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KAERSUTITE-BEARING MYLONITIC GABBRO FROM THE LANZO-PERIDOTITE (WESTERN ITALIAN ALPS)[1]

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ABSTRACT

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A mylonitic gabbro, intruding and partly re-equilibrating the Lanzo peridotite in Val di Viù, is described. It consists of Ol + Opx + Cpx + Ti-rich Ho porphyroclasts included in a fine-grained matrix, where primary plagioclase is replaced by the Jd + Zo ± Qz assemblage. Geothermobarometric calculations have given T ≃ 1000 °C and P ≃ 0.5 GPa (5 kbar) for the gabbro crystallization. Both gabbro and host spinel/plagioclase lherzolite are crosscut by mm-sized mylonitic veins of brown Ho + Ilm + Ap ± Plag. Geologic and petrologic considerations suggest that these veins crystallized from a highly differentiated tholeiitic magma, introduced – most likely immediately after gabbro crystallization – into both gabbro and peridotite. Mineralogic and petrologic evidences indicate that both gabbro and host lherzolite experienced a subsolidus polyphase HT deformation and recrystallization from hornblende granulite- to amphibolite-facies conditions. The metamorphic re-equilibrations, characterized by initial Hp mineral assemblages and late greenschist-facies parageneses, indicate an Alpine orogenic history consistent with that inferred elsewhere for the internal Western Alps.

INTRODUCTION

The Lanzo Massif fig. 1, one of the largest and better studied ultramafic bodies of the Western Alps (for a review see NICOLAS, 1966 and BOUDIER, 1976; 1978) consists of a peridotite core surrounded by a serpentinized peridotite rim, grading externally to massive or schistose antigorite serpentinites.

The ultramafics are represented by spinel lherzolite, partially re-equilibrated in the plagioclase facies, and by subordinate harzburgite and dunite, containing gabbro and, occasionally, diabase dikes; plagiogranite dikes have also been recently reported (LOMBARDO & POGNANTE, 1982).

The overall lithology of the Massif reveals metamorphic Alpine re-equilibrations (COMPAGNONI & SANDRONE, 1979). In particular, there are frequent parageneses, even in the peridotite core, that are related to the eclogite facies early-Alpine event, which produced antigorite, olivine, Ti-clinohumite, magnetite and Mg-chlorite in the ultramafics, and jadeite ± quartz and/or omphacite pyroxene, garnet, Mg-chlorite, rutile, chloritoid, talc and zoisite in the mafic rocks. The greenschist facies Lepontine event is much less developed, especially in the peridotite core.

Gabbroic rock outcrop amounts to less than 1% of the Massif surface. These rocks have been interpreted as the products of the partial fusion of the lherzolite and have been divided into three types: 1– *feldspathic lenticles and dikelets,* i.e. cm- to dm-sized plagioclase irregular veinlets or pockets oblique to the peridotite foliation plane; 2– *in situ dikes,* i.e. larger (dm- to m-sized) gabbro lenses with irregular boundaries, surrounded by dunite, outwards grading to harzburgite and lherzolite; these gabbros are considered as the product of local ('*in situ*') partial fusion of the host lherzolite; 3– *intrusive dikes,* showing sharp contacts against the host peridotite and definitively intruded into it (BOUDIER & NICOLAS, 1972).

This paper describes an uncommon mylonitic brown horn-

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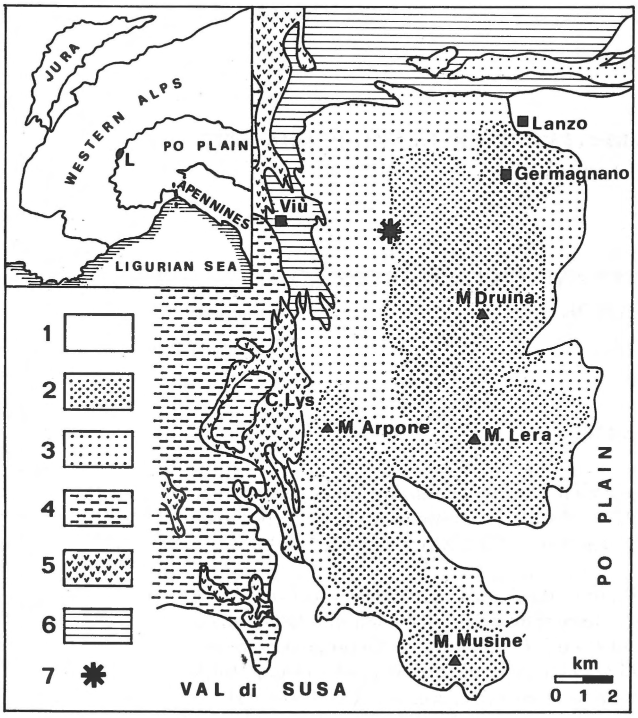

Fig. 1
Geolithological sketch-map of the Lanzo Massif (modified after Nicolas, 1974). 1: Po Plain and Val di Susa Quaternary cover; 2: peridotite of the Lanzo Massif; 3: serpentinite of the Lanzo Massif and other bodies of the Piemonte Zone; 4: metaophiolites of the Piemonte Zone; 5: metasediments ('calcescisti') of the Piemonte Zone; 6: gneisses and metabasics of the Sesia Zone; 7: location of the Ho-bearing mylonitic gabbro of Val di Viù. In the index map L indicates the location of the Lanzo Massif.

blende gabbro, the peculiar mineralogy and structure of which suggest a complex metamorphic-structural pre-Alpine evolution, previously unreported in the Lanzo Massif.

GEOLOGY

Outcrops of the mylonitic gabbro are found in Val di Viù, at km 42.5 of the provincial road, on the north-western boundary of the peridotite core, near the contact with the serpentinized peridotite (Fig. 1). The gabbro forms a network of anastomosing veins, from a few millimetres to several decimetres wide; its structure is always mylonitic. Macroscopic analysis reveals grey-brown pyroxene and black amphibole porphyroclasts in a matrix which ranges from whitish to dark grey, made up mainly of plagioclase or its alteration products. The widest veins also contain reddish-brown lenticular nodules, up to several decimetres long, consisting of host peridotite fragments.

The attitude of the mylonitic foliation, usually subvertical and approximately north-south trending, is locally complicated by folds, which can be attributed to at least three deformation phases. The original coarse-grained magmatic structure is usually completely destroyed by shearing, but the primary intrusive relations between the gabbro veins and the host lherzolite are still locally preserved.

PETROGRAPHY

The gabbro consists of clinopyroxene-, orthopyroxene-, olivine-, brown hornblende-, and rare plagioclase porphyroclasts included in a foliated matrix which is mainly composed of altered plagioclase. Fine-grained aggregates of the same minerals occur as porphyroclasts.

The porphyroclasts, which usually show wavy extinction, kink bands and local subgrain texture, are commonly surrounded by finer-grained aggregates, derived from porphyroclasts by mechanical grain-size reduction and/or recrystallization.

The very-pale pinkish coloured orthopyroxene is locally replaced by brown hornblende + opaque aggregates, or altered to talc.

The plagioclase, very rarely fresh, occurs either as large crystals with mortar texture or as recrystallized fine-grained aggregates.

Brown hornblende porphyroclasts show a patchy zoning with paler portions characterized by α = pale yellow, $\beta \simeq \gamma$ = yellowish-brown and by very fine unmixing lamellae on (110). The deeper coloured portions are characterized by α = violet reddish-brown, $\beta = \gamma$ = deep reddish-brown and unmixing lamellae on (010). Hornblende porphyroclasts locally contain euhedral crystals of apatite and altered plagioclase, or rare and corroded remnants of Ca-pyroxene. Homoaxial growth suggests that the amphibole mainly developed at the expense of the clinopyroxene.

Apatite occurs either as euhedral crystals up to 5 mm long or as aggregates of rounded grains ($\leqslant$ 50 µm in diameter), mainly derived from mechanical grain-size reduction and/or recrystallization of the euhedral crystals.

Opaque minerals (ilmenite), as monomineralic aggregates or in close association with brown hornblende and/or apatite, locally appear to protrude into the jadeite pseudomorphs after plagioclase.

As to the Alpine metamorphic re-equilibrations, especially plagioclase is pseudomorphically replaced by an aggregate, where two main phases can be recognized: a granular phase (from 200 to 10 µm in diameter) characterized by a very low birefringence, and a sheaf-like, almost isotropic, phase consisting of needles a few tens of µm long and less than a µm across. An X-ray check has shown the granular phase to be Na-clinopyroxene $\pm$ quartz and the needle-like phase to be zoisite.

Small ($\leqslant$ 10 µm) colourless garnets, which developed a euhedral shape only towards the 'plagioclase' side, sometimes form a rim, a few µm thick, at the contact between Na-clinopyroxene and opaque minerals. Very fine-grained garnet, together with Mg-chlorites, also developed along fractures crosscutting brown hornblende. Frequently the jadeite-hornblende contact is marked by a thin rim of pale

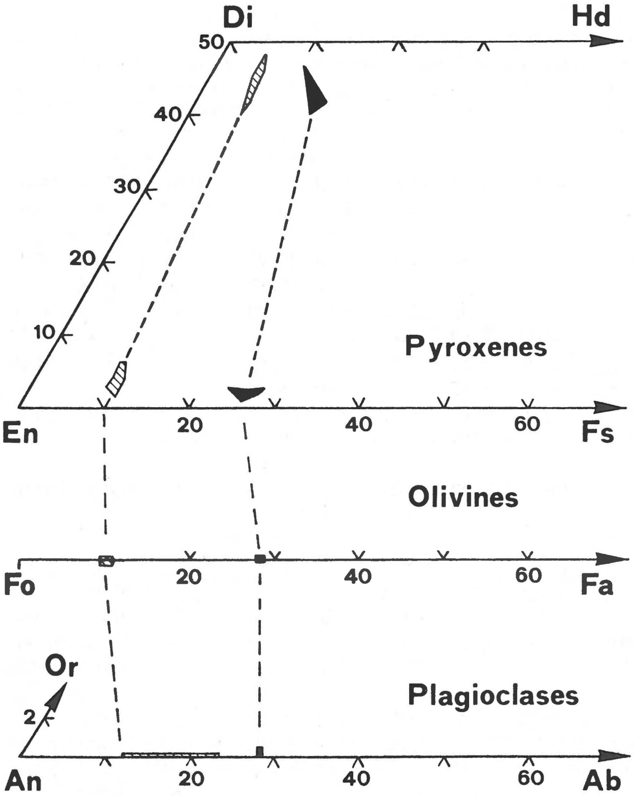

Fig. 2
Representative diagrams for primary minerals of Val di Viù mylonitic gabbro (filled areas) and Lanzo Massif peridotite (hatched areas; data from Boudier, 1976; Ernst, 1978; Sandrone et al., in press).

glaucophane, that homoaxially overgrew the hornblende, but mainly developed at the expense of jadeite.

The host lherzolite consists of olivine, orthopyroxene, clinopyroxene and brown spinel, which is almost completely replaced by plagioclase or its Alpine metamorphic products. The lherzolite exhibits a typical porphyroclastic texture MERCIER & NICOLAS, 1975) characterized by large kinked orthopyroxene and olivine porphyroclasts, surrounded by a finer-grained matrix of partly recrystallized olivine. Locally, near dike selvages, the recrystallized grains of mosaic olivine appear deformed and flattened parallel to the dike. At the contact with the gabbro dikes (to depths of 1-2 cm) or within the lherzolite xenoliths, the peridotite shows microscopic features. These suggest that the peridotite suffered a partial re-equilibration, such as recrystallization of clinopyroxene, often intergrown with pargasite, development of intergranular pargasite and transformation of brown- into opaque-spinel.

Locally the gabbro-peridotite contact is marked by a continuous Alpine metamorphic rim of interwoven needles of colourless chloritoid in the gabbro.

Gabbro and host lherzolite are commonly cut by mm-sized very fine-banded mylonitic veins, typically parallel to the foliation of the host mylonite, and mainly consisting of brown hornblende, ilmenite and apatite ± plagioclase.

MINERAL CHEMISTRY

The composition of the main mineral phases in the gabbro has been determined by electron microprobe analysis in the wavelength dispersive mode on an ARL-SEMQ instrument. Method and accuracy are discussed in SANDRONE ET AL. (in press) and the analytical results are reported in Table I and plotted in Figs. 2 and 3.

Porphyroclastic olivine is an iron-rich chrysolite with a Mg/(Mg + Fe) ratio averaging 0.72. The Ca and Mn contents are notably higher than that of the average Lanzo lherzolite (two and three times respectively), while the Ni content is one half or one third as much (BOUDIER, 1976; ERNST, 1978; SANDRONE ET AL., in press). The Al content ranges from 0.83 to 0.05 wt.% suggesting heterogeneous distribution, possibly related to the presence of submicroscopic inclusions. The olivine chemistry definitely indicates – in spite of its textural features suggest a peridotitic xenocryst nature – that it belongs to the original gabbro magmatic assemblage.

Orthopyroxene porphyroclasts are iron-rich bronzites with an average Mg/(Mg + Fe) ratio near 0.73. The Al content is one third to one fourth that of the Lanzo peridotite orthopyroxene, while the Mn content is three to four times higher (BOUDIER, 1976).

Clinopyroxenes, which have a Mg/(Mg + Fe) ratio near 0.73, plot at the augite-salite boundary. Calculation of structural formula reveals the presence of Fe^{3+} (PAPIKE ET AL., 1974). As with the orthopyroxene, the Al content of gabbro clinopyroxene is one third to one fourth that of the Lanzo peridotite clinopyroxene, whereas the Mn content is about three times higher (BOUDIER, 1976). Porphyroclast rims (see second clinopyroxene analysis of table I) have a higher Ca content and Mg/(Mg + Fe) ratio, suggesting a partial re-equilibration during the metamorphic evolution, which followed gabbro crystallization.

The plagioclase, analyzed in a single sample, is a sodic bytownite with An_{71} (Table I).

The brown hornblende porphyroclasts exhibit a Mg/(Mg + Fe) ratio ranging from 0.61 to 0.71, lower than that of the associated mafic silicates. The Ti content, ranging from 0.385 to 0.521 per formula unit, is significantly high. According to the LEAKE (1978) and HAWTHORNE (1981) classifications, the analyzed amphiboles plot at the boundary between edenitic hornblendes and ferroan pargasitic hornblendes, or within the field of kaersutites. To stress the high Ti-content of most of the gabbro amphiboles and the fact that the oldest amphibole phase recognized petrographically is a red-brown pleochroic kaersutite, the primary brown hornblende of the gabbro will in what follows be called kaersutite.

The opaque mineral is ilmenite, with stoichiometric Ti and low Mg- and Mn-contents.

Among the Alpine metamorphic minerals, only the ubiquit-

Table I
Representative microprobe analyses and anatomic proportions for olivine-, orthopyroxene-, clinopyroxene-, plagioclase- and brown hornblende porphyroclasts, ilmenite and early-Alpine metamorphic Na-clinopyroxene after plagioclase from Val di Viù mylonitic gabbro.

	olivine	orthopyroxene			clinopyroxene			plagio-clase	brown hornblende					ilmenite	Na-cpx	
SiO_2	37.69	54.46	54.84	53.98	52.08	52.71	52.36	61.17	44.67	44.87	44.24	44.28	43.11	0.05	57.26	59.07
TiO_2	—	0.22	0.12	0.26	0.87	0.53	0.63	0.06	3.48	3.80	4.41	4.13	4.68	52.69	—	0.03
Al_2O_3	0.52	1.33	0.36	0.77	2.42	1.90	1.84	23.75	10.45	9.07	9.97	10.15	10.02	0.12	24.55	23.97
FeO_t	24.83	15.78	17.54	17.45	9.32	6.56	9.25	0.12	11.61	11.31	14.02	11.36	9.97	45.94	2.06	1.74
MnO	0.47	0.42	0.42	0.64	0.42	0.19	0.39	—	0.19	0.16	0.18	0.22	0.21	0.25	0.08	—
MgO	36.31	26.66	26.32	25.32	14.40	14.81	15.57	0.11	13.03	13.95	12.17	13.54	14.00	0.45	0.61	0.24
CaO	0.10	1.03	0.73	1.11	19.44	22.02	18.89	6.01	10.32	9.83	9.74	10.78	10.59	0.04	2.37	0.33
Na_2O	—	—	—	0.05	0.97	0.74	0.83	8.22	2.96	3.15	3.24	3.27	3.49	0.03	13.44	14.70
K_2O	—	—	—	—	—	—	—	0.09	0.13	0.13	0.10	0.10	0.11	—	—	—
NiO	0.14	—	—	—	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr_2O_3	—	—	—	0.08	—	—	0.06	—	—	0.07	—	—	0.17	—	—	—
Total	100.06	99.90	100.32	99.66	99.92	99.46	99.81	99.53	96.84	96.34	98.06	97.84	96.35	99.57	100.37	100.08
Si	0.993	1.969	1.988	1.976	1.931	1.950	1.936	10.926	6.571	6.631	6.506	6.471	6.382	0.002	1.950	2.002
Al^{IV}	0.016	0.031	0.012	0.024	0.069	0.050	0.064	5.001	1.429	1.369	1.494	1.529	1.618	0.007	0.050	—
Al^{VI}		0.026	0.003	0.009	0.037	0.033	0.016		0.383	0.211	0.234	0.220	0.131		0.935	0.958
Ti	—	0.006	0.003	0.007	0.024	0.015	0.017	0.008	0.385	0.422	0.488	0.454	0.521	2.000	—	0.001
Fe^{2+}	0.547	0.477	0.532	0.534	0.235	0.164	0.216	0.018	1.428	1.398	1.724	1.388	1.234	1.939	0.059	0.049
Fe^{3+}	—	—	—	—	0.054	0.039	0.070	—	—	—	—	—	—	—	—	—
Mn	0.011	0.013	0.013	0.020	0.013	0.006	0.012	—	0.024	0.020	0.022	0.027	0.026	0.010	0.002	—
Mg	1.426	1.436	1.422	1.381	0.795	0.817	0.858	0.029	2.857	3.072	2.667	2.949	3.089	0.033	0.031	0.012
Ca	0.003	0.040	0.028	0.043	0.772	0.873	0.749	1.150	1.627	1.557	1.535	1.688	1.680	0.002	0.086	0.012
Na	—	—	—	0.003	0.070	0.053	0.060	2.847	0.844	0.903	0.924	0.927	1.002	0.003	0.887	0.966
K	—	—	—	—	—	—	—	0.021	0.024	0.024	0.019	0.019	0.021	—	—	—
Ni	0.003	—	—	—	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	—	—	—	0.002	—	—	0.002	—	—	0.008	—	—	0.020	—	—	—
O	4	6	6	6	6	6	6	32	23	23	23	23	23	6	6	6

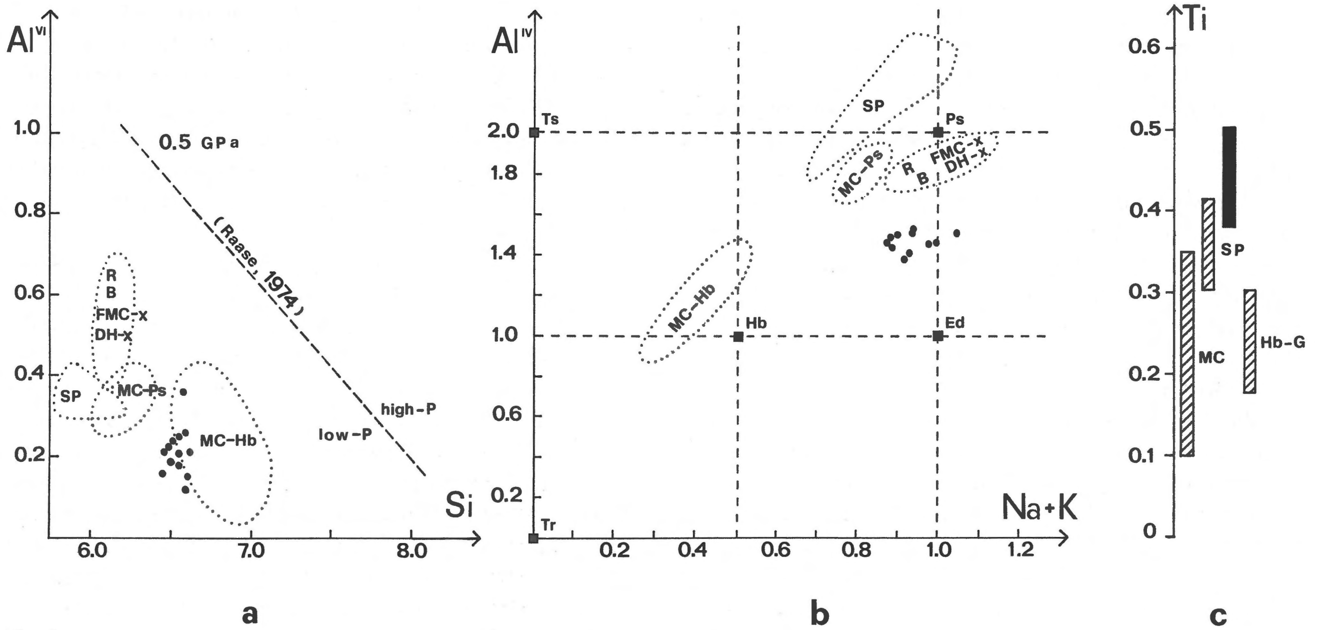

Fig. 3
Al^{VI} vs. Si (a), Al^{IV} vs. alkalis (b) diagrams and scale of Ti contents for brown hornblendes of Val di Viù mylonitic gabbro (full dots). For comparison, compositional fields are reported for brown amphiboles of St. Paul rocks (SP: data from Melson et al., 1972), Ronda (R: Obata, 1980) and Balmuccia (B: Ernst, 1978) peridotites, Massif Central (FMC-x: Brown et al., 1980) and Dish Hill (DH-x: Wilshire et al., 1980) xenoliths, Monginevro-Chenaillet (MC; MC-Ps = pargasites; Mc-Hb = hornblendes: Mevel et al., 1978) gabbros and amphibolites, hornblende-granulite facies (Hb-G: Raase, 1974) rocks.

Table II
K and Ar analytical data for brown hornblende separates $\lambda = 5.543 \times 10^{-10} y^{-1}$, $\lambda_e/\lambda = 0.10481$, $^{40}K/K = 0.01167$ %). Analyses performed at Centre de Sédimentologie et Géochimie de la Surface du CNRS, Université de Strasbourg, France.

Sample	% K_2O	%	$^{40}Ar^*$ cc/g STP 10^{-6}	t (Ma)	$^{40}Ar/^{36}Ar$	$^{40}K/^{36}Ar$ 10^{-6}
OF 1245	0.20	69.52	3.19	347 ±18	969.5	23.40
OF 1246	0.16	53.95	13.94	1651 ±97	641.7	2.20
OF 1247	0.14	54.91	5.74	962 ±56	655.4	4.87
OF 1248	0.11	62.25	5.90	1178 ±91	782.8	5.03
OF 1249	0.05^{+}	69.41	2.47	1110 ±105	966.0	7.51

* Poor separation

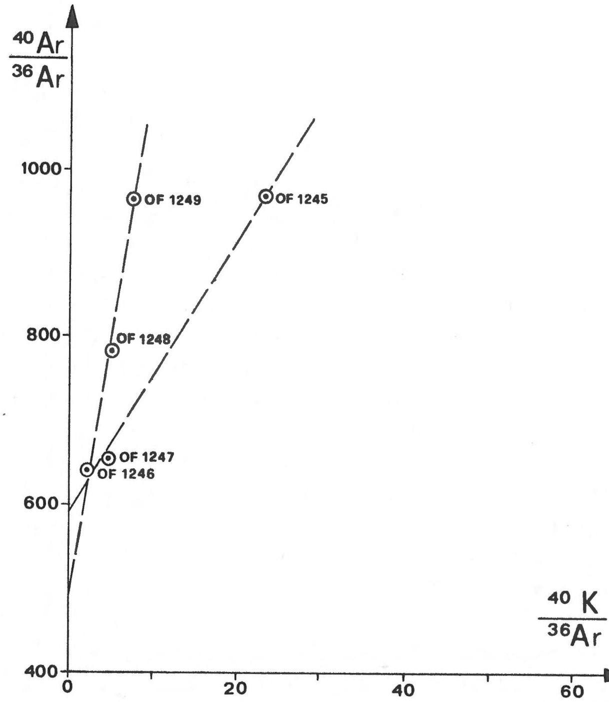

Fig. 4
$^{40}Ar/^{36}$ Ar vs. $^{40}K/^{36}Ar$ correlation plot.

ous Na-clinopyroxene was analyzed. The jadeite content varies from 89 to 96 mole percent (CAWTHORN & COLLERSON, 1974) and is apparently controlled by the composition of the mafic minerals that were originally in contact with the plagioclase grains.

In conclusion, the primary gabbro minerals seem to be in equilibrium, as suggested by the close values of their Mg/(Mg + Fe) ratio. The variation range of the brown hornblende Mg/(Mg + Fe) ratios, from values close to that of the primary igneous minerals (see e.g. kaersutite of the last brown hornblende analysis of Table I) towards iron-enriched values, indicates a crystallization and/or recrystallization history of the amphiboles much more complicated than that of the other gabbro minerals.

PRELIMINARY K-Ar MEASUREMENT

We attempted to date brown hornblendes from the mylonitic bands by conventional K-Ar analysis. Five hornblende separates were prepared, but very high purity could not be achieved owing to the ubiquitous presence of very small grains of the other gabbro mafic minerals. The results of the five analyses are reported in Table II and plotted in a $^{40}Ar/^{36}Ar$ vs. $^{40}K/^{36}Ar$ diagram (Fig. 4).

The apparent ages calculated by subtraction of atmospheric trapped argon show a wide range of values from 440 Ma to 1650 Ma. These cannot be taken to have any chronological significance and are in all likelihood due to inherited ^{40}Ar. The Ar isotopic plot in Fig. 4 does not allow one to calculate a single isochron age, as the points show considerable scatter. The two lines drawn through the experimental points, which would correspond to vastly different 'isochron ages' if taken at face value, are shown only to indicate that initial ratios $^{40}Ar/^{36}Ar$ are always well above the atmospheric value and are also variable (498 to 593).

DISCUSSION

The foregoing data indicate that the Val di Viù mylonitic metagabbro was derived from the original olivine-two pyroxene-gabbro, which experienced a complex pre-Alpine polyphase structural and metamorphic evolution.

The main differences between the Lanzo mylonitic gabbro and most ophiolitic gabbros of the Western Alps lie in the preservation in the former of primary relations with the host rock and in the widespread occurrence of kaersutitic amphiboles. These kaersutites either developed by late crystallization during the magmatic stage or they crystallized under influence of a fluid phase introduced into both gabbro and peridotite along fractures. To the fluid phase can also probably be attributed the partial re-equilibration of peridotite minerals and the development of pargasite along the lherzolite selvages.

Many occurrences of amphiboles have been reported in ultramafics. The range of the amphibole composition (pargasite to kaersutite), the structural relations between amphibole (interstitial, granular or poikilitic) and associated peridotite, and the textures appear to be identical in Alpine (ophiolitic) peridotite, ocean dredged ultramafics and xenolith occurrences (see e.g. WILSHIRE ET AL., 1980).

Occurrences of hornblende-bearing mylonitic gabbros are reported from different oceanic environments, including the Mid-Atlantic Ridge near 24°-30° N (MIYASHIRO ET AL., 1971) and 6° N (BONATTI ET AL., 1975), DSDP Site 334 (HELMSTAED & ALLEN, 1977), the Azores/Gibraltar Fracture Zone (PRICHARD & CANN, 1982), the St. Paul Ridge segment and Fracture Zone (MELSON ET AL., 1972), the Mid-Indian Ridge (CHERNYSHEVA, 1970) and the Mid-Cayman Rise (MALCOM, 1981). Such occurrences of deformed and metamorphosed gabbros show a similar pattern of HT deformation and recrystallization, accompanied by widespread development of brown amphiboles. With the exception of St. Paul rocks (which may be representative of a mantle, which yielded alkali olivine basalts by partial fusion: see MELSON ET AL., 1972), the brown amphiboles of the oceanic gabbros are Ti-rich hornblendes, characterized by high Na_2O- and low K_2O-contents (see PRICHARD & CANN, 1982).

As far as the ophiolites are concerned, only those of the Liguria-Piemonte basin are considered here. In the Chenaillet ophiolite (Western Alps) MEVEL ET AL., (1978) described an isotropic gabbro containing bands of amphibolitized flaser-gabbro and amphibolite, characterized by the presence of Ti-rich brown hornblende and pargasite, and by a polyphase HT deformation and recrystallization. Amphibolitization of the gabbro is explained by an episode of sub-horizontal plastic flow, which took place in the oceanic gabbroic layer near the axis of a slowly spreading ocean ridge.

A similar process of polyphase deformation and recrystallization was described in detail by CORTESOGNO ET AL., (1975) in amphibolitized gabbros from several localities of Eastern Liguria and the Northern Apennines. They proved that the intrusive portion of the ophiolitic sequence was affected by Ht deformation and metamorphism prior to the emplacement of basaltic dikes; a later polyphase metamorphic evolution, suggestive of a continuous cooling process from initial greenschist facies to very low grade PT conditions, partially re-equilibrated the magmatic assemblages of basaltic dikes and the HT parageneses of the intrusive amphibolitized rocks.

The HT gneissic structure of amphibolitized gabbros was attributed by DECANDIA & ELTER (1972) to mechanical deformation during sliding of the continental crust over the upper mantle. However, GALLI ET AL., (1972) and GIANELLI & PRINCIPI (1977) suggested that the HT assemblages formed in an oceanic ridge environment.

Discussing the pre-orogenic metamorphism observed in the ophiolites of the Liguria-Piemonte basin, DAL PIAZ (1974) suggested that the reddish-brown hornblende developed through autometamorphosis within gabbros, which intruded into continental crust during tectonism which preceded the opening of the oceanic basin. CORTESOGNO ET AL., (1975) rejected this hypothesis on the ground of paragenetic and structural evidence and considered that the HT deformation and metamorphism of sheared metagabbros from Liguria and Tuscany took place near an active ridge axis of a mature ocean basin. These authors, however, did not exclude the possibility that such a HT process may have developed during thinning of continental crust at early stages of continental rifting.

The strong heterogeneities produced by sub-solidus reworking prevent the determination of the original composition of the mylonitic gabbros from Lanzo, but the chemistry of pyroxenes indicates that they crystallized from basaltic magma under P and T conditions around 0.5 GPa (5 kbar) and 1000 °C respectively, according to the HERZBERG (1978) grid.

The magma emplacement occurred during, or immediately after, a HT deformation of the peridotite, such as observed for example in the Monte Maggiore Massif (Alpine Corsica) by JACKSON & OHNENSTETTER (1981).

As seldom observed in most ophiolitic and present-day oceanic gabbros, the Lanzo mylonitic gabbro apparently crystallized from a magma that contained a hydrous fluid phase, which produced kaersutitic amphibole in the gabbro, and pargasite in the peridotite, together with a partial peridotite re-equilibration at the gabbro dike selvages. Similar amphibole composition changes from kaersutite in the veins to pargasite in the peridotite, and systematic compositional variations of the anhydrous lherzolitic minerals at the selvages of the veins have also been observed in peridotite xenoliths from alkaline basaltic rocks (BEST, 1974; FRANCIS, 1976; STEWART & BOETTCHER, 1977; BOETTCHER ET AL., 1979; WILLSHIRE ET AL., 1980).

The HT deformation, which preceded and/or accompanied the magma emplacement, continued as well after the gabbro crystallization, as shown by subsolidus HT deformation and recrystallization of magmatic minerals. Almost at the same time the amphibole-rich veins formed within both gabbro and peridotite. Because of the significant difference in chemical composition between vein- and gabbro- (or peridotite) -minerals the amphibolitization cannot be considered a simple metamorphic process. It is evident therefore that some matter was introduced into the system in a fluid phase. Mineral chemistry and petrology of the hornblende + ilmenite + apatite ± plagioclase veins support the supposition that the fluid phase was relatively enriched in H_2O, Fe, Ti, Na, P, ^{40}Ar and possibly other components as well. Different hypotheses, involving either a metasomatic or a magmatic process, may be suggested regarding the origin of the fluid phase.

According to the metasomatic model the fluid phase is introduced into the gabbro and peridotite along re-activated, or newly-formed, shear planes. Such a process has been suggested by several authors (see e.g. WILSHIRE ET AL., 1980) to account for the development of the hornblende-rich veins that are locally found in lherzolite xenoliths from basalts. It has been proposed that metasomatism of this type within the upper mantle is a precursor to the generation of alkaline basalt (BOETTCHER & O'NEIL, 1980; MENZIES & MURTY, 1980).

The alternative hypothesis considers the fluid phase the result of a differentiation process involving a more complex silicate melt that intruded into the peridotite. In this interpretation the hornblende + ilmenite + apatite ± plagioclase assemblage of the Val di Viù veins crystallized from a melt. Such a melt could have formed from an original tholeiitic magma by advanced differentiation in a high diffusion and slow cooling environment under low oxygen fugacities. This would be similar to the process which produced Fe-gabbroid and Fe-dioretic melts in the Northern Apennines and Western Alps (BOY ET AL., 1976; BECCALUVA & PICCARDO, 1978) immediately before or during the initial phases of the opening of the Liguria-Piemonte basin. It is possible that some interaction between the fractionated tholeiitic melt and the sheared country rock occurred during vein crystallization. This is suggested by the K/Ar measurements, which indicate the presence of a fluid, rich in inherited Ar, that circulated in the rock at the time of the hornblende crystallization and/or recrystallization.

CONCLUSIONS

From field, microscopic and chemical data the following pre-Alpine history can be inferred for the Lanzo peridotite and the included kaersutite-bearing gabbro:

A very early uplift took place, accompanied by a partial re-equilibration of an original spinel lherzolite in the plagioclase field at PT conditions around 0.6-0.7 GP a (6-7 kbar) and 1000 °C (SANDRONE ET AL., in press). Such adiabatic or quasi-adiabatic uplift of the Lanzo peridotite was accompanied by fracturing and intrusion of a gabbroic magma generated at greater depth. Geothermobarometry (HERZBERG, 1978) tentatively performed on the magmatic minerals (porphyroclasts) indicate temperatures around 1000 °C at a pressure around 0.5 GPa (5 kbar) for the gabbro crystallization (or earliest re-equilibration). The lherzolite partial re-equilibration at the gabbro selvages and the interstitial pargasite development indicate that the gabbro magma was rich in a hydrous fluid phase, from which kaersutite very likely crystallized. During the early phase of high temperature gabbro deformation and recrystallization, a melt rich in H_2O, Fe, Ti, P, Na and inherited Ar, from which a kaersutitic amphibole + ilmenite + apatite ± plagioclase assemblage crystallized, was introduced into both the gabbro and the peridotite assemblage along reactivated shear planes.

Further deformation with reactivation of shear planes both within the gabbro dikes and the host lherzolite took place and was accompanied by mineral recrystallization or new mineral growth still at high temperature, certainly higher than 550 °C (see LIOU ET AL., 1974). This corresponds to the high rank amphibolite facies or possibly hornblende-granulite facies, suggested by the orthopyroxene recrystallization and the development of very high-Ti hornblendes (cf. RAASE, 1974). Because of lack of almandine-pyrope garnet in the rock of gabbroic composition (WINKLER, 1979) and the Al^{VI}/Si ratio in amphiboles (RAASE, 1974), such recrystallization should have occurred at a pressure not exceeding approximately 0.5 GPa (5 kbar).

This high temperature evolution preceded the intrusion of the basaltic dikes by a long time, as indicated by the very fine grain-size and chilled borders of the dikes, which demonstrate shallow level intrusion into an already cooled country rock.

The subsequent history (COMPAGNONI & SANDRONE, 1979; SANDRONE & COMPAGNONI, 1983) is consistent with the Alpine evolution of the Pennidic realm (FREY ET AL., 1974; BOCQUET ET AL., 1978), which is characterized by an early HP metamorphism suggestive of subduction followed by progressive uplift, accompanied by a prograde greenschist facies metamorphism resulting from gradual rise of geotherms and progressive isostatic uplift.

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