Comparison among the Albanian and Greek ophiolites: in search of constraints for the evolution of the Mesozoic Tethys ocean.

COMPARISON AMONG THE ALBANIAN AND GREEK OPHIOLITES: IN SEARCH OF CONSTRAINTS FOR THE EVOLUTION OF THE MESOZOIC TETHYS OCEAN

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ABSTRACT

In this paper the stratigraphical, structural, geochemical and petrological features of the Mirdita (Albania) and Pindos, Vourinos, Koziakas, Othrys and Argolis (Greece) ophiolitic nappes are summarised and then compared. These ophiolitic nappes occur as a 700 km long belt running from Albania to Greece. These ophiolitic nappes are located between the west-verging imbricate stack of thrust sheets derived from the Adria plate continental margin to the west and the Pelagonian zone to the east. Each ophiolitic nappe is represented by several end-members represented by the sub-ophiolite mélange, the ophiolite sequence(s) with their sedimentary oceanic cover and the supra-ophiolite deposits. The latter can be divided in syn- and post-emplacement deposits, the first ones are recognised only in Albania. All the described ophiolite sequences are characterised at their base by a well-developed metamorphic sole that represents a further end-member of the ophiolitic nappe. The comparison among the features of all the end-members recognised in the studied ophiolitic nappes allows providing further constraints for the geodynamic reconstructions of the Mesozoic Tethyan oceanic basin located eastwards of the Adria plate.

INTRODUCTION

The Hellenic-Dinaric belt is characterised by the widespread occurrence of ophiolites that represent the remnants of the lithosphere belonging to oceanic basin(s) located between the Eurasia and Adria plates. The geological and petrological features of these ophiolites record the opening of this oceanic basin and the following convergence events, whose final stage consists in the obduction of the oceanic lithosphere onto the continental margin. All these ophiolites occur as a north-south trending, continuous alignment (Fig. 1) enclosed in the Hellenic-Dinaric orogenic belt, from Greece to Serbia throughout Macedonia, Albania, Bosnia, Montenegro, Serbia and Croatia.

Probably, the best-preserved and well-exposed ophiolites occur along the alignment running from Mirdita (Albania) to Argolis (Greece) areas, both located in the western areas of the Hellenic-Dinaric belt. These ophiolites crop out along an about 700 km long belt where the geological and petrological features of the oceanic lithosphere belonging to the same oceanic basin can be usefully investigated. The aim of this paper is to present a review of the researches on Hellenic-Dinaric ophiolites carried out by the authors in the past decade, as well as by other researchers. In this paper the features of these ophiolites are summarised and their characteristics are compared in order to highlight the similarities as well as the differences. This comparison can provide further constraints for the reconstruction of pre- and syn-convergence evolution of the Mesozoic Tethyan oceanic basin located between the Adria and Eurasia plates. Whether Hellenic-Dinaric ophiolites represent the ancient Pindos and/or Vardar oceans is still matter of debate and is beyond the scope of this paper.

GEOLOGICAL BACKGROUND

In the present day tectonic frame of the Hellenic-Dinaric orogenic belt, the ophiolites preserved in the Mirdita (Albania) and Pindos, Vourinos, Koziakas, Othrys and Argolis (Greece) areas are located at the top of the west-verging imbricate stack of thrust sheets derived from the Adria plate continental margin to the west and at the top of the Pelagonian zone to the east (e.g. Aubouin et al., 1970). The west-verging imbricate stack of thrust sheets consists, from east to west and from top to the bottom, of the Pindos (known as Krasta-Cukali in Albania), the Gavrovo (known as Kruja in Albania) and the Ionian units (Fig. 1). They are characterised by sequences detached from the Adria margin, that include Triassic to Paleocene neritic to pelagic carbonates topped by Eocene to Miocene siliciclastic turbidites. The inception age of the turbiditic deposition ranges from Late Cretaceous, in the Krasta-Cukali unit, to Oligocene in the Ionian unit. This shifting is interpreted as the result of the westwards migration of the deformation across the continental margin of the Adria plate. These units were thrust onto the pre-Apulian zone, which is regarded as the easternmost, undeformed margin of the Adria plate. The Pelagonian (known as Korab in Albania) zone is represented by an assemblage of tectonic units consisting of a pre-alpine basement intruded by Late Paleozoic granitoids and covered by a Permian to Early Triassic siliciclastic deposits followed by Middle Triassic to Late Jurassic carbonates. These units show a post-Jurassic deformation history associated to metamorphism ranging from very low- to low-grade (e.g. Mountrakis, 1984 and quoted references). In Albania, the Pelagonian tectonic units are characterised by a Paleozoic basement consisting of an Ordovician-Devonian sequence

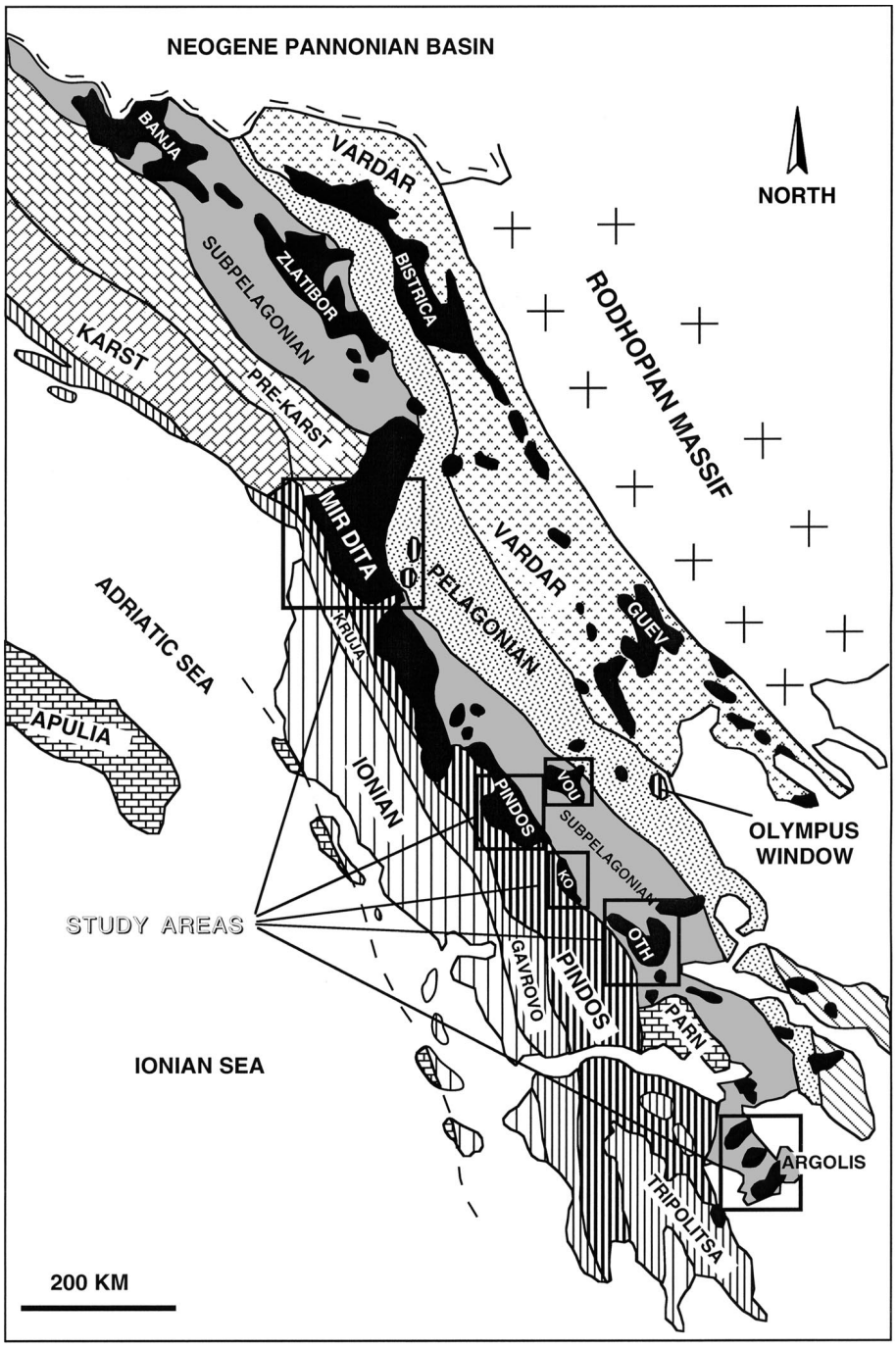

Fig. 1 - Tectonic scheme and location of the main ophiolitic massifs (solid black) for the Dinaric-Hellenic belt, modified after Aubouin et al. (1970). Abbreviations: Guev = Guevgueli; Vou = Vourinos; Ko = Koziakas Oth = Othris; Parn = Parnassus Zone. Box indicates the investigated area.

unconformably covered by a Permo-Triassic clastic sequence grading upwards to Triassic and Jurassic neritic and pelagic, mainly carbonate, deposits. The Pelagonian zone (including also the sub-Pelagonian zone) is considered belonging to a micro continent (e.g. Doutsous et al., 1993) between two oceanic areas or, alternatively, as part of the Adria plate (e.g. Schermer, 1993). It is noteworthy that in some tectonic windows below the units of Pelagonian zone, mainly in Peskophi and Sillatina areas, the Pindos, Gavrovo and Ionan units crop out. In addition, in the tectonic windows of the Olympus and Ossa mts., continental sequences affected by blueschist-facies metamorphism (e.g. Schermer, 1993) older than 84.5 + 3.3 Ma crop out (Lips et al., 1998). Westwards, the sub-Pelagonian and Pelagonian zones are thrust by the units belonging to the Vardar zone. This zone is represented by a composite assemblage of continental-derived units, but it also includes Triassic and Jurassic ophiolitic units. The ophiolitic bodies constitutes a semi-continuous ophiolite nappe over a distance of no more than 200 kilometres from the Vardar zone up to the ophiolites located at the top of the Pelagonian zone and the Pindos unit.

The relationships between the ophiolitic units and the neighboring continental units are sealed by the “molasse” deposits of the Meso-Hellenic trough, unconformably covering all the nappe pile. These deposits, ranging in age from Eocene to Miocene, were sedimented in a NW-SE basin extending from southern Greece to northern Albania.

In all the proposed models, these ophiolites are regarded as fragments of lithosphere derived from one or more oceanic basins located between the Eurasia and Adria plates (Robertson and Dixon, 1984, and quoted references). Some authors, as for instance Bernoulli and Laubscher (1972), Zimmermann (1972), Vergely (1976), Jacobshagen et al. (1978) and Collaku et al. (1992), regarded the ophiolites as the remnants

of an unique oceanic area located between the Adria and European continental plates; by contrast, their origin from two distinct oceanic basins has been postulated by Nance (1981), Jones and Robertson (1991), Shallo et al. (1992), Smith (1993), Beccaluva et al. (1994) and Ross and Zimmermann (1996). In both the hypothesis, many aspects of the reconstructions remain controversial: the time (Triassic vs. Jurassic) of oceanic opening after the break up of the Gondwanaland, the age of inception of the subduction, the age of the obduction of the ophiolites nappes and the time (Early Cretaceous vs. Early Tertiary) of its final emplacement.

In the model proposed by Bortolotti et al. (1996; 2002; 2003) only a single oceanic basin (Vardar ocean) existed in the area. This oceanic basin opened following the rifting along the northern margin of the Gondwanaland from Late Permian? - Early Triassic time onwards. Subsequently, during the Middle Triassic-Jurassic time span, the break-up led to the birth of oceanic basin bordered by a pair of passive continental margins. The oceanic basin underwent in the Jurassic time to convergence as result of motion between the Eurasia and Africa plates. This convergence led to an intraoceanic subduction associated to development of a wide oceanic basin above the subduction zone. In the Middle Jurassic, the continuous convergence between the Eurasia and Adria plates resulted in the obduction of ophiolites onto the Adria continental margin before the continental collision. After the continental collision up to Neogene, the continuous convergence affected the continental margin of the Adria plate, that was progressively deformed in west-verging, thick-thinned fold and thrust sheets represented by the Pelagonian, Pindos (Krasta-Cukali), Gavrovo (Kruja) and Ionian units. In the resulted orogenic belt, the ophiolites of Albania and Greece are incorporated as huge thrust sheets floating above the continental margin-derived units.

THE MIRDITA OPHIOLITIC NAPPE

Geological framework

The Mirdita ophiolitic nappe is an assemblage of two main tectonic units (Fig. 2): the ophiolite units and the underlying sub-ophiolite mélange (known as Rubik complex, Bortolotti et al., 1996). The ophiolite units can be subdivided in two NNW-SSE trending subparallel subunits: the Western and the Eastern ophiolitic belts, each showing ophiolites with different stratigraphical, petrological and geochemical characteristics

The ophiolite unit is thrust onto the sub-ophiolite mélange and their relationships are sealed by the Barremian-Senonian carbonate deposits (Fig. 2). Each ophiolite subunits include, from bottom to the top: a well developed metamorphic sole, the ophiolite sequences overlain by a thin sedimentary cover, consisting of bedded radiolarites, known as Kalur Cherts (Bortolotti et al., 1996) and the Upper Jurassic-Lower Cretaceous Simoni Mélange-Firza Flysch. In addition, Upper Tertiary transgressive “molasse” deposits of the Meso-Hellenic trough, unconformably covered all the end-members of the ophiolitic nappe.

The sub-ophiolite mélange

The sub-ophiolite mélange is represented by an assemblage of thrust sheets derived from both continental and oceanic domains. In the geological literature the sub-ophiolite mélange is also reported as “volcano-sedimentary formation”, “carbonate periphery”, “Rubik complex” or “peripheral complex” (Kodra et al., 1993; Shallo 1991, 1992 and 1994, Bortolotti et al., 1996 and Robertson and Shallo, 2000).

This mélange mainly consists of slices of Triassic-Jurassic carbonate successions. According to Shallo (1991, 1992), Kodra et al. (1993), the commonest succession consists of Middle Triassic cherty limestones grading upwards to Upper Triassic to Lower Liassic platform carbonates, which are often characterised by dolomitized, stromatolitic levels. At the top of the platform carbonates, a few meters of Middle to Upper Liassic, *Ammonitico rosso*-type nodular limestones and Dogger to Malm, *protoglobigerina*-bearing pelagic marly and cherty limestones occur. This sequence is, somewhere, stratigraphically overlain by pelites alternating with cherts where an Aalenian/Bajocian to Bathonian radiolarian assemblage have been found by Marcucci et al. (1994). Other carbonate successions are characterised by Middle Triassic to Malm pelagic cherty limestones alternating with radiolarites. In addition slices of volcano-sedimentary sequence occur in the sub-ophiolite mélange. The volcano-sedimentary sequence *sensu strictu* consists of pillow-lava picritic basalts and trachybasalts alternating with thin-bedded cherts of Anisian age (Kodra et al., 1993; Bortolotti

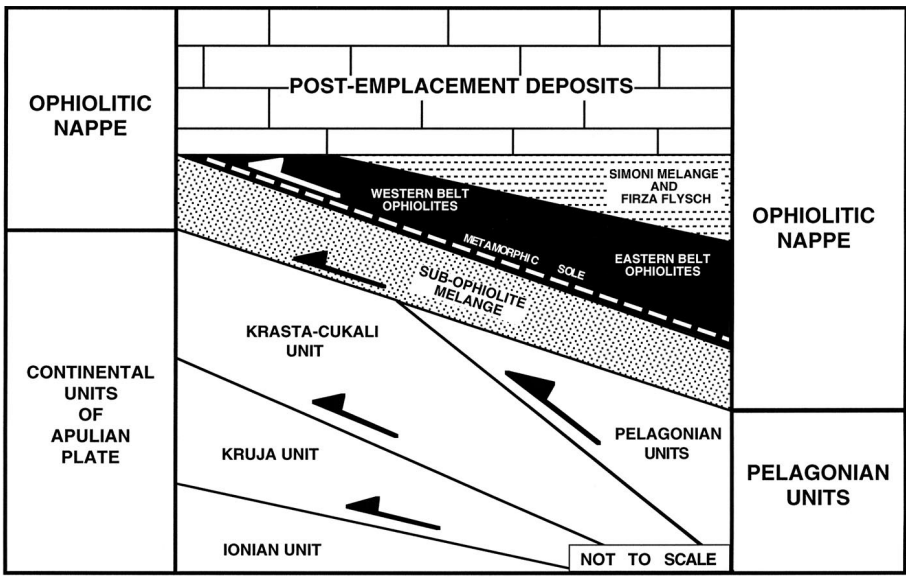

Fig. 2 - Sketch of the tectonic setting of Mirdita area (Albania).

et al, 1996). Small bodies of trachytes and rhyolites also occur, whereas the mafic rocks display a within-plate to transitional affinity (Shallo, 1992).

In the sub-ophiolite mélange, slices of lherzolites and associated polimictic breccias occur. The lherzolites, generally highly serpentinized, occur as thin slices, not thicker than 100 metres, whereas the polimictic breccias are represented by serpentinite, basalt and gabbro clasts set in a shaly matrix, of undetermined age. Recently, Bortolotti et al. (in press), have reported the occurrence in the sub-ophiolite mélange of basalts with MORB affinity alternating with shales and radiolarites of Late Triassic age (Marcucci et al., 1994, Chiari et al., 1996). The N-MORB affinity of these basalts is highlighted by flat HFSE patterns and by slightly LREE depleted patterns (Fig. 3), typical of present-day basalts generated at mid-ocean ridge. The occurrence of Late Triassic basalts with MORB affinity suggests that the phases of oceanization following the Triassic continental break-up were already reached in the Albania area during the Late Triassic time span. In addition, slices consisting of Upper Jurassic - Lower Cretaceous sedimentary deposits also occur at the base of the sub-ophiolite mélange. The slices of the sedimentary deposits are mainly represented by less than 200 m thick breccia, where serpentinites and gabbros, as well as sandstones, Triassic basalts, Triassic radiolarites and limestones are observed as clasts and/or olistoliths in a shaly or arenitic matrix.

At the base of the sub-ophiolite mélange, a 300 m thick slice of ophiolite-bearing and carbonate turbidites occur. These turbidites can be roughly subdivided in three members: the lower member is characterised by the occurrence of ophiolite-bearing pebbly sandstones and mudstones, whereas in the middle and upper members the calcareous and ophiolites-bearing turbidites are prevailing. Nannofossils findings imply uppermost Tithonian - Late Valanginian age of these turbidites.

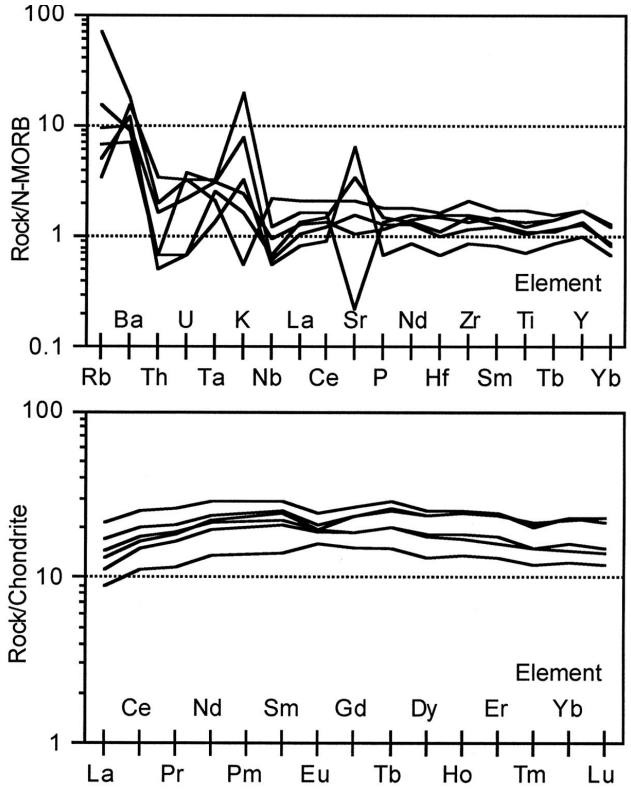

Fig. 3 - Incompatible element and REE patterns for representative Triassic MORBs from the sub-ophiolite mélange. Modified from Bortolotti et al. (2004). Normalization values are from Sun and McDonough (1989).

The ophiolite sequences

On the base of geological and petrochemical data (Shallo et al., 1991; Shallo, 1992; Beccaluva et al., 1994, Bortolotti et al., 1996; 2002), the ophiolites from Mirdita area can be subdivided into the NNW-SSE trending subparallel Western and Eastern belts (ISPGJ-IGJN, 1990). They show different stratigraphical, petrological and geochemical characteristics, which suggest the occurrence of two paired ophiolite sequences (Fig. 4). The boundary between these belts is represented by the Rreshen-Blinisht tectonic line, where the Eastern ophiolites overthrust the Western ophiolites (Fig. 4). The

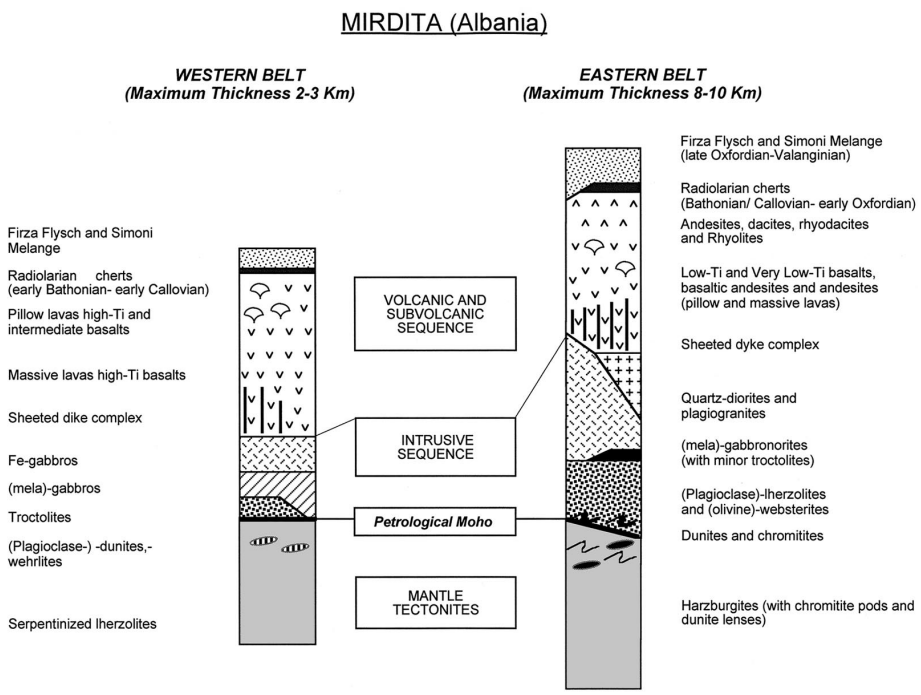

Fig. 4 - Generalised stratigraphy of the ophiolite sequences for the Western and Eastern belt (Modified after Bortolotti et al., 1996).

tectonic relationships between Western and Eastern ophiolites have been acquired during the Cretaceous tectonic events.

The Western belt

Magmatic sequence. - The Western belt is characterised by a partially dismembered ophiolite sequence whose reconstructed stratigraphy (Fig. 4) includes, from bottom to top: lherzolitic mantle tectonites, mafic-ultramafic cumulates and a volcanic sequence (Shallo, 1991, 1994; Beccaluva et al., 1994; Bortolotti et al., 1996). The lherzolitic mantle consists of high strained to mylonitic lherzolites (Nicolas et al., 1999). The gabbroic complex (with a reduced thickness) consists of cumulus dunites, mela-troctolites, troctolites, norites, gabbros, diorites, Fe-gabbro, Fe-diorites, and minor plagiogranites (Beccaluva et al., 1994; Cortesogno et al., 1998). The gabbroic complex is overlain by a very thin sheeted dike complex with mid-oceanic ridge basalts (MORB) affinity. In some areas the sheeted dyke complex as well as the gabbroic complex are lacking, and the crustal section only consists of the volcanic sequence (Nicolas et al., 1999). The volcanic sequence is largely composed of pillow lava basalts and subordinate doleritic basaltic dykes and sills, showing high-Ti (MORB) affinity (Beccaluva et al., 1994). The most complete ophiolitic sequences in the Western belt show a thickness (from mantle tectonites to volcanites) not more than 3-4 km. This type of ophiolites has been interpreted as originated in a mid-oceanic ridge with slow to intermediate spreading rate (Cortesogno et al., 1998; Nicolas et al., 1999).

The geochemical fractionation trends show remarkable Fe-Ti enrichment, and the crystallization order (olivine ± chromite followed by plagioclase and then clinopyroxene) typical of MOR magmatism (Beccaluva et al., 1995). The overall petrographical and geochemical characteristics indicate that this ophiolitic belt can be interpreted as being formed in a mid ocean ridge setting (Beccaluva et al., 1994).

Although Western belt is largely characterised by MOR-type ophiolites, volcanic sequences showing IAT and MOR-IAT intermediate geochemical features, as well as very low-Ti, boninitic dykes are also found (Bortolotti et al., 1996; 2002; Hoeck et al., 2002). The IAT and MOR-IAT intermediate-type volcanites are mostly represented by pillow lava basalts directly overlying the more typical MORB sequences. According to Bortolotti et al. (1996, 2002) and Hoeck et al. (2002), well exposed sections where the MORB basalts are interlayered with IAT and MOR-IAT intermediate-type volcanites have been recognised in the central Mirdita area. In these sections, high-Ti basalts alternate with basalts showing MOR-IAT intermediate characteristics, whereas the top of the volcanic sequence is represented by andesitic massive lava flow displaying boninitic geochemical affinity (Bortolotti et al., 1996, 2002).

Sedimentary cover - The radiolarian cherts, found at the top of the Western ophiolites, are characterised by a thickness of 2-6 m. but some sequences with a thickness up to 15/20 m are also present. The age for the stratigraphic base of the cherts sampled in the Western belt areas range from Late Bajocian/Early Bathonian to Late Bathonian/Early Callovian, whereas the top displays a Late Bathonian/Early Callovian radiolarian assemblage (Marcucci et al., 1994; Marcucci and Prela, 1996).

The Eastern belt

Magmatic sequence. - The Eastern belt shows a well developed generalised sequence (Fig. 4) including, at the base, harzburgitic mantle tectonites with ultramafic cumulates which occur as both lenses inside the upper part of the mantle tectonites and as layers limited to the lower part of the intrusive sequence. The latter includes chromite-bearing dunites, chromitites, dunites, olivine-websterites, and websterites, mafic cumulates mainly composed of (olivine-) gabbronorites, followed by isotropic gabbros, quartz-diorites and plagiogranites. The intrusive sequence is topped by a sheeted dike complex showing a transition to a volcanic sequence including massive and pillow-lava basalts, basaltic andesites, andesites, dacites and rhyolites (Shallo, 1992; 1994; Shallo et al., 1992; Beccaluva et al., 1994; Xoxha and Boullier, 1995; Bortolotti et al., 1996; Robertson and Shallo, 2000). The most complete ophiolitic sequences in the Eastern belt are observed in the northern sector of the Mirdita nappe, showing a thickness (from mantle tectonites to volcanites) more than 8 km.

According to the geochemical data, the Eastern belt ophiolites show low-Ti affinity. Rarely, very low-Ti basalts and basaltic andesites comparable to high-Ca boninites occur as dykes in several areas (Beccaluva et al., 1994). Mass balance calculations suggest that the main cumulitic sequence may have derived by fractional crystallization in an initially open system from low-Ti picritic parental magma (Beccaluva et al., 1994). These petrological features indicate the generation of Eastern belt ophiolites in a supra-subduction zone (SSZ) setting (Beccaluva et al., 1994).

Sedimentary cover - At the top of the pillow lava basalts, a sequence of radiolarites showing the lithostratigraphic features similar to those of Western belt can be recognised. According to Marcucci et al. (1994), Prela (1994) and Marcucci and Prela (1995; 1996), the radiolarian assemblages found at the base of cherts from Eastern belt ophiolites suggest an age ranging from Late Bathonian/Early Callovian. In addition, decimetre-thick sequences of cherts recognised in the uppermost part of the basalt flows show Late Bajocian/Early Bathonian radiolarian assemblage (Chiari et al., 1994). The top of the cherts sampled in the Eastern belt ophiolites from the northernmost areas of Albania shows Middle Callovian/Early Oxfordian radiolarian assemblage (Marcucci et al., 1994; Prela, 1994; Marcucci and Prela, 1996).

The metamorphic sole

The Western and Eastern ophiolites show a metamorphic sole at their base (ISPGJ-IGJN, 1990), analogous to those recognised in other Eastern Mediterranean ophiolites (e.g. Spray et al., 1984). According to Collaku et al. (1991) and Carosi et al. (1996), the metamorphic sole, ranging in thickness from few to 700 metres, includes garnet-bearing amphibolites, coarse- to fine-grained amphibolites, garnet-bearing micaschists and garnet-bearing paragneisses. Based on their geochemical signature, the inferred protoliths for amphibolites are mid-ocean ridge basalts (MORB), cumulate gabbros, and ocean island basalts (OIB), whereas paragneisses and micaschists probably represent siliciclastic sediments. Ar-Ar datings with ages ranging from 160 to 174 Ma have been provided by Dimo-Lahitte et al. (2001) for the Albanian ophiolites. A systematic younging from south to north, with a difference from 14 Ma along the 140 km length of the belt is suggested by these authors. In the Mirdita area the datings ranges from 160 to 170 Ma without differences along the east-west trending transects.

The supra-ophiolite deposits

Syn-emplacement deposits

The Simoni Mélange and the Firza Flysch represent a thick sedimentary sequence (Fig. 2) overlying the cherts on both the Western and Eastern ophiolitic belts.

The Simoni Mélange unconformably overlies the cherts, or directly the pillow-lava and massive basalts (Carosi et al., 1996). It is about 200-300 m thick, and occurs throughout the whole Mirdita region for over 150 square kilometres. The Simoni Mélange is a typical "blocks in matrix-type" mélange showing a fabric, which includes blocks ranging from several centimetres to several hundred meters in size, set in a well-foliated shaly matrix. The sedimentary structures as grading or bedding are generally lacking. However, the occurrence of layers of arenites in the uppermost levels of the mélange marks the transition to the Firza Flysch. Lithologies in the blocks include both continent- and ocean-derived rocks (e.g. Kodra et al., 1996). The continental-derived lithologies are volumetrically dominant. They include, in order of abundance, sandstones, Triassic volcanics, Triassic cherts, carbonates and minor metamorphic rocks. The carbonate blocks include both shallow-water, oolite-bearing limestone (Late Triassic) followed by *Ammonitico rosso*-type nodular pelagic limestones (Middle Liassic), and well bedded cherty limestones (?Liassic). The metamorphic rocks are mainly represented by marble and micaschists of unknown age deformed under greenschists facies metamorphism. The continent-derived blocks probably represent a dismembered continental margin, which includes a crystalline basement overlain by a Triassic platform and Liassic pelagic carbonates. The ocean-derived lithologies are represented by the entire ophiolite sequence; in order of abundance basalts, mantle ultramafics, gabbros and cherts occur. The mantle ultramafics are generally represented by highly weathered, serpentinized lherzolites or, occasionally, by hydrothermal weathered, ophicalcite-like, peridotites. Pillow-lavas and massive basalts are also present. Other rocks are very rare, but gabbros, plagiogranite, Jurassic cherts and amphibolite blocks are reported by Shallo (1991). According to Shallo (1991; 1992), the occurrence of both high-Ti and low-Ti basaltic blocks suggests that the source area of the mélange included ophiolites from the Eastern and Western belts. The Simoni Mélange has not yet been definitively dated. Nevertheless, good age constraints are provided by the deposits stratigraphically linked to the Simoni Mélange. In the study area, the mélange overlies the Late Bathonian - Early Callovian cherts, whereas the overlying Firza Flysch shows Late Tithonian - Late Valanginian nannofossil assemblages. In summary, Simoni Mélange sedimentation probably occurred in a time span ranging from Late Oxfordian to Tithonian. The blocks dated as no younger than Callovian are coherent with the previously suggested age. The stratigraphical transition to the Firza Flysch, as well as the sedimentary features, corresponding to a high sedimentation rate, suggest a Tithonian age.

The Simoni Mélange shows gradual transition to the Firza Flysch, a turbidite deposit dated as uppermost Tithonian - Late Valanginian by *Calpionellids* and nannofossil assemblages (Gardin et al., 1996 and quoted references). At the base of the Firza Flysch, debris flow deposits are intercalated in the turbidites. The main feature of the Firza Flysch is the occurrence of ophiolite-bearing polimictic pebbly sandstones and mudstones at different stratigraphical levels.

The overall features of the Simoni Mélange and Firza Flysch suggest that Simoni Mélange and Firza Flysch, which are unconformably found over the cherts and the basalts, can be regarded as syn-emplacement deposits, sedimented after the inception of ophiolite deformation (e.g. Bortolotti et al., 1996).

The post-emplacement Barremian-Senonian deposits

This succession consists of thick, well-developed shallow-water deposits, showing a thickness up to 1500 m (ISPGJ-IGJN, 1990). It includes a Barremian conglomerate characterised by pebbles derived from the entire ophiolite sequence; its thickness is about 100 m. The ophiolite-bearing Barremian conglomerates grade upwards to Aptian-Albian shallow water carbonates. In the uppermost part of this succession Maastrichtian shallow-water deposits were found (Peza and Arkaxhiu, 1988). The Barremian-Senonian sequence unconformably overlies the ophiolite sequence from peridotites to volcanics of the Eastern belt. The Barremian-Senonian sequence seals also the relationships between the sub-ophiolite mélange and the ophiolite sequence.

THE PINDOS OPHIOLITIC NAPPE

Geological framework

The Pindos ophiolitic nappe crops out in the northwestern Pindos Mts., western Greece (I.G.M.E., 1983). This

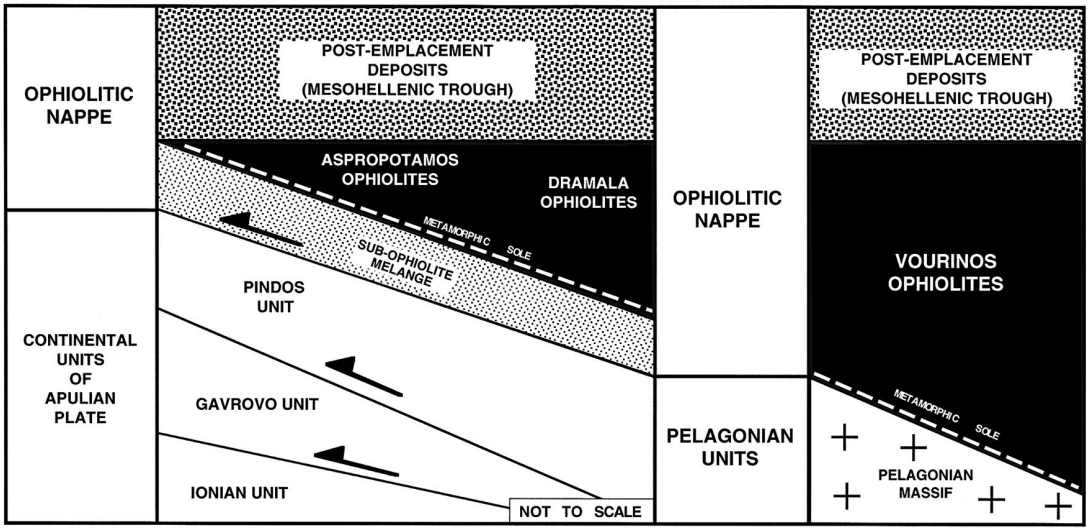

Fig. 5 - Sketch of the tectonic setting of Pindos and Vourinos areas (Greece).

nappe is thrust over the Pindos flysch unit that mainly consists of Paleocene (?) to Eocene siliciclastic turbidites (Fig. 5). The Pindos flysch unit belongs to the Pindos zone, correlated with the Krasta-Cukali zone in Albania; it is thrust directly over the Ionian zone.

The Pindos ophiolitic nappe can be subdivided in three major tectonic units that include at the bottom the Dio Dendra Group, consisting of Upper Jurassic – Upper Cretaceous ophiolite-bearing turbidites, and the Avdella mélange. The Advella mélange is thrust by the Pindos ophiolite that can be subdivided in two subunits, characterised, respectively, by the Dramala and the Aspropotamos sequences. The relationships between the different units of the Pindos ophiolitic nappe are sealed by the deposits of the Eocene-Miocene Meso-Hellenic molasse.

Sub-ophiolite mélange

Below the Pindos ophiolites, the Avdella mélange (Jones and Robertson, 1991), reported also as Perivoli complex (Kemp and McCaig, 1984), crops out extensively. This mélange, up to 1 km thick, consists of slices of different lithologies, derived both from oceanic and continental domains. The slices are set in a strongly deformed shaly matrix that shows tectonic relationships with the surrounding lithologies. The matrix of the mélange is also represented by debris flow deposits consisting of pebbles in fine-grained, generally shaly matrix. The pebbles include basalt, chert, limestone, gabbro, siliciclastic turbidites, peridotite i.e. the same lithologies detected in the large slices.

The most representative slices consist of Late Triassic massive and pillow-lava basalts, locally interbedded with *Halobia*-bearing pelagic limestones and cherts. Others well represented slices consist of thick-bedded, pelagic limestones and associated Late Triassic and Early Jurassic carbonate breccias. In a huge slice, a sequence consisting of Triassic carbonates overlain by pink nodular limestones ("*Ammonitico rosso* facies") and cherts of probably Bathonian-Callovian age has been recognised. Slices entirely made up of cherts are also widespread. Slices of sequences, up to 250 m thick, made up of well-bedded siliciclastic turbidites represented by quartz-bearing arenites and shales have been found. These sequences have been interpreted as derived from the succession belonging to Paleozoic Pelagonian basement (Jones and Robertson, 1991). In addition, also slices derived from ophiolite sequence are widespread. The most representative slices consist of peridotites, but also slices from sheeted dyke complex and from pillow-lava basalts have also been found.

Below the Avdella mélange, an assemblage of slices mainly consisting of sedimentary rocks have been reported by Terry and Mercier (1971), Kemp and McCaig (1984) and Jones and Robertson (1991). In these slices, that overlain the Pindos unit, four succession can be roughly discriminated, as suggested by Jones and Robertson (1991). Two of these formations, reported as Karamoula and Ayos Nicolaos Fm., consist of successions made up by turbidites with mixed composition alternating with carbonate turbidites. This turbidite succession, reported as "flysch", is assigned to Early Cretaceous, probably Berrasian, by Terry and Mercier (1971). The main characteristic is represented by the ophiolitic fragments found in the fine-grained arenites from Karamoula Fm. and in arenites and siltites from Ayos Nicolaos Fm. These fragments mainly consist of serpentinites, basalts, gabbros and cherts. However in both the formations, carbonate turbidites represented by well-bedded marly limestones and marls characterised by the occurrence of *Calpionellids* have been found.

The ophiolite sequences

In the Pindos area (Fig. 6), two different ophiolite sequences, known as Dramala and Aspropotamos Complexes, crop out (Jones and Robertson, 1991 and quoted references). The relationships between these sequences occur by a thrust where the Dramala ophiolites overlain the Aspropotamos Complex.

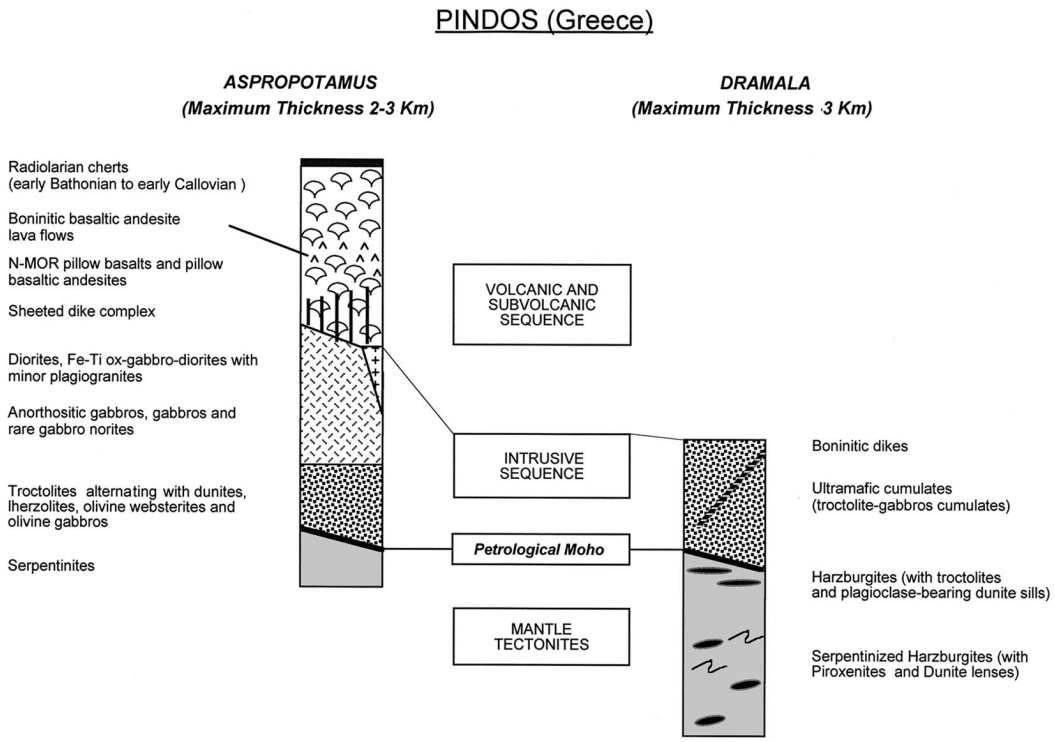

Fig. 6 - Generalised stratigraphy of the Dramala and Aspropotamos ophiolite sequences (Modified after Jones and Robertson 1991; Saccani and Photiades, in press).

Dramala ophiolites

The Dramala complex is mainly represented by mantle ultramafics (Fig. 6). They consist of serpentinized hazburgites showing well-developed tectonite fabric. Dunite and pyroxenite layers also occur within the mantle harzburgites and gabbroic complex. In the northern area, the mantle harzburgites show a transition to a thick sequence of ultramafic cumulates representing the crustal section. The transition mantle to crust in the Dramala ophiolites is represented by harzburgites intruded by sills of plagioclase-bearing dunite and troctolite followed by troctolite- gabbro cumulates. Locally, cumulates are cut by boninitic dykes. Ti-Y and Zr-Y plots of the Dramala mantle point out their original location in a supra-subduction zone (Rassios and Smith, 2000).

Aspropotamos ophiolites

Magmatic sequence - The Aspropotamos complex is represented by an ophiolite sequence dismembered in different slices with variable size, up to 2.5 km thick and several kilometres long (Jones and Robertson, 1991). The reconstructed sequence (Fig. 6) includes serpentinites, an intrusive sequence, a sheeted dyke and a volcanic complex. The intrusive sequence includes troctolites alternating with dunites, lherzolites, olivine websterites and olivine gabbros. The upper part of the cumulate sequence is represented by anorthositic gabbros, gabbros and rare gabbronorites. In the complete sections, these cumulate rocks show a transition to diorites, Fe-Ti oxide gabbro-diorites with minor plagiogranites (Capedri et al., 1982). The sheeted dyke complex consists of several phases of dikes, showing a transition to volcanic sequence. According to Saccani and Photiades (2004), the volcanic sequence is represented by pillow basalts and pillow basaltic andesites, but in the Aspropotamos River some massive lava flows represented by basaltic andesite are intercalated in the pillow lavas. According to Saccani and Photiades (2004), the cumulate sequence shows a MOR affinity. By contrast, the volcanic sequence shows the occurrence of rocks with different geochemical signature (Capedri et al, 1980, 1981; Jones and Robertson, 1991; Saccani and Photiades, 2004). The pillow basalts located in the lower part of the volcanic sequence show N-MORB affinity, whereas the same rocks collected in the upper part show the same affinity but with many geochemical differences. In turn, the massive lava and dykes can be classified as boninites (Jones and Robertson, 1991; Saccani and Photiades, 2004).

Sedimentary cover - The cherts at the top of the ophiolite sequence are assigned to Early Bathonian to Early Callovian (Jones et al., 1992).

The metamorphic sole

At the base of the Pindos ophiolites slices of a metamorphic sole occur. The metamorphic sole is mainly represented by amphibolites, but greenschists facies metabasites associated to metasedimentary rocks, as garnet-bearing micaschists, quarzites, marbles and gneisses also occur (Jones and Robertson, 1991). The inferred protoliths for amphibolites are represented by mid-ocean ridge basalts (MORB) and within plate basalts (WPB) (Jones and Robertson, 1991), whereas paragneisses, quarzites and marble probably represent oceanic sedimentary deposits. In the Pindos area the amphibolites have been dated by Ar/Ar method at 173±3 Ma and 172±3 Ma by Roddick et al. (1979) and Spray and Roddick (1980).

Supra-ophiolite deposits

In the Pindos area the ophiolites are directly topped by Eocene to Miocene deposits of the Meso-Hellenic trough (Fig. 5). No evidences of syn- or post-emplacement Mesozoic deposits have been recognised in this area.

THE VOURINOS OPHIOLITIC NAPPE

Geological framework

The Vourinos ophiolites are located 50 km east of the Pindos area (I.G.M.E., 1983). The ophiolite sequences cropping out in the Pindos and Vourinos areas are separated by the deposits of the Eocene-Miocene Meso-Hellenic trough; however a continuous linkage between these two ophiolite sequences in the subsurface is suggested by geophysical investigations (Makris, 1977). The Vourinos ophiolite sequence overlain the western side of the Pelagonian massif (Fig. 5); their pristine relationships, probably achieved during the Upper Jurassic tectonic events, are strongly modified during the Tertiary extensional tectonics (e.g. Doutsous et al., 1993)

Sub-ophiolite mélange

In the Vourinos area, a discontinuous slices of mélange, known as Ayios Nicolaos Fm., outcropping below the ophiolitic sequence has been described by Zimmermann (1972) and Naylor and Harle (1976). The thickness of this mélange, generally not more than 200 m., is strongly reduced by tertiary extensional tectonics. This mélange is characterised by slices of serpentinites, cherts, basalts as well as pelagic and neritic limestones enclosed in a deformed shaly matrix. Naylor and Harle (1976) have also described pebbly mudstones with limestone and siltstone clasts. On the whole, their features can be regarded as similar to those of the Avdella mélange.

The ophiolite sequence

In the Vourinos area, a complete ophiolite sequence, though affected by strong brittle deformation, can be fully reconstructed. It consists of two main bodies (Western and Eastern Vourinos and three minor satellite bodies (Krapa Hills, Zyghosti Creek and Mikrikastro.

Magmatic sequence - The Vourinos ophiolite sequence include a complete section of oceanic lithosphere that consists of mantle ultramafics, a gabbroic complex, a sheeted dike complex and a volcanic sequence (Fig. 7). The whole sequence is about 7 to 10 km thick. The mantle ultramafics consists of harzburgites with tectonitic fabric with minor coarse-grained dunites and chromite bodies (Moores, 1969, Ross et al., 1980; Rassios and Smith, 2000). The mantle harzburgites, up to 7 km thick, is overlain by a 3 km thick gabbroic complex. The lower part of the gabbroic complex includes dunites, wherlites, websterites, gabbronorites and pyroxenites that show a well developed magmatic layering associated to lineations. According to Rassios et al., (1983), the lower part of the gabbroic complex is characterised by the occurrence of multiple types of cyclic units with a marked lateral variations. The upper part of the gabbroic complex includes poorly layered gabbros, olivine-gabbros and gabbronorites showing a transition to isotropic diorites and hornblende-diorites. In the upper part basaltic dykes

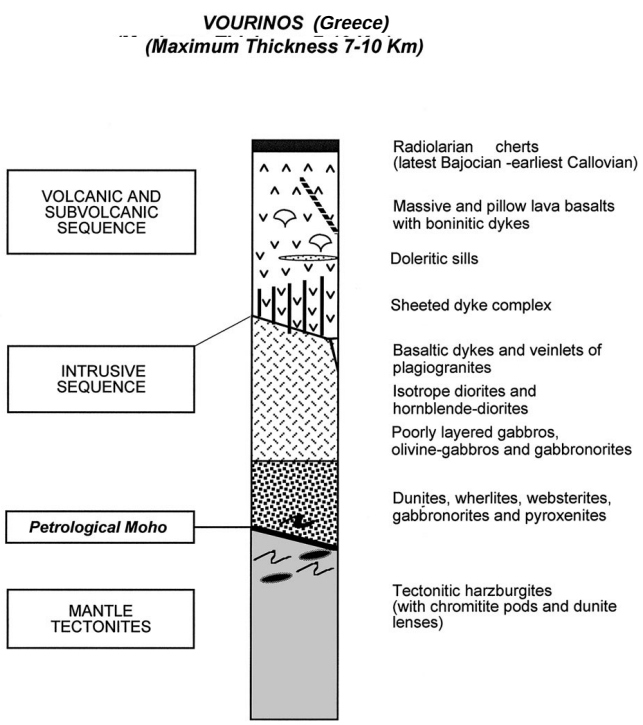

Fig. 7 - Generalised stratigraphy of the Vourinos ophiolite sequence (Modified after Beccaluva et al., 1984).

and veinlets of plagiogranites also occur. The gabbroic complex is topped by a 1 km thick sheeted dyke complex intruded in the upper part by doleritic sills. The volcanic sequence is in turn made up of multiple volcanic flows with both massive and pillow structures as well as boninitic dykes (Beccaluva et al., 1984). According to Beccaluva et al. (1984), the volcanic sequence of the Vourinos Massif ophiolites includes two geochemically distinct series: (1) the low-Ti series of the Krapa Hills consisting of basalts, basaltic andesites, andesites, and dacites; (2) the very low-Ti series of the Asprokambo, which includes basalts, basaltic andesites, andesites, dacites, and rhyolites. The Krapa low-Ti basalts have Ti/Zr and Zr/Y ratios, as well as general REE distributions typical of island arc tholeiites (Beccaluva et al. 1979). By contrast, the Asprokambo basaltic dykes display close similarities with the boninitic lavas found in the forearc regions of oceanic island arcs (Beccaluva et al., 1984), as suggested by their low Ti/Zr, Zr/Y, Al_2O_3/TiO_2 ratios, very low contents of incompatible elements (e.g., Ti, P, Zr and Y), and a general depletion in REE, sometimes associated with U-shaped REE patterns (Montigny, 1975).

Sedimentary cover - At the top of the volcanic sequence, in the minor satellite bodies, a thin sedimentary cover consisting of a thin level of cherts is present. The radiolarian assemblages gave the following ages: Early Bathonian in the Krapa Hills, latest Bajocian at Microkastro and latest Bajocian-Early Callovian at Zygosti Creek (Chiari et al., 2003).

The metamorphic sole

In the Vourinos area, the metamorphic sole consists of garnet-bearing amphibolites, but greenschists facies metamorphic rocks as micaschists and marbles also occur (Pichon and Brunn, 1985). The lower level of the metamorphic sole is represented by very low-grade metalavas with remnants of pillow texture. The amphibolites have been dated at 179±4 Ma by Ar39/Ar40 (Spray and Roddick, 1980).

The supra-ophiolite deposits

In the Vourinos area, ophiolites are topped by Upper Jurassic carbonate deposits. In the Krapa Hills, the basalts from the ophiolite sequence are covered by a succession that includes Upper Jurassic, *Calpionellids*-bearing cherty limestones topped by lower Cretaceous, *Rudistid*-bearing massive limestones (Pichon and Lys, 1976).

THE KOZIAKAS OPHIOLITIC NAPPE

Geological framework

The Koziakas ophiolitic nappe (Fig. 8) crop out at the western boundary of the Thessaly plain and extends, with a NNW-SSE trend, between the Pindos ophiolites to the north and the Othrys ophiolites to the south (I.G.M.E., 1983). This ophiolitic nappe is thrust over the Cretaceous Thymiama succession belonging to Beotian zone and the Pindos Flysch belonging to the Pindos zone. This nappe can be subdivided

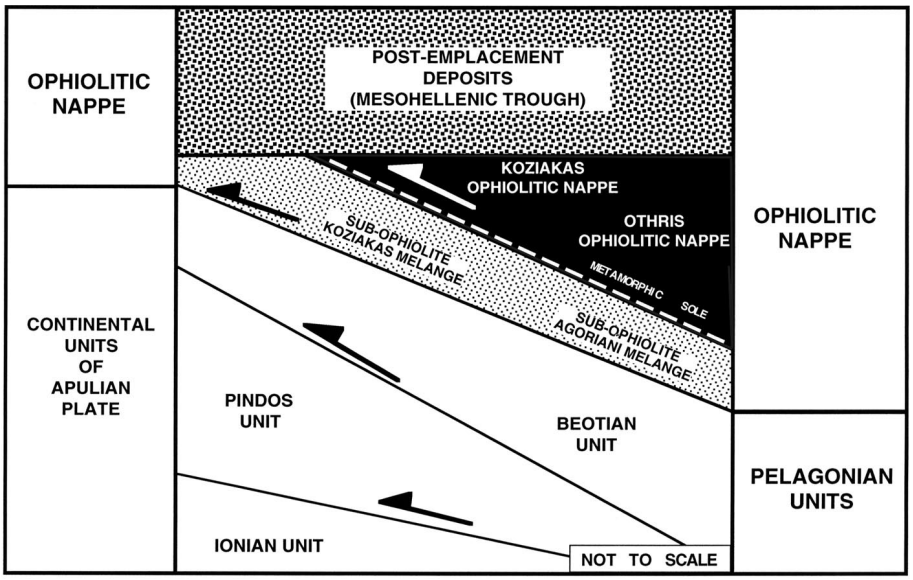

Fig. 8 - Sketch of the tectonic setting of Koziakas and Othris areas (Greece).

(Saccani et al., 2003) in two main tectonic units that include, from bottom to top: the sub-ophiolite mélange and the ophiolitic unit. All the tectonic units from the Koziakas ophiolitic nappe are unconformably overlain by the Oligocene-Miocene molasse deposits of the Meso-Hellenic trough, which in turn are covered by the Quaternary deposits of the Thessaly plain.

Sub-ophiolite mélange

The sub-ophiolite mélange (Koziakas Mélange), corresponding to the volcanic (lower) ophiolitic unit of Capedri et al. (1985), consists of stacked thrust-bounded slices. The lowermost slice consists of Triassic to Jurassic cherty limestones with oolite-bearing carbonates and cherts at the top. The others slices are represented by red cherts with calcarenite intercalations characterised in their upper part by a Middle-Late Jurassic manganesiferous red cherts (Skarpelis et al. 1992; Chiari et al., in press). However, the main body of the sub-ophiolite mélange is represented by well preserved volcanic sequences associated to chert levels. Radiolarian assemblages indicate two distinct age ranges: Middle-Late Triassic and Middle-Late Jurassic (Chiari et al., in press). Although radiolarian cherts are not stratigraphically related to any of the volcanic sequences, it is tempting to assume that the distinct magmatic sequences might be different in age. Volcanic sequences include pillowed and massive lava varieties, which are frequently crosscut by dykes of various natures, including boninitic dykes. The volcanic sequences composing the Koziakas sub-ophiolite mélange can be geochemically subdivided into three main groups: 1) transitional to alkaline series; 2) mid-ocean ridge basalts (MORBs); and 3) boninitic basaltic andesites and andesites.

The transitional to alkaline series includes both pillowed and massive lavas, and is mainly represented by basalts and basaltic andesites, and subordinate trachyandesites and trachytes. The transitional to alkaline rocks display OIB-Iike trace element and REE characteristics, suggesting that they represent seamounts formed by magma generation associated with mantle plumes. This conclusion is supported by the Zr/Y ratios (4-11), which, according to Pearce (1983), are the typical values for within-plate ocean island basalts. MORBs are represented by both pillow lava and dykes. They display LREE enrichment (Fig. 9) similar to E-MORB (Sun and McDonough, 1989). Saccani et al. (2003) suggested that the chemistry of N-MORBs is compatible with a genesis from primary magmas originating from depleted N-MORB type sub-oceanic mantle sources, with no influence of enriched OIB-type material. By contrast, E-MORBs possibly represent melts derived from more enriched sources (i.e., depleted mantle sources variably metasomatized by OIB-type components) or, alternatively, from lower degrees of partial melting. Saccani et al. (2003) suggested that E-MORBs from the Koziakas Mélange are compatible with about 10% partial melting of a theoretical mixed plume / MORB mantle source.

Boninitic basaltic andesites and andesites are exclusively represented by dykes. The very low TiO_2 contents (0.20-0.58 wt%), very low Ti/V (4-10) and Nb/Y (< 0.1) ratios are comparable with those of typical boninitic rocks from various ophiolitic complexes (e.g. Beccaluva and Serri, 1988).

At the base of the sub-ophiolite mélange a slice consisting of Early Cretaceous sedimentary deposits occurs. These deposits, known as Thymiama succession, include turbidites made up of arenites alternating with shales and marls. The arenites are characterised by fragments of carbonates and ophiolites. In the turbidites, intercalations of pebbly mudstones with clasts of gabbros, basalts, peridotites and cherts are widespread. The presence of *Calpionellids* point out to a Berriasian age of the lower part of these deposits, which locally also displays Late Cretaceous forams associations.

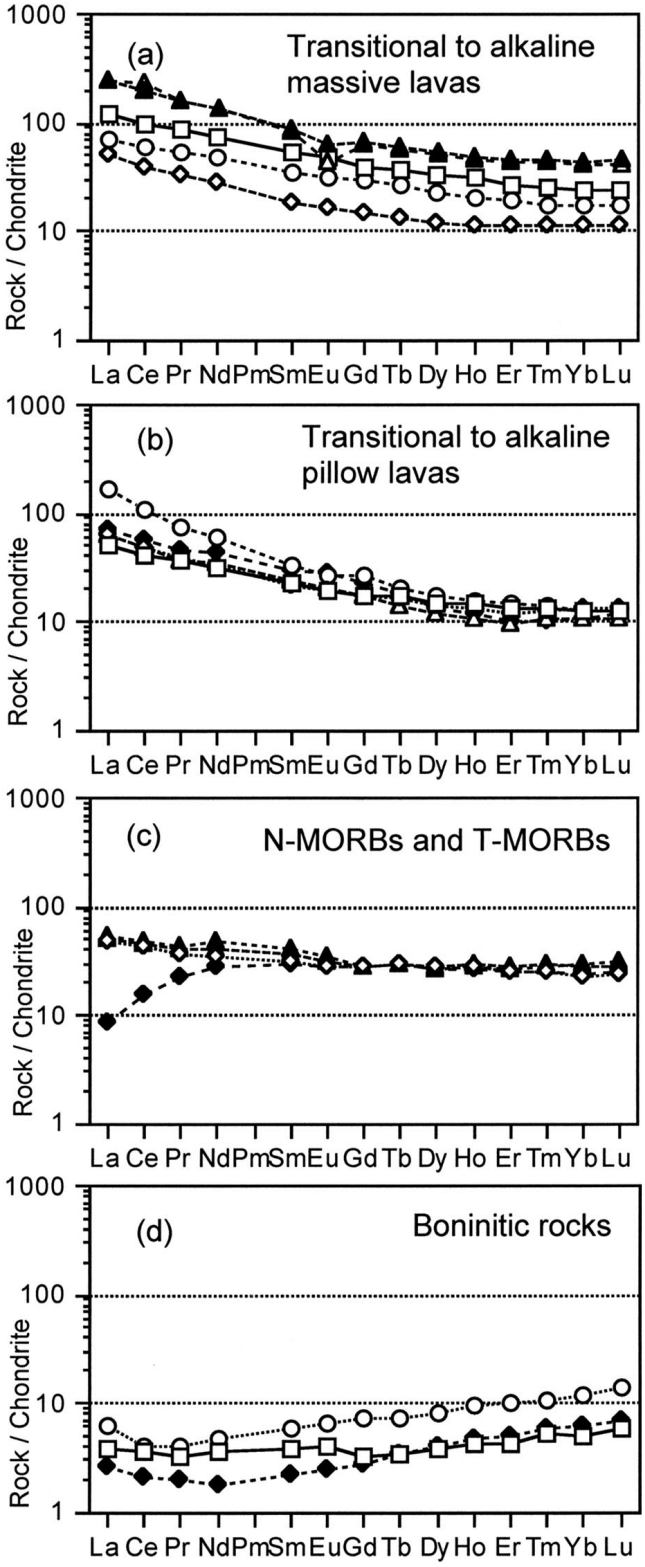

Fig. 9 - Chondrite-normalized REE patterns for volcanic and subvolcanic rocks from the Koziakas Mélange unit. Normalizing values are from Sun and McDonough (1989). a: transitional to alkaline massive lavas; b: transitional to alkaline pillow lavas; c: mid-ocean ridge basalts (MORBs); e: boninitic basaltic andesites and andesites.

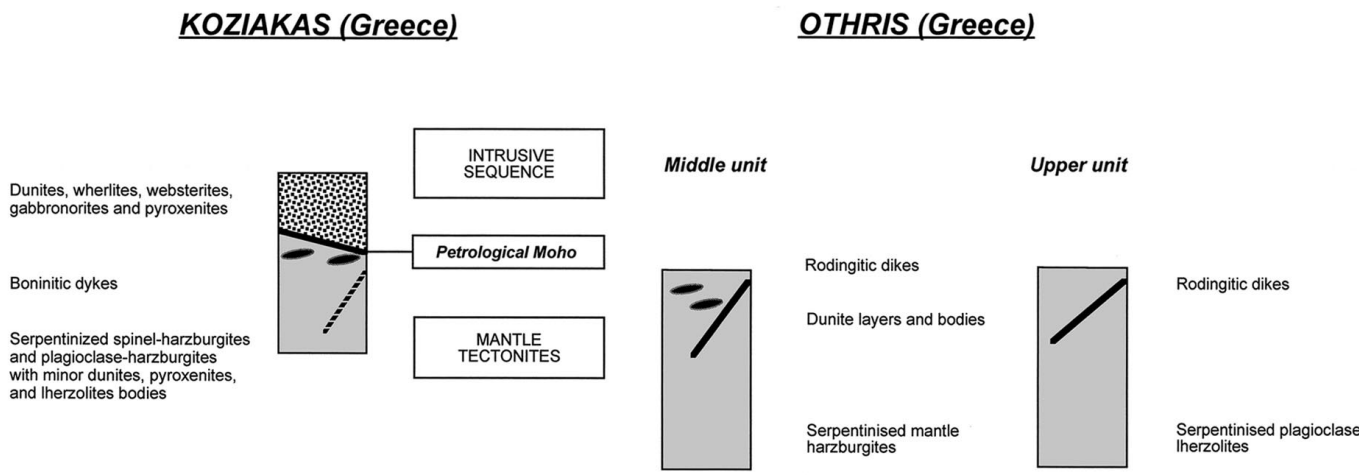

Fig. 10 - Generalised stratigraphy of the Koziakas and Othris ophiolite sequences.

The ophiolite sequence

The ophiolite sequence (Fig. 10) is composed of mantle tectonites represented by serpentinized spinel- and plagioclase-harzburgites with minor dunites, pyroxenites, and lherzolites. Olivine-gabbros are very rarely found as dykes intruded in mantle peridotites. By contrast, boninitic dykes are frequent. Generally, mantle tectonites exhibit porphyroclastic textures with porphyroclasts set in granoblastic, fine-grained matrix. The predominant mineralogical phase is olivine, orthopyroxene varies from 5 to 30%, and clinopyroxene is very scarce. Spinel occurs as anhedral grains in both porphyroclastic and matrix portions. Plagioclase is usually observed as coronas around matrix spinels. Spinel- and plagioclase-harzburgites have very similar chemical composition (Capedri et al., 1985).

Gabbros display banded textures with banding parallel to the margins of dykes marked by plagioclase / mafic phases variations. Magmatic phases are frequently deformed with deformation decreasing towards the dyke core. The overall petrological characteristics and the occurrence of boninitic dykes suggest many similarities between Koziakas ophiolites and mantle harzburgites of the Vourinos Complex.

The metamorphic sole

Slices of amphibolites have been found at the base of the mantle tectonites. The amphibolites are associated with minor schists and paragneisses. The protoliths of the amphibolites include basic rocks with both MORB and IAT affinity (Pomonis et al. 2004). K-Ar datings yielded ages of 171±3 and 161±1 Ma.

The supra-ophiolite deposits

In the Koziakas area the ophiolites are directly topped by Oligocene to Miocene deposits of the Meso-Hellenic trough or by Quaternary continental deposits of the Thessaly plain. No evidences of syn- or Mesozoic post-emplacement deposits have been recognised in this area.

THE OTHRIS OPHIOLITIC NAPPE

Geological framework

The Othrys ophiolitic nappe is thrust onto the Pindos unit to the west and onto the Pelagonian/Sub-Pelagonian units to the east (Fig. 8). The ophiolitic nappe includes three tectonic units, from the bottom upwards: a sub-ophiolite mélange (the Agoriani Mélange), the Middle unit made up of prevailing harzburgitic serpentinites and the Upper unit mainly consisting of serpentinised plagioclase lherzolites (Célet et al., 1980).

Sub-ophiolite mélange

The Agoriani Mélange consists of a tectono-sedimentary mélange, which, besides the continent-derived material, contains fragments of basalts, gabbros, harzburgites, serpentinites, and slivers of basalts linked to radiolarian cherts. The basalts are of different affinities: high-Ti MOR-type basalt and basaltic andesites, intermediate between low-Ti island arc tholeiites and high-Ti MORBs, and very low Ti basaltic andesites and andesites (Photiades et al., 2003). The radiolarian cherts, linked to the basalts show Late Triassic and Middle Jurassic ages, in different outcrops (Chiari et al., 2004, in press). No geochemical data are available for basalts stratigraphically linked to the cherts, but a Late Triassic age of some high-Ti basalts can be regarded as valuable suggestion, like in the Argolis area.

The ophiolite sequence

Two different tectonic units can be recognised (Fig. 10). The Middle unit consists of serpentinised mantle harzburgites, characterised by a tectonitic fabric with well-developed mineral stretching and spinel lineations (Rassios and Smith, 2003). Some dunite layer and body are present near the their top. They are cut by rodingitic dikes. In addition, dunite layers and/or bodies are common in the upper part of the harzburgites. The harzburgites are characterised by a highly serpentinized level at their base (Photiades et al., 2003). The upper unit consists of serpentinised plagioclase-lherzolites very deformed and sheared (especially near the base), cut by rodingitic dikes (Photiades et al., 2003; Rassios and Smith, 2003).

On the whole, the ophiolites from Othrys area are regarded as MOR-type (e.g. Rassios and Smith, 2003), even if further investigations are required to assess their geodynamic setting of origin.

The metamorphic sole

Amphibolites are present at the base of both the ophiolite unit: they constitute slivers common at the base of the Mid-

dle unit and local inclusions in the highly sheared serpentinites at the base of the upper unit.

No data about the features of this metamorphic sole are available. Radiometric data about the amphibolites at the base of the Middle unit point out an age of 177±4 by Spray and Roddick (1980).

The supra-ophiolite deposits

In the Othrys area, no evidences of syn- or post-emplacement Mesozoic deposits showing stratigraphic relationships with the ophiolites have been recognised.

THE ARGOLIS OPHIOLITIC NAPPE

Geological framework

In the Argolis Peninsula, the south-easternmost ophiolites of the continental Greece crop out (Fig. 11). This nappe can be subdivided in three thrust-bounded tectonic units thrust, in turn, onto the Trapezona unit, of Pelagonian pertinence (I.G.M.E, 1983). These tectonic units include, from the bottom upwards: the Dhimaina Ophiolitic unit, the Iliokastron Mélange, and the Adheres Mélange (Bortolotti et al., 2003). The thrusting of Iliokastron and Adheres Mélanges onto the Dhimaina Ophiolitic unit is regarded as achieved in the Tertiary time.

Sub-ophiolite mélange

At the top of the Trapezona unit, unconformably lies the Potami Fm. (Baumgartner, 1985) which consists in a sedimentary mélange which contain fragments of arenites, cherts, pelagic and shallow water limestones, serpentinites, basalts and boninitic and boninitic-type rocks (the latter group derived from an Island Arc; Dostal et al., 1991; Capedri et al., 1996). According to Baumgartner (1985), the continent-derived fragments derive from the topmost formations of the underlying Trapezona unit. The age of the mélange is unknown, but it is comprised between the Late Oxfordian-Early Kimmeridgian age of the top formations of the Trapezona unit and the Cenomanian of a “mesoautochthonous” cover.

The ophiolite sequence

Magmatic sequence - In the Argolis area, the best preserved ophiolites are found in the Migdalitza Ophiolitic Complex, that represents the lower part of the Dhimaina Ophiolitic unit. This complex consists of an assemblage of ophiolitic slices, up to 400 m thick. Owing their structural setting, this complex has been generally regarded as a tectonic mélange, but Bortolotti et al. (2003) have interpreted it as a true ophiolitic nappe, even if highly tectonized. The ophiolites consist of scattered serpentinite slivers at the base of the Migdalitza Ophiolitic Complex. They are, in turn, topped by thrust sheets of pillow lavas and minor massive lavas and pillow breccias affected by a low-grade greenschist oceanic metamorphism. On the whole, no reconstruction of the pristine ophiolite sequence can be attempted. From the geochemical data (Saccani et al., 2004) they can be subdivided in two main groups represented by T-MORB and N-MORB volcanics, but Ocean Island basalts are also reported.

Sedimentary cover - The basalts are characterised by scattered intercalations of radiolarian cherts, that are found also at the top of the volcanic sequences. They consist of 5-15 cm thick red radiolaritic chert beds, separated by thin red siliceous shales. The intercalations constitute thin levels (up to 8,50 m near Voitiki). Well-preserved radiolarian assemblages indicate two different ages: Middle and Late Triassic, Early and Middle Jurassic (Bortolotti et al., 2003). Even if rare, scattered Triassic MORBs are reported in the Dinaric-Hellenic orogenic belt, but the basalts of the Argolis, with their serpentinite slivers, constitute, till now, the oldest well dated (Middle Triassic) oceanic crust of this belt. The presence in the Migdalitza Ophiolitic Complex, of Lower and Middle Jurassic basalts, suggest that the ocean, opened in the Middle Triassic, and continued its spreading until Middle Jurassic.

The metamorphic sole

At the base of the ophiolite sequence no metamorphic soles have been found up to now.

The supra-ophiolite deposits

In the Argolis, on top of the Migdalitza Ophiolite unit, and somewhere also of the underlying Trapezona unit, seal-

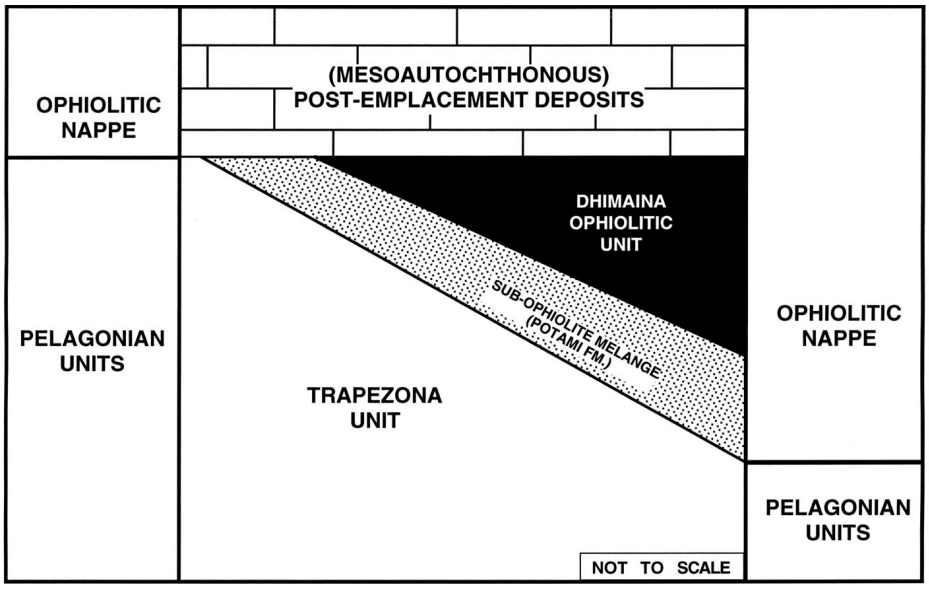

Fig. 11 - Sketch of the tectonic setting of Argolis area (Greece).

ing their tectonic superposition, a “Mesoautochthonous” cover crop out. It consists of Cretaceous limestones: from bottom to top Cenomanian shallow water limestones, Campanian-Maastrichtian breccias rich in basalt and chert clasts, Paleocene - Middle Eocene pelagic and reef limestones. The succession ends with an Eocene turbidites.

COMPARISON AMONG THE ALBANIAN AND GREEK OPHIOLITES: DISCUSSION

By comparison among the ophiolitic nappes of Mirdita, Pindos, Vourinos Koziakas, Othrys and Argolis, common features and differences can be clearly outlined, all able to provide valuable constraints for the reconstruction of the geodynamic evolution of the Mesozoic Tethyan oceanic area between the Adria and the Eurasia plates.

The main feature detected in the ophiolite belt is represented by the occurrence of two sequences with MOR e SSZ affinities in the Mirdita and Pindos area. Conversely, in the Vourinos and Koziakas ophiolitic nappe only ophiolite sequences with SSZ affinity have been detected. However, the occurrence of MORBs in the sub-ophiolite mélange suggests that the association of MOR and SSZ sequences was a characteristic of the ophiolites also in the Koziakas area. By contrast, the Argolis ophiolitic nappe is characterised by a MOR ophiolite sequence whereas in the sub-ophiolite mélange SSZ ophiolites have been recognised (Bortolotti et al., 2003 and quoted references). Therefore, the coupling of MOR and SSZ ophiolite sequences can be regarded as a continuous feature over the entire examined ophiolitic belt.

All the well-studied Jurassic MOR ophiolite sequences are cut by IAT and boninitic dykes and/or covered by MOR-IAT intermediate and IAT volcanic sequences. This occurrence is well documented in the Western belt of Mirdita (Bortolotti et al., 1996; 2002) and in Aspropotamos sequence of Pindos (Capedri et al., 1981; Jones and Robertson, 1991; Saccani and Photiades, 2004) sequences. For the Othrys ophiolites, regarded as MOR-type, the lacking of the upper part of the crustal section prevents any investigations. The occurrence of MOR, MOR-IAT intermediate and IAT volcanic sequences seems to favor the hypothesis that the oceanic basin, from which these ophiolites were derived, has experienced a two-stage of crustal growth. In the first stage, MOR-type oceanic lithosphere was generated at a mid-ocean ridge spreading centre. Subsequently, during the second stage, a portion of this lithosphere was trapped in the supra-subduction setting (most probably in a proto-forearc region) with consequent generation of intermediate-type basalts and very low-Ti dykes. In this picture, the SSZ oceanic lithosphere was only successively generated in the same oceanic basin during a mature stage of the subduction processes. The ophiolites representative of this SSZ lithosphere are today represented by Eastern belt of Mirdita, Dramala sequence of Pindos, Vourinos and Koziakas.

In order to explain the coexistence in the Jurassic time of MOR, MOR-IAT intermediate and IAT volcanic sequences as reported by Bortolotti et al. (1996, 2002) and Hoeck et al. (2002), a model based on the complexity of the magmatic processes that may take place during the initiation of a subduction in the proximity of an active mid-ocean ridge has been proposed by Insergueix-Filippi et al. (2000) and by Bortolotti et al. (2002). This model implies that the initiation of subduction processes close to an active mid-ocean ridge leads to contemporaneous eruptions in a fore-arc setting of MORBs generated from the extinguishing mid-ocean ridge, and of intermediate basalts generated in the SSZ mantle wedge from a moderately depleted mantle source. The development of the subduction in a young, hot lithosphere caused the generation of island arc tholeiitic basalts and boninites from strongly depleted mantle peridotites in the early stages of subduction, soon after the generation of MOR and MOR-IAT Intermediate basaltic rocks.

Differently from the others ophiolite sequence, the Argolis is characterised by the occurrence of T-MORBs (Photiades et al., 2003). These basalts can probably be interpreted as the remnants of the oceanic crust originated in the first stage of the spreading process. This interpretation is coherent with the occurrence of the oldest chert successions found at the top of ophiolitic basalts.

The available ages of the cherts derive by samples collected immediately above the basalts with MOR-IAT intermediate and IAT affinities. The age of these cherts is everywhere Middle Jurassic, not older than Bajocian-Bathonian time span. These ages are confirmed by radiometric datings performed on both ophiolitic rocks and metamorphic sole of the Eastern belt of Albania (Dimo-Lahitte et al., 2001). In addition, these radiometric ages indicate that the formation of the SSZ crust and its obduction must have been closely related in time. It follows that if the SSZ ophiolites can be interpreted as a subduction-related magmatism, the generation of MOR-type oceanic must be older than Middle Jurassic subduction. Assuming that a time span of 10-15 Ma from the inception of subduction is required to develop the SSZ magmatism, the convergence should have started in the lowermost Middle Jurassic or, most likely, in the Early Jurassic.

According to evidences provided by Bortolotti et al. (2002) and Saccani and Photiades (2004), the MORBs today preserved in the Albania and Pindos ophiolitic nappe are slightly older than or coeval with the SSZ analogues, i.e. of Middle Jurassic age. The age of the oldest MOR oceanic lithosphere can be assessed in the sub-ophiolite mélange of Albania, where Triassic MORBs are found (Bortolotti et al., 2004). This finding is confirmed by the occurrence of Middle to Late Triassic, Early Jurassic and Middle Jurassic MORBs reported by Bortolotti et al. (2003) in the Dhimaina ophiolite sequence from Argolis Peninsula. This occurrence points out to an oceanic basin already opened in the Middle Triassic. This Triassic MOR oceanic lithosphere was subsequently destroyed in the subduction zone and only small slices are preserved in the ophiolitic nappes.

All the examined ophiolite sequences, except in Argolis, are characterised by a well-developed metamorphic sole. The metamorphic sole is generally consisting of an assemblage (up to 800 m thick) of ocean-derived rocks metamorphosed under granulite, amphibolite and greenschist facies. The peridotite overlying the metamorphic sole shows low-temperature (<400°) mylonitic deformation (e.g. Xoxha and Boullier, 1995; Rassios and Smith, 2000). The metamorphic sole is regarded as developed during the intraoceanic convergence in correspondence of a detachment zone within the oceanic mantle as a high-temperature shear zone between two sections of young and still hot oceanic lithosphere. Thermal flux from involved mantle tectonites can support the temperatures required for the metamorphic processes, that are coherent with a geothermal gradient higher than 40°C/km. This geothermal gradient is consistent with an obduction process of ophiolite emplacement, and it cannot be regarded as acquired in a subduction setting where the structural features and the metamorphic

petrology are completely different.

The Ar-Ar radiometric datings of the amphibolites from the Albanian metamorphic sole ranges from a mean of 160 Ma in the northern area to 174 Ma in the southern area. In the Pindos area, the amphibolites show a mean age of 176 Ma, whereas in the Vourinos area the mean age is 179 Ma. In the Othrys area, the mean age is 177 Ma, whereas in the Koziakas area the available ages (K-Ar methods) are 174 and 161 Ma. On the whole, these data confirm the picture proposed by Dimo-Lahitte et al. (2001) for the Albanian ophiolites, where a continuous youngening of the age of the metamorphic sole from north to south is proposed. This picture implies that the inception of the obduction processes were diachronous and started before in the northern area of the oceanic basin.

In addition, the age detected in the metamorphic sole at the base of Albanian and Greek ophiolites are roughly analogous to the ages provided by the radiolarian assemblages found in the cherts intercalated and/or at the top of the same ophiolite sequence. Despite the problems about the correlations between paleontological and radiometric ages, these data point out to the inception of convergence in the oceanic basin contemporaneous or slightly older of the magmatic events, as detected in others examples of obducted ophiolites (e.g. the Oman ophiolites, e.g. Michard et al., 1991).

All the ophiolite sequences are thrust over a sub-ophiolite mélange, whose characteristics are analogous from Greece to Albania. The mélange mainly consists of slices detached from a continental margin during the emplacement of the ophiolite nappe. The result of this process is a tectonic wedge, sandwiched between the obducted ophiolites and the units derived from the continental margin. The origin of this mélange is probably a multi-stage process, with interference of sedimentary and tectonic events. The occurrence of ophiolite slices involved in the mélange is a puzzling feature. This feature can be explained as a result of tectonic erosion that affected the overlying ophiolites nappe or, alternatively, as remnants of an older, preexisting accretionary wedge developed during the Middle/Lower Jurassic subduction leading to development of supra-subduction oceanic lithosphere. In the latter hypothesis, the accretionary wedge was enclosed in the sub-ophiolite mélange during the displacement of the ophiolitic nappe towards the continental margin.

In the sub-ophiolite mélange, the evolution of the continental margin from the oceanic opening to the ophiolite obduction can be fully reconstructed through the analyses of the successions preserved in the slices. This inception of the rifting processes are testified by the Middle Triassic "volcano-sedimentary sequence" characterised by pillow-lava volcanics, mainly picritic basalt and trachybasalt, alternating with shales and radiolarites. These sequences can be interpreted as a product of syn-rift magmatism associated with thinning of the continental margin (Kodra et al., 1993). The sinking of the continental margin is well documented in some sequences by the Early Liassic pelagic deposits, such as *Ammonitico rosso*, whereas in others the pelagic deposits already occurred in the Middle Triassic. Nevertheless, all the carbonate sequences recognised in sub-ophiolite mélange are characterised by Middle Liassic pelagic deposits; this evidence suggests that the easternmost domains of the Adria continental margin underwent to complete sinking during the Early Jurassic.

In all the studied ophiolitic nappes, slices consisting of Upper Jurassic-Lower Cretaceous, turbidites characterised by ophiolite-derived fragments in arenites or ophiolite clasts in breccias occur at the base of the sub-ophiolite mélange. This slice can be recognised only in the western side of the ophiolitic nappe, sandwiched between the sub-ophiolite mélange and the units derived from the Adria continental margin, as observed, for instance, in the Koziakas area (Aubouin and Bonneau, 1977; Jaeger and Chotin, 1978). This turbidite succession can be correlated with the Beotian Flysch described by Célet et al. (1976) and Ferrière (1982) or with the Bosnian Flysch by Blanchet et al. (1969; 1970). Therefore, a continuous basin characterised by ophiolite-derived detritus can be hypothisized in the Late Jurassic-Early Cretaceous time span. These deposits can be regarded as sedimented in a foredeep basin located onto the Adria continental margin at the front the ophiolite nappe, during its emplacement. These deposits were subsequently deformed and partially enclosed at the base of the sub-ophiolite mélange during the progressive emplacement of the ophiolitic nappe.

The Albanian ophiolites differ from those from Greece by the occurrence of the Simoni Mélange and Firza Flysch. The latter deposit show the same age of the ophiolite-bearing deposits found as slice below the sub-ophiolite mélange. Therefore, a picture where the syn-tectonic deposits were deposited in front and at the top of the ophiolitic nappe during its emplacement can be proposed, but only for the Albanian area. Robertson and Shallo (2000) proposed for these deposits an origin connected with mud-diapir(s) along large-scale fault in the ophiolitic nappe, where fragments of the sub-ophiolite mélange were dragged up to the top of the ophiolitic nappe. However, the occurrence of turbidite, as those of the Firza Flysch, is contrasting with the sedimentary facies expected in mud-diapir setting. An alternative explanation is represented by an out-of-sequence thrust cutting the whole ophiolitic nappe and able to expose the sub-ophiolite mélange and the underlying continental margin. The latter represented the source-areas of the Simoni Mélange and Firza Flysch. This out-of-sequence thrust must be located eastwards to the present-day Eastern belt of the Albanian ophiolites.

Further constraints can derived from the post-emplacement, supra-ophiolitic deposits. In Albania, the first, post-emplacement deposits consist of Barremian conglomerates, whereas in the Vourinos area the same deposits are represented by the latest Jurassic carbonates found in the Krapa Hills. However in the Koziakas area, the same deposits are Cenomanian in age.

CONCLUSIONS

Some conclusions can be drawn by the data discussed in this paper. The occurrence of Triassic MORBs in the sub-ophiolite mélange from the Mirdita ophiolitic nappe suggests that an oceanic basin already existed between Adria and Eurasia plates in the Late Triassic. This conclusion is confirmed by data provided by Bortolotti et al. (2003) for Dhimaina ophiolitic unit of the Argolis peninsula. Therefore, an opening of the Mesozoic Tethyan basin characterised by a shifting in age from Middle Triassic in the southern areas to Late Triassic in the northern areas, can be envisaged, even if further investigations are required to confirm this picture. Subsequently, probably in the Early Jurassic time, the oceanic basin was affected by convergence, when a subduction zone was developed as result of the sharp change in the motion between the Adria and Eurasia plates. The existence of this subduction zone is

provided by the occurrence of the SSZ ophiolite sequences found in the Mirdita, Pindos and Vourinos areas, where the Late Bajocian – Early Bathonian age has been found in the oldest cherts intercalated and at the top of the SSZ-related basalts. In the supra-subduction zone, a coexistence of MOR oceanic lithosphere with SSZ magmatism has been found in Western Belt of Mirdita and Pindos sequences. This MOR lithosphere is regarded as trapped in the SSZ basin (most probably in a proto-forearc region) with consequent emplacement of intermediate-type basalts and very low-Ti dykes. In the same basin, a SSZ lithosphere was subsequently generated in a more mature stage of the subduction process. On the whole, all the studied Upper Jurassic ophiolites from Albania and Greece represent a composite oceanic crust belonging to the same oceanic basin, i.e. a supra-subduction basin, which experienced two different accretion events, respectively in a mid-ocean ridge spreading centre and, after the inception of the convergence, in a supra-subduction setting. Therefore, during the Middle Jurassic the Mesozoic Tethyan ocean basin eastwards of the Adria plate was characterised by a subduction zone separating the lower plate with MOR oceanic lithosphere, today preserved only in the sub-ophiolite mélange, from an upper plate where a trapped MOR oceanic lithosphere was coexisting with the SSZ lithosphere. The continuous convergence between the Adria and Eurasia plates resulted during the Middle Jurassic in the obduction of the SSZ oceanic lithosphere; this event is probably connected with the involvement of continental crust in the subduction zone with transfer of the compression in the supra-subduction zone. According to Michard et al. (1991), the obduction process consists of two different stages, respectively the intraoceanic and marginal stages. The intraoceanic stage is characterised by the thrusting of a section of oceanic lithosphere over the neighboring one. The development of high-grade metamorphic rocks, i.e. the amphibolite sole, occurred in correspondence of the high-temperature shear zone between the two sections of young and still hot oceanic lithosphere. According to radiometric datings, this stage seems to be occurred earlier in the Greek ophiolites than in the Albanian ophiolites. This shifting fit very well with the data available for the oceanic opening, where the oceanic areas that were formerly generated, was affected earlier by the closure events. The second marginal stage was characterised by the emplacement of the ophiolitic nappe onto the continental margin. During this second stage the sub-ophiolite mélange developed as result of continuous thrusting of the continental margin driven by the emplacement of the ophiolitic nappe. If the ophiolitic nappe derived from a SSZ basin, as testified by the geochemical affinity of the intrusive and magmatic sequences, part of the accretionary wedge, developed in correspondence of the subduction zone, can be deformed and partially enclosed at the base of the ophiolitic nappe during its displacement. During this second stage, a basin filled by ophiolite-bearing deposits was developed in front of the ophiolitic nappe. The final emplacement of the ophiolites is marked by the unconformable sedimentation of the carbonate deposits at the top of the ophiolitic nappe. The age of these deposits range from Barremian in Albania to latest Jurassic or Cenomanian in Greece; these data, even if further investigations are required, confirms that the emplacement of the ophiolitic nappe was ultimated in the Early Cretaceous time and from the Late Cretaceous onwards the convergence mainly affected the continental margins.

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REFERENCES

Aubouin J., Blanchet R., Cadet P., Celét P., Charvet J., Chorovic J., Cousin M., and Rampnoux J., 1970. Essai sur la géologie des Dinarides. Bull. Soc. Géol. France, 12: 1060-1095.

Aubouin J. and Bonneau M., 1977. Sur la présence d'un affleurement de flysch éocrétacé (Béotien) au front des uniés du Koziakas (Thessalie, Grèce): la limite entre les zones externes et les zones internes dans les Hellénides. C.R. Acad. Sc. Paris, 284: 2075-2078.

Baumgartner P.O., 1985. Jurassic sedimentary evolution and nappe emplacement in the Argolis Peninsula (Peloponnesus, Greece). Mém. Soc. Helv. Sci. Nat., 99:1-111.

Beccaluva L., Ohnenstetter D. and Ohnenstetter M., 1979. Geochemical discrimination between ocean-floor and island-arc tholeiites-application to some ophiolites. Canadian Jour. Earth Sci. 16: 1874-1882.

Beccaluva L., Ohnenstetter D., Ohnenstetter M. and Paupy, A., 1984. Two magmatic series with island arc affinities within the Vourinos ophiolite. Contrib. Mineral. Petrol., 85: 253-271.

Beccaluva L. and Serri G., 1988. Boninitic and low-Ti subduction-related lavas from intraoceanic arc-backarc systems and low-Ti ophiolites: a reappraisal of their petrogenesis and original tectonic setting. Tectonophysics, 146: 291-315.

Beccaluva L., Coltorti M., Premti I., Saccani E., Siena F. and Zeda O., 1994. Mid-ocean ridge and supra-subduction affinities in ophiolitic belts from Albania. In: Beccaluva L. Ed, Special Issue on "Albanian ophiolites: state of the art and perspectives". Ofioliti 19 (1): 77-96.

Bernoulli D. and Laubscher H. , 1972. The palinspastic problem of the Hellenides. Eclogae Geol. Helv., 65: 107-118.

Bortolotti V., Kodra A., Marroni M., Mustafa F., Pandolfi L., Principi G. and Saccani E., 1996. Geology and petrology of the ophiolitic sequences in the Mirdita region, northern Albania. Ofioliti , 21: 3-20.

Bortolotti V., Marroni M., Pandolfi L., Principi G. and Saccani E., 2002. Alternation of MOR and SSZ Basalts in Albanian Ophiolites: Evidences of interactions between Mid-Ocean Ridge and subduction-related processes in an infant arc setting. Journal of Geology, 110: 561-576.

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. and Principi G., 2002. New geological observations and biostratigraphic data on the Argolis Peninsula: paleogeographic and geodynamic implications. Ofioliti, 27: 43-46.

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. and Principi G., 2003. Argolis peninsula in the paleogeographic and geodynamic frame of the Hellenides. Ofioliti, 28: 79-94.

Bortolotti V., Chiari M., Kodra A., Mustafa F., Principi G. and Saccani E., in press. Triassic MOR basalts in the sub-ophiolitic Rubic Complex, Mirdita Zone, Albania. Ofioliti, in press.

Blanchet R., Cadet J.P., Charvet J. and Rampnoux J.P., 1969. Sur l'existence d'un important domaine du flysch tithonique - crétacé inférieur en Yougoslavie: l'unité du flysch bosniaque. Bull. Soc. géol. France, 11(7): 871 - 880.

Blanchet R., Duran Delga M., Moullade M. and Sigal J., 1970. Contribution a l'étude du Crétacé des Dinarides internes: la région de Maglaj, Bosnie (Yugoslavie). Bull. Soc. géol. France, 12(7): 1003-1009.

Capedri S., Venturelli G., Bocchi G., Ostal J., Garuti G. and Rossi A., 1980. The geochemistry and petrogenesis of an ophiolitic sequence from Pindos, Greece. Contrib. Min. Petr., 74: 189-200.

Capedri S., Venturelli G., Bebien J. and Toscani L., 1981. Low and high-Ti ophiolites in northern Pindos: petrological and geological constraints. Bull. volcanologique, 44: 439-444.

Capedri S., Venturelli G. and Toscani L., 1982. Petrology of an ophiolitic cumulate sequence from Pindos, Greece. Journ. of Geology, 17: 223-242.

Capedri S., Lekkas E., Papanikolaou D., Skarpelis N., Venturelli G. and Gallo F., 1985. The ophiolite of the Koziakas range Western Thessaly (Greece). Neues Jahrb. Miner. Abh., 152: 45-64.

Carosi R., Cortesogno L., Gaggero L. and Marroni M., 1996. Geological and petrological features of the metamorphic sole from the Mirdita ophiolites, northern albania. Ofioliti, 21: 21-40.

Carosi R., Kodra A., Marroni M. and Mustafa F., 1996. Deformation history of Jurassic Kalur Cherts from the Mirdita nappe, Albanian ophiolites. Ofioliti, 21: 41-46.

I.G.M.E. (1983). Geological map of Greece (1:500.000 scale), Athens.

Celet P., Clement B. and Ferriere J., 1976. La zone béotienne en Grèce: Implications paléogéographiques et structurales. Eclogae Geol. Helv., 69(3): 577-599.

Celet P., Courtin B. and Ferrière J., 1980. Les ophiolites des Hélénides centrales dans leur contexte géotectonique. In: A. Panayiotou (Ed.), Ophiolites, Proceed. Intern. Ophiolite Symp., Cyprus 1979. Geol. Surv. Dept., Cyprus: 360-371.

Chiari M., Marcucci M. and Prela M., 1994. Mirdita Ophiolite Project: 2. Radiolarian assemblages in the cherts at Fushe Arrez and Shebaj (Mirdita area, Albania). Ofioliti, 19: 313-318.

Chiari M, Marcucci M., Cortese G., Ondrejickova A. and Kodra A., 1996. Triassic Radiolarian assemblages in the Rubik area and Cukali zone, Albania. Ofioliti, 21: 77-84.

Chiari M., Marcucci M. and Prela M., 2002. New species of Jurassic radiolarians in the sedimentary cover of ophiolites in the Mirdita area, Albania. Micropal., 48, Suppl. 1: 61-87.

Chiari M., Bortolotti V., Marcucci M. , Principi G. and Photiades A., 2003. The Middle Jurassic siliceous sedimentary cover at the top of the Vourinos Ophiolite (Greece). Ofioliti, 28: 95-104.

Chiari M., Marcucci M. and Photiades A., Triassic and Jurassic radiolarian assemblages from the Koziakas area (Greece). Ofioliti, in press.

Clift P.D. and Robertson A.H.F., 1989: Evidence of a late Mesozoic ocean basin and subduction/accretion in southern Greek Neo-Tethys. Geology, 17: 559-563.

Collaku A., Cadet J.P., Bonneau M. and Kienast J.R., 1991. La semelle métamorphique infra-ophiolitique de la nappe de la Mirdita, son métamorphisme inverse et ses relations avec la série volcano-sédimentaire (région de Lura, Albanie Septentrionale). C.R. Acad. Sci. Paris, 313 (II): 251-258.

Collaku A., Cadet J.P., Bonneau M. and Jolivet L., 1992. L' édifice structural de l'Albanie septentrionale: des éléments de réponse sur les modalité de la mise en place des ophiolites. Bull. Soc. Géol. France, 163(4): 455-468.

Cortesogno L., Gaggero L., Jaho E., Marroni M., Pandolfi L and Shtjefanaku D., 1998. The gabbroic complex of the western ophiolitic belt, northern Albania: an example of multilayered sequence in an intermediate-spreading oceanic ridge. Ofioliti, 23(2): 49-64.

Dimo-Lahitte A., Monié P. and Vergély P., 2001. Memtamorphic soles from the Albanian ophiolites: petrology, 40Ar/39Ar geochronology, and geodynamic evolution. Tectonics, 20: 78-96.

Doutsos T., Pe-Piper G., Boronkay K. and Koukouvelas I., 1993. Kinematics of the central Hellenides. Tectonics, 12: 936 - 953.

Ferriere J., 1982. Paléogeographies and tectonique surposée dans les Héllénides internes: les massifs de l' Othris e du Pelion (Grèce continentale). Soc. Géol. Nord, 8(1), 970 pp.

Gardin S., Kici V., Marroni M., Pandolfi L., Pirdeni A. and Xhomo A., 1996. Litho- and biostratigraphy of the Firza flysch, ophiolite Mirdita nappe, Albania. Ofioliti, 21: 47-54.

Hoeck V., Koller F., Meisel T., Onuzi K. and Kneringer E., 2002. The Jurassic south Albania Ophiolites: MOR- vs. SSZ-type ophiolites. Lithos, 65: 143-164.

Hoxha M. and Boullier A.M., 1995. The peridotites of Kukes ophiolite (Albania): structure and kinematics. Tectonophysics, 249: 217-231.

Insergueix-Filippi D., Dupeyrat L., Dimo-Lahitte A., Vergely P. and Bébien J., 2000. Albanian ophiolites. II - Model of subduction zone infancy at a Mid-ocean ridge. Ofioliti, 25: 47-53.

ISPGJ-IGJN, 1990. Gjeologjia e RPSSH. MMKS, Tirana, Albania.

Jacobshagen V., Durr S., Kockel F., Kopp K.O., Kowalczyk G., Berckhemer H. and Buttner D., 1978. Structure and geodynamic evolution of the Aegean region. In: Cloos H., Roder D. and Schidmt K. Eds., Alps, Apennines and Hellenides. Schweitzerbart Stuttgart: 537-564.

Jaeger P. and Chotin P., 1978. La série du flysch béotien (Tithonique-Berriasien supérieur) au front du Koziakas (Mouzaki, Province de Karditsa, Grèce). C. R. Soc. géol. France, 1: 28-31.

Jones G . and Robertson A.H.F, 1991. Tectonostratigraphy and evolution of the Mesozoic Pindos ophiolite and related units, northwestern Greece. J. Geol. Soc. London, 148: 267-288.

Jones G., De Wever P. and Robertson A.H.F., 1992. Significance of radiolarian age data to the Mesozoic tectonics and sedimentary evolution of the northern Pindos Mountains, Greece. Geological Magazine, 129: 385-400.

Kemp A.E.S. and Mccaig A.M., 1984. Origins and significance of the rocks in an imbricate thrust zone beneath the Pindos ophiolite, northwestern greece. In: Dixon J.E. and Robertson A.H.F. (Eds.), The Geological evolution of the Eastern Mediterranean. Geol. Soc. of London, Spec. Pubbl.: 569-580.

Kodra A., Vergely P., Gjata K., Bakalli F. and Godroli M., 1993. La formation volcano-sédimentaire du Jurassique supérieur: témoin de l'ouverture du domaine ophiolitique dans les Albanides internes. Bull. Soc. Géol. France, 164(1): 61-67.

Kodra A., Marroni M., Mustafa F. and Pandolfi L., 1996. The characteristics of the sandstone blocks from the Simoni Mélange, Albania. Ofioliti, 21: 55-62.

Lips, A. L. W., White, S. H., Wijbrans, J. R., 1998. (super 40) Ar/(super 39) Ar laserprobe direct dating of discrete deformational events; a continuous record of early Alpine tectonics in the Pelagonian Zone, NW Aegean area, Greece. Tectonophysics, 298: 133-153.

Makris J., 1977. Geophysical investigations of the Hellenides. Hamburger Geophysikalishe Einzelschriften, 33.

Marcucci M., Kodra A., Pirdeni A. and Gjata T., 1994. Radiolarian assemblages in the Triassic and Jurassic cherts of Albania. Ofioliti, Special Issue on "Albanian ophiolites: state of the art and perspectives"(Beccaluva Ed.), 19: 105-115.

Marcucci M. and Prela M., 1996. The Lumi zi (Puke) section of the Kalur Cherts: radiolarian assemblages and comparison with other sections in northern Albania. Ofioliti, 21: 71-76.

Michard A., Chopin C. and Goffé B., 1991. Obduction versus subduction and collision in the Oman case and in the other Tethyan setting. In: Peters T.J., Nicolas A. and Coleman R.G. Eds, Ophiolite genesis and evolution of the oceanic lithosphere. Petrol. and Struct. Geol., 5: 447-467.

Montigny R.,1975. Géochimie comparée des des cortèges des roches océaniques et ophiolitiques. Problème de leur génese. Thèse Doctorat d'etat. Univ. Paris, 288 pp.

Moores E.M. , 1969. Petrology and structure of the Vourinos ophiolitic complex of Northern Greece. Geol. Soc. Am. Spec. Pap., 118, 74 pp.

Mountrakis D., 1986. The pelagonian zone in Greece: a polyphase deformed fragment of the Cimmerian continent and its role in the geotectonic evolution of the eastern mediterranean. Journal of Geology, 83, 707-720.

Nance D., 1981. Tectonic history of a segment of the Pelagonian zone. Can. Journal of Earth Science, 18: 1111-1126.

Naylor M.A. and Harle T.J., 1976. Paleogeographic significance of rocks and structures beneath the Vourinos ophiolite, Northern Greece. Journal Geol. Soc. of London, 132: 667-675.

Nicolas A., Boudier F. and MeshiI. , 1999. Slow spreading accretion and mantle denudation in the Mirdita ophiolite (Albania). Journal of Geophysical Research, 104, B7: 15155-15167.

Peza L.H. and Arkaxhiu F., 1988. Aspekte të Kretakut të zonës Mirdita. Bul. Shk. Gjeol.: 95-103.

Photiades A., Saccani E. and Tassinari R., 2003. Petrogenesis and tectonic setting of volcanic rocks from the subpelagonian ophiolitic mélange in the Agoriani area. Ofioliti, 28: 121-136.

Pichon J.F. and Lys M., 1976. Sur l'existence d'une série du Jurassique superieur a Crétacé inferieur, sourmountant les ophiolites, dans les collines de Krapa (massif de Vourinos, Grèce C.R. Acad. Sci. Paris, 282: 523-526.

Pichon J.F. and Brunn J.H., 1985. An inverted metamorphism below the Vourinos ophiolitic suite, Greece. In: Desmons J. Ed. Ophiolites through time. Ofioliti, 10: 363-374.

Pomonis P., Tsikouras B. and Hatzipanagioutou K., 2004. Origin, evolution and radiometric dating of subophiolitic metamorphic rocks from the Koziakas ophiolite (W.Thessaly, Greece). Neues Jarbuch fur Mineralogie – Abh., 3: 255-276.

Prela M., 1994. Mirdita Ophiolite Project: 1.Radiolarian biostratigraphy of the sedimentary cover of the ophiolites in the Mirdita area (Albania): initial data. Ofioliti, 19(2): 279-286.

Rassios A., Beccaluva L., Bortolotti V. Mavrides V. and Moores E.M., 1983. The Vourinos ophiolitic complex: the field excursion guidebook. Ofioliti, 8: 275-292.

Rassios A. and Smith A.G., 2000. Constraints on the formation and emplacement age of western greek ophiolites (Vourinos, Pindos and Othris) inferred from deformation structure in peridotites. In Dylek Y., Moores E.M., Elthon D. and Nicolas A. Eds. Ophiolite and oceanic crust: new insights from field studies and ocean drilling program. Geological Society of America Special paper 349: 473-483.

Robertson A.H.F and Dixon J.E., 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. Dixon J.E. and Robertson A.H.F. (Eds.), The Geological evolution of the Eastern Mediterranean. Geol. Soc. of London, Spec. Pubbl.: 1 - 73.

Robertson A.H.F. and Shallo M., 2000. Mesozoic-Tertiary tectonic evolution of Albania in its regional eastern Mediterranean context. Tectonophysics, 316: 197-254.

Roddick, J. C., Cameron, W. E., Smith, A. G., 1979. Permo-Triassic and Jurassic (super 40) Ar- (super 39) Ar ages from Greek ophiolites and associated rocks. Nature, 279, I5716: 788-790.

Ross J.V., Mercier J.C.C., Avé Lallemant H.G., Carter N.L. and Zimmermann J., 1980. The Vourinos ophiolite complex: the tectonic suite. Journal of Structural Geology, 15: 571-591.

Ross J.V. and Zimmermann J., 1996. Comparison of evolution and tectonic significance of the Pindos and Vourinos ophiolite suites, northern Greece. Tectonophysics, 256: 1-15.

Saccani E., Photiades A. and Padoa E., 2003. Geochemistry, petrogenesis and tectono-magmatic significance of volcanic and subvolcanic rocks from the Koziakas Mélange (Western Thessaly, Greece). Ofioliti, 28: 43-57.

Saccani E. and Photiades A., 2004. Mid-ocean ridge and supra-subduction affinities in the Pindos ophiolites (Greece): implications fro magma genesis in a forearc setting. Lithos, 73: 229-253.

Saccani E., Padoa E. and Photiades A., 2004. Triassic mid-ocean ridge basalts from the Argolis Peninsula (Greece): new constraints for the early oceanization phases of the Neo-Tethyan Pindos basin. In: Dilek Y. and Robinson P.T. (Eds.) "Ophiolites in earth history", Geol. Soc. London Sp. Publ., 218: 109-127.

Schermer E.R., 1993. Geometry and kinematics of continental basement deformation during the Alpine orogeny, Mt. Olympos region, Greece. Journal of Structural geology, 15: 571-591.

Shallo M., 1991. Ophiolitic mélange and flyschoidal sediment of the Tithonian - lower Cretaceous in Albania. Terra Nova, 2: 476-483.

Shallo M., Kote D. and Vranai A., 1987. Geochemistry of the volcanics from ophiolitic belts of Albanides. Ofioliti, Special Issue on Geochemistry of ophiolites, 12 (1): 125-136.

Shallo M., Kodra A. and Gjata K., 1992. Geotectonics of the Albanian ophiolites. Malpas et al. (Eds.), Proceedings of the Internat. Ophiolite Symp. on "Troodos ophiolite and oceanic lithosphere, Cyprus,1990: 265-269.

Shallo M., 1992. Geological evolution of the Albanian ophiolites and their platform periphery. Geolog. Rund., 81/3: 681-694.

Shallo M., 1994. Outline of the Albanian Ophiolites. In: Beccaluva L. Ed., Special Issue on "Albanian ophiolites: state of the art and perspectives". Ofioliti, 19 (1): 57-75.

Skarpelis N., Hatzipanagiotou K. and Kaiserloglou M., 1992. Manganiferous cherts in siliceous sediments overlying the Koziakas ophiolite, western Thessaly, Greece. Can. Mineral., 30: 415-420.

Smith A.G., 1993. Tectonic significance of the hellenic-Dinaric ophiolites. In. Prichard H.M., Alabaster T., Harris N.B.W. and Neray C.R. Eds, magmatic processes and Plate tectonics. Spec. publ. Geol. Soc of London, 76: 213-243.

Spray J.G. and Roddick J.C., 1980. Petrology and 40Ar/39Ar geochronology of the some Hellenic sub-ophiolite metamorphic rocks. Contrib. Miner. Petrol., 72: 43-55.

Sun S.-S. and McDonough W.F., 1989. Chemical and isotopic-systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders A.D. and Norry M.J. (Eds.) Magmatism in the Ocean Basins, Geol. Soc., London, Spec. Publ., 42: 313-345.

Terry J. and Mercier M., 1971. Sur l'existence d'une série détritique berriasienne intercalèe entre la nappe des ophiolites et le flysch éocène de la nappe du Pinde (Pinde septentrionalal, Grèce). C.R. Somm. géol. France, 2: 71 -73.

Vergely P., 1976. Origine "vardarienne", chevauchement vers l'ouest et rétrocharriage vers l'est des ophiolites de macedonie (Grèce) au cours du Jurassique supèrieure-Eocrétace. C.R. Acad. Sci. Paris, 280: 1063-1066.

Zimmerman J., 1972. Emplacement of the Vourinous ophiolite complex, northern Greece. In. Shagam R. et al. Eds., Studies in earth and Space Sciences. Geol. Soc. Am. Memoirs, 132: 225-239.

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