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METALLIFEROUS SULPHIDE AND OXIDE SEDIMENTS RELATED TO PERMO-TRIASSIC RIFTING OF THE PELAGONIAN ZONE, MAINLAND GREECE

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Abstract

The field setting of formerly economic, metamorphosed sulphide and oxide-sediments of the Pelagonian Zone in central eastern mainland Greece (E. Thessaly) is detailed here. The metalliferous deposits relate to Permo-Triassic rifting of the Pelagonian microcontinent from Apulia. The metamorphic protoliths include terrigenous clastics, limestones, chert and basic extrusives. Extrusives are intercalated with lenses of Fe-rich oxide sediments, massive and disseminated sulphides and ferruginous oxide sediments. Manganese-rich, siliceous sediments were deposited on adjacent lavas away from the sulphide-depositing zones. Manganiferous cherts and mudstones were also interbedded with mafic extrusives and terrigenous sediments over a wide area of the rift zone. After metalliferous sedimentation ended, the rift was infilled with lavas and terrigenous sediments and then overlain by a carbonate platform of Late Triassic-Jurassic age. The metalliferous deposits underwent successive stages of metamorphism in Late Jurassic/Early Cretaceous and Early Tertiary time. These deposits are interpreted as hydrothermal precipitates within a Permo-Triassic rift zone, in contrast to most other metalliferous deposits in the Greek area which are related to ocean floor spreading and preserved associated with ophiolites.

Introduction

As part of an on-going investigation of hydrothermal metalliferous sediments formed within Mesozoic ocean basins in the Greek area (Robertson and Varnavas, 1990, in press), we document here the field relations of metalliferous sulphide and oxide-sediments of the Pelagonian Zone in Eastern Thessaly, mainland Greece (Figs 1, 2). The Pelagonian Zone (Mountrakis, 1984; Jacobshagen and Wallbrecher, 1984) is interpreted as a microcontinent that rifted from Apulia in the Permo-Triassic, giving rise to two small ocean basins, the Pindos ocean in the west and the Vardar (Axios) ocean in the east (Smith, 1979; Robertson et al., 1991). These small ocean basins finally closed following continental collision in the Early Tertiary. Hydrothermal sediments have been previously documented in a wide range of ancient (e.g. Tethys; Robertson and Boyle, 1983; Varnavas and Panagos, 1986) and modern oceanic settings (e.g. Klein, 1991). However, there have been few studies of metalliferous sedimentation related to ancient rift settings exposed on land, including the Tethyan area. The deposits studied here have undergone several stages of regional metamorphism. The mineralogy and field relations were outlined by Panagos, (1960), Maratos (1962), Migiros (1979) and Konti (1984). However, this is the first study to relate the metamorphosed sulphide and oxide-deposits specifically to hydrothermal processes related to continental rifting.

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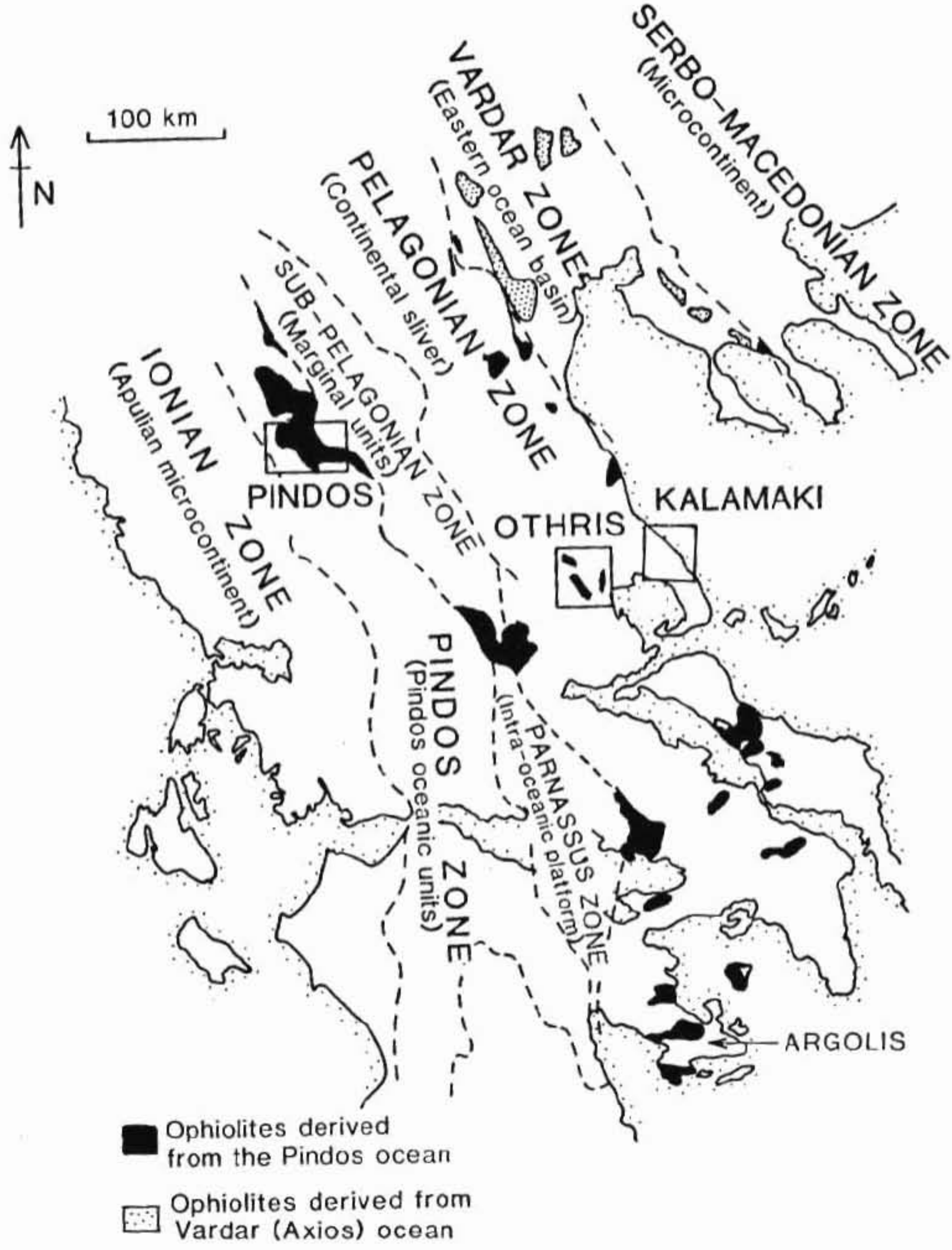

Fig 1 Isopic zones of Greece, showing the study area. The locations of previously discussed metalliferous oxide and sulphide sediments associated with ophiolitic rocks are also shown. In contrast the deposits discussed in this paper are related to Permo-Triassic rifting of the Pelagonian Zone.

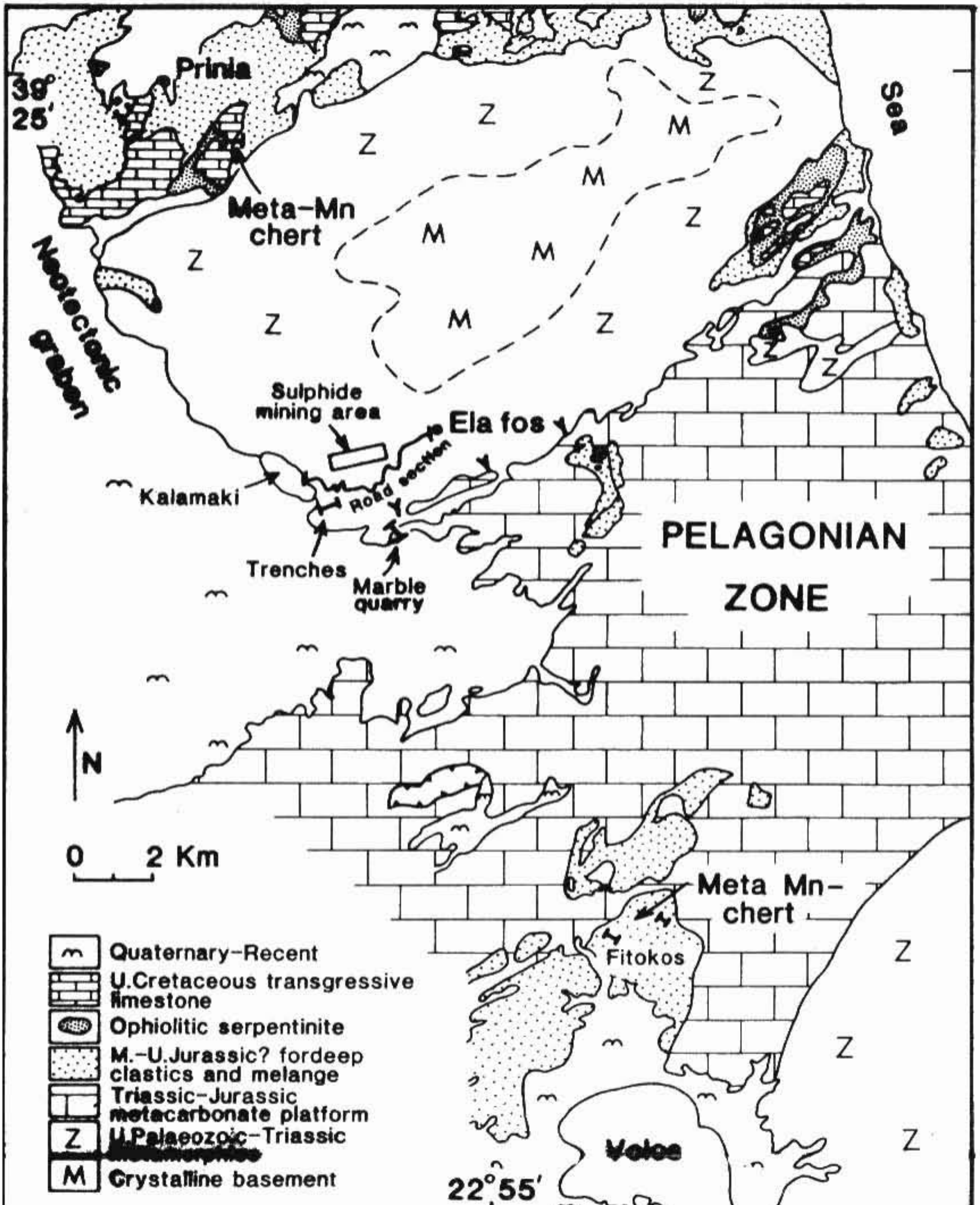

Fig 2 Outline geological map of the study area in the Pelagonian Zone of central eastern Greece. Based on Katsikatsos et al., 1981, 1986 and Migiros et al., 1984. Outcrops of unrelated ophiolitic Mn-rich oxide sediments within the Pelagonian Zone near Volos are also shown (Robertson and Varnavas, 1992), but not discussed here.

Tectono-stratigraphy of the Pelagonian Zone

In the area of the Pelagonian Zone studied (Fig 2), according to mapping by Katsikatsos et al. (1981) and Migiros and Vidakis (1984), crystalline basement is depositionally overlain by up to 800m of strongly deformed gneisses, schists and amphibolites, with minor marbles, meta-cherts and sulphides. This unit is, in turn, overlain by thick marbles with minor meta-bauxites (Fig 3). The marbles are succeeded by up to several hundred metres of schists, meta-basic rocks and marbles. Meta-basites, found as blocks within this unit are associated with metalliferous oxide sediments of hydrothermal origin (Robertson and Varnavas, 1992, in press). Thrust sheets of ophiolitic rocks, mainly serpentinite, are found above this in the south of the area, near Volos (Fig 2).

Transgressive Late Cretaceous shallow-water limestones crop out in the north of the area and are, in turn, unconformably overlain by unmetamorphosed Neogene-Quaternary sediments. Other structurally high units exposed in the south of the area (i.e. W of Volos, Fig 2; Katsikatsos et al., 1986) will not be discussed here (i.e. 'Eohellenic nappe' and 'Neohellenic nappe' remnants).

Fossils are scarce in the metamorphic Pelagonian Zone and the ages of the metamorphosed metalliferous deposits have to be inferred from associated units. The basement in the area is assumed to be mainly of Late Palaeozoic age (Mountrakis, 1984; Migiros, 1986; Katsikatsos et al., 1986), while the overlying lithologically varied unit, that includes the metalliferous deposits, is Late Permian and/or Triassic. Overlying marbles are Late Triassic-Jurassic (Migiros and Vidakis, 1984; Katsikatsos et al., 1981).

The Pelagonian Zone in the area studied was subjected to three main regional metamorphic events: i) Greenschist (mid Jurassic-Early Cretaceous); ii) Blueschist (post-Cretaceous to pre-Late Eocene); iii) Low-grade (Middle Eocene) (Katsikatsos et al., 1986; Migiros, 1986).

Lithologies associated with the metalliferous deposits

Massive sulphides and oxide-sediments are well exposed near Kalamaki (Fig 2), within an alternating succession of micaschists, amphibolites and minor metacherts. In this area the dominant schistosity is gently inclined, cut by numerous normal faults that delineate the margins of a Neotectonic graben situated to the southwest (Fig 2). In the vicinity of the mining area (Fig 2), the schistosity dips gently northward, while further south the dip is southward, beneath the meta-carbonate platform unit of inferred Late Triassic-Jurassic age. Evidence of medium-scale and small-scale folds indicates that the whole unit is strongly folded.

The succession in the former mining area consists of micaschists and amphibolites, alternating on a tens-of-metre scale. Flattened clasts can occasionally be recognised within amphibolites, suggesting an origin as lava flows and lava breccias rather than as intrusives. Gneisses and schists locally exhibit relict sedimentary bedding and are interpreted as meta-terrigenous clastic sediments. Thin intercalations of varicoloured quartzites are interpreted as meta-cherts. Minor occurrences of metamorphosed sulphides, red schists (rich in iron oxide and disseminated sulphide) and black Mn-rich quartzite are interpreted as primary metalliferous deposits. Upwards, tens-of-metre thick marble units are intercalated with greenschists, possibly of volcaniclastic origin. The base of the overlying marbles, interpreted as the base of the Late Triassic-Jurassic carbonate platform succession, is well exposed in a small quarry (Fig 2), where steeply-dipping greensch[illegible] overlain by thick-bedded, well jointed marbles. Our observations support previous mapping of this important contact as being depositional rather than tectonic (Migiros and Vidakis, 1984).

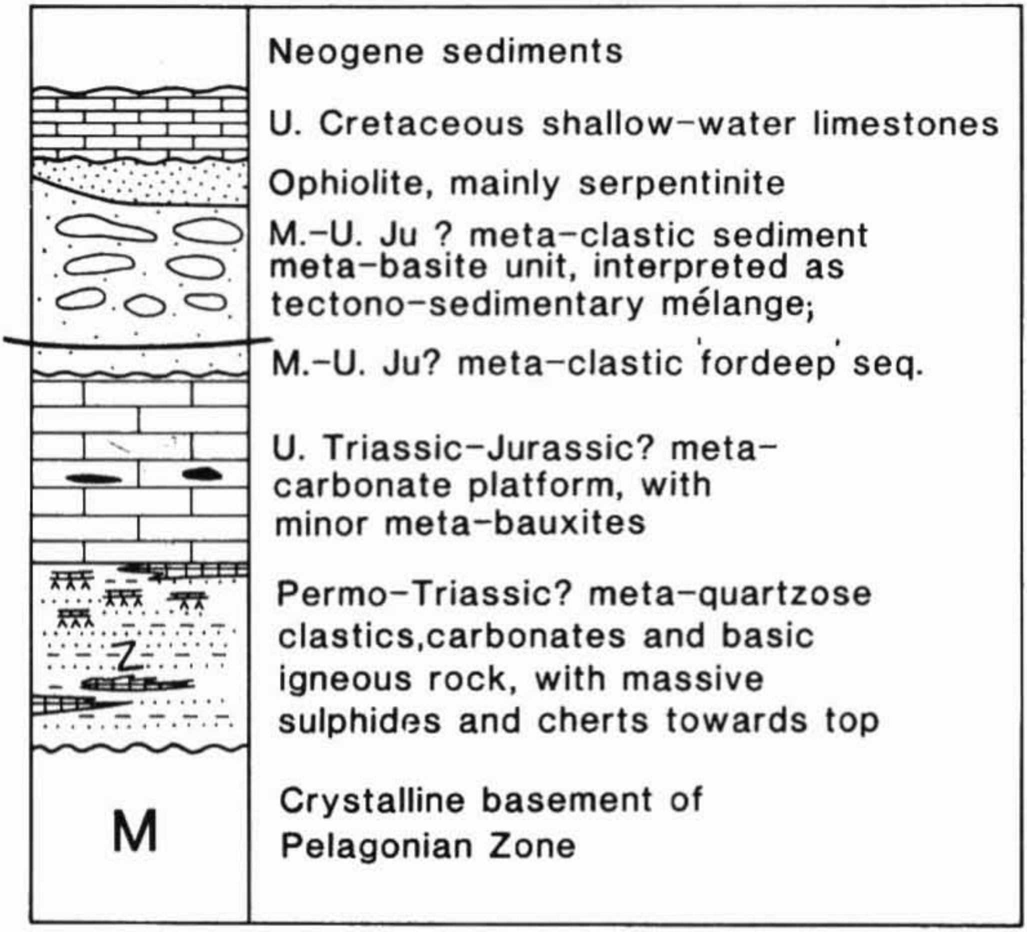

Fig 3 Simplified stratigraphical column to show the tectono-stratigraphy of the Pelagonian Zone in the area studied. Based on Katsikatsos et al. (1981, 1986) and Migiros et al. (1984). Note that a thrust is shown separating the Triassic-Jurassic carbonate platform succession from overlying tectono-sedimentary melange in this study.

Sulphides and ferruginous-oxide sediments

Metalliferous deposits are well exposed in the vicinity of mine shafts in a small wooded valley east of Kalamaki (Fig 4), where they are cut by numerous small post-metamorphic normal (Neotectonic?) faults. In this area, the metalliferous deposits are underlain by meta-basalts, up to tens-of-metres thick, traceable laterally more than 400m. The meta-lavas contain discontinuous lenses of pink meta-chert, up to 2-3m long by up to 30cm thick, as well as zones rich in epidote and occasional small pockets of disseminated sulphides (up to tens of cm sized).

Meta-basalts are intercalated with orange massive sulphide (now mainly oxidised), exposed in a mine shaft entrance (Figs 4 loc A, 5A, 6). Adjacent meta-lavas are silicified and cut by numerous veins of iron-stained quartzite, with disseminations of secondary copper minerals. Above this, amphibolites are overlain by dark grey to orange, meta-siliceous sediment (quartzite), with finely crystalline disseminated sulphide. These sediments are overlain by meta-clastic sediments (micaschists), containing scattered lenses of pink chert, and then by a thin layer of black chert. This is overlain, in turn, by meta-chert, then by meta-clastic sediments (to the top of the steep-sided valley; Fig 5A). These schists contain several, metre-thick lenses of amphibolite, with Fe-oxide staining and black quartzite layers, up to 20cm thick.

Eastward along strike, several smaller sulphide lenses again overlie amphibolites. For example, 250m (upstream) from the main locality described above (Fig 4, loc C), a several metre-long, <1m thick lens of meta-chert contains disseminated sulphide. Also, ca. 180m west of the sulphide mine shaft entrance mentioned above (Fig 4 Loc A), meta-lavas are interbedded with thin layers of red ferruginous chert (Figs 4 loc B; 5B).

Manganiferous-oxide sediments

Manganiferous oxide-sediments are exposed laterally (i.e. along strike) from the massive sulphides and also as numerous layers within the schist-amphibolite successions further south. In the Kalamaki sulphide mining area (Fig 4), black Mn-rich meta-chert forms a continuous blanket overlying meta-lavas, extending ca. 250m southward from the mining area, locally thinning to 15-25cm, then thickening again to 1.8m. The meta-cherts pass gradationally upward into brown-metaclastic sediments (Fig 5B).

Black, Mn-rich chert is also well exposed in contact with amphibolite, within exploration trenches near Kato Kalamaki (termed Kalamaki South in Fig 2). Assuming the black Mn-rich chert, there, overlies the meta-basalt (way-up criteria are absent), the succession is inverted (Fig 5C). If so, meta-lava is succeeded by black quartzitic chert, then by meta-lava, and banded black chert. The meta-chert contains dark Mn-rich segregations mostly within 5-6cm of the meta-lava contact. This is followed by dark coloured schist, interpreted as meta-mudstone, and finally by pale brown mica schist, interpreted as meta-terrigenous clastic sediment.

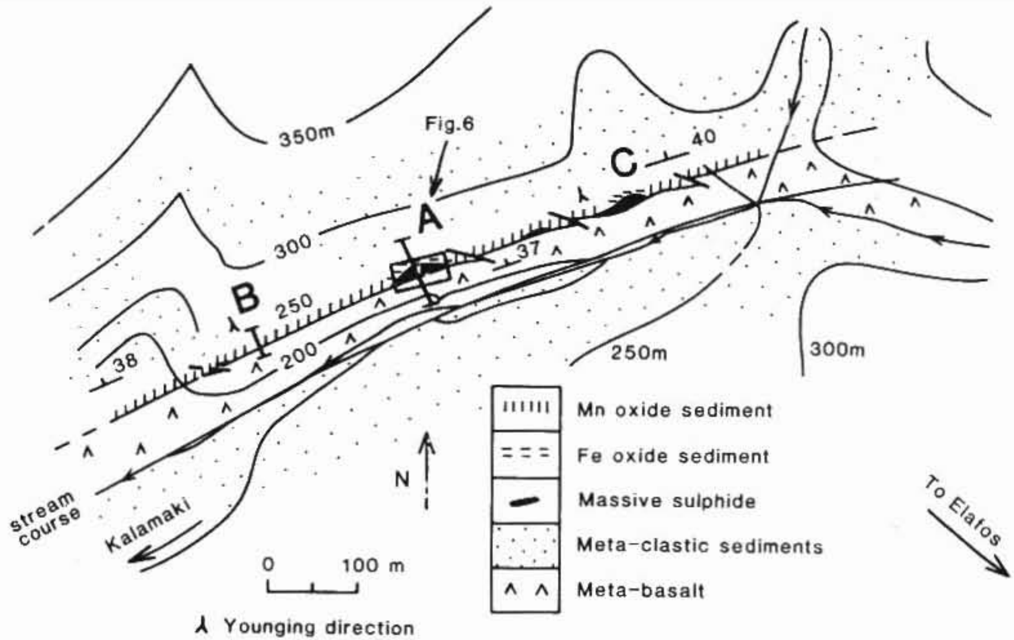

Fig 4 Sketch map of the sulphide mining area near Kalamaki. Note location of sketch maps and logs shown in Figs 5 and 7.

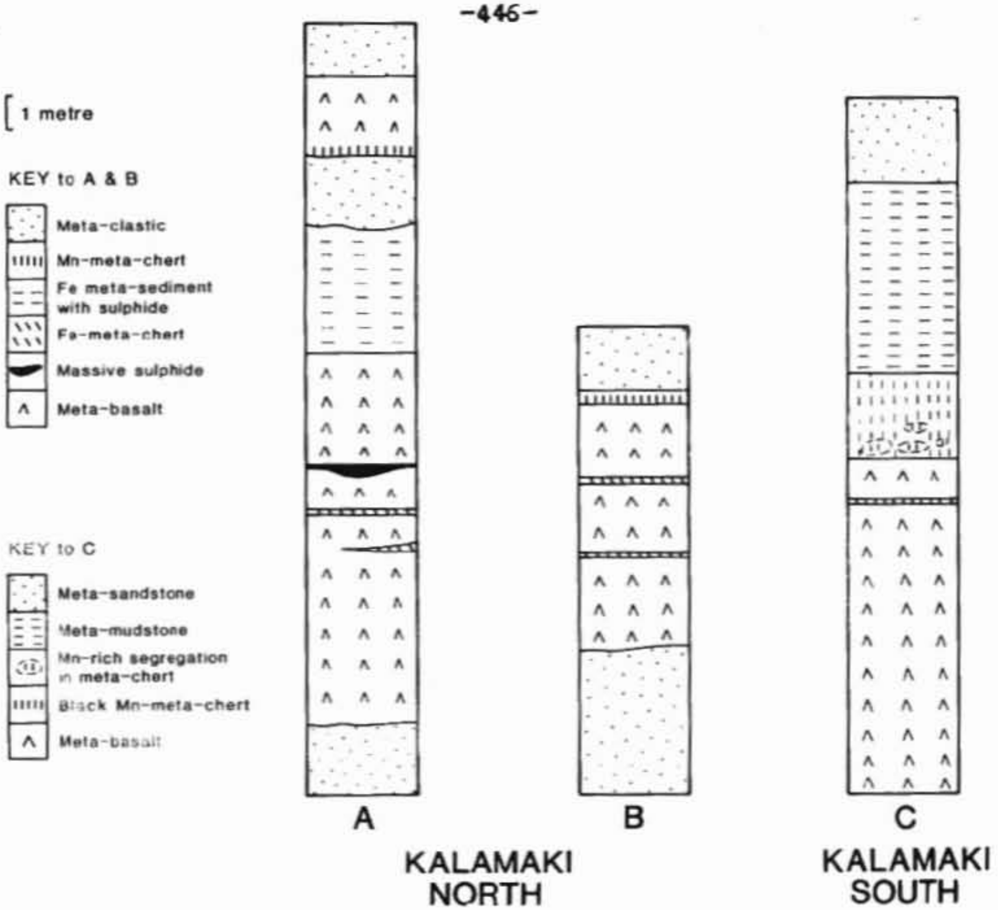

Fig 5 Logs of metalliferous deposits in the Kalamaki (former) mining area; See Fig 4 for locations.

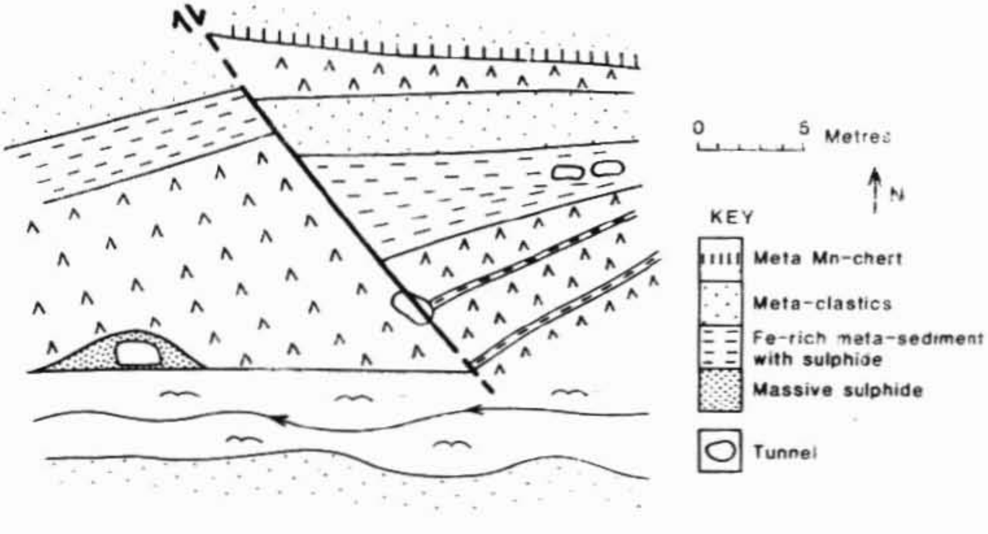

Fig 6 Field sketch of faulted sulphide and oxide-sediment in the (former) mining area.

Metalliferous meta-cherts, alternating with meta-lavas and meta-clastic sediments, are also well exposed in road cuttings from Kalamaki to Elafos (Fig 2). Meta-cherts, there structurally overlie a 10m thick unit of calc-schist and pink marble, exposed in a small quarry (200m SW of Elafos). Other marble intercalations, up to 50m thick, are present in the vicinity (Migiros and Vidakis, 1984). Amphibolites are locally rich in epidosite and contain rare pockets of disseminated sulphide. Layers of dark coloured meta-manganese-rich sediments are intercalated with the meta-volcanic and meta-sedimentary rocks. These Mn-rich layers vary from hard splintery, black meta-chert, to soft brown-weathering schist, and seams of chocolate brown, finely crystalline meta-sediment, <0.15m thick. The upper contacts of the cherts are sharp, while those of the meta-mudstones are more gradational. Individual layers can be traced laterally up to 12m in the road cuttings. The black cherts are associated with occasional thin layers of pale quartzite.

Mineralogy and Chemistry

The mineralogy of the Kalamaki deposits (Maratos, 1962, Migiros, 1979; Konti, 1984) is mainly coarsely crystalline pyrite, often replaced by chalcopyrite, as thin veinlets within pyrite. Very rarely chalcopyrite is replaced by bornite, and, in turn bornite by covellite. Sphalerite is also a major mineral and both chalcopyrite and pyrite are enclosed within many individual sphalerite crystals as replacement products.

Within the adjacent micaschists and amphibolites, magnetite is common, reaching 30% of the total mineralogy. Locally, the magnetite is associated with minor pyrite, chalcopyrite and bornite. Hematite and ilmenite are also common, often partly altered to magnetite, generally from the outside of crystals inwards.

Electron microprobe analysis of representative samples of pyrite indicated 46.59-53.84% Fe and 53.59-53.84% S, while chalcopyrite comprised 33.52-35.16% Cu, 29.64-30.70 Fe% and 34.29-36-52% S. The sphalerite has 0.36-1.82% Fe and 0.12-0.30% Cu (Konti, 1984).

Discussion

The crystalline basement of the Pelagonian Zone rifted in the Permo-Triassic (Mountrakis, 1984; Migiros, 1986; Katsikatsos et al., 1986). Successions of terrigenous clastics, minor carbonates, meta-basic extrusives and minor meta-cherts formed during rifting. The rift zone within the Pelagonian basement had stabilised by the Late Triassic and was transgressively overlain by shallow-water carbonates, interupted periodically by bauxite development. By the Late Triassic, the Pindos ocean was open to the west and the Vardar (Axios) ocean to the east (Smith, 1979; Robertson et al., 1991).

The sulphides and metalliferous oxide-sediments in the Kalamaki area relate to Permo-Triassic rifting, volcanism and terrigenous sedimentation within the Pelagonian Zone (Fig 7). The terrigenous sediments were shed into the rift zone and intercalated with mafic extrusives. The rift zone was later transgressed by a carbonate platform of Late Triassic-Jurassic age. Carbonate platforms are known to have transgressed rift basins elsewhere within the Pelagonian Zone (e.g. in Argolis; Clift and Robertson, 1990).

Sulphides were precipitated as small disseminations within the lavas, as small massive orebodies (within and above the lavas) and as disseminations within associated ferruginous oxide-sediments. The ferruginous and siliceous sediments above the massive sulphides are interpreted as hydrothermal deposits in the vicinity of high temperature vent systems. Red siliceous, oxidising sediments also accumulated on adjacent lavas. The sulphide and oxide-sediments in the mining area were overlain by lava flows and blanketed by a more laterally persistent layer of siliceous and manganiferous hydrothermal sediment. Numerous other manganiferous cherts and schists in the vicinity are likewise interpreted as hydrothermal precipitates.

In the Middle Jurassic, the Pindos ocean partly closed, with thrusting of ophiolites and related units onto the Pelagonian microcontinent. However, a remnant Pindos ocean basin survived into the Early Tertiary, before final suturing (Jones and

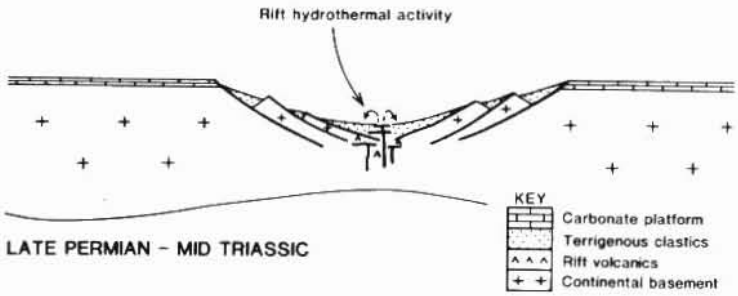

Fig 7 Sketch illustrating a rift setting for hydrothermal metalliferous sulphide and oxide deposition. See text for further explanation.

Robertson, 1991). Associated with Upper Jurassic-Lower Cretaceous ophiolite emplacement, the carbonate platform subsided to form a foredeep into which clastic sediments, melange, and ophiolitic slices (mainly serpentinite) were emplaced. Metalliferous oxide-sediments of hydrothermal origin are associated with meta-basalts which form blocks within the meta-clastic 'foredeep' succession (Robertson and Varnavas, 1992, Fig 2). These basalts and sediments are interpreted as vestiges of Mesozoic oceanic crust emplaced onto the Pelagonian Zone in the Late Jurassic-Early Cretaceous. Following a Late Cretaceous shallow-water carbonate transgression, the Vardar (Axios) ocean to the east finally closed in the Early Tertiary, with westward overthrusting of the Pelagonian Zone.

The first metamorphic event (low P and T) in the Eastern Thessaly area corresponds to the emplacement of ophiolites onto the Pelagonian microcontinent in Late Jurassic-Early Cretaceous time. The second event (high P) relates to Early Tertiary subduction of the Vardar (Axios) ocean basin. The third and final regional event (low P) corresponds to regional suturing of the Tethys ocean (Migiros, 1986; Katsikatsos et al., 1986).

Conclusions

Metamorphosed sediments of hydrothermal origin, exposed in the Pelagonian Zone comprise sulphide, silica-, Fe- and Mn-rich sediments, related to volcanism within a Permo-Triassic rift. The rift zone was dominated by terrigenous clastic sediments with surbordinate carbonates and chert and localised basic lava flows. The intra-continental rift was later depositionally overlain by a Jurassic carbonate platform, and subjected to several phases of deformation and regional metamorphism.

Acknowledgements

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