PETROGENESIS AND TECTONIC SETTING OF VOLCANIC ROCKS FROM THE SUBPELAGONIAN OPHIOLITIC MÉLANGE IN THE AGORIANI AREA (OTHRYS, GREECE)

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ABSTRACT

In the northwestern end of the Othrys Massif, the lowermost unit of the Othrys ophiolitic complex is represented by the Agoriani Mélange, which is a typical tectono-sedimentary mélange developed at a convergent margin, and comprises ophiolite-derived turbidites and debris flow deposits including, in turn, various oceanic-crust lithotypes. The volcanic rocks recorded in the Agoriani Mélange are represented by chemically distinct rock groups.

Group 1 is characterized by MOR-type basalt and basaltic andesite, showing high-Ti geochemical affinity, and flat HFSE patterns, as well as mild LREE depletion (La_N/Sm_N = 0.48-0.69) coupled with an overall enrichment for HREE. The chemistry of these rocks is compatible with about 20% partial melting of an undepleted MORB-type mantle source.

Group 2 is represented by basalts whose geochemical characteristics are intermediate between typical low-Ti island arc tholeiites and pure high-Ti MORBs. Nonetheless, the strong depletion of Th, Nb, and LREE (La_N/Sm_N = 0.02-0.20) and the mild depletion of HFSE are consistent with the compositions of magmas generated in supra-subduction zone settings from partial melting of refractory mantle sources. In particular, these rocks are compatible with about 10% partial melting from a mantle source that had experienced about 20% previous MORB melt extraction.

Group 3 includes basaltic andesites and andesites showing chemical features typical of very low-Ti (boninitic) rocks: that is, strong depletion of HFSE and depleted, U-shaped REE patterns. The chemical features displayed by Group 3 rocks are compatible with 10 - 20% partial melting of mantle sources (enriched in LILE and LREE by subduction-derived fluids), representing the residua after Group 2 primary melt extraction.

One sample is represented by alkaline basalt, as testified by the incompatible elemental ratios, as well as the marked LILE and LREE enrichments. The overall chemical features are comparable to those of typical ocean island basalts (OIBs), and are consistent with ca. 5% partial melting of a theoretical plume source.

According to the regional reconstruction of the Neo-Tethys, the volcanic lithologies included in the Agoriani Mélange are consistent with the magmatic activities that occurred in the Pindos oceanic basin from the Permian-Triassic rifting stage and Triassic-Jurassic oceanization (including seamounts) to the Middle-Late Jurassic intra-oceanic subduction.

Group 2 basalts, in particular, correspond to basalts with peculiar chemistry sporadically found in both north and south Albania. The genesis and tectono magmatic significance of these basalts is discussed in this paper on the bases of three possible models.

INTRODUCTION

Mélanges are common at convergent plate margins, and they result from a combination of tectonic and sedimentary processes operating at subduction zones.

Many tectono-sedimentary mélanges incorporate tectonically eroded and/or fragmented blocks of both oceanic and continental material; they are sometimes affected by variable metamorphic imprinting. Sources of blocks include materials deposited in the trench axis, materials derived from the forearc region and overriding plate and materials derived from the oceanic subducting plate.

The compositional and petrological character of volcanic rocks included in mélanges thus provide important information about the magmatic activities that developed from the early stages of generation of oceanic lithosphere (including seamounts) up to its consumption in a converging setting.

The Mirdita-Subpelagonian Zone (Fig. 1) consists of Jurassic ophiolites and related sedimentary rocks. Ophiolites include sequences generated in both a mid-ocean ridge and in a supra-subduction zone (Beccaluva et al., 1994; Robertson, 2002). Sedimentary rocks mainly include a sub-ophiolitic mélange, radiolarian cherts at the top of the ophiolitic volcanics, a supra-ophiolitic flysch, and Triassic neritic carbonates and pelagic cherty limestones.

According to Robertson (2002 and references therein), and Pe-Piper and Piper, (2002 and references therein), the Mirdita-Subpelagonian Zone represents an oceanic paleotectonic settings, which was located between the Adria continental margin, in the west and the Pelagonian continental margin, in the east. At present, these fundamental paleo-tectonic settings are represented by westward-verging tectonostratigraphic zones (Fig. 1).

The Agoriani Mélange is part of a discontinuous belt of ophiolitic mélange terranes that crop out in the Mirdita-Subpelagonian Zone of the Dinaride-Albanide-Hellenide orogenic belt, like, for example, the Rubik Complex in Albania (Bortolotti et al., 1996), Avdella Mélange in the Pindos Massif (Jones and Robertson, 1991), Koziakas Mélange in the Koziakas Massif (Saccani et al., 2003a), and Argolis Mélange (Clift, 1996; Saccani et al., 2003b).

The Agoriani Mélange surfaces at the northwestern end of the Othrys ophiolitic massif (Fig. 1), where it occupies the lowermost tectonic position; for this reason, it has previously been described as the "Lower Ophiolitic Unit" of the Othrys ophiolitic massif. It comprises: (1) Carnian-Norian cherty limestone (Courtin, 1979; Ferrière, 1982); (2) radiolarian cherts; (3) ophiolite-derived turbidites, debris flow and slide deposits, which are in turn represented by various oceanic-crust lithotypes. The variety of blocks and clasts, the nature of the matrix, and the intense tectonic deformation collectively suggest that the Agoriani Mélange repre-

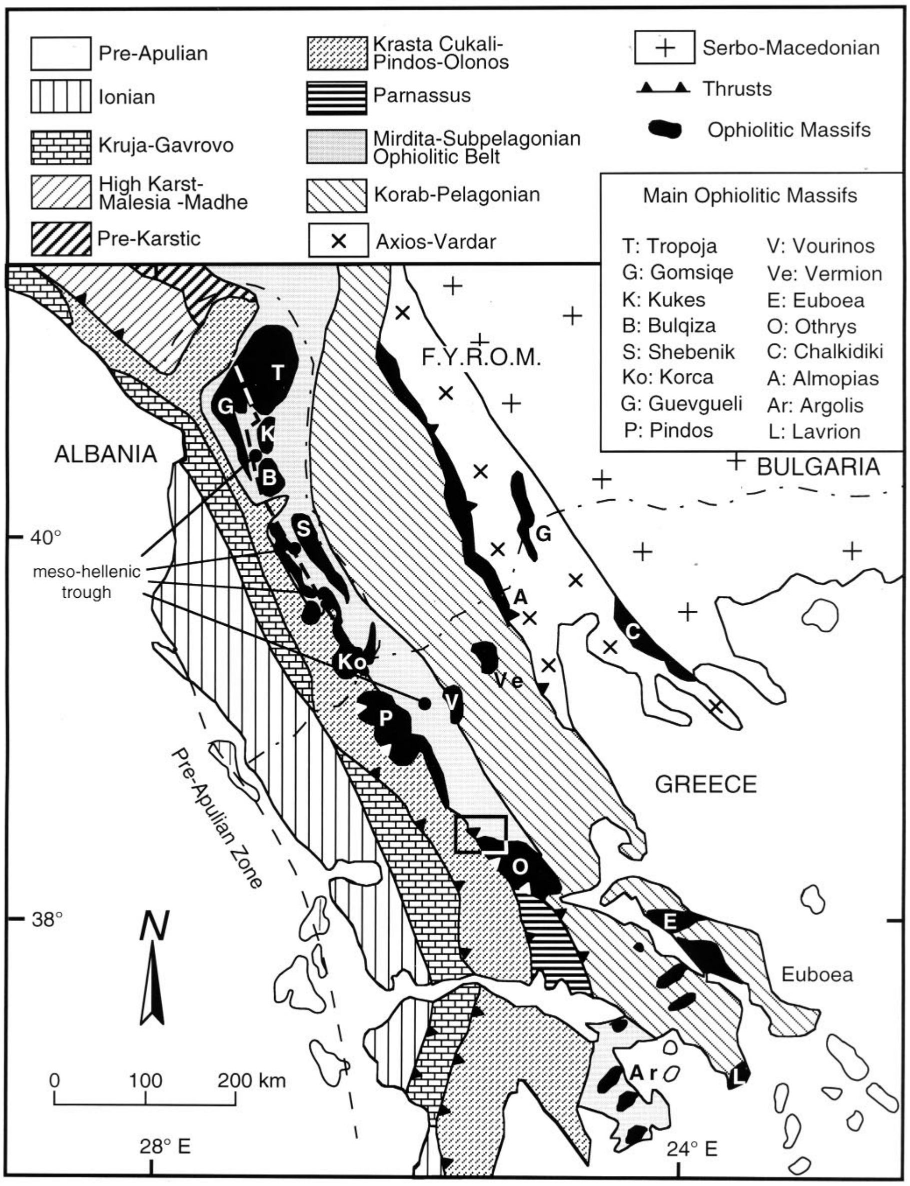

Figure 1: Simplified tectonic map of the central Dinaride-Albanide-Hellenide area showing the main tectono-stratigraphic units. Compiled after Robertson (2002 and reference therein). Box indicates the studied area expanded in Fig. 2.

sents a typical tectono-sedimentary mélange that was developed at a convergent margin within the Neo-Tethys oceanic basin (Ferrière et al., 1988; Robertson, 1991). A careful examination of the volcanic rocks included in the Agoriani Mélange can provide information and constraints on the nature of magmatic activities during the generation of the Neo-Tethyan oceanic lithosphere, as well as on the magmatic processes that occurred during the intra-oceanic convergent phase.

The purpose of this paper is thus to document the occurrence of different types of ophiolitic rocks and seamount material in the Subpelagonian Agoriani Mélange, with particular regard to their chemistry, in order to constrain the nature of magmatism, and its tectonic significance, associated with oceanic crust generation in the Othrys sector of the Triassic-Jurassic Neo-Tethyan Pindos oceanic basin.

GEOLOGICAL SETTING

The Othrys ophiolite complex (Fig. 1) is one of the major Subpelagonian ophiolite complexes cropping out in continental Greece. In northwestern Othrys, the ophiolite complex is generally thrust over the Maastrichtian - Eocene Pindos Flysch of the Pindos Zone (Fig. 2). Nonetheless, it overthrusts in places either the Koziakas (Subpelagonian Zone) or the Thymiama (Beotian Zone) sedimentary successions, which, in turn are thrust onto the Pindos Flysch (Fig. 2) (Ferrière, 1982; Ferrière et al., 1988). In the study area, the Koziakas succession consists of Triassic-Jurassic red chert sequences bearing redeposited limestone beds, whereas the Thymiama succession is composed of Late Cretaceous conglomerates and calcarenite limestones (Hatzipanagiotou et al., 1994).

In the north-western part of the Othrys Massif (Agoriani area), the ophiolitic complex consists of a stack of thrust units (Fig. 2) that have been subdivided as follows: 1) a Lower Unit, representing the Agoriani ophiolitic mélange, 2) a Middle Unit, mainly consisting of serpentinized mantle harzburgites, and 3) an Upper Unit, predominantly comprising serpentinized mantle plagioclase lherzolites (Celet et al., 1980; Photiades, 1999).

In the areas of Agoriani and Makrirachi (Fig. 2) a sedimentary sequence including Late Cretaceous limestones and Paleocene flysch uncomformably overlie the ophiolitic units (Hatzipanagiotou et al., 1994). The limestones are rich in rudist fragments at the base, whereas their upper parts are nodular with abundant chert, passing to red carbonate mudstones and, finally, to a Lower Tertiary flysch (not surfacing in the studied area). "Décollement" contacts, referred to Tertiary compressional events, can be observed in places between the limestones and underlying ophiolite units (Ferrière, 1982; Ferrière et al., 1988).

Finally, Upper Oligocene-Miocene molasse deposits consisting of ophiolitic conglomerates, coarse-grained sandstones and fine-grained sandstones top the whole ophiolitic thrust system (Fig. 2).

The Lower Ophiolitic Unit consists of a tectono-sedimentary ophiolitic mélange, which comprises slivers of: Carnian-Norian thin cherty platy limestone (Courtin, 1979; Ferrière, 1982); radiolarian red-cherts sequences showing both Triassic and Jurassic age (Chiari, personal comunication); ophiolite-derived turbidite and debris flow olistostrome sequences of Malm age (Ferrière et al., 1988), and altered pillow lavas topped by red cherts.

In the area between Ekara and Agoriani (Fig. 2) the turbidite and debris flow successions are 150 - 200 m thick and are underlain by bedded radiolarian red-cherts. Matrix-supported conglomerates predominate, interbedded with coarse- and fine-grained sandstones, whereas subordinate horizons of clast-supported conglomerates are locally found. Conglomerates contain a variety of rock types, including ophiolite-derived rocks (e.g., basalts, dolerites, gabbros, harzburgites, serpentinites), sedimentary rocks (e.g., red-cherts, limestones, and greywackes), and rare metamorphic rocks (amphibolites and schists). Similar lithologies are also found in the turbiditic sandstones. It should be noted that a large variety of both intrusive and extrusive mafic lithologies included in the debris flow conglomerates no longer surface in the overlying ophiolite thrust sheets.

The turbidite and debris flow successions were probably emplaced onto the continental margin during tectono-sedimentary events related to the Upper Jurassic closure of the Pindos oceanic basin.

The Middle Ophiolitic Unit: consists of thrust sheets of variably serpentinized mantle harzburgites (Hynes, 1972; Menzies, 1974) characterized by moderate to well-developed tectonitic structures (mainly represented by mineral stretching and spinel lineation), and which are cut by rodingitized gabbro dikes. In addition, dunite layers and/or irregular bodies are frequent in the upper part of the harzburgite masses, whereas mylonitized serpentinites are common at the base of the thrust sheets.

Thin amphibolite slivers commonly occur at the base of the Middle Unit. These amphibolites yield radiometric dates ranging from 177±4 Ma to 162-153 Ma (Spray and Roddick, 1980; Ferrière, 1982; Hatzipanagiotou et al., 1994), which testifies for a Late Jurassic intra-oceanic decoupling of the Othrys ophiolites.

The Upper Ophiolitic Unit: consists of serpentinized plagioclase-lherzolites, which are affected by both brittle and ductile deformations and are characterized by the occur-

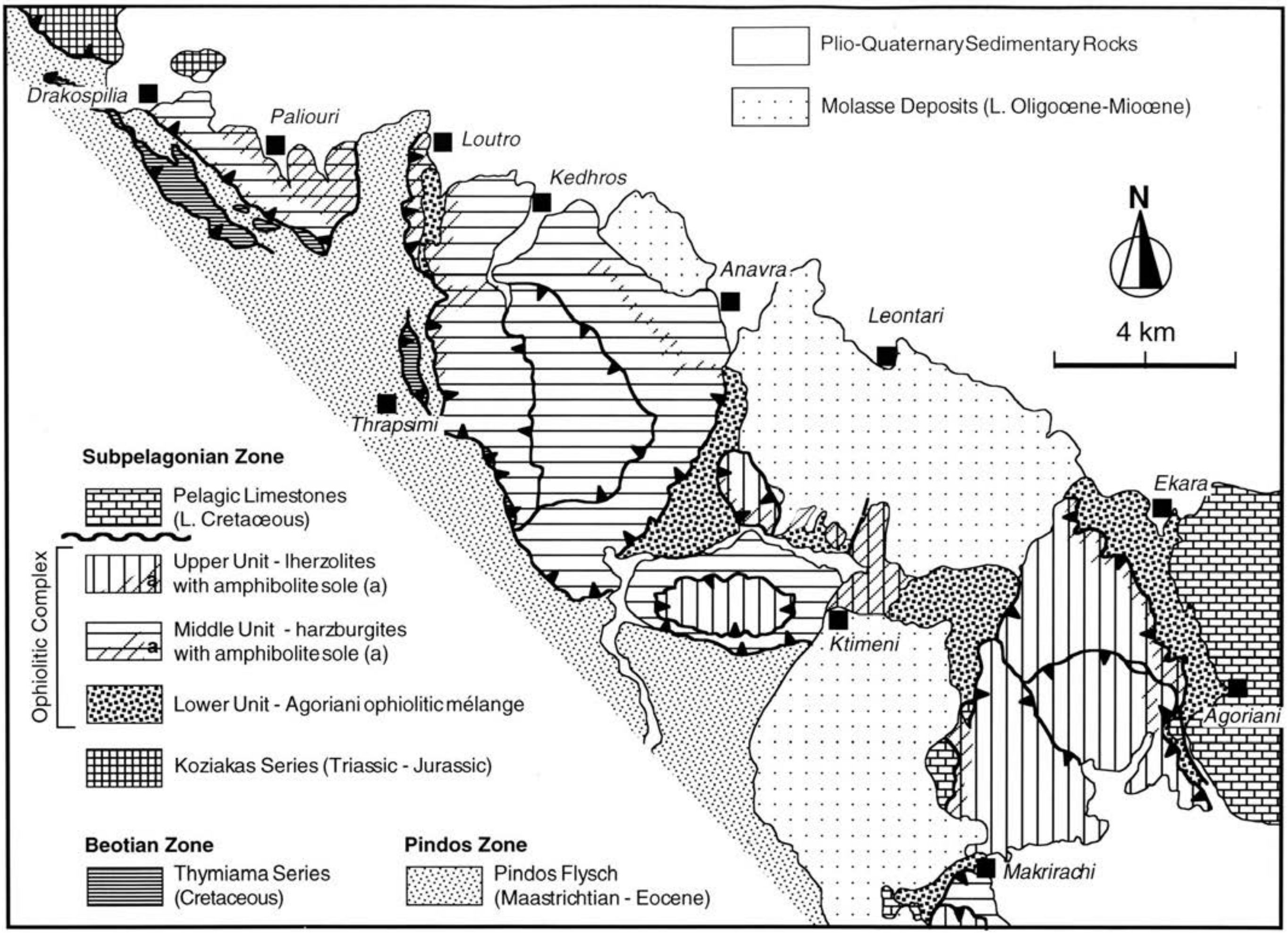

Fig. 2 - Simplified geological map of the Agoriani area. Modified after Marinos et al. (1962).

rence of several shear zones. Like the Middle Unit, lherzolites are cross-cut by rodingitized gabbro dykes, while the base of the Unit consists of highly sheared serpentinites with local inclusions of gabbro and amphibolite slivers.

In northwestern Othrys, the Middle and Upper ophiolitic units tectonically overthrust the tectono-sedimentary ophiolitic mélange of the Lower Unit.

On the bases of structural data, previous works (Smith et al., 1975; Ferrière and Vergely, 1976; Ferrière, 1982; Rassios and Konstantopoulou, 1993) concluded that the emplacement of the Subpelagonian ophiolites occurred from W (SW) to E (NE) during the Late Jurassic-Early Cretaceous. Smith and Woodcock (1976) proposed a similar direction for the tectonic transport, though they suggested a mid Cretaceous age for these movements. This internal thrusting of the Othrys ophiolitic complex occurred during the intra-oceanic compressional phases related to the early convergent tectonics that affected the Pindos oceanic basin, as testified by the occurrence of amphibolitic metamorphic soles. Afterward, ophiolitic sequences were discordantly covered by Upper Cretaceous limestone and Lower Tertiary flysch. Subsequently, the westward or southwestward overthrusting of the Othrys Subpelagonian ophiolitic stack onto the Pindos Flysch occurred during a post-Upper Eocene late compressional phase.

Finally, the whole area has been affected by different Oligocene-Miocene normal faulting events, which also allowed deposition of the molasse deposits.

SAMPLING AND METHODS

Although a variety of intrusive and extrusive lithologies are represented in the Agoriani Mélange, for the present study sampling was exclusively focused on mafic volcanic types in order to investigate geochemical variability in the upper part of the oceanic crust and seamounts of the Neo Tethys oceanic basin. A total of sixteen samples were collected, mostly from the area between the villages of Ekara and Agoriani (Fig. 2), where the best preserved outcrops are found. Samples consist of clasts and blocks included in the mélange, thus no stratigraphical relationships can be assumed between them; nonetheless, they represent volcanic varieties existing in the former oceanic basin.

Bulk-rock major and trace element analyses were performed by X-ray fluorescence (XRF) and by inductively coupled plasma-mass spectrometry (ICP-MS) at the Department of Earth Sciences of the University of Ferrara. Chemical compositions are given in Table 1. The XRF apparatus used was a Philips PW 1400 automated spectrometer, while the ICP-MS apparatus was a VG Elemental Plasma Quad PQ2 Plus spectrometer. Accuracy and detection limits were determined using a set of international standards. Accuracy for trace element XRF analyses is less usually than 6%, with the exception of Ba (8%), Th (10%), and Nb (13%). Detection limits are: Zn, Ba = 5 ppm; Ni, Co, Cr, V = 1 ppm; other elements = 2 ppm. The precision of XRF analyses (determined by replicate analyses using a Philips PW 1470 at the University of Modena) was less than 5% for all elements. Accuracy for ICP-MS analyses is in the range 2 - 7 relative %, with the exception of Nb (12%), Ta (16%), and U (9%). Detection limits (in ppm) are: Sc = 0.29; Y, Nb, Hf, Ta = 0.02; Th, U = 0.01; light and medium REE < 0.07; heavy REE < 0.13.

PETROGRAPHY

All samples underwent variable degrees of ocean-floor hydrothermal alteration under static, low- to intermediate-greenschist facies conditions. This alteration has commonly resulted in intensive recrystallization of the primary igneous phases - including the replacement of plagioclase by albite or clay minerals - as well as the transformation of clinopyroxene into actinolite-tremolite minerals or, subordinately, into chlorite. By contrast, the primary igneous textures are well preserved.

The petrographical features of the analyzed samples are presented below according to the four different rock varieties recognized on chemical bases.

Group 1: high-Ti basalt and basaltic andesite show a variety of textures. They include very fine-grained aphyric varieties with ophitic to sub-ophitic groundmasses, coarse-grained aphyric types characterized by plagioclase and poikilitic clinopyroxene, and slightly porphyritic types (PI < 10%), in which plagioclase phenocrysts are settled in sub-ophitic to intergranular groundmasses. In all samples groundmass mineral assemblage includes euhedral plagioclase and anhedral to interstitial clinopyroxene. In few samples small veins filled by chlorite occur.

Group 2: intermediate-Ti basalt display textures very similar to those observed in high-Ti rocks, ranging from aphyric to moderately porphyritic. Both varieties show groundmasses from ophitic to sub-ophitic. In porphyritic varieties, phenocrysts are represented either by plagioclase (sample EK1d), or plagioclase and clinopyroxene (sample EK2i). In basalt EK2a a coarse-grained groundmass characterized by plagioclase and poikilitic clinopyroxene is observed.

Group 3: very low-Ti basaltic andesite and andesite display textures ranging from medium-grained aphyric to porphyritic varieties (PI = 2 - 30), with phenocrysts of clinopyroxene and subordinate plagioclase set in intergranular to sub-ophitic, variably-sized groundmasses. A coarse-grained doleritic texture is observed in basaltic andesite EK2F, while andesite EK2C is characterized by a moderate amount of lobate opaque minerals and rare chlorite-filled veins. Andesite EK1L displays microlites of clinopyroxene, entrapped in poikilitic plagioclase, while andesite EK2D is the only sample that shows glomeroporphyritic texture with plagioclase and clinopyroxene phenocrysts.

Alkaline basalt is represented by only one sample showing hyalophitic texture with scarce calcite-filled amygdules. The volcanic glass, deeply altered, is replaced by a cryptocrystalline assemblage of clay minerals and chlorite.

GEOCHEMISTRY

The geochemical results (Table 1) indicate that, in many samples, ocean-floor hydrothermal processes lead to a variable mobilization of large ion lithophile elements (LILE), such as Ba, Rb, K, and Sr. By contrast, the transition metals (V, Cr, Mn, Fe, Co, Ni, Zn) and high field strength (HFS) elements (Zr, Y, Nb, Ti, Hf, P and REE) are relatively immobile, and largely reflect magmatic abundance (Pearce and Norry, 1979; Shervais, 1982; Pearce, 1983; Beccaluva et al., 1983). For these reasons, the discussion on the geochemical and petrogenetic features of the studied rocks is mainly based on those elements which are immobile during metamorphic and alteration processes.

The data presented in this paper point out the occurrence of four geochemically distinct groups of lavas in the Agoriani Mélange: 1) high-Ti basalt and basaltic andesite; 2) intermediate-Ti basalt; 3) very low-Ti basaltic andesite and andesite; 4) alkaline basalt. The major geochemical differences between these groups lie in the different concentrations of high field strength elements (HFSE) such as P, Zr, Ti, Y, and REE, as well as V, Cr, and Ni.

Group 1: high-Ti basalt and basaltic andesite

Group 1 basalts range in composition from basalts to basaltic andesite (SiO_2 = 43.78-52.26 wt%). The generally high MgO (7.99-11.16 wt%) and CaO (10.35-14.27 wt%) contents, coupled with high Mg# (Fig. 3), indicate a rather primitive nature. TiO_2 typically range from 0.76 to 1.35 wt% (these values are not correlated with FeO_t, Table 1), whereas they show good correlation with incompatible elements including P_2O_5 (0.17 - 0.25 wt%), Zr (47-102 ppm), Y (17-32 ppm), and Nb (1.09-2.25 ppm). The Ti/V ratios displayed by Group 1 basalts range from 26 to 34 (Fig. 4) and cluster in the field for basalts generated at mid-ocean ridge settings (Shervais, 1982), with the exception of sample EK2a, which shows a Ti/V ratio = 17. Basalts display rather high Cr (372-531 ppm) and Ni (127-208 ppm) contents (Table 1, Fig. 3). The relative distribution of high field strength elements (HFSE) concentrations (Fig. 5a) indicates that these rocks share affinities with ocean-floor

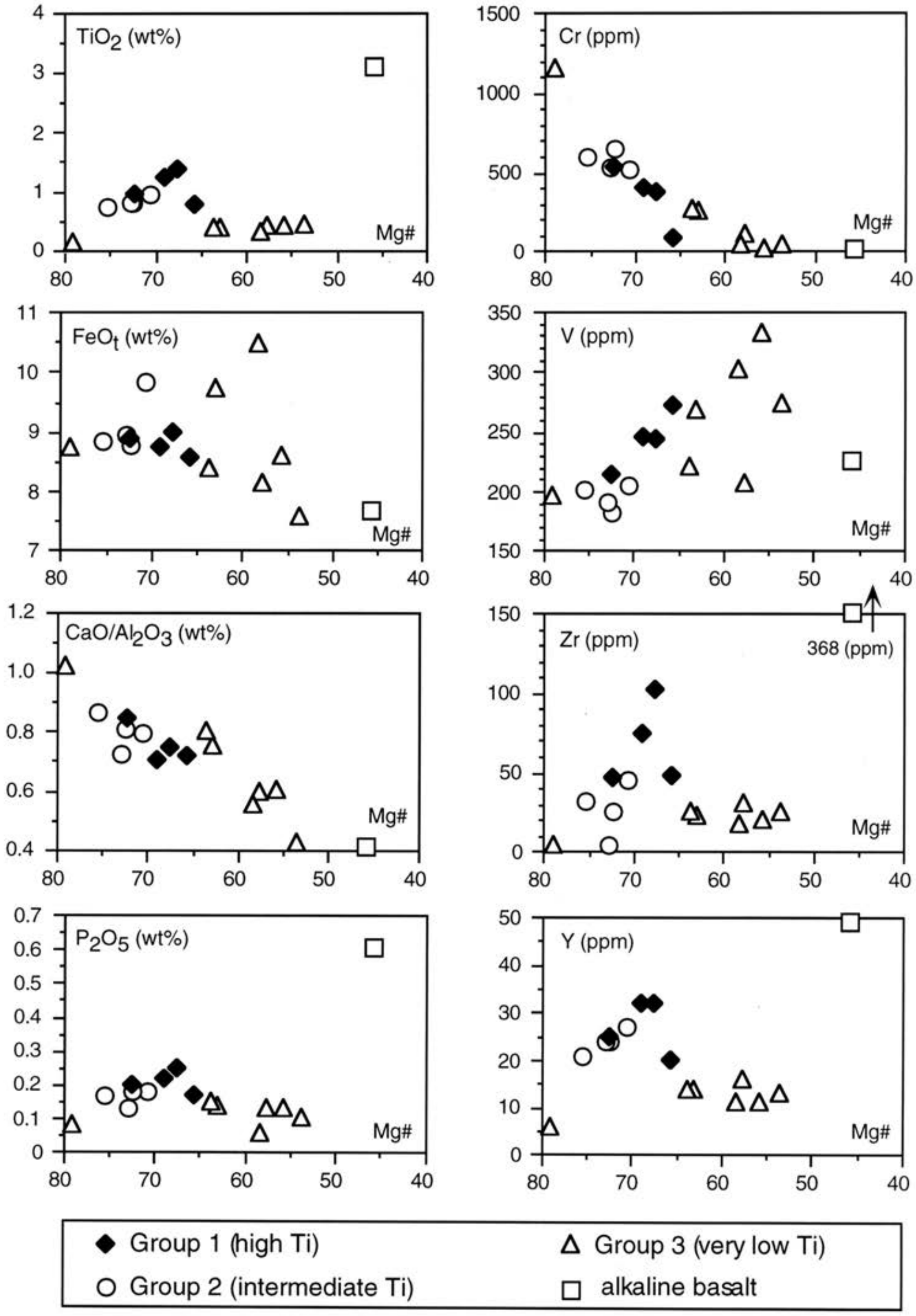

Fig. 3 - Variation of selected major and trace elements vs. Mg# for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit).

Table 1 - Bulk rock major and trace element analyses of volcanic rocks from the “Lower Ophiolitic Unit” of the Agoriani area.

	Group 1 (high Ti)				Group 2 (intermediate Ti)			
Sample	EK 1j	EK 1f	EK 2j	EK 2a	EK 1d	EK 1g	EK 2i	EK 1a
Rock	Bas.	Bas.	Bas.	Bas.And.	Bas.	Bas.	Bas.	Bas.
XRF Analyses:								
SiO_2	43.78	48.62	50.11	52.26	41.46	42.14	44.47	44.88
TiO_2	0.92	1.35	1.20	0.76	0.91	0.71	0.79	0.77
Al_2O_3	16.87	15.40	14.67	15.45	17.67	15.75	17.18	17.22
Fe_2O_3	1.14	1.17	1.14	1.12	1.26	1.11	1.13	1.16
FeO	7.61	7.81	7.57	7.48	8.37	7.37	7.56	7.72
MnO	0.14	0.16	0.18	0.22	0.24	0.17	0.14	0.16
MgO	11.16	9.12	9.41	7.99	11.25	12.68	11.15	11.61
CaO	14.27	11.52	10.35	11.08	13.99	13.68	13.89	12.48
Na_2O	1.29	2.73	3.19	2.21	1.12	0.88	1.39	1.62
K_2O	0.01	0.34	0.28	0.19	0.04	0.01	0.01	0.04
P_2O_5	0.19	0.25	0.22	0.17	0.17	0.16	0.17	0.13
L.O.I.	2.62	1.54	1.67	1.07	3.52	5.33	2.12	2.18
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mg#	72.3	67.5	68.9	65.6	70.6	75.4	72.4	72.8
Zn	42	47	9	65	76	75	64	77
Ni	208	134	127	41	211	296	290	231
Co	41	37	41	36	46	43	46	48
Cr	531	372	404	78	522	600	655	534
V	215	244	246	272	206	201	183	192
Rb	n.d.	3	n.d.	2	n.d.	n.d.	n.d.	n.d.
Sr	329	235	145	141	227	182	100	75
Ba	23	57	25	33	29	31	31	26
Th	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	n.d.	2	n.d.	2	n.d.	n.d.	n.d.	n.d.
Zr	47	102	75	48	45	32	26	5
Y	25	32	32	20	27	21	24	24
ICP-MS Analyses:								
Sc	54.0	50.0		35.4	32.0	28.5	35.5	28.2
Nb	1.25	2.25		1.09	0.22	0.17	0.08	0.15
La	1.42	3.50		1.41	0.43	0.40	0.24	0.04
Ce	3.99	10.4		3.92	2.30	1.61	1.15	0.32
Pr	0.81	1.85		0.68	0.58	0.38	0.41	0.16
Nd	5.34	9.80		3.73	4.08	2.57	2.91	1.79
Sm	1.91	3.25		1.37	1.95	1.26	1.56	1.28
Eu	0.81	1.16		0.56	0.71	0.45	0.66	0.51
Gd	3.27	3.93		1.62	2.20	1.63	2.54	1.66
Tb	0.68	0.74		0.37	0.53	0.39	0.54	0.42
Dy	4.45	4.73		2.48	3.58	2.71	3.58	2.97
Ho	0.97	1.02		0.61	0.87	0.66	0.82	0.72
Er	2.74	2.88		1.60	2.29	1.74	2.31	1.93
Tm	0.42	0.42		0.27	0.37	0.29	0.37	0.32
Yb	2.57	2.72		1.73	2.34	1.85	2.22	2.00
Lu	0.39	0.40		0.26	0.35	0.28	0.33	0.30
Hf	1.90	2.39		1.04	1.24	0.84	0.84	0.62
Ta	0.19	0.19		0.11	0.13	0.08	0.05	0.10
Th	0.09	0.11		0.11	0.01	0.01	0.01	0.01
U	0.03	0.02		0.09	0.01	0.01	0.01	0.01
FeO_t	8.87	9.00	8.74	8.58	9.85	8.84	8.77	8.96
Ti/V	26	34	30	17	28	22	27	25
Zr/Y	1.86	3.14	2.34	2.44	1.68	1.49	1.10	0.21
Nb/Y	0.05	0.07		0.06	0.01	0.01		0.01
$(La/Sm)_N$	0.48	0.69		0.66	0.14	0.20	0.10	0.02
$(Sm/Yb)_N$	0.99	1.33		0.88	0.93	0.76	0.78	0.71
$(La/Yb)_N$	0.40	0.92		0.59	0.13	0.15	0.08	0.01

Fe_2O_3 = FeO x 0.15; Mg# = 100 x Mg/(Mg+Fe^{2+}), where Mg = MgO/40 and Fe = FeO/72. n.d. = not detected. Normalization values for REE ratios are from Sun and McDonough (1989).

	Group 3 (very low Ti)							Alkaline basalt
Sample	EK 1b	EK 5	EK 2e	EK 2f	EK 2c	EK 2d	EK 1l	EK 1c
Rock	B.And.	B.And.	B.And.	B.And.	And.	And.	And.	Bas.
XRF Analyses:								
SiO_2	52.19	53.82	54.10	54.99	56.96	58.69	58.77	51.33
TiO_2	0.14	0.32	0.40	0.38	0.42	0.40	0.42	2.92
Al_2O_3	10.19	14.96	14.15	14.26	15.74	14.97	15.82	15.48
Fe_2O_3	1.14	1.34	1.28	1.10	1.13	1.07	0.99	0.96
FeO	7.59	8.91	8.50	7.31	7.50	7.10	6.58	6.40
MnO	0.19	0.18	0.24	0.14	0.09	0.16	0.08	0.20
MgO	16.04	6.98	8.08	7.18	5.30	5.42	4.28	3.04
CaO	10.42	8.28	10.68	11.46	9.47	8.95	6.67	6.40
Na_2O	0.37	1.61	1.34	1.69	1.97	1.96	4.28	6.34
K_2O	0.03	0.20	0.17	0.22	0.26	0.16	0.48	0.73
P_2O_5	0.08	0.06	0.14	0.15	0.13	0.13	0.10	0.57
L.O.I.	1.58	3.31	0.94	1.12	1.02	0.98	1.52	5.62
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mg#	79.0	58.3	62.9	63.6	55.7	57.6	53.7	45.8
Zn	52	73	79	21	n.d.	38	15	120
Ni	323	21	65	60	8	32	19	29
Co	49	36	37	36	28	31	23	22
Cr	1162	41	256	264	18	108	41	24
V	197	302	269	222	332	208	274	227
Rb	n.d.	5	4	n.d.	2	n.d.	5	5
Sr	23	115	82	113	107	107	138	300
Ba	31	34	37	34	18	16	50	135
Th	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6
Nb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	49
Zr	4	18	23	26	21	31	26	368
Y	6	11	14	14	11	16	13	49
ICP-MS Analyses:								
Sc	48.9	50.2	36.3			31.2	36.4	20.8
Nb	0.46	0.66	0.99			0.71	0.96	52.4
La	0.35	1.12	1.55			1.87	1.78	45.6
Ce	0.70	2.17	3.66			4.75	3.99	104
Pr	0.12	0.36	0.50			0.66	0.54	10.6
Nd	0.53	1.59	2.39			3.20	2.57	43.1
Sm	0.22	0.61	0.82			1.08	0.88	10.4
Eu	0.09	0.24	0.29			0.40	0.30	3.15
Gd	0.39	0.96	1.01			1.38	1.11	10.5
Tb	0.09	0.20	0.21			0.29	0.24	1.65
Dy	0.70	1.43	1.51			2.01	1.73	8.83
Ho	0.19	0.36	0.36			0.48	0.44	1.73
Er	0.61	1.09	1.03			1.34	1.24	4.59
Tm	0.11	0.19	0.17			0.23	0.21	0.66
Yb	0.77	1.29	1.12			1.56	1.42	3.76
Lu	0.13	0.21	0.17			0.24	0.24	0.61
Hf	0.23	0.69	0.76			1.07	0.88	10.2
Ta	0.06	0.20	0.09			0.06	0.07	3.71
Th	0.08	0.26	0.45			0.50	0.46	6.92
U	0.04	0.12	0.20			0.22	0.17	1.60
FeO_t	8.75	10.45	9.74	8.40	8.60	8.14	7.59	7.69
Ti/V	4	7	9	10	8	12	9	82
Zr/Y	0.67	1.71	1.66	1.87	1.94	1.98	1.95	7.56
Nb/Y	0.08	0.06	0.07			0.13	0.15	1.08
$(La/Sm)_N$	1.05	0.84	1.22			1.12	1.31	2.83
$(Sm/Yb)_N$	0.31	0.51	0.81			0.77	0.69	3.07
$(La/Yb)_N$	0.33	0.43	1.00			0.86	0.90	8.70

basalts. In particular, elements from Nd to Yb exhibit rather flat patterns ranging from 0.5 to 1 times N-MORB (Sun and McDonough, 1989) contents. Accordingly, REE patterns (Fig. 5b) are consistent with N-MORB compositions, as they have a mild light REE (LREE) depletion (La_N/Sm_N = 0.48-0.69) and an overall enrichment for heavy REE (HREE) of 10 - 20 times chondrite (Fig. 5b).

The basaltic andesitic sample shows the highest SiO_2 and lowest Mg# (Table 1) which, however are, coupled with the lowest enrichment of HFSE and REE (Figs. 3, 5a, b).

Group 2: intermediate-Ti basalt

Group 2 volcanic rocks are exclusively represented by basalts with silica content ranging from 41.46 to 44.88 wt%. Table 1 and Fig. 3 report their markedly uniform geochemical characteristics (e.g., TiO_2 = 0.71 - 0.91 wt%, P_2O_5 = 0.13 - 0.17 wt%, Zr = 5 - 45 ppm, Y = 21 - 27 ppm). The Ti/1000 vs. V diagram of Fig. 4 shows that these basalts plot in the MORB field, with Ti/V ratios ranging from 22 to 28. However, this conclusion is in contrast with the strong depletion of Th, Nb and LREE, as well as with the mild depletion of HFSE and the very low Zr/Y ratios, with respect to the N-MORB composition (Figs. 5c, d), which account for an island arc tholeiite affinity (Beccaluva et al., 1984). The marked LREE-depleted nature of these samples is exemplified by the La_N/Sm_N ratios, which are included between 0.02 and 0.20; by contrast, they are characterized by medium to HREE patterns (Fig. 5d) quite similar to those of Group 1 basalts (Fig. 5b), as well as similar amounts of enrichment (10 - 15 times chondritic abundance). Accordingly, the high Mg# (75.4 - 70.6) and Cr (522 - 655 ppm) contents are in the typical range of basalts from low-Ti ophiolites generated in supra-subduction zone (SSZ) settings (Beccaluva et al., 1983).

Group 2 basalts generally show chemical characteristics, which are intermediate between typical high-Ti and low-Ti ophiolitic basalts (Beccaluva et al., 1983). Moreover, in many respects these basalts are chemically comparable to the basalts of "medium-Ti" ophiolites from the northern part of the western ophiolite belt of Albania (Bortolotti et al., 1996; 2002), as well as to the intermediate Ti and Zr ophiolites of southern Albania (Hoeck et al., 2002).

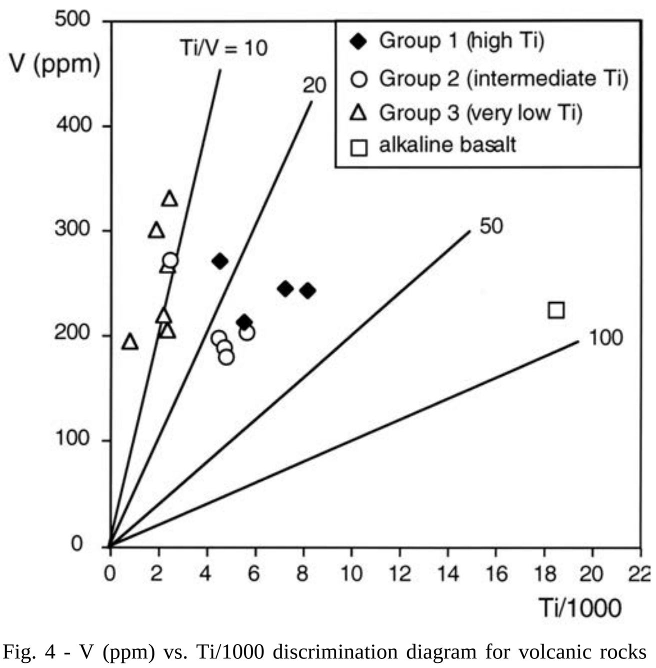

Fig. 4 - V (ppm) vs. Ti/1000 discrimination diagram for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Modified after Shervais (1982). Ti/V < 20 field for convergent plate margin basalts, 20 < Ti/V < 50 field for mid-ocean ridge basalts, Ti/V > 50 field for alkaline within-plate basalts.

Both Albanian analogues, like Group 2 basalt, are characterized by Ti/V ratios greater than 20 and absence of negative Ti anomalies (Fig. 5c).

In summary, though the major element composition of Group 2 basalts does not allow a clear definition of their magmatic affinity, HFSE and REE unequivocally indicate that they bear SSZ magmatic features.

Group 3: very low-Ti basaltic andesite and andesite

Group 3 rocks include basaltic andesites and andesites (SiO_2 = 52.19-58.77), which are typically characterized by very low TiO_2 (0.14 - 0.42 wt%), Zr (4 - 31 ppm), and Y (6 - 16 ppm) contents combined with relatively high amounts of MgO and CaO.

Apart from sample EK1b, which may represent a rather primitive basalt (Mg# = 79), Cr and Ni contents are very low (Table 1, Fig. 3), reflecting early fractionation of olivine, chromite and pyroxene. Among the other chemically distinctive features is the Ti/V ratio (4-12) (Fig. 4) typical of very low-Ti (boninitic) rocks (Shervais, 1982; Beccaluva et al., 1984). On the whole, these rocks show correlation between Mg# and both major and trace elements with the exception of FeO_t and V, which are not correlated for all samples (Fig. 3).

Basaltic andesite EK1b is the most primitive sample of this rock group; it is characterized by low TiO_2 and Al_2O_3 contents coupled with high amounts of MgO, CaO, and Cr (Table 1).

Group 3 basalts are characterized by a strong depletion in HFSE (0.1 - 0.5 times N-MORB composition) and absence of Th, Ta, and Nb negative anomalies (Fig. 5e). REE display the mild U-shaped pattern (Fig. 5f) characteristic of many boninites (Beccaluva and Serri, 1988, Crawford et al., 1989), ranging in concentration between 1 and 5 times medium-REE chondritic abundance.

These features suggest close similarities with very low-Ti (boninitic) lavas found in the forearc regions of oceanic island arcs (Crawford et al., 1989; Shervais, 2001), as well as in many ophiolitic complexes (Beccaluva and Serri, 1988; Bédard, 1999).

Alkaline basalts

The Nb/Y and Zr/Y ratios (Table 1), respectively 1.08 and 7.56, evidence the alkaline character of this rock.

Apart from K and Sr, which may have leached during weathering, the incompatible element abundance (Fig. 5g) is characterized by a regularly decreasing pattern from Th to Yb; there is also a generalised enrichment with respect to MORB, particularly evident for large ion lithophile elements (LILE). The REE pattern (Fig. 5h) displays marked LREE enrichment with respect to HREE, exemplified by a La_N/Yb_N ratio = 8.70. The overall REE enrichment ranges from 20 to 200 times chondrite for Yb and La, respectively.

These chemical features are comparable to those of typical within-plate alkaline basalts, such as ocean island basalts (OIBs) (Frey and Clague, 1983; Lipman et al., 1989; Haase and Dewey, 1996).

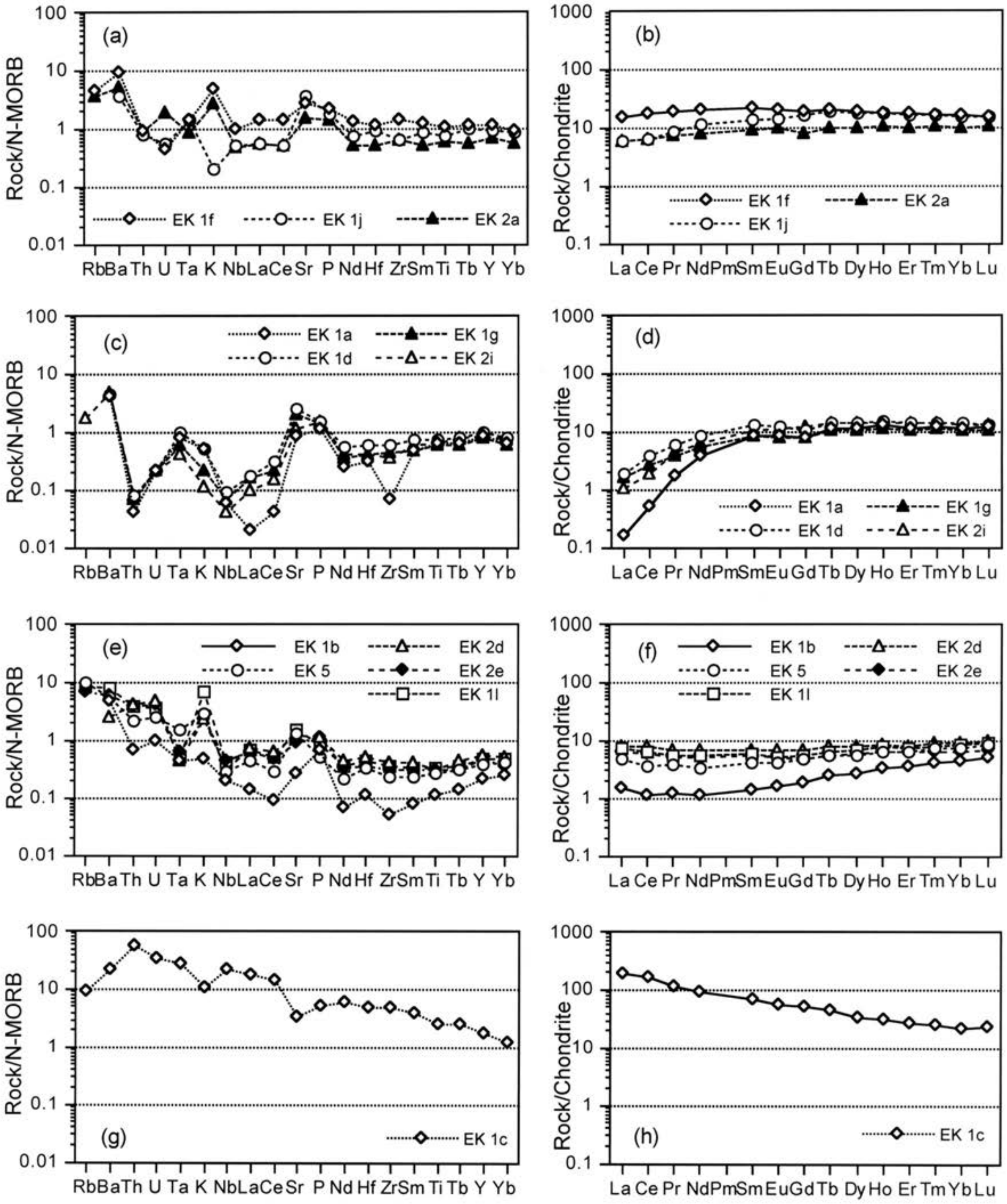

Fig. 5 - N-MORB normalized incompatible element abundance patterns and chondrite-normalized REE abundance patterns for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Normalization values from Sun and McDonough (1989). a, b- high-Ti basalt and basaltic andesite; c, d- intermediate-Ti basalt; e, f- very low-Ti basaltic andesite and andesite; g, h- alkaline basalt.

PETROGENESIS AND TECTONO-MAGMATIC INTERPRETATION

One of the main objectives of this study is to evaluate the nature and tectonic significance of magmatic events that occurred in the Othrys sector of the Tethys, as revealed by the oceanic crust material included in the Agoriani Mélange.

Blocks in this mélange comprise four compositionally different groups of volcanic rocks, which may be related to different source characteristics, associated in turn with distinct tectono-magmatic formation settings. Since no genetic relationships between rocks within each single chemical group are proven, the petrogenetic evolution of the different lava groups cannot be satisfactorily evaluated. The discussion will therefore be restricted to identifying of the possible mantle sources of the distinct lava groups and their related tectonic formation settings.

Group 1: high-Ti basalt and basaltic andesite

The chemistry of the high-Ti basalts suggests melt generation in a mid-ocean ridge tectonic setting. In agreement with Pearce and Norry (1979), in the Zr/Y versus Zr plot of Fig. 6 the partial melting path of the high-Ti rocks intersects the path of the primary or slightly depleted mantle source, suggesting that they probably derived from slightly different primary mantle sources.

The nature (degree of depletion) and degree of melting of

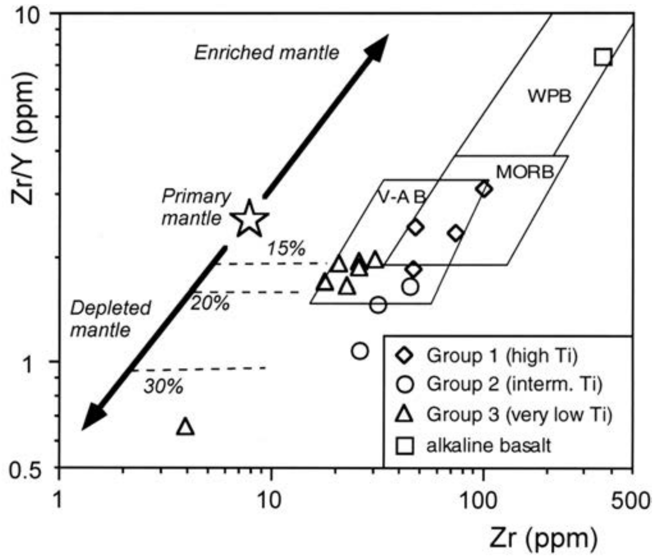

Fig. 6 - Zr/Y vs. Zr discrimination diagram for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Modified after Pearce and Norry (1979). V-A B- volcanic-arc basalts, MORB- mid-ocean ridge basalts, WPB- within-plate basalts.

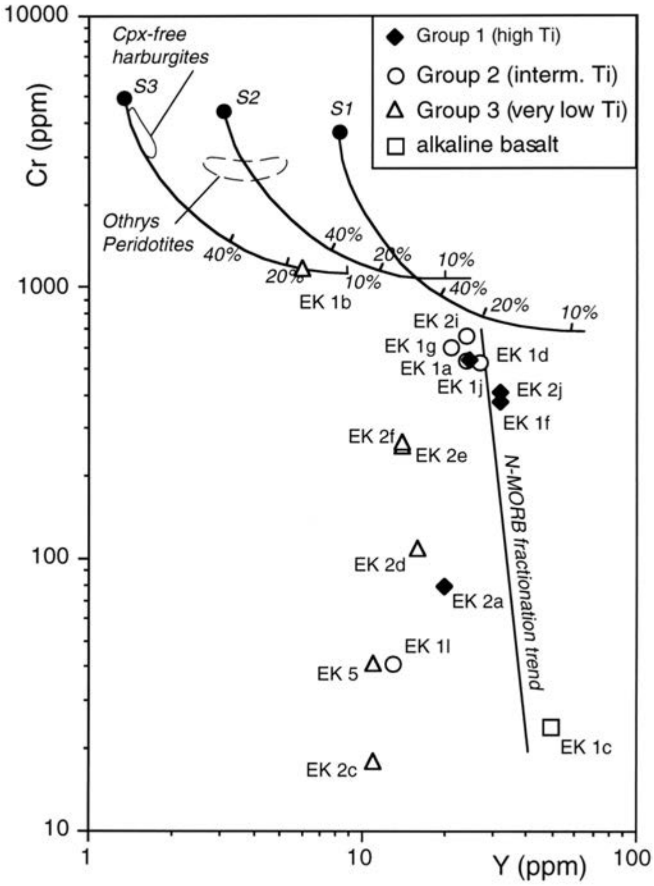

Fig. 7 - Cr vs. Y diagram for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Modified after Pearce (1983). Mantle source compositions and melting paths for incremental batch melting are from Murton (1989). S1- calculated MORB source; S2- residue after 20% MORB melt extraction from source S1; S3- residue after 12% melt extraction from source S2. See text for explanation. Compositional fields of harzburgites from the Pindos Massif (authors' personal data) and of peridotites from the Othrys Massif (Menzies and Allen, 1974) are reported for comparison.

the mantle source(s) can be inferred by plotting a compatible versus an incompatible element, since compatible element abundance is not significantly modified during the progressive mantle source depletion, whereas abundance of incompatible elements is closely related to source depletion and degree of melting (Pearce, 1982; 1983).

The Cr vs. Y diagram of Fig. 7 illustrates an attempt to depict the possible mantle sources and relative degrees of partial melting of the different lava types studied in this paper. Three possible mantle sources are considered in this diagram, in accordance with the model proposed by Murton (1989). From this figure it can be inferred that the high-Ti basalts from the Agoriani Mélange are compatible with about 20% partial melting of an undepleted MORB source (S1), calculated according to Pearce (1982). However, the high-Ti basaltic andesite EK2a intersects the melting curve of the undepleted MORB source S1 at about 40% partial melting, which is a considerably high value. In contrast with its fairly evolved nature, this rock exhibits lower incompatible elements and REE enrichments (Figs. 5a, b), suggesting a genesis from primary melts which originated from high degree partial melting or, alternatively, from slightly depleted mantle sources. Actually, in the model in Fig. 7 this sample intersects the melting path at about 10% partial melting of a depleted source (S2), calculated by Murton (1989) as the residue after 20% MORB melt extraction.

Genesis of this group of rocks from melts derived from relatively undepleted MORB-type sources at mid-ocean ridge is also confirmed by the Th/Yb and Ta/Yb ratios plotted in Fig. 8, where the studied rocks plot close to the typical N-MORB composition (Sun and McDonough, 1989).

Group 2: intermediate-Ti basalt

Many authors (e.g., Pearce, 1982; Beccaluva et al., 1983; Shervais, 2001) have suggested that the depletion of

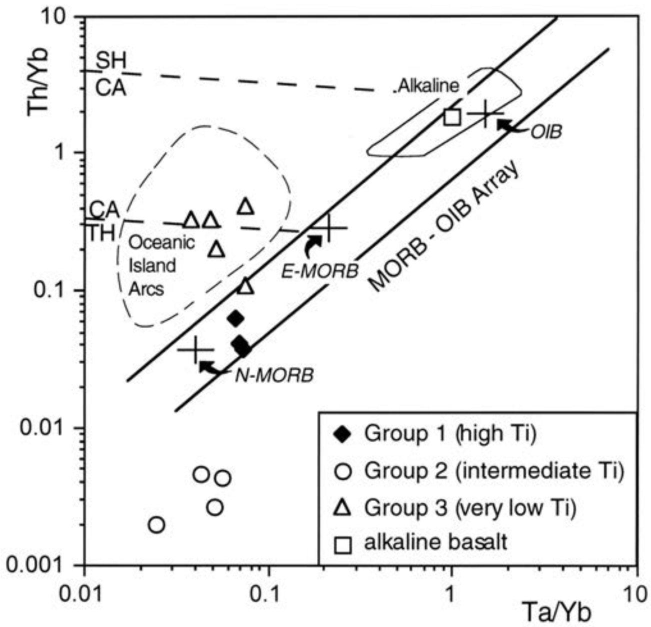

Fig. 8 - Th/Yb vs. Ta/Yb diagrams for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Modified after Pearce (1982). Compositions of Modern N-MORB, E-MORB and OIB (crosses) are from Sun and McDonough (1989). Variations of elemental ratios of modern oceanic island arcs (Pearce, 1982) and alkaline mafic volcanic rocks from various localities of the Hellenides (Capedri et al., 1997; Pe-Piper, 1998) are reported for comparison.

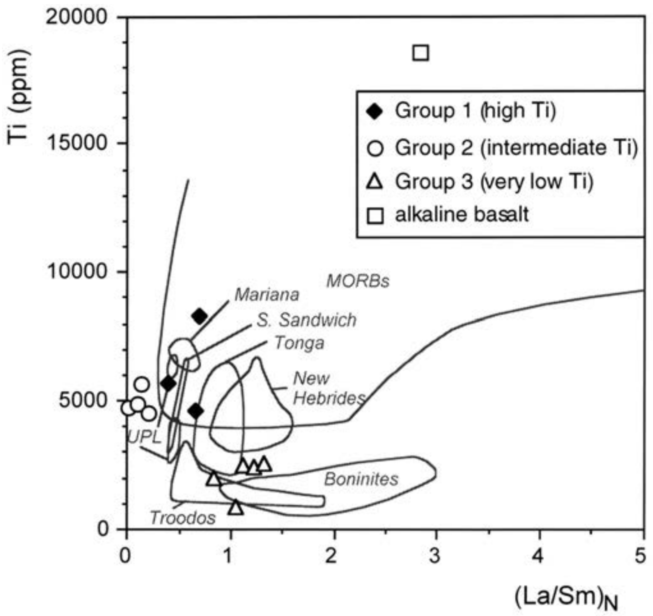

Fig. 9 - $(La/Sm)_N$ vs. Ti diagram for volcanic rocks from the Agoriani Mélange (Lower Ophiolitic Unit). Simplified after Beccaluva and Serri (1988). MORBs and boninites from various localities, boninites from Troodos, as well as IAT data for New Hebrides, Tonga, South Sandwich, Mariana forearc, and Troodos upper pillow lavas (UPL), are reported for comparison (see Beccaluva and Serri, 1988 for references).

incompatible elements (such as, Th, Ta, Nb, Ti) and LREE relative to N-MORB are distinguishing features of subduction-related magmas. This geochemical signature results from partial melting of mantle sources that experienced multi-stage mantle depletion. Accordingly, the strongly depleted LILE and LREE and poorly depleted HREE patterns of low-Ti samples (Figs. 5c, d) indicate that Group 2 rocks are consistent with the compositions of magmas generated in SSZ settings from partial melting of refractory mantle sources. This conclusion is supported by the Zr/Y ratios plotted in Fig. 6, where the partial melting path of these rocks intersects depleted mantle source compositions, as well as by the extremely low Th/Yb (Fig. 8) and La/Sm (Fig. 9) ratios. In particular, from these two figures it can be observed that Group 2 basalts are characterized by much lower Th/Yb and $(La/Sm)_N$ ratios than those observed in MORBs. According to Beccaluva and Serri (1988), such ratios are compatible with high degrees of melting of mantle sources that had experienced previous extraction of basaltic melts without significant subduction-derived enrichment events.

Nonetheless, the major element and HFSE composition of these rocks - which is very similar to those of basalts generated at mid-ocean ridge settings from primitive mantle sources - is in contrast with this conclusion. However, assuming that low-Ti rocks originated from an undepleted MORB-type mantle source (S1 in Fig. 7), the possible trend of fractional crystallization would intersect the melting path at an unreasonably high degree of partial melting (about 40 %). By contrast, these rocks are adequately compatible with about 10% partial melting from a mantle source (S2) that had experienced previous MORB melt extraction at about 20%. This mantle source corresponds to a depleted spinel lherzolite composition, with Zr/Y and Zr/Ti ratios lower than those of chondrite, and depleted LREE patterns. Lherzolites showing similar chemical compositions are documented in the Upper Ophiolitic Unit of the Othrys Massif by Menzies (1976) and Menzies and Allen (1974). These may hence represent a suitable source for Group 2 basalts, as confirmed by their Cr and Y composition plotted in Fig. 7. In terms of melt-source-residua, the extraction of about 10-12% melts from source S2 would leave residual compositions ranging from cpx-poor lherzolites to cpx-rich harzburgites. These mantle types are too common in the Mirdita-Subpelagonian ophiolitic belt (Menzies and Allen, 1974; Beccaluva et al., 1984; 1994).

Basaltic rocks showing chemistry similar to that of Group 2 basalts are observed in northern Albania (medium-Ti basalts of Bortolotti et al., 1996; 2002) and in southern Albania (Hoeck et al., 2002). In both cases they are found in complex relationship with MOR basalts, and they are interpreted taking into account different mantle sources variably modified by subduction influences.

Group 3: very low-Ti basaltic andesite and andesite

A marked depletion of HFSE and REE coupled with relative enrichment in LILE can be observed in very low-Ti rocks from the Agoriani Mélange. In addition, these rocks exhibit mild LREE enrichment relative to medium-REE, and relative depletion of medium-REE compared to HREE: that is, the typical U-shaped REE patterns of boninitic rocks (Beccaluva and Serri, 1988; Crawford et al., 1989).

These chemical features are commonly attributed to high degrees of hydrous (but not necessarily water-saturated) melting of mantle sources that have experienced previous extraction of mafic melts (i.e., MORB generation) and further enrichment in LILE and LREE by subduction-derived fluids (Beccaluva et al., 1984; Beccaluva and Serri, 1988; Pearce, 1982). The LILE enrichment is, however, difficult to identify in ophiolitic rocks since they are commonly altered.

Zr/Y ratios, besides Cr-Y variation for the studied rocks (Figs. 6, 7), are compatible with various degrees of partial melting of variably depleted mantle sources. In detail, assuming that these rocks originated from variably depleted sources - i.e., source S2, defined above, and source S3, calculated by Murton (1989) as the residue after about 12% melt extraction from S2 - some samples would require approximately 20% melting of source S2, whereas others would require from 10% to 20% melting of source S3 (Fig. 7). The very low contents of HFSE and REE are in agreement with this conclusion. Nevertheless, according to the proposed models for boninite genesis (Bloomer, 1987; Stern et al., 1991), the LILE and LREE relative enrichments (Figs. 8, 9) suggest that the assumed mantle sources have been affected by metasomatizing fluids from a subduction zone. Harzburgites from the Middle Ophiolitic Unit of the Othrys Massif can reasonably be considered as a possible source of very low-Ti rocks from the Agoriani Mélange; these are characterized by 0.3-1 times REE chondrite abundance and marked LREE enrichment (Menzies, 1976). Unfortunately, no data on the Cr and Y composition of Othrys Middle Unit harzburgites are available, although Cpx-free harzburgites from the Pindos Massif (author's personal data) plotted in Fig. 7 confirm the assumption that Cpx-free mantle harzburgites may represent the source of very low-Ti rocks. The residual mantle composition after boninitic melt extraction at this stage would range from very depleted harzburgite to dunite; these rock types are very common in the Mirdita-Subpelagonian ophiolites (Beccaluva et al., 1984; 1994).

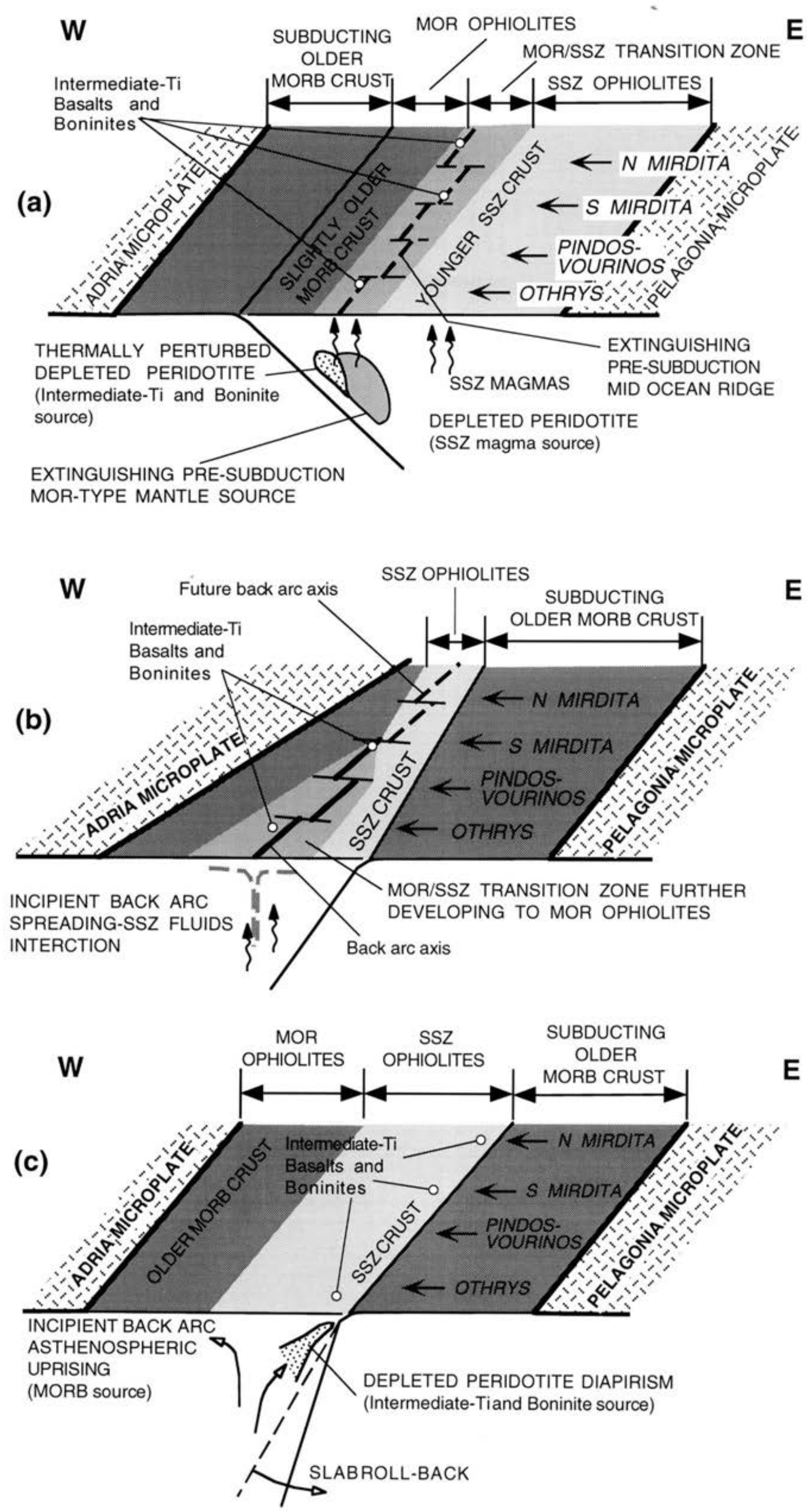

Fig. 10 - Schematic melting models for the formation of depleted and undepleted melts (and associated ophiolites) during the Middle-Upper Jurassic early stages of subduction in the Mirdita-Pindos sector of the Neo-Tethys. (a) Subduction initiated in proximity of a former mid-ocean ridge (modified from Bébien et al., 2000 and Bortolotti et al., 2002). (b) Triangular-shaped back arc basin spreading (loosely based on Pearce et al., 1995). (c) Slab roll-back model (simplified after Beccaluva et al., 2003). See text for further explanations.

Alkaline basalt

The alkaline basalt displays trace-element and REE characteristics (Figs. 5g, h) very similar to those of OIBs from various Pacific seamounts (Frey and Clague, 1983; Lipman et al., 1989; Haase and Dewey, 1996), suggesting that this basalt represents seamount material formed by magma generation associated with mantle plumes.

The Th/Yb and Ta/Yb ratios, which are included in the MORB - OIB array (Fig. 8), indicate this rock as generated from an enriched mantle-type source in a within-plate oceanic setting. This conclusion is in agreement with the Zr/Y ratio (Fig. 6), which is in the typical range of values for within-plate ocean island basalts (Pearce, 1982).

According to the melting model proposed for similar rocks from the Easter seamount chain by Haase and Dewey (1996) (not shown in this paper), the $(Dy/Yb)_N$ and $(Ce/Yb)_N$ ratios indicate that the alkaline basalt studied here is consistent with ca. 5% partial melting of a theoretical plume source.

Similar alkaline volcanic rocks, some of which dated as Triassic, are documented in several localities of the Hellenides (Capedri et al., 1997; Pe-Piper, 1998 and references therein). Alkaline within-plate basalts (some of which dated as Triassic) are also common in many mélange terranes along the Albanide-Hellenide ophiolitic belts: for example, in the Rubik Complex (Beccaluva et al., 1984), the Avdella Mélange (Jones and Robertson, 1991), and the Koziakas Mélange (Saccani et al., 2003a). All these rocks are interpreted as having originated in intraplate oceanic island settings. Although the alkaline basalt studied in this paper is not unequivocally dated, it is reasonable to assume that it was originated in a similar tectonic setting.

DISCUSSION AND CONCLUSIONS

The different magmatic associations represented in the Uper Mesozoic-Cenozoic mélange complexes scattered along the Subpelagonian ophiolitic Zone (e.g., Avdella Mélange: Jones and Robertson, 1991; Pangodas Mélange: Danelian and Robertson, 2001; Ermioni Complex: Clift, 1996; Angelokastron Mélange: Capedri et al., 1996) reflect the igneous activity that occurred in the Hellenide sector of the Neo-Tethyan oceanic basin, from the Permian-Triassic rifting stage and Triassic-Jurassic oceanization to the Middle-Late Jurassic intra-oceanic subduction (Pe-Piper, 1998; Jones and Robertson, 1991; Danelian and Robertson, 2001; Robertson, 2002).

The Agoriani Mélange represents a typical tectono-sedimentary mélange generated in a convergent plate margins setting during ophiolite obduction (Ferrière et al., 1988; Robertson 1991; 2002).

The volcanic rocks forming blocks included in the Agoriani Mélange represent four distinct magmatic groups showing different magmatic affinities, which originated in distinct tectono-magmatic settings (i.e., mid-ocean ridge, seamount, and supra-subduction zone). In this paper we relate the different volcanic rocks from the Agoriani Mélange to their possible mantle sources associated with the tectono-magmatic evolution of the south Hellenide sector of the Neo-Tethyan Pindos basin.

The N-MORB signature displayed by Group 1 basaltic rocks indicates that these are dismembered fragments of oceanic crust generated at a mid-ocean spreading ridge, and that they represent remnants of an oceanic lithosphere. This is consistent with the regional reconstruction of the Neo-Tethyan basin in the eastern Mediterranean, which implies the existence of the Mirdita-Pindos oceanic basin between the Adria (in the west) and Pelagonian (in the east) continental margins during the Late Triassic-Middle Jurassic (Robertson et al., 1991; Jones and Robertson, 1991; Beccaluva et al., 1994; Robertson, 2002; Saccani et al., 2003b).

The alkaline basalt represent a fragment of a seamount, which in turn imply the existence of OIB-type enriched mantle sources related to plume activity. Actually, similar alkaline rocks (some of which dated as Middle-Late Triassic) have previously been described in several Hellenides ophiolitic mélanges (Jones and Robertson, 1991; Pe-Piper, 1998; Danelian and Robertson, 2001), and are interpreted as fragments of rift-related volcanics or seamounts, both associated to a widespread plume activity that developed in the Pindos ocean since its Lower Triassic initial continental break-up and oceanization (Pe-Piper, 1998).

The subduction-related geochemical characteristics displayed by intermediate Ti (Group 2) and very low Ti (Group 3) indicate that they originated from partial melting of variably depleted peridotites in SSZ tectonic settings. This conclusion is consistent with the existence of an intra-oceanic subduction during the Middle-Late Jurassic, as testified by the occurrence of many SSZ ophiolitic complexes scattered along the Mirdita-Subpelagonian Zone (e.g., Beccaluva et al., 1984; 1994; Capedri et al., 1996; Bortolotti et al., 2002; Robertson, 2002).

Many similarities are observed between the volcanic rock types included in the Agoriani Mélange and those included in other main Hellenide mélange complexes. However, the results presented in this paper outline a major distinguishing feature, which is represented by the occurrence of basalts (Group 2 basalts) showing chemical characteristics intermediate between typical IATs and pure MORBs.

The occurrence of this type of rock has been documented in volcanic sequences from the northern sector of the Mirdita ophiolites (northern Albania), where they are interlayered with typical MORBs (Bortolotti et al., 1996; 2002), as well as in southern Mirdita (southern Albania) (Hoeck et al., 2002). In both cases, these rocks crop out in a discontinuous, narrow belt marking the transition between the Western (MOR-type) and Eastern (SSZ-type) Ophiolitic Belts of Albania. MORB-IAT intermediate basalts are always in close spatial and temporal association with typical MOR- and SSZ-type volcanic rocks, indicating that undepleted MOR-type and variably depleted SSZ-type mantle sources were contemporaneously active in a relatively restricted sector of the supra-subduction region (Bortolotti et al., 1996; 2002; Bébien et al., 2000; Hoeck et al., 2002).

Although possible relationships between MORB-IAT intermediate basalts and other ophiolitic rock types in the Othrys Massif cannot be established, the occurrence of these basalts along a considerable portion (from North Albania to Othrys) of the Mirdita-Subpelagonian ophiolitic zone indicates that the tectono-magmatic processes which produced these basalts must have been effective on a regional scale, rather than being the result of localised along-strike variations in the mantle sources.

Several models have been provided for explaining the coexistence of MORB and SSZ mantle sources (and associated magma types), as well as the genesis and tectono-magmatic significance of MORB-IAT intermediate basalts from the Mirdita Zone.

In accordance with the two-dimensional geophysical model proposed by Bébien et al. (2000) and Insergueix-Filippi et al. (2000), MORB-IAT intermediate basalts have been interpreted by Bortolotti et al. (2002) and Hoeck et al. (2002) as having generated from partial melting of relatively hot, depleted peridotites in a supra-subduction mantle wedge which was occasionally thermally perturbed by a nearby active mid-ocean ridge (Fig. 10a).

An alternative model proposed by Hoeck et al. (2002) is based on a comparison with the triangular-shaped, present-day Lau Basin, where the back-arc spreading axis is oblique with respect to the subduction zone (Fig. 10b). Consequently, as the back arc basin becomes narrower, subduction-related fluids rich in LILE influence its spreading axis (and its associated asthenospheric mantle source). However, the extremely LILE and LREE depleted nature of MORB-IAT intermediate basalts (Figs. 5c, 5d, 8, 9) account for partial melting of depleted peridotites without any influence of subduction-related fluids. In fact, these chemical features are most compatible with derivation from partial melting of depleted peridotites which have previously experienced MORB-type melt extraction as a consequence of thermal perturbation of the source, rather than being induced by fluids driven off the subduction zone.

The model recently proposed by Beccaluva et al. (2003) could explain the partial melting of depleted sub-arc mantle portions not influenced by subduction-derived fluids. This model implies a roll-back of the subducted slab which allowed an asthenospheric diapirism toward the forearc region, with consequent shallow partial melting of a depleted sub-arc mantle and the generation of boninites and intermediate MORB-IAT composition (Fig. 10c). This model also implies the progressive transition in magma composition from SSZ-related magmas to pure MORB, which is, however, not adequately documented in the Subpelagonian ophiolites.

In summary, the volcanic rocks included in the Agoriani Mélange record various magmatic events, which occurred during the evolution of the Pindos oceanic basin, including generation of a MOR-type oceanic crust, existence of seamounts, and development of a SSZ-type crust with boninitic and MORB-IAT intermediate volcanic rocks. All the models presented above (Fig. 10) can effectively explain the existence of MORB-IAT intermediate basalts, as well as the along-strike compositional variations in lava types along the Mirdita-Subpelagonian ophiolitic belt.

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