The Jurassic-Cretaceous orogenic event and its effects in the exploration of sulphide ores, Albanian ophiolites, Albania

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The Jurassic-Cretaceous orogenic event and its effects in the exploration of sulphide ores, Albanian ophiolites, Albania

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Key words: Albanian ophiolites, Jurassic-Cretaceous orogenic event, sulphide mineralization

ABSTRACT

Very detailed geological surveys carried out continuously over the past 30 years in searching of sulphide ores, bring new constraints, especially concerning the geological setting of Albanian ophiolites. The study area, located in central northern Albania, represents the most complete and preserved section of western and eastern type Albanian ophiolites.

Relying on the existence of a stack of thrust sheets, internally highly disrupted, it can be shown that the westward ophiolite emplacement took place during the Late Jurassic-Early Cretaceous onto a Late Triassic-Liassic carbonate platform overlain by mélange. This orogenic event was followed by two additional events: westward thrusting of the carbonate platform onto Early Cretaceous flysch-like deposits and the last one onto the Eocene flysch during Alpine movements.

The structural framework of the Jurassic-Cretaceous orogenic event, is used successfully in exploration of sulphide ores, whilst the evidence of two additional orogenic events brings new constraints, important not only in a theoretical point of view but also in a practical one.

RESUME

Des études géologiques très détaillées et continues pendant ces dernières trente ans à la recherche de minerais de sulfure, apportent de nouvelles contraintes concernant spécialement la mise en place des ophiolites albanaises. La région étudiée, située en Albanie nord-centrale, présente la coupe la plus complète et la mieux préservée des ophiolites albanaises de type occidental et oriental.

Sur la base de l'existence d'une série de chevauchements, ayant subi de fortes déformations internes, on peut montrer que le chevauchement vers l'ouest des ophiolites s'est fait, au cours du Jurassique supérieur-Crétacé inférieur, sur une plate-forme carbonatée triasique-liasique recouverte par une zone de mélange. Cet événement orogénique a été suivi par deux autres événements : le chevauchement vers l'ouest de la plate- forme carbonatée sur une série flyschoide du Crétacé inférieur puis, plus tard, sur le flysch éocène pendant les mouvements alpins.

Le cadre structural de l'événement orogénique jurassique-crétacé est utilisé avec succès pour l'exploration du minerais de sulfure, alors que la présence de deux phases orogéniques supplémentaires apporte de nouvelles contraintes, non seulement d'un point de vue théorique mais aussi pratique.

Introduction

Albanian ophiolites, extending over 4 000 km^2 or 1/7 of Albania's territory, belong to the SSE trending Dinaric mountainous system (Nowack 1929) and link Dinaric ophiolites with Hellenic ophiolites (Aubouin & Ndojaj, 1964).

Albanian ophiolites represent one of the most complete and coherent sequences among the Mediterranean ophiolites and are constituted by NNW-SSE trending sub-parallel belts, the western ophiolite belt and the eastern ophiolite belt (Shallo et al. 1985; Beccaluva et al. 1994).

Questions that have led to many controversies were 1) autochthonous vs. allochthonous character of the ophiolites, 2) the timing of their emplacement and the relationships with the external zone (e.g. Pindos zone origin, Robertson & Shallo 2000), 3) the age of the volcanic sequences and especially of the so-called "heterogeneous coloured mélange".

Early views have been that *the serpentine zone (Mirdita nappe)* is totally exotic in Albania and the *serpentine mass* was overthrusted onto Middle-Late Eocene flyschs of the Cukali zone (Nowack1929; Aubouin & Ndojaj 1964) or regarded as overthrusted upon Late Cretaceous-Early Paleocene lower sub-stage (Shatski et al. 1962).

Later on in the Albanian geological and tectonic maps of Albania (ISPGJ-IGJN* 1982, 1983; ISPGJ-INGJ-FGJM** 1985) and according to most of the authors in Albania, the idea that the ophiolites are autochthonous, was advanced considering vertical tectonics drive all deformation.

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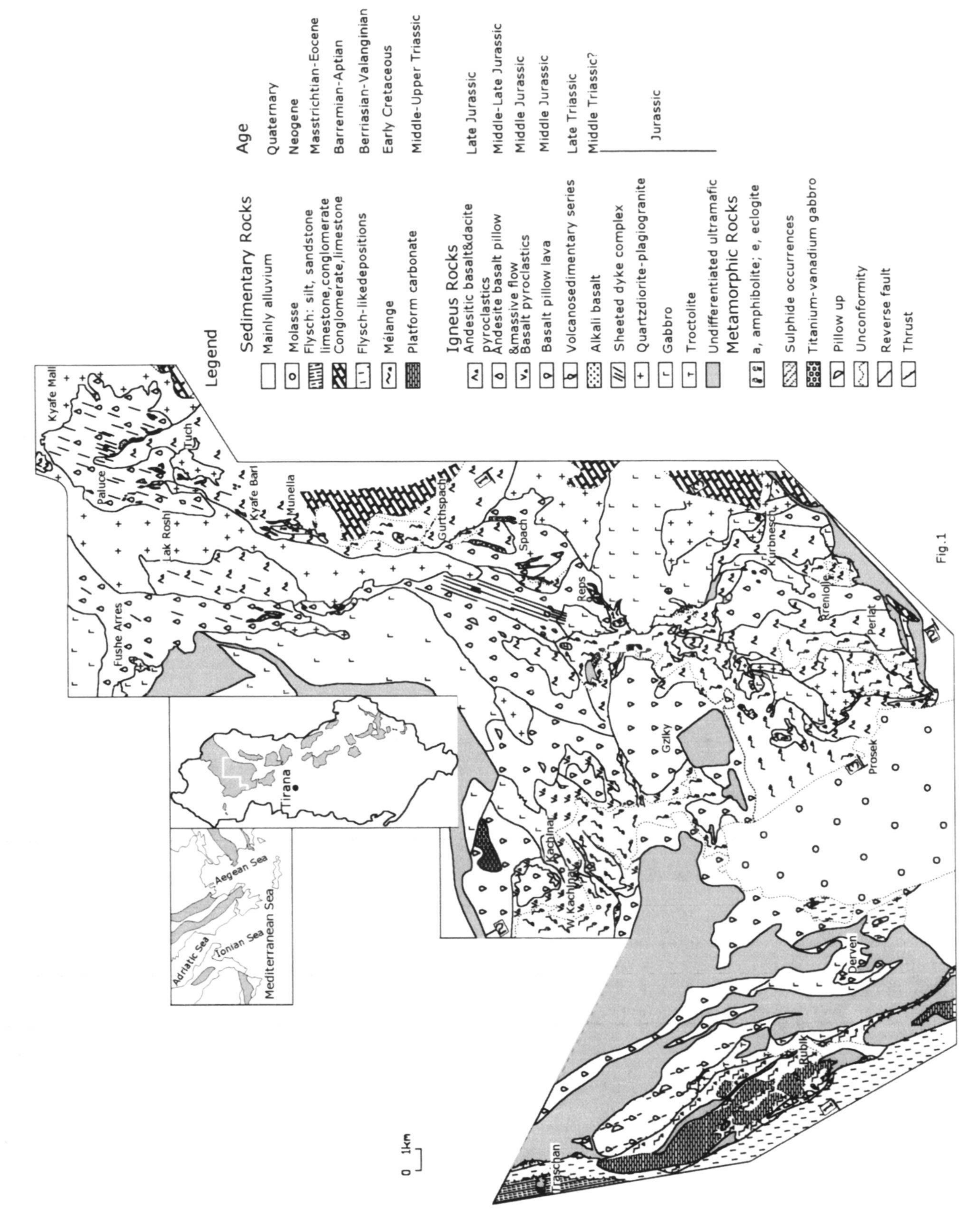

Fig. 1. Simplified geological map of central northern ophiolites with sulphide occurrences. Inset: Location of Albanian ophiolites in the Mediterranean realm and study area within the Albanian ophiolites.

The emplacement of Albanian ophiolites constrained by Kimmeridgian-Tithonian depositions (ISPGJ-IGJN, 1982, 1983; ISPGJ-ING-FGJM 1985; Shallo et al. 1985) and due to Jurassic-Cretaceous orogenesis was regarded as resulting from a limited obduction and a fragmentary uplifting (Shallo 1994).

Based on the existence of a stack of thrust sheets in front and inside the ophiolites, the opinion of an overall westward ophiolite overthrusting, internally disrupted during Late Jurassic-Early Cretaceous orogenesis, and not after Eocene times, was expressed (Hoxha et al. 1988; Hoxha, 1990, 1992, 1995).

In the western part of the ophiolites is distinguished the Rubiku unit (Late Jurassic volcanosedimentary series with a Triassic-Jurassic carbonate basement) in front of the Mirdita ophiolite nappe, overthrusted on Late Jurassic-Early Cretaceous flysch.

Recently, for the Mirdita region, in North Albania, views that the ophiolites and associated sedimentary sequence were affected by a Middle Jurassic-Early Cretaceous deformation during their obduction, followed by the emplacement of the oceanic slabs onto the continental margin, with inverse metamorphism of the amphibolitic sole, were also expressed (Çollaku & Cadet 1991; Bortolotti et al. 1996).

In a regional context ophiolites-mélange relationships in the Pindos mountains and central and northern Euboea (SE continuation of Albanian ophiolites in Greece) is as follows: Late Middle Jurassic (ca. 165 Ma) ophiolite underlain by Middle Jurassic amphibolite-greenschist sole are structurally underlain by unmetamorphosed units of Middle Triassic-Late Jurassic Avdella mélange (Jones et al. 1991) or, ophiolite underlain by Late Early Jurassic amphibolite-greenschist sole, are overthrusted onto the Pagondas mélange which, in turn, is underlain by Late Jurassic limestone (Robertson 1991). The westward emplacement of these ophiolitic nappes onto the marginal units of the Pelagonian domain was recently re-emphasized by De Bono (1998).

According to Pamic (1999) in the Dinarides the first ophiolite obduction took place in Late Jurassic/Early Cretaceous time. In a larger context, the Late Jurassic-Early Cretaceous time is regarded as the time of Vardar obduction/collision (Stampfli 2000; Stampfli et al. 2001) following plate tectonic rearrangement at that time.

The age of both volcano-sedimentary and volcanic rocks, were considered to be Late Jurassic (ISPGJ-IGJN. 1982; ISPGJ-IGJN.1983; Kodra et al.1991) but based on radiolarian biostratigraphy, this age extends from Triassic to Jurassic (Kelliçi 1990; Marcucci et al.1994 and references therein; Hoxha 1995).

In the study area, representing the best preserved one, an enormous amount of data obtained by regional and prospect scale drilling programs carried out by Rubiku and Puka Geological enterprises and CGGE, Tirana, Albania, from the late 1960's through the 1990's, allow the westwards ophiolite emplacement, during Late Jurassic-Early Cretaceous orogenic event, to be clarified and especially its effects on exploration of sulphide ores.

Geology and Metallogeny Outline

The study area, located in the central northern part of Albania, consists mainly of ophiolites and sedimentary rocks affected by thrust and reverse and normal faults (Fig. 1).

From west to east the following sequences are found: the Maastrichtian-Eocene flysch, the Middle-Late Triassic platform carbonates, the western type Early Cretaceous mélange and flysch, the western type Triassic-Jurassic ophiolites, the eastern type Early Cretaceous mélange, the eastern type Jurassic ophiolites, the Barremian-Aptian platform as well as the Neogene molasses and Quaternary deposits.

The Maastrichtian-Eocene flysch of Krasta zone (analogous of the Budva zone in the Dinarides and the Pindos zone in the Hellenides) - Crops out at the western part of the Late Jurassic-Early Cretaceous flysch-like deposits. Its uppermost parts belong to the Eocene (ISPGJ-IGJN 1983). In the study area, it consists mainly of intercalation of argillite, sandstone and marl and more rarely limestones and conglomerates. *Globigerina tricolunides, Globorotalia angulata, Globigerina* spp. and *Globorotalia* belonging to the Middle Paleocene have been found in the limestone. In biomicritic marls, overpopulated by planktonic forms, are also found *Chondrites* up to 7 centimeters long, considered to be Late Cretaceous in age.

The Middle-Late Triassic platform carbonates are located at the western and eastern peripheral parts of the studied ophiolites, on the western side. These rocks, although disrupted, outcrop from the highest peak of the area (Vela, 1170 m above sea level) down to about 100 m above sea level (Fandi River), with an apparent width from ten and hundred meters to 2 km and much more (outside study area). They are considered as "carbonate periphery" of ophiolites (Shallo et al. 1985) or "continental margin of the Adria (= Apulia) plate" (Bortolotti et al. 1996), or in a more precise way they are the lateral equivalent of the Pelagonian marginal units of Greece (Baumgartner 1985; De Bono et al. in press). They consist of micritic marls and stromatolitic limestones with *Involutina* sp. and Ostracoda of Late Triassic (Norian-Rhaetian)-Early Liassic age.

The western type mélange

The heterogeneous colored mélange – The uppermost part of the western and eastern volcanic ophiolite is overlain by a remarkable deposition, a "block-in-matrix-type" mélange set in an argillite matrix, considered to be Late Jurassic-Early Cretaceous in age, throughout the study area (ISPGJ-IGJN 1982; Shallo et al.1985; Shallo 1994).

In the Rubiku area, the apparent uppermost part, argillaceous-siliceous shales and chert succession (deep sea sediments) of the volcano-sedimentary series as well as Late Triassic platform carbonates followed by a few meters to 10 meters of argillaceous-siliceous depositions (e.g.Vela area), are overlain by mélange, consisting of sandstone, basic volcanic, volcanic hosted massive sulphide ores (e.g. Vela area), metamor-

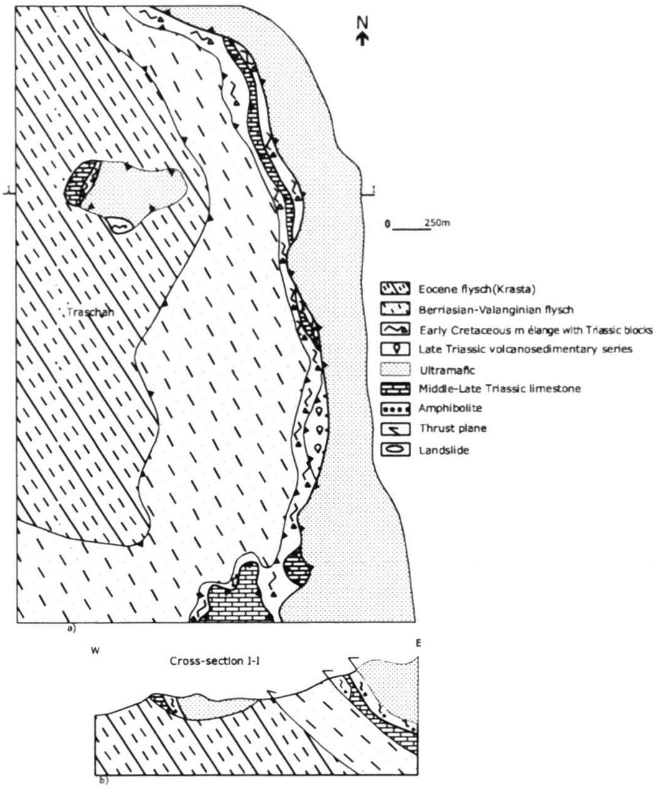

Fig. 2. Geological sketch (a) and cross-section (b) of northern ophiolites, Traschan area, showing Jurassic-Cretaceous and Eocene thrusting events.

phic ultramafics (ophicalcite), Triassic limestone blocks and clasts, ranging from about 100 m to tens of meters and meter scale. Based on the finding of *Calpionellidae* its age is considered to be Late Jurassic-Early Cretaceous (ISPGJ-IGJN 1982; Shallo 1994) or Early Cretaceous (Hoxha 1990). From the age of the youngest Late Jurassic blocks comprising the mélange its age can be considered as Early Cretaceous. Its thickness is about 350 m.

In the Kachinar-Gziky area, the top part of Late Bajocian-Early Callovian manganiferous argillitic-siliceous series with chert (deep sea sediments) at the base, as well as the volcanic successions, are overlain by the mélange consisting of turbidites, Jurassic volcanics, Triassic limestone, chert, metamorphic ultramafics (high grade serpentinized harzburgite mixed up with kaolinite-clay, chromium grains, magnetite, hematite and chlorite, so-called ophicalcite), from about hundred meters to tens of meters and meters of thickness. This mélange could represent a shallow water, Early Cretaceous post obduction deposits.

Radiolarian assemblages found in the cherts at the base, indicate Late Bathonian-Early Callovian ages (Marcucci et al. 1994; Prela 2000). The drill proved thickness of the mélange at Kachinar area is about 350 m.

The western type flysch

Late Jurassic-Early Cretaceous (Tithonian-Berriasian) flysch-like deposits – crop out inside and outside the ophiolites, at the western part of the mélange-limestone association.

In the Derven area, relying on findings of the *Crassicollaria* biozone at the base of a 200 m to 300 m thick succession of flysch-like deposits overlying transgressively the ophiolites, the succession was dated as Tithonian-Berriasian (Gjata et al. 1989).

In the western part of the ophiolite-mélange-limestone association, flysch-like depositions are represented by a highly folded northwest trending formation, composed by marl, limestone, and sandstone intercalations. *Calpionellidae* and *Calpionellopsis oblonga* belonging to Late Berriasian-Early Valanginian age were found whereas at Traschan area (Fig. 2) *Saccocoma*, *Cadosina* sp., *Globochaete alpina* and *Calpionella alpina* dated the Tithonian-Berriasian (Hoxha 1990). These deposits represent a syn- to post-obduction deposition and seem to be equivalent with the lower Cretaceous Bosnian and Beotian (Greece) flysch belts.

The western type Triassic-Jurassic ophiolites

Western belt ophiolite – It consists of high-Ti tholeiites within volcano-sedimentary series in the western peripheric parts and a volcanic sequence in the western part (Fig. 3), associated with lherzolite mantle suite and minor harzburgite and dunite tectonite and ultramafic and mafic cumulates (Shallo et al. 1985; Beccaluva et al. 1994).

Westernmost part ophiolites of the Rubik-Vela area – The apparent lithological-stratigraphical sections comprise volcano-sedimentary series topped by hematitic radiolarian chert and underlain by intrusive rocks. It must be emphasized that ultramafic rocks underlain volcano-sedimentary rocks (e.g. Vela area, Fig. 1) and give "wedges" both in the volcano-sedimentary rocks (e.g.Rubik-Vela area) and volcanics of the Derveni area (ISPGJ-IGJN 1982; Hoxha 1990).

The volcano-sedimentary series (Fig. 3a) comprises high-Ti tholeiitic pillow lavas of MORB affinity (Shallo et al. 1985; Beccaluva et al. 1994), with scarce intercalation of argillitic-siliceous-sericitic or sericitic-siliceous-carbonated shales and slates, and infrequently, hematitic radiolarian chert, varying in thickness from 2 m up to 5 m. The series is about 600 m thick, northwest trending with a dip of pillows and sedimentary intercalation of 50° to 80° to the NE, and 80° to 85° to the SW at the Rubiku sulphide deposit area.

The radiolarian assemblages (*Capnodoce anapetas* De Wever, *Capnuchosphaera tricornis* De Wever, *C. deweveri* Kozur et Mostler, *C. triassica*, *C.* sp., *Sarla* cf. *hadrecaena* (De Wever), *Spongostulus carnicus* Kozur et Mostler, *Triassocampe* sp., *Canoptum* sp., *Xiphoteca?* sp., *Corum perfectum* Blome group*) of the chert specimens, intercalated with massive sulphide ores, indicate a Middle-Late Carnian age, possibly including the Early Norian (Hoxha 1995).

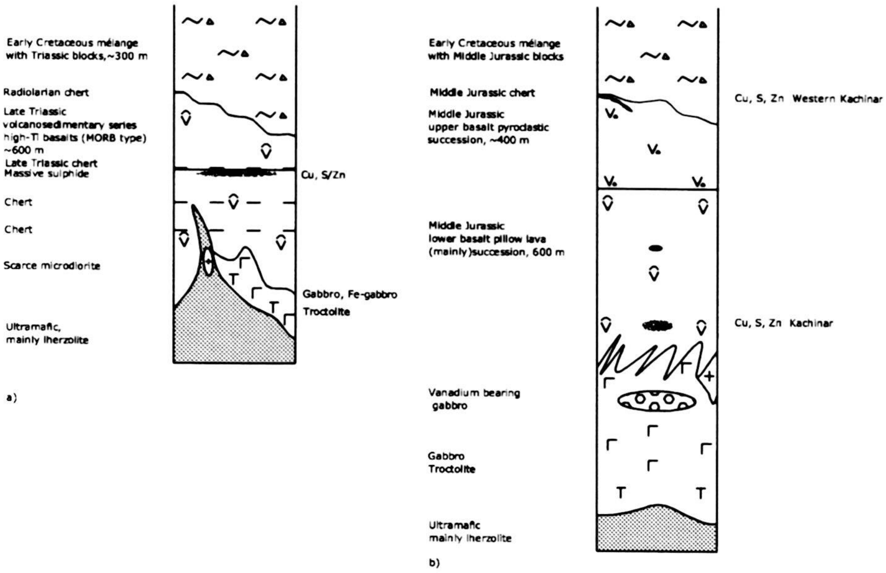

Fig. 3. Generalized lithological-stratigraphical section of the Western ophiolites. (a) Westernmost ophiolites of Rubiku area. (b) Western ophiolites of Kachinar-Gziky area.

The presence of Triassic radiolarian assemblages in the volcano-sedimentary series and radiolarian cherts of Rubiku have been emphasized previously by Kelliçi (1990) and Marcucci et al. (1994).

At Rubiku and its vicinities, basaltic pillow lavas are overlain by agglomerate and argillitic-siliceous shales topped by yellow-reddish hematitic manganiferous radiolarian chert.

Volcano-sedimentary series are underlain by gabbro, troctolite, ferro-gabbro, very scarce minor microdiorite (Rubik) as well as ultramafic injections and "wedges", ranging in thickness from a few meters up to 100 m (Derven sulphide deposit).

Altered ultramafic rocks, serpentinites as well as greenschist-amphibolite facies represent metamorphic rocks.

It must be emphasized that all western type ultramafics are significantly serpentinised and in many cases changed to serpentinites.

The greenschist-amphibolite facies is widespread in the western ophiolite belt; it is located along the volcano-sedimentary-ultramafic contact with thickness from a few meters up to 120 m, with 2 to 4 m of amphibolites (Fig. 4). The metamorphic sole is supposed to have been formed due to a westward overall regional obduction in a context of intraoceanic subduction (Hoxha 1995). $^{39}Ar/^{40}Ar$ radiometric dating of metamorphic sole specimens taken in the northwestern part (not far away form the study area) carried out in the Montpellier University laboratory indicate a Bajocian-Bathonian age (Dimo 1997).

In the southern continuation of the greenschist-amphibolite facies, in lherzolite breccias, in the vicinity of the Derveni sulphide deposit are found *eclogite of griquatite* type (Gjata 1990). At Rubiku, volcanic hosting massive pyrite-chalcopyrite ores are in close association with yellow-reddish radiolarian chert.

Western part ophiolite of Gziky-Kachinar area - The lithological-stratigraphical section consists of volcanic sequence overlain by Middle Jurassic hematitic shales and is underlain by gabbro, scarce plagiogranite and ultramafic rocks (Fig. 3b).

The volcanic sequence consists of an Upper basaltic pyroclastic succession averaging 400 m and a Lower basaltic pillows (mainly) and massive succession, about 600 m thick.

The radiolarian assemblages of the chert specimens taken at the uppermost part of Gziky and West Kachinar deposit volcanics, indicate a Late Bathonian-Early Callovian age (Marcucci et al. 1994; Prela 2000).

Volcanic hosted massive and stockwork sulphide, mainly pyrite-chalcopyrite and lesser sphalerite, affected by hydrothermal alteration, are found in the lowermost part of the pillow succession (Kachinar) and in the uppermost part of the pyroclastic succession (Western Kachinar).

The enormous resources of vanadium-bearing titaniferous gabbros of the Kachinar area located in their uppermost part, at the base of volcanics, averaging TiO_2 7%; Fe_2O_3 17% and V_2O_5 about 0.2%, should be noted.

The eastern type mélange

In the Kyafe Mali-Reps area the mélange consists of the same rocks as in the Kachinar-Gziky area as well as huge limestone blocks, sub-alkali volcanics (trachyandesite, trachybasalt, not components of ophiolites), occasionally mixed up, and serpentine blocks, along a 1.7-kilometer long zone. It should be noted that olistoliths of limestone, from tens of meters to meter scale are found all along the front of the Kurbnesch-Reps thrust (Fig. 1).

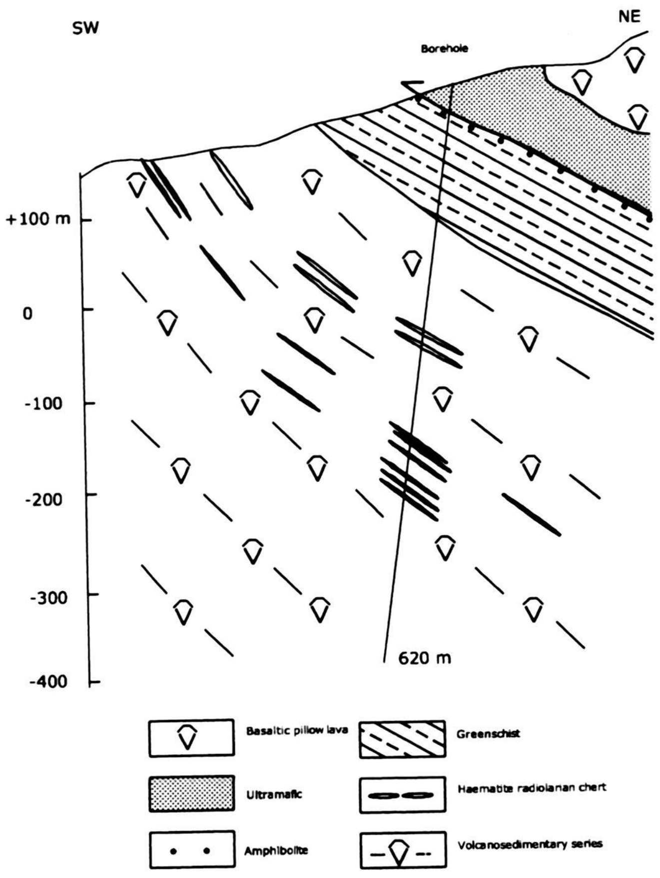

Fig. 4. Cross-Section through the ultramafic-greenschist-amphibolite sole in the volcanosedimentary series, Vela area.

In the Reps area limestones are rich in fauna: *Ptychites* sp., *Sturia* ex gr. *sansonorini* Mays, *Gymnites* ex.gr. *incultus* (Beyrich) belonging to the Anisian. In biomicritic marl and phosphatic olistolithic blocks 1 to 3 m in size are found: Pelagic Bivalves, *Nodosaridae, Frondicularia* sp., Ostracoda, *Ophthalmidiinae, Ophthalmidium* sp., *Ophthalmidium* cf. *carinatum* of pelagic and neritic facies, ranging in age from Ladinian to Late Triassic, possibly Liassic. The thickness of the mélange based on drillings is about 250 m.

In the northern most part of the study area, near the Munella deposit, a block of granite 2 × 3 m in size was found within the mélange.

In the Perlat-Kurbnesch area the top part of the volcanic sequence is overlain normally by Late Middle Jurassic argillaceous-siliceous shales with radiolarian chert succession (deep sea sediments) which in turn, is overlain by a mélange, consisting of Jurassic and Triassic blocks: sandstone, volcanics, very scarce limestone, conglomerate and very rarely sulphide clasts (shallow water deposits). The mélange is a post obduction deposit and its age can be dated as Early Cretaceous. Its drill proved thickness is about 200 m.

The eastern type Jurassic ophiolites

The *Eastern belt ophiolite* – This belt is characterized by low-Ti tholeiites of basalt-andesite and andesite-dacite (rhyolite) series underlain by sheeted dyke complex, and quartzdiorite-plagiogranite and gabbros (ISPGJ-IGJN 1982; Shallo et al. 1985; Beccaluva et al.1994) extending from Kyafe Mali in the north to Perlati in the south, offering the best prospects regarding copper-pyrite-zinc and precious metals mineralizations.

Due to some differences between the northern and the southern parts they will be described separately.

Northern Kyafe Mali-Spach area – It comprises two volcanic successions the lower and the upper one (Fig. 5a).

The Middle-Late Jurassic lower andesite-basalt pillow lava succession - It consists mainly of pillows (spilite) and occasional massive flows, about 1 000 m thick. The pillows have ellipsoidal or spherical, generally from 0.3 m to 2 m in size. They have glassy rim and quenched glass filling interstitial cavities. The inside shows an amygdaloidal texture, with elongated vesicles, ranging in size from a few millimeters to 20 millimeters, filled with secondary minerals as carbonate, quartz, zeolite and rarely pyrite and chalcopyrite.

Dykes, extending over more than 30 km, from Reps to Kyaf Mali, several centimeters to 2–3 m thick, consist of dolerite, microdiorite, andesite, dacite or rhyodacite and rare boninite dykes (Shallo 1994; Beccaluva et al. 1994).

The Late Jurassic upper andesitic basalt and dacite pyroclastic succession, about 700 m thick, consists mainly of pyroclastic rocks and occasionally pillows. This succession is followed by a 1 meter to 10 m thick manganese-bearing hematitic radiolarian chert sequence.

The radiolarian assemblages taken in the chert at the uppermost part of Kyafe Bari volcanics indicate Late Callovian to Early Oxfordian age (Marcucci et al. 1994; Prela 2 000).

Sulphide mineralization

The most important sulphide deposits discovered so far as well as the greatest potential resources are hosted especially along the northeast-trending, 25 km long Kyafe Mali- Reps belt (Bezhani et al. 1985; ISPGJ-FGJM 1989; Hoxha, 1995; Avxhiu & Hoxha 1998), exhibiting significant vertical and longitudinal continuity, and a distinct sulphide vertical zoning.

Stockwork and disseminated chalcopyrite mineralization overlain by massive pyrite ores occur in the lower basalt andesite (spilite) pillow lavas and sheeted dyke complex (e.g. Spach deposit with more than 10 million tons of ores, half of them already depleted). At and along the contact between pillow lavas and the upper volcanic succession are hosted the main reserves of chalcopyrite-pyrite-sphalerite mineralization with precious metals (e.g. Kyafe Bari, Gurthspach and Munella deposits, with more than 15 million tons of drill-proved ore reserve).

In the middle and upper part of the pyroclastic succession are found disseminated sphalerite-chalcopyrite/pyrite mineral-

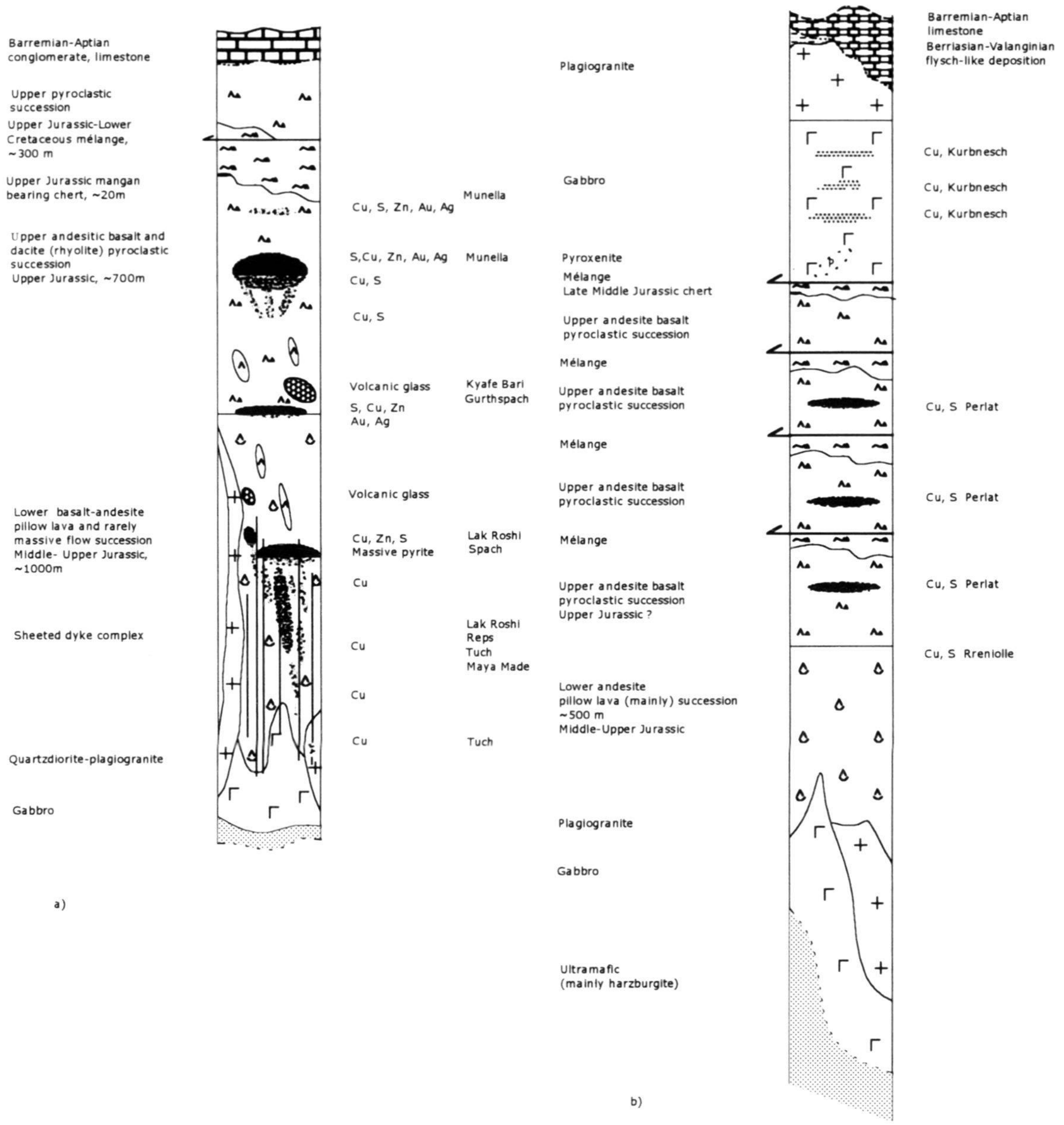

Fig. 5. Generalized lithological-stratigraphical sections of the eastern ophiolites. (a) Northeastern section, Spach-Munella area. (b) Tectonostratigraphy of southeastern, Perlat-Kurbnesch area.

ization, poor in precious metals. The chalcopyrite mineralization of Tuch, Reps, and Maya Made occur at the lowermost part of the lower basalt andesite succession. Copper mineralization occurs also in plagiogranite.

Southern Perlat-Kurbnesch area

The rocks of this area are internally disrupted, due to intense thrust tectonics. Tectono-stratigraphy of the area (Fig. 5b) consists of a Middle-Late Jurassic lower andesite basalt pillow lava succession, about 500 m thick and Late Jurassic upper andesite basalt pyroclastic succession, about 300 m thick overlain by an argillaceous-siliceous succession with radiolarian chert. The radiolarian assemblages indicate an Early Tithonian (Hoxha 1995) or late Middle Jurassic age (Prela 2 000).

Sulphide mineralization – In the lower part of the pillow lava succession only very little pyrite, chalcopyrite, sphalerite mineralizations were found so far, whereas in the upper pyroclastic succession about 4 million tons of chalcopyrite-pyrite type were found by drilling. The ore bodies have a northeast

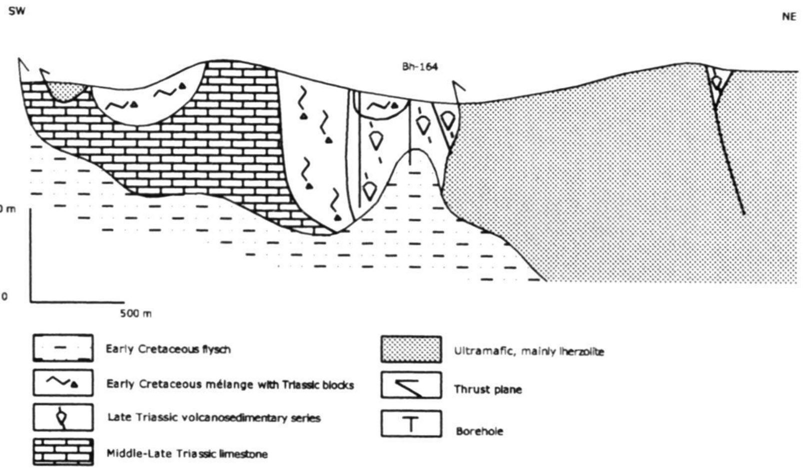

Fig. 6. Cross-section of Rubiku area, showing thrusting of Upper Triassic limestone-volcanosedimentary and ultramafic rock association onto the Jurassic-Cretaceous flysch.

strike; they are very restricted in width, about 100 m, with real possibilities for extension along strike (Leka et al.1995).

In the gabbroid rocks, within an about 250 m hydrothermaly altered zone (already depleted), more than 3.5 million tons of phyrrotite-chalcopyrite-quartz were found in the Kurbnesch deposit (ISPGJ-FGJM 1989).

Late Jurassic-Early Cretaceous (Tithonian-Berriasian) flysch-like depositions

In the Kurbnesch area, the plagiogranite is overlain by a horizon of carbonated microbreccia (volcanic, ultramafic and gabbro grains), about 5 m thick, followed by a succession of flysch-like deposition, about 40 m thick, comprising marl, sandstone, biomicritic limestone and thin limestone layers. Finding of *Tintinnidae, Calpionella alpina, Tintinnopsella oblonga, Tintinopsella carpathica* dated this sequence as Berriasian-Valanginian. According to Shallo et al. (1981) this sequence would postdate the emplacement of the mélanges, whereas the following deposits are clearly post obduction, they consist of:

Barremian-Aptian limestones – The ophiolite section, mélanges and Berriasian-Valanginian flysch-like depositions, are overlain transgressively by Barremian-Aptian deposits.

According to Shallo et al. (1981), Berriasian-Valanginian flysch-like deposits are overlain conformably by Hauterivian-Aptian neritic carbonates whereas Peza et al. (1983) accept a break in deposition, during the Hauterivian, followed by an overall Barremian conglomerate-platform carbonate transgression on ultramafic, gabbro and plagiogranite.

In the Gurthspach area, boreholes have encountered neritic limestone of *coral-algae* facies with *Orbitolinae* and *Trocholina* belonging to the Barremian-Aptian overlying mélange and volcanics (Hoxha et al. 1988)

Neogene molasses consist of clay, sand and conglomerate transgressively overlying the whole ophiolite section, mélange and flysch-like deposits.

Quaternary deposits, consists mainly of rivers alluvium and colluvium sediments.

Discussion

Ophiolite emplacement onto the Late Triassic-Liassic platform carbonate is preceded by distinct events.

1. an intra-oceanic convergence with an inferred eastward dipping subduction zone, around Early Jurassic-Early Middle Jurassic time, with the amphibolite-greenschist metamorphic sole overprint, accompanied by
2. an accretionary complex (mélanges) with detached blocks from the descending slab of MORB type basalts, hosting massive sulphides, along a northwest trending, 11 km long disturbed zone.

The above intra-oceanic orogenic events are followed by syn- to post-obduction (thrusting) Late Jurassic-Early Cretaceous flysch-like deposits in front of the overriding prism and in basins inside the ophiolitic complex.

In the southern part of the Rubik massive copper deposit, borehole B-164 was drilled about 2 km inside the front of the Rubik thrust sheets, and after intersecting 300 m of volcano-sedimentary series, it passed for about 150 m into a very metamorphosed carbonate-argillitic slaty sequence, the same as at the front of the thrust (Fig. 6).

In the northwestern Traschan area, Jurassic-Cretaceous and Eocene orogenic events are visible (Fig. 2).

In conclusion, the tectonostratigraphy of the western area consists of three thrust sheets, from top to bottom:

- The sheet of upper Triassic to lower Jurassic volcano-sedimentary series overlain by mélange with a metamorphic overprint (probably Middle Jurassic) and underlain by ultramafics.
- The sheet of Triassic platform carbonate (Apulia s.l. – Pelagonia) overlain by Early Cretaceous mélange with Triassic blocks.
- The sheet of Late Jurassic-Early Cretaceous flysch.

Eastwards, within a 12 km wide zone extending from the Kachinar sulphide deposit to the Perlat sulphide deposit, a

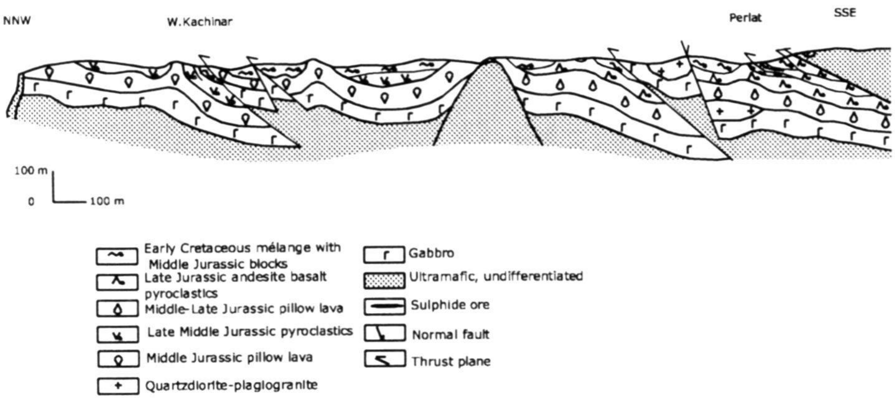

Fig. 7. Cross-section 2–2, Kachinar-Perlat area.

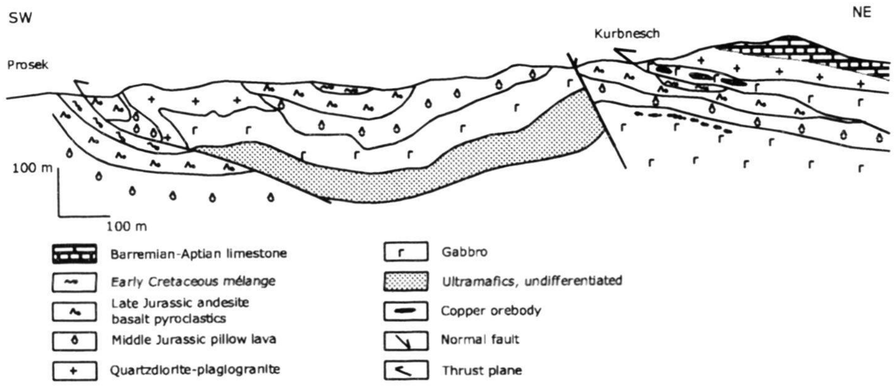

Fig. 8. Cross-section 3–3, Prosek-Kurbnesch area.

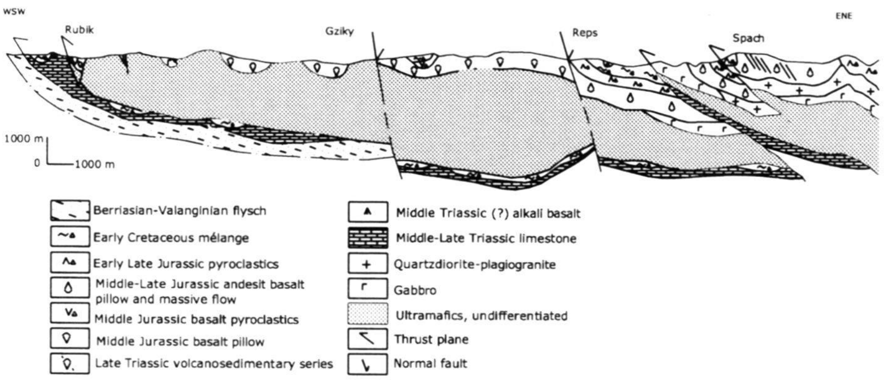

Fig. 9. Cross-section 1–1, Rubik-Spach area.

stack of thrust sheets represented by a complete ophiolitic section (including ultramafic and gabbro) is found (Fig. 7) whilst at Prosek-Kurbnesch area volcanites and gabbros are directly thrusted onto the mélange (Fig. 8).

It must be emphasized that the biggest thrust sheet of the study area is the Perlat deposit-Kurbnesch deposit-Reps thrust, outcropping along a 20 km zone and exposing a complete ophiolitic section (Fig. 1). In the front of the thrust sheet, beginning from about 5 km northwest of the Kurbnesch deposit up to the Reps area meter-scale to tens of meters limestone blocks are found in the mélange and at Repsi a Middle-Late Triassic subalkali volcanic limestone-serpentine mélange is found. It must be stressed that Middle-Late Triassic limestones blocks are much smaller in size in comparison with Triassic platform carbonate slices at the western front of the ophiolite thrust sheets. So, the subalkali volcanites and limestones

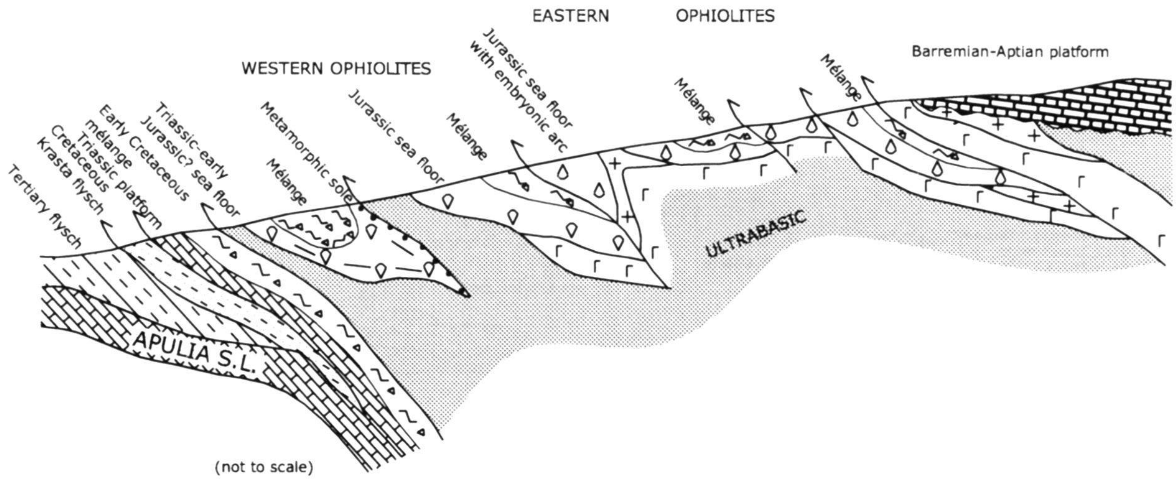

Fig. 10. Geodynamic scheme of Albanian ophiolites evolution.

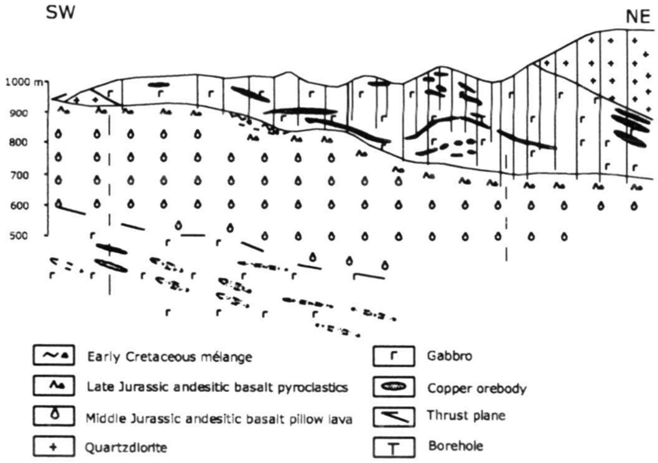

Fig. 11. Thrust sheet of Kurbnesh copper deposit.

are exotic in the mélange, and can be considered as detached by the ophiolite overthrusting, and incorporated into the accretionary mélange during the Late Jurassic-Early Cretaceous orogenic event. They can be regarded as former seamounts resting on the descending oceanic slab (Meliata-Maliac ocean of de Bono 1998, de Bono et al. in press, Stampfli et al. 2001), whereas the obducted ophiolite-embryonic arc series would represent the Vardar back-arc ocean.

In a cross section from the western through the eastern parts of the study area, overthrusting of the western and the eastern type ophiolites onto Late Triassic limestones overlain by Early Cretaceous mélange is quite clear, they in turn, are underthrusted by Early Cretaceous flysch-like deposits (Fig. 9). The overthrusting of basalts onto ultramafics (lherzolite and associated cumulates) proposed by previous authors (Bortolotti et al., 1996) seems unreliable.

Gravity data indicate a maximum ophiolite thickness of about 5 km at Gziky with a bilateral gradual decreasing, and about 2.5 km ophiolite thickness above the detached blocks area (Bushati & Dema 1988).

Based on the above, a scheme of Albanian ophiolites distribution is presented in Fig. 10.

Effects of Jurassic-Cretaceous orogenic event in exploration of sulphide ores

Thrust tectonic, as a tool for exploration of sulphide ores, was applied since the last decade (Hoxha et al. 1988), almost all sulphide deposits of Albanian ophiolites are affected by the above mentioned thrusting events.

As shown on the map (Fig. 1), the northeast trending, about 30 km long Kyafe Bari-Perlat belt, hosts the principal sulphide deposits discovered so far as well as the greatest potential resource.

The Munella deposit, the biggest discovered so far (more than 10 million tons of copper-zinc-pyrite-gold-silver ores) and the Spach one (with more than 7 million tons depleted ores) imply exploring beneath the thrust sheets. In the southern part of the Gurthspach deposit, boreholes have encountered massive ores beneath the thrust sheet.

The Kurbnesch and Perlat deposits are the most significant ones, regarding the effects of thrust tectonics and its use as a tool in exploration. At Kurbnesch, copper deposit hosted by gabbros, boreholes have encountered mélange below 450 m to 500 m of sulphide bearing gabbros, proving an horizontal displacement of more than 7 km and not a high angle reverse fault, as considered previously. An additional 680 m deep

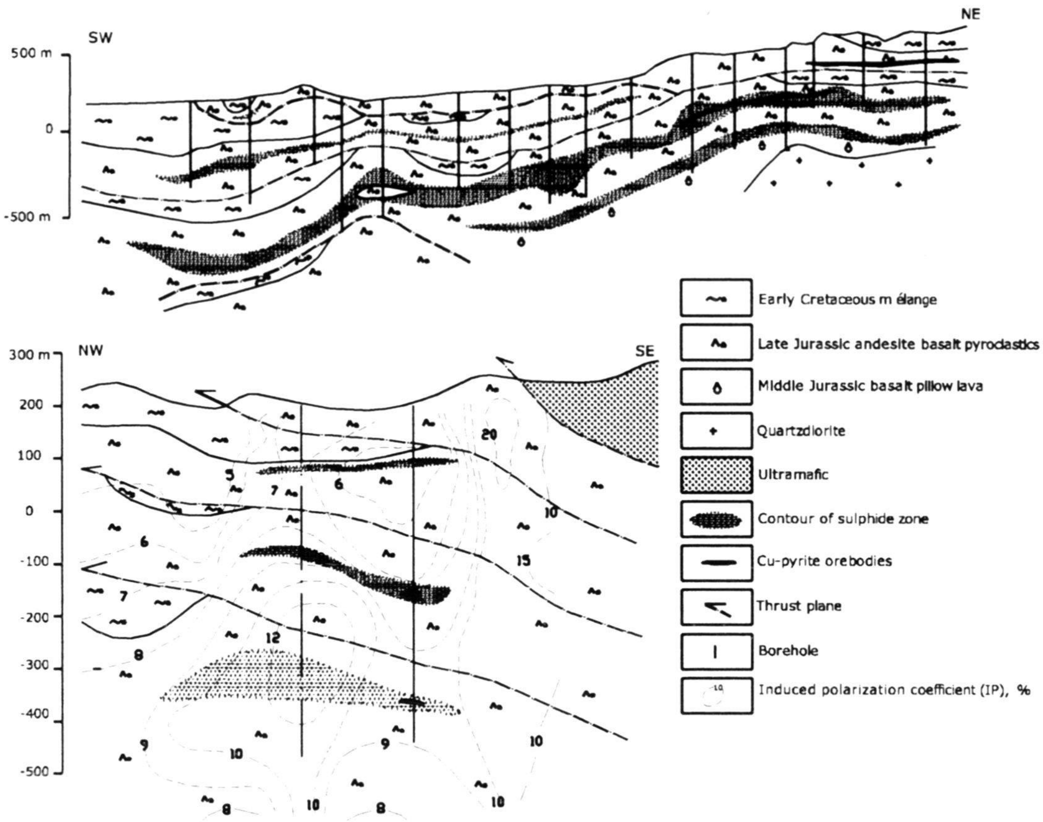

Fig. 12. A stack of thrust sheets at Perlati deposit.

borehole (N-8) was drilled beneath the thrust plane and encountered gabbros with sulphides, opening new possibilities for prospecting at depth (Fig. 11).

The Perlati deposit, discovered in the early 70's has more than 4 million tons of drill proved, high grade reserve. Very detailed mapping, based on tens of thousand of meters of drilling, clearly shows three parallel thrust planes of volcanic hosted sulphide ores above the mélange (Fig. 12), with more than 1 kilometer horizontal displacement. Very detailed integrated geological-geophysical exploration, using Induced Polarization (IP) method followed by drillings, opened the prospecting at depth and especially along strike, increasing the size of the prospective area by more than 1.5 time (Hoxha et al. 1988; Leka et al. 1995).

Conclusions

The study area, located in central northern Albania, represents the most complete and well preserved section of Albanian ophiolites, hosting the principal sulphide reserves found so far, as well as the greatest potential resources.

The Western Triassic-?Jurassic ophiolites (Maliac-Meliata) and the eastern Jurassic supra-subduction type ophiolites (Vardar) are covered by Early Cretaceous mélange of accretionary prism type.

A western part can be distinguished with three thrust sheets: the sheet of volcano-sedimentary series overlain by mélange and underlain by ultramafics, with a metamorphic sole overprint at the contact with the ultramafics; the sheet of Triassic platform carbonate (Apulia s.l. – Pelagonia) overlain by mélange and the sheet of Early Cretaceous flysch-like deposit.

The platform carbonate (Pelagonian) zone and the Early Cretaceous flysch-like deposit constitute two separate tectonic units, clearly located west of the oceanic area where the ophiolites originated.

The existence of a stack of thrust sheets in the eastern ophiolite, the best-preserved section, indicates that they were internally disrupted. Triassic limestone blocks along the front of the biggest thrust and sub-alkali volcanites (not belonging to the ophiolite series) in the center of the ophiolites, in the Reps area, indicate the presence of exotics emplaced during the Late Jurassic-Early Cretaceous ophiolite obduction, and are possibly derived from seamounts resting on the descending Triassic oceanic slab (Maliac-Meliata).

The effects of the Jurassic-Cretaceous orogenic event in exploration of sulphide ores are used successfully, especially in the 30 km long Kyafe Bari-Perlat belt, hosting the principal reserves discovered so far, as well as potential resources for the future.

The evidence of two additional orogenic events brings new constraints, important not only from an academic point of view but also from a practical one.

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