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THE ORIGIN OF THE IVREA-VERBANO BASIC FORMATION (ITALIAN WESTERN ALPS) — MICROSTRUCTURAL DATA ON PERIDOTITES FROM THE AREA OF SESIA VALLEY **

RIASSUNTO. — Ricerche precedenti hanno mostrato che le ultrafemiti della formazione basica Ivrea-Verbano, in Valsesia, possono essere distinte in due gruppi: *a*) una peridotite residuale, derivata dalla fusione parziale di materiale del mantello (peridotite di Balmuccia); *b*) una serie di peridotiti derivate da differenziazione gravitativa (peridotiti della serie stratiforme).

Le microstrutture osservate nei due gruppi di peridotiti riflettono la loro differente origine:

- la peridotite di Balmuccia mostra tre tipi principali di tessiture: 1) la tessitura protogranulare; 2) la tessitura porfiroclastica; 3) una serie di tessiture foliate con varia intensità. A questi tipi tessiturali si associa generalmente una fabric α dell'olivina. Complessivamente si può affermare che le microstrutture della peridotite di Balmuccia sono l'effetto dei processi deformazionali avvenuti a varia profondità, per cui questo corpo ultrafemico si può considerare come materiale del mantello con evoluzione di tipo alpino;
- le peridotiti della serie stratiforme, nonostante la deformazione sovraimposta, mostrano alcuni caratteri che possono essere considerati come effetti di un processo di accumulo. Essi sono in particolare: 1) la configurazione dello spinello, che spesso si comporta come fase di intercumulus; 2) la mancanza in molti casi di una fabric dell'olivina; 3) quando una fabric α dell'olivina esiste è in generale una fabric composta, legata in parte a processi deformazionali e in parte alla originale superficie di layering. In quest'ultimo caso la fabric dell'olivina è probabilmente il risultato di una apposizione di cristalli di olivina durante il processo di accumulo, controllata dalla forma dei cristalli stessi.

ABSTRACT. — Previous researches have shown that the ultramafites of the Ivrea-Verbano basic formation, in Sesia Valley, can be distinguished into: *a*) residual peridotite from mantle partial melting (Balmuccia peridotite); *b*) peridotites formed by gravitative differentiation (layered series peridotites).

The results of microstructural investigations reflect the different origin of the two peridotite types:

- the Balmuccia peridotite displays mainly three textural types: 1) the protogranular texture; 2) the porphyroclastic texture; 3) the textures foliated with various intensities. A general α-olivine fabric is associated to these textural configurations. The structures of the Balmuccia peridotite appear to be controlled mainly by deformational processes, so that this ultramafic body can be regarded as upper mantle matherial with alpine-type evolution;
- the layered series peridotites, in spite of superimposed deformation, still display features that can be regarded as caused by cumulus processes: They are: 1) the particular configuration of the spinel which locally occurs as intercumulus phase preserved by deformation; 2) the fairly dispersed fabric of olivine, which occurs in many samples; 3) when a fabric is present, it is a composed fabric, with α-maxima related to the foliation (which is a deformation feature) and to the original layering surface. This last fabric is probably the result of shape-controlled apposition of olivine crystals during gravitative accumulation.

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Introduction

According to RIVALENTI et al. (1975) two main units can be distinguished in the Ivrea-Verbano basic formation, along the Sesia Valley: 1) the Balmuccia peridotite, interpreted as residue from partial melting of mantle matherial; 2) the layered series, composed of a sequence of ultramafic-mafic interlayered rocks, formed by gravitative differentiation.

A support to the different origins of the two peridotite-types is given by factorial analysis, which has shown that the peridotites belonging to the two units differ for a number of geochemical characters (CAPEDRI et al., this volume). The most remarkable discriminating factor is the higher Fe/Mg ratio in the cumulitic peridotites.

Purpose of this paper is: 1) to give a first description of the textures of the peridotites and of their olivine fabric; 2) to investigate if these features reflect the different origin of the two peridotite types.

Textures and olivine fabrics of the Balmuccia peridotite

The mineralogical and chemical composition of the Balmuccia rocks, and their petrology have been completely examined by LENSCH (1971) and by RIVALENTI et al. (1975).

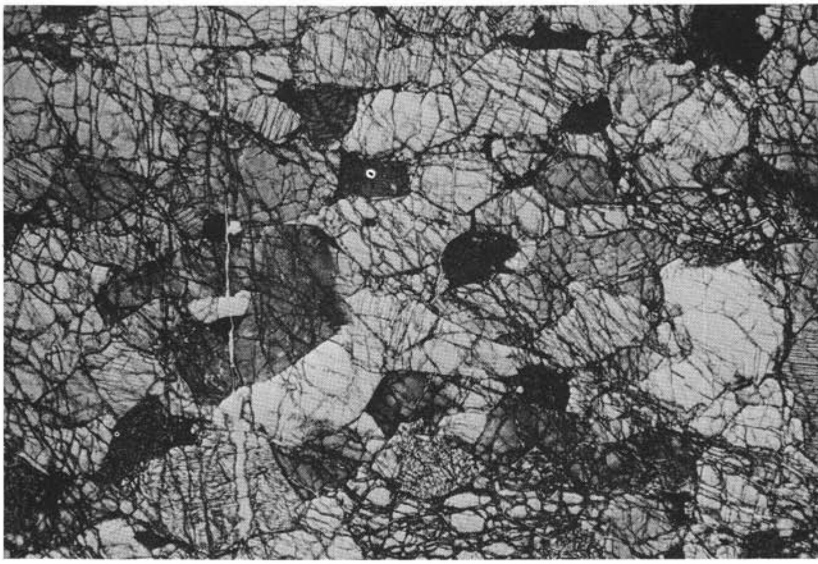
The Balmuccia peridotite mainly consists of spinel-lherzolites, and locally of harzburgites and dunites. It generally displays a foliation related to isoclinal folding, and marked by subconcordant and discordant pyroxenitic dikes. Towards the eastern boundary of the Balmuccia body the foliation appears to be stronger, expecially at the contact with the rocks of the layered series. When exposed, the contact is knife-sharp, and apparently it is not marked by faults, mylonites and serpentinization (RIVALENTI et al., 1975).

Three main textural types have been identified in the Balmuccia peridotite, and they are considered in order of abundance as follows:

Foliated and strongly foliated textures (Fig. 1 A, B)

They are by far the most widespread textural types in the Balmuccia body. The grains are medium sized. Foliation may have different intensities and it is mainly the result of the flattening of the olivine crystals. Flattened olivine may have discoidal or lozenge shape. Olivine grains show wavy extinction and a marked kinkbanding. This last feature is mostly developed according to glidesystem: $T = (0kl)$, $t = [100]$.

Orthopyroxenes do not have particular features, they only seem to be less elongated than olivines. Clinopyroxenes and spinels generally occur as small crystals in between adiacent grains of olivine and orthopyroxene. However they may be present as rounded or euhedral inclusions in olivines. A particular feature observed



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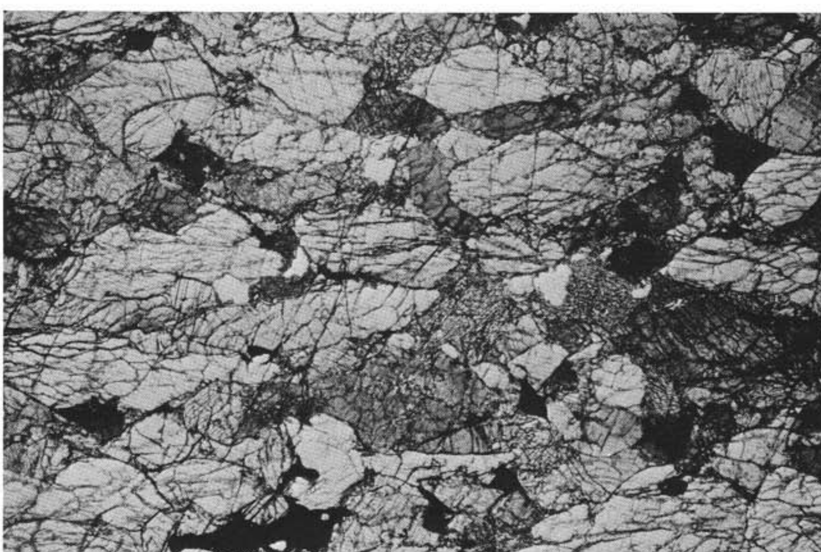

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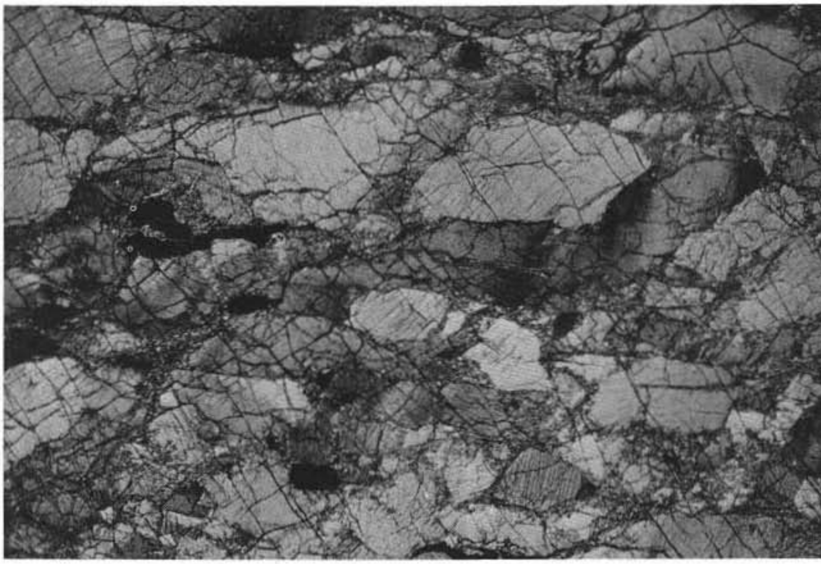
Fig. 1. — Plane of foliation is normal to, and parallel to the longer side of the micrograph. - **A**) Foliated texture (sample Ma 386): this texture is the most widespread in the Balmuccia body. **B**) Strongly foliated texture (sample Mo 281 a): this texture is largely widespread at the contact between the Balmuccia peridotite and the rocks of the layered series.



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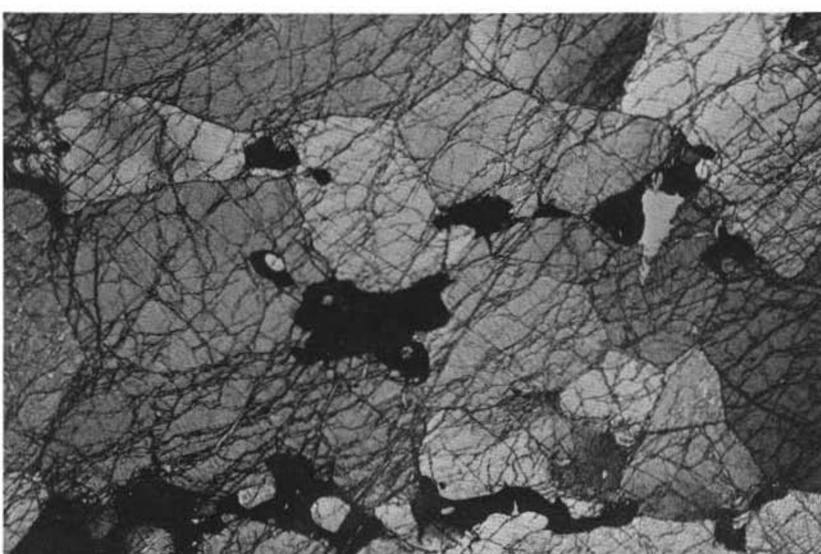

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Fig. 2. — **A**) Porphyroclastic texture (sample Mo 6): plane of foliation is normal to, and parallel to the longer side of the micrograph. Note the presence of microgranular matrix at the borders of deformed porphyroclasts. **B**) Protogranular texture (sample Mo 9): in this texture deformation features are moderate. Note the presence of triple points among grains.

in some foliated textures is the presence of very small grains of olivine on the borders of the flattened olivines. Olivine crystals exhibit a marked preferred orientation: the α-ol forms maxima and partial girdles normal to the foliation, while β-ol and γ-ol describe girdles which lie in the foliation plane. β-ol and γ-ol maxima might develop in the girdles (Fig. 4 A, B).

The strongly foliated lithotypes, occurring at the contact with the stratiform series, have some slight differences in the orientation pattern: γ-ol appears to be strongly lineated in the foliation plane. α-ol maxima normal to the foliation plane are less evident than in the other cases (Fig. 5 A).

Porphyroclastic texture (Fig. 2 A).

This texture has been observed only in a few samples. It is characterized by the presence of a microgranular matrix, often optically unresolvable, which includes large crystals of olivine, orthopyroxene and clinopyroxene (porphyroclasts).

The ratio by volume between the microgranular matrix and the porphyroclasts is always low (around 1 to 4, or more).

Locally, in the matrix, small polygonal crystals of olivine occur without any deformation. On the contrary the olivine porphyroclasts are either very flattened, with a length/width ratio up to 5 (or more), or lozenge-shaped. They are always strongly kinked according to the glidesystems observed in the foliated textures, T = (0kl) being the dominant glideplane. The pyroxene porphyroclasts generally have features similar to the olivine porphyroclasts, although usually they are less flattened or elongated. Spinel may behave as in the foliated textures described above, although it occurs often as large fragments or shreds in the microgranular matrix.

In the porphyroclastic textures the foliation is defined by the plane of flattening of the olivines and by the elongation of the lozenge-shaped crystals. Moreover, two shear-planes S1 and S2 may be recognized: they form an angle of intersection of about 60°, which is bisected by the foliation (Fig. 5 B).

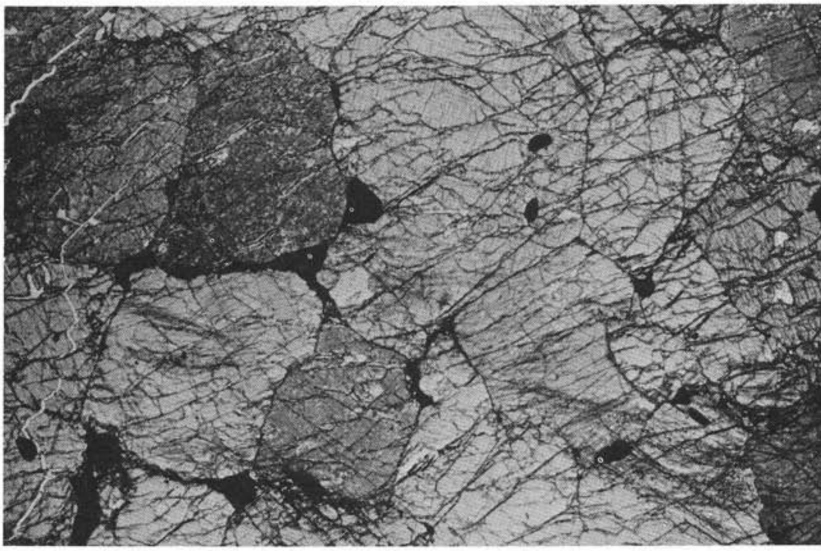
The microgranular matrix appears to develop parallely to these shear-planes.

The orientation pattern of the large olivine porphyroclasts is rather complicated: β-ol is the best oriented axis. It defines a partial girdle with a marked maximum at the intersection of the two shear-planes and the foliation. α-ol forms a large girdle has some pronounced maxima nearly normal to the shear-planes and the foliation. γ-ol forms partial girdles at right angle to the intersection S1-S2-F. Some marked points of maximum in the girdles suggest that γ-ol is lineated in the shear-planes and in the foliation (Fig. 5 B).

No significant orientation pattern has been obtained on the microgranular matrix, because of the small number of grains suitable for optical orientation under the Universal Stage.

Protogranular texture (Fig. 2 B)

It is rare. Generally an homogeneous coarse size of grains defines the texture. The reciprocal relationships of the mineralogical phases are similar to those observed



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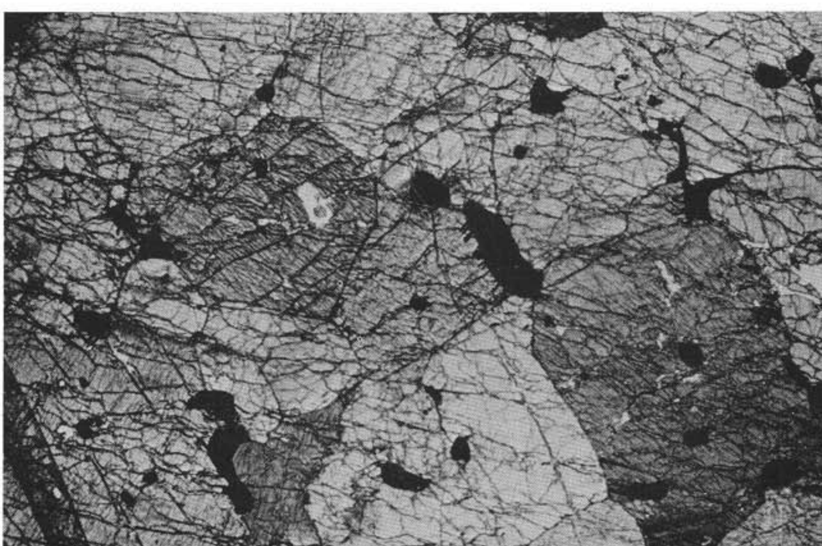

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Fig. 3. — **A**) and **B**) Textures of the non-foliated peridotites from the layered series (samples Mo 359 and Mo 362). Note the behaviour of the spinel occurring as coat around the olivine crystals (**A**).

in the foliated lithotypes: in particular olivines contain occasional inclusions of spinel. Spinel, however, is usually an interstitial phase, associated with orthopyroxene.

The olivine crystals are characterized by curvilinear boundaries and locally by triple points among grains.

A moderate deformation affects the olivines, which show wavy extinction and kinkbanding generally according to the glide-systems: T = (010), (001), (0kl) and t = [100].

The olivine crystals may display a weak elongation, defining a faint foliation. Sometimes small olivine-grains and spinels occur in bands parallel to the faint foliation, which hence stands out clearly.

The protogranular textured peridotites have a simple orientation pattern: the indicatrix-axes of the olivines give maxima or partial girdles roughly at right angles (Fig. 6 B). In particular, when the weak foliation is present, it coincides with the β-γ-plane, and the α-directions are normal to it (Fig. 6 A).

Samples bearing this texture occur as a patches in rocks dominated by the foliated and porphyroclastic textures.

Textures and olivine fabrics of the layered series peridotites

The layered series peridotites consists of dunites, harzburgites and lherzolites, occurring as layers at different structural levels. A complete account of their mineralogical and chemical composition, and of their petrology, has been given by Rivalenti et al. (1975).

The layered series is deformed by probably two generations of isoclinal folds producing a foliation, generally striking 315°-20° W, and dipping 40° to nearly vertical. However non-foliated lithotypes may be found which are equigranular and with randomly oriented grains.

Peridotites are generally coarsely grained. When foliation is lacking, spinel is present as inclusions in olivine or as coats on olivine grains. Kinkbands are the only observed deformation features (Fig. 3 A, B). When foliation is present, it is mainly the result of the slight flattening of olivine crystals. The foliated peridotites may have foliation and layering slightly discordant. In this case spinel is represented by three types: 1) inclusions in olivine; 2) coats on olivine grains; 3) interstitial crystals laying in the layering plane.

Two olivine fabrics have been identified in the foliated peridotites: 1) when foliation and layering are coincident (Fig. 7 B), olivine shows very marked α-maximum normal to the foliation-layering plane, while β-ol and γ-ol define a girdle in this plane; 2) when foliation and layering are discordant, and some deviation between the elongation (F) of the crystals and spinel alignment (L) may be observed, a weak α-maximum of olivine is formed at the pole of the layering plane (L), while β-ol and γ-ol define girdles in the layering and foliation planes (Fig. 7 A).

No preferred orientation has been formed in non-foliated peridotites (Fig. 8 A, B).

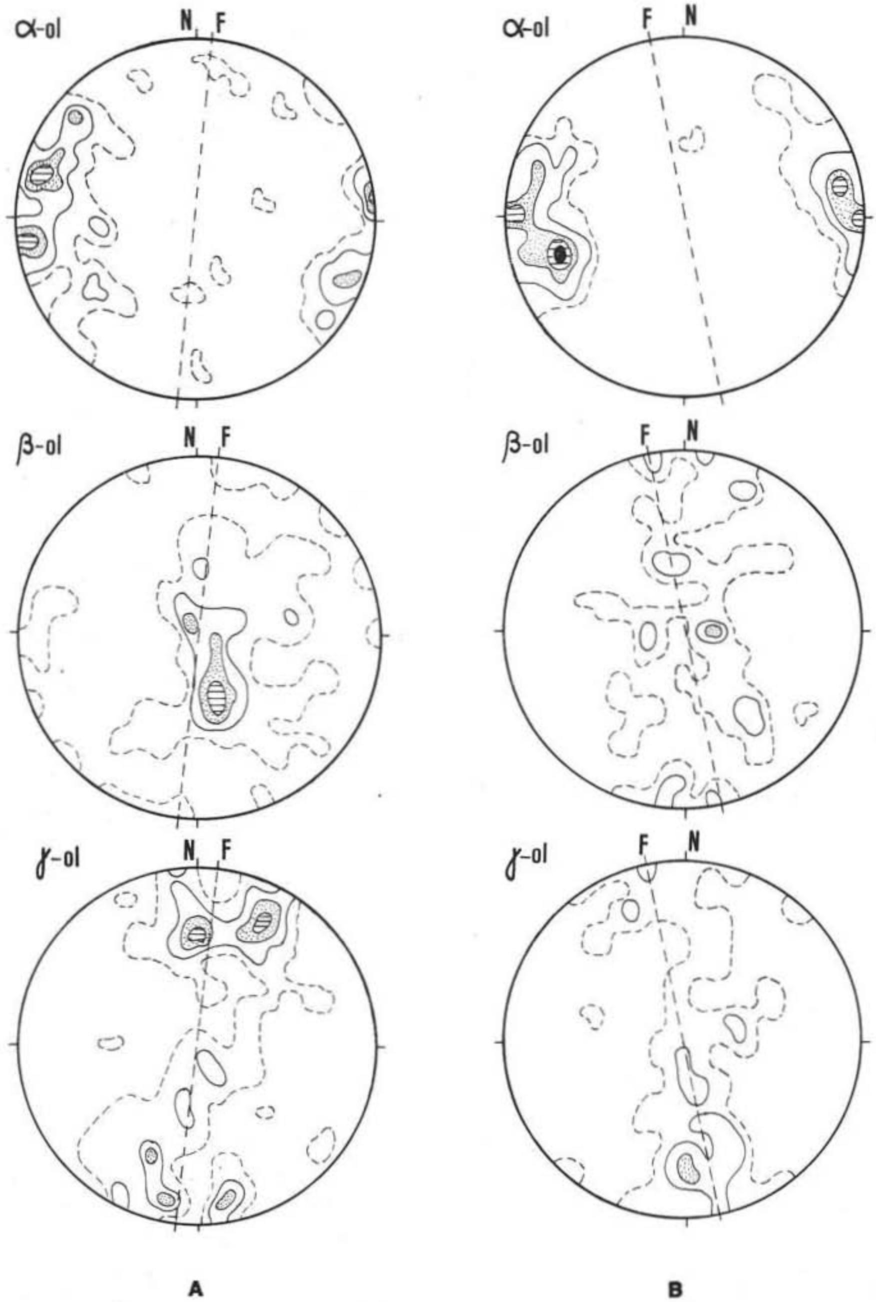

Fig. 4. — Olivine fabrics in the foliated texture. - **A)** Sample Mo 386, **B)** sample Mo 374. See the Appendix for the ornamentation. - **F = foliation plane.**

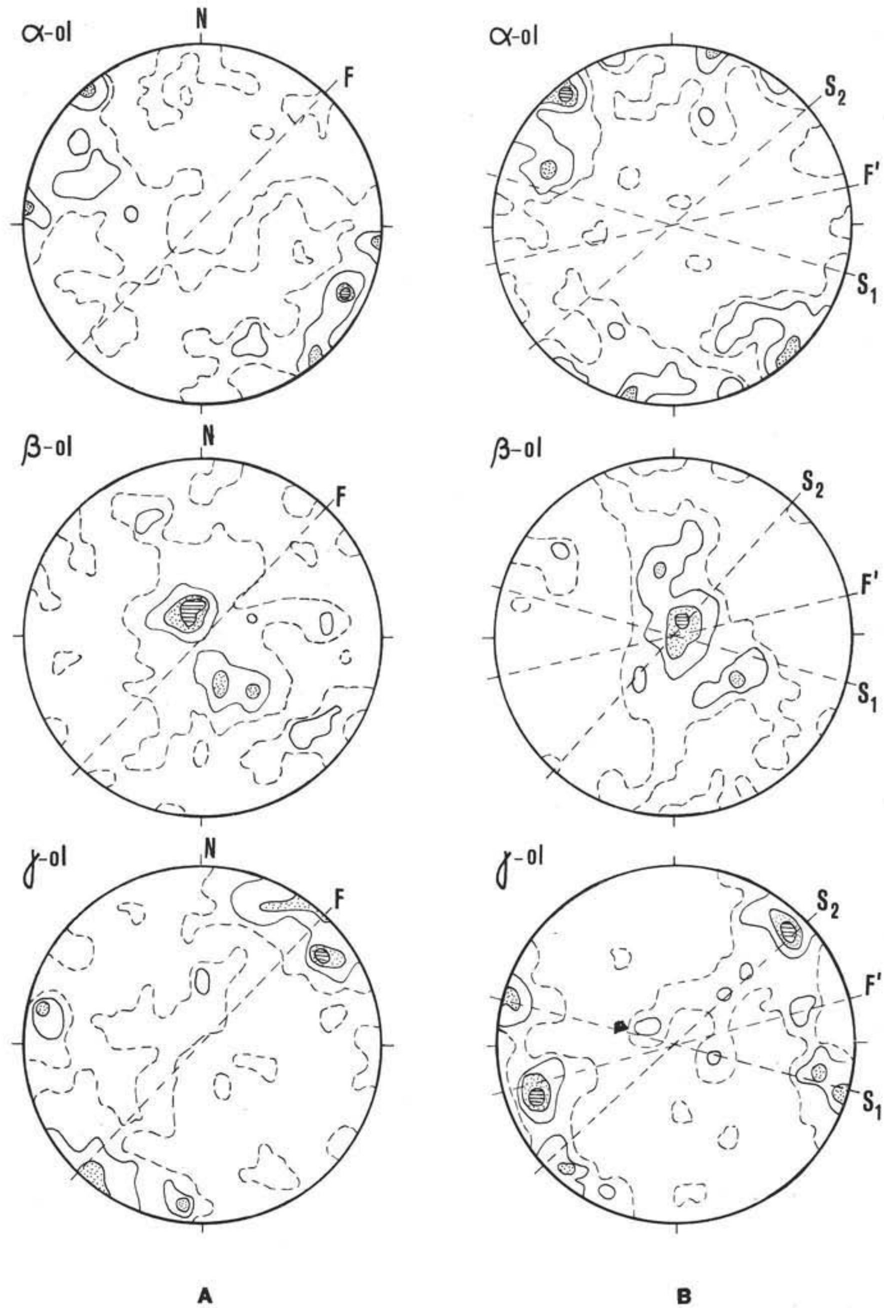

Fig. 5. — **A**) Olivine fabric in the strongly foliated texture (sample Mo 281 a). **B**) Olivine fabric in the porphyroclastic texture (sample Mo 6). F = F′ = foliation plane; S1 and S2 = shearing planes.

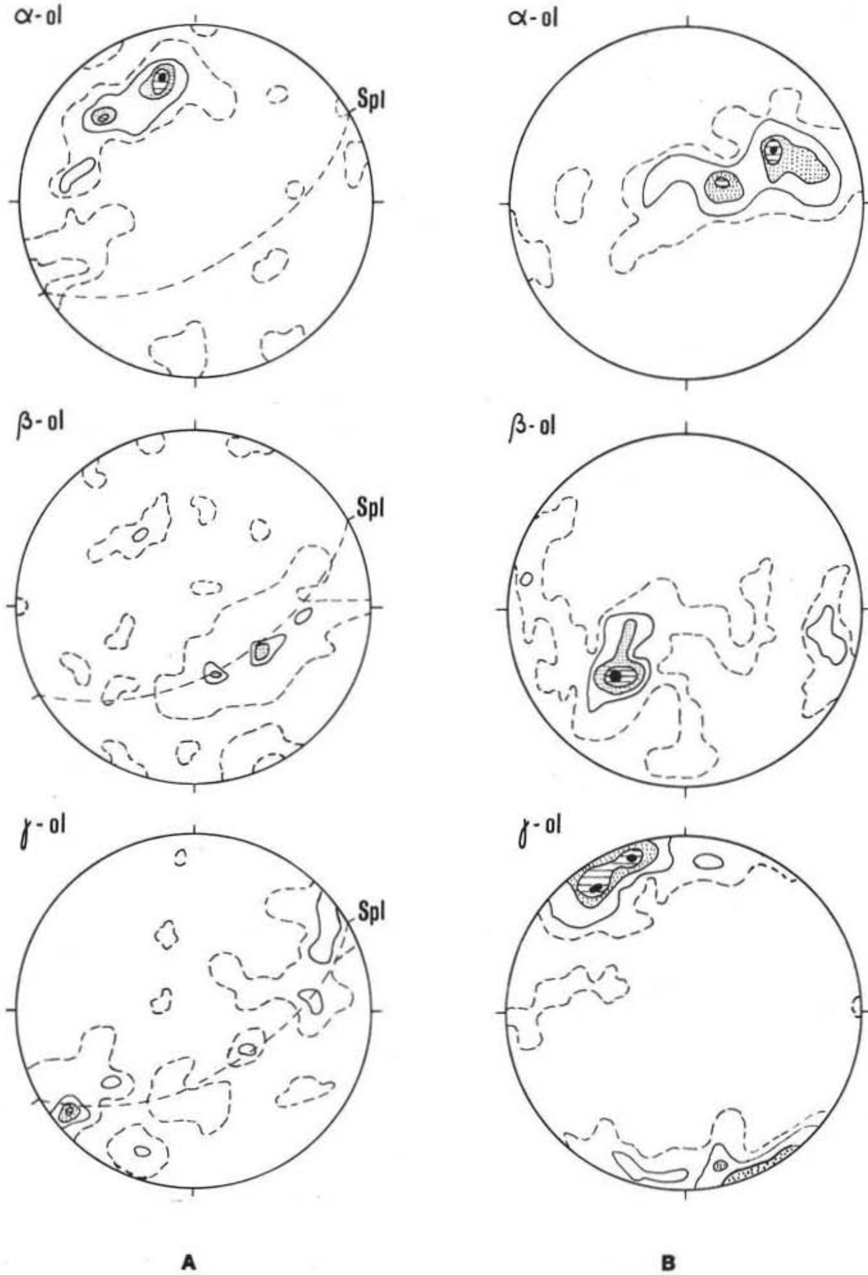

Fig. 6. — Olivine fabric in the protogranular texture. - **A)** Sample Mo 9. The strong fabric of the olivine is related to the faint foliation, which sometimes occurs in this texture (see the text for explanation). **B)** Sample Mo 73. Note the strong fabric of the olivine in absence of any foliation.

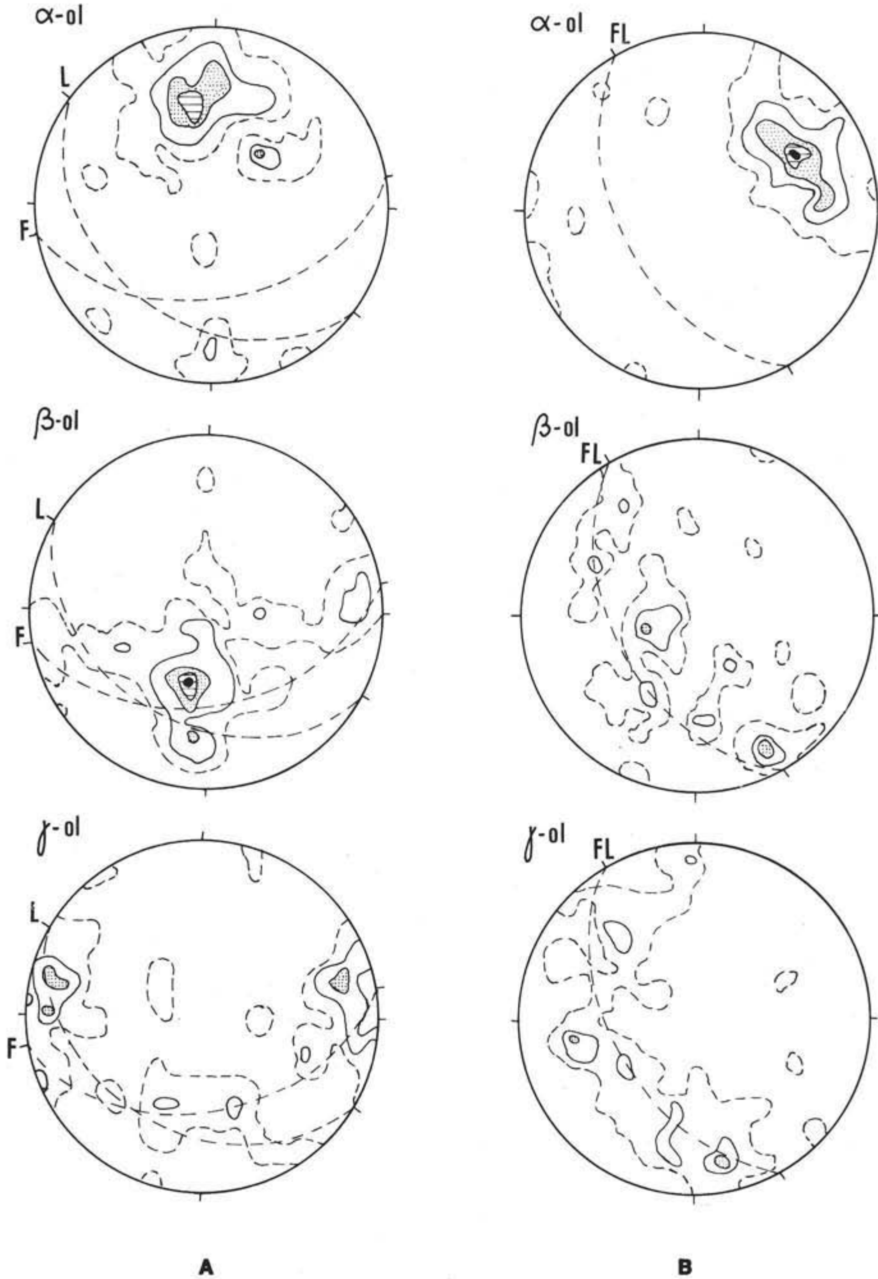

Fig. 7. — Olivine fabric in the foliated peridotites of the layered series. **A)** Sample Mo 43: layering (L) and foliation (F) are discordant. **B)** Sample Mo 44: layering (L) and foliation (F) are coincident (see the text for explanation).

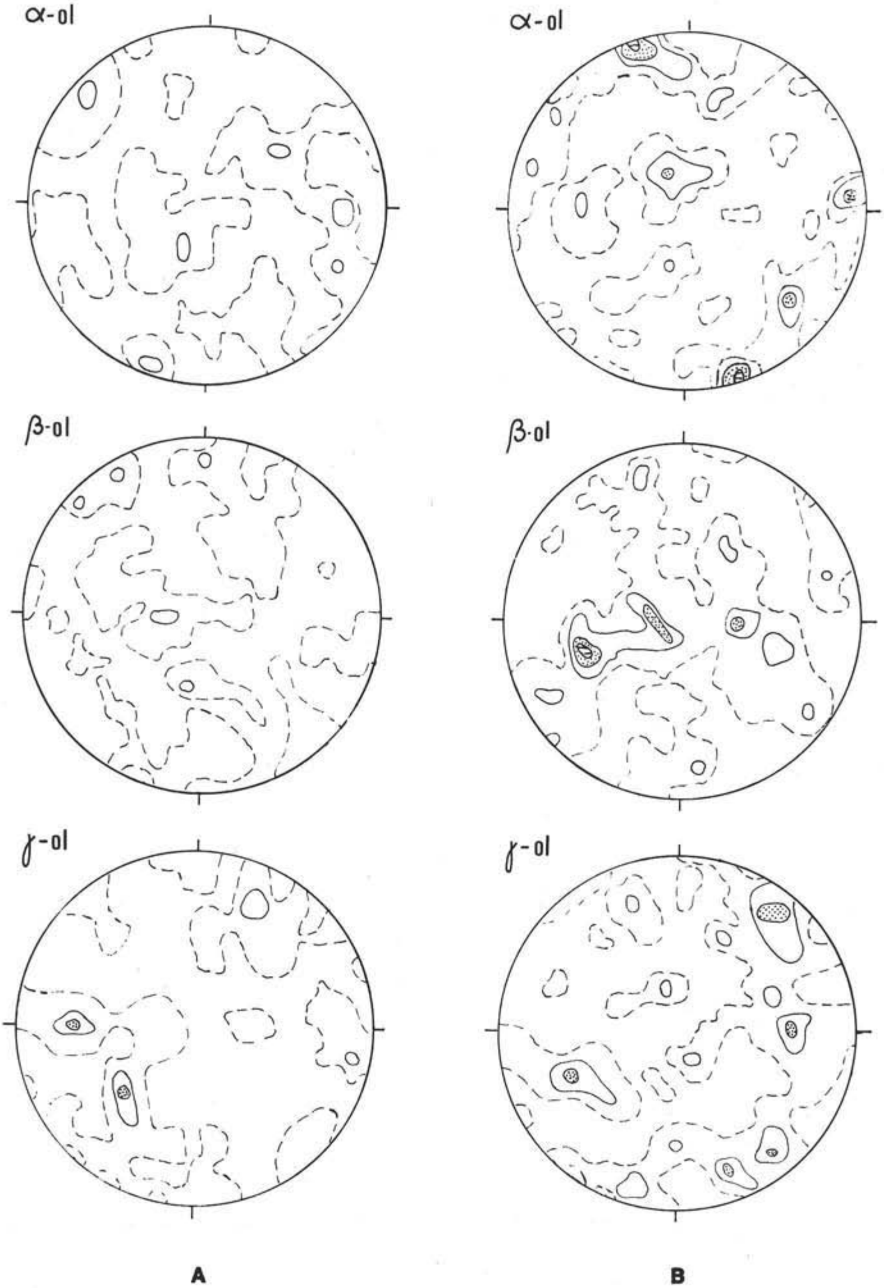

Fig. 8. — Olivine fabric in non-foliated peridotites of the layered series. **A**) Sample Mo 362; **B**) sample Mo 359.

Considerations on textural features and olivine fabrics of the Balmuccia peridotite

— The porphyroclastic and the foliated textures of the Balmuccia peridotite and their olivine fabrics appear to be controlled by deformational processes. In fact deformational features as: foliation, kinkbanding, ondulatory extinction and shearing effects (this last expecially in the porphyroclastic texture) are largely widespread and intense in these types. The general orientation of the structures results by elongation as well as by flattening of crystals in the foliation plane. In particular, olivine exhibits a strong shape and lattice fabric which is strictly related to deformational features as foliation (in the foliated textures) and shearing planes (in the porphyroclastic texture).

In the protogranular texture deformational effects are moderate. They are represented expecially by ondulatory extinction and kinkbands affecting olivines and pyroxenes.

When foliation is present it is mainly displayed by the alignment of small olivines and spinels along bands and by a slight elongation and flattening of crystals. The strong olivine fabric, however, appears to be related to this deformational feature.

— Although the present data do not provide sure indications of the chronological succession of the described textural types, the protogranular texture, occurring only locally as a relict preserved by further strong deformations, could be regarded as the oldest structure in the Balmuccia peridotite body.

The strongly deformed types of the Balmuccia peridotite (porphyroclastic texture, foliated and strongly foliated textures) are probably younger than the protogranular texture. Although field evidences are not sufficiently precise to define unequivocally the chronological relationship among these textures of strong deformation, the following points may be put forward:

1) the tiny grains which occur in some foliated samples, concentrated along the borders of olivine crystals, could represent an incimpient formation of micro-granular phases. The foliation observed in the porphyroclastic texture may be considered a previous feature, partly obliterated by shearing. These considerations suggest the existence of transitional stages between the foliated textures and the porphyroclastic type;
2) a strong superimposed foliation has been observed near the contact between the Balmuccia body and the layered series;
3) no foliation has been observed superimposed to the porphyroclastic type.

These facts support the hypothesis that the porphyroclastic texture is posterior to the foliated type, and that the strongly foliated texture is somehow related to the contact between the Balmuccia body and the layered series.

— The protogranular type observed in the Balmuccia body is similar to structures which have been described by MERCIER and NICOLAS (1975) in one group of xenoliths from the upper mantle, and in moderately deformed facies of other ultramafic massifs (NICOLAS et al., 1971).

If this assumption is correct, the Balmuccia peridotite, which has been considered of mantle origin (LENSCH, 1971; NICOLAS & JACKSON, 1972; RIVALENTI et al., 1975; CAPEDRI et al., this volume) should have aquired the protogranular texture in the shallower zones of the upper mantle, as the result of more deformation-recrystallization metamorphic cycles (MERCIER & NICOLAS, 1975). This conclusion is mainly based on the behaviour of the spinel with respect to the olivine, which indicates that this texture of the Balmuccia peridotite may be ascribed to the « secondary » type (in the sense of MERCIER & NICOLAS, 1975).

The foliated textures, the porphyroclastic texture, and relative olivine fabrics of the Balmuccia Peridotite recall the structures produced experimentally on ultramafic matherials (RAILEIGH, 1968; AVÈLALLEMANT & CARTER, 1970; NICOLAS et al., 1973), and those described for ultramafic massifs with alpine-type evolution (NICOLAS et al., 1971; JACKSON & THAYER, 1972; CAPEDRI, 1974) and for some xenoliths from the upper mantle (MERCIER & NICOLAS, 1975). These strongly deformed types are interpreted as the result of deformation and re-orientation of crystals (expecially olivine) under high-strain conditions.

Considerations on textural features and olivine fabrics of the layered series peridotites

The textures and the olivine fabrics described for the foliated peridotites from the layered series are evidently influenced by the isoclinal folding that affected the formation, and do not support the chemically inferred cumulitic origin. There are, however, some points which may indicate that a cumulitic process occurred: 1) the thin coats of spinel covering the olivine crystals may be regarded as an intercumulus phase preserved by the deformation; 2) the alignment of spinels parallel to the layering may represent the old accumulation plane; 3) the existence of a second α-ol maximum normal to the layering plane, should be the result of shape controlled apposition of olivine crystals (DEN TEX, 1969; JACKSON, 1961; 1971) during accumulation.

The lack of any foliation and the fairly dispersed olivine fabric observed in other peridotites are susceptible of at least two interpretations that have not yet been investigated: 1) they represent structures related to the primary layering without any superimposed foliation; 2) they could be structures of recrystallization by high temperature annealing in the absence of an axial strain that might induce a shape and lattice fabric.

Of these two possibilities we prefer the first one for the following reasons:

1) there are no evidences that this structure is the result of high-temperature annealing (such as polygonal shape and very small size of grains, characteristics of peridotites from high-grade metamorphic terrains); 2) the behaviour of spinels, occurring as intercumulus phase, suggests a cumulitic origin.

Conclusions

From the microstructural study of ultramafites of the Ivrea-Verbano basic formation, in Sesia Valley, the following points can be drawn:

1) three main structural types have been identified in the mantle peridotite of Balmuccia: the protogranular texture, the foliated and strongly foliated texture, the porphyroclastic texture. All these types have been produced by more superimposed deformations, which were active with variable intensities. Possibly, the protogranular type arises from deformations at mantle depth, while the foliated and porphyroclastic types, which are the most widespread structures, are created during an evolution of alpine type.
2) The peridotites of the layered series can be distinguished in foliated and equigranular types. The foliated peridotites display a composed lattice fabric which is mainly controlled by deformation, but partly is the result of a primitive process of gravitational accumulation.

The equigranular peridotites characterized by a dispersed lattice fabric of the olivine may be considered as primary structures, without any superimposed foliation. If this is the case, the existence of two types of cumulitic peridotites, either with α-ol fabric or lacking it, must be admitted at different levels of the layered series. The absence of orientation in the fabric of olivine could be due either to the minor anisotropy of the crystal shape or to the different dynamic conditions of the magma (DEN TEX, 1969; JAKSON, 1961; 1971).

These points lead to the conclusion that microstructural criteria can probably contribute in determining the character of the peridotites in the whole basic formation Ivrea-Verbano.

Appendix

The diagrams of the olivine fabrics are represented by equal-area projections on the lower hemisphere of at least 100 points. Density contours and areas have been obtained using a point counter (TURNER & WEISS, 1963); they are: 1 % = = dashed line; 2 % = continous line; 4 % = dotted areas; 8 % = parallel-lined areas; more than 8 % = black areas.

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