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ISTVÁN KUBOVICS* – A. M. ABDEL-KARIM*

COMPARATIVE PETROLOGY AND GEOCHEMISTRY OF SOME ULTRAMAFICS FROM THE WESTERN ALPS OPHIOLITES

(11 Figs., 1 Tab.)

Abstract: Data on petrology and geochemistry of rocks from seven ultramafic suites from Piedmont Zone in the Western Alps have been presented and compared, together with basic field data.

They suffered the eo-Alpine HP and following greenschist facies conditions metamorphism and appear to be represented by fragments of Tethyan oceanic lithosphere (Pognante et al., 1985). They have extensively serpentinized and scarcely chloritized and obliterated original textures and mineral associations. In a few cases, on the basis of structural mineral relics, geochemical data and by comparison with less altered peridotites of the Western Alps, it can be concluded that these rocks were probably derived from lherzolites and pyroxenites in Arc Valley and spinel lherzolite in Monviso and are depleted in fusible elements and followed a very high T (1300 °C). The Roche Noire and Chenaillet ultramafics are probably less depleted and followed slightly lower T (1200 °C) Pognante et al. (1986).

The serpentinization of these ultramafics is mostly characterized by enrichment in MgO and La and depletion in Al_2O_3, CaO, Sc and Y, while the chloritization shows decrease in MgO and Nb and increase in Al_2O_3, Cao, TiO_2, Zr and Sc contents. The P_2O_5, FeO (total) and Al_2O_3 contents obviously increase, while MgO content decrease with increasing M. I. Based on chemical composition they fall into the ophiolitic ultramafic field (Jensen, 1976), ultramafic cumulate and scarce metamorphic peridotite (Coleman, 1977; Strong – Malpas, 1975).

Резюме: В статье приводятся и сравниваются петрологические и геохимические данные. Так как данные полученные при полевых работах, о породах пиедмонтской зоны в Западных Альпах. Эти породы претерпели эо-альпийский метаморфизм при высоких давлениях, в условиях фации зеленых сланцев. Они репрезентированы фрагментами тетидной океанской литосферы (Pognante et al., 1985). Они интензивно серпентинизованы и редко хлоритизованы и первичные структуры и минеральные ассоциации были разрушены. В некоторых случаях на основе структурных минеральных остатков, геохимических данных и сравнением с менее измененными перидотитами западных Альп можно заключить что эти породы происходят из пироксенитов из долины Арк и спинеловых лерзолитов из Монвизо и они обеднены плавкими элемтами и претерпели очень высокую температуру (T = 1300 °C). Ультрамафиты из Роше Ноар и Шеналет были правдеподобно менее обеднены этими элементами и они претерпели немножко более низкую температуру (1200 °C) (Pognante et al., 1986). Серпентинизацию этих ультрамафических пород можно охарактеризовать обогащением MgO и La и обеднением Al_2O_3, CaO, Sc и Y, затем что хлоритизация показывает понижение содержаний MgO и Nb и повышение Al_2O_3, CaO, TiO, Zr и Sc. Содержания P_2O_5, FeO (tot) и Al_2O_3 повышаются и MgO понижается с повышением M. I. На основе химического состава эти породы можно присоединить к офиолитовым ультрамафическим породам (Jensen, 1976), ультрамафическим кумулятам и редким метаморфическим перидотитам (Coleman, 1977; Strong– Malpas, 1975).

Key words: petrology, geochemistry, ultramafics, Western Alps, Piedmont Zone.

* Prof. I. Kubovics, A. M. Abdel-Karim, Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest-1088, Hungary.

Introduction

Ultramafic rocks from Piedmont Zone of the Western Alps have been considered as a part of Late Cretaceous subducted Late Jurassic–Cretaceous oceanic lithosphere (Dal Piaz, 1974).

They are always weathered, sheared and strongly serpentinized, and only a few of them have dominantly lherzolitic composition.

The ultramafic rocks of the Western Alps have been geochemically and petrologically studied in Arc Valley (Bocquet, 1974), Montgenévre (Bertrand et al., 1982), Monviso (Monviso, 1980; Lombardo–Compagnoni, 1988) and Queyras (Lemoine, 1980). Recent studies in these areas are carried out by Kubovics–Abdel-Karim (in press; 1, 2), Abdel-Karim–Bilik, and Abdel-Karim–Puskás (in press).

Seven representatives of metaultramafic suites from Pre clos la Clapera, Refuge d'Averole and Modane (Arc Valley), Chenaillet (Montgenévre), Petit Belvedere and Pain Del Re (Monviso) and Roche Noire (Fig. 1) have been studied from petrographical, mineralogical and geochemical point of view and are also compared with each other.

Field relationships

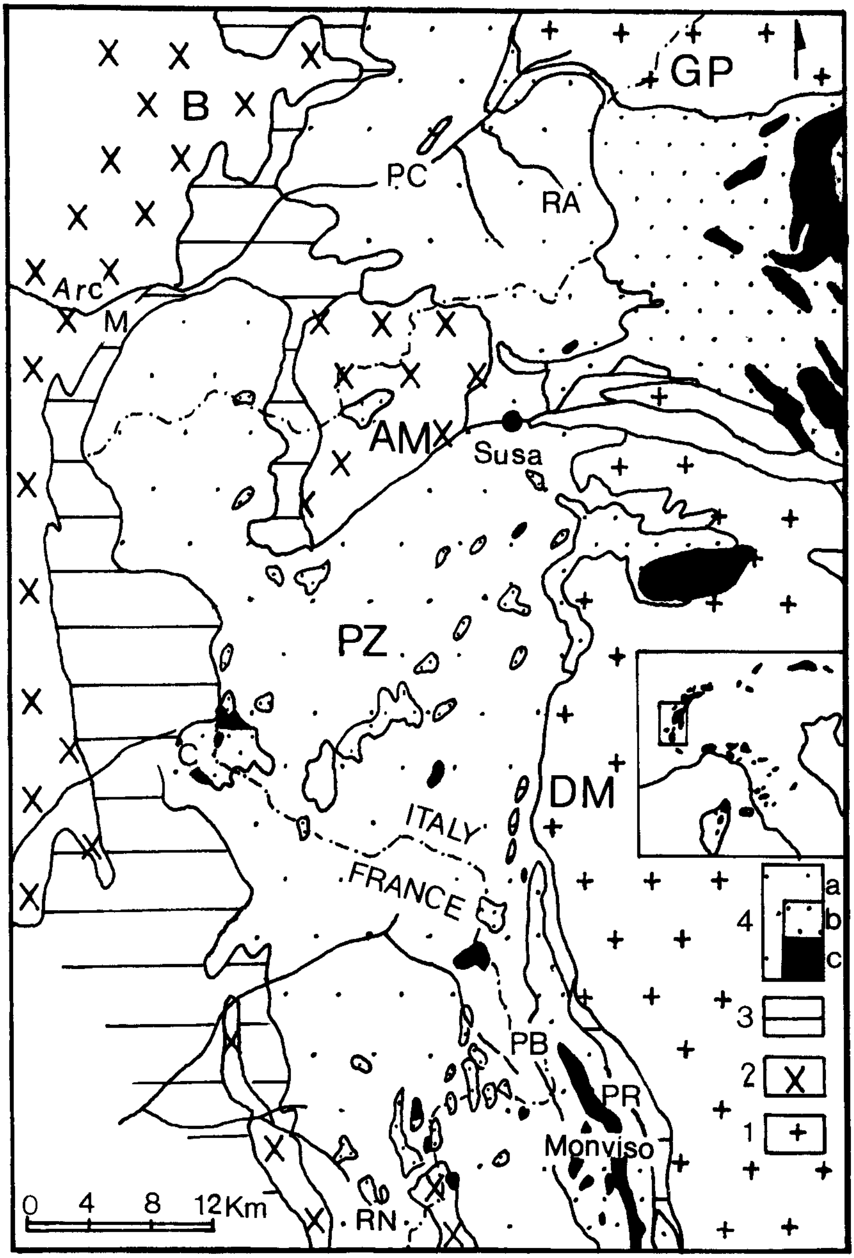
The tectonite-peridotites of the Western Alps ophiolites are usually serpentinized, but rare fresh bodies and textural and mineral relicts within poorly-deformed serpentinites indicate that they are represented by spinel- and plagioclase lherzolite with minor harzburgites, dunites and pyroxenites (Pognante et al., 1986). They are characterized by widespread mylonitic deformation and recrystallization under eclogite/blueschist and greenschist facies conditions.

The Arc Valley occupies the area between Gran Paradiso and Ambin unit in the Central Piedmont ophiolite nappe. Metaultramafics in the Arc area form large (a few kilometres) sheets and slices and are represented by serpentinized peridotite-tectonites (Pre clos la Clapera). In addition to folded asbestos veins, the serpentinites at the Refuge d'Averole often contain small boudins, lenses and dykes (a few metres to a few tens metre thick) greenschist and eclogitic metagabbros. The Arc Valley ultramafics are distinguished by a centimetre to decimetre tremolitic- to garnetic-chlorite schist layers (pyroxenitic origin) particularly along margins. Most ultramafics in the Arc area are completely serpentinized and foliated. Some chlorite-and carbonate-bearing serpentinites (ophicalcites) are frequently tectonized and located near the contact between ultramafic and calc-schist at Pre clos la Clapera and Modane.

Fig. 1. Tectonic sketch map of the Internal Western Alps showing the locations of the main ophiolite complexes (Lombardo–Pognante, 1982).

Legend: 1 – Dora-Maire (DM) and Gran Paradiso (GP) continental units (European Paleomargin); 2 – Vanoise, Ambin (AM) and Brianconnais (B) continental units (European Paleomargin); 3 – Mesozoic epicontinental covers; 4 – Piedmont Zones (PZ) Schistes Lustres' nappe (Mesozoic, mainly oceanic material): a) undifferentiated metasediments with subordinate ophiolites, b) ophiolite complex with minor metasediment, c) metagabbro bodies.

Location of samples: PC/ Pre clos la Clapera; RA/ Refuge d'Averole; M/ Modane; C/ Chenaillet; PB/ Petit Belvedere; PR/ Pain Del Re; RN/ Roche Noire.


B
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RA
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DM
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4
a
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3
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1

Fig. 1

The Chenaillet metaultramafics are situated on the western periphery of the Montgenévre ophiolite. They are mostly represented by serpentinite and are in faulted contacts with the other members of the ophiolite complex (gabbros and volcanics). The serpentinite contains assorted tectonic inclusions of ophiolite fragments (volcanic, gabbroic and serpentinitic rocks) and presumably represent a mobile base over which the higher members of the ophiolite complex were emplaced onto the pre-Piedmont zone. This serpentinite with the inclusion of ophiolite fragments, also occurs as a diapiric intrusion up a fault intersection (Lewis – Smewing, 1980).

The Monviso ultramafics mainly occur as basal serpentine unit about 500 m thick. They are located in the eastern side of the Piedmont zone in both sides of the French Italian border (Petit Belvedere-Pain Del Re). They are commonly crosscut by rodingitized gabbro dykes (a few metres thick) and include a large eclogite body exposed over an area of a tens of m. Other metagabbro bodies occur in the upper part of the basal serpentinite. The serpentinites situated at the Pain Del Re form massive and sheared borders and blocks (a few tens square centimetre to a few square metres).

The Roche Noire ultramafics are situated in the south-western margin of the Piedmont Zone and are mainly represented by serpentinite and scarcely chlorite schist. The chlorite schist forms thin rims (a few cm to a few tens cm thick) of the serpentinite. The ultramafic bodies commonly enclose small masses of basaltic glaucophanite and gabbro breccia. The inclusion of gabbro in the Roche Noire serpentinite might be the result of serpentinite diapirs in an oceanic fracture zone environment (Lemoine – Tricart, 1979). Some blocks (a few tens metres) of serpentinite are enclosed in the metasedimentary cover (Post-Liassic to Cretaceous age) of the ophiolite complex.

Analytical methods

The identification of the serpentine minerals and textures were determined as recorded by Tertsch (1922); Wicks – Zussman (1975), Wicks – Whittaker (1977), Wicks et al. (1977), Dungan (1979), Wicks – O'Hanley (1988) and others.

X-ray diffraction and DTA analyses were performed to determine the main mineralogical composition of the rocks particularly serpentine and carbonate minerals.

Major and trace element analyses were carried out for eight selected ultramafic samples (Tab. 1). SiO_2 and FeO were determined by thermographimetrical method. TiO_2 and P_2O_5 analyses were performed by spectrophotometry method. H_2O and CO_2 were determined by DTA. The remaining oxides and Ba, Rb and Sr were analysed by atomic absorption method (Model AA-475). Be, Nb, Y, La, Zr and Sc have been quantitively determined by optical atomic spectrographical method (Model PGS-2 C. Zeiss Jena).

Petrography and mineralogy

1 – In the *Arc Valley,* in the central Piedmont Zone, metalherzolite (Pre clos la Clapera), tremolite chlorite schist and garnet-bearing chlorite schist (Refuge d'Averole), antigorite serpentinite (Refuge d'Averole and Pre clos la Clapera) and ophicalcite (Pre clos Clapera and Modane) were recognized.

1a – *The metalherzolite* is often tectonized and serpentinized and from primary magmatic minerals only clinopyroxene preserved. It occurs both in massive and sheared varieties. Metalherzolite consists mainly of variable amounts of clinopyroxene together with subordinate serpentine, Mg-Fe chlorite, tremolite and magnesite. Opaque minerals are represented by magnetite and hematite.

Clinopyroxene (45 vol. %) is preserved as a 1.8 mm long porphyroblast, it has been deformed and altered to lizardite ± chlorite and magnetite, or it is originally represented by diopside rimmed by tremolitic amphibole (Fig. 2). Serpentines (30 vol. %) consist of interlocking-spherulitic texture usually formed during serpentinization of olivine. Thin parallel veins of chrysotile are crossing the rocks. The serpentine is replaced by magnesite (5 vol. %). Chlorite (11 vol. %) is Mg-Fe rich and forms aggregates. Tremolite (2.5 vol. %), is developed at the expense of clinopyroxene and is partly replaced by chlorite. Magnetite (5 vol.%) and scarce hematite have been recorded.

1b – In *tremolite chlorite schist,* relics of magmatic clinopyroxene are found. It consists mostly of tremolite, chlorite, and clinopyroxene with iron ores, leucoxene, apatite, and biotite accessories.

Clinopyroxene is preserved as a relict diallage which is partly replaced by Mg-Fe rich chlorite ± iron ore, or altered to tremolite (Fig. 3). The tremolite (0.7–5.5 mm long) is the most common mineral (57 vol. %), and it probably originated from clinopyroxene. The former clinopyroxene and tremolite are replaced by Mg-Fe chlorite (33 vol. %). Titanomagnetite is replaced by leucoxene while Ti-biotite grows after tremolite.

On the basis of structural and mineral relics it can be concluded that the tremolite-chlorite schist is most probably derived from primary pyroxenite.

1c – In *garnet-bearing chlorite schist,* scarce primary clinopyroxene relics are still survived. The rock consists of chlorite and garnet and accessory clinopyroxene, titanite and stilpnomelane.

The Mg-Fe rich chlorite is the predominant mineral (92 vol. %) and it is commonly developed after the primary ferromagnesian minerals and garnet. Garnet (5 vol. %) forms brown tectonically deformed crystals (pyrope?) up to 0.9 mm across, partly altered to chlorite. Clinopyroxene (6.5 vol.%) is replaced by chlorite while titanite (2 vol.%) and stilpnomelane are commonly embedded in the chlorite. The original material that altered to garnet-bearing chlorite schist was probably garnet-bearing clinopyroxenite in which the clinopyroxene is altered to Mg-chlorite, garnet is remained stable.

1d – *Antigorite serpentinite* is made up mainly of antigorite with minor magnetite and chlorite. The antigorite is displayed interpenetrating texture. Magnetite forms grains (1.6 mm across) and lenses usually associated with antigorite. Mg-rich chlorite is associated with antigorite.

1e – In *ophicalcite,* relics of magmatic clinopyroxene are survived. It occurs in both massive and sheared and tectonized varieties. It mainly consists of serpentine, calcite, chlorite, clinopyroxene and tremolite with accessory iron ores and titanite.

Calcite (60 vol. %) forms subhedral grains. Serpentine (20 vol.%) occurs as interpenetrating texture compacted with calcite. Chlorite (10 vol.%) is developed after clinopyroxene and tremolite and is associated with serpentine (Fig. 4). The clinopyroxene (cpx) relics are altered to serpentine or chlorite ± magnetite. Less altered diopside (6 vol. %) is commonly tectonized and has an undulatory extinction. Tremolite (0.8 mm long crystal) is frequently dislocated (Fig. 4).

2 – Around the *Chenaillet* (Montgenévre) in the western side of the Piedmont ophiolite nappe, lizardite serpentinite is recorded.

In this body, the primary minerals disappeared except some relics of spinel.

Lizardite is the common mineral which gives rise to pure hourglass texture and scarce mesh texture. The mesh center is commonly filled by isotropic serpentine. The Cr-rich spinel (picotite) occurs in crystals up to 2 mm long which are altered to serpentine, chlorite and opaques.

3 – From *Monviso* in the eastern side of the Piedmont ophiolite nappe, metalherzolite (in

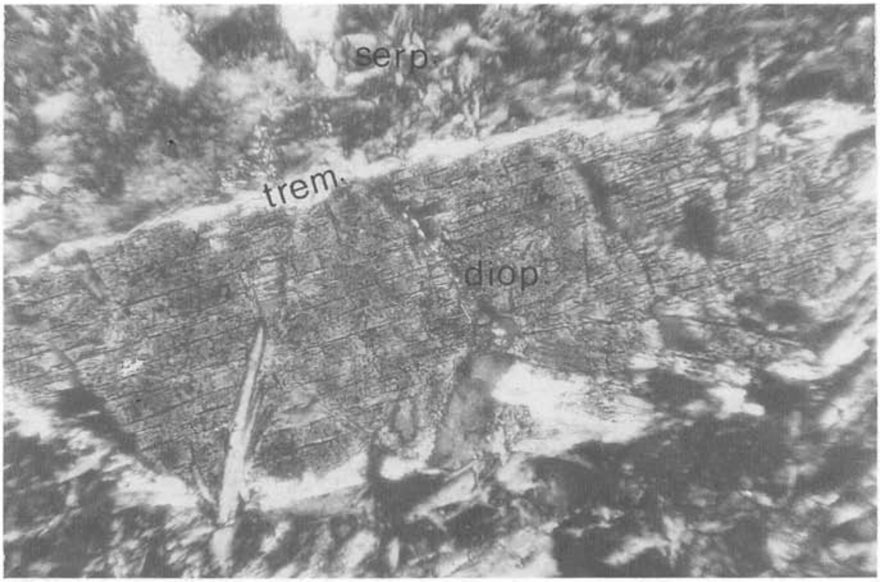

Fig. 2. Clinopyroxene (diopside) porphyroclast rimmed by tremolitic amphibole which is embedded in a fine-grained serpentine mass. C. N., magn. 67×.

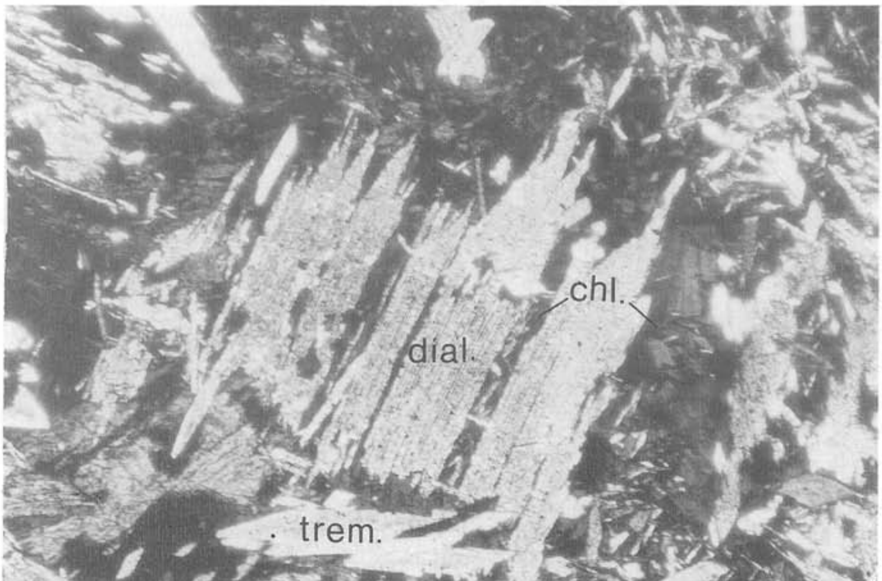

Fig. 3. The replacement of clinopyroxene (diallage) by chlorite associated by tremolite. C. N., magn. 67×.

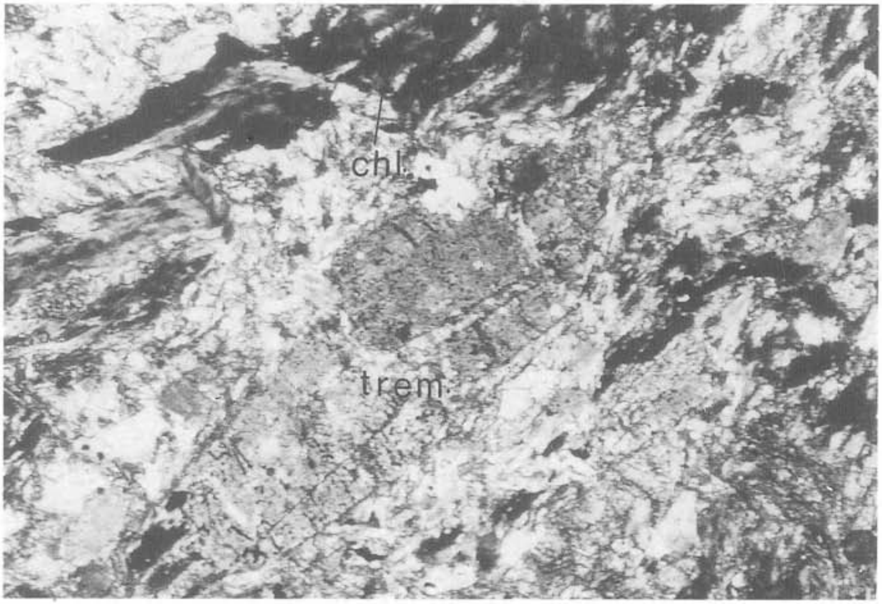

Fig. 4. Tectonized and dislocated xenomorphs of tremolite and chlorite. C. N., magn. 67×.

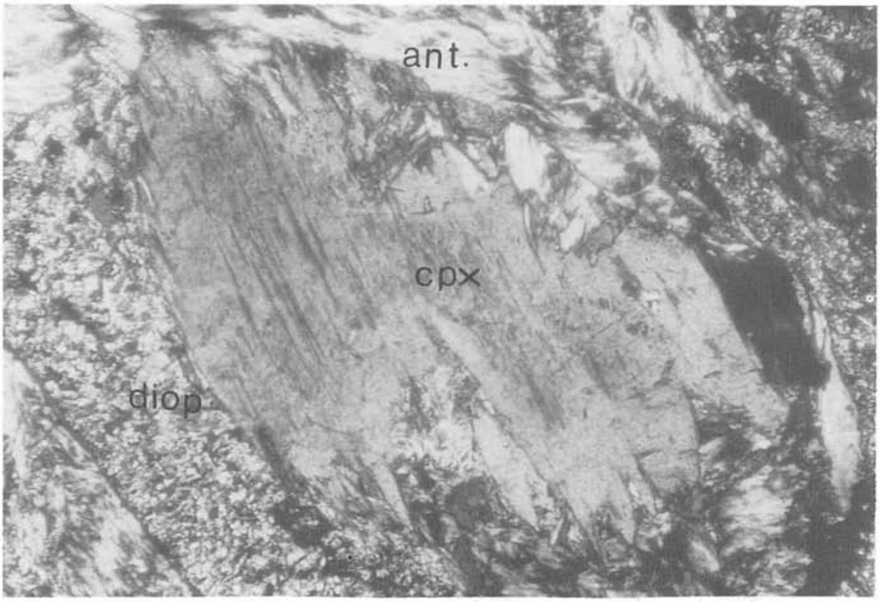

Fig. 5. Clinopyroxene altered to antigorite ± magnetite or partly recrystallized to a fine-grained diopside aggregate. C. N., magn. 67×.

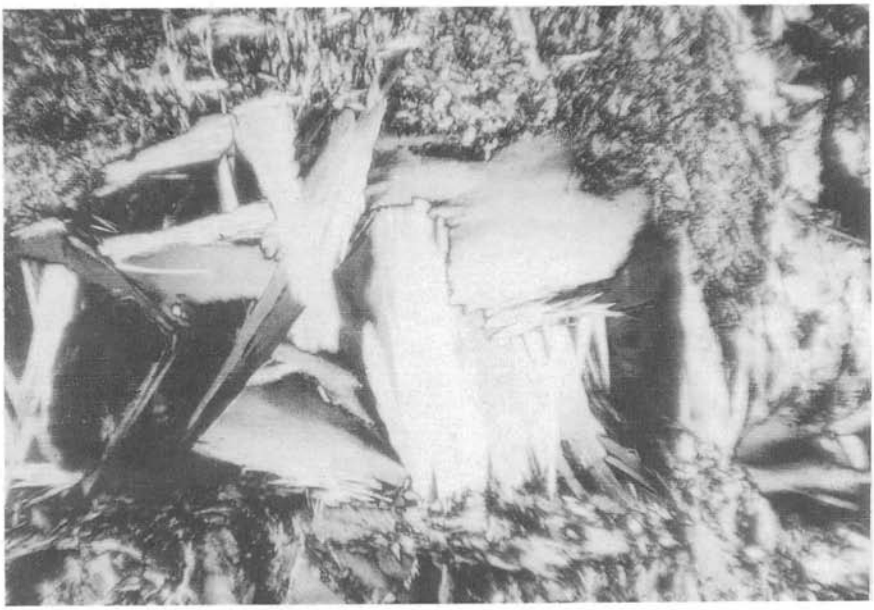

Fig. 6. Xenoblastic blades of a recrystallized antigorite resulting in interpenetrating texture. C. N., magn. 58×.

Fig. 7. Typical lizardite mesh texture. The mesh center and margin are lines by magnetite. C. N., magn. 67×.

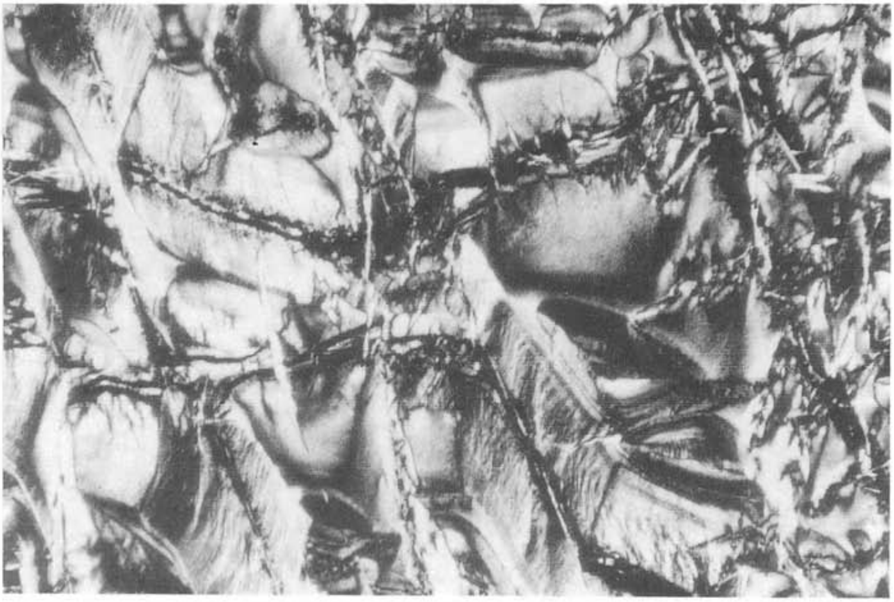

Fig. 8. Well developed hourglass texture C. N., magn. 67×.

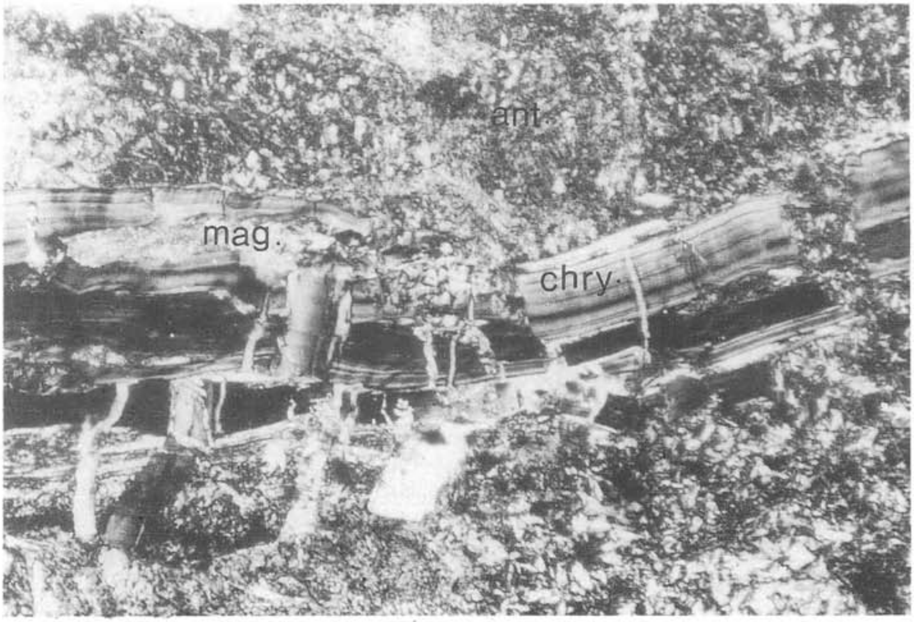

Fig. 9. Chrysotile vein texture embedded in antigorite interlocking texture which are replaced by magnesite. C. N., magn. 67×.

the Pain Del Re, Italian Monviso) and antigorite serpentinite, and lizardite-chrysotile serpentinite (in the Petit Belvedere, French Monviso) were studied.

3a – *Metalherzolite* is represented by both massive and sheared varieties. It is essentially composed of largely variable amounts of cpx, antigorite, brucite, Mg-Fe rich chlorite, Ti-rich clinohumite, olivine and chrysotile with minor amounts of opaques such as magnetite, native Fe-Ni and sulphides.

Clinopyroxene (40 vol.%) is locally preserved as dusty porphyroclasts (up to 0.5 cm in diameter) clouded with magnetite. It was altered to antigorite ± magnetite or partly recrystallized to fine-grained diopside (Fig. 5) probably due to metamorphic influence during serpentinization. Serpentine (30 vol.%) is dominantly antigorite, which forms interpenetrating blades. Thin later formed veins of chrysolite are crosscutting the rock. Mg-Fe chlorite (10 vol.%) forms lensoid aggregates, mostly pseudomorphic after primary spinel. Brucite (2 vol.%) forms fibrous scaly aggregates with anomalous interference colour. It is developed at the expense of metamorphic olivine. Veins of olivine ∓ magnetite, native Fe-Ni and Ti-clinohumite are crosscutting the rock. Ti-clinohumite is grown as anhedral crystals partly serpentinized. It shows large $2\,V_Z$ and high RI.

On the basis of structural and mineral relics and by comparison with less altered peridotite from the Western Alps, it can be concluded that these rocks probably derived from primary spinel lherzolite. Similar results were recorded by Lombardo – Compagnoni (1988).

3b – *The antigorite serpentinite* mainly consists of antigorite and magnesite with small amounts of talc, tremolite, magnetite and chlorite.

The antigorite (54 vol.%) blades form mesh texture whose center is filled with a very fine-grained isotropic antigorite and is sometimes replaced by talc (6.3 vol.%). Xenoblastic blades of antigorite result in interpenetrating texture (Fig. 6) is observed too. Magnesite (15 vol.%) is usually associated with talc. Tremolite (5 vol.%) is embedded in serpentine. Magnetite partly occupies the former olivine.

3c – *Lizardite-chrysotile serpentinite* is made up of chrysotile, lizardite and magnetite with accessory talc, spinel ± chlorite.

Lizardite forms fine fibrous blades lying at high angles to the original fractures forming mesh rims. The typical mesh texture (Fig. 7) with mesh rims and centers lined with magnetite is well shown. Well developed hourglass texture (Fig. 8) is visible too. Chrysotile occurs as interpenetrating texture. Well developed vein texture crosscutting the serpentinite is common. Magnetite is concentrated in the mesh center or lined the mesh rims. Brown spinel is cracked and altered to chlorite. Talc, associated with serpentine is also locally found. Both serpentine and spinel are rimmed by Mg-Fe rich chlorite.

4 – In the area of *Roche Noire* in the southeastern side of the Piedmont nappe, two serpentinite varieties and monomineral chlorite schist were recognized, namely:

4a – *Chrysotile lizardite serpentinite,* consists mainly of lizardite and chrysotile accompained by variable amounts of calcite, orthopyroxene, brucite and opaque ores.

Lizardite occurs as xenomorphic plates commonly uniformly replacing the former orthopyroxene. It is developed as mesh texture. The mesh center contains dusty lizardite ± brucite associated with secondary magnetite which is concentrated along the mesh center-rim boundaries. Chrysotile forms crosscutting fibre veins. Serpentines are sometimes replaced by calcite. Dusty relics of orthopyroxene are deformed and altered to serpentine. Brucite commonly forms dusty relics enclosed in the mesh centers. The opaques may form fine stringes and grains of magnetite and subhedral rectangular crystals of spinel.

4b – *Chrysotile-antigorite serpentinite* consists of antigorite, chrysotile and magnesite with subordinate amounts of magnetite and chlorite.

Antigorite occurs as interlocking blades which are originated either through the recrystallization of the serpentinite texture of probably directly through the serpentinization of primary olivine and pyroxene. Chrysotile forms typical multilayer crosscutting fibre veins (up to 0.2 mm thick) producing veins texture (Fig. 9).

They are deformed and brecciated and replaced by magnesite (13.2 vol.%). Magnetite forms disseminated blebs or linear segregations. Mg-Fe rich chlorite is usually associated with serpentine.

4c – *Monomineral chlorite-schist* consists of chlorite and clinochlore in which minor magnetite is embedded. Both chlorite and clinochlore form spherulitic and interlocking texture. Later, they occur in veins filling the rock fracture.

Petrogenesis

The examined rocks are strongly altered as a result of hydrothermal processes evidenced by their textures and metamorphic mineralogy, and relatively high H_2O (5.1 – 17.2 %) and Na_2O (<0.10 – 0.31 %) contents (Tab. 1), which indicate that they have undergone extensive hydrothermal oceanic-type metamorphism (Mével, 1984). Nevertheless, the elements considered to be relatively immobile during hydrothermal metamorphism such as Ti, Mg, Fe and P as well as, Zr, Nb and Sc will be preferrentially used in this study.

The investigated metaultramafics are characterized by high MgO (28.30 – 38.42), low Al_2O_3 (0.57 – 2.66) and CaO (0.15 – 3.89), similar to the spinel lherzolite of Coleman (1977). Based on CIPW norm these rocks have significant contents of olivine and pyroxene. Significantly higher value of CaO (8.57) in Monviso serpentinite among other serpentinites from the studied areas in the Western Alps is recorded probably due to the replacement of original plagioclase by carbonate.

Ophicalcites and carbonate-bearing serpentinites from Pre clos la Clapera and Petit Belvedere have higher values of CaO (9.4 and 8.5 %) and CO_2 (2.0 and 2.4 %) when compared with other ultramafics from the Western Alps, due to the modal calcite. On the other hand, higher values of Al_2O_3 (7.13 – 11.44), CaO (8.11) and lower MgO (28.3 – 30.88) are recorded in the chlorite schists of Arc Valley, due to the abundance of clinopyroxene, garnet and chlorite. However, (in CIPW norm), these rocks originally had large amounts of anorthite and olivine or pyroxene. The chlorite schists have higher content of Zr (14 – 71 ppm) and Sc (15 – 19 ppm) and lower Nb (2 – 3 ppm) than ultramafics, that can probably be ascribed to the presence of iron ores and Ti-biotite. Moreover the garnet bearing chlorite schist shows higher Al_2O_3 (and corundum in CIPW norms), Zr, Sc, and Ti than the other chlorite schists because of modal garnet and minor titanite and stilpnomelane. High MgO value (30.88, Tab. 1) in garnet-bearing chlorite schist may indicate that garnet is pyrope in composition supporting that the origin of this rock (i.e. garnet-bearing clinopyroxenite).

The major element composition (Tab. 1) and their variations against the M. I. [FeO^+/(FeO^++MgO) ratio] is shown in Fig. 10. In the Western Alps metaultramafics, the P_2O_5, FeO^+ and Al_2O_3 % obviously increase, while MgO% decrease with increasing M. I. The CaO and SiO_2 % are scattered what suggests some differences in their genetic environments and the consequeme of the metamorphic processes.

The (FeO^++TiO_2)-Al_2O_3-MgO diagram (Fig. 11a) was applied by Jensen (1976) to present the differentiation in ophiolitic series. The metaultramafics of the Western Alps are

FeO^+ = FeO + Fe_2O_3

Table 1

Major element analyses (in wt. %), trace element (in ppm) and CIPW norm of some ophiolitic metaultramafics from Piedmont Zone, Western Alps

Locality	Arc Valley					Chenaillet			Monviso Petit Belvedere	Roche Noire
	Pre clos la Clapera		Refuge d'Averole		Pre clos la Clapera					
Rock name	lherzolite (tectonites)		Trem-chl schist (pyroxenite)	garnet-bearing chl schist	ophicalcite	lizardite (Bertrand et al., 1982) *serpentinites*		tectonite	lizardite chrysotile	chrysotile antigorite
Sample No. Symbols	(⌀) 1	(⌀) 2	(○) 3	(○) 4	(∗) 5	(◐) 6	(◐) 7	(◐) 8	(⊖) 9	(●) 10
SiO_2	43.32	43.27	43.35	36.01	44.21	41.43	37.10	39.18	33.20	43.8
TiO_2	0.11	0.10	0.16	0.78	0.10	<0.10	0.07	0.05	<0.10	<0.10
Al_2O_3	2.0	1.52	7.13	11.44	0.98	1.36	2.04	2.66	0.57	0.67
Fe_2O_3	3.11	6.70	2.27	0.94	4.06	4.06	8.35	5.17	1.14	<0.10
FeO	4.72	2.33	4.05	6.11	4.13	3.39	1.42	2.99	4.29	4.39
MnO	0.07	0.10	0.13	0.21	0.05	0.10	0.29	0.11	0.09	0.07
MgO	34.05	32.35	28.3	30.88	28.90	35.04	37.20	36.21	32.17	38.42
CaO	3.89	2.73	8.11	2.99	9.40	0.15	0.90	0.96	8.57	0.15
Na_2O	0.10	0.17	0.15	<0.10	<0.10	0.16	0.10	0	0.31	<0.10
K_2O	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0	0	<0.10	<0.10
H_2O^+	4.99	10.28	5.35	9.23	6.20	12.94	12.0	12.28	15.8	4.30
H_2O^-	0.36	0.22	0.35	0.77	0.40	0.89	—	—	1.4	0.80
CO_2	3.57	0	0	0	2.0	0	0	0.25	2 4	6.40
P_2O_5	0.01	0.10	0.02	0.05	<0.01	0.01	0	0	0.01	<0.01
Total	100.20	99.97	99.37	99.41	100.43	99.53	99.37	99.86	99.95	99.00
M. I.	0.19	0.22	0.18	0.18	0.22	0.17	0.21	0.18	0.14	0.10

Be	<1	—	<1	<1	<1	—	—	—	<1	<1
Nb	6	—	<2	3	10	—	—	—	7	21
Y	2.5	—	3	4	<2	—	—	—	<2	2.5
Zr	4.5	—	14	71	8	—	—	—	13	13
La	<10	—	<10	<10	21	—	—	—	21	24
Sc	11	—	15	19	6	—	—	—	6	9
Ti	659	—	959	4676	599	—	—	—	599	599
Ba	250	—	407	185	629	—	—	—	552	<10
Rb	<2.5	—	3.5	21.0	4.1	—	—	—	4.1	2.9
Sr	<10	—	<10	<10	<10	—	—	—	36	<10
or	0.59	0.59	0.59	0.59	0.59	0.59	0	0	0	0.59
ab	0.84	1.43	1.26	0.84	0.84	1.35	0.85	0	0	0.84
an	0	3.08	18.48	14.50	1.92	0.67	4.47	3.18	0	0
ne	0	0	0	0	0	0	0	0	1.28	0
ac	0	0	0	0	0	0	0	0	0.21	0
di	0	7.62	16.96	0	25.05	0	0	0	21.42	0
hy	52.94	44.34	16.13	12.29	32.34	43.91	22.91	35.22	0	42.14
ol	26.75	22.91	36 67	52.56	22.62	32.52	48.88	39.52	57.03	43.43
mt	4.5	7.54	3.29	1.36	5.88	5.88	5.32	7.5	1.54	0.14
il	0.2	0.18	0.30	1.48	0.18	0.18	0.13	0.09	0.18	0.18
ap	0.02	0.23	0.04	0.11	0.02	0.02	0	0	0.02	0.02
c	1.72	0	0	5.85	0	0.73	0.24	1.49	0	0.39
lc	0	0	0	0	0	0	0	0	0.46	0
cs	0	0	0	0	0	0	0	0	3.05	0
hm	0	1.49	0	0	0	0	4.68	0	0	0
cc	8.11	0	0	0	4.54	0	0	0.57	5.45	14.55

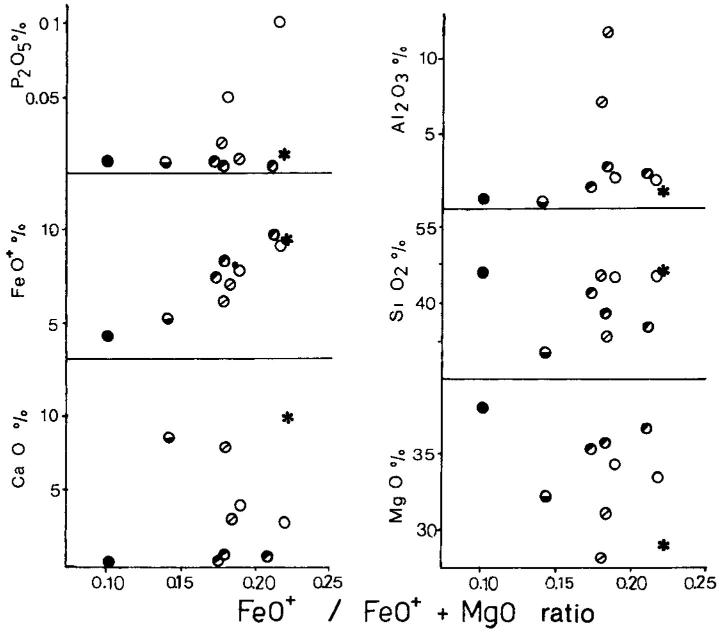

Fig. 10. Major element oxides % versus FeO^{+}/FeO^{+} + MgO ratio for metaultramafics from the Western Alps metaophiolites (symbols see Tab. 1).

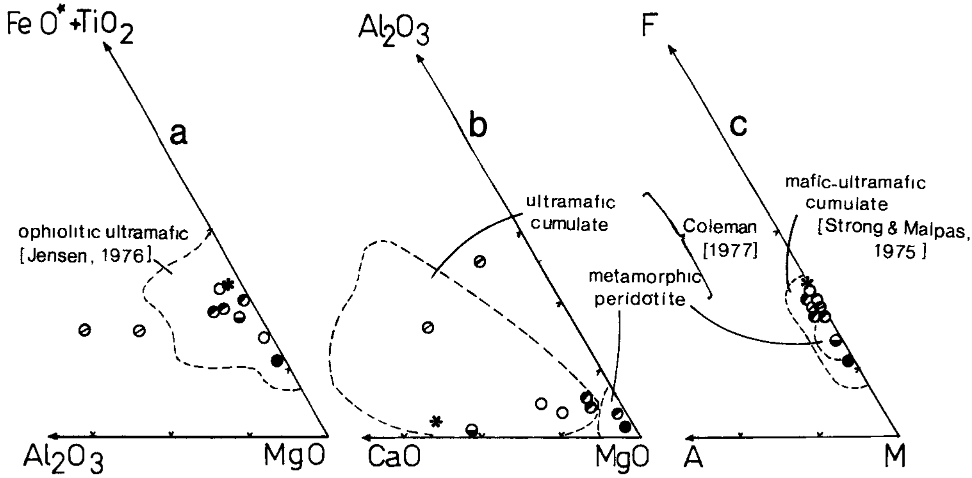

Fig. 11. FeO+TiO_2–Al_2O_3–MgO diagram (after J e n s e n , 1976), Al_2O_3–CaO–MgO diagram (after C o l e m a n , 1977) and AFM diagram (S t r o n g – M a l p a s , 1975) for metaultramafics from the Western Alps (symbols see Tab. 1).

mostly situated in the ophiolite ultramafic field except the chlorite schists of the Refuge d'Averole (Arc Valley) which have a higher Al_2O_3 content probably due to the presence namely of chlorite-clinopyroxene and garnet.

The Al_2O_3-CaO-MgO diagram (Fig. 11b) can be used for the distinction of the ophiolite ultramafic and mafic cumulates as proposed by Coleman (1977). The Western Alps metaultramafics fall in the field of ultramafic cumulates. Serpentinites from Roche Noire and Chenaillet fall into the fields of metamorphic peridotite showing very high contents of MgO.

The AFM diagram (Fig. 11c) was used as proposed by Strong–Malpas (1975) and Coleman (1977). The metaultramafics from the Western Alps typically plot into the field of mafic-ultramafic cumulate of Strong–Malpas, while serpentinites of Roche Noire, Monviso and one sample from Chenaillet are situated in the metamorphic peridotite in the Coleman's diagram.

Discussion and conclusion

The petrological and geochemical studies of the ultramafic rocks from the Arc Valley, Montgenévre, Monviso and Roche Noire ophiolites confirm some similarity in their evolution shown in widespread hydration (serpentinization) and sometimes chloritization processes.

Petrographical study shows that most ultramafic textures and mineral associations have for the most part disappeared as well as typical serpentine textures (mesh, hourglass, interpenetrating...) are developed. Only, in a few cases, on the basis of primary mineral relics (clinopyroxene, spinel, garnet,...), shape of serpentine textures which show it was primary olivine and when compared with other ultramafics from the Western Alps, it can be concluded that these rocks were probably derived from primary lherzolite and pyroxenite (in Arc Valley) and spinel lherzolite (in Monviso). The relatively widespread chlorite schists at the serpentinite margins indicative the metasomatic influence during serpentinization. In a few cases, the chlorite schists contained preserved clinopyroxene relics suggesting their clinopyroxenite origin. Moreover, the presence of stable garnet (pyrope?) and clinopyroxene in some chlorite schists probably indicate that the original rocks were garnet bearing clinopyroxenites.

The ultramafics from the Western Alps displayed some significant geochemical characteristics with respect to each other, that may be due to the different compositions and tectonic settings of their protoliths and the influence of metamorphism. The serpentinization of the studied ultramafics is usually associated with increase in MgO and La and decrease in Al_2O_3, CaO, Sc and Y contents, while the chloritization results in a decrease in MgO and Nb and increase in Al_2O_3, CaO, TiO_2, Zr and Sc.

Generally, the metaultramafics from the Western Alps increase in P_2O_5, FeO^+ and Al_2O_3 contents and decrease in MgO content with respect to the M. I. They mostly fall in the ophiolite ultramafic fields (Jensen, 1976), ultramafic field (Jensen, 1976), ultramafic and scarce metamorphic peridotite (Coleman, 1977; Strong–Malpas, 1975).

The investigated ultramafics were extensively serpentinized and appear to have experienced both early-Alpine and Lepontine metamorphic re-equilibration and are believed to represent fragment of the Tethyan oceanic lithosphere. Similar observations on Lanzo Massif are recorded by Pognante et al. (1985) and Sandrone–Compagnoni (1986).

Based on the mineral chemistry, thermobarometry and geochemical data of some peridotites from the Western Alps which are carried out by Pognante et al. (1986), it can be concluded that the ultramafics of the Eastern Arc Valley (Refuge d'Averole) and Monviso in the Eastern Piedmont Zone are very depleted in fusible elements and have been affected by a very high temperature (1300 °C) while the Middle Arc Valley (Pre clos la Clapera and Modane), Chenaillet and Roche Noire ultramafics in the Western Piedmont Zone are less depleted, have undergone decompression at slightly lower temperature (1200 °C) and might represent sections of shallower subcontinental mantle.

The peridotites are associated with magmatic sequences showing affinities with N-MORB. These sequences derive from partial melting processes which are similar to the Eastern Piedmont Zone peridotites, but probably different from the Western Piedmont Zone peridotites.

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