PRELIMINARY INVESTIGATIONS ON A RECENTLY DISCOVERED COPPER MINERALIZATION IN THE LYCIAN NAPPES, SW TURKEY

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ABSTRACT

This study reports preliminary textural, mineralogical and bulk-rock chemical data on a newly discovered copper mineralization in SW Turkey. The sampled 3 meter length outcrop includes pieces of a chalcopyrite + sphalerite + pyrite bearing massive and tabular ore vein oriented sub-parallel to the foliation planes of the sheared micro-grained dolerite host. The continuation of the ore vein is unknown. Fragments of radiolarian chert locally acting as foot-wall to the ore are also found along the foliation planes. The micro-grained dolerite is mainly sterile; however, the radiolarian chert is locally impregnated by chalcopyrite. The mineralization appears to be a fragmented distal section of an ophiolite-hosted volcanogenic massive sulphide (VMS) deposit emplaced during obduction of the ocean-floor units. More field, mineralogical and chemical data are needed to evaluate the mineralization and to find the main massive sulphide lens.

INTRODUCTION

Over 20% of the surface of Turkey is covered by ophiolitic terranes. They are located in suture zones either as isolated outcrops or as E-W trending nappe belts emplaced during the closure of Neo-Tethys. Various studies have been performed on Turkish ophiolites, focusing either on the many world-famous chromite deposits from the upper mantle section (e.g., Uysal et al., 2005) or on the ophiolite-hosted volcanogenic massive-sulphide deposits, such as the Ergani copper (south-eastern Turkey, Griffitts et al., 1972; Galley and Koski, 1999) and the Küre cupriferous pyrite deposits (northern Turkey, Güner, 1980; Galley and Koski, 1999; Fig. 1).

The Lycian Nappes (LN) are among the most-studied yet debated tectonic assemblages that include a huge amount of ophiolitic rocks, connecting the Jurassic ophiolites of the Dinaride-Hellenide chain in Greece and the Cretaceous ophiolites of the Tauride Chain in south-western Turkey (e.g., Alçiçek, 2007; Uysal et al., 2007). Various studies focused on the tectonic relations, age and direction of emplacement of the LN. Studies on the ore deposits of the LN are mainly confined to the rich and high-grade chromite deposits in the peridotite nappes (e.g., Borchert, 1958; Engin, 1969; Birgili et al., 1987) and to some rare manganese occurrences (e.g., Çelebi et al., 1989). Research lately expanded to the platinum group metals enrichment in and around the chromite deposits in the last decade (e.g., Uçurum et al., 2000; Uysal et al., 2005). No other types of deposits are found in the region, except for some pyrite and chalcopyrite occurrences reported from some rare localities in the large literature focusing on the Teke Peninsula.

A recently discovered copper mineralization is located immediately SE of the Sandras Mt. (4105414N, 666728E), in the volcano-sedimentary mélange rocks of the LN (Fig. 2). A first operation in the mineralization was conducted during the spring of 2007 by a foreign mining company and some ore was exported. The prospect is currently ongoing by the same company. The aim of this paper is to present a preliminary set of data on this mineralization and to introduce a new perspective to the mining operations and exploration in the area, other than chromium mining. This study

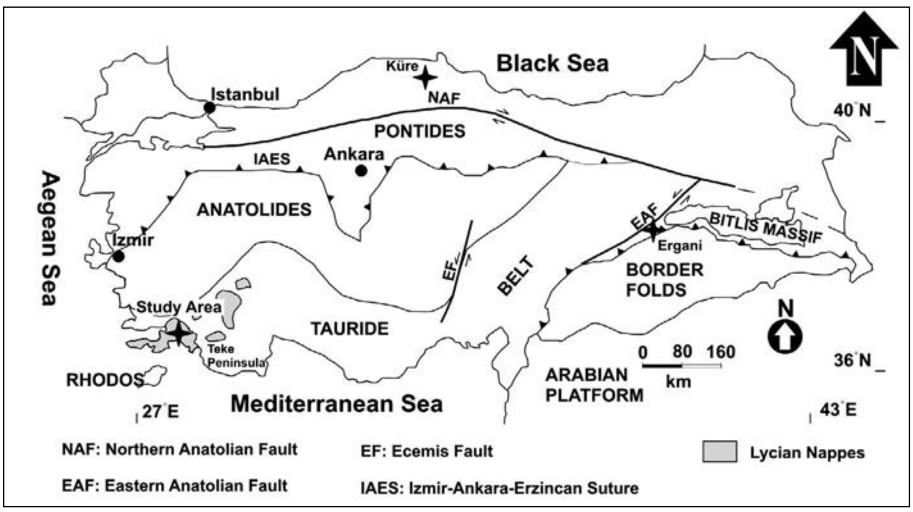

Fig. 1 - Tectonic belts of Turkey and location of the study area (modified after Önen, 2003). Küre and Ergani deposits are two of the well-known ophiolite-hosted VMS in Turkey.

presents preliminary data on the paragenesis, ore textures and emplacement of the copper mineralization and provides a basis of knowledge for further studies.

GEOLOGICAL SETTING

The mountains of the Teke Peninsula, located between the Antalya Gulf and the Aegean Sea, are called “Western Taurides” in the Turkish literature (Fig. 1). The region is largely named as the “Lycian Taurides” in the current geological literature, referring to its ancient geographical position. The complexity of its geological setting is confirmed by the many leading geologists that visited and studied the region for many decades.

De Graciansky (1972) envisaged a scheme including a Cenomanian - Lower Burdigalian tabular autochthonous substratum overlain by slabs of the so called “intermediate complex” and “nappes of diabases” that are all thrust by “peridotite nappes”. The slabs of “intermediate complex” of de Graciansky (1972) that are made of volcanic and sedimentary rocks are lately interpreted as individual nappes or thrust sheets (e.g., Şenel, 1997; Şenel and Bilgin, 1997; Collins and Robertson, 1998; 2003).

The “intermediate complex” is a chaotic group of three or four different series of volcanic and sedimentary rocks. However, the part of the series located in the study area mainly includes Triassic to Cretaceous chemical and pelagic sediments (Fig. 2). The “intermediate complex” series is overlain by the “nappes of diabases” made predominantly of a micro-grained dolerite matrix mélange including radiolarian chert fragments, in this region. All of this pile is overlain by the biggest and most continuous of the thrust sheets: the “peridotite nappes”. The basement of the peridotite nappes is characterized by important serpentinite occurrences, by rodingites formed from isolated dolerite dykes and by lenses of metamorphic rocks (the metamorphic sole). The peridotites are mainly harzburgites with minor dunites. The chromite deposits are ubiquitous in the series; however none is reported from the immediate vicinity of the study area. The investigated copper mineralization is located in the “nappes of diabases”, near their immediate contact with the “peridotite nappes”(Fig. 2).

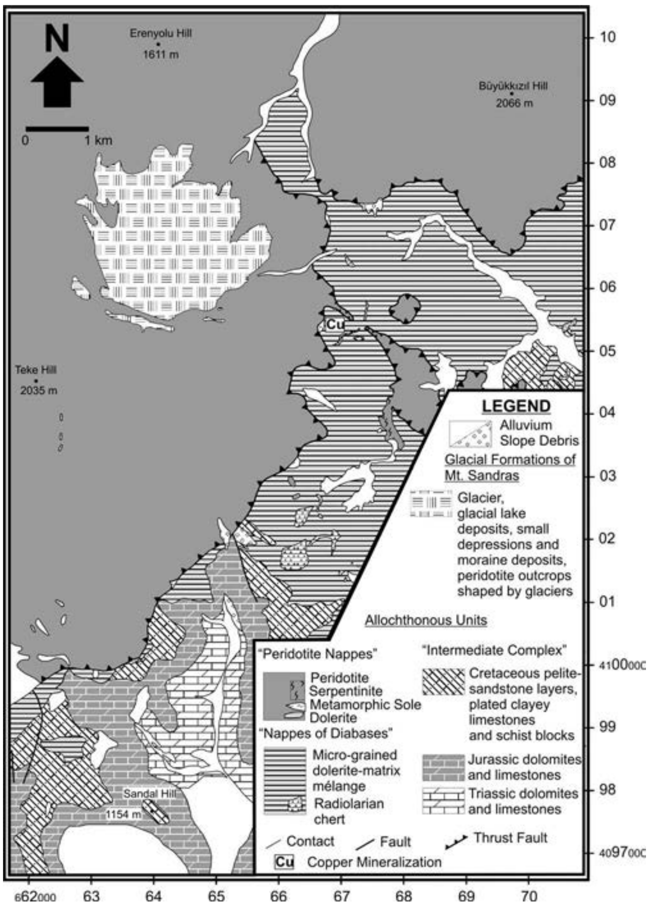

Fig. 2 - Geology of the surroundings of the copper mineralization (after De Graciansky, 1972).

HOST ROCKS AND COPPER MINERALIZATION

The host rocks are abundantly made of foliated micro-grained sub-volcanic basic rocks containing fragments of radiolarian cherts. Both rocks are pervasively tectonized and altered. The micro-grained basic rocks are macroscopically aphanitic. They include subordinate amounts of fine tremolite-actinolite crystals probably alteration products from pyroxenes, leucoxene, quartz, and epidote (as clusters or fillings in small veinlets) embedded in a matrix of very-fine grained plagioclase microlites. These micro-textured rocks were previously called “micro-grained dolerite” by de Graciansky (1972).

The red -coloured radiolarian chert fragments are brecciated and made mainly of silica and iron-oxides. These fragments include primary silica and secondary and pervasive carbonate veinlets.

The copper mineralization occurs as pieces of a chalcopyrite bearing massive and tabular ore vein and is subparallel to the foliation planes of the sheared micro-grained dolerite. The investigated outcrop is the remnant of a mine tailing which is approximately 3 m in length and with unknown continuation (Fig. 3a). The thickest part of the traceable massive ore vein reaches 30 centimetres (Fig. 3b). In addition to the intensive shearing and foliation of the host rocks, the vein is cut by small en echelon faults.

Where the radiolarian chert fragments occur, the ore deposition took place at the contact between the hanging-wall micro-grained dolerite and the foot-wall radiolarian chert (Fig. 3c). The micro-grained dolerite is mainly sterile; however the radiolarian chert lenses are locally found impregnated by chalcopyrite (Fig. 3d).

The main ore mineral in the mineralization is massive chalcopyrite, followed by lesser amounts of sphalerite and subordinate amounts of pyrite. Hematite is found in trace amounts in the radiolarian chert footwall. Quartz is found as an ubiquitous phase in both the massive ore vein and the radiolarian cherts. No layering is apparent in the micro-texture. The succession observed in two polished sections is the following: hematite crystallizes in the first stage while silica is released to the environment. Afterwards, the main ore precipitation starts with pyrite. Pyrite is followed by sphalerite. The abundant chalcopyrite starts to precipitate during the last stages of sphalerite precipitation, both replacing the pyrite and the sphalerite. Quartz crystallized as cracks filling in the radiolarian cherts and massive ore (Figs. 4 and 5) and is followed by pervasive carbonate (calcite) crystallization in the radiolarian cherts.

Preliminary whole-rock chemical data from the massive ore and the host rocks are given in Table 1. The major oxides, trace and rare earth elements analyses of the radiolari-

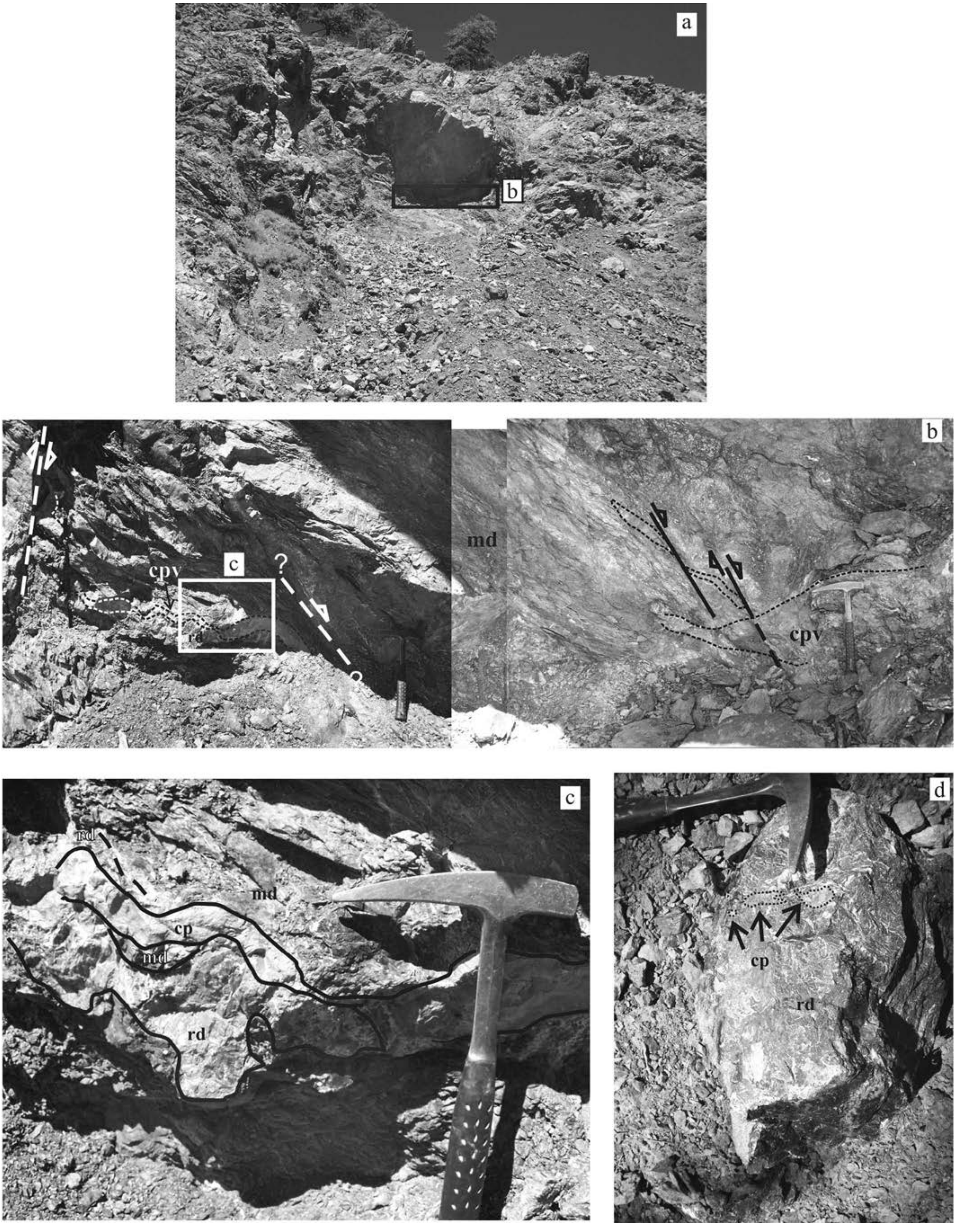

Fig. 3 - Field photos of the investigated and sampled outcrop; a) general view of the outcrop; b) chalcopyrite dominant massive vein (cpv) in the mainly micro-grained dolerite (md) host; c) contact relation of the fragmented radiolarian chert (rd) intercalations in the micro-grained dolerite and chalcopyrite vein (borders are marked with lines); d) chalcopyrite (cp) impregnated radiolarian chert fragments.

Table 1 - Whole-rock analysis results of the massive ore and host rocks.

sample		*TCC1*	*TCC4*	*TCC5B*
		Massive ore	Radiolarian chert	Micro-grained dolerite
SiO_2	wt %	10.64	64.18	46.7
Al_2O_3	wt %	0.75	0.3	13.25
Fe_2O_3	wt %	27.36	10.24	12.21
MgO	wt %	2.32	0.19	7.28
CaO	wt %	22.03	14.74	15.04
Na_2O	wt %	1.03	<0.01	0.68
K_2O	wt %	0.12	0.02	0.04
TiO_2	wt %	0.01	<0.01	1.07
P_2O_5	wt %	0.033	0.035	0.097
MnO	wt %	0.16	0.1	0.28
Cr_2O_3	wt %	0.08	0.02	0.018
SrO	wt %	<0.01	n.a.	n.a.
BaO	wt %	0.02	n.a.	n.a.
LOI	wt %	5.46	8.4	3.2
Sum	wt %	70.01	98.23	99.87
Co	ppm	97.75	52.2	84.8
Ga	ppm	6.88	3.8	22.2
Rb	ppm	0.9	0.6	0.8
Sr	ppm	17.7	18	254
V	ppm	38	178	345
Zr	ppm	1.9	31.1	55.7
Y	ppm	0.73	4	30.8
La	ppm	1.0	0.6	1.9
Ce	ppm	0.4	0.3	6
Pr	ppm	0.10	0.18	1.18
Nd	ppm	0.5	0.8	7
Sm	ppm	0.09	0.2	2.46
Eu	ppm	<0.02	0.02	1.02
Gd	ppm	0.14	0.42	4.02
Dy	ppm	0.06	0.44	5.06
Tb	ppm	0.02	0.06	0.81
Ho	ppm	0.04	0.09	1.11
Er	ppm	0.10	0.37	3.34
Tm	ppm	<0.01	0.03	0.51
Yb	ppm	0.06	0.26	3.25
Lu	ppm	0.02	0.05	0.5
Mo	ppm	65.5	4.9	0.1
Cu	ppm	>10000	>10000	**<0.1**
Pb	ppm	20	2.2	0.2
Zn	ppm	>10000	124	40
Ni	ppm	128	9.3	29.9
As	ppm	3	8.7	<0.5
Cd	ppm	160	0.9	<0.1
Sb	ppm	0.15	<0.1	<0.1
Bi	ppm	0.59	0.2	<0.1
Ag	ppm	29	1.5	<0.1
Au	ppb	0.4	22.3	40
Se	ppm	690	29.6	<0.5
Cu	**wt %**	**16.10**	**1.40**	n.a.
Zn	**wt %**	**2.33**	n.a.	n.a.
TOTAL	wt %	8.52	1.43	<0.02

an cherts and micro-grained dolerites were performed at the ACME analytical laboratories Ltd. (Canada) by Lithium Metaborate - Tetraborate fusion followed by dilute nitric acid digestion and ICP-AES and ICP-MS finish, respectively. The REE analysis of the massive ore was also performed at the ACME analytical laboratories Ltd. Major oxides, trace elements and ore-grade Cu and Zn values of the massive ore were analyzed at the ALS Chemex Ltd. (Canada). Cu and Zn were obtained by aqua regia digestion followed by ICP-AES and/or AAS finish.

The analyses support the macro and microscopic observations showing nearly no enrichment in the micro-grained dolerites and up to 1.40 wt% Cu enrichment in the radiolarian cherts. The massive ore bears 16.10 and 2.33 wt% Cu and Zn, respectively. Mo, Ni, Pb, Cd, Ag and Se values are also high in the massive ore. Cu, Zn and Pb values of the massive ore were also plotted on the Cu-Zn-Pb ternary diagram in order to compare them with the ophiolite-hosted VMS deposits worldwide (data from detailed compilation of Galley and Koski, 1999, Fig. 6a). The plot emphasizes the Pb-poor nature of the mineralization, and a high Cu/Cu + Zn ratio which is also typical for the other well-known ophiolite-hosted VMS deposits.

SIGNIFICANCE OF THE MINERALIZATION AND CONCLUDING REMARKS

This preliminary investigation reports a small ore body associated with the volcano-sedimentary mélange of LN. The mineralization is found as pieces of a chalcopyrite ore body and is hosted by a sheared, micro-grained and microlitic basic lava rock containing radiolarian chert fragments. Due to thrusting and shearing that affected the host rock and to the limited mine tailing information in the field, the continuity of the ore body is hard to follow. The sterile nature of the micro-grained rocks, the Cu enrichment in radiolarian chert fragments and the analogous C1 chondrite normalized REE patterns of the massive ore and radiolarian cherts (Fig. 6b) indicate that the hydrothermal fluids precipitated copper after the release of silica into a marine environment, during the formation of radiolarian chert. The limited chemical and petrographic data indicates a massive sulphide nature for the mineralization. The main metal assemblage (Cu and Zn) and the relation of the ore vein with the host rocks do not allow to assert the exact nature of the occurrence, however, a rough discussion on its genesis is given below.

In the archetypal Cyprus-type massive sulphide deposit, the main stratiform sulphide lens occurs at the contact of two different volcanic units, with a root system of stockwork veins and breccia marking the hydrothermal pipe. A sediment cap made of Fe-rich and siliceous pelagic mudstones, hydrothermal sediments and oxidized massive sulphides including sandy pyrite beds and fragments of colloform pyrite (Searle, 1972; Galley and Koski, 1999) mark the surface of the paleo-ocean floor. In some deposits this cap is made of siliceous limestone and tuff that are interbedded with Fe oxides (Mathiati deposit, Cyprus), and in some others it consists of cherts and well-layered mafic tuff (Skouriotissa deposit, Cyprus) (Constantinou and Govett, 1972). Commonly, radiolarian bearing, well-layered jasper-quartz-magnetite rich sediments and interlayered detrial sulphide can form an apron for several tens of meters around some deposits (Galley and Koski, 1999).

However, all of the deposits do not show the general Cyprus-type deposition characteristics (Galley and Koski, 1999). In some deposits in Cyprus, the mineralization occurs at the contact between Upper Pillow Lavas and Umber sediments (Constantinou and Govett, 1973) marking a late stage hydrothermal event. Moreover, the Aarja and Lasail deposits in Oman, have bedded structures; the former with interlayers of banded sulphides within hematite-rich pelagic and hydrothermal sediments along the contact of the massive sulphide lens (Ixer et al., 1986; Gibson and Koski, 1995; Galley and Koski, 1999). The latter has interlayers of Fe oxide rich sediments at the western and northern flanks of the main massive sulphide lens (Koski et al., 1990; Galley and Koski, 1999). In Lasail the interlayering is in some places thought to be related to the *lit-par-lit* replacement of earlier sediments by the sulphides. However, the bedded sulphides are mostly of clastic origin (Galley and Koski, 1999).

The investigated ore body in LN includes and excludes several characteristics discussed above. The lithological characteristics of the radiolarian chert in the mafic volcanic assemblage resemble the distal pelagic sedimentary apron of the classical Cyprus-type. However, these are found as fragments mainly associated with pieces of the tabular chalcopyrite body and not are continuous. The texture of the

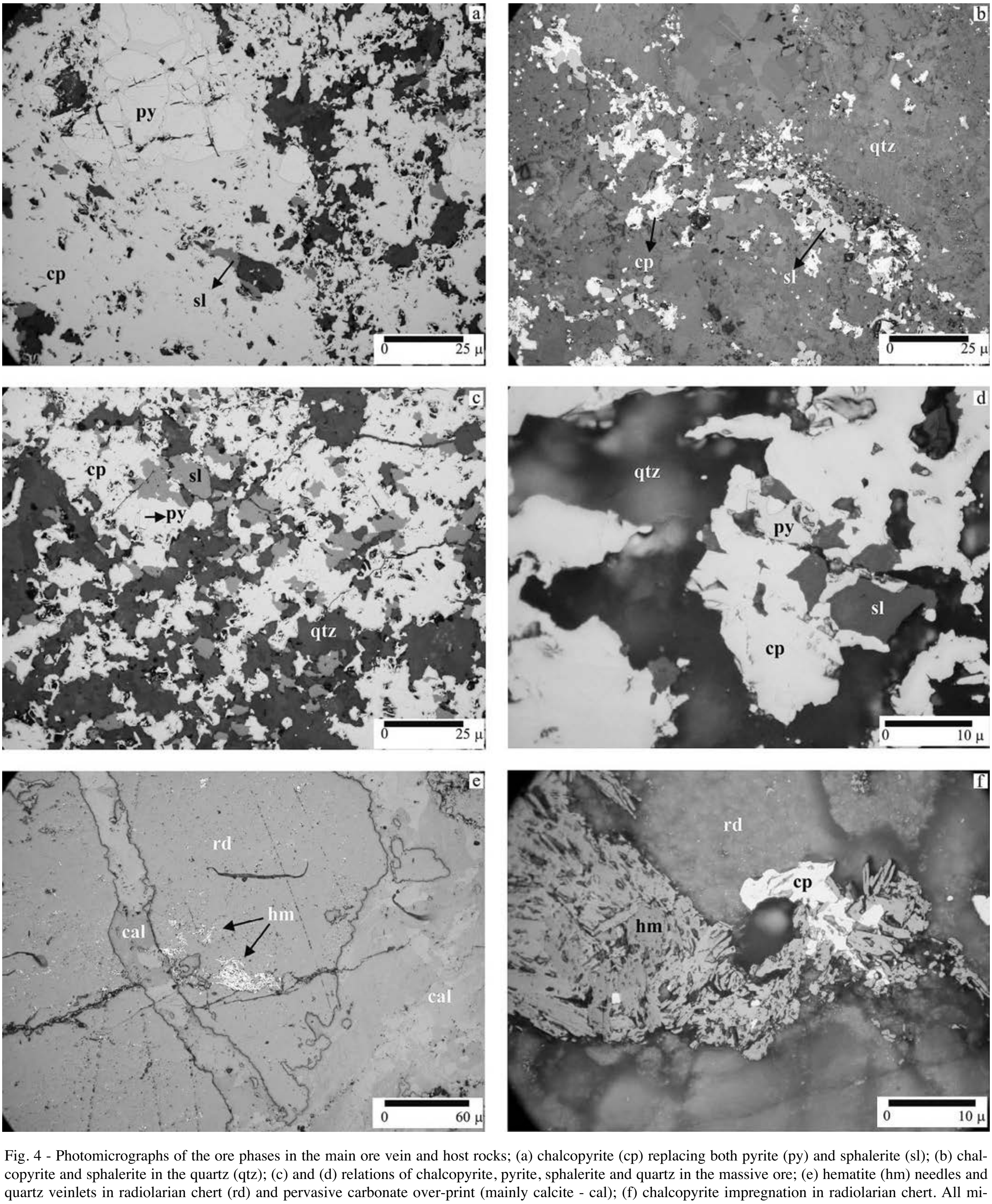

Fig. 4 - Photomicrographs of the ore phases in the main ore vein and host rocks; (a) chalcopyrite (cp) replacing both pyrite (py) and sphalerite (sl); (b) chalcopyrite and sphalerite in the quartz (qtz); (c) and (d) relations of chalcopyrite, pyrite, sphalerite and quartz in the massive ore; (e) hematite (hm) needles and quartz veinlets in radiolarian chert (rd) and pervasive carbonate over-print (mainly calcite - cal); (f) chalcopyrite impregnation in radiolarian chert. All microphotos are taken under reflected light //N; photos (a), (b), (c) and (e) are in air, (d) and (f) are in oil immersion.

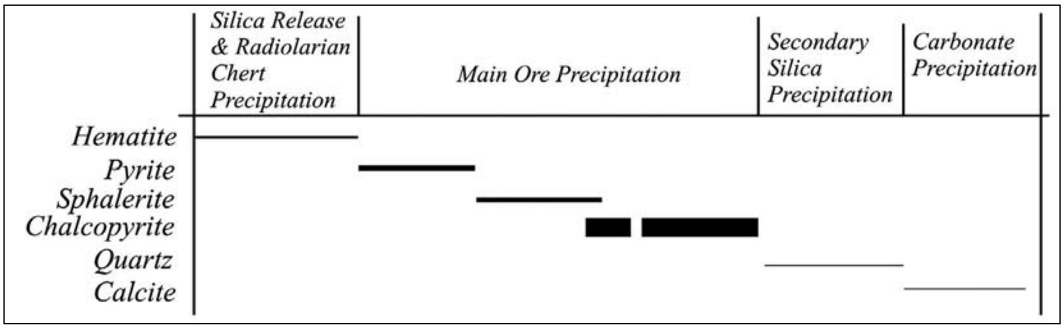

Fig. 5 - A limited Table of paragenesis according to the investigated two polished sections.

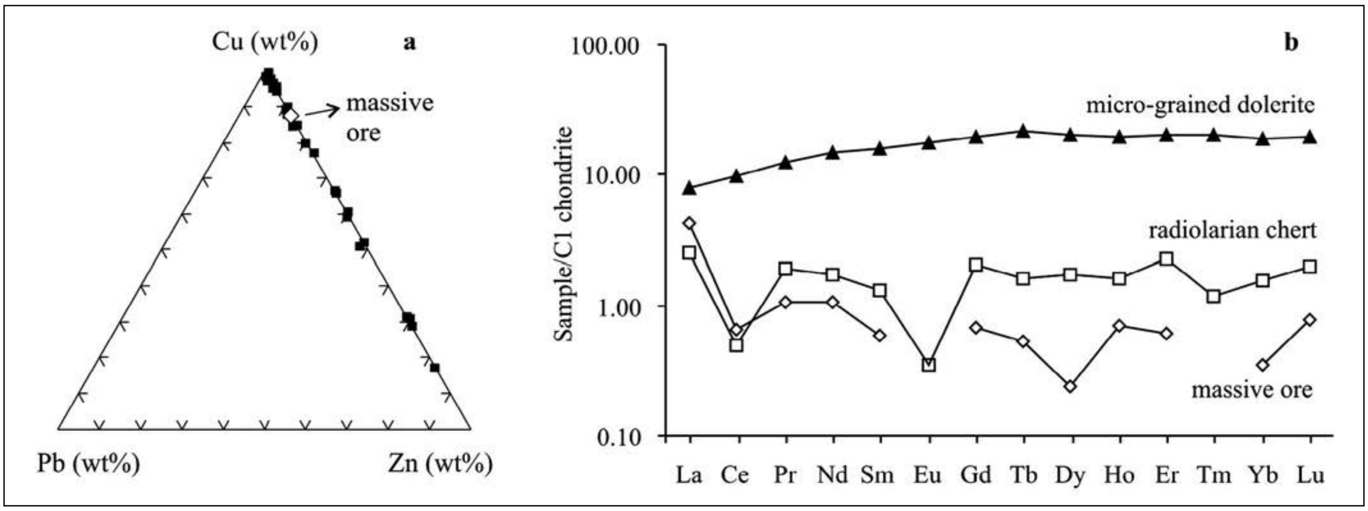

Fig. 6 - (a) Cu-Zn-Pb (wt %) ternary plot comparing the Cu, Zn and Pb content of the massive ore from the investigated mineralization (open diamond) and several ophiolite-hosted VMS deposits wordwide (closed squares; data from Galley and Koski, 1999); (b) C1 chondrite normalized REE diagram of the massive ore, radiolarian chert and micro-grained dolerite (normalization values are La- 0.237; Ce- 0.612; Pr- 0.095; Nd- 0.467; Sm- 0.153; Eu- 0.058; Gd- 0.2055; Tb- 0.0374; Dy- 0.2540; Ho- 0.0566; Er- 0.1655; Tm- 0.0255; Yb- 0.170; Lu- 0.0254).

chalcopyrite ore-body also does not support detrial nor clastic origin. On the contrary, it is a typical example like those found in a high temperature hydrothermal ore body.

Thus, based on the comparison with Cyprus-type deposits and the preliminary data on the characteristics of the investigated ore body, this mineralization appears to be a fragmented distal part of an ophiolite-hosted VMS. It seems that during the obduction of the ocean-floor sequence, the distal part of the mineralization was dislocated from the proximal part and emplaced together with the volcanic pile onto its present location. The proximal sulphide lens seems to be missing.

The data obtained with this study comes from a limited outcrop. Despite the ongoing prospection in the area, no other data are available on the continuity and reserve of the mineralization. Because of the severe deformation and dislocation that occurred together with the host rock during obduction (Galley and Koski, 1999), more field, chemical and mineralogical data is needed to evaluate the mineralization and to find the main massive sulphide lense. However, the Cu and Zn grades from the sampled outcrop are promising

The ophiolite-hosted VMS deposits should have formed during an extensional regime that permitted circulation of hydrothermal fluids within the oceanic crust. This kind of extensional regime may either be found at sea-floor spreading centres along mid-oceanic ridges, or at supra-subduction zones along the fore-arc and back-arc basins (Galley and Koski, 1999). The Lycian Nappes (LN), bearing significant amounts of fore-arc peridotites (Uysal et al., 2005; 2007, and unpublished data of the authors) and the related basaltic volcanic assemblages are a promising location for the ophiolite-hosted VMS prospection. This preliminary investigation indicates that serious Cu prospections and a re-evaluation of the Cu potential are needed in the region. This type of mineralization is not unknown in Turkey, since there are very well known examples of VMS such as the Ergani copper and Küre cupriferous pyrite deposits; however, it is new for the region which is only well-known for its high-quality chromium potential.

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