Comparative major and trace element geochemistry of gabbroic and volcanic rock sequences, Montgenèvre ophiolite, Western Alps*

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Abstract

The Montgenèvre ophiolite complex is one of the best preserved in the Alps. Ultramafic, gabbroic and basaltic rocks occur as distinct tectonic units.

Fifty-four representative samples from the gabbroic and the volcanic rocks have been analysed. The gabbroic sequence exhibits a very wide compositional range from troctolite to evolved ferrogabbro and albititic rocks. The volcanic sequence, which is mostly composed of pillowed basalts, is characterized by its rather small compositional range. Both the gabbroic and volcanic sequences show typical tholeiitic differentiation trends.

The results are discussed using the following variation diagrams: MgO versus TiO_2, Ni versus TiO_2, Ti/1000 versus V, Sc versus Ni, Zr versus Y and Zr versus Zr/Y. In the first three, the gabbros and basalts obviously show distinctive differentation trends, whereas a similar trend is observed in the last three. This observation is interpreted as reflecting crystallization of comparable melts under different P, T and oxygen fugacity conditions.

The early stage of differentiation is characterized by fractionation of olivine, spinel, clinopyroxene and plagioclase within a rather closed system. Part of the melt crystallized as troctolites and olivine-rich-gabbros, and partly as clinopyroxene gabbros. There is no evidence that part of the deep-seated "gabbroic melt" has escaped to higher levels to crystallize as basalts.

During crystallization of clinopyroxene gabbros, Fe and Ti are drastically enriched in the residual melt. Within the same system, and probably at deeper crustal levels ($\geqq 2$ kb), ferrogabbros could crystallize from this residual melt. The appearance of amphibole, however, indicates infiltration of H_2O and possibly also an increase in oxygen fugacity.

In the final stage of differentiation, a small volume of remaining melt, enriched in SiO_2, Na_2O and incompatible elements, crystallized as albititic dikes within the gabbroic sequence. The basalts exhibit characteristics clearly indicating a magmatic origin comparable to MORB.

Major and trace element data from the volcanic and plutonic rocks sugggest an independent magmatic evolution for the gabbroic and basaltic sequences. This conclusion is supported by field relations that show basaltic dikes to crosscut the gabbroic sequence.

Keywords: Ophiolites, bulk rock chemistry, variation diagrams, magmatic differentiation, Montgenèvre, Western Alps.

Introduction

The Montgenèvre ophiolite represents one of the best preserved ophiolite complexes in the Alps. As the rocks show only weak effects of Alpine deformation and metamorphism, they display exceptionally well preserved original textures and, in part, primary mineral assemblages. However, no complete succession is observed. The ultramafic, gabbroic and basaltic

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lithologies occur as separate tectonic units, as is typically the case for a dismembered Alpine ophiolite. Primary contacts between these lithologies or clear transition zones are not observed. As usual in the Western Mediterranean area, a sheeted dike complex is missing. Nevertheless, when compared to modern oceanic lithosphere, a reconstructed succession of the dismembered lithologies shows the Montgenèvre massif to exhibit many of the characteristics of the ideal ophiolite sequence. The effects of magmatic differentiation, especially in the gabbroic sequence, are remarkable.

Previous work on this ophiolite was mainly concerned with its tectonic setting and with the description of lithology and structure. Older references are listed in PUSZTASZERI (1969) and LEMOINE (1971). In the context of seafloor spreading and plate tectonics, the Montgenèvre ophiolite is being restudied from a geochemical, petrological and structural point of view (MÉVEL, 1975; LEWIS and SMEWING, 1980; BERTRAND et al., 1981, 1982, 1984, 1985). The rocks have been subjected to various degrees of oceanic alteration processes. Subsea floor metamorphism in the gabbros has locally produced flaserisation and foliated amphibolites (GIROD and CABY, 1975; MÉVEL et al., 1978; STEEN et al., 1980).

With respect to the large amount of available data on basalt geochemistry in the Western Alps and Apennines, comparatively few data have been published on gabbros (OHNENSTETTER et al., 1975; BECCALUVA et al., 1977, 1980; SERRI, 1980, 1981; SERRI and SAITTA, 1980; LOMBARDO and POGNANTE, 1982; POGNANTE et al., 1982 and 1985). This is partly due to the scarcity, or even absence, of gabbroic rocks in many alpine ophiolites, as well as to tectonic and metamorphic overprint. The Montgenèvre ophiolite exhibits pillow lavas piled up to 600 m thickness and two main gabbro units exposed over 200 m thickness. The serpentinised peridotitic units crop out mainly at the eastern part of the masssif (Fig. 2). The ultramafic, gabbroic and basaltic lithologies show many textural and chemical variations (BERTRAND et al., 1981, 1982).

The main purpose of this paper is to compare the major and trace element geochemistry of the gabbroic rocks to that of the basaltic rocks in order to establish their differentiation histories, and gain insight into their oceanic geotectonic environment.

The new data provide further information on the origin and evolution of the Piemont-Ligurian oceanic domain as part of the Mesozoic Tethys. The results are discussed taking into account chemical evidence from ophiolites in Corsica, the Northern Apennines, and from the Rocciavré and Lanzo ophiolites in the Western Alps. Chemical data from the present-day oceanic crust are also drawn upon for comparison.
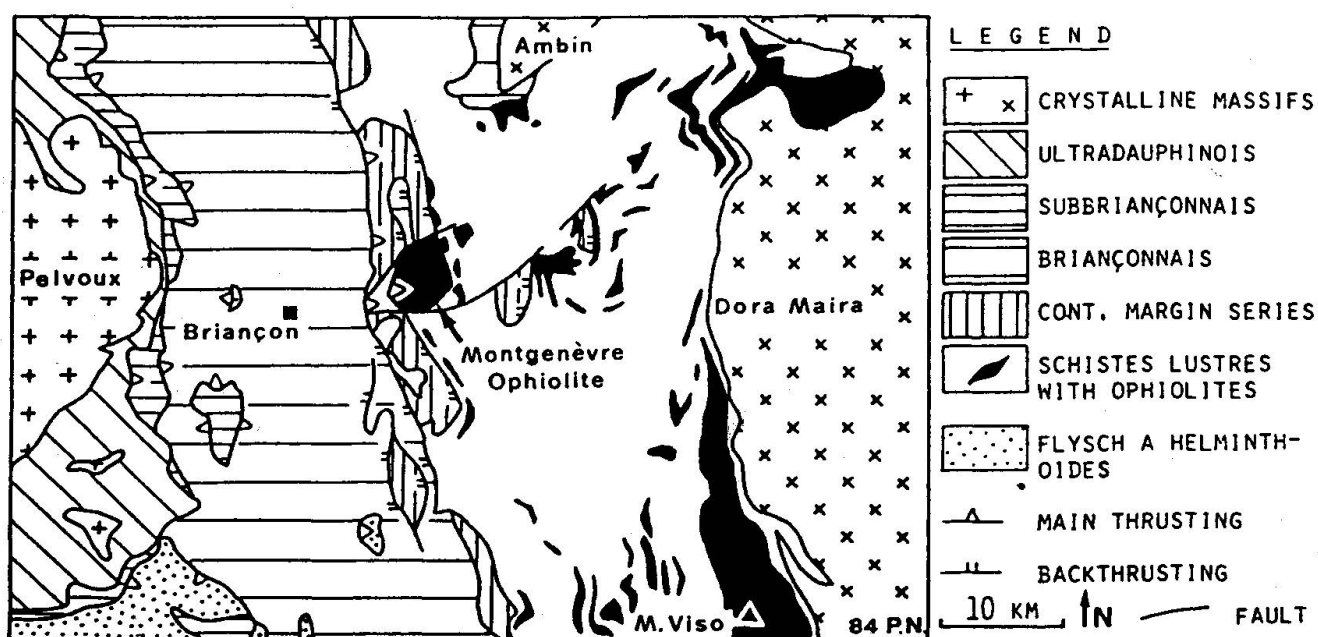

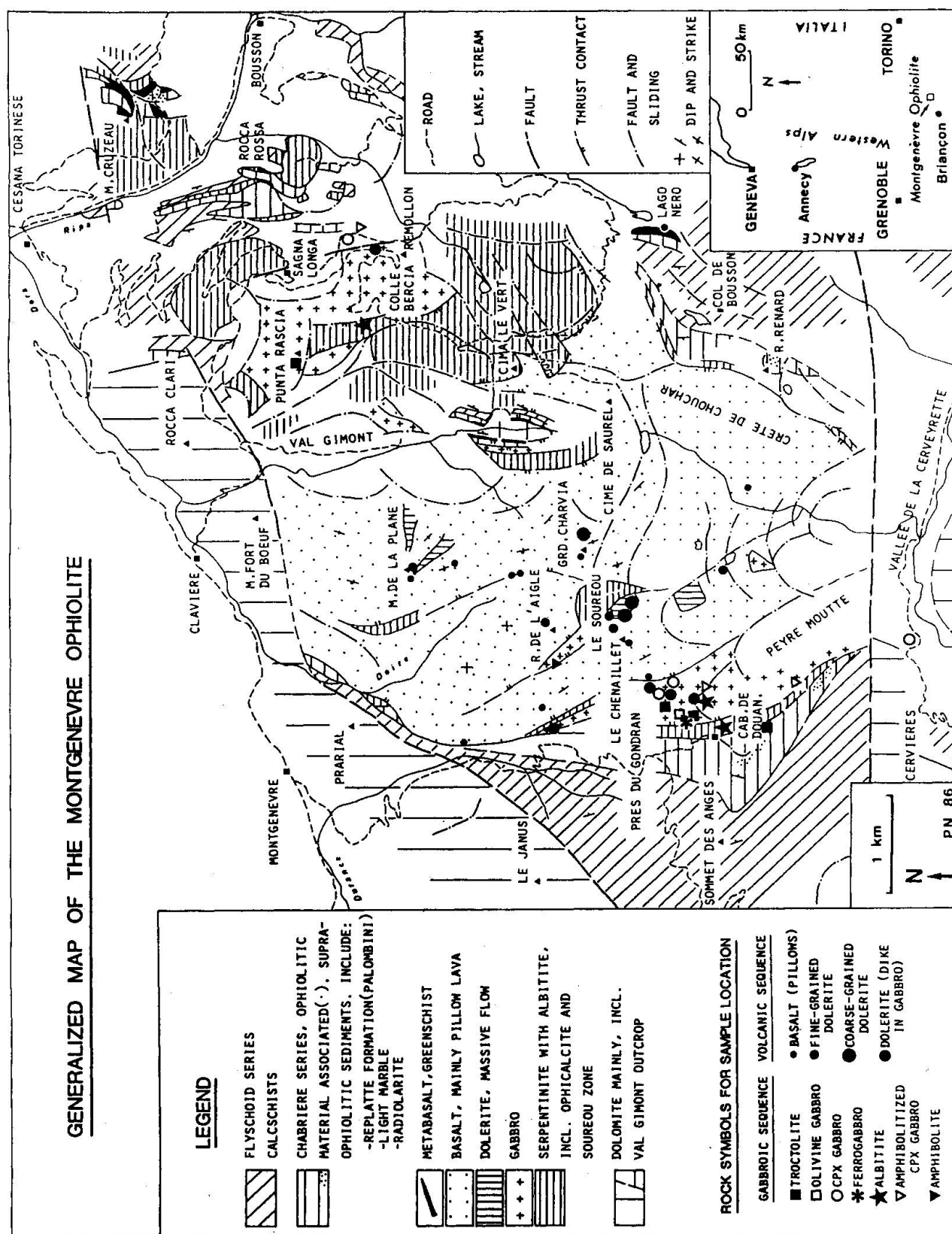Fig. 1   Tectonic setting of the Montgenèvre ophiolite.

Fig. 2 Geological map of the Montgenèvre ophiolite with sample location.

Geological setting

Situated 8 km East of Briançon at the French-Italian border, the Montgenèvre ophiolite massif covers an area of approximately 30 km^2 (Fig. 1 and 2). The Mesozoic ophiolite and the associated sediments, which belong to the "zone des schistes lustrés piémontais" of the internal Western Alps, are thrusted on a Mesozoic continental margin series formerly called "zone prépiémontaise" (LEMOINE and TRICART, 1986; POLINO et al., 1986). To the North and to the South, faults limit the Montgenèvre compartment that occupies a peculiar position in a region of prominent backthrusting tectonics. Although extensive Quaternary sliding within the ophiolite has obscured many thrust contacts, especially in the South East and in Val Gimont, the general structure of the massif is recognizable. Two parts can be distinguished (BERTRAND et al., 1984, 1985):

a) *The Montgenèvre ophiolite sensu stricto* consists of several thrust units of ultramafic, gabbroic and basaltic rocks. No trace of a pelagic sediment cover is observed, but ophiolitic arenites and breccia layers and even a block-rich zone (Souréou zone) give ample evidence of reworking of a complex seafloor. Almost no deformation and only incipient Alpine metamorphism are characteristic in these units (BERTRAND et al., 1984; MARTIN, 1984).

b) *The underlying zone of the schistes lustrés sensu lato* is mainly composed of Jurassic and Cretaceous sediments often deposited on an ultramafic basement. The pelagic radiolarite-marble-limestone/shale (Palombini) succession of the supraophiolitic Chabrière series (LEMOINE et al., 1970; TRICART, 1974) is overlain by flyschoid rocks (POLINO and LEMOINE, 1984). Detrital ophiolitic material is observed at the base and at several levels in the pelagic sediment sequence (POLINO and LEMOINE, 1984; BERTRAND et al., 1984, 1985; LEMOINE and TRICART, 1986). This underlying zone is characterized by more intense and often polyphase deformation and metamorphism (BERTRAND et al., 1984, 1985), with highly spilitized metabasalts (analysis MG 44) and widespread occurrence of high pressure/ low temperature minerals like lawsonite, Na-pyroxene and Na-amphibole. Typical

examples of this zone underlying the Montgenèvre ophiolite s. str. are found in the tectonic window of Val Gimont, at Mont Cruzeau, Rocca Rossa, Lago Nero, Mont Corbioun (East of Lago Nero), Rocher Renard zone and West of Cabane de Douaniers (Fig. 2).

Main lithology

The ultramafic sequence (70 to 100% serpentinised) mainly consists of lherzolitic tectonites with minor pods or lenses of cumulate rocks. Pyroxenitic layers often occur within the lherzolites; dunites and harzburgites are subordinate. The cumulates are lherzolitic, wehrlitic, troctolitic and gabbroic in composition. Locally, the ultramafic sequence is crosscut by early coarse-grained gabbroic and late fine-grained basaltic and albititic dikes. Gabbroic and basaltic dikes show effects of rodingitisation.

The gabbroic sequence exhibits a great variety of rock types with often complex contact relationships. The main part is made up of clinopyroxene gabbros. Troctolites with adcumulate-heteradcumulate textures, and olivine gabbros with heteradcumulate textures mainly occur at the base of the units. A common feature is the great variation in grain size and the heterogeneous distribution of clinopyroxene, plagioclase and even olivine. Transitions to dioritic and plagioclase-rich compositions are observed. Late albititic dikes also cut the gabbros. Ferrogabbros seem to form lenticular and dike-like bodies, and appear to have been strongly affected by near-seafloor hydrothermal alteration producing secondary mineral assemblages with chlorite, epidote, sulfides, etc. They predominantly occur at the lower part of the Chenaillet unit. Evidence of subseafloor metamorphism is locally found, mostly in the clinopyroxene gabbros. Porphyroclastic textures, recrystallization of clinopyroxene to a later stage augite and/or hornblende and flaserisation with more extensive growth of hornblende is common. Stronger deformation and recrystallization produced foliated amphibolites (GIROD and CABY, 1975; MÉVEL et al., 1978, STEEN et al., 1980) The gabbroic sequence is cut by plagioclase-porphyritic and aphyric basaltic dikes exhibiting chilled margins. They postdate the flaserisation and the albititic dikes.

The volcanic sequence is best preserved in the northwestern part of the Montgenèvre ophiolite where no sliding occured. Pillow lavas accompanied by pillow breccias and subordinate hyaloclastites form the major part of the volcanic pile (VUAGNAT and PUSZTASZERI, 1965, 1966; MÉVEL, 1975). Aphyric and plagioclase-porphyric lavas showing flow interfingering are observed. In several places, a transitional passage from massive coarse-grained flows through finer-grained and brecciated varieties at the edge into pillowed lavas is found. In some outcrops, a transition from feeder paths to lava tubes, to pillows and brecciated pillows can be observed. Locally, pillow breccias form well defined layers. Intercalations of sediments are restricted. They consist mainly of arenites with volcanic, gabbroic and serpentinitic detritus (BERTRAND et al., 1984). Neither basaltic nor albititic dikes were found in the volcanic sequence.

Mineralogy and petrography

The mineralogy and petrography of the gabbros and the basalts have been described in more detail by MÉVEL (1975), MÉVEL et al. (1978) and BERTRAND et al. (1981, 1982). The

Tab. 1a Main petrographic features of representative rock types from the Montgenèvre gabbroic ophiolitic sequence.

Sample No	Rockname	Locality	Texture	Main primary minerals (magmatic and late-stage magmatic)	Main secondary minerals (hydrothermal and metamorphic)
MG 15	Troctolite	Chenaillet (SW ridge)	adcumulate-heteradcumulate	ol,cpx,pl,[sp]	chl,act-trem,Ca-sil (fine-grained)
MG 16	"	Punta Rascia	"	"	"
MG 17	Melatroctolite	Chenaillet (SW ridge)	"	"	chl,act-trem
MG 18	Olivine-gabbro	" "	"	"	"
MG 19	Cpx-gabbro	Punta Rascia (Sagna Longa)	heteradcumulate	cpx(di-sal),pl,ox,[ol], [hbl]	ab,amph,chl,ep,pump
MG 20	"	Chenaillet (SW ridge)	"	"	"
MG 21	"	Chenaillet (SE side)	"	"	"
MG 22	Amphibolitised cpx-gabbros	Chenaillet (SW ridge)	heteradcumulate	"	"
MG 23	"	" "	"	"	"
MG 8	"	Chenaillet (SE side)	"	"	"
MG 24	Flaserised amphibolitised cpx-gabbro	" "	porphyroclastic (oriented)	cpx(di-sal),pl,ox,[hbl]	ab,cpx(aug),amph,chl, ep,pump
MG 25		Punta Rascia /Sagna Longa)	"	"	"
MG 26	Amphibolite	Souréou Valley	granoblastic porphyroclastic (foliated)	"	"
MG 11	Ferrogabbro	Chenaillet (SW ridge)	granular (unknown primary texture)	pl,am(?),ilm,ap	chl,ep
MG 12	"	" "		pl,am(?),[ilm]	"
MG 13	"	" "		pl,am(?),ilm	chl,ep,amph,sph,[ru]
MG 14	"			"	chl,ep,amph,sph
MG 1,MG 2	Albitite	Chenaillet (Gondran)	granular-granoblastic	olig(?),hbl,cpx,[ap], [Zr],[all]	ab,act,chl,pump
MG 3,MG 4	"	" "		"	"
MG 6	"	Chenaillet (SE side)	"	"	"
MG 9	"	Colle Bercia	"	"	"
MG 10	"	Colle Bercia	"	", more hbl rich	", more chl rich

Abreviations: ol: olivine; cpx: clinopyroxene; di-sal: diopside-salite; aug: augite; pl: plagioclase; olig: oligoclase; hbl: hornblende; am: amphibole; ilm: ilmenite; ap: apatite; zr: zircon; chl: chlorite; act-trem: actinote-tremolite; act: actinote; amph: Mg-hbl, pargasite, actinote; Ca-sil: Ca-silicates; ab: albite; ep: pistacite-clinozoisite; all: allanite; pump: pumpellyite; ox: Fe-Ti oxides; sph: sphene; ru: rutile.

[ ]: subordinate mineral; (?): uncertain primary origin

primary (magmatic and late-stage magmatic) and the secondary (hydrothermal and metamorphic) mineral assemblages and textures are summarized in Tables 1a and 1b. Some features will be summarized in the following paragraph.

In the gabbros, changes in grain size appear more prominent than variations in mineral proportions. The main primary constituents were plagioclase, clinopyroxene, olivine and accessory minerals such as spinels, Fe–Ti oxides, apatite and zircon. The only magmatic minerals partly preserved, excluding accessories, are clinopyroxene ranging from diopsidic augite to diopsidic salite, and some horn-

Tab. 1b   Main petrographic features of representative rock types from the Montgenèvre volcanic ophiolitic sequence.

Sample No	Rockname	Locality	Texture	Main primary minerals (magmatic and late-stage primary)	Main secondary minerals (hydrothermal and metamorphic)
Doleritic dikes within the gabbros					
MG 27	Dolerite	Chenaillet (SW ridge)	f.-g. intersertal porph.	pl,cpx, [hbl],[ol],ox	ab,act,chl,pump,ep,[preh]
MG 28	"	" "	f.-g. intersertal sl. porph.	"	"
MG 29	"	Chenaillet (W side)	f.-g. intersertal	"	"
MG 30	"	Punta Rascia (Sagna Longa)	f.-g. intersertal	"	"
MG 31	"	Chenaillet (SW ridge)	m.-g. intersertal	"	"
MG 32	"	Chenaillet (W side)	"	"	"
MG 33	"	Punta Rascia (Sagna Longa)	c.-g. intersertal	"	"
MG 7	"	Chenaillet (SE ride)	m.-g. intersertal	"	"
MG 60	"	Chenaillet (SW ridge)	m.-g. intersertal sl. porph.	"	"
Coarse grained dolerites within the lava flows					
MG 34	Dolerite	Chenaillet (SE ridge)	ophitic	pl,cpx+Ti-ox,sph,[ol], [hbl]	ab,act,chl,preh,pump,ep
MG 40	"	Mont la Plane	intersertal		"
MG 51	"	Chenaillet (ESE ridge)	subophitic	"	"
MG 59	"	Grand Charvia (E side)	intersertal	"	"
Fine grained dolerites within the lava flows					
MG 37	Dolerite	Chenaillet (NE side)	intersertal	pl,cpx(Ti-sal,aug),ox,+ol	ab,chl, preh,pump,ep,[act], ca,zeol
MG 36	"	" "	"	"	"
MG 38	"	" "	"	"	"
MG 39	"	Rocher de l'Aigle	"	"	"
MG 35	"	Chenaillet (NE side)	"	"	"
MG 50	"	Chenaillet (SE side near lac Noir)	"	"	"
Pillow basalts (core)					
MG 41	Basalt	Chenaillet (W side)	intersertal div. porph.	pl,cpx(Ti-sal,aug),ox,+ol	ab,chl,preh,pump,ep,[act], ca,zeol
MG 43	"	Colette verte (Mt.la Plane-Gd.Charvia unit)	intersertal div. aphyric	"	"
MG 42	"	Grand-Charvia	"	"	"
MG 44	Spilitic basalt	Lago Nero	intersertal arb. aphyric	"	ab,chl,lx,ca,hem
MG 52	Basalt	Chenaillet (SW ridge)	intersertal div. aphyric	"	ab,chl,preh,pump,ep,[act], ca,zeol
MG 53	"	Chenaillet (summit)	intersertal sl. porph.	"	"
MG 54	"	" "	"	"	"
MG 55	"	Crête de Chouchar	intersertal div. aphyric	"	"
MG 56	"	Chenaillet (NW ridge)	intersertal div. porph.	"	"
MG 57	"	Colette verte (Mt.la Plane-Gd.Charvia unit)	intersertal div. aphyric	"	"
MG 58	"	Mont la Plane	intersertal sl. porph.	"	"

Abreviations: idem table IA, and: preh: prehnite; cpx+Ti: titaniferous cpx; Ti-sal: titaniferous salite;
ca: calcite; zeol: zeolite; hem: hematite. +: variable from on sample to another.
f.-g.: fine-grained; m.-g.: medium-grained; c.-g.: coarse-grained;
div.: divergent; arb.: arborescent; porph.: porphyric; sl. porph.: slightly porphyric.

blende. Occasionally, clinopyroxene is rimmed by late-magmatic, brown hornblende which, in turn, is overgrown by green hornblende and even light-colored actinolite-tremolite. Olivine is completely replaced by actinolite-tremolite and chlorite. Plagioclase is always transformed to albite and saussurite. Former Fe–Ti oxides now appear as ilmenite-sphene-leucoxene assemblages.

In the troctolites a range between olivine-rich and plagioclase-rich varieties is observed; clinopyroxene is subordinate. Similar variations exist from melano- to leuco-olivine gabbros. Ferrogabbros have most strongly suffered from metasomatism, which is probably related to near-surface oceanic hydrothermal activity in fractured zones of the gabbroic section. Clinopyroxene is locally preserved. The accessories apatite, Fe–Ti oxides and zircon may be abundant in this rock type. Plagioclase is completely replaced by epidote and chlorite. Fe-rich pargasitic amphibole is the main mafic constituent. Extensive growth of epidote, chlorite and Fe-sulfides is thought to represent oceanic hydrothermal activity. Actinolite and sphene-leucoxene-rutile assemblages are also observed. The magmatic mineral assemblage *in the albitite* was mainly Na-rich plagioclase—probably oligoclase—some clinopyroxene and hornblende as well as zircon, apatite and allanite. Albite possibly crystallized already during subseafloor metasomatism (MARTIN, 1984). Cataclastic textures formed before growth of Alpine Na-pyroxene and Na-amphibole (BERTRAND et al., 1984). *In the gabbroic* sequence, some actinolite as well as epidote, pumpellyite and prehnite are thought to represent Alpine metamorphic minerals, in some cases not excluding an early oceanic origin (MÉVEL, 1981). Oceanic alteration in the gabbroic rocks is shown by Na enrichment.

For the basaltic rocks the same Na-enrichment is observed, with metabasalts even more highly spilitized (MG 44). In addition, hematite and sometimes calcite impregnations that developed near the seafloor are locally important. The altered basalts mostly comprise pillow lavas and include some massive flows and dikes (both named dolerites in this paper). Only the inner parts of massive flows (shown in Fig. 2) display coarse-grained ophitic to intersertal textures. The outer parts of the dolerites, dikes and pillow cores have finer-grained intersertal textures. However, nearly all the pillows exhibit arborescent textures. Some dikes and pillows are coarsely plagioclase-phyric (LEWIS and SMEWING, 1980; BERTRAND et al., 1984). The aphyric pillow lavas are variolitic, have a chlorite selvage (older glassy margin) and often exhibit the classical variation from intersertal to divergent and arborescent textures from core to rim (VUAGNAT, 1946).

The phyric pillows show no significant textural variations. Plagioclase phenocrysts are observed even within the outermost part. Primary magmatic minerals in the basaltic rocks were clinopyroxene, calcic-plagioclase and some olivine; the latter two are totally replaced by albite and chlorite/serpentine, respectively. The clinopyroxene composition varies from augite to titaniferous salite. MÉVEL (1975) mentioned Ti-zonation in clinopyroxene, which is most pronounced in the purple, Ti-rich varieties of the coarse-grained dolerites. The secondary mineral assemblages crystallized during both subseafloor and Alpine metamorphism (not easy to distinguish) and include albite, brown and green amphibole, epidote, pumpellyite, prehnite, actinolite, chlorite and sphene. More locally, zeolites, hematite and calcite have are abundant.

Sampling and analytical techniques

A total of 54 representative samples were chosen for bulk-rock chemical analyses. Up to 3 kg samples of gabbroic rocks were carefully selected to avoid grain-size effects. From dikes and pillow lavas only the interior parts were taken in order to eliminate chilled margins and variolitic rims. These are known to have been subjected to significant metasomatic changes during seafloor alteration (HUMPHRIS AND THOMPSON, 1978a and b) and Alpine metamorphism (MÉVEL, 1975; DIETRICH et al., 1974; VON HEUGEL, 1982).

Bulk major element chemical composition was determined by XRF analysis of glass beads. The beads were fused from 1 g rock and 5 g $Li_2B_4O_7$ powder mixtures in a gold-platinum crucible at 1150 °C (MAXWELL and JOHNSON, 1981). XRF major element analyses were performed with a Philips PW 1540 spectrometer at the department of Mineralogy of the University of Geneva.

Trace element and S abundances were determined by XRF analyses at the Eidgenös-

sische Materialprüfungsanstalt (EMPA), Dübendorf and at the ETH, Zürich. Ten grams rock powder samples were analyzed using synthetic background methods and relying on known major element content. Data treatment was computer-performed (NISBET et al., 1979). USGS reference sample were used for calibration. The resulting accuracies were ± 2-3% at 1000 ppm, ± 5-10% at 100 ppm and ± 10-20% at 10 ppm. A chromium tube was used, and detection limits range between 3 and 5 ppm for most trace-elements.

Major and trace element geochemistry

Major element analyses of Montgenèvre ophiolite rocks have already been published and discussed (BERTRAND et al., 1982). Harker plots, AFM and other diagrams involving elements such as Ti, P, Mg and Fe were used for rock classification and discrimination between major magmatic series (PEARCE and CANN, 1973; FLOYD and WINCHESTER, 1975; WOOD et al., 1979a). Despite oceanic alteration processes that caused some changes in major element composition, the Montgenèvre gabbroic and basaltic rocks were chemically distinguishable as abyssal tholeiites.

The data presented here are used to evaluate magmatic processes (e.g. fractional crystallization and magma mixing) and to study the relationship between the plutonic and volcanic rock suites (Tables 2a and 2b). In particular, did the gabbros and basalts originate from the same parental melt, or should they be regarded as separately differentiated rock series derived from different magma sources? Furthermore, have these rocks undergone a separate magmatic evolution at different times and in different geotectonic environments (e.g., young rift system, oceanic spreading system, transform fault zone)?

The four analyses of the *troctolites and olivine gabbro* represent composition of the most typical cumulate part of the gabbroic sequence (Table 2a). High MgO, Ni and Cr values are consistent with a more primitive nature of the magma and the partly ultramafic character of these rocks. The wide range of some major element compositions (MgO, Al_2O_3, CaO, Na_2O) can easily be explained by variations in the modal abundances of olivine, plagioclase, as well as some clinopyroxene and spinel, which

were the first mineral phases crystallizing during fractional crystallization of a primitive tholeiitic melt. Low contents of V and Sc agree with the observation that clinopyroxene is only a minor constituent in the earlier cumulates.

The major part of the whole gabbroic sequence is made up of *clinopyroxene gabbros* (ca. 90%) including *amphibolitized and flaserized types* (ca. 5%). Clinopyroxene appears as a new major mineral constituent and strongly controls the bulk chemistry. However, the analyses of the clinopyroxene gabbros are more difficult to interpret than those of troctolites. Common features are the low TiO_2 abundances, a rather small range in the Mg-values, and rather high SiO_2 contents when compared to those of the basaltic rocks. The range in chemical composition is again due to variations in modal proportions (compare samples MG 19 and 20). Sc and, to a lesser extent, V and Ti abundances correlate with clinopyroxene contents. By contrast Cr shows no clear correlation with the major mineral phase distribution; it probably occurs in minor constituents randomly distribued in the gabbros. The rather erratic distribution of Ba and Sr could be an effect of post-magmatic transformations.

The three analyses of strongly *amphibolitized and flaserized gabbros* show chemical characteristics similar to those of "normal" clinopyroxene gabbros, with the exception of higher Y and Zr values that are difficult to explain with the available data.

In *ferrogabbros,* the wide compositional range is certainly due to the irregular distribution of amphibole and Fe–Ti-rich oxide rich primary mineral assemblages, and to later transformation products. Chlorite and epidote (MG 13, 14), and sulfides are attributed to oceanic metasomatic transformation processes. Characteristics of the ferrogabbros are the high Fe-, Co- and Ti-contents and the positive correlation of Co with Fe. P_2O_5 values are significantly higher in two samples (MG 11, 13), and Cr and Ni abundances seem rather high compared to average clinopyroxene gabbros. Cu and Zn values remain the same. High contents of the more hygromagmatophile elements Ba, Sr, La, Ce and Nd might be due to enrichment in the evolved melt or to later hydrothermal activity. The very low Na_2O abundances reflect the replacement of primary plagioclase by epidote and chlorite.

The bulk chemistry of the *albititic rocks*

Tab. 2a Chemical composition of representative rock types from the Montgenèvre gabbroic ophiolitic sequence.

Sample No:	TROCTOLITES-OLIVINE GABBRO				CLINOPYROXENE GABBROS (more or less amphibolitised)						(amphibolitised and flaserised)		
	MG 15	MG 16	MG 17	MG 18	MG 19	MG 20	MG 21	MG 22	MG 23	MG 8	MG 24	MG 25	MG 26
weight %													
SiO_2	42.83	42.62	41.69	47.45	50.21	50.54	55.76	53.83	54.24	55.87	53.00	56.63	51.89
TiO_2	0.22	0.25	0.15	0.19	0.45	0.18	0.63	0.29	0.31	0.31	0.52	0.64	0.30
Al_2O_3	15.26	16.23	8.86	21.18	14.91	21.61	18.45	16.45	16.08	13.10	16.90	15.61	18.36
Fe_2O_3	1.81	2.07	5.04	1.01	1.26	0.77	1.20	1.09	1.16	1.93	1.34	1.92	0.96
FeO	5.55	4.10	4.07	2.71	3.46	1.26	3.31	2.61	2.99	2.88	4.00	3.61	2.91
MnO	0.13	0.09	0.11	0.08	0.12	0.07	0.08	0.12	0.11	0.14	0.13	0.13	0.08
MgO	18.51	18.10	27.39	8.49	9.02	4.51	4.42	7.05	7.43	8.62	7.30	6.04	8.20
CaO	6.63	7.94	4.61	10.03	13.45	12.77	5.62	10.53	9.43	10.17	8.66	7.24	9.92
Na_2O	1.30	1.30	n.d.	3.21	2.90	3.92	6.87	4.56	4.88	4.67	4.85	5.91	4.28
K_2O	0.12	0.18	n.d.	0.26	0.10	0.35	0.32	0.19	0.43	n.d.	0.29	0.11	0.14
P_2O_5	0.03	n.d.	0.03	0.03	0.03	0.02	0.04	0.03	0.02	0.06	0.08	0.10	0.06
H_2O^+	6.77	6.76	7.12	4.98	3.74	3.68	3.11	2.63	2.62	1.29	2.74	1.75	3.12
CO_2	0.11	0.11	n.d.	n.d.	0.02	0.08	0.29	n.d.	n.d.	0.08	0.06	0.14	0.26
Total	99.27	99.75	99.07	99.62	99.67	99.76	100.10	99.19	99.70	99.13	99.87	99.83	100.48
$Mg/(Mg+Fe^{2+})$	0.84	0.86	0.86	0.82	0.80	0.82	0.67	0.80	0.79	0.79	0.74	0.69	0.81
Fe_2O_3/FeO	0.33	0.51	1.24	0.37	0.36	0.61	0.36	0.42	0.39	0.67	0.34	0.53	0.33
Trace elements (ppm)													
Ba	3	6	2	4	12	9	155	7	11	6	12	4	7
Rb	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Sr	112	151	7	198	98	316	229	146	232	188	326	287	278
Nb	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
La	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
Ce	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23
Nd	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
Y	<4	<4	<4	<4	6	<4	6	16	36	6	59	37	33
Zr	<4	8	10	<4	16	6	24	78	275	10	472	275	532
U	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6
Th	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
Pb	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
V	25	28	29	56	228	98	205	143	140	171	136	121	112
Cr	84	81	343	323	238	686	10	529	330	1276	607	163	825
Ni	532	633	1054	237	134	81	25	93	97	98	140	99	184
Co	77	56	72	31	35	<6	29	16	30	30	39	36	23
Cu	88	80	<7	10	53	<7	<7	<7	14	<7	8	<7	<7
Zn	36	28	27	18	17	<5	22	32	34	21	49	38	20
Ga	<2	<2	<2	3	5	3	10	5	7	4	11	6	8
Sc	4	3	4	7	55	22	33	35	34	44	33	21	27
S	26	<16	<16	<16	100	<16	<16	<16	29	<16	<16	<16	<16

Tab.2a Continued.

		FERROGABBROS			ALBITITES						
Sample No:	MG 11	MG 12	MG 13	MG 14	MG 1	MG 2	MG 3	MG 4	MG 6	MG 9	MG 10
weight %											
SiO_2	23.00	29.70	38.79	42.60	67.59	66.20	64.16	67.36	60.37	66.43	49.88
TiO_2	5.78	0.76	7.03	2.58	0.22	0.30	0.31	0.27	0.97	0.33	0.20
Al_2O_3	18.48	22.34	11.89	10.98	18.37	17.50	19.04	18.20	21.08	19.29	19.68
Fe_2O_3	8.18	8.45	7.50	6.94	0.82	1.53	1.86	0.84	1.06	0.20	0.71
FeO	21.23	13.45	6.35	9.47	0.55	1.26	0.67	0.59	1.42	0.76	2.11
MnO	0.34	0.23	0.34	0.19	0.02	0.04	0.02	0.02	0.04	n.d.	0.09
MgO	7.24	7.81	8.66	13.17	0.75	0.87	0.43	0.80	0.77	0.79	11.33
CaO	5.52	9.73	15.28	9.99	0.97	1.38	2.80	1.08	5.45	0.33	4.49
Na_2O	1.19	0.10	0.26	1.07	11.18	10.41	10.15	10.92	7.45	10.75	5.33
K_2O	0.29	0.10	0.10	0.10	0.10	0.10	0.10	0.10	n.d.	0.09	0.09
P_2O_5	0.68	0.06	0.77	n.d.	0.02	0.04	0.06	0.02	0.07	0.06	0.05
H_2O^+	7.88	7.06	2.39	2.86	0.23	0.31	0.96	0.35	0.74	0.76	5.64
CO_2	n.d.	0.39	0.30	0.18	0.10	0.10	0.10	0.10	0.27	n.d.	n.d.
Total	99.81	100.18	99.66	100.13	100.92	100.04	100.66	100.65	99.69	99.79	99.60
$Mg/(Mg+Fe^{2+})$	0.33	0.42	0.57	0.62	0.54	0.40	0.27	0.54	0.39	0.62	0.89
Fe_2O_3/FeO	0.39	0.63	1.18	0.73	1.49	1.21	2.78	1.42	0.75	0.26	0.34
Trace elements (ppm)											
Ba	105	37	100	39	29	19	43	31	37	23	34
Rb	<4	<4	<4	<4	<4	<4	4	<4	<4	<4	<4
Sr	319	622	520	74	6	23	19	6	396	30	77
Nb	<3	<3	5	<3	12	24	40	8	9	27	40
La	51	<12	108	<12	<12	<12	<12	20	<12	<12	<12
Ce	148	72	57	48	<23	76	<23	124	68	35	38
Nd	100	44	34	34	<12	52	18	78	40	<12	<12
Y	78	18	86	94	197	307	235	274	186	85	127
Zr	142	78	214	176	835	1047	1000	972	1165	365	325
U	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	4	<1.6	<1.6	<1.6	<1.6
Th	<6	<6	<6	<6	<6	<6	13	<6	<6	<6	<6
Pb	<6	<6	<6	<6	8	8	15	8	8	8	8
V	53	145	182	468	<3	<3	<3	<3	<3	<3	<3
Cr	118	385	124	571	<10	<10	<10	<10	<10	4	19
Ni	133	216	170	291	23	16	34	11	19	13	57
Co	228	152	63	88	24	42	30	32	58	28	21
Cu	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7
Zn	66	59	35	40	<5	<5	<5	<5	<5	<5	35
Ga	35	17	12	12	47	62	56	44	13	22	24
Sc	61	10	77	50	<0.4	1	<0.4	<0.4	2	<0.4	<0.4
S	906	914	207	<16	<16	<16	<16	<16	<16	<16	<16

Mg-values calculated on the basis of $Fe^{3+}/(Fe^{2+}+Fe^{3+}) = 0.1$
n.d.:not detected

Tab. 2b Chemical composition of representative rock types from the Montgenèvre volcanic ophiolitic sequence.

DOLERITES
(dikes within gabbros)

Sample No:	MG 27	MG 28	MG 29	MG 30	MG 31	MG 32	MG 33	MG 7	MG 60
weight %									
SiO_2	50.67	52.65	51.94	51.20	50.06	50.46	50.74	53.00	50.56
TiO_2	1.83	2.32	2.07	1.46	1.61	1.54	1.64	1.31	1.30
Al_2O_3	16.02	13.96	14.94	14.86	16.10	15.87	15.08	15.29	16.01
Fe_2O_3	3.00	2.50	2.63	2.33	2.94	2.80	2.54	2.89	1.72
FeO	5.86	7.47	7.09	5.37	5.72	5.71	6.34	4.60	5.85
MnO	0.19	0.24	0.24	0.16	0.18	0.16	0.17	0.16	0.18
MgO	6.76	5.28	5.56	7.16	7.01	7.77	7.47	7.69	7.68
CaO	8.09	7.31	7.76	8.30	8.77	7.47	7.34	6.77	8.98
Na_2O	4.21	5.07	4.98	4.65	4.28	4.59	4.79	4.59	3.76
K_2O	0.16	0.13	0.16	0.12	0.13	0.10	0.11	0.02	0.05
P_2O_5	0.24	0.32	0.29	0.20	0.24	0.21	0.19	0.19	0.18
H_2O^+	2.71	2.17	2.00	3.61	3.09	3.51	3.21	2.33	2.22
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.21	0.42	
Total	99.74	99.42	99.66	99.42	100.13	100.19	99.83	99.26	98.49
$Mg/(Mg+Fe^{2+})$	0.61	0.52	0.54	0.66	0.62	0.65	0.64	0.68	0.70
Fe_2O_3/FeO	0.51	0.34	0.37	0.43	0.51	0.49	0.40	0.63	0.29
Trace elements (ppm)									
Ba	17	25	28	11	12	13	15	9	4
Rb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Sr	258	187	141	88	210	220	215	257	246
Nb	<3	<3	<3	<3	<3	<3	<3	<3	<3
La	<12	12	<12	<12	<12	<12	<12	<12	<15
Ce	<23	<23	<23	<23	<23	<23	<23	<23	<10
Nd	<12	<12	<12	<12	<12	<12	12	<12	<10
Y	30	42	42	26	34	30	32	25	26
Zr	141	205	200	117	148	140	135	122	131
U	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1
Th	<6	<6	<6	<6	<6	<6	<6	<6	<5
Pb	<6	<6	<6	<6	<6	<6	<6	<6	<6
V	290	365	354	249	238	250	250	206	227
Cr	244	64	138	190	247	217	196	254	269
Ni	96	48	49	84	112	115	86	109	145
Co	63	49	53	103	52	53	55	53	30
Cu	34	23	50	53	30	53	75	<7	40
Zn	50	73	71	64	59	64	70	51	52
Ga	10	11	12	6	10	8	8	6	10
Sc	39	41	41	31	35	32	33	35	35
S	<16	235	373	291	28	483	<16	<16	20

Tab. 2b Continued.

Sample No:	DOLERITES (coarse-grained within lava pile)				DOLERITES (fine-grained within lava pile)					
weight %	MG 34	MG 40	MG 51	MG 59	MG 37	MG 36	MG 38	MG 39	MG 35	MG 50
SiO_2	49.75	48.80	48.74	48.69	50.01	48.77	49.94	49.77	49.03	49.44
TiO_2	1.50	1.99	1.43	1.85	1.13	1.35	1.55	1.77	1.98	1.67
Al_2O_3	16.16	15.63	16.80	14.91	16.99	16.31	15.87	15.11	14.77	15.03
Fe_2O_3	2.44	4.72	1.25	2.07	2.24	3.35	2.85	2.78	2.69	1.56
FeO	5.41	4.68	6.70	7.65	5.00	4.98	5.67	5.90	6.80	7.50
MnO	0.16	0.17	0.15	0.16	0.14	0.13	0.16	0.18	0.18	0.17
MgO	6.63	5.06	7.09	6.52	7.72	7.02	6.90	5.66	6.12	7.19
CaO	9.59	9.95	9.88	9.41	9.90	9.26	9.30	9.54	9.83	8.85
Na_2O	3.91	4.86	3.68	3.15	3.79	5.60	4.13	4.32	4.30	4.36
K_2O	0.25	0.32	0.16	0.88	0.01	0.01	0.01	0.01	1.01	0.20
P_2O_5	0.18	0.28	0.17	0.22	0.22	0.18	0.01	0.22	0.26	0.22
H_2O^+)I.L.	3.31	3.01	2.91	3.02	3.59	3.51	3.20	3.13	3.69	2.07
CO_2)I.L.	0.01	0.42			0.01	0.21	0.28	0.89	0.01	
Total	99.30	99.89	98.96	98.53	100.75	100.68	99.87	99.28	100.67	98.26
$Mg/(Mg+Fe^{2+})$	0.63	0.53	0.64	0.58	0.69	0.63	0.62	0.57	0.57	0.62
Fe_2O_3/FeO	0.45	1.01	0.19	0.27	0.45	0.67	0.50	0.47	0.40	0.21
Trace elements (ppm)										
Ba	19	44	5	10	27	20	22	25	53	5
Rb	<4	<4	<4	4	<4	<4	<4	<4	<4	<4
Sr	186	202	212	89	189	233	197	231	85	249
Nb	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
La	<12	<12	<15	<15	<12	<12	<12	<12	<12	<15
Ce	<23	34	<10	<10	<23	26	<23	25	50	<10
Nd	<12	32	<10	<10	15	17	21	27	34	<10
Y	26	42	30	44	21	24	25	32	42	39
Zr	119	211	118	170	90	102	120	154	199	150
U	<1.6	<1.6	<1	<1	<1.6	<1.6	<1.6	<1.6	<1.6	<1
Th	<6	<6	<5	<5	<6	<6	<6	<6	<6	<5
Pb	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
V	269	143	215	250	174	184	222	244	260	240
Cr	189	128	176	192	540	191	222	178	109	198
Ni	79	66	104	80	142	116	90	71	59	77
Co	47	41	25	35	205	85	50	67	53	24
Cu	48	44	42	37	18	43	44	54	41	45
Zn	67	88	50	61	51	60	65	67	80	64
Ga	9	14	13	13	10	10	11	10	14	13
Sc	31	22	29	33	26	25	30	30	25	31
S	842	<16	390	<20	160	686	1634	<16	28	314

Mg-values calculated on the basis of $Fe^{3+}/(Fe^{2+} +Fe^{3+}) = 0.1$

* (sl. porph.): slightly porphyric; (porph.): porphyric; (aph.): aphyric

Tab.2b Continued.

PILLOW BASALTS
(core)

Sample No:	MG 53 *(sl.porph.)	MG 54 (sl.porph.)	MG 52 (aph.)	MG 56 (porph.)	MG 57 (aph.)	MG 41 (porph.)	MG 43 (aph.)	MG 42 (aph.)	MG 55 (aph.)	MG 58 (sl.porph.)	MG 44 (aph.)
weight %											
SiO_2	49.18	49.67	51.20	49.22	51.62	49.56	47.35	49.58	49.75	49.88	54.79
TiO_2	1.21	1.22	1.54	1.76	1.63	1.63	1.64	1.71	1.86	1.94	1.71
Al_2O_3	16.65	16.25	15.78	16.62	15.31	14.56	16.18	15.65	15.05	14.89	16.76
Fe_2O_3	1.21	1.10	1.37	1.06	1.88	3.03	3.49	3.64	2.11	3.07	4.80
FeO	5.90	5.95	6.85	7.15	6.55	5.60	5.03	5.75	7.45	6.85	4.38
MnO	0.13	0.16	0.18	0.14	0.14	0.17	0.18	0.19	0.17	0.16	0.04
MgO	7.71	7.04	6.72	6.37	6.44	6.35	4.95	5.46	5.61	5.14	3.60
CaO	9.00	9.72	7.45	7.81	7.38	9.11	11.37	9.69	9.17	8.97	2.00
Na_2O	4.22	4.67	4.97	4.70	5.07	5.12	3.89	4.18	4.50	4.86	8.23
K_2O	0.03	0.02	0.01	0.03	0.03	0.10	0.01	0.10	0.09	0.03	0.01
P_2O_5	0.16	0.17	0.21	0.25	0.21	0.22	0.01	0.23	0.24	0.25	0.25
H_2O^+)l.l.	3.22	2.80	2.58	3.17	2.85	3.52	4.24	3.46	2.92	2.59	2.80
CO_2						0.77	1.45	0.10			0.10
Total	98.62	98.77	98.86	98.28	99.11	99.74	99.79	99.74	98.92	98.63	99.47
$Mg/(Mg+Fe^{2+})$	0.69	0.67	0.62	0.61	0.61	0.60	0.55	0.55	0.54	0.51	0.45
Fe_2O_3/FeO	0.21	0.18	0.20	0.15	0.29	0.54	0.69	0.63	0.28	0.45	1.10
Trace elements (ppm)											
Ba	4	4	4	5	6	26	35	21	6	8	16
Rb	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Sr	309	331	211	294	206	261	127	114	208	170	101
Nb	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
La	<15	<15	<15	<15	<15	<12	<12	<12	<15	<15	<12
Ce	<10	<10	<10	<10	<10	28	41	<23	<10	<10	<23
Nd	<10	<10	<10	<10	<10	22	23	21	<10	<10	12
Y	24	27	32	38	35	34	32	31	40	43	31
Zr	114	117	153	178	153	168	170	157	167	180	145
U	<1	<1	<1	<1	<1	<1.6	<1.6	<1.6	<1	<1	<1.6
Th	<5	<5	<5	<5	<5	<6	<6	<6	<5	<5	<6
Pb	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
V	215	220	234	239	246	249	335	284	265	278	105
Cr	231	225	251	180	166	239	191	175	95	59	341
Ni	126	124	75	126	102	131	80	83	74	63	73
Co	17	15	23	22	23	41	52	47	23	27	35
Cu	29	21	60	33	43	41	45	49	35	36	25
Zn	37	37	84	52	55	67	70	79	66	70	105
Ga	10	11	9	12	11	11	9	13	12	12	11
Sc	28	31	36	25	32	29	36	40	33	35	38
S	32	27	<20	<20	<20	<16	422	24	265	62	<16

Mg-values calculated on the basis of $Fe^{3+}/(Fe^{2+} +Fe^{3+}) = 0.1$
* (sl. porph.): slightly porphyric; (porph.): porphyric; (aph.): aphyric

(equivalent to the plagiogranites and trondh-jemites in other ophiolite complexes) reflects, in four analyses, nearly pure albite composition. The chemical variation of the other samples of these late intrusive rocks is caused by the appearance of pyroxene and hornblende (MG 6). In one case (MG 10), the high MgO and Al_2O_3 contents reflect chloritization processes due to metasomatism within the serpentinite hostrock. Strong enrichment in Zr, Y, Nb, Ga, and partly of the light rare-earth elements, supports the idea of crystallization of these albititic rocks from the late evolved melts. Low Cr and Ni, as well as Sc, V and Sr values, are consistent with this interpretation.

In the *volcanic sequence,* the variation in bulk-rock chemistry is rather small (Table 2b). No significant changes in modal mineral abundances are observed compared to the rocks from the gabbroic sequence. The chemical composition is somewhat more variable in pillow lavas than in doleritic massive flows and dikes. This probably reflects an effect of metasomatism during cooling, devitrification and recrystallization processes (VUAGNAT, 1946;

MÉVEL, 1975). In fact, the compositional ranges in the doleritic dikes, as well as in the massive and pillowed lavas, are very similar (Table 2b). Both the highest and lowest Mg-, Ni- and Cr-values are observed in the doleritic dikes (MG 60 and 28) and in the pillow basalts (MG 53 and 58). The most primitive composition yield MgO = 7.7. wt%, Ni = 145 ppm, Cr = 269 ppm with TiO_2 = 1.2 wt%. The compositional range of the massive flows within the pillows is however significantly smaller (Mg-values between 0.69 and 0.57). The slight data scatter might also be due to sampling effect and/or to mixing effects of differently evolved melts within continuously refilling magma chambers (RHODES et al., 1979). No ferrobasalts are present in the whole volcanic sequence. The textural changes between aphyric, slightly and strongly plagioclase-phyric pillow basalts are apparently not reflected by their bulk chemistry. LEWIS and SMEWING (1980) indicated a differentiation trend within the Chenaillet pillow lava flows. The new chemical data on the Montgenèvre volcanic suite do not confirm this interpetation nor do they reveal
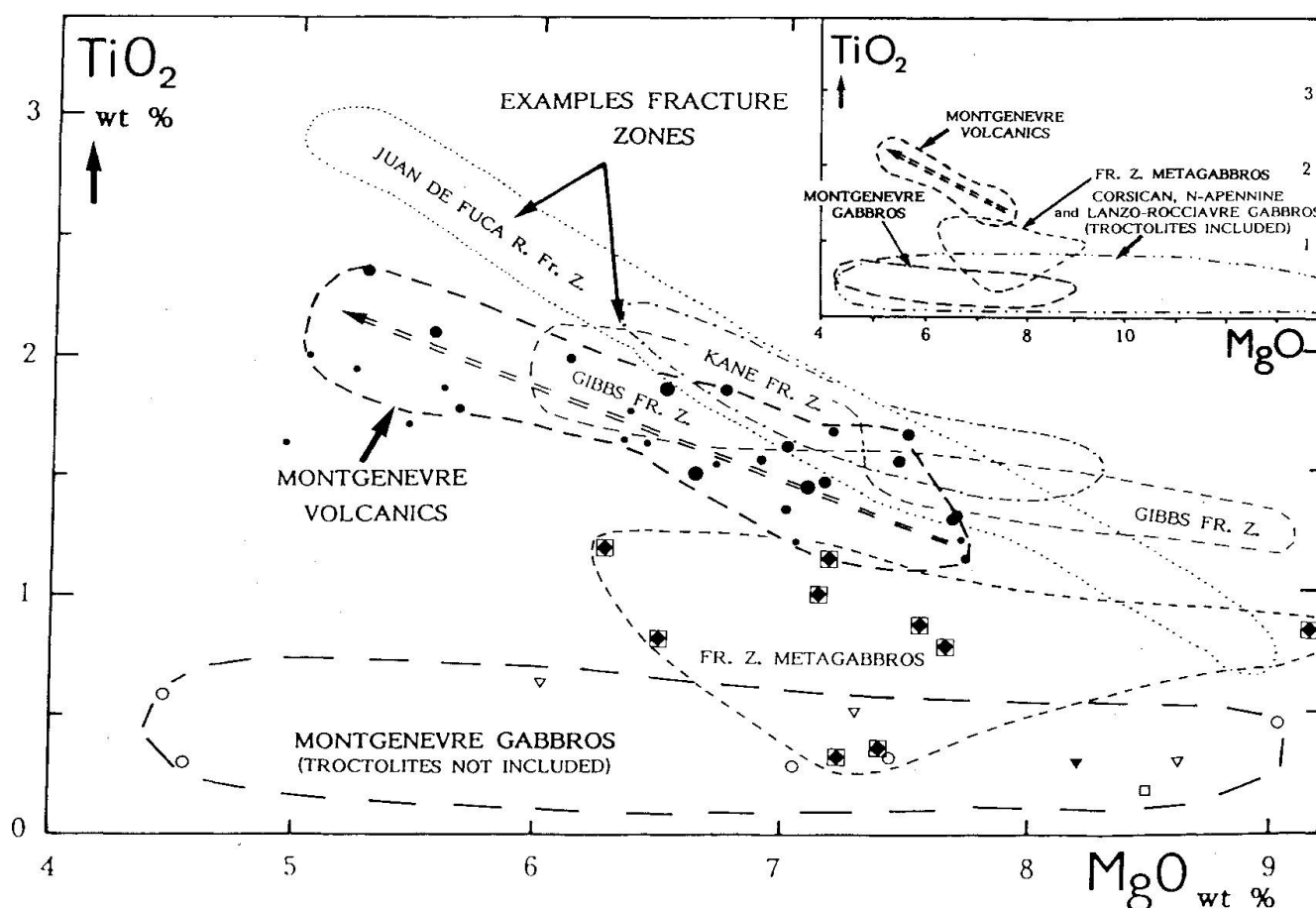

Fig. 3 TiO_2 vs MgO diagram (LANGMUIR and BENDER, 1984). Discussion in text. For rock symbols see Fig. 4.
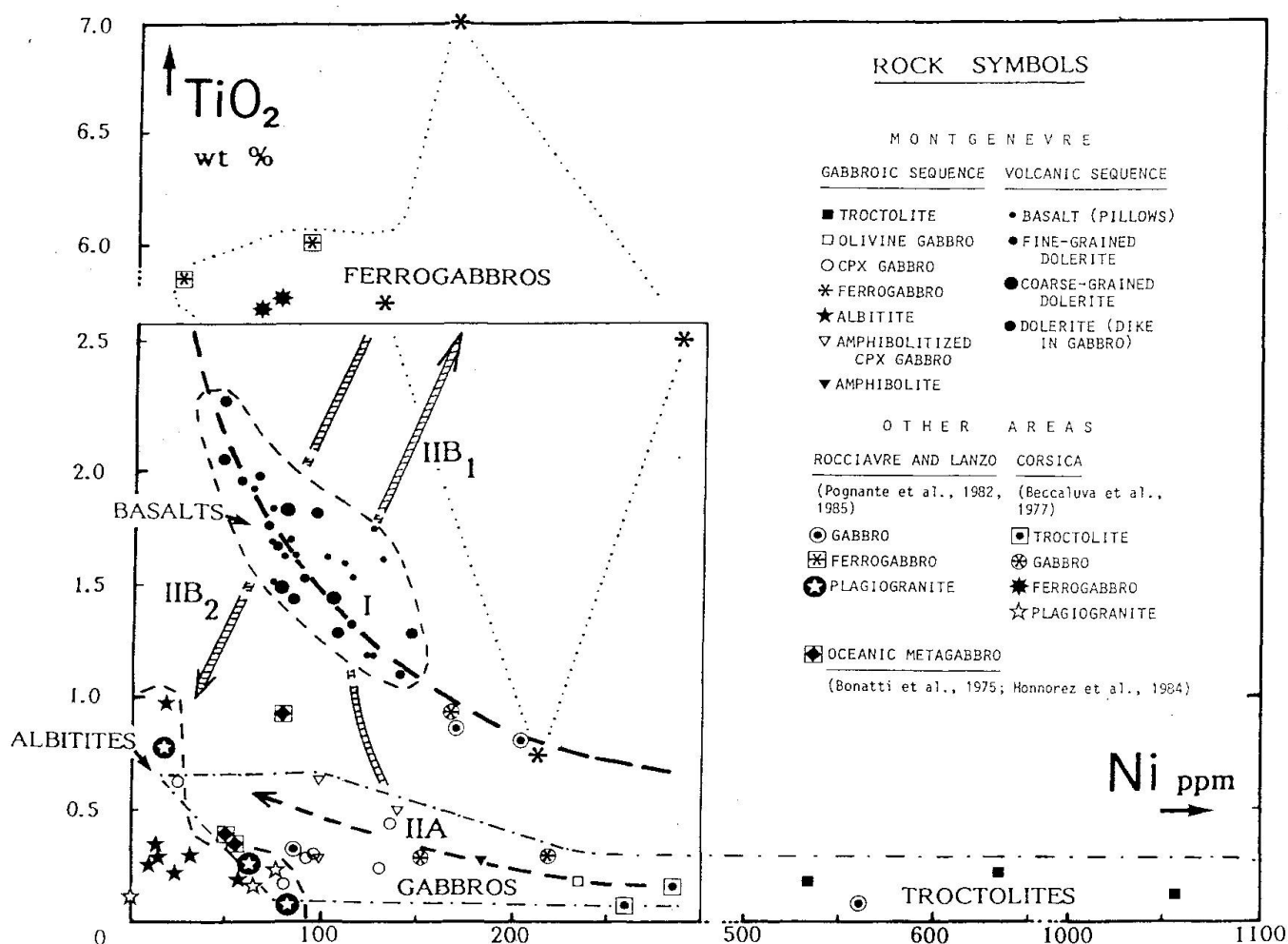
7.0

TiO_2
wt %

6.5

6.0

FERROGABBROS

2.5

2.0

IIB_1

BASALTS

1.5

IIB_2

I

1.0

ALBITITES

0.5

IIA

GABBROS

0   100   200   500   600   1000   1100

Ni ppm

TROCTOLITES

ROCK SYMBOLS

M O N T G E N E V R E

GABBROIC SEQUENCE   VOLCANIC SEQUENCE

■ TROCTOLITE   • BASALT (PILLOWS)
□ OLIVINE GABBRO   ● FINE-GRAINED
○ CPX GABBRO   DOLERITE
✱ FERROGABBRO   ● COARSE-GRAINED
★ ALBITITE   DOLERITE
▽ AMPHIBOLITIZED   ● DOLERITE (DIKE
   CPX GABBRO   IN GABBRO)
▼ AMPHIBOLITE

O T H E R   A R E A S

ROCCIAVRE AND LANZO   CORSICA

(Pognante et al., 1982,   (Beccaluva et al.,
1985)   1977)

⊙ GABBRO   ⊡ TROCTOLITE
⊞ FERROGABBRO   ⊛ GABBRO
✪ PLAGIOGRANITE   ✱ FERROGABBRO
                                         ☆ PLAGIOGRANITE

◆ OCEANIC METAGABBRO

(Bonatti et al., 1975; Honnorez et al., 1984)

Fig. 4   TiO$_2$ vs Ni diagram and list of rock symbols. Discussion in text.

any clear textural control. The observed element variations in the dikes within the gabbros, massive flows and pillow lavas are very similar, and are typical of a tholeiitic differentiation trend. The very low abundances of more hygromagmatophile elements such as K, Ba, Rb, Nb and the rare-earth elements clearly indicate a magmatic origin comparable to MORB (HEKINIAN and THOMPSON, 1976; SUN et al., 1979; WOOD et al., 1979b; BRYAN et al., 1981; LANGMUIR and BENDER, 1984).

Discussion

The basaltic rocks are generally lower in SiO$_2$, MgO and CaO contents, and higher in Fe and Ti when compared to clinopyroxene gabbros. These features and other fundamental chemical differences between the gabbros and basalts will be discussed with reference to several selected diagrams (Fig. 3 to 8).

Figure 3, which does not include ferrogabbros and albitite, shows the relationship between MgO and TiO$_2$, a typical negative correlation between a compatible (Mg) and an incompatible element (Ti). The compositional fields of several oceanic environments are outlined for comparison with the Montgenèvre volcanic rocks. The Montgenèvre data have clear affinities with MORB, but also overlap and show a similar trend to that observed in volcanic rocks dredged from large oceanic transform fault zones, e.g. the Gibbs fracture zone (HEKINIAN and THOMPSON, 1976). The Montgenèvre plutonic rocks, however, plot in a totally different field defined by their low TiO$_2$ values and the large variation in the MgO content. This compositional field is similar to those obtained from other ophiolites (BECCALUVA et al., 1977; SERRI, 1980, 1981; SERRI et al., 1980; POGNANTE et al., 1982, 1985), as well as from the Atlantic, Indian and Pacific oceans (for a review, see FOX and STROUP, 1981; BONATTI et al., 1975; HONNOREZ et al., 1984;

MIYASHIRO and SHIDO, 1980, see also insert). The transitional field for the foliated gabbros from the Mid-Atlantic ridge fracture zone is noteworthy.

Further information on the magmatic evolution of the plutonic and volcanic rocks can be taken from the TiO_2 versus Ni diagram (Fig. 4). Four distinct trends, interpreted as differentiation paths, are clearly noticeable. Trend I shows a regular evolution in the volcanic sequence from less differentiated basalts (with Ni contents up to 150 ppm and TiO_2 about 1.2 wt%) to more evolved basalts (with Ni contents about 50 ppm and TiO_2 up to 2.3 wt%). The gabbroic rocks show different patterns. Trend II A is similar to trend I in the basalts, but at lower Ti contents (0.15–0.64 wt%). The beginning of fractionation from a primitive tholeiitic melt seems to have taken place in a system with no or little influence of fluid activity and under low oxygen fugacity (fO_2) conditions. Cumulitic troctolites and olivine gabbros are products of this early stage. The subsequently crystallized clinopyroxene gabbros caused further chemical evolu-

tion in the remaining melt, in particular a Ti and Fe enrichment. Ferrogabbros, rich in amphibole and Fe–Ti oxides, crystallized in this later differentiation stage (trend II B_1). The introduction of water into the system, probably raising fO_2 conditions, is evident. This late fractionation process led to residual melts substantially different in composition, and probably small in volume (trend II B_2). These melts were enriched in Si, Na, P and incompatible elements such as Nb, Zr, Y, Ga, Th, V, and highly depleted in the transitional elements Fe, Ti, Mn and Sc. They presumably crystallized as albititic rocks. Liquid immiscibility mechanisms (PHILPOTTS and DOYLE, 1983) are not taken into account because there are no indications for such processes from field and/or microscopic investigations (see also SERRI, 1980).

Similar processes and evolution trends have been discussed for the Lanzo gabbroic rocks (POGNANTE et al., 1982, 1985). The processes outlined above could be favoured by vertical displacements along deep trending fracture zones. Fracturing mechanism in a dynamic, oceanic environment could more easily allow
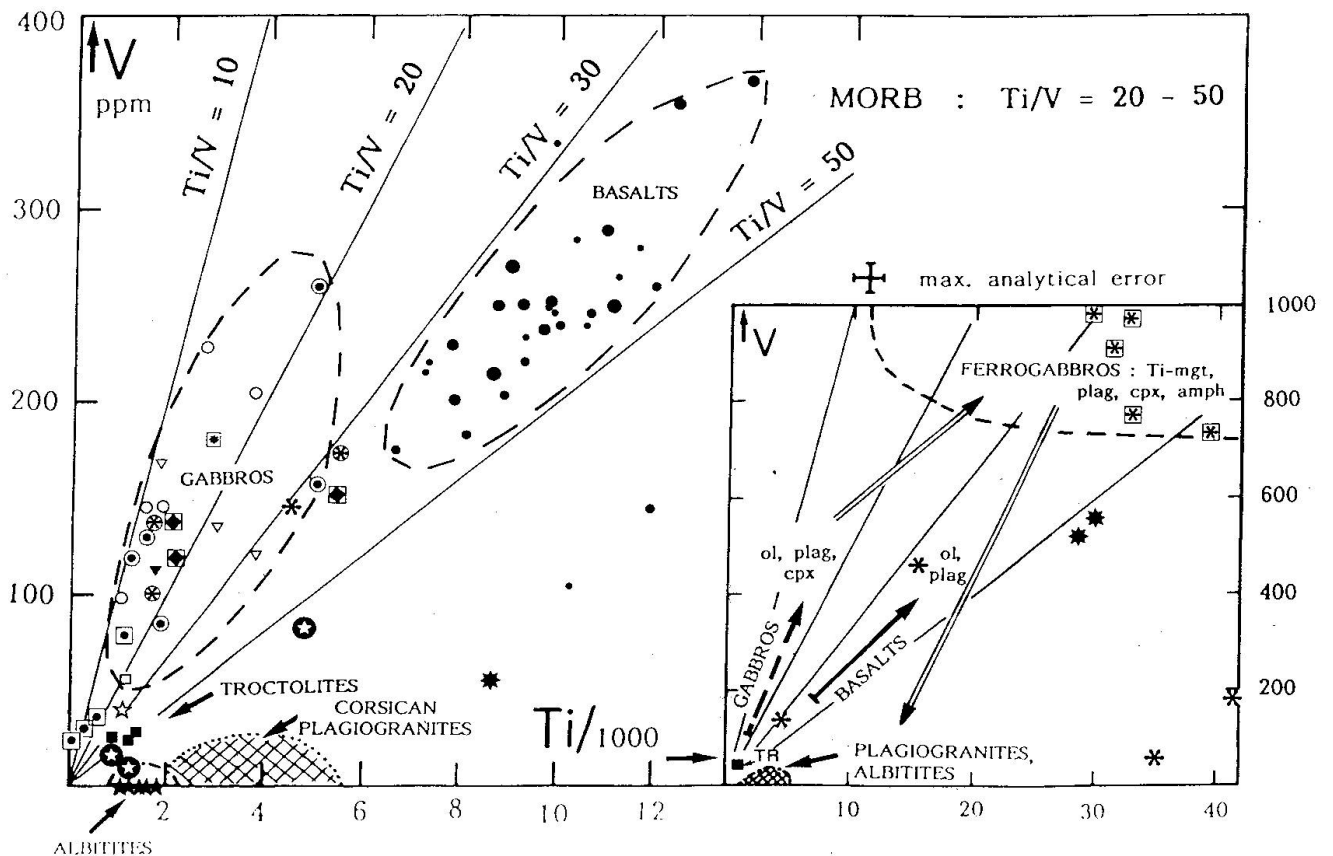

Fig. 5 V vs Ti/1000 diagram (SHERVAIS, 1982). Discussion in text. For rock symbols see Fig. 4. Insert: tr = troctolites.
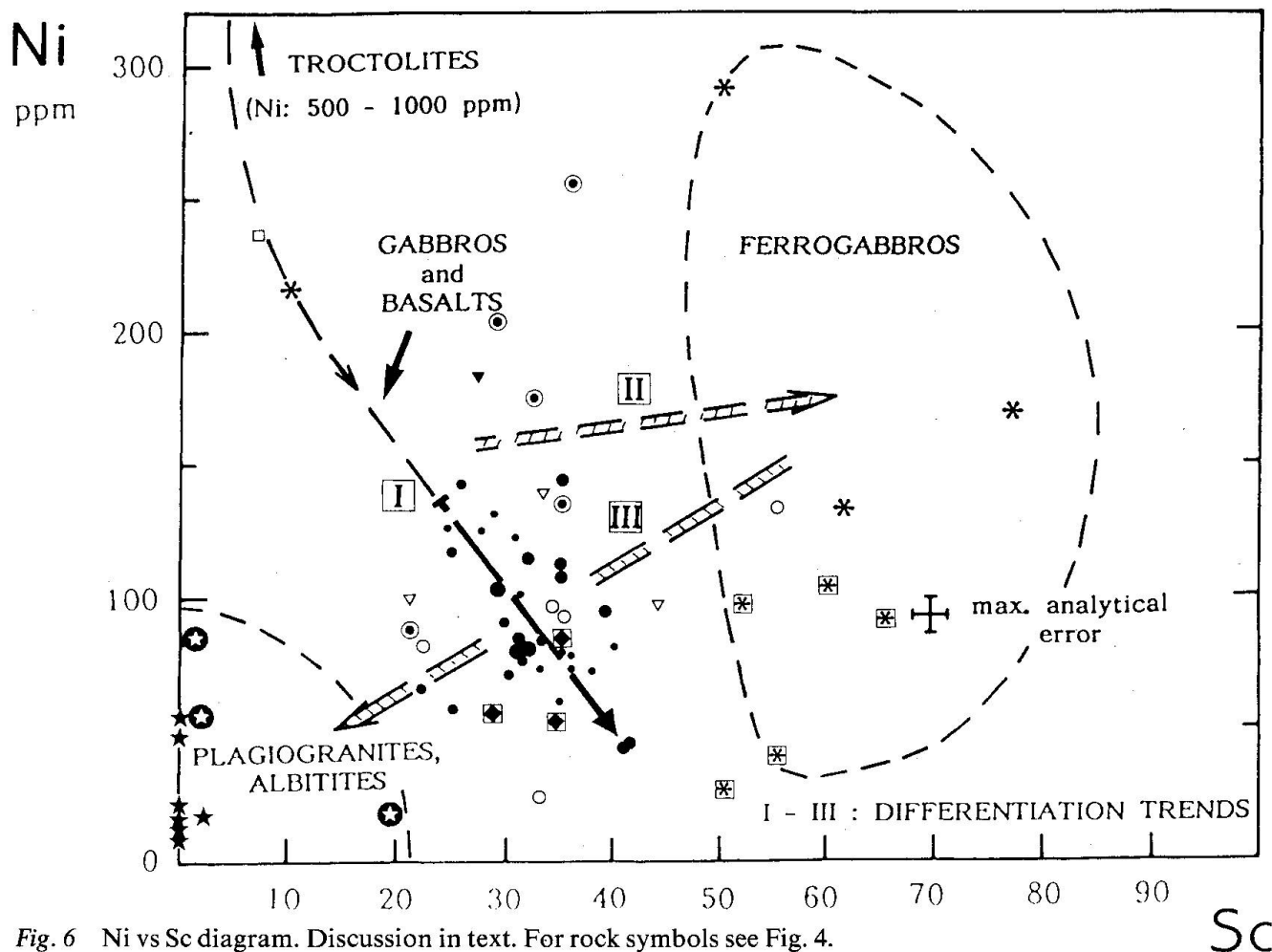
Fig. 6 Ni vs Sc diagram. Discussion in text. For rock symbols see Fig. 4.

magma ascent into higher levels as well as water infiltration (SERRI, 1980; OHNENSTETTER and OHNENSTETTER, 1980). Also, the separation of magma batches undergoing independent differentiation would be more probable in such an environment (e.g. LANGMUIR and BENDER, 1984). From experimental studies (DIXON-SPULBER and RUTHERFORD, 1983) it was concluded that amphibole formation in ferrogabbros is independent of fO_2 conditions in the melt. Amphibole crystallization, which is possible at pressures $\geq$ 2 kb, and $fO_2 \geq$ 0.6 P_{fluid}, seems to be the major process leading to the final Si- and Na-rich albititic melts.

The Ti/1000 versus V variation diagram (Fig. 5), using two incompatible elements, shows basically the same features as discussed above. The basalts have MORB characteristics with a simple differentiation trend, apparently controlled by olivine and plagioclase fractionation. In the extruded basaltic melts, plagioclase, clinopyroxene and Fe-Ti oxides probably crystallized at high fO_2 conditions. By contrast, the gabbros have significantly lower

Ti/V ratios. The same is true for the Corsican gabbroic rocks. Early fractional crystallization of olivine, plagioclase and clinopyroxene in a system characterized by low fO_2 as mentioned above (with reference to Fig. 4) producing Fe-Ti-rich gabbroic melts is again demonstrated (see insert). The ferrogabbros, including those from Rocciavré and Corsica, are strongly dispersed, probably indicating variable late-magmatic conditions. The drastic reversed change during further differentiation for the leucocratic rocks is again evident. The Montgenèvre albitites plot in a similar but more restricted field from the Corsican and Lanzo-Rocciavré plagiogranites (OHNENSTETTER and OHNENSTETTER, 1980; POGNANTE et al., 1982, 1985).

In contrast to the diagrams described above, the next three show an obviously different relationship between the gabbros and basalts. The differentiation paths during early fractionation are the same for the gabbroic and basaltic rocks.

Figure 6 uses Sc as incompatible and Ni as a strongly compatible element. A chemical rela-

tionship indicating similar parental melts of MORB character for both the gabbros and the basalts can be deduced from the distribution pattern. The scatter of data points in the late-stage ferrogabbros probably reflects variations in the modal composition and/or hydrothermal alteration. In this diagram, partitioning of Sc into clinopyroxene and amphibole during late-stage differentiation (trend II) is evident. Sc preferentially enters the amphibole structure. This is substantiated by the total lack of Sc in the residual leucocratic melt (trend III).

Figures 7 and 8 use Y and Zr as two strongly incompatible elements. In the simple Y versus Zr ratio diagram (Fig. 7), the basalts plot in the MORB range. Continuous enrichment of Y and Zr during fractional crystallization leads to maximum contents in the ferrogabbros and plagiogranites (see insert) which, however, as in the Corsican, Rocciavré and Lanzo equivalents, show a strong scatter. The different location of the foliated gabbros from the Mid-Atlantic ridge fracture zone is again interesting to note.

The Zr/Y versus Zr diagram (Fig. 8) again displays similar trends during early fractionation. Then, however, probably due to crystallization of amphiboles which incorporate more Y, the Zr/Y ratio jumps from 4 to 2 for the ferrogabbro analyses (see vectors). This ratio remains low and constant in the residual melt (albitites). By contrast, the plagiogranite data from Corsica, Lanzo and Rocciavré show a wide scatter. In this diagram, the Montgenèvre basalt and MORB fields (PEARCE and NORRY, 1979) do not strictly overlap. In addition, the Zr and Y contents in the gabbroic amphibolites from Montgenèvre and the oceanic crust are quite different, each plotting within distinctive, but separate fields.

In summary, the major and trace element data from the volcanic and plutonic rocks of the Montgenèvre ophiolite show two distinct trends in differentiation processes suggesting independent magmatic processes for the gabbroic and basaltic sequences.

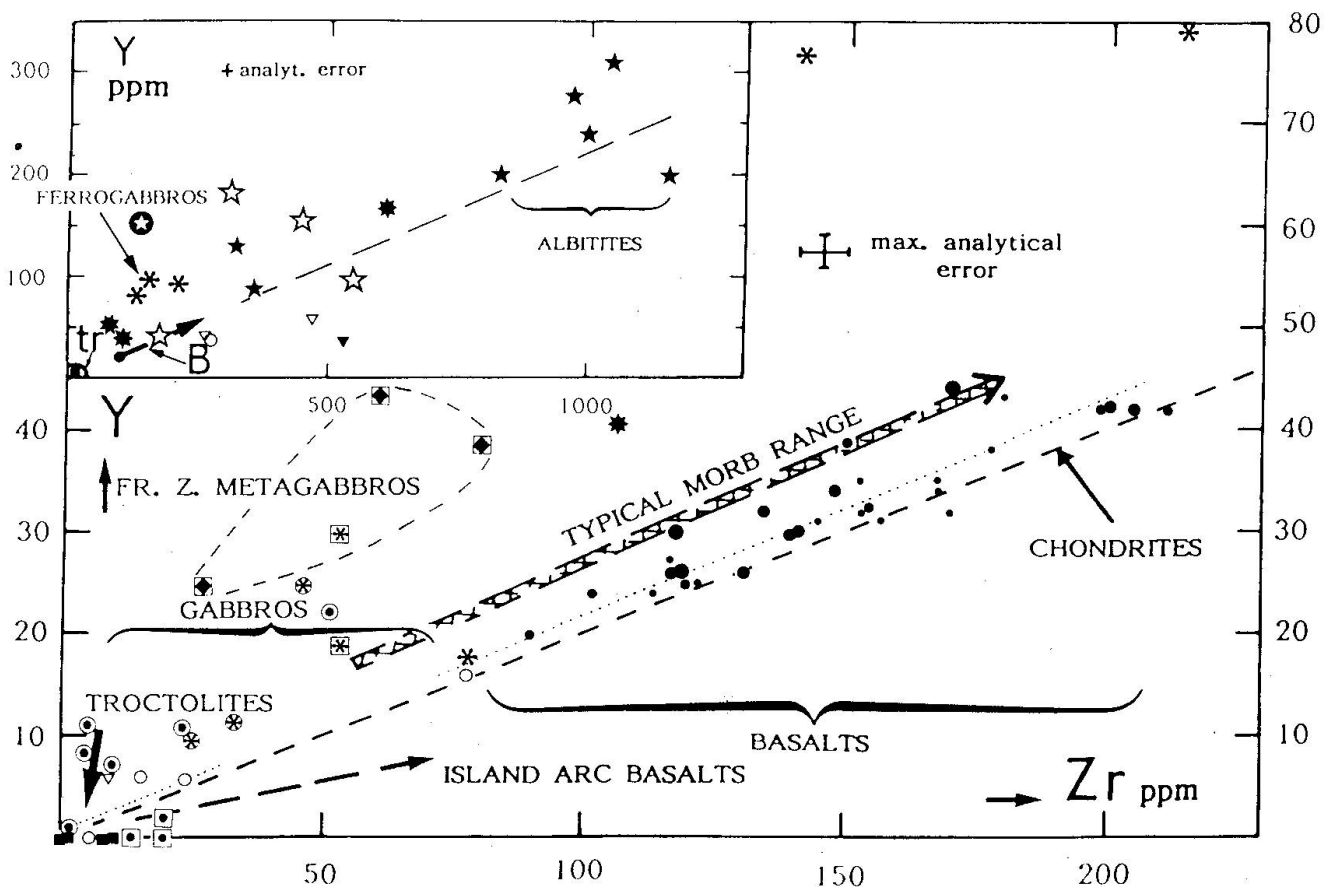The *volcanic rocks* have a narrow range in composition. No picritic, ferrobasaltic or even

Fig. 7   Y vs Zr diagram (BECCALUVA et al., 1977). Discussion in text. For rock symbols see Fig. 4. Insert: tr = trocolites; b = basalts.
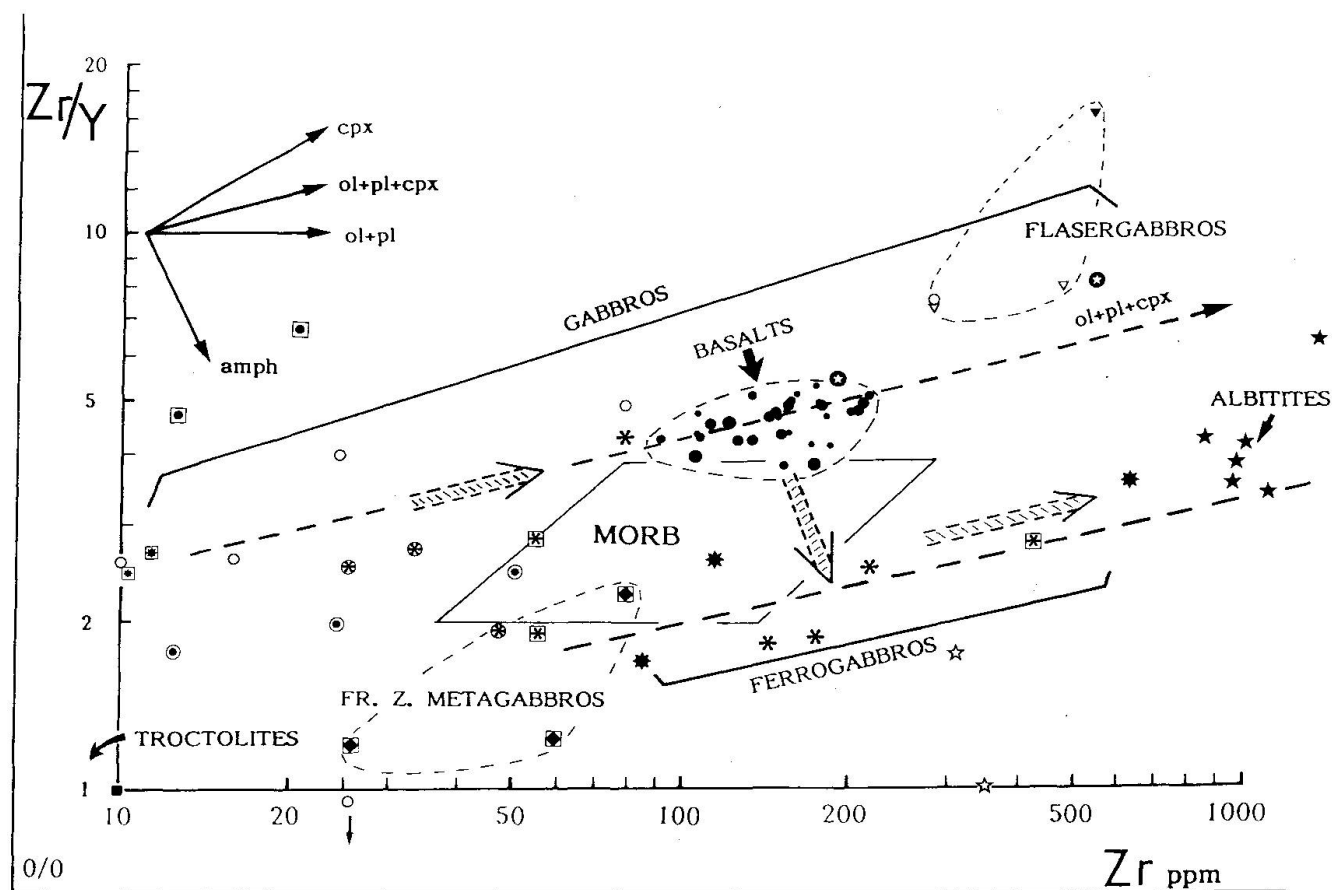
Fig. 8 Zr/Y vs Zr diagram (POGNANTE et al., 1982). Discussion in text. For rock symbols see Fig. 4.

more evolved rock types were found. A simple "liquid line-of-descent" due to fractional crystallization of olivine and plagioclase, generally assumed for the tholeiitic series from mid oceanic ridges, seems also to be valid for the Montgenèvre rocks. This mineral fractionation occurred in magma chambers at intermediate to shallow depths (plagioclase–phyric basalts), and normally would have led to Fe and Ti enrichment in the remaining melts. This, however, would not to be the case in an open magmatic system being continuously refilled with new primitive melt. Such a process is assumed for the Montgenèvre basalts and could explain the narrow compositional range observed. Magma mixing effects, reported for MORB (RHODES et al., 1979) cannot be demonstrated from chemical or textural evidence in the Montgenèvre volcanics. However, such effects might partially explain the slight scatter of the data.

On the other hand, the *plutonic rocks* show a wide range in composition and rather marked changes in element concentrations and ratios during late-stage differentiation. The early

stages are characterized by fractionation of olivine, spinel, plagioclase and some pyroxene at rather low fO_2 and f_{H_2O} conditions. The troctolites and olivine gabbros with clear cumulate textures, and some clinopyroxene gabbros crystallized from these melts. No evidence indicates that such melts escaped to higher levels to erupt as volcanics. This seems also true for other ophiolite complexes as well as for MOR systems (LOMBARDO and POGNANTE, 1982; ENGEL and FISHER, 1975; MIYASHIRO and SHIDO, 1980). Further differentiation within the same magmatic system led to Fe and Ti enrichment in the residual melt and permitted the ferrogabbros to crystallize.

The crystallization of amphibole indicates the presence of probably higher fO_2 conditions in the magma chamber still situated at deeper levels ($\geq$ 2 kb. DIXON-SPULBER and RUTHERFORD, 1983). Finally, the very small volume of residual melt with high Si and Na contents as well as high incompatible element concentrations crystallized as albititic rocks. Such highly evolved rocks, which are also found within the overlying volcano-sedimentary sequence in

Corsica (OHNENSTETTER and OHNENSTETTER, 1980), were never found in the Montgenèvre basaltic sequence.

From bulk-rock analyses and from inferred fractionation trends, it appears that no melt fraction from the plutonic system contributed to the volcanic system which developed independently. In addition, field evidence strongly suggests that the volcanic complex was built later than the plutonic one. This is supported by geochronological data (CARPENA and CABY, 1984) and by the basaltic dikes which crosscut the gabbros and albitites displaying similar chemical and textural features as the basalts from the volcanic complex. These dikes are considered as feeders to the overlying basaltic lava flows.

Such a relationship between an earlier formed plutonic basement and a later emplaced volcanic cover is comparable to situations known from present-day mid-ocean ridges (ENGEL and FISHER, 1975) and from other ophiolite complexes of the Western Alps (e.g. LOMBARDO and POGNANTE, 1982).

Conclusions

The significant differences between the basalts and gabbros with regard to major and trace element contents reflect different magmatic evolutions under variable conditions, e.g. open and closed magmatic system with variable fO_2 and f_{H_2O} at different crustal levels. The differentiation paths can be explained by crystal fractionation. In spite of their differing bulk-rock chemistry, a similar magma source for the plutonic and volcanic rock suites can be assumed using trace elements like Y, Zr, Sc and suitable variation diagrams.

With the available data, MORB-type parental magmas and differentiation paths typical for abyssal tholeiites can be inferred for the Montgenèvre igneous rock suites. In the Western Mediterranean ophiolites, MORB characteristics with slight affinities to within-plate basalts have been pointed out by many authors (e.g. ROCCI et al., 1975; FERRARA et al., 1976; BECCALUVA et al., 1977, 1980; SERRI, 1980, 1981; SERRI and SAITTA, 1980; Pearce, 1980). Basalts with MORB characteristics are also known from marginal basins (HAWKINS, 1980) and transform fault zones (HEKINIAN and

THOMPSON, 1976; LANGMUIR and BENDER, 1984).

Lavas from the Western Mediterranean ophiolites are also comparable to those from Red-Sea-type setting (PEARCE, 1980). By contrast, for the Eastern Mediterranean ophiolites, MORB with island arc affinities have been reported, which suggests a marginal basin setting in relation to a subduction zone (PEARCE, 1980); PEARCE et al., 1984) with developed spreading centres. This demonstrates the difficulties in deducing geotectonic settings alone from geochemical data.

From a geological point of view, the oceanic environment of the Western Tethys appears to be mainly related to the formation of rather small ocean basins characterized by little or no well developed spreading and with variable importance of pure extensional and transverse tectonics. Support for such a model (GIANELLI and PRINCIPI, 1977; ABBATE et al., 1980; LEMOINE, 1980; BERNOULLI and WEISSERT, 1985) comes from palinspastic reconstruction correlating movement in the Mediterranean area, as well as structural, petrologic and stratigraphic lines of evidence.

In the Western Alps, some ophiolites are thought to comprise upper mantle sections of different chemical and thermal histories, probably including subcontinental relics of pre- and synrift material (BONATTI et al., 1981) emplaced by diapiric uprise during the opening of the Mesozoïc Tethys (POGNANTE et al., 1986). These highly serpentinized ultramafics mainly consist of lherzolite tectonites; harzburgites and dunites are very subordinate. Sheeted-dike complexes that would indicate rather continous magmatic activity at spreading centres are missing. This suggests an eruptive setting different from that at normal mid-ocean ridges. Moreover, evidence for distinctive metamorphic and tectonic processes that happened during the oceanic stage have been recognized in many Western Mediterranean ophiolite complexes (MÉVEL et al., 1978; STEEN et al., 1980; CORTESOGNO and LUCCHETTI, 1984; BERTRAND et al., 1985; TRICART and LEMOINE, 1986). Further support for such a highly dynamic environment is given by the rather irregular spatial distribution of the serpentinites and gabbros which are both crosscut by albitites in the Montgenèvre ophiolites. Various types of sediments comprising ophiolite and serpentinite breccias that include ophicalcites (CORTEGO-

SONO et al., 1978) attest to the erosion of a fractured and heterogeneous ultramafic and gabbroic ocean floor of accentuated relief (LEMOINE, 1980) on which the basaltic lava extruded.

Such complicated structural relationships, restricted magmatism, thinned oceanic crust, rough morphology, and erosion of mantle derived ultramafics are known from the vicinity of ridge-transform intersections and transform fault zones (FOX and GALLO, 1984; KARSON and DICK, 1983). Observations from ophiolites in the Western Alps and Apennines with similar characteristics resulted in the interpretation that the Piemont-Ligurian domain was characterized by numerous fractures (GIANELLI and PRINCIPI, 1977; LEMOINE, 1980; LEMOINE et al., 1986) and a peculiar lithosphere (ABBATE et al., 1980). Coarse terrigenous detritus deposited on an ultramafic seafloor (POLINO and LEMOINE, 1984) is indicative of continental crust near these oceanic basins of the Piemont-Ligurian domain. Recently, another mechanism for the development of the oceanic Piemont-Ligurian domain involving the Wernicke lithospheric extensional fault model has been suggested (LEMOINE et al., 1986).

References

ABBATE, E., BORTOLOTTI, V. and PRINCIPI, G. (1980): Apennine ophiolites: A peculiar oceanic crust. Ofioliti, Spec. issue, Tethyan ophiolites, 1, 59–96.

BECCALUVA, L., OHNENSTETTER, D. and M. and VENTURELLI, G. (1977): The trace element geochemistry of Corsican ophiolites. Contr. Mineral. Petrol., 64, 11–31.

BECCALUVA, L., PICCARDO, G. B. and SERRI, G. (1980): Petrology of Northern Apennine ophiolites and comparison with other Tethyan ophiolites. In: PANAYIOTOU, A. (Ed.), Proc. int. Opiolite Conf., Nicosia, Cyprus 1979, 314–331.

BERNOULLI, D. and WEISSERT, H. (1985): Sedimentary fabrics in Alpine ophicalcites, South Pennine Arosa zone, Switzerland. Geology, 13, 755–758.

BERTRAND, J., COURTIN, B. and VUAGNAT, M. (1981): Le massif ophiolitique du Montgenèvre (Hautes-Alpes, France, et province de Turin, Italie): Données nouvelles sur un vestige de manteau supérieur et de croûte océanique liguro-piémontais. Bull. suisse mineral. pétrogr., 61, 305–322.

BERTRAND, J. COURTIN, B. and VUAGNAT, M. (1982): Elaboration d'un secteur de lithosphère océanique liguro-piémontais d'après les données de l'ophiolite du Montgenèvre (Hautes-Alpes, France et province de Turin, Italie). Ofioliti, 7. 155–196.

BERTRAND, J., NIEVERGELT, P. and VUAGNAT, M. (1984): Oceanic sedimentary processes and alpine metamorphic events in the Montgenèvre ophiolite, Western Alps. Ofioliti, 9, 303–320.

BERTRAND, J., NIEVERGELT, P. and VUAGNAT, M. (1985): Interprétation paléo-océanique d'une série pélagique à matériel ophiolitique: la série de Chabrière, complexe de base du massif ophiolitique du Montgenèvre (Alpes occidentales). C. R. Acad. Sc. Paris, 301, II/16, 1199–1204.

BONATTI, E., HAMLYN, P. and OTTONELLO, G. (1981): Upper mantle beneath a young oceanic rift: periodites from the island of Zabargad (Red sea). Geology, 9, 474–479.

BONATTI, E., HONNOREZ, J., KIRST, P. and RADICATI, F. (1975): Metagabbros from the Mid-Atlantic ridge at 06° N: contact-hydrothermal-dynamic metamorphism beneath the axial valley. J. Petrol., 83, 61–78.

BRYAN, W. B., THOMPSON, G. and LUDDEN, J. N. (1981): Compositional variation in normal MORB from 22–25° N: Mid-Atlantic ridge and Kane fracture zone. J. geophys. Res., 86, 11815–11836.

CARPENA, J. and CABY, R. (1984): Fission-track evidence for Late triassic oceanic crust in the French Occidental Alps. Geology, 12, 108–111.

CORTESOGNO, L., GALBIATI, B., PRINCIPI, G. and Venturelli, G. (1978): Le brecche ophiolitiche della Liguria orientale: nuovi dati e discussione sui modelli paleogeografici. Ofioliti, 3, 99–160.

CORTESOGNO, L. and LUCCHETTI, G. (1984): Ocean floor metamorphism of metagabbros and striped amphibolites (T. Murlo, Southern Tuscany, Italy). N. Jb. Min. Abh., 148, 278–300.

DIETRICH, V., VUAGNAT, M. and BERTRAND, J. (1974): Alpine metamorphism of mafic rocks. Bull. suisse minéral. pétrogr., 54, 291–332.

DIXON-SPULBER, S. and RUTHERFORD, M. J. (1983): The origin of rhyolite and plagiogranite in oceanic crust: an experimental study. J. Petrol., 24, 1–25.

ENGEL, C. G. and FISHER, R. L. (1975): Granitic to ultramafic rock complexes of the Indian ocean ridge system, Western Indian Ocean. Bull. Geol. Soc. Amer., 86, 1553–1578.

FERRARA, G., INNOCENTI, F., RICCI, C. A. and SERRI,

G. (1976): Oceanfloor affinity of basalts from North Apennine ophiolites: geochemical evidence. Chem. Geol. 17, 101–111.

FLOYD, P. A. and WINCHESTER, J. A. (1975): Magma type and tectonic setting discrimination using immobile elements. Earth Planet. Sci. Lett. 27, 211–218.

FOX, P. J. and GALLO, D. G. (1984): A tectonic model for ridge-transform-ridge plate boundaries: implications for the structure of oceanic lithosphere. Tectonophysics, 104, 205–242.

FOX, P. J. and STROUP, J. B. (1981): The plutonic foundation of the oceanic crust. In Emiliani C. (Ed.), The oceanic lithosphere, The Sea, vol. 7, 119–218. John Wiley, New York.

GIANELLI, G. and PRINCIPI, G. (1977): Northern Apennine ophiolite: an ancient transcurrent fault zone. Boll. Soc. geol. ital., 96, 53–58.

GIROD, M. and CABY, R. (1975): Faciès amphibolite dans la croûte océanique: exemple des méta-gabbros du massif du Chenaillet (Hautes-Alpes). 3e Réun. annu. Sci. Terre, Montpellier.

HAWKINS, J. W. (1980): Petrology of back-arc basins and island arcs: their possible role in the origin of ophiolites. In: Panayiotou, A. (Ed.) Proc. int. Ophiolite Conf., Nicosia, Cyprus, 244–254.

HEKINIAN, R. and THOMPSON, G. (1976): Comparative geochemistry of volcanics from rift valleys, transforms and aseismic ridges. Contr. Mineral. Petrol., 57, 145–162.

HEUGEL, VON, H. (1982): Die Zonierung in Pillows. Ein Vergleich von frischen ozeanischen bis zu alpinen metamorphen Pillowlaven. Inauguraldissertation, Universität Bern, 116 p.

HONNOREZ, J., MÉVEL, C. and MONTIGNY, R. (1984): Occurrence and significance of gneissic amphibolites in the Vema fracture zone, equatorial Mid-atlantic ridge. In GASS, I. G., LIPPARD, S. J. and SHELTON, A. W. (Ed.), Ophiolites and oceanic lithosphere, Geol. Soc. (London), Spec. Publ. 13, 121–130. Blackwell, Oxford.

HUMPHRIS, S. E. and THOMPSON, G. (1978a): Hydrothermal alteration of oceanic basalts by seawater. Geochim. Cosmochim. Acta., 42, 107–120.

HUMPHRIS, S. E. and THOMPSON, G. (1978b): Trace element mobility during hydrothermal alteration of oceanic basalts. Geochim. Cosmochim. Acta., 42, 127–136.

KARSON, J. A. and DICK, H. J. B. (1983): Tectonics of ridge-transform intersection at the Kane fracture zone. Mar. geophys. Res., 6, 51–98.

LANGMUIR, C. H. and BENDER, J. F. (1984): The geochemistry of oceanic basalts in the vicinity of transform faults: observations and implications. Earth Planet. Sci. Lett., 69, 107–127.

LEMOINE, M. (1971): Données nouvelles sur la série du Gondran près de Briançon. Réflexions sur les problèmes statigraphiques et paléontologiques de la zone piémontaise. Trav. Lab. Géol. Fac. Sci. Grenoble, 47, 181–201.

LEMOINE, M. (1980): Serpentinites, gabbros and ophicalcites in the Piemont-Ligurian domain of the Western Alps: possible indicators of oceanic fractures zones and of associated serpentinite protrusions in the Jurassic-Cretaceous Tethys. Proceed. Intern. Symp. on Tectonic Inclusions and associated Rocks in Serpentinites, Genève, 1979.

Arch. Sci. Genève, 33, 103–115.

LEMOINE, M. BOILLOT, G. and TRICART, P. (1986): Les fonds océaniques ultramafiques et gabbroïques de la Téthys Ligure (Alpes, Corse, Apennin): recherche de modèles. C. R. Acad. Sci. Paris, 303, II/9, 851–856.

LEMOINE, M., STEEN, D. and VUAGNAT, M. (1970): Sur le problème statigraphique des ophiolites piémontaises et des roches sédimentaires associées: observations dans le massif de Chabrière en Haute-Ubaye (Basses-Alpes, France). C. R. Soc. Phys. Hist. Nat. Genève, 5, 44–59.

LEMOINE, M. and TRICART, P. (1986): Les schistes lustrés pémontais des Alpes occidentales: approche statigraphique, structurale et sédimentologique. Eclogae geol. Helv., 79, 194–217.

LEWIS, A. D. AND SWEMING, J. D. (1980): The Montgenèvre ophiolite (Hautes-Alpes, France): Metamorphism and trace elements geochemistry of the volcanic sequence. Chem. Geol., 28, 291–306.

LOMBARDO, B. and POGNANTE, U. (1982): Tectonic implications in the evolution of the Western Alps ophiolite metagabbros. Ofioliti, 7, 371–394.

MARTIN, R. F. (1984): Patterns of albitization in the Montgenèvre ophiolite, Western Alps. Bull. Minéral., 107, 345–356.

MAXWELL, J. A. and JOHNSON, W. M. (1981): Rock and Mineral Analysis. Second Edition. Wiley-Interscience Publication, John Wiley and Sons, New York.

MÉVEL, C. (1975): Les zonations chimiques dans les pillow-lavas spilitiques du Chenaillet et des Gets (Alpes françaises). Pétrologie, I, 319–333.

MÉVEL, C. (1981): Occurrence of pumpellyite in hydrothermally altered basalt from the Vema fracture zone (Mid-Atlantic ridge). Contr. Min. Petr., 76, 386–393.

MÉVEL, C., CABY, R. and KIENAST, J.-R. (1978): Amphibolite facies conditions in the oceanic crust: example of amphibolitized flaser-gabbro and amphibolites from the Chenaillet massif (Hautes-Alpes, France). Earth Planet. Sci. Lett., 39, 98–108.

MIYASHIRO, A. and SHIDO, F. (1980): Differentiation of gabbros in the Mid-Atlantic Ridge near 24° N. Geochem. J., 14, 145–154.

NISBET, E. G., DIETRICH, V. and ESENWEIN, A. (1979): Routine trace element determination in silicate minerals and rocks by X-ray fluorescence. Fortschr. Mineral., 57, 262–279.

OHNENSTETTER, D., OHNENSTETTER, M. and ROCCI, G. (1975): Tholeiitic cumulates in a high pressure metamorphic belt. Pétrologie, I/4, 291–317.

OHNENSTETTER, M. and OHNENSTETTER, D. (1980): Comparison between corsican albitites and oceanic plagiogranites. Proceed. Intern. Symp. on Tectonic Inclusions and associated Rocks in Serpentinites, Genève, 1979. Arch. Sci. (Genève), 33, 201–221.

PEARCE, J. A. (1980): Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites. In: Panayiotou, A. (Ed.), Proc. int. Ophiolite Conf., Nicosia, Cyprus 1979, 261–272.

PEARCE, J. A. AND CANN, J. R. (1973): Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth Planet. Sci. Lett. 19, 290–300.

PEARCE, J.A., LIPPARD, S.J. and ROBERTS, S. (1984): Characteristics and tectonic significance of supra-subduction zone ophiolites. In: Kohclaar B.P. and Howells, M.F. (Ed.), Marginal basin geology. Geol. Soc. (London), Spec. Publ., 16, 77–94.

PEARCE, J.A. and NORRY, M.J. (1979): Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks. Contrib. Miner. Petrol., 69, 33–47.

PHILPOTTS, A.R. and DOYLE, C.D. (1983): Effects of magma oxidation state on the extent of silicate liquid immiscibility in a tholeiitic basalt. Amer. J. Sci., 283, 967–986.

POGNANTE, U., LOMBARDO, B. and VENTURELLI, G. (1982): Petrology and geochemistry of Fe–Ti gabbros and plagiogranites from the Western Alps ophiolites. Bull. suisse minéral. pétrogr., 62, 457–472.

POGNANTE, U. PERROTO, A., SALINO, C. and TOSCANI. L. (1986): The ophiolitic perioditites of the Western Alps: Record of the evolution of a small oceanic type basin in the Mesozoic Tethys. Tscherm. mineral. petrogr. Mitt., 35, 47–65.

POGNANTE, U., RÖSLI, U. and TOSCANI, L. (1985): Petrology of ultramafic and mafic rocks from the Lanzo perioditite body (Western Alps). Lithos, 18, 201–214.

POLINO, R. and LEMOINE, M. (1984): Détritisme mixte d'origine continentale et océanique dans les sédiments jurassico-crétacés supra-ophiolitiques de la Théthys ligure: la série du Lago Nero (Alpes occidentales franco-italiennes). C.R. Acad. Sc, Paris, 298, II/8, 359–364.

POLINO, R. MONTICELLI, F. and VACCARO, D. (1986): L'unità piemontese Chaberton-Grande-Hoche (Val Susa, Alpi Occidentali): Evoluzione lithostatigrafia, asseto structurale e rapporti con i complessi circonstati. Mem. Soc. geol. ital., 26, 489–498.

PUSZTASZERI, L. (1969): Etude pétrographique du massif du Chenaillet (Hautes-Alpes, France). Bull. suisse minéral, pétrogr., 49, 425–466.

RHODES, J.M., DUNGAN, M.A., BLANCHARD, D.P. and LONG, P.E. (1979): Magma mixing at mid-ocean ridges: evidence from basalts drilled near 22° N on the mid-atlantic ridge. Tectonophysics, 55, 35–61.

ROCCI, G., OHNENSTETTER, D. and OHNENSTETTER, M. (1975): La dualité des ophiolites thétysiennes. Pétrologie, I, 172–174.

SERRI, G. (1980): Chemistry and petrology of gabbroic complexes from the Northern Apennines ophiolites. In: Panayiotou, A. (Ed.), Proc. int. Ophiolite Conf., Nicosia, Cyprus 1979, 296–313.

SERRI, G. (1981): The petrochemistry of ophiolite gabbroic complexes: a key for the classification of ophiolites into low-Ti and high-Ti types. Earth Planet. Sci. Lett., 52, 203–212.

SERRI, G. and SAITTA, M. (1980): Fractionation trends of the gabbroic complexes from high-Ti and low-Ti ophiolites and the crust of major oceanic basins: a comparison. Ofioliti, 5 (2/3), 241–264.

SHERVAIS, J.W. (1982): Ti–V plots and petrogenesis of modern and ophiolitic lavas. Earth Planet. Sci. Lett., 59, 101–118.

STEEN, D., VUAGNAT, M. and WAGNER, J.-J. (1980): Early deformations in Montgenèvre gabbros. Proc. Colloq. Int. CNRS No 212, BUMA (Grenoble), 1977, 97–103.

SUN, S.S., NESBITT, R.W. and SHARASKIN, A.Y. (1979): Geochemical characteristics of mid-ocean ridge basalts. Earth Planet. Sci. Lett., 44, 119–138.

TRICART, P. (1974): Les schistes lustrés de Haut-Cristillan (Alpes cottiennes, France): lithostratigraphie, architecture et tectogenèse. Géol. Alp. (Grenoble), 50, 131–152.

TRICART, P. and LEMOINE, M. (1986): Mégaboudinage alpin et fracturation téthysienne dans les Schistes lustrés piémontais à l'Ouest du Mont Viso (Alpes occidentales). C.R. Acad. Sc. Paris, 302, II/8, 599–604.

VUAGNAT, M. (1946): Sur quelques diabases suisses. Contribution à l'étude des spilites et des pillow lavas. Bull. suisse minéral. pétrogr., 26, 116–128.

VUAGNAT, M. and PUSZTASZERI, L. (1965): Sur la présence de hyaloclastites dans le massif du Montgenèvre (Hautes-Alpes). Arch. Sci. (Genève), 18, 120–123.

VUAGNAT, M. and PUSZTASZERI, L. (1966): Réflexions sur la structure et le mode de formation des coulées en coussins du Montgenèvre. Arch. Sci. (Genève), 18, 686–689.

WOOD, D.A., JORON, J.L. and TREUIL, M. (1979a): A reappraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings. Earth Planet. Sci. Lett., 45, 326–336.

WOOD, D.A., TARNEY, J., VARET, J., SAUNDERS, A.D., BOUGAULT. H., JORON, J.L., TREUIL, M. and CANN, J.R. (1979b): Geochemistry of basalts drilled in the North-Atlantic by IPOD Leg 49: implications for mantle heterogeneity. Earth Planet. Sci. Lett., 42, 77–97.