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Mantle peridotites from the Austroalpine Mt. Mary nappe (Western Alps)

by *B. Cesare*[1], *S. Martin*[2] and *L. Zaggia*[3]

Abstract

A possible fragment of the Insubric continental upper mantle occurs as a slice of spinel - amphibole - harzburgite within the intermediate unit of the Austroalpine Mt. Mary nappe.

This contribution reports petrographic data as well as electron microprobe analyses of the mineral constituents, and major, trace and Rare Earth element abundances of the bulk rock.

The data are consistent with a metamorphic reequilibration of a former spinel lherzolite under pre-Alpine high temperature amphibolite/granulite facies conditions, followed by partial serpentinization during the Alpine orogeny.

Keywords: Austroalpine, Italian Western Alps, Mt. Mary nappe, peridotite, metamorphism, mineral chemistry, bulk rock compostion.

1. Introduction

This paper records the first occurrence of spinel - amphibole - harzburgites in the Austroalpine continental crust of the Mt. Mary nappe, Italian Western Alps.

The peridotitic rocks form a small lens located at 2610m on the southern slope of the Mt. Mary - P.te de Genève ridge, between the Valpelline and Aosta Valleys (Fig. 1). They are tectonically associated with the kinzigitic paragneisses of the Intermediate unit of Mt. Mary nappe, which exhibit a polymetamorphic history and widespread mylonitic deformation (CANEPA et al., 1987 and in press). Additional fragments of serpentinized peridotites occur in the rock debris on the northern side of Mt. Mary (upper Comba Verzignoletta and Comba d'Arpisson).

Similar associations of peridotite tectonites with high-grade paragneisses have already been reported from other units of the Austroalpine nappe system; they occur for instance in the Upper unit of the Sesia-Lanzo (2nd Diorito-Kinzigitic zone; FRANCHI, 1903; BECCALUVA et al., 1978) and Dent Blanche (Valpelline unit; ARGAND, 1934; NICOT, 1977) composite nappes.

In the Southern Alps, spinel lherzolites occur as isolated slices associated to the lower continental crust of the Ivrea-Verbano unit (Baldissero, Finero and Balmuccia peridotites, VOSHAGE et al., 1987 and refs. therein). All the above ultramafic rocks have been interpreted as "continental peridotites". They are believed to represent relics of lithospheric, continental, uppermost mantle.

In contrast, the largely preserved spinel and plagioclase peridotites of the Lanzo massif (POGNANTE et al., 1985) and of Balangero (SANDRONE and COMPAGNONI, 1986), which experienced the eo-Alpine HP-LT metamorphism, could represent fragments of the Tethyan oceanic lithosphere.

2. Geological Setting

The Austroalpine Mt. Mary nappe is located between the Aosta, Valpelline and Valtournanche valleys. In the earlier literature, the Mt. Mary nappe was defined as a single nappe consisting of the Arolla and Valpelline series (ARGAND, 1906) or else as a composite nappe formed by two sliding tectonic units ("Gleitbretter"; DIEHL et al., 1952). The Mt. Mary nappe tectonically overlies the Piedmont ophiolite system and in turn is overthrust by the Dent Blanche composite nappe. The Mesozoic

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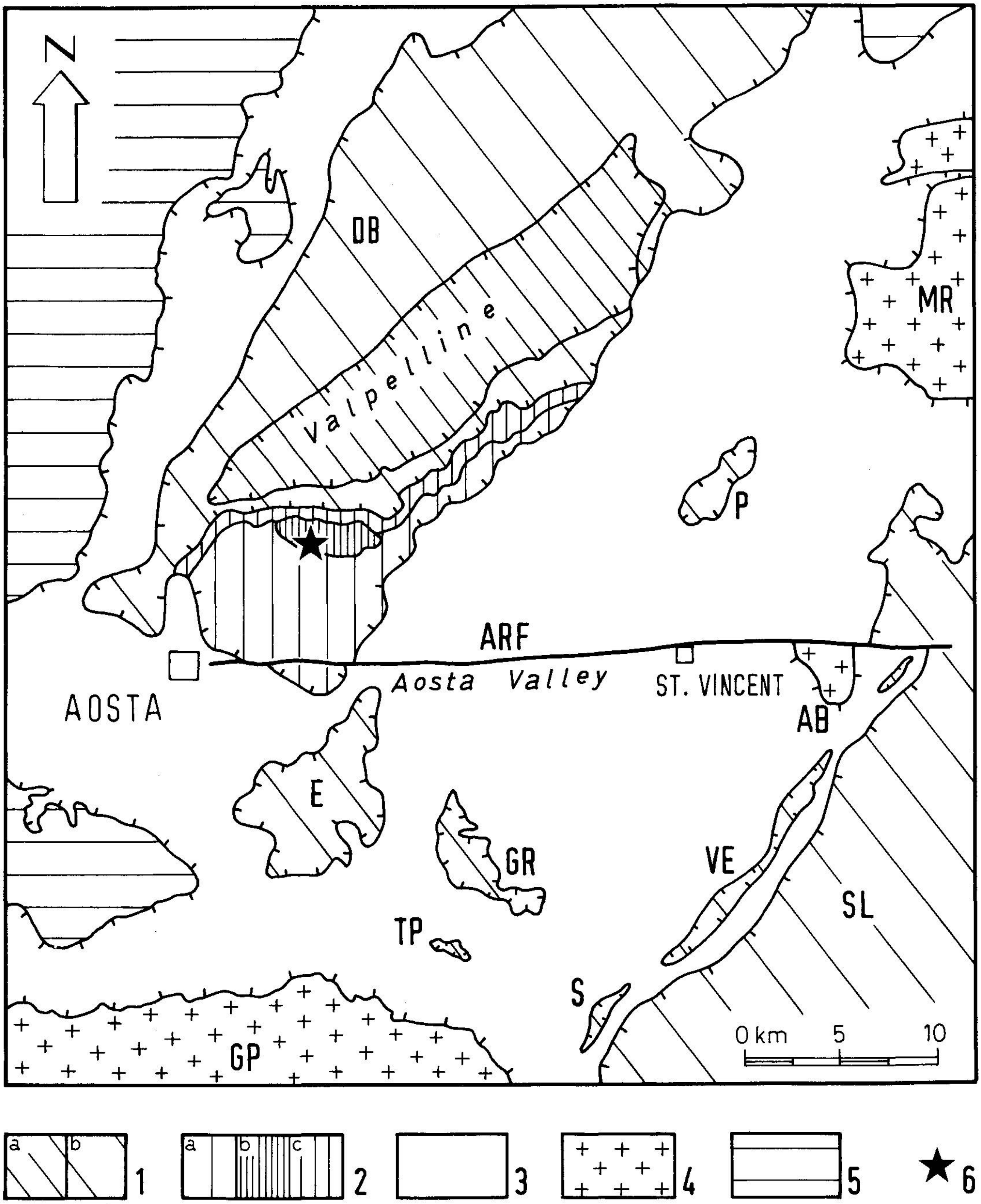

Fig. 1 Tectonic sketch-map of the Italian North-Western Alps.
1) Austroalpine Dent Blanche (DB) and Sesia-Lanzo (SL) composite nappe system, including Mt. Emilius (E), Glacier-Rafray (GR), Tour Ponton (TP), Pillonet (P), Santanel (S) and Verres (VE) Klippen: a) Upper element, b) Lower element. 2) Austroalpine Mt. Mary composite nappe: a) Lower unit; b) Intermediate kinzigitic unit; c) Upper unit. 3) Tethyan ophiolites. 4) Upper Penninic Monte Rosa (MR), Gran Paradiso (GP) and Arcesa-Brusson (AB) nappes; 5) Middle Penninic Gr. St. Bernard nappe. 6) Location of Mt. Mary peridotite body. ARF: Aosta-Ranzola fault.

sequence of the Roisan zone, located between the Mt. Mary and Dent Blanche basement units, was interpreted as the sedimentary cover of the Mt. Mary unit (MASSON, 1938; DIEHL et al., 1952; ELTER, 1960).

Recent studies in this area (CESARE, 1987; ZAGGIA, 1987; CANEPA et. al.,1987; in press), reveal that the internal structural setting of Mt. Mary needs to be revised by introducing an uppermost third unit. This unit is composed of a pervasively sheared cover and basement series (Fig. 1). Therefore, the composite nappe of Mt. Mary consists of three tectonic units which are distinguished by different lithological compositions and are separated by meter-size mylonitic horizons.

From bottom to top the three units are:

i) The Lower unit (ARGAND's Arolla Series), which is composed of high-grade paragneisses of unknown age (Hercynian or older) and of Permo-Carboniferous granitoids; they suffered a pervasive Alpine metamorphic overprint under glaucophane-bearing greenschist facies conditions;

ii) The Intermediate unit (ARGAND's Valpelline Series) which consists of high-grade kinzigitic paragneisses, metabasites and marbles, locally overprinted by an Alpine retrogression of undefined age. The high temperature granulite/amphibolite metamorphism is supposed to be of Hercynian (or older) age by comparison with the Dent Blanche nappe and the Ivrea zone (DAL PIAZ et al., 1972; HUNZIKER, 1974; HUNZIKER & ZINGG, 1980).

iii) The Upper unit, which overthrust both the underlying units and is predominantly composed of mylonites derived from locally preserved Triassic-Cretaceous cover series (Roisan Zone) and from granitoid rocks. This unit exhibits an intense Alpine metamorphism under greenschist facies conditions.

3. Spinel peridotite of Mont Mary

3.1. PETROGRAPHIC DESCRIPTION

The spinel - amphibole - harzburgite of Mt. Mary displays a high-grade metamorphic fabric and is composed of olivine, orthopyroxene, amphibole, green spinel and minor magnetite. Olivine, orthopyroxene (locally with clinopyroxene exsolution lamellae) and amphibole are the most abundant phases; green spinel and magnetite occur as inclusions in orthopyroxene and as interstitial gratins. The rock is fine grained, although the prophyroblastic orthopyroxene, often including olivine and amphibole, may reach 4-5 mm in length. The microstructural relationships indicate an equilibrium texture between olivine, orthopyroxene, spinel and amphibole (the latter possibly derived from a former clinopyroxene); reaction rims or pseudomorphic replacements have not been observed.

The local development of chlorite-rims around interstitial spinel is attributed to a subsequent reequilibration during which amphibole remained stable. Finally all the major mineral phases are strongly deformed (undulose extinction) and anastomosing micro-shear zones developed. The latter are marked by the transformation of olivine to serpentine and magnetite, which has also been observed inside microcracks. The serpentinization postdates the chlorite growth.

3.2. MINERAL CHEMISTRY

Microprobe analyses were obtained from all major mineral phases using the ARL-SEMQ microprobe of C.N.R. at the Department of Earth Sciences of Milano University; they are given in Tab.

Tab. 1 Electron microprobe analyses of pyroxenes, olivine and amphiboles from harzburgite M157 of Mont Mary

	Opx		Olivine		Amphibole	
SiO_2	53.76	54.18	39.03	39.21	46.75	47.01
TiO_2	n.d.	n.d.	n.m.	n.m.	0.06	0.09
Al_2O_3	2.94	2.82	n.d.	n.d.	11.02	11.27
Cr_2O_3	0.08	0.08	n.m.	n.m.	0.23	0.22
FeO*	10.55	10.14	14.94	15.18	5.45	5.31
MnO	0.35	0.30	0.28	0.28	0.16	0.11
MgO	31.93	32.19	45.79	45.27	19.17	19.44
CaO	0.38	0.29	n.d.	0.02	12.68	13.20
Na_2O	n.d.	n.d.	n.m.	n.m.	1.31	1.47
K_2O	n.m.	n.m.	n.m.	n.m.	0.25	0.22
Total	99.99	100.00	100.04	99.96	97.08	98.34
Cations						
Si	1.898	1.906	0.982	0.987	6.652	6.610
Ti	0.000	0.117	0.000	0.000	0.006	0.009
Al	0.122	0.117	0.000	0.000	1.848	1.867
Cr	0.002	0.002	0.000	0.000	0.025	0.024
Fe	0.311	0.298	0.315	0.320	0.648	0.624
Mn	0.010	0.008	0.006	0.006	0.019	0.013
Mg	1.680	1.688	1.714	1.699	4.066	4.075
Ca	0.014	0.010	0.000	0.001	1.933	1.988
Na	0.000	0.000	0.000	0.000	0.361	0.400
K	0.000	0.000	0.000	0.000	0.045	0.039
Total	4.037	4.029	3.017	3.013	15.603	15.649
x_{Mg}^{**}	0.843	0.849	0.845	0.841	0.862	0.867

*Total Fe as FeO

**x_{Mg} = Mg/Mg+Fe, where Fe is total iron

Tab. 2 Electron microprobe analyses of spinels, chlorites and serpentines from harzburgite M157 of Mont Mary.

	Spinel		Chlorite		Serpentine	
SiO_2	n.d.	n.d.	31.97	32.57	40.46	44.32
Al_2O_3	57.95	57.96	17.46	15.79	2.34	0.33
Cr_2O_3	5.11	4..29	n.m.	n.m.	n.m.	n.m.
FeO*	19.38	19.54	3.15	3.82	1.45	3.86
MnO	0.24	0.22	n.d.	0.05	0.01	0.07
MgO	16.86	16.93	36.22	36.91	43.65	41.99
CaO	n.m.	n.m.	n.d.	n.d.	n.d.	n.d.
Total	99.54	99.94	88.81	89.14	87.91	90.40
Cations						
Si	0.000	0.000	5.911	6.027	1.872	1.999
Al	1.799	1.806	3.808	3.445	0.128	0.018
Cr	0.106	0.089	0.000	0.000	0.000	0.000
Fe^{3+}**	0.095	0.104	0.000	0.000	0.000	0.000
Fe^{2+}	0.333	0.330	0.487	0.591	0.056	0.146
Mn	0.005	0.005	0.000	0.008	0.000	0.000
Mg	0.662	0.667	9.980	10.180	3.009	2.829
Ca	0.000	0.000	0.000	0.000	0.000	0.000
Total	3.000	3.001	20.186	20.251	5.065	4.992
x_{Mg}^{***}	0.607	0.606	0.953	0.945	0.982	0.951

*Total Fe as FeO
**Fe^{3+} in the spinel formula was recalculated with the charge balance method
***x_{Mg} = Mg/Mg+Fe, where Fe is total iron

1 and 2. The applied correction program was MAGIC IV of COLBY (1972).

Olivine exhibits an uniform composition of Fo 0.84 (chrysolite).

Orthopyroxene is a Mg-rich bronzite (En 0.84÷0.85) with moderate XAl_2O_3 (2.9 wt%) and low Cr_2O_3 (0.08 wt%) and CaO (0.3 wt%) contents. TiO_2 and Na_2O contents have not been detected.

Green spinel is aluminous and contains less Cr_2O_3 (4.3÷5.1 wt%) than the ones reported by ERNST (1978) from the peridotites of the Western Alps (often around 9.1÷13.1. wt%).

Amphibole is a Mg-hornblende according to the scheme proposed by LEAKE (1978) and is characterized by very low TiO_2 contents. The XMg (XMg = Mg/Mg+Fe, where Fe is total iron) of the amphibole is 0.87; it is similar but slightly higher than the corresponding values for olivine and orthopyroxene (≈ 0.85). This relationship is in agreement with the

$$Kd^{\text{ol-amph}}_{\text{Fe-Mg}} - \text{values}$$

reported by ROBINSON et al. (1982). On a Na+K (A-site) versus Si diagram, the Mg-hornblendes of the Mt. Mary harzburgite plot at the upper end of ROBINSON et al.'s (1982, Fig. 46, p. 101) data points from olivine – orthopyroxene – Al-spinel ± chlorite bearing ultramafites, close to the array of chlorite-free assemblages.

Chlorite occurring as overgrowth rims on Al-spinel is Mg-rich (clinochlore).

3.3. BULK ROCK GEOCHEMISTRY

Major and trace element concentrations of sample M157 have been obtained by X-ray fluorescence analysis at the C.N.R. laboratory of Department of Mineralogy and Petrology of Padova University and are reported in Tab. 3. Rare Earth element (REE) concentrations, analysed by ICP spectrometry at the Laboratoire de Spectrochimie of Nancy, are listed in Tab. 3.

The major element composition of the spinel-amphibole-harzburgite from the Mt. Mary nappe reveals some remarkable differences with the other peridotites from the Western Alps: the Mt. Mary harzburgite shows anomalously high Al_2O_3, Fe_2O_3, CaO and Na_2O contents, and rather low MgO content with respect to the mean values of the peridotites from the Western Alps (ERNST, 1978). These data may be explained by the large abundance of green spinel and amphibole in the investigated samples.

The minor element concentrations, in particular Ni and Cr, are lower than those reported from the Western Alps' peridotites (OTTONELLO et al., 1984). They are, however, very similar to the values

Tab. 3 Bulk rock analysis of major elements*, transitional elements** and REE*** of harzburgite M157 of Mont Mary.

Oxide	wt.%	Element	ppm	Element	ppm
SiO_2	42.35	Y	5	La	0.50
TiO_2	0.29	Zr	13	Ce	3.30
Al_2O_3	6.91	Nb	–	Nd	1.68
Fe_2O_3	11.35	Zn	52	Sm	1.04
MnO	0.18	Cr	1540	Eu	0.26
MgO	29.57	Sr	8	Gd	0.99
CaO	4.00	Rb	–	Dy	1.32
Na_2O	0.27	Ni	1219	Er	0.79
K_2O	0.11	Ba	–	Yb	0.89
P_2O_5	0.02			Lu	0.12
L.O.I.	4.23				
Total	99.28				

Analytical methods:
*Atomic absorption, wet-method
**X-ray fluorescence spectrometry
***Inductively coupled plasma-atomic spectrometry

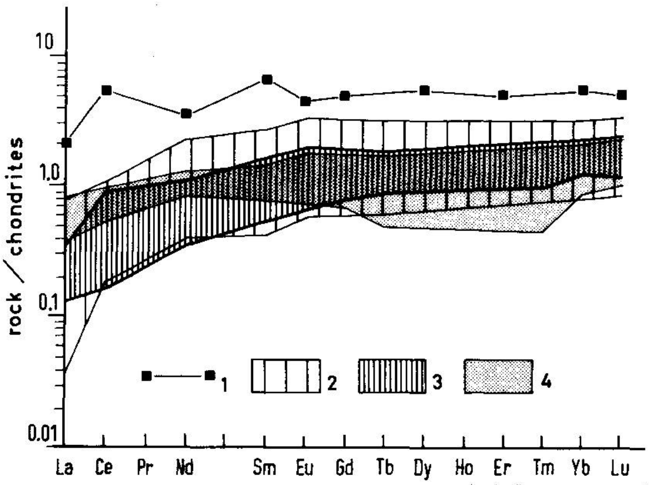

Fig. 2 Chondrite-normalized (normalizing values used were those of EVENSEN et al., 1978) REE composition of Mt. Mary peridotite (1), in comparison with the composition patterns of subcontinental peridotites from Baldissero (2), Finero (3) and Alpe Arami (4) (OTTONELLO et al., 1984 and references therein.).

obtained for the pyroxenite body of Mt. Emilius Klippe (BENCIOLINI, 1988).

The chondrite-normalized REE concentrations of the Mt. Mary harzburgite (Fig. 2) show a flat REE-distribution pattern with an average mean value of approximately 5 times chondritic. They differ considerably from the trends observed for similar lithologies from the Alpe Arami, Baldissero, Finero and Balmuccia peridotite bodies, which show lower concentrations and marked light REE depletion (OTTONELLO et al., 1984). The depletion of the light REE relative to the heavier REE has been interpreted as the result of a previous partial melting and melt extraction events.

4. Metamorphic evolution

Temperature estimates of (peak?) metamorphic conditions of the Mt. Mary harzburgite were obtained from different calibrations of the olivine-spinel Fe-Mg partition geothermometer. The calculations gave the following results: FABRIES (1979) 800°C, O'NEILL (1981) 700°C, SACK (1982) 900°C and ROEDER et al. (1979) 950°C. The widely scattered data from the same olivine-spinel pairs are mainly due to the large extrapolation from the experimental data obtained at very high temperatures and probably to some reequilibration effects. Indeed, the studies of LEHMANN (1983) and OZAWA (1984) have shown the importance of Fe-Mg diffusion between olivine and spinel and its influence on thermometric calibrations. The presented estimates, however, give a reasonable order of magnitude of the metamorphic temperature suffered by the harzburgite of Mt. Mary.

The mineralogy, textures and estimated temperature ranges are consistent with a complete reequilibration of the utramafic body under high-temperature amphibolite/granulite facies conditions. JENKINS (1983) proposed a simplified petrogenetic grid for hydrous ultramafites in the CNMASH system. Based on this grid, the observed amphibole-spinel and amphibole-spinel-chlorite assemblages are consistent with the inferred metamorphic conditions. Similar assemblages have also been reported by ROBINSON et al. (1982, Tab. 6, page 100).

The evolution of the Mt. Mary harzburgite may be traced, starting from a former spinel lherzolite stage (any traces of plagioclase or garnet are missing). A lherzolitic composition of the former protholith may be inferred from the high CaO content of the rock, which is now retained in the abundant amphibole.

The lack of tremolite-rich amphiboles and the Al-rich composition of the hornblende indicate that the peridotite underwent metamorphic reequilibration above 10 kbars in the chlorite - amphibole field, i.e., above the [Gt] invariant point of JENKINS (1981; 1983).

These relationships have been obtained from Fe-free CMASH and NCMASH assemblages. The mineral phases in the present study show considerable Fe contents (XMg(bulk rock) = 0.82), which affects the location of the univariant curves in the P-T space. CAIRONI & TROMMSDORFF (1988, Fig. 25, page 46) indicate qualitatively that the univariant curves for the tremolite and chlorite stability limits are displaced to lower temperatures.

The latest tectono-metamorphic event recorded by the ultramafite is the serpentinization of olivine along micro-shear zones under lower temperature and pressure conditions. This last event is most probably of Alpine age.

5. Conclusions

The presented structural, petrographic and geochemical data of the Mont Mary peridotite are consistent with a metamorphic reequilibration of a former spinel lherzolite under HT amphibolite/ granulite facies conditions, at pressures possibly exceeding 10 kbars. A lherzolitic protholith is inferred by the high CaO content of the rock, now retained in the amphiboles, but probably derived from former clinopyroxenes.

The association of the ultramafic slice with continental lithologies, as well as the geochemical features, suggests a non-ophiolitic origin of the rocks. Consequently, they may be interpreted as a fragment of the subcontinental mantle, which has been emplaced and reequilibrated at lower crustal levels (granulite-facies conditions) and subsequently underwent exhumation and deformation during the Alpine orogenesis.

Another possible interpretation of the ultramafic lens of Mont Mary is a cumulate origin of the rock body, resulting from fractional crystallization of calc-alkaline or tholeiitic magmas. Such an interpretation has been suggested by one of the reviewers, basing on the low MgO, high Al_2O_3 and FeO_{tot} concentrations of the bulk rock sample and the relatively low XMg of the mineral phases of the hornblende-harzburgite.

We object to this interpretation because of the absence of clearly related magmatic rocks of basic and intermediate composition. Such rocks do, in general, accompany cumulate-type ultrabasic rocks (e.g. Klamath Mountains, California, SNOKE et al., 1981).

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