Bulletin de la Société belge de Géologie	98-2	pp.239-244	Bruxelles 1989
Bulletin van de Belgische Vereniging voor Geologie	98-2	pp.239-244	Brussel 1989

COPPER DISTRIBUTION PATTERNS IN THE PALEO-MESOZOIC CLASTIC SEQUENCE OF SOUTHERN ISRAEL AND NORTHEAST SINAI

by

T. WEISSBROD, I.B. BRENNER & R. BOGOCH [1]

SUMMARY

The Paleozoic-Mesozoic clastic sequence in southern Israel and northeastern Sinai consists mainly of subarkose and quartz arenite with minor siltstone, shale and carbonate. Some 800 samples were measured for their copper contents, and four anomalous zones (including the Lower Cambrian Timna copper deposit) were indicated. Two of these zones contain Cu-concretions which were mined in antiquity. Except for the ore deposit, the sediments in each of the zones are light grey to white, unlike the surrounding multicoloured sandstones.

The copper in the lower two zones (I and II) was probably derived from an exposed Late Precambrian andesite to rhyolite series. The sediments in these zones were deposited in tidal flats and lagoons and the copper is originally syngenetic to early diagenetic. The source of copper in the upper zones (III and IV) was mainly the underlying rocks. Copper was dissolved at source by Cl-bearing waters and transported as Cu-chlorides. The sediments in these zones are fluviatile (active channel fill), and the copper is epigenetic. Deposition occurred where contact was made with a lower pH environment at sites of decomposition of organic material (plant fragments, etc.), or in the case of Zone III, were scavenged by clays in siltstone.

The copper-bearing sequences are similar to red-bed type deposits.

RESUME

La séquence clastique d'âge Paléozoïque - Mésozoïque au sud d'Israel et au nord-est de la péninsule du Sinai consiste essentiellement en subarkoses et arénites quartzeuses associées à quelques siltstones, shales et carbonates. Quelques 800 échantillons de roches ont été analysés pour leur teneur en cuivre, et quatre zones anomales (y compris le dépôt de cuivre de Timna d'âge Cambrien inférieur) ont pu être délimitées. Deux de ces zones contiennent des concrétions de cuivre qui ont été exploitées durant l'antiquité. Hormis le gisement de Timna, chacune de ces zones se caractérise par des dépôts grisâtres à blanchâtres bien différents des grès bigarrés environnants.

Le cuivre des deux zones inférieures (I et II) dérive probablement de l'altération supergène de séries andésitiques à rhyolitiques du Précambrien terminal. Leurs sédiments ont été déposés dans un système de platiers littoraux et de lagunes, et le cuivre est d'origine syngénétique précoce. Le cuivre des deux zones supérieures (III et II) par contre, dérive essentiellement des roches sous-jacentes. Au départ, le cuivre a été dissous de son dépôt d'origine par des eaux riches en chlore, puis, remobilisé sous forme de chlorure de cuivre. Les dépôts de ces deux dernières zones sont fluviatiles (remplissage actif de chenaux), et le cuivre est épigénètique. Sa mise en place a eu lieu au contact de milieux à pH plus faible, dans des sites de décompostion de matière organique (restes végétaux, etc.), ou dans le cas de la zone III, a été sequestré par le matériel argileux des silstones.

Ces séries cuprifères sont semblables aux dépôts de type red-bed.

KEY WORDS

Paleozoic-Mesozoic, Israel, Sinai, sandstone, copper enrichment.

MOTS CLE

Paléozoïque-Mésozoïque, Israel, Sinai, grès, enrichissement de cuivre.

1. INTRODUCTION

A thick Paleo-Mesozoic clastic sequence was deposited on the northern periphery of the Afro-Arabian craton (Fig. 1), unconformably overlying all Late Precambrian clastic rocks and the igneous

[1] Geological Survey of Israel, Malkhei Yisrael Str. 30 - 95501-Jerusalem, Israel

basement. In most exposures, the upper contact, generally with Cretaceous carbonate rocks, is diachronous. Most of the sequence consists of sandstone, with minor intercalations of siltstone, shale, and near the base ; of carbonates. The sandstones display a distinct pericratonic facies and show a gradual upward trend of maturation, evolving from arkose to quartz arenite. For most of the period of deposition, the region remained largely continental or marginal marine.

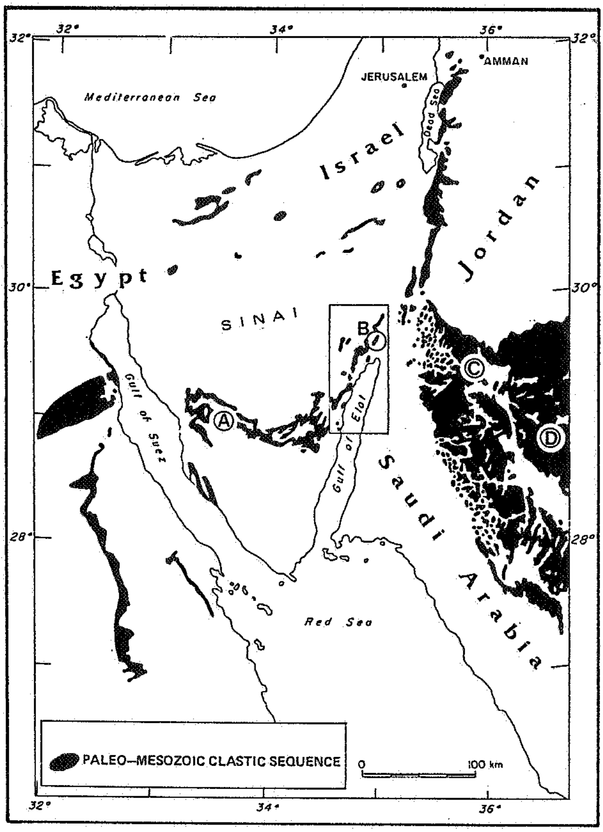

Figure 1. : Distribution of Paleozoic-Mesozoic clastic sequence in southern Israel and neighbouring countries. Studied area is outlined. A to D are locations of the sections shwon in Fig. 2.

During the Paleozoic and Early Mesozoic, three major cycles of uplift, erosion and reburial took place, which resulted in a varying truncated section. Thus in Israel, northeastern Sinai and southern Jordan, the exposed clastic section is represented only by the Cambrian and Lower Cretaceous, whereas in neighbouring areas, either Lower Paleozoic (SE Jordan, NW Saudi Arabia) or Upper Paleozoic (SW Sinai), sections are well represented (Fig. 2).

Although the Precambrian basement was for most of the Paleozoic - Mesozoic covered by a sedimentary blanket, there were recurrent partial exposures and erosion through several stages, and particulary during the Cambrian.

The clastic sequence in Israel and Sinai was divided into lithostratigraphic units using several criteria. Most of the units are coloured red, reddish-brown to yellowish brown. However, three of them are exceptionally light (light grey to white) perhaps representing post-lithification bleaching phenomena.

Over 800 samples from sections in Israel and Sinai were analysed for their copper contents. The results indicate an enrichment in the three light coloured units, in addition to the ore-bearing horizons of the Lower Cambrian Timna Formation where copper has recently been exploited. Cu-rich concretions were mined in antiquity from the Lower Cretaceous Avrona Member in southern Israel (Negev) and from the equivalent of the Cambrian Shehoret Formation in southern Jordan (Edom). The Cu-enriched intervals each exhibit different characteristics and are described below.

2. METHODS

The samples were crushed, dissolved in an HF-$HClO_4$-HNO_3mixture and analysed by flame atomic absorption spectroscopy. Duplicate samples from the Cu-bearing horizons were dissolved in acetic acid and analysed to determine the approximate ratio of strongly to weakly bound Cu. In addition, Cr, Mn, Pb and Zn contents were determined on selected samples mainly from the Nahal Shehoret area. Samples containing visible copper mineralization were avoided. The Timna Formation, which contains a stratabound copper ore deposit, was not included in the present geochemical study.

3. COPPER-ENRICHED ZONES

The distribution of copper in the Nahal Shehoret section is given in Fig. 3. Similar results were obtained in the other measured sections from Israel and northeastern Sinai. Four distinct Cu-enriched zones are indicated : (I) Cu-ore in the Timna Formation (Timna Type) ; (II) Cu-anomaly (mean : 250 ppm), Shehoret Formation (Edom Type) ; (III) Cu-anomaly (mean : 260 ppm), Amir Formation (Amir Type) ; (IV) Cu-anomaly (mean : 400 ppm), Hatira Formation (Negev Type). The host rocks of Zones I and II are of Cambrian age, and those of III - IV, are Lower Cretaceous.

Separate extractions using acetic acid and hydrofluoric acid, indicate that 20-50 % of the copper in Zones II and IV are present as stable phases, whereas nearly all the copper in Zone III is weakly bound. The copper has a significant positive correlation with Pb and Zn in Zones II and IV, and with Mn only in Zone II.

3.1. Zone I - Timna Type

Stratabound copper ore (mined until recently) is present in the Sasgon Member of the Timna Formation (Fig. 3), approximately 100 m above the Precambrian/Cambrian boundary. The ore consists mainly of copper silicates, with fewer amounts of carbonates , chlorides and phosphates, occurring in shale and siltstone mainly as disseminations,

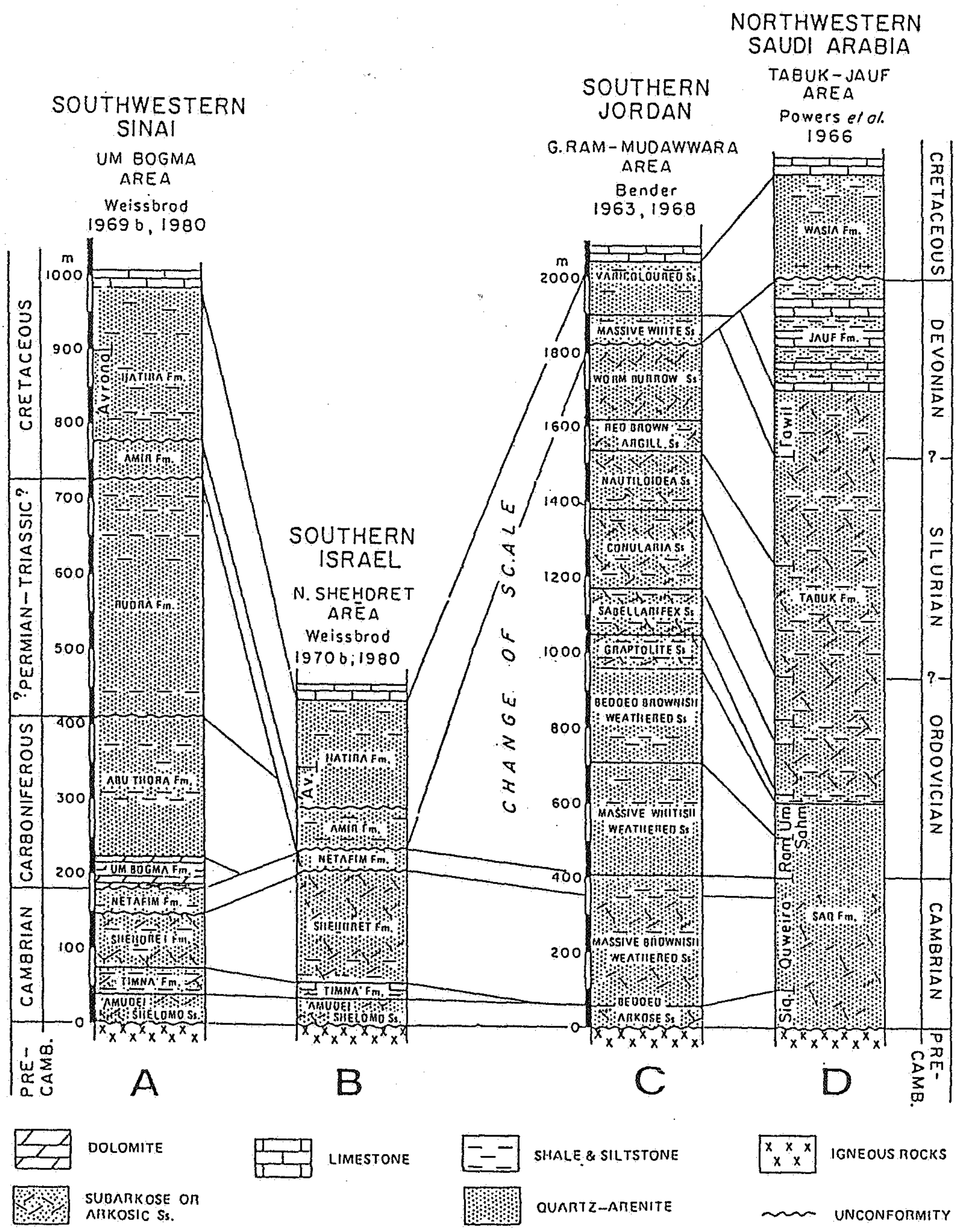

Figure 2. : Selected composite stratigraphic sections of Paleozoic-Mesozoic clastic sequences in southwestern Sinai, southern Israel, southern Jordan and northwestern Saudi Arabia.

along bedding planes and veinlets. Manganese mineralization also occurs in this zone.

Segev (1986) considered the ore to have formed as a result of the dissolution of syngenetic to early diagenetic copper-bearing silty dolostones, whereby the copper was redeposited together with the clastic fractions. Previous studies (e.g., Bartura & Wurzburger, 1974) suggested that copper was syngenetically deposited with the host rocks in a shallow marine basin. The initial source of the copper in either case, was the surrounding Precambrian terrain.

3.2. Zone II - Edom Type

The host to the copper anomaly is the subarkose of the lower part of the White Member (Shehoret Fm.). At the time of its deposition in tidal flats and lagoons (Weissbrod, 1987) under reducing bottom environments related to organic material, the Precambrian terrain was still partly exposed. Copper-rich concretions up to several centimetres in size are scattered through the rock ; at Wadi Abu Khusheiba and other locations in Jordan, where the concretions are more abundant, they were mined for copper in antiquity. The concretions consist of a core of chalcocite and bornite with veinlets of cuprite, surrounded by an outer zone of malachite (Bender, 1965). There appears to be a spatial as-

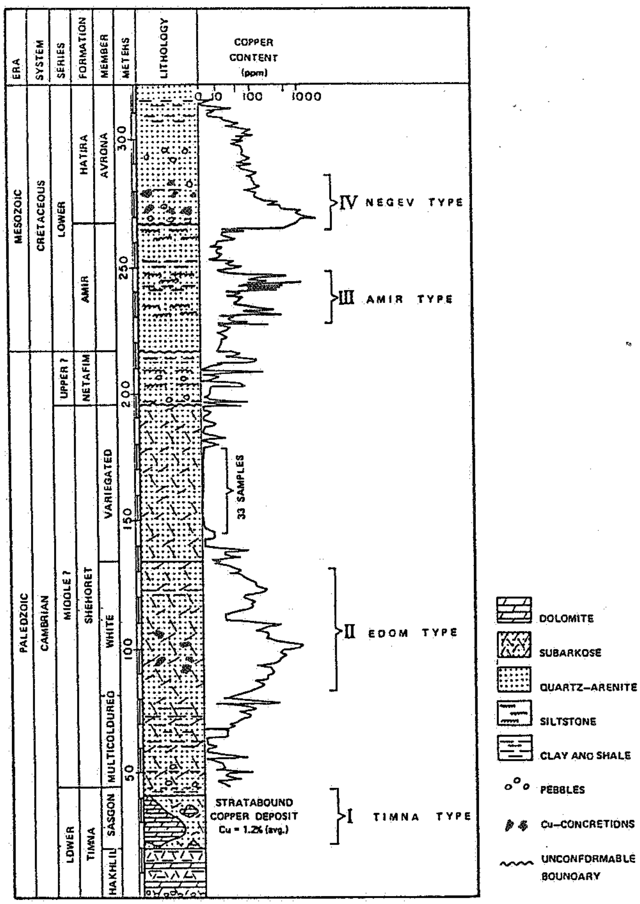

Figure 3. : Composite stratigraphic section of Cambrian and Early Cretaceous rock units showing copper distribution. Four anomalous zones (including the Timna ore deposit) are indicated.

sociation between the concretions and *Skolithos* (burrows). Layers enriched in Mn-oxide minerals are also present in this zone.

3.3. Zone II - Amir Type

The copper anomaly is located mainly in the middle part of the Amir Formation associated with fine-grained clastic intercalations (Fig. 3). The Precambrian basement was buried during the Mesozoic, and therefore could not have provided detrital copper to the basin of deposition of the Amir sediments (nor to the overlying sediments).

3.4. Zone II - Negev Type

The copper-rich zone occurs within the quartz arenite in the lower part of the Avrona Member (Hatira Fm.). It should be noted that the upper part of this unit is also somewhat anomalous in copper. The medium to coarse-grained sandstone was deposited as active channel fill in a braided river system and consists largely of cross-bedded channel bar and braid bar sands. Copper-bearing concretions are locally abundant in this zone, and were mined in antiquity. Minor pyrite pseudomorphs are observed in places. The concretions generally have cores of chalcocite surrounded by secondary Cu-carbonates. Slatkine (1961) and Keidar (1984) also identified native copper, cuprite and covellite. The cores of many of the concretions contain fossilized wood fragments.

4. DISCUSSION

The average copper contents in sandstones is in the order of 10-30 ppm (Pettijohn, 1963 ; Van de Kamp *et al.*, 1976) and in argillaceous rocks, 30-60 ppm (Wedepohl, 1974). Similar values are present in most of the sections examined. Zone II subarkose and Zone IV quartz arenite (mean : 250 and 400 ppm, respectively) are thus clearly anomalous. Zone III rocks average 260 ppm, but this value includes quartz arenite samples ; the fine-grained clastic rocks alone, exceed 300 ppm.

These zones have many affinities with red bed-type Cu-deposits, including the lithology of the host rocks (subarkose, quartz arenite, shale) ; their stratabound nature ; deposition in near-shore and fluviatile environments and the presence of plant remains (Rose, 1976 ; Gustafson & Williams, 1981) with associated concretions (Papenfus, 1931 ; Woodward *et al.*, 1974). One apparent difference from red bed deposits is that Zones II to IV are light grey to white in colour.

The source, transporting medium and deposition of the copper varied in these zones.

Late Precambrian andesitic to rhyolitic extrusive and intrusive rocks exposed along both sides of the Arava Valley (Bender, 1974 ; Bentor, 1961) could have been the source of copper for Zones I and II (which are also similar in the presence within both of associated Mn mineralization). These rocks are copper-anomalous ; significant (sub-economic) copper mineralization (including chalcopyrite, chalcocite and covellite) is present within these rocks in the Wadi Abu Khusheiba and Wadi Abu Barqa area of Jordan (Burgath *et al.*, 1984). A southward shift of the andesite to rhyolite exposures in Jordan by 105 km (amount of sinistral strike-slip displacement along the Dead Sea transform ; Freund *et al.*, 1970), sets these rocks opposite the studied area in southern Israel and northeastern Sinai.

Since the Precambrian basement was not exposed in the area at the time of deposition of the host sediments of Zones III and IV, and, in fact, was buried at least unitl the Neogene, two other sources may be considered : (1) the subsurface Zones I and II ; (2) Cu in iron oxides within the sediments. Evidence for the latter is the absence of ferrous iron oxides from the sandstones. Rose (1976) noted that red bed deposits are typically grey or greenish (Fe^{2+}) in comparison to the adjacent sandstones with oxidized iron minerals. This suggests that in the present case, the iron oxides were dissolved (contributing some Cu, see Haynes, 1986) and largely removed in solution after deposition of the copper. This requires that the transporting medium be outside the stability field of hematite. The local presence of pyrite-pseudomorphs near some of the concretions suggests that minor amounts of the iron were deposited together with the copper under reducing conditions.

Most red bed copper deposits are geographically close to evaporites. This has led to the concept that Cl-bearing waters dissolved the source copper and transported it in the form of Cu-chloride complexes (Helgeson, 1964 ; Smith, 1976 ; Rose, 1976). Other suggested sources for the Cl-solutions are connate marine water (Rose, 1976 ; Haynes, 1986) and simulated evaporation of dilute inflow waters from igneous provenances (Haynes & Bloom, 1987). Since evaporites are absent from the areas studied, the other sources would appear to be more likely for the solutions in southern Israel.

These solutions, with an intermediate pH could dissolve copper form the initial source (underlying Cu-enriched zones or Precambrian basement) and migrate mainly by diffusion (since the evidence for fault-related conduits is limited) and along bedding planes or aquifers. Cu could also be introduced into the solutions by dissolution of ferrous minerals.

Deposition in Zones II and IV (Edom and Negev types with associated Cu-concretions) would occur mainly when contact was made with reducing environments related to the decomposition of organic matter. In the Edom Type, this may have occurred syngenetically together with deposition of the sediments in tidal flats and lagoons, whereas in the Negev Type, which are hosted in fluviatile active channel fills, the deposition was apparently epigenetic (after decomposition of plant debris). Rose (1976) suggested that the reducing environment would extend some distance from the original organic matter due to transport and mixing of H_2S, CH_4, and other dissolved agents with surrounding waters. This could lead to the deposition of stable Cu-phases (not including the concretions) responsible for the Cu anomalies in Zones II and IV. In Zone III (Amir Type) the copper was largely scavenged by clay minerals from the same transporting solutions involved in the deposition of copper of the Negev Type (Zone IV).

REFERENCES

BARTURA, Y. & WURZBURGER, U., 1974 - The Timna copper deposit. *In* : Gisements stratiformes et Provinces Cuprifères. Liège, 277-285.

BENDER, F., 1963 - Stratigraphie der "Nubischen Sandsteine" in Sud-Jordanien. *Geol. Jb., 81*: 237-276.

BENDER, F., 1965 - Zur Geologie der Kupfererzvorkommen am Ostrand des Wadi Araba, Jordanien. *Geol. Jb., 83*: 181-208.

BENDER, F., 1968 - Geologie von Jordanien. *Gebruder Borntraeger, Berlin*, 230 p.

BENDER, F., 1974 - Explanatory notes on the Geological Map of the Wadi Araba, Jordan. *Geol. Jb., 10B*, 62 p.

BENTOR, Y.K., 1961 - Petrographical outline of the Precambrian in Israel. *Bull. Res. Counc. Isr., 10G*: 19-63.

BURGATH, K.P., HAGEN, D. & SIEWERS, U., 1984 - Geochemistry, geology, and primary copper mineralization in Wadi Araba, Jordan. *Geol. Jb., 53(B)*: 3-53.

FREUND, R., GARFUNKEL, Z., ZAK, I., GOLDBERG, M., WEISSBROD, T. & DERIN, B., 1970 - The shear along the Dead Sea Rift. *Phil. Trans. Roy. Soc. London, 267A*: 107-130.

GUSTAFSON, L.B. & WILLIAMS, N., 1981 - Sediment-hosted stratiform deposits of copper, lead and zinc. *Econ. Geol., 75th Anniv. Vol.*, 139-178.

HAYNES, D.W., 1986 - Stratiform copper deposits hosted by low-energy sediments : II. Nature of source rocks and composition of metal-bearing water. *Econ. Geol., 81*: 266-280.

HAYNES, D.W. & BLOOM, M.S., 1987 - Stratiform copper deposits hosted by low-energy sediments : III. Aspects of metal transport. *Econ. Geol., 82*: 635-648.

HELGESON, H.C., 1964 - Thermodynamics of hydrothermal systems at elevated temperatures and pressures. *Am. J. Sci., 267*: 729-804.

KEIDAR, Y., 1984 - Mineralogy and petrography of copper nodules in the Upper White Nubian Sandstone in Timna Valley. *MSc Thesis, Ben-Gurion Univ., Beer Sheva*, 101 p. (in Hebrew, English abst.).

PAPENFUS, E.B., 1931 - "Red Bed" copper deposits in Nova Scotia and New Brunswick. *Econ. Geol., 36*: 314-330.

PETTIJOHN, F.J., 1963 - Chemical composition of sandstones - excluding carbonate and volcanic sands. *In* : M. Fleisher (Tech. Ed.), Data of Geochemistry (6th ed.), *U.S. Geol. Surv., Prof. Pap., 440-S*, 21 p.

POWERS, R.W., RAMIREZ, L.F., REDMOND, C.D. & ELBERG, E.L. Jr., 1966 - Sedimentary geology of Saudi Arabia. *U.S. Geol. Surv. Prof. Pap., 560-D*, 147 p.

ROSE, A.W., 1976 - The effect of cuprous chloride complexes in the origin of Red-Bed copper and related deposits. *Econ. Geol., 71*: 1036-1048.

SEGEV, A., 1986 - Lithofacies relations and mineralization occurrences in the Timna Formation, Timna Valley. *PhD Thesis, Hebrew Univ. Jerusalem*, 131 p. (in Hebrew, English abst.).

SLATKINE, A., 1961 - Nodules cuprifères du Negev méridional (Israel). *Bull. Res. Counc. Isr.*, ***10G***: 292-301.

SMITH, G.E., 1976 - Sabkha and tidal-flat facies control of stratiform copper deposits in north Texas. *In* : K.H. Wolf (Ed.), Handbook of Strata-Bound and Stratiform Ore Deposits, Elsevier, ***6***: 407-437.

VAN DE KAMP, P.C., LEAKE, B.E. & SENIOR, A., 1976 - The petrography and geochemistry of some Californian arkoses with application to identifying gneisses of metasedimentary origin. *J. Geol.*, ***84***: 195-212.

WEDEPOHL, K.H., 1974 - Copper. *In* : K.H. Wedepohl (Ed.), Handbook of Geochemistry, ***II-3***, sect. 29 K.

WEISSBROD, T., 1969 - The Paleozoic of Israel and adjacent countries. Part II. The Paleozoic outcrops in southwestern Sinai and their correlation with those of southern Israel. *Isr. Geol. Surv. Bull.*, ***48***, 32 p.

WEISSBROD, T., 1980 - The Paleozoic of Israel and adjacent countries (lithostratigraphic study). *PhD Thesis, Hebrew Univ., Jerusalem*, 276 p. (in Hebrew, English abst.).

WEISSBROD, T., 1987 - The Paleozoic of Sinai and the Negev. *In*: G. Gvirtzman *et al.* (Eds.), Sinai, Eretz, Tel Aviv, 43-56 (in Hebrew).

WOODWARD, L.A., KAUFMAN, W.H., SCHUMACHER, O.L. & TALBOTT, L.W., 1974 - Strata-bound copper deposits in Triassic sandstone of Sierra Nacimiento, New Mexico. *Econ. Geol.*, ***69*** : 108-120.