silty clay.

Illite and kaolinite form 10-50 % of the rock. Manganese oxides generally occur as cementing material (1-5 %) and in concretions which contain up to 50 % MnO_2. In places, these concretions form up to 80 % of the whole rock mass. Characteristic of the sedimentary structures in this formation are slump rolls, usually a few centimeters, but up to several meters across and breccia containing large angular sandstone blocks. These originated in the overlying Nubian Sandstone and became embedded in the clays at the top of the Mikhrot Fm. This was explained by Bentor (1956) as a result of the accumulation of sand on the sea bottom during the drying up of the sea.

A point was reached where the still plastic and hydrated clays were unable to support the sands and the structure collapsed. In places, copper rich fragments are found embedded in relatively copper poor clay or vice versa.

Mineralization

Copper mineralization in the marine Cambrian is largely concentrated in the Nehushtan and the Mikhrot Fms. The thickness of the minable ore bed is 4-8 m with an average copper content of 1.0-2.0 %. The distribution of the copper mineralization is heterogeneous, partly due to the extensive faulting which shifted copper rich against copper poor blocks.

Copper mineralization occurs in the following forms:

1. Massive concretions of copper minerals in various sizes and shapes, related in places to bedding planes.

2. Filling of cracks and joints ranging in thickness from a few microns to several centimeters. These veins criss-cross the rock without any relation to bedding planes.

3. Thin crustations on faces of 1-10 mm open cracks and joints.

4. Thin bands (2-5 mm) of copper minerals parallel to bedding planes known mainly from the clays and siltstones. In places, the bands follow slump rolls or form a coating on brecciated sandstones at the top of the Mikhrot Fm.

The copper bands locally merge into veins and veinlets.

5. Sandstones and silts cemented by copper minerals.

6. Copper minerals replacing quartz grains.

The main copper mineral in the Timna deposit is chrysocolla, a general name for a group of copper silicates which in Timna consists of two end members and several types in between. Other silicates identified at Timna include plancheite, bisbeeite and the relatively rare dioptase.

Other minerals are malachite, paratacamite, pseudomalachite and brochantite.

Chrysocolla and malachite make up approximately 90 % of the copper minerals at Timna. This copper mineral assemblage, which is typical of an "oxidized zone" is found to a depth of 900 m (800 below the recent water table). No sulphides have been encountered.

Gangue minerals include quartz, illite, kaolinite, dolomite and calcite. Lesser amounts of barite, wilkeite, palygorskite, detrital feldspars, halite, gypsum and several manganese oxides are also present.

A typical chemical analyses of ore is presented below:

SiO_2	67.42 %	MnO_2	2.90 %
CuO	1.54 %	Na_2O	0.20 %
Al_2O_3	9.00 %	K_2O	3.34 %
Fe_2O_3	3.12 %	Cl	0.09 %
TiO_2	0.53 %	P_2O_5	1.74 %
CaO	3.75 %	SO_4	0.15 %
MgO	1.28 %	$+H_2O$	2.94 %

Trace elements: Aside from manganese and phosphate (fluor-apatite), which are locally highly concentrated (up to 60 % MnO_2 and 32 % P_2O_5), the ore body is relatively poor in trace elements (Brener, 1971). Lead is generally anomalous, up to 3 % in selected samples. Barium reaches up to 6 % in selected samples and titanium varies from 500 to 5 000 ppm. Zinc may reach 3 000 ppm, but is commonly less than 200 ppm. No other trace elements have been encountered.

Paragenesis. An investigation of the ore textures indicates replacement phenomena and evidence of the migration of copper solutions after deposition. The replacement mechanism is apparently a continual solution in the host rock and deposition of the guest at the replacement front. Open spaces characteristically fill before replacement. Where the matrix is impregnable, such as in clays, replacement starts in the quartz grains; otherwise, the matrix is affected first. Certain minerals (chrysocolla, pseudomalachite and others) show colloform textures indicating solution and secondary development of crystals. Bands of colloform chrysocolla are commonly associated with chalcedony.

In a few samples where copper minerals occur in bands parallel to bedding planes, specular hematite aggregates are also found in a similar orientation. Hematite and limonite are locally surrounded by colloform textured copper minerals. Several samples exhibit secondary copper minerals pseudomorphic after unknown minerals of elongated prismatic structure.

A very fine mixture of chrysocolla and wilkeite occurs in late veins cutting all other minerals (Wurzburger, 1970). The only mineral apparently connected with late faulting is dioptase which occurs in minor amounts as idiomorphic crystals along fault planes.

The replacement phenomena may be summarized as follows:

1. Chrysocolla replaces quartz.

2. Malachite replaces manganese oxides.

3. Chrysocolla replaces malachite.

4. Pseudomalachite replaces chrysocolla.

5. Paratacamite and chrysocolla + wilkeite occur as veins cutting all the other minerals.

Paragenesis is not clearly definitive due to the presence of more than one generation of chrysocolla. However, the sequence appears to be: chrysocolla-malachite-chrysocolla-pseudomalachite-chrysocolla + wilkeite-paratacamite-calcite-dioptase.

CONCLUSIONS

The significant data related to the genesis may be summarized as follows:

1. Copper mineralization is essentially confined to a specific stratigraphic horizon.

2. Copper mineralization occurs in slump rolls and in brecciated sandstone on top of the Mikhrot Fm.

3. There is no mineralization related to faults, except for insignificant amounts of dioptase.

4. Intrusive dykes do not occur in the ore bed in Timna. However, they have been reported in the related copper deposit in Jordan.

5. There is no apparent zoning in relation to depth.

6. Sulphides are absent. However, certain pseudomorphic forms may represent original sulphide mineralization.

7. The trace elements content would be atypical of an epigenetic origin.

8. Significant amounts of the copper mineralization occurs in cracks and joints.

9. The copper content is spatially highly variable.

10. Iron oxides are locally surrounded by colloform hydrated copper minerals.

These data appear to indicate a syngenetic sedimentary origin followed by significant diagenetic alterations.

The source for copper may have been in the Precambrian massif, or possibly related to undersea volcanic activity. Precipitation of copper occurred together with sedimentation, possibly under oxidized conditions, although some may have been precipitated as sulphides. Diagenetic processes resulted in migration and a redistribution of copper.

The lowermost of the two overlying copper bearing horizons (Paleo-Mesozoic Nubian Sandstone) apparently originated by a precipitation from copper bearing solutions resulting from underground leaching of the main ore body.

The upper copper bearing horizon is very widespread and is known to extend from the southern part of the Sinai Peninsula to the Dead Sea. It may represent a second syngenetic sedimentary deposit, possibly, as suggested by the presence of sulphides, in a reducing environment.

References

Bartura, Y. (1966). — Type sections of Paleozoic formations in the Timna area. *Geol. Surv. of Israel*, Report 3/66.

Bender, F. (1965). — Zur Geologie der Kupfererzvorkommen am Ostrand des Wadi Araba, Jordanien. *Geol. Jb.*, 83, p. 181-208.

Bentor, Y. K. (1952). — Report on the copper and manganese deposit of Wadi Menayeh. *Geol. Surv. of Israel*, unpublished report.

Bentor, Y. K. (1956). — The manganese occurrences at Timna, a lagoonal deposit. *Inter. Geol. Cong. 20th, Mexico.*

Bentor, Y. K. (1961). — Petrographical outline of the Precambrian in Israel. *Bull. Res. Coun. Israel*, Vol. 10 G.

Brener, I. B. (1971). — Spectrochemical analysis of Paleozoic sedimentary rocks from the Timna ore. *Geol. Surv. of Israel*, Inter report.

Freund, R., Zak, I. and Garfunkel, Z. (1968). — Age and rate of the sinistral movement along the Dead Sea rift. *Nature*, Vol. 220/5164, p. 253-255.

Freund, R., Garfunkel, Z., Zak, I., Goldberg, M., Weissbrod, T. and Derin, B. (1970). — The shear along the Dead Sea rift. *Phil. Trans. Roy. Soc. Lond.*, A 267, p. 107-130.

Karcz, I. and Key, C. A. (1966). — Note on the Pre-Paleozoic morphology of the basement in Timna area. *Israel Jour. of Earth Sc.*, Vol. 15, p. 47-56.

Lenz, H., Bender, F., Besang, C., Harre, H., Muller, P. and Wendt, I. (1972). — The age of early tectonic events in the zone of the Jordan geosuture based on radiometric data. *Int. Geol. Cong. Canada*, Sec. 3.

Parnes, A. (1971). — Late Cambrian trilobites from the Timna area and Har Amram. *Israel Jour. Earth Sc.*, Vol. 20, p. 179-205.

PICARD, L. (1942). — New Cambrian fossil and Paleozoic problematica from the Dead Sea and Arabia. *Bull. Geol. Dept. Hebrew Univ. Jerusalem.*
SEILACHER, A. (1965). — Trilobitenspuren als Zeitmarken im Jordanischen Palaeozoikum. *Z. dtsch. Geol. J.*, p. 502.
VERED-WEISS, J., GRABER, E. A. and GOOD, J. E. (1971). — How Timna Copper Mines increased output and raised worker efficiency. *World Min.*, January 1971.
WEISSBROD, T. (1969). — The Paleozoic of Israel and adjacent countries. *Geol. Surv. of Israel Bull.*, No. 48.
WÜRZBURGER, U. S. (1969). — Sulphides and oxides in igneous rocks of the Timna massif. *Israel Jour. Earth Sc.*, Vol. 18, Nos. 3-4.
WÜRZBURGER, U. S. (1970). — Copper silicates in the Timna ore deposit. *Israel Jour. Chem.*, Vol. 8, p. 442-457.
ZLATKINE, A. and WÜRZBURGER, U. S. (1957). — Eruptive rocks of Timna (Negev). *Geol. Surv. of Israel Bull.*, No. 14.