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PIEDMONT, RECHNITZ AND MELIATA ZONE: A PETROGRAPHIC-GEOCHEMICAL COMPARISON OF METAMORPHIC OPHIOLITES OF THE ALP-CARPATHIAN SYSTEM

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ABSTRACT

In spite of the polyphase metamorphic history and intense deformation there are a lot of ultramafic, gabbro, and plagiogranite, mafic dykes, volcanic and deep-sea sediment occurrences of Mesozoic age in the Alp-Carpathian system. Our petrographic-geochemical comparison of these rock-types focuses on two zones of the Alpine belt: the Western Alps (Piedmont) and the Eastern Penninic Alps (Rechnitz) and one zone of the Carpathians: the North Hungarian and South Slovakian Meliaticum. The first zone is characterized by the abundant relics of high pressure metamorphism of Cretaceous age which survived the greenschist facies metamorphism of Tertiary age, while the two latter show relatively limited relics of the (eoalpine) glaucophane schist facies conditions.

The special interest of a comparison derives from the fact that the first two zones form a a typical Jurrasic-Cretaceous ophiolite nappe occurring in the west- and easternmost zones of the Alpine belt. These two zones display a genetic similarity. On the other hand, the third zone is considered as a Triassic-Jurassic incomplete ophiolite suite occurring in the present Innermost Carpathian belt.

Based on detailed field and laboratory studies we compare the three zones in terms of their upper mantle rocks (serpentinite and pyroxene-rich chlorite schist), mafic plutonic suite (coarse grained eclogite, glaucophane schist- and greenschist-facies metagabbro and plagio-granite), volcanic suite (fine grained eclogite, glaucophane schist- and greenschist-facies metavolcanic) and sedimentary cover (radiolarite, ophiolitic breccia, ophicarbonate, calcschist, micaschist and quartzite).

The lithologies of the two zones of the Alps are relatively similar and comparable to the Western Alps metaophiolites (N- and T-type MORB volcanics, range of plutonic rocks from primitive Mg-Al rich gabbros to late fractionated plagiogranites, predominance of depleted lherzolites and/or harzburgites among the ultramafics). On the other hand, the lithology of the third zone (Meliaticum) of the Innermost Carpathians is relatively different from the ophiolite zones of Alpine belt (E- and T-type MORB, spilitic volcanics, albite-rich gabbros, dominant harzburgitic and minor lherzolitic ultramafics) which may exclude a close genetic connection between the two belts. Moreover, the volcanic (and probably the plutonic) rocks of the Alps show a much greater compositional variability, suggesting a relatively slow spreading rate. In contrast, the Meliata volcanics display almost a limited compositional variation and sometimes spilitic pillow lavas, suggesting a relatively fast spreading rate with occasional interaction with seawater.

There are minor but interesting similarities among these ophiolites. All of them are high-Ti type, have tholeiitic affinitites with a tendency to "transitional" MORB character. All these ophiolite-sequences show a progressive enrichment of both rare earth and incompatible elements starting from ultramafics toward the effusive members as a result of magmatic differentiation. However, we found a Ba enrichment in all volcanic members, which can be derived from the deep-sea sediments covering the volcanics. All of these ophiolites have undergone some oceanic alterations and the complex Alpine regional metamorphic events, and mixed or covered by marine sediments.

In conclusion, the comparison between the Alpine and Carpathian ophiolites lead to assign a peculiar significance among them (as previous) in relation to the various tectonic events dominating in the Jurassic-Cretaceous Piedmont-Ligurian basin and in the Triassic-Jurassic Vardar basin.

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INTRODUCTION

Both the Piedmont and Rechnitz zones belong to the Penninic domain ophiolite in the Western and Eastern Alps respectively, whereas the Meliata zone appears to be related to the Pannonian basin in the Innermost Western Carpathians and/or Inner Dinarids. In the Piedmont zone, much more tectonometamorphic complications and more typical metaophiolite sequences have been developed with respect to that found in the Rechnitz and Meliata zones. These zones together form a west-east geotraverse of about 1100 km from Montgenévre to South Slovakia (*Fig.1*). Although an increasing number of studies with emphasis on petrogenesis and geochemical aspects are available (Western Alps: LOMBARDO and POGNANTE 1982; LOMBARDO *et al.* 1978; LEWIS and SMEWING 1980; DAL PIAZ *et al.* 1980, 1981; BERTRAND *et al.* 1987; PFEIFER *et al.* 1989; Rechnitz zone: PAHR and KOLLER 1980; KOLLER 1985; HÖCK and KOLLER 1989; Meliata zone: HOVORKA 1983, 1985; RÉTI 1986; ÁRKAI and KOVÁCS 1986; KUBOVICS *et al.* 1990), the comparison of the three regions are often neglected or not explicitely considered in the framework of the evolution of the Alp-Carpathian system in the Western Tethys.

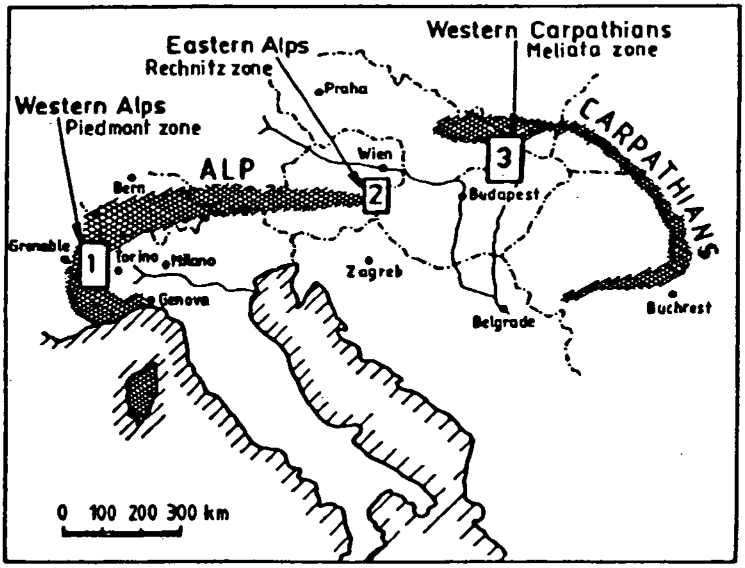

Fig. 1. Location of the three regions studied.

ROCK TYPES

Most of the common members of the Western Tethys ophiolite suites have been identified along the whole traverse explored here, independently of the metamorphic grade. Table 1 summarizes the different rock types encountered. The ultramafic, gabbroic and volcanic rocks are sporadically distributed and occurred mostly in separated tectonic slices.

Ultramafic rocks, in the Western Alps region typically occur as large (some km^2) sheets, sometimes containing a few metre thick lenses and boudins of gabbros

TABLE 1.

Metamorphic analogues of the different series of an ophiolite suite: rock types as a function of metamorphic grade (typical HP-facies to greenschist facies in the Western Alps, greenschist facies with blueschist relics in the Eastern Alps and slightly greenschist with blueschist relics in the western Carpathians)

ORIGINAL OPHIOLITE MEMBER	METAMORPHIC EQUIVALENT western region Western Alps (Piedmont zone)	 middle region Eastern Alps (Rechnitz zone)	 eastern region Western Carpathians (Meliata zone)
sediments - calcareous sed. - siliceous sed. - ophiolitic detritus	 - phengite-, chloritoid-bearing calcschists; cpx-bearing marbles; garnet-, tourmaline-bearing micaschists - quartzites - serpentinite breccias; ophicalcites	 - phyllite; marbles; albite-bearing chlorite schists - quartzites - ophicalcites	 - crystalline limestones; phyllites - argillites; radiolarites - serpentinite breccias; ophicalcites
volcanic rocks - acidic differentiates - hyaloclastites (partially pillows) - basalts s.l.	 - no equivalent found - glaucophanites; prasinites; ovardites; (fine-grained) - omphacite-rich eclogites; cpx-plag-metabasalts	 - no equivalent found - prasinites; tuffites; (fine-grained); glaucophane metabas. - greenschists (fine-grained)	 - keratophyres; qtz-porphyres - glaucophane metabasalts - cpx-plag-metabasalts; spilites (fine-grained lava flows and pillows)
dykes	- eclogites (fine-grained); basalts and dolerites (porphyritic) usually cutting gabbros	- greenschists (fine-grained)	- microgabbros; dolerites (variable grain-size)
 mafic plutonites - Mg-Al gabbros (normal gabbros) - intermediate gabbros - Fe-Ti gabbros	- plagiogranites (albitites) - greenschist facies metagabbros; tourmaline cummingtonite metagabbros; smaragdite metagabbros; chloritized metagabbros; eclogites (coarse-grained) - cpx-metagabbros - eclogitic metagabbros; glaucophane-metagabbros; ferrogabbros	- plagiogranites (blueschists) - sheared cpx-metagabbros; flaser gabbros - glaucophane metagabbros; ferrogabbros	- no equivalent found - normal gabbros; spilitic metagabbros (medium grained) - ferrogabbros (?)
ultramafic rocks - dunites/harzburgites - lherzolites - pyroxenites - metasomatic ultramafic rocks	 - diopside-Ti-clinohumite-bearing serpentinites; trem-cpx serpentinites - cpx-tremolite-, cpx-garnet-chlorite rocks - chlorite schists, talc serpentinites	 - antigorite serpentinites - lizardite-chrysotile serp. - cpx-pump-garnet chlorite rocks - talc-chlorite schists; trem-chlorite-schists; talc serp.	 - ol-opx-cpx-sp-serpentinites - lizardite-chrysotile serpentinites
Ca-rich mafic rocks	- garnet-diopside-epidote-Fe-Ti spinel rocks often cutting serpentinites	- cpx-garnet-chlorite-pump-plag rocks	- garnet-cpx-chlorite-serpentine rocks (?)

and eclogites. Those ultramafics also occurring as some tens of metres within the mafic rocks. In the Inner Western Carpathians (Meliata zone) the ultramafics are the most abundant rocks, occurring as bodies of various size (up to a few km^2) in an evaporitic melange (RÉTI 1985). In all the three regions, the exact origin of the rocks (tectonic mantle peridotites, or cumulate series at the crustal mafic plutonic suite) cannot be determined due to the intensive deformation (dismembering and folding). All the ultramafics are metamorphic, intensively serpentinized and reflect the Late Mesozoic metamorphism. Only a few relics spinel, clinopyroxene and very scarce olivine were preserved in these rocks. In the marginal parts of ultramafic masses, thin layers or dykes (few dm thick) of tremolite-chlorite schists and/or metapyroxenites can be observed.

Mafic plutonic rocks, in the Western and Eastern Alps scarce relics of magmatic stage have survived the polyphase metamorphism. The gabbros are systematically coarser grained (flaser structure at cm-scale) and are mostly lighter green colour than the volcanic rocks. The best preserved gabbros in the Western Alps are found in Montgenévre containing cpx ranges from augite to salite (BERTRAND *et al.* 1987). In both Western and Eastern Alps zone, the gabbroic sequence include primitive members (Mg-Al gabbros) and more differentiated Fe-Ti gabbros and plagiogranites. On the other hand, in Meliata zone, the gabbroic rocks are very rare and different from the former gabbros. Those are moderately spilitized and overprinted by greenschist facies condition.

Ca-rich mafic rocks (metarodingites), in all the three regions garnet-cpx inclusions of metre-scale with rim of chlorite-amphibole rocks occur in close relationship to ultramafic masses. These metarodingites are strongly boudinaged, but in some places their original gabbroic content can still be recognized in the Piedmont and Rechnitz zone (DAL PIAZ *et al.* 1980; KOLLER 1985). In Meliata zone rodingitic contacts of ultramafics with accompanying sedimentary structure also occur (HOVORKA 1985).

Dykes, outcrops of subvolcanic rocks are very scarce and are often found as a few cm to several dm thick dykes crosscutting the gabbros and more rarely ultramafics. Generally, a proper sheeted dykes complex originally situated between the plutonic and volcanic suite can not be found in either region (DIETRICH 1980; LOMBARDO and POGNANTE 1982; KOLLER 1985; KUBOVICS *et al.* 1990).

Volcanic rocks, on the Piedmont and Rechnitz zone. Original pillow structure are mostly preserved (OBERHÄNSLI 1980; LEWIS and SMEWING 1980; BERTRAND *et al.* 1987). In some of these volcanic rocks, original structure as well as the primary mineral were disappeared. However, in the Meliata volcanics, the pillow structure is frequently preserved (HOVORKA and SPISIAK 1988).

Sedimentary rocks, in the Piedmont zone thick piles of calcschists together with marble, micaschist, quartzite +/- ophicarbonate and ophiolitic breccias occur. A large part of the calc-schists appear to be Cretaceous in age (MARTHALER 1984; LAGABRIELLE 1987). Most of the sediments of the Piedmont zone contain detritus of both oceanic and continental crust (SARTORI 1987; STECK 1989). These sediments are usually mixed with resedimented volcanic materials (layers of eclogite and greenschist). In the Rechnitz, the sediments are dominantly consisting of phyllitic rocks and are equivalent to oceanic sediments (PAHR and KOLLER 1980). In Meliata zone, the sediments are mainly represented by Middle Triassic radiolarite (KOZUR and RÉTI 1986), argillite and siltstone and are considered as oceanic sediments (KOVÁCS 1984; RÉTI 1987).

Oceanic metamorphism, in the Piedmont zone, produced only local development of brown- and green hornblende. In the Rechnitz, oceanic metamorphism is characterized by barroisite and Mg-hornblende with temperature of formation lower than 750 °C and pressure about 1 kbar (KOLLER 1985).

Cretaceous (Early-Alpine) high pressure facies, in the Piedmont zone, the Early-Alpine event is polystadial with an early blueschist facies followed by an eclogitic facies for which maximum conditions of 470—450 °C and 10 kbar for Monviso ophiolite (MONVISO 1980) and 600—500 °C and about 24—18 kbar for regions around Zermatt and Saas Fee have been established (OBERHANSLI 1980, 1986; MEYER 1983; BARNICOAT and FRY 1986; GANGUIN 1986, 1988). These eclogites were pervasive and produced mineral assemblages consisting of Na-pyroxene, garnet, epidote, rutile +/- Mg-chlorite and talc. Blueschist facies have been recorded in all three zones but with different strength, condition and abundance. They include Na-pyroxene, Na-amphibole, albite +/- garnet and white mica. This paragenetic assemblage appears to yield temperatures of 450, 370—330, 450—380 °C and pressures of 8—7, 8—6 and 7 kbar for blueschists from Monviso in the Piedmont (MONVISO 1980), Rechnitz (KOLLER 1985) and Meliata zone (ÁRKAI and KOVÁCS, 1986; HOVORKA, 1990, pers. comm.) respectively.

Tertiary (Meso-Alpine) greenschist facies, the first retrograde overprint in the Piedmont zone areas produced typical barroisitic and pargasitic amphibole and albite (GANGUIN 1988). This stage correspond to be barroisitic blueschist facies of MONVISO (1980). Their conditions of formation is estimated at about 500—450 °C and 10—6 kbar (PFEIFER *et al.* 1989). The second retrograde overprint of early-Alpine parageneses in the Alps (Western and Eastern Alps) produced mineral assemblage including albite, Fe-chlorite, Fe-epidote, actinolite and titanite which indicate greenschist facies conditions. In the Piedmont, these occur at about 400 or 500—450 °C and 5—3 kbar (MONVISO 1980; PFEIFER *et al.* 1989). The greenschist facies parageneses of both Rechnitz and Meliata zones seem to be characterized by the same conditions of temperature and pressure showing 430—390 °C and about 3 kbar (KOLLER 1985; ÁRKAI and KOVÁCS 1986). Furthermore, in addition to greenschist; prehnite-pumpellyite facies is also recorded in the Meliata zone (Table 2.).

Metamorphism of ultramafic rocks, because ultramafic rocks are little sensitive to high pressure, the early- and meso-Alpine mineral associations are difficult to distinguish. They were frequently deformed and serpentinized. However, fragments already serpentinized (in the oceanic environment) more easily crystallized to metamorphic serpentinite (PFEIFER *et al.* 1989).

BULK ROCK COMPOSITION

General chemical feature, in a systematic survey of the mentioned W—E geotraverse around 46 mafic and 24 ultramafic samples have been analyzed from the three ophiolite regions. The bulk rock (major, trace and rare earth element) analyses of all rock type are given in ABDEL-KARIM (1990) and KUBOVICS *et al.* (in this volume). The ultramafic rocks of all three regions have similar values of Mg, Mn and Sc. Furthermore, in both Piedmont and Meliata zone, these ultramafic show similar values of Al, Fe, K, Y and Zr, too. The gabbroic rocks of the Piedmont and Rechnitz zone are correlated each other in their major and trace element compositions, showing similar values of Si, Ti and Mn. However, higher values

TABLE 2.
Possible metamorphic facies conditions and their mineral assemblages distributions of ophiolite suites from the Alp-Carpathian system

METAMORPHIC FACIES	WESTERN ALPS Piedmont zone	EASTERN ALPS Rechnitz zone	WESTERN CARPATHIANS Meliata zone
1. Oceanic event			
Pressure (kb)+		≤1	
Temperature (°C)+		< 750 (?)	
Min. assemblages:			
barroisite	———— - -	———— - -	
Mg-hornblende	———— - -	———— - -	
2. Eclogite facies			
Pressure (kb)+	10; 24-18		
Temperature (°C)+	470-450; 600-550		
Min. assemblages:			
Na-pyroxene	——————————	— -(?)	
garnet	——————————	— -(?)	
epidote	——————————		
rutile	——————————		
± Mg-chlorite	——————————		
± talc	——————————	———— -	
3. Blueschist facies			
Pressure (kb)+			
Temperature (°C)+	8-7	8-6	7
Min. assemblages:	450	370-330	330-450
Na-pyroxene	——————————	——————————	
Na-amphibole	——————————	——————————	——————————
albite	——————————	——————————	——————————
± white mica (phengit)	——————————	———— -	— -(?)
± garnet	——————————	——	——— -
4. Barroisitic blueschist facies			
Pressure (kb)+	10-6		
Temperature (°C)+	500-450		
Min. assemblages:			
albite	——————————		
barroisite (blue-green hornblende)	——————————	— -	
5. Greenschist facies			
Pressure (kb)+			
Temperature (°C)+	5-3	3	3
Min. assemblages:	400; 500-450	430-390	350
albite	——————————	——————————	——————————
Fe-chlorite	——————————	——————————	——————————
Fe-epidote	——————————	——————————	——————————
amphibole (trem.-actin.)	——————————	——————————	———————— -
titanite	——————————	——————————	—————— -
± biotite (stilpnom. ?)	———————— -	———— - -	— -

+Data were compiled after MONVISO 1980; KOLLER 1985; PFEIFER *et al.* 1989; ÁRKAI and KOVÁCS 1985; HOVORKA 1990 (pers. comm.)

of Mg, Sr, Y, Zr, Sc but lower Ba and Rb contents of the Piedmont zone when compared with Rechnitz are observed. On the other hand, the gabbroid rocks of Meliata zone are mostly different from that of the two former zones. The glaucophane schist facies metavolcanics of the Piedmont and Meliata zone are similar in most major element compositions however, significant higher values of Rb, Cr, Hf and light REE are associated with Meliata indicating their strong tendencies with the E-type MORB. The greenschist facies metavolcanics of both Rechnitz and Meliata metavolcanics are enriched in Ba, Sr, Nb, REE but lower Rb, Y and Cr when compared with the two other zone probably due to their E-type MORB characters.

Mafic (volcanic and plutonic) and ultramafic rocks are in general well discriminated on a number of major and trace element diagrams. In AFM-diagram (*Fig.* 2), the ultramafic rocks of the three regions fall within the metamorphic peridotite (COLEMAN 1977) and mafic-ultramafic cumulate field drawn by STRONG and MALPAS (1975). However, the chlorite schists (including chloritites) of the Rechnitz zone locate on the F-M side showing an enrichment of FeO^t in comparison with the ultramafics. Comparing the Meliata zone with the other two regions, true Alpine gabbros (Mg-Al rich and Fe-Ti rich gabbros) are absent in the former, that may be attributed to the enrichment of these gabbros in Ca instead of Mg and the effect of spilitic process. In the Piedmont zone, the altered intermediate gabbros and most volcanic rocks are enriched in alkalis may be due to variable element mobilization during the different Alpine metamorphic events. All the Alpine gabbros fall into the oceanic gabbro field (BONATTI *et al.* 1971; THOMPSON 1973; PRINZ *et al.* 1976; CAYTROUGH 1979). The albitites (in Piedmont) and keratophyres (in Meliata) show a rather calc-alkaline tendency. However, the ophiolites of the three regions show tholeiitic character with a marked Fe-Ti enrichment trend.

REE patterns of the mafic-ultramafic rocks of all three regions normalized to the chondrite values given by NAKAMURA (1974) are shown in *Fig. 3*. The ultramafic rocks of both the Piedmont and Meliata zone exhibit the same compositional trend, showing slight light REE-depletion. However, LREE-depletion and HREE enrichment are more distinct in the former zone than in the latter. The serpentinite, rodingite and chlorite schist of the Rechnitz zone have relatively the same trend. Comparing the gabbroic rocks of Piedmont zone with that from Rechnitz wide compositional range and a more abundant REE-content are recorded with the former. The REE patterns of the Meliata gabbros have the narrowest compositional range and is significantly different from that the other two zones. The albitites from Montgenévre (in the Piedmont zone) and the plagiogranites (blueschists) from Rechnitz zone are similar in REE patterns. The mafic volcanic rocks of the Piedmont and Rechnitz zone are characterized by analogous REE-abundances showing a N-MORB character that different from Meliata zone which exhibit an E-MORB affinity. In the all three regions, a progressive REE-enrichment from ultramafics through gabbroics and volcanics to plagiogranites occur. These data are consistent with the results given by the patterns of incompatible trace and minor elements in normalized spiderdiagrams (after THOMPSON *et al.* 1984; *Fig. 4*) of the same rocks from the three regions. The most of the REE and incompatible elements show typical magmatic rock trends which confirm that the original bulk rock-trace element compositions can be preserved even during the different stage of the metamorphism.

Ultramafic rocks, all the three regions, the trends observed during petrographic inspection are confirmed by the bulk rock chemistry: Al- and Ca-poor dunitic and harzburgitic compositions are limited to strongly deformed, and probably Ca-depleted serpentinites; some rocks contain typical Al_2O_3 contents of lherzolite,

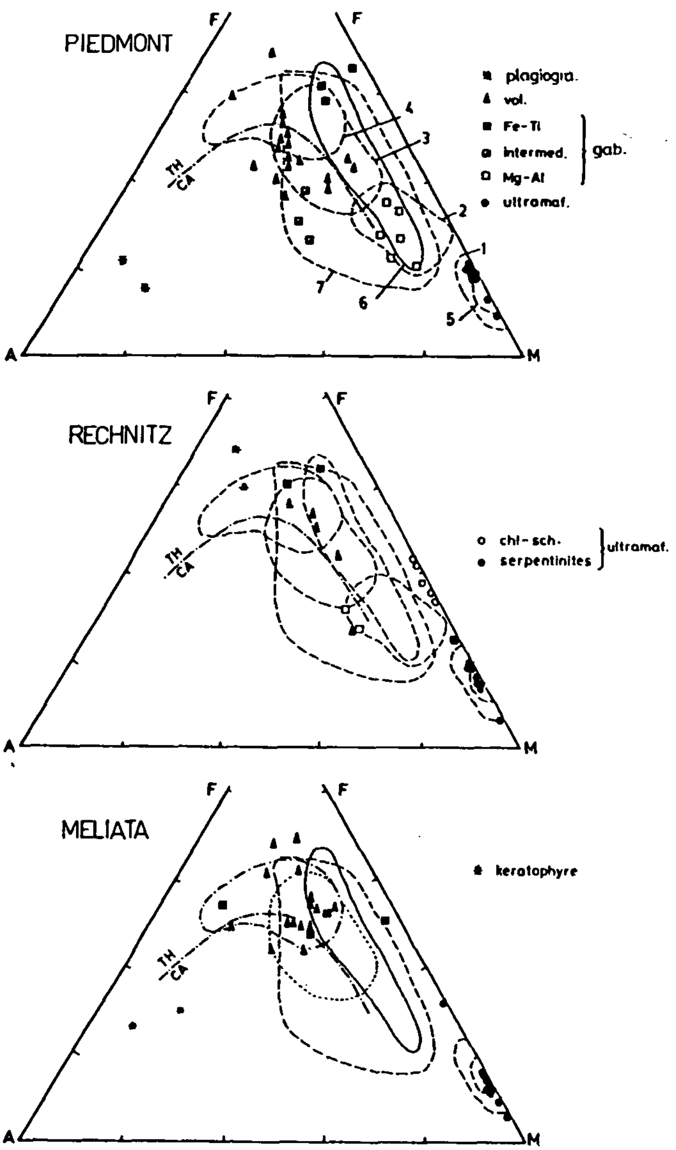

Fig. 2. Mafic-ultramafic rock compositions in the AFM diagram (in weight %) as a function of the different regions (A: K_2O+Na_2O, M: MgO, F: FeO^t). Fields-1: mafic-ultramafic cumulates, 2: gabbros, 3: sheeted dykes, 4: lavas (after STRONG and MALPAS 1975), 5: metamorphic peridotites (COLEMAN 1977), 6: gabbros from Mid Atlantic Ridge (BONATTI *et al.* 1971; THOMPSON 1973; PRINZ *et al.* 1976). 7: gabbros from Mid Cayman Ridge (CAYTROUGH 1979).

harzburgite and rare pyroxenites, comparable to other western Tethyan ultramafics (BECCALUVA *et al.* 1984; POGNANTE *et al.* 1986; KUBOVICS and ABDEL-KARIM 1990).

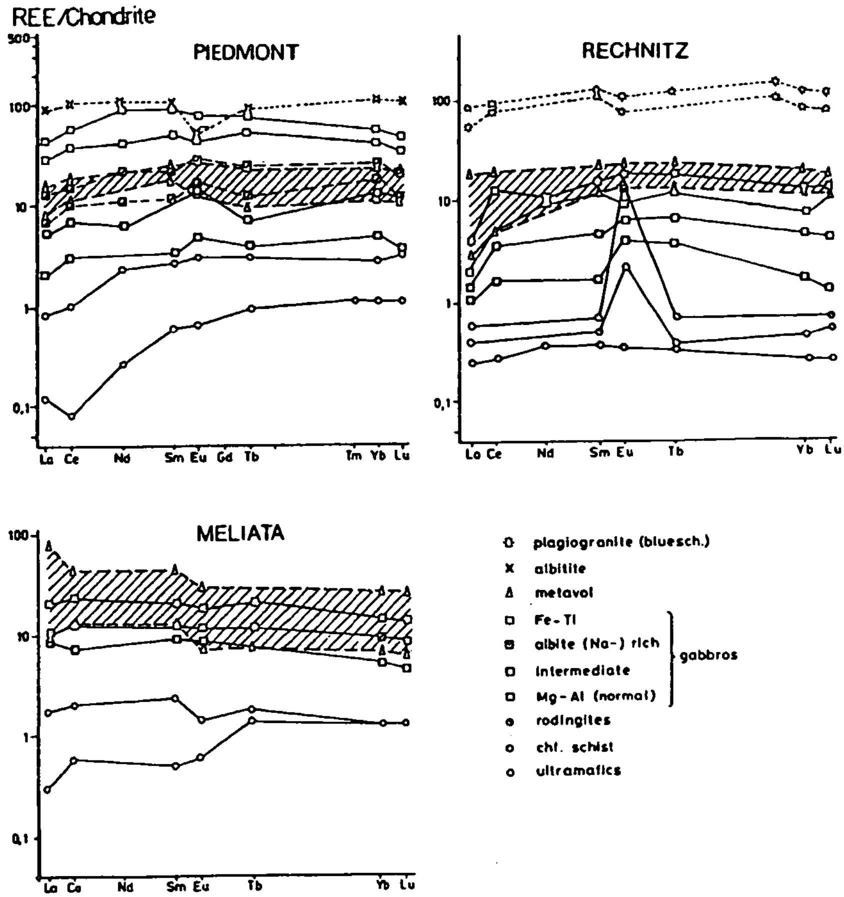

Fig. 3. Rare earth element patterns of the ophiolite suites from the three regions, normalized to chondrite values of NAKAMURA (1974) and LEWIS and SMEWING (1980). Sources of data from Piedmont zone (LEWIS and SMEWING 1980; PICCARDO *et al.* 1988 c,d; our unpublished data) and from Rechnitz zone (KOLLER 1985; our unpublished data).

Pattern of 3-d transition elements normalized to "primitive" mantle estimated of JAGOUTZ *et al.* (1979) of the ultramafic rocks of all the three regions desplay compositions comparable to each other (*Fig. 5*). In detail, there are some remarkable differences between them. Comparing the Rechnitz zone with the Piedmont and Meliata zone, it is significant higher Ti and Fe and lower Ni values of the former. However some ultramafics from Piedmont zone show lower Ti and higher Co values with respect to other two. Many ultramafic rocks of Meliata zone are depleted in V and Mn and enriched in Co and Ni contents, as compared with the Rechnitz zone.

Plutonic rocks, because magmatic mineral phases have been preserved rarely, protoliths of metagabbroic rocks are identified either based on their coarse grained texture or on major and trace element patterns (*Fig. 2*). Three groups can be recognized: (1) Mg-Al rich metagabbros (normal gabbros) with higher MgO,

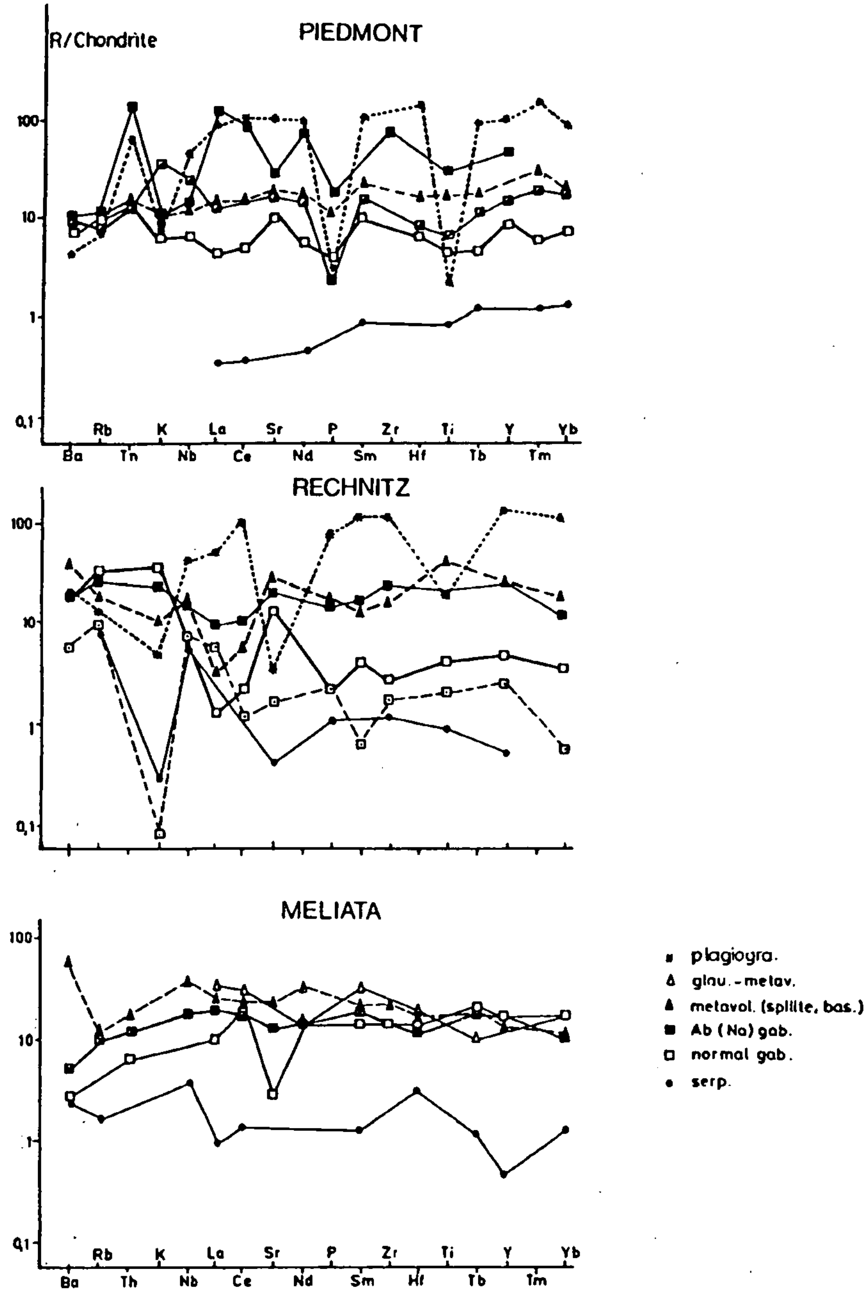

Fig. 4. Composition of the common trace element contents (as ppm) of ophiolite suites from the three regions normalized to chondrite values of THOMPSON *et al.* (1984). Sources of data from Piedmont ultramafics (OTTONELLO *et al.* 1984) and from Rechnitz (KOLLER 1985; our unpublished data).

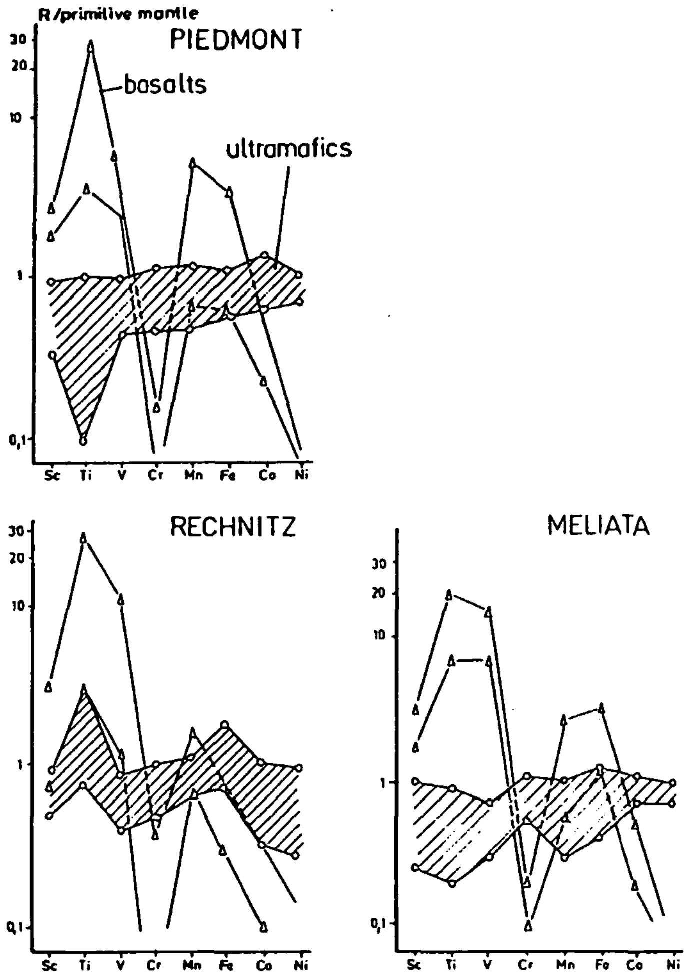

Fig. 5. 3-d transition element composition of ultramafic and volcanic rocks of the three regions, normalized to the primitive mantle composition (JAGOUTZ *et al.* 1979). Sources of data from Piedmont zone (POGNANTE *et al.* 1986), Rechnitz zone (KOLLER 1985) and from Meliata zone (HOVORKA 1985; our unpublished data).

Al_2O_3 and Cr and with low FeO^t/FeO^t+MgO values; (2) intermediate metagabbros with an intermediate value of FeO^t, FeO^t/FeO^t+MgO, (about 0.3—0.5) and Y, corresponding to plagioclase-pyroxene-gabbros and (3) Fe-Ti group of ferrogabbros and rarely glaucophane gabbros, with very high FeO^t, TiO_2, FeO^t/FeO^t+MgO (> 0.6) and with low SiO_2. The three groups of gabbros considered as typical stages of tholeiitic differentiation. The gabbroic rocks of the Alps (from Piedmont and Rechnitz zone) characterized by a progressive enrichment of REE and incompatible elements (*Fig. 3—4*) during their differentiation from Mg-Al gabbro to Fe-Ti gabbro and plagiogranite. On the other hand, very little progressive enrichment trend from Ca-rich (normal) gabbros to Na-rich (albite) gabbros have been found.

The *volcanic rocks* of all three zones display composition comparable to present-day mid-ocean ridge or marginal basin basalt of constructive oceanic plate margins (MORB, *Fig. 6—7*). However there are a few minor but interesting differences among the three regions. In the REE pattern (*Fig. 3*) and Hf-Th-Ta diagram (WOOD *et al.* 1979; *Fig. 6*) the Piedmont basalts show closer similarities with normal and transitional (N- and T-) MORB; the Rechnitz basalts are typically N-MORB (KOLLER 1985), while the Meliata basalts exhibit closer affinities with enriched and transitional (E- and T-) MORB.

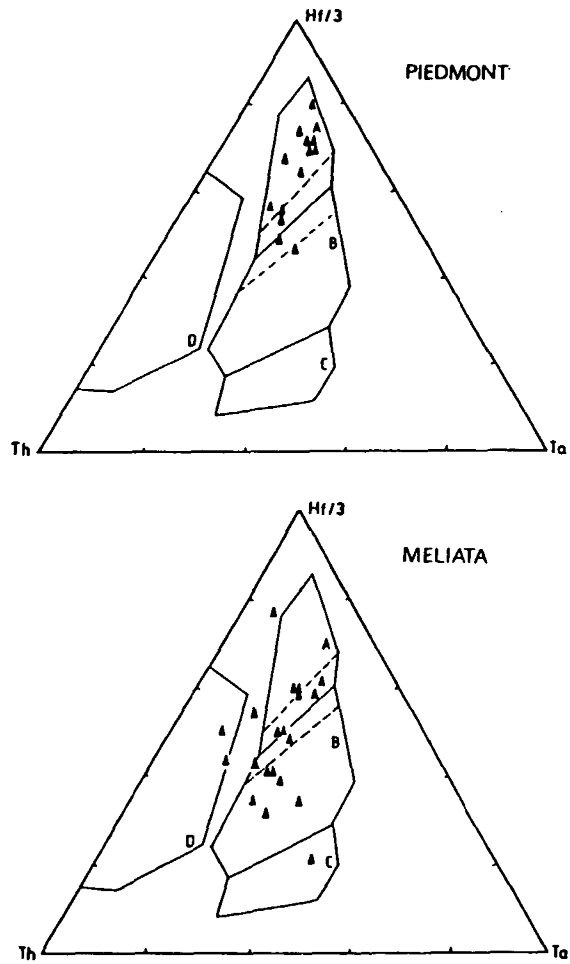

Fig. 6. Th-Hf/3-Ta diagram of basaltic rocks for the Piedmont and Meliata zones. A: N-type MORB; B: E-type MORB; C: alkalic within-plate basalts; D: magmas at destructive plate margins (after WOOD *et al.* 1979a). Sources of data: Piedmont basalts from LEWIS and SMEWING (1980) and our unpublished data.

The volcanic rocks of both Piedmont and Rechnitz zone plot quite well on a straight line passing through the origin of diagrams relating two hydromagmatophile elements (WOOD *et al.* 1979a) indicating that they are related by crystal

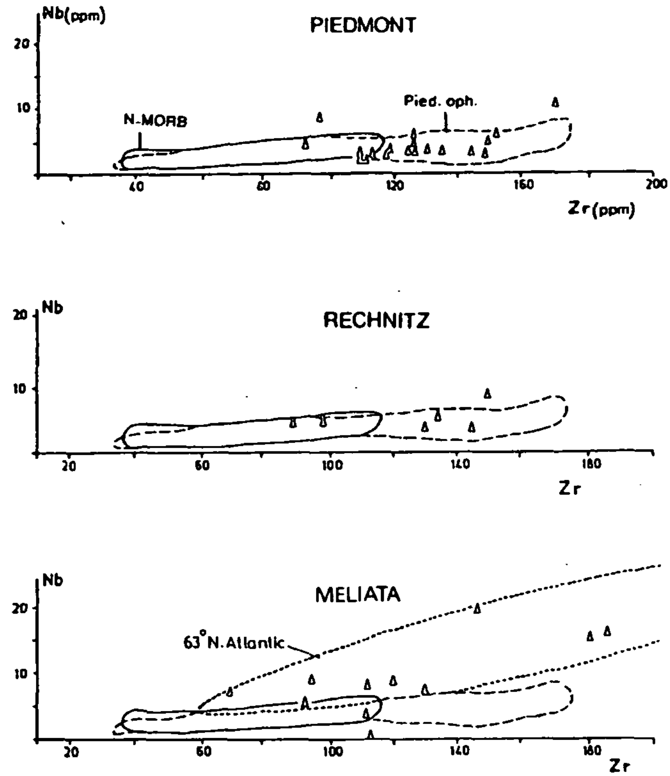

Fig. 7. Nb-Zr diagram (in ppm) of basaltic rocks for the three regions. The field of Piedmont basalts (LOMBARDO *et al.* 1978; LEWIS and SMEWING 1980; DAL PIAZ *et al.* 1981; BECCALUVA *et al.* 1984b; POGNANTE *et al.* 1982,1985). The fields of some MORB and some basalts sampled at different latitudes in the North Atlantic (PEARCE and CANN 1973; SUN *et al.* 1979; WOOD *et al.* 1979; LE ROEX *et al.* 1982) are shown for comparison. Sources of data from Piedmont zone (LEWIS and SMEWING 1980): our unpublished data and from Rechnitz zone (KOLLER 1985).

fractionation processes. That is apparent from Nb-Zr diagrams (*Fig. 7*) which indicate close similarities with the other basalts of the Piedmont ophiolites and with ocean floor basalt in particular N-MORB. This correlation is less evident in the case of Meliata volcanics which are typically similar to the North Atlantic basalts (WOOD *et al.* 1979a) reflecting their higher Nb contents with respect to the volcanic rocks of the Piedmont and Rechnitz zones. Estimation of the degree of partial melting on a Cr-Y diagram (*Fig. 8*) shows that Rechnitz zone have higher Cr values comparing with the other two. Most volcanic rocks of the Piedmont and Rechnitz and a few samples from Meliata are situated on the subvertical line marking the fractionation pass for typical oceanic tholeiites (PEARCE 1983; PEARCE and NORRY 1979) which starts at about 17% partial melting. A few points of both Rechnitz and Meliata volcanics are fallen into the island arc field, that can be probably ascribed to the metasomatism (in Rechnitz) and partly from spilitic processes and/or secondary alteration (in the Meliata zone).

Patterns of incompatible trace and minor elements normalized spider-diagrams (after THOMPSON *et al.* 1984 and PEARCE 1983; *Fig. 4* and *9*) are aside from the already discussed similarities of REE patterns (*Fig. 3*), nearly similar. In all the three regions, these volcanics show slight enrichment of the elements situated

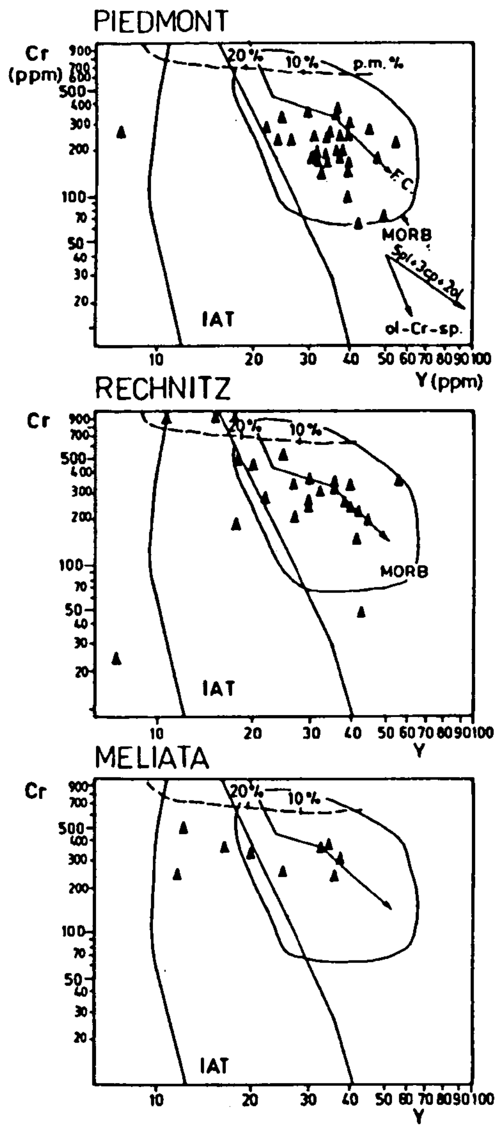

Fig. 8. Cr-Y diagrams (in ppm) of the basaltic rocks for the three regions to discriminate oceanic ridge basalts (MORB) from island are tholeiites (IAT). The horizontal dashed line shows the partial melting (p.m.) path with the amount of mantle melting indicated in %. The subvertical line marks the fractional crystallization (f.c.) path for typical oceanic tholeiite (after PEARCE 1983; PEARCE and NORRY 1979), which starts at about 17% melting. Closed system fractionation segments are subvertical (pl-sp), open system crystallization segments subhorizontal (plag+ol+cpx, HÖCK and MILLER 1987). Sources of data as *Fig. 7*.

on the left side of the diagram (mobile elements: series Sr-Ta of *Fig. 9*), toward plume-type MORB-composition a tendency which has been called "transitional" (T-type) by SUN *et al.* (1979) as well as WOOD *et al.* (1979a, b); LE ROEX *et al.*

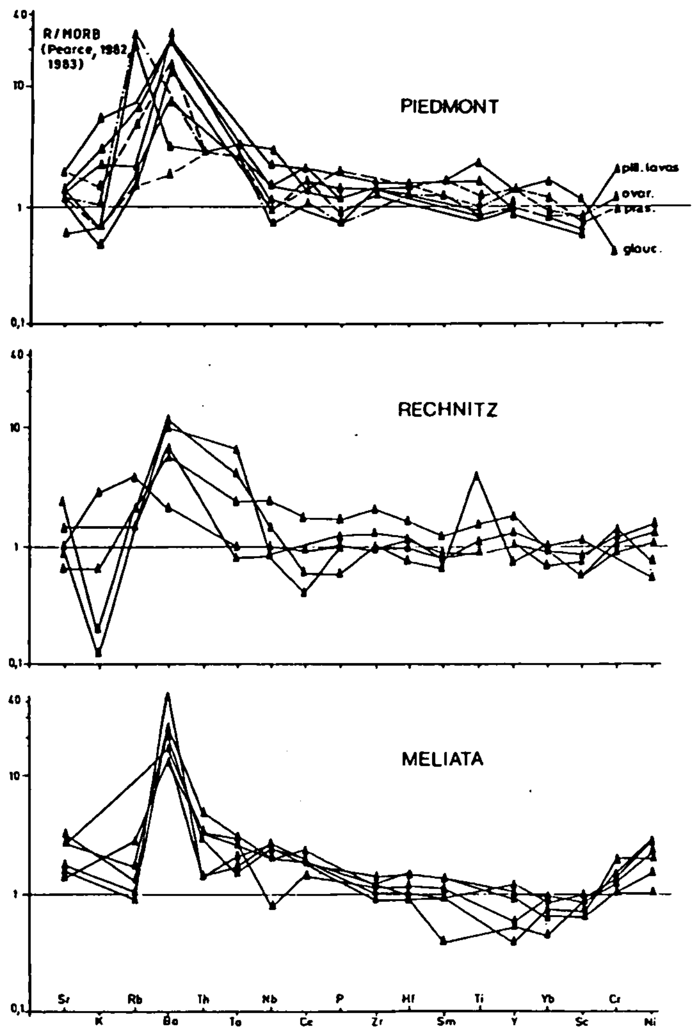

Fig. 9. Comparison of the common trace element contents (as ppm ratios) of basaltic rocks for the three regions with the "normal-MORB" composition of PEARCE (1983). Sources of data as *Fig. 7.*

(1983). In particular, these show closer similarities with N- and T-type (Piedmont zone) E- and T-type (Meliata zone) and with N-type MORB composition (Rechnitz zone). The same tendency was found by POGNANTE *et al.* (1986) and PFEIFER *et al.* (1989) from samples from Piedmont zone and by KOLLER (1985) for the Rechnitz zone. The three regions are enriched in Ba element, moreover, some samples of the Piedmont zone show an enrichment in Rb and K (*Fig. 9*), which can be attributed to metasomatism.

After a review of the ophiolites within the Alpine and Carpathian belts, Penninic and Vardar ocean in the Western Tethyan basin is to be compared.

(1) In the Tethyan basin, Jurassic Piedmont-Ligurian ocean in the Western Alps (including Arc valley, Monviso, Montgenévre and Roche Noire ophiolites) as well as the East one (including Rechnitz ophiolite) opened to the south and to the westward respectively. On the other hand, Triassic Vardar ocean (including Meliata ophiolite) opened to the south. However, both the Penninic and Vardar oceans (in the South Apuseni Mts. and East Carpathians) are overlapped each other (KÁZMÉR and KOVÁCS 1989).

(2) The Western Alps ophiolite, in the Piedmont zone, is composed of polyphase metamorphic dismembered ophiolite bodies and their most Liassic to Cretaceous sedimentary cover (mostly calc-schists). In the easternmost part of the Alps (i.e. the Rechnitz zone) it consists of a less metamorphosed sequence and Mesozoic metasediments. On the other hand, the Meliata zone of the Western Carpathians is composed of fragments of dismembered ophiolite sequence and its Middle Triassic deep-sea sediments (HOVORKA 1985; KUBOVICS *et al.* 1989) and Jurassic shale (KOVÁCS 1990 pers. comm.).

(3) All ophiolite suites, apart from some oceanic alteration, have more or less undergone a complex history of Alpine regional metamorphism with variable grade (eclogite to greenschist facies in the Arc valley and Monviso; glaucophane to greenschist facies in the Roche Noire, Rechnitz and Meliata and greenschist facies to prehnite-pumpellyite facies in the Montgenévre and Meliata).

(4) All units of the Monviso and Eastern Arc valley in the Eastern Piedmont ophiolite share a similar metamorphic history consisting of four stages: (1) oceanic event; (2) eclogitic stage; (3) blueschist stage and (4) greenschist stage. The oceanic metamorphism produced only local development of brown and green hornblende. The eclogitic stage was very pervasived and produced mineral assemblages composed of Na-pyroxene, garnet, epidote and rutile. The blueschist stage was characterized by the widespread development of Na-amphibole (mostly at the expense of Na-pyroxene), albite and locally garnet and phengite. The greenschist event produced irregular development of chlorite, albite, Fe-epidote and locally stilpnomelane. The Rechnitz, Roche Noire and Meliata units are mostly characterized by mineral assemblages of the blueschist to greenschist facies conditions. The best preserved, weakly metamorphosed units are observed in Montgenévre and Meliata ophiolites. These are characterized by prehnite-pumpellyite to greenschist facies mineral assemblages including albite, chlorite, epidote, prehnite, pumpellyite and iron oxide.

(5) Consequently, the grade of metamorphism is perhaps decreased from the Western Alps (Piedmont zone) through Eastern Alps (Rechnitz zone) to Inner Carpathians (Meliata zone).

(6) The amount of serpentinites, compared with the extrusives, are high in the Alpine and Carpathian belt. Serpentinite with harzburgitic composition are more dominant in the Eastern Alps and Inner Carpathians, while those with mostly lherzolitic and subordinately harzburgitic composition are more frequently in the Western Alps. The ultramafics of both the Alp and the Carpathian belt are mostly less abundant in REE as compared to chondritic values with more distinct light REE depletions. They are depleted in Ti (Piedmont zone) and V (Meliata zone) and enriched in Ti and Fe (Rechnitz zone) with respect to the estimated primitive mantle (JAGOUTZ 1979). Ophicarbonate is common in the Alpine belt.

(7) The magmatic (plutonic and volcanic) rocks in the Alps (i.e. Western and Eastern Alps) are characterized by wider compositional range of major, trace and rare earth elements as compared to that from the Carpathians (Meliata zone). The intensity of magmatism is decreased from the Western Alps through Eastern Alps to the Western Carpathians.

(8) The amount of intrusives compared to the extrusives decreased from Piedmont through Rechnitz to Meliata zone.

(9) Proper sheeted dyke complexes are missing in the Alp-Carpathian system.

(10) Most extrusive rocks from Eastern and Western Alps display compositions comparable to "normal" and "transitional" (N-/T-) MORB, perhaps indicating origin from heterogeneous sources by different degree of crystal-fractionation and/or lower degree of partial melting. Conversely, the Meliata basalts which strongly enriched in light and middle REE, show "enriched" and "transitional" (E-/T-) MORB character, and should have been derived by partial melting of differently (or anomalously) enriched sources, probably accompained by little fractionation. These "enriched" basalts are also recorded in the Piedmont zone (BECCALUVA *et al.* 1984b; POGNANTE *et al.* 1986) supporting evidences for heterogeneities in the local sources, as observed in the North Atlantic by WOOD *et al.* (1979).

(11) Ophiolites of the Alpine and Carpathian belt have mostly tholeiitic character with high Ti and Ba contents. They are characterized by a progressive enrichment in the incompatible and rare earth elements starting from ultramafics through intrusives to extrusives and plagiogranites. However, these elements follow a typical magmatic trend, confirming that the original bulk rock-trace elements composition can be preserved even during the different stages of metamorphism.

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