BASE METAL MINERALISATION IN THE EVROS REGION, THRACE, N.E. HELLAS

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In: G.H. Friedrich, P.M. Herzig (Editors), 1988. Base metal sulphide deposits in sedimentary and volcanic environments. Proceedings of the DMG-GDMB-SGA-Meeting Aachen, 1985. Special Publication No. 5 of the Society for Geology Applied to Mineral Deposits. Springer-Verlag, Berlin, Heidelberg, p.168-181.

Abstract

The stratiform and vein base metal sulphide mineralisation of the Evros region has been emplaced during three major metallogenetic periods: the Pre-, Early- and Mid-Alpidic orogenic era. The Pre-Alpidic mineralisation is associated with a metamorphosed ophiolitic mafic-ultramafic sequence (Rhodope Massif), the Early Alpidic with tholeiitic metabasalt (Circum-Rhodope Belt) and the Mid-Alpidic mineralisation has its major development in Tertiary sedimentary and calc-alkaline igneous rocks.

These types of mineralisation, depending on their geotectonic setting, are considered to be similar to that of the Limassol Forest Plutonic Complex (Rhodope Massif), to volcanic-exhalative and analogous to Cyprus volcanogenic massive sulphides (Circum-Rhodope Belt), and to stratiform sediment hosted and veins of volcanic affiliation (Tertiary volcano-sedimentary basins).

1. Introduction

The Evros region is situated in north-eastern Hellas and is bounded to the north and east by Bulgaria and Turkey (Fig. 1). It shows a history of some minor exploration and mining activity which started during the Turkish and Bulgarian occupation of Thrace in the late 19th and early 20th century. Over the last ten years, exploration activities by the Hellenic Institute of Geology and Mineral Exploration (I.G.M.E.) have increased. The use of such exploration techniques as stream sediment, soil and rock geochemical surveys, geophysics, and drilling investigations has led to the delineation of new target regions. A number of mineralised areas have now been located by the I.G.M.E., and although the most important of these are base metal prospects, the Evros region also contains gold, silver, chromite, and manganese mineralisation (Constantinides et al., 1983).

2. Geology

Geologically, the Evros region is comprised from three major structural units (Fig. 1):

(i) the Rhodope Massif with medium to high grade metamorphic rocks,

(ii) the Mesozoic Circum Rhodope Belt consisting of weakly metamorphosed volcano-sedimentary and flysch formations, and
(iii) the Tertiary volcano-sedimentary basins. Metallogenetically, the Evros region is part of the East Rhodope metallogenetic district which extends northwards into Bulgaria (Jankovic 1979; Boncev 1980).

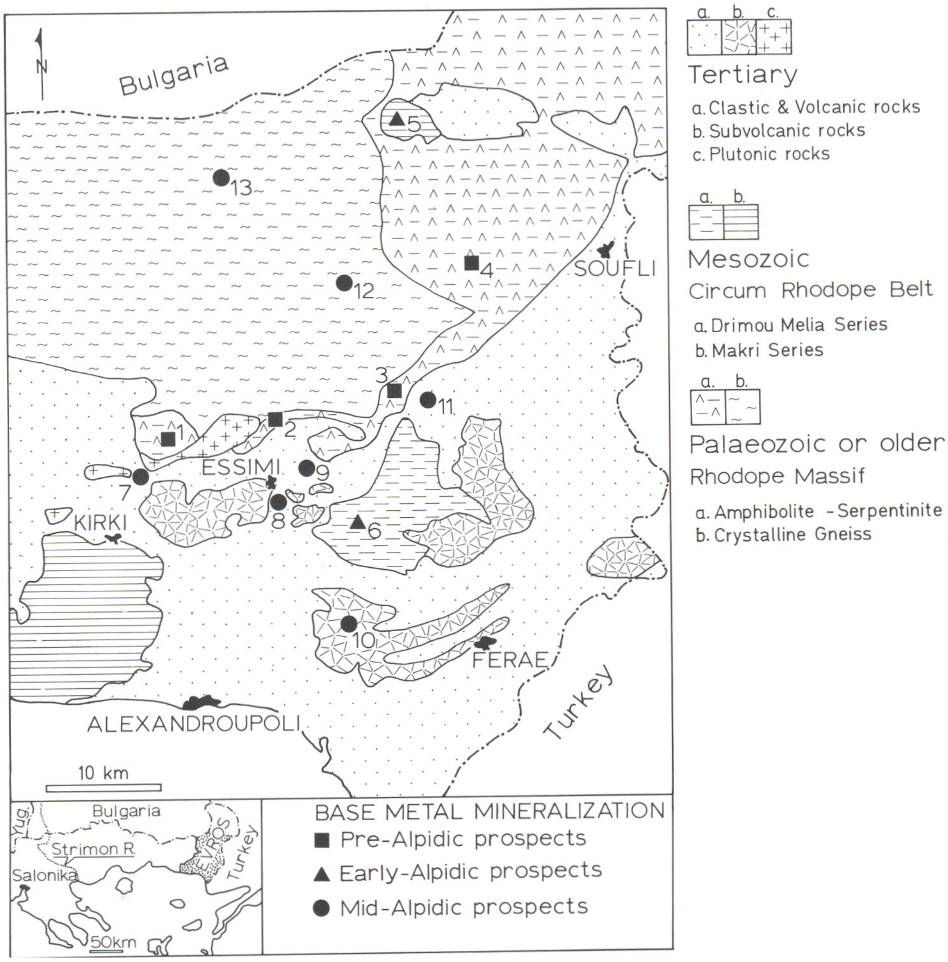

Figure 1. Simplified geological map of the Evros region showing the location of the major base metal prospects. The names of the numbered prospects are given in Table 1 (After Constantinides et al. 1983).

Table 1. Classification of the Evros region base metal prospects into metallogenetic epochs (for their location see Fig. 1)

Pre-Alpidic	*Early-Alpidic*	*Mid-Alpidic*	
1. Aberdeen	5. Mikro Dherio	7. St. Philip	11. Virini
2. Baiko	6. Elia	8. Mili	12. Tris Vrises
3. Pessani		9. Prophitis Elias	13. Ano Kambi
4. Yiannouli		10. Pefka	

Note: The numbers assigned to each prospect represent their location in Fig. 1. The most important prospects are discussed in the text.

2.1. Rhodope Massif

The oldest rocks in the Evros region are the metamorphics of the Rhodope Massif. They comprise deformed and highly metamorphosed sedimentary and igneous rocks. Several phases of deformation have affected the massif during which metamorphism reached upper greenschist to lower amphibolite facies (Papanikolaou and Scarpelis 1980; Papanikolaou et al. 1982; Zachos and Dimadis 1983). The present-day stratigraphy of the Rhodope Massif in the Evros region consists of a lower unit of leucocratic orthogneiss, mica-schist, amphibolite and thin marble horizons, and an upper unit of ophiolitic amphibolite and serpentinite. The latter unit is important with respect to base metal mineralisation, hence its geology is elaborated further.

The Amphibolite-Serpentinite Unit comprises a lower sequence of mafic amphibolite and banded quartz-amphibolite, a mid-sequence of amphibolite and marble and an upper of podiform serpentinite. Field relationships and the preservation of igneous layering and massive gabbroic textures in the coarse grained mafic amphibolite, the primary igneous minerals, such as olivine, pyroxene and plagioclase in the centres of large podiform serpentinite masses, and the mafic units of 0.5-1.5 m thickness in the banded quartz-amphibolite, which are interpreted as representing highly deformed dykes, all suggest that the Amphibolite-Serpentinite Unit may represent a deformed and metamorphosed mafic-ultramafic complex, which has been intruded by granitic material, presumed to be the plagiogranite of ophiolite complexes.

2.2. Circum-Rhodope Belt

The Circum-Rhodope Belt formations overlie unconformably the crystalline basement and comprise sub-greenschist facies volcano-sedimentary sequences. It is subdivided into two units, the Makri or Phyllite Series of Jurassic to Lower Cretaceous age and the Drimou Melia Series of Cretaceous age. The Makri Series mainly consist of clayey, sericitic, calcareous, and quartzitic phyllite, limestone, and greenstones. The Drimou Melia Series unconformably overlies the Makri Series and comprises shale, clayey-bituminous marl, quartzite, sandstone, conglomerates, pyroclastics, and mafic volcanic rocks (Papadopoulos 1980).

2.3. Tertiary Volcano-Sedimentary Basins

The Tertiary basins in the Evros region (e.g., Kirki-Essimi) are elongated with the major axis trending E-W and/or NE-SW, directions followed by deep crustal faults. Basin subsidence was initiated during Mid-Eocene (Papadopoulos 1980) with sedimentation followed by concurrent intense volcanic activity from Upper Eocene to Oligocene (Fytikas et al. 1979, 1984; Innocenti et al. 1984). Sedimentation and volcanism are both controlled by reactivated faults of mainly E-W, N-S and NE-SW directions.

The Tertiary formations belong to three stratigraphic eras: (a) Lutetian (Middle Eocene), (b) Priabonian (Upper Eocene), and (c) Oligocene. Each formation is characterised by an unconformity to the underlying rocks. A notable feature of the Lutetian is the complete absence of volcanic products and mineralisation.

The Lutetian Stage (Middle Eocene) consists of a basal breccio-conglomerate, marl and nummulitic limestone. The Priabonian Stage (Upper Eocene) is made-up of a basal breccio-conglomerate, shale, clayey sandstone, calcareous sandstone, and volcanic rocks, such as andesite, dacite, tuff and tuffite, which occur within the sedimentary strata. The volcano-sedimentary sequence is cross-cut by subvolcanic rocks of intermediate composition. The Oligocene Stage includes mainly felsic volcanic rocks, e.g., tuff, volcanic breccia, and rhyolite porphyry in the form of domes and dykes, but also granitoid stocks occur. Its sedimentary rocks have a restricted regional development.

3. Mineralisation

The base metal mineralisation of the Evros region has been classified into three metallogenetic epochs, the Pre-, Early- and Mid-Alpidic orogenic era, according to its emplacement relative to the different phases of activity during the Alpine orogeny (Constantinides et al. 1983). The most important base metal prospects of the region were classified using this scheme (Table 1, Fig. 1).

3.1. Pre-Alpidic Mineralisation

The base metal mineralisation in the metamorphic basement is closely associated with the Amphibolite-Serpentinite Unit, where a number of disseminated and massive pyrite-chalcopyrite (±sphalerite ±galena) prospects have been located. The most important are those at Aberdeen, Baiko, and Pessani (Fig. 1). The styles of mineralisation recognised in all three prospects are stratiform and vein type.

The ***Aberdeen prospect*** occurs in the lower part of the serpentinite unit close to its contact with the mafic amphibolite, and lies at the intersection of two N-S and E-W trending vertical fault zones. The stratiform pyrite-chalcopyrite mineralisation follows the foliation and is confined to the mafic amphibolite horizon. The minor constituents are sphalerite, galena, marcasite, enargite, bornite, magnetite, rammelsbergite, bismuthinite, argentite, hessite, siegenite, and sulphosalts of Bi, Pb, Ag, and Te. Chromite is widespread in the host rocks. The effects of deformation and metamorphism on the base metal mineralisation may be observed in crystalloblasts of pyrite and chalcopyrite. The epigenetic vein-type mineralisation, on the other hand, occurs as fracture filling mainly along the N-S fault zone, and as minor veinlets crosscutting the stratiform mineralisation. The major and minor ore mineral association is similar to that in the stratiform mineralisation, but in the vein-type pyrite and chalcopyrite have been brecciated by tectonic movements and are cemented by quartz.

At the ***Baiko prospect*** two mineral associations, disseminated pyrite-chalcopyrite (±sphalerite ±galena) and disseminated magnetite-pyrite-chalcopyrite, have been recognised. The disseminated pyrite-chalcopyrite association occurs close to the contact between the mafic amphibolite and the serpentinite. Pyrite is present both as a fine-grained disseminated phase orientated parallel to the regional foliation, and as an euhedral phase occurring in lenses and veins. Chalcopyrite typically occurs in veinlets, which crosscut the regional foliation. Disseminated magnetite-pyrite-chalcopyrite mineralisation is found in a unit of amphibolite marble. The mineralisation is concentrated in metasomatic, epidote-rich halos at the contacts of marble horizons with amphibolite bands. The presence of carbonate horizons within the metabasite suggests that this unit represents a thin sequence of intercalated mafic volcanics and carbonates.

The stratiform mineralisation at the ***Pessani prospect*** is subdivided into two types (Michael et al. 1984; Billett and Nesbitt 1986). The first is concentrated in metasomatic, epidote-rich halos at the contacts of marble horizons with amphibolite bands. The mineralisation is mainly disseminated and rarely occurs in aggregates. The major mineral is pyrite. Chalcopyrite is usually a minor constituent, but locally becomes more abundant. Actinolite, tremolite, garnet, epidote, and chlorite are closely associated with the mineralisation. The second type occurs close to the contact of the banded quartz amphibolite with large serpentinite bodies. It comprises disseminations and small lenses (5-30 cm) of mainly fine-grained and crystalloblastic pyrite. Chalcopyrite and galena occur as minor constituents. The fine-grained pyrite appears rarely in relict spherical forms of probably colloidal origin. Most of the pyrite has been recrystallised in crystalloblasts, which are often brecciated and cemented by chalcopyrite, whereas galena shows signs of plastic deformation. The epigenetic mineralisation consists of small quartz veins with pyrite, galena, sphalerite and chalcopyrite, which occur in the amphibolite with a NW-SE trend.

3.2. Early-Alpidic Mineralization

The base metal mineralisation of the Early-Alpidic epoch is associated with the mafic volcanics of the Circum-Rhodope Belt at Mikro Dherio (Makri Series) and Elva (Drimou Melia Series) (Fig. 1). In both cases, the mineralisation occurs as disseminations and veinlets in a sequence of deformed, weakly metamorphosed and altered basaltic pillow lavas. Chlorite, epidote, and zeolites appear as alteration minerals.

3.3. Mid-Alpidic Mineralisation

The Mid-Alpidic base metal sulphides mainly occur in rocks of the Tertiary volcanosedimentary basins in two styles, stratiform and vein form. The latter is also present in the Rhodope Massif and Circum-Rhodope Belt.

Vein Mineralisation. The vein mineralisation in the Evros region is widespread in contrast to the known statiform ore (Fig. 1). It occurs in fracture zones of NW-SE (Prophitis Elias area) and/or N-S (St. Philip) general trend (Fig. 2). Within these fracture zones, apart from the vein mineralisation, disseminated ores of restricted development, and rarely veinlets forming stockworks may be observed. The ore veins have a thickness of a few centimetres up to 3 m, whereas their length and vertical dimension vary from a few to about 100 m. The vein mineralisation is irregularly distributed, both in the vertical and horizontal sense and even over short distances.

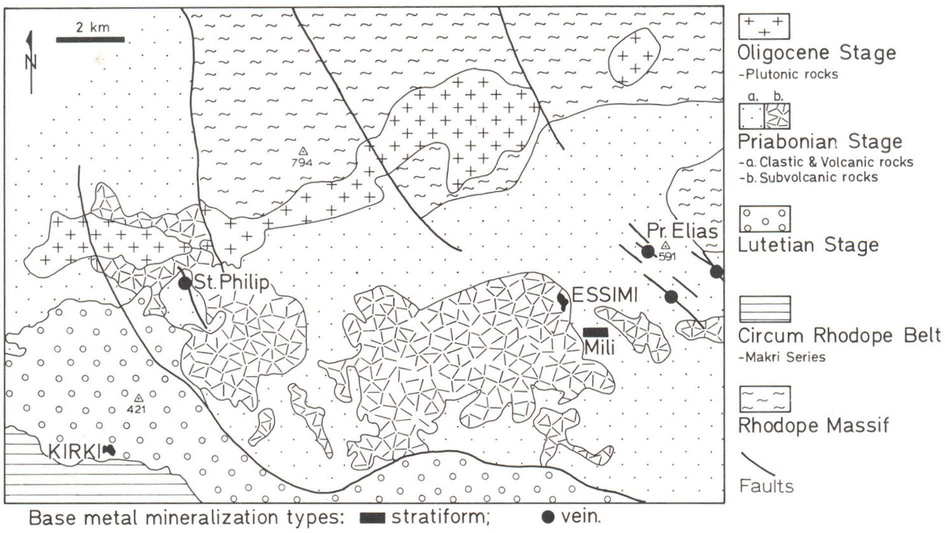

Figure 2. Simplified geological map of the Kirki-Essimi Tertiary volcano-sedimentary basin showing the location of the major stratiform and vein mineralisation prospects (After more detailed maps by P. Papadopoulos, K. Arikas, I. Romaides, E. Dimadis, C. Michael and C. Katirtzoglou)

At ***Prophetis Elias*** pyrite-sphalerite-galena and chalcopyrite mineralisation with minor arsenopyrite, marcasite, pyrrhotite, cosalite and bismuthinite has been described (Constantinides et al. 1983), associated with veins in the Priabonian sediments. The gangue minerals are calcite (with some dolomite), quartz, chlorite, and epidote.

The ***St. Philip*** vein base metal mineralisation is presently the only one in the Evros region with known economic potential (Figs. 1, 2, 3). The 1986 estimated ore reserves are 1.2 million tons with an average grade of 9 wt.-% combined Pb+Zn and 50-150 ppm Ag. Two ore mineral associations have been recognised: (a) sphalerite, galena, and pyrite, and (b) chalcopyrite, pyrite, and As-, Sb-sulphosalts as well as Bi- and Sn-sulphides (e.g., bismuthinite, stannite, tennantite, luzonite, seligmannite, jordanite, and tetrahedrite). Quartz, carbonates and baryte are gangue minerals. The first mineral association is commonly found vertically above the second one (Fig. 3).

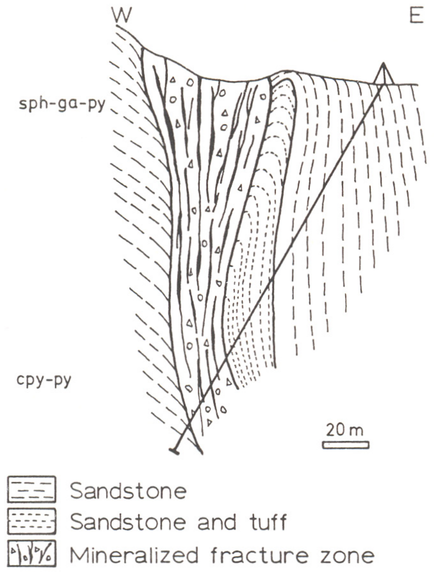

Fig. 3. Diagrammatic geological section of the St. Philip mineralised fracture zone.

The ***Pefka*** area is covered by basic and acid calc-alkaline volcanic rocks, which were emplaced in a continental environment (lahar forms), with local indications of shallow sea conditions. T he polymetallic sulphide mineralisation of the Pefka prospect comprises two ore-mineral associations: (a) galena, sphalerite, and pyrite, and (b) pyrite, chalcopyrite, tetrahedrite, antimonite, tennantite, and gold. The gangue minerals include quartz, baryte, and carbonates. There is an apparent mineral zonation, the ore minerals of the first association are above those of the second one. Native gold has been observed in the form of grains of a few microns in diameter within quartz and rarely as inclusions in tenantite-tetrahedrite. The veins occur in silicified N-S and E-W trending fracture zones within intensely altered volcanic rocks. The main ore concentrations are located at the intersections of cross-cutting faults.

Stratiform Mineralisation. The stratiform base metal sulphides of the Mili prospect (Figs. 1, 2) are concentrated in certain horizons, all of which occur in the centre of a clastic sedimentary sequence belonging to the Priabonian Stage (Fig. 4). The mineralisation varies from semi-massive to disseminated ores, and passes laterally to pyrite only. The ore minerals are generally finer-grained than those of the vein mineralisation and include sphalerite, galena, and pyrite, with minor marcasite, bornite, bournotite, and arsenopyrite. The gangue minerals are calcite, ankerite, dolomite, quartz, chlorite, sericite, and baryte. The most dominant authigenic minerals in the mineralised area are ankerite and chlorite with large amounts of sericite and quartz. The only allogenic mineral is quartz in variable quantities.

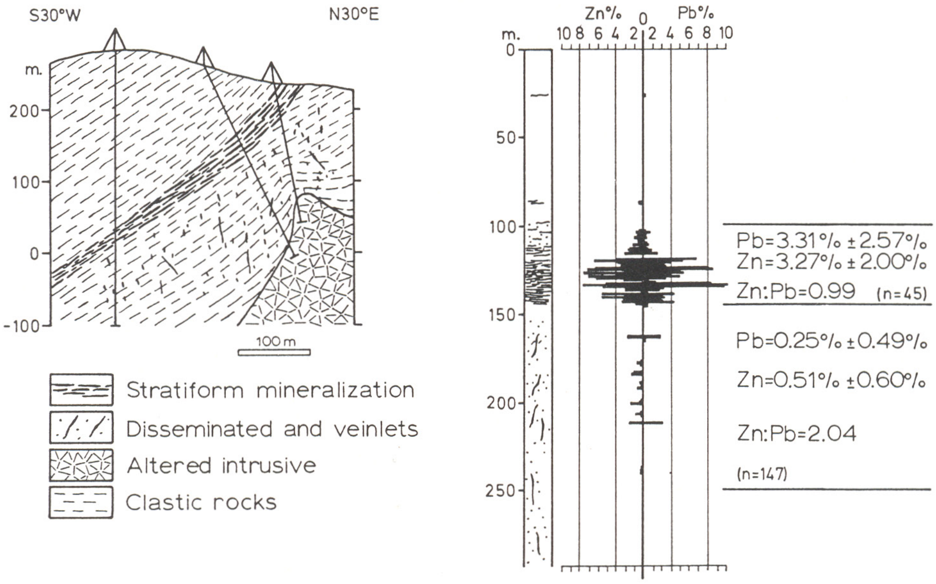

Figure 4. Diagrammatic section of the Mili stratiform sediment hosted base metal mineralisation (left) and diamond drill-hole section showing the mineralised zone and the Zn and Pb distribution (right).

The clastic sedimentary rocks underlying the mineralised sequence are silicified, and contain large amounts of sericite, ankerite and chlorite, as well as veinlets and disseminations of base metal sulphides. Secondary silicification has produced epitaxic quartz grains. The overlying clastic rocks, on the other hand, contain considerable amounts of calcite and abundant ankerite, sericite, montmorillonite, and some albite and kaolinite. Carbonate appears to have been extensively recrystallised.

Porphyritic igneous rocks of felsic composition which are intruded into the clastic sedimentary sequence are strongly carbonated and feldspars are converted to sericite, indicating the activity of hydrothermal fluids. The adjoining clastic sedimentary rocks are also intensely altered. Pyrite appears to have been crystallised later than silicate and carbonate minerals, but its widespread distribution and the presence of some pyrite-rich bands suggests that Fe and S were either original components of the host rocks or the hydrothermal fluids were enriched in these two constituents. Sphalerite (with minor chalcopyrite) and galena were the last minerals to crystallise and appear to be interstitial or to replace some feldspar and possibly quartz. The general appearance of quartz and particularly the irregular and ragged nature of the carbonate patches suggests that recrystallisation took place in the presence of fluids.

4. Geotectonic Setting

The variation of Cr and Ni versus total FeO/MgO in the mafic amphibolite and serpentinite is shown graphically in Figure 5. On the Cr versus total FeO/MgO diagram the mafic and ultramafic rocks exhibit a continuous fractionation trend of decreasing Cr content with increasing fractionation index. The Ni versus total FeO/MgO plot, however, shows a distinct composition gap between Ni-rich serpentinite and relatively Ni-poor mafic amphibolite. According to Billett and Nesbitt (1986), we are dealing with a comagmatic suite of mafic and ultramafic rocks, possibly of ophiolitic affinity. Furthermore, the trace element data, particularly the gap in the Ni distribution, suggests that at least parts of the serpentinite unit are residual ultramafic rocks, i.e., tectonites in ophiolite terminology. A tectonic environment is envisaged similar to that of the Troodos Ophiolite Complex, which is an early back-arc at a constructive plate margin (Smith 1971; Pearce 1975; Shelton and Gass 1980). At some stage in the Lower Paleozoic or even Precambrian, the mafic-ultramafic sequence was obducted onto the sedimentary-igneous rocks of the Rhodope Massif. Both units were then affected by the thermodynamic metamorphism of at least the Caledonian, Hercynian and Alpine orogenic cycles (S. Zachos, pers. commun.).

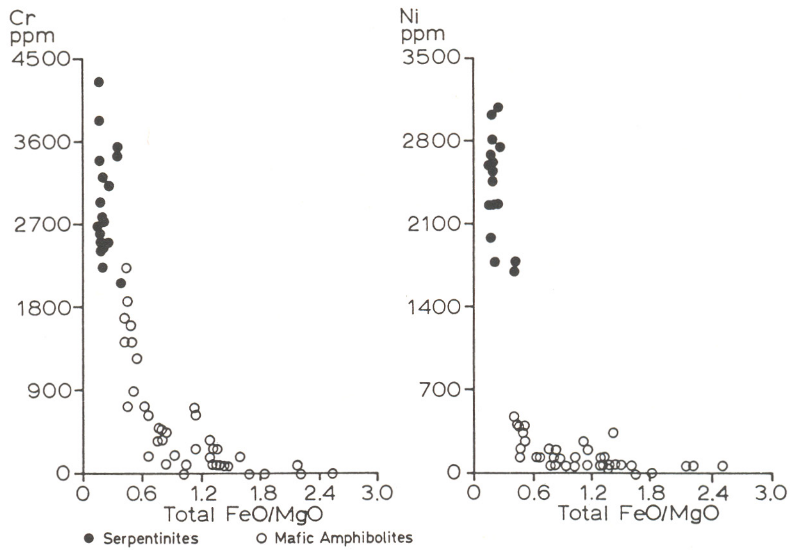

Figure 5. Cr vs. total FeO/MgO and Ni vs. total FeO/MgO variation diagrams for the mafic amphibolite and serpentinite (After Billett and Nesbitt 1986).

Two discrimination plots Ti versus Zr (Pearce and Cann 1973) and Zr /Y versus Zr (Pearce and Norry 1979) have been used for the identification of the tectonic environment of the voleanic rocks (Fig. 6). The metabasalts of the Circum-Rhodope Belt (Makri Series, Mikro Dherio prospect) fall in the low K-tholeiite field of the Ti versus Zr diagram and in the island arc tholeiite of the Zr /Y versus Zr plot. The interpretation given is that the metabasalts were formed at a constructive plate margin back-arc environment, similar to the Cyprus pillow lavas setting.

The Tertiary calc-alkaline volcanics from Essimi and Pefka areas plot as two distinct populations on the above two diagrams. Both sets fall in the orogenic calc-alkaline basalt field of the Ti versus Zs diagram. On the Zr /Y versus Zr diagram the Essimi volcanics plot in the mid-ocean ridge basalt (MORB) field, and those from Pefka at the boundary between MORB and within plate basalt (WPB). It can be argued that the Essimi calc-alkaline volcanics were emplaced in Priabonian times during the initial rifting and subduction of the Apulian microplate under the Rhodope Massif, the southern margin of Eurasia (Fytikas et al. 1984). During the Oligocene, the emplacement of the majority of the more differentiated calc-alkaline volcanics, subvolcanic and plutonic rocks took place. The Pefka volcanics with a higher Zr content were most likely emplaced in a continental setting.

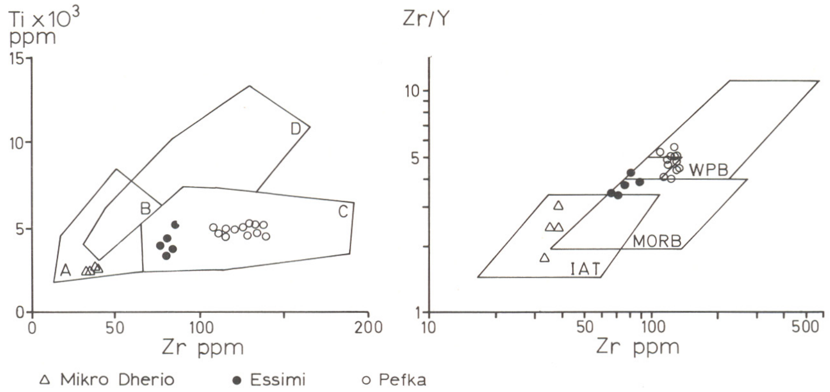

Figure 6. Position of metabasalts from Mikro Dherio (Makri Series, Circum Rhodope Belt) and basic members of the calc-alkaline volcanics from Essimi (Priabonian) and Pefka (Oligocene) plotted on Ti vs. Zr (Pearce and Cann 1973) and Zr /Y vs. Zr (Pearce and Norry 1979) discrimination diagrams (A + Blow potash island arc tholeiite; B + C calc-alkaline basalt; D ocean-floor basalt; IAT island arc tholeiitic basalt; MORB mid-ocean ridge basalt; WPB within plate basalt).

5. Discussion and conclusions

The base metal sulphide mineralisation of the Evros region occurs in three different geological settings: in the ophiolitic Amphibolite-Serpentinite Unit, in the tholeiitic lavas of the Circum-Rhodope Belt and the Tertiary volcano-sedimentary basins, and was emplaced during three different metallogenetic epochs: the Pre-, Early- and Mid-Alpidic orogenic era.

The mineralisation in the Amphibolite-Serpentinite Unit has different modes of origin. The amphibolite of the amphibolite-marble member is considered to be a submarine metabasalt. This inference is supported by field relationships and the presence of marble horizons. The base metal sulphides are believed to be of syngenetic-exhalative origin, analogous to Cyprus-type volcanogenic massive sulphides. The occurrence of mineralisation, close to the contact between the maficamphibolite and serpentinite, suggests that the latter may have played an important role in the remobilisation and concentraction of sulphides, possibly during the introduction of fluids into the system, which mobilised metals from the amphibolite. Alternatively, fluids may have been introduced along the ductile contacts between the ultramafic bodies and the amphibolite. The suggestion that mobilisation of sulphides has taken place close to the contacts is supported by the presence of epigenetic pyrite-rich veins in the alteration zone between the two units. This type of mineralisation, associated with serpentinite masses, is rather unusual, because high base metal contents tend to be associated with mafic extrusive rather that with ultramafic plutonic rocks. An analogy can be drawn, however, to the deposits of the Limassol Forest Plutonic Complex, where lensoid, disseminated, and vein type Cu-Ni-Co-Fe sulphide deposits are sporadically distributed along the peripheral zone in the shattered serpentinite (Panayiotou 1980).

The base metal mineralisation associated with the tholeiitic pillow lavas in the Circum-Rhodope Belt (Makri and Drimou Melia Series) is considered to be of volcanic-exhalative origin and, consequently, there is probably a potential for Cyprus-type massive sulphides.

The calc-alkaline magmatic activity and mineralisation associated with the Tertiary volcano-sedimentary basins are connected with the continental collision and subduction of the African plate under the Eurasian (Innocenti et al. 1984; Fytikas et al. 1984). I n the Evros region this activity occurred from the Upper Eocene to Oligocene.

The following genetic concept is proposed for the Tertiary stratiform and vein mineralisation (Fig. 7). Early tensional conditions related to an incipient rifting of the basement (Rhodope Massif and Circum Rhodope Belt) caused the creation of intra-continental sedimentary basins, filled by fine to medium-grained quartz, feldspar, and considerable carbonate sediments. Apparently, the sediments derived from the weathering of the metamorphic basement rocks also contained Fe sulphides and small amounts of Zn, Pb, and other metallic elements. The latter is supported by geochemical analyses of unmineralized clastic sedimentary rocks, which give metal contents above normal values. The possible early introduction of metals by hydrothermal fluids due to the existence of high geothermal gradients cannot be precluded.

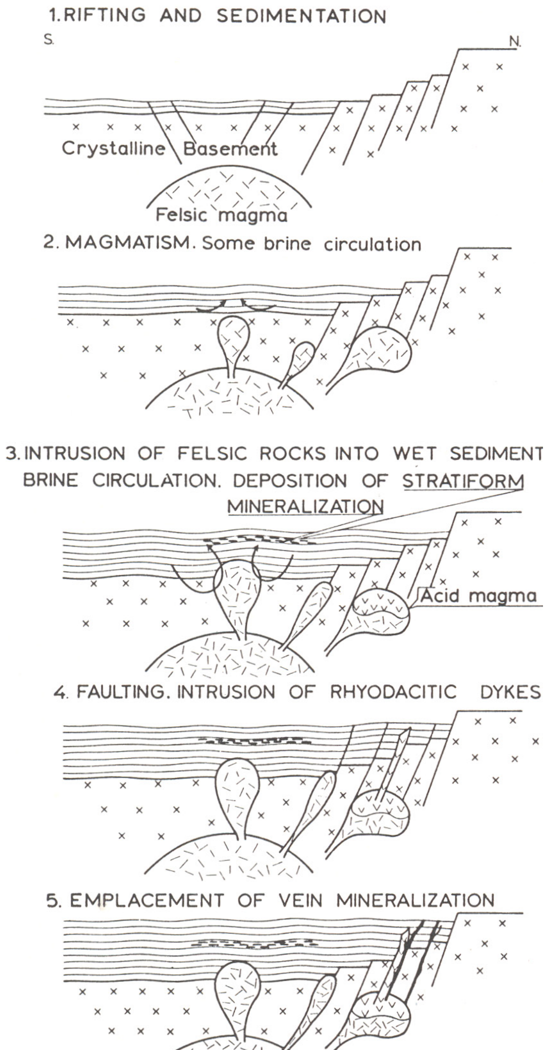

Figure 7. Conceptual diagrams showing the history of development of the Tertiary Kirki-Essimi volcano-sedimentary basin and the emplacement of stratiform and vein mineralisation.

During the later stages of deposition, and while the sediments were still saturated with brines, felsic intrusives were injected into the sedimentary sequence. The location of these intrusives was controlled, in part, by major deep-seated fracture zones in mainly E-W and NW-SE directions. The intrusions became strongly carbonated due to reaction with the wet carbonaceous sediments, and base metals, such as Zn, Pb, and small amounts of Cu were released into the brines. The intrusives also formed heat centres, causing brine circulation through the sediments and leaching of additional Zn, Pb, and other metallic elements.

The more porous beds were suitable for the migration of solutions and metal deposition took place when temperature decreased, and/or where the physicochemical environment was suitable, e.g., high porosity and change in carbonate content. The above mechanism does explain the emplacement of the stratiform mineralisation, and particularly, its limited lateral extent, the proximity to intensely altered felsic intrusives and the irregular layering of the ore minerals.

After diagenesis of the sediments, other subvolcanic masses of andesite-dacite composition intruded during the late Priabonian (Upper Eocene). Finally, in the Oligocene, granodioritic plutons were emplaced followed by rhyolitic dykes, which intruded along reactivated fracture zones of mainly NW -SE direction. In a very close temporal and spatial relationship, the main phase of epigenetic vein mineralisation took place. This felsic intrusive and mineralising phase appears to have affected earlier mineralisation in the Amphibolite-Serpentinite Unit and Circum-Rhodope Belt, e.g., the fracture-filling mineralisation at Aberdeen, Baiko, and Pessani prospects is considered to be due to remobilisation of the primary stratiform mineralisation.

The above metallogenetic model may be modified or changed when additional information will be available. For example, the role of the calc-alkaline granitoids, which are the subject of current investigations, has to be evaluated.

Acknowledgments

Financial support by the E.E.C. R. & D. programme (Project No MSM 133 G R) and IGME is gratefully acknowledged, as well as the permission to published the results.

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