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STRUCTURAL STUDY OF THE BALMUCCIA MASSIF (WESTERN ALPS): A TRANSITION FROM MANTLE TO LOWER CRUST[1]

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ABSTRACT

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Among the ultramafic bodies included in the Ivrea zone, the Balmuccia lherzolite massif offers a particularly well-preserved contact with the granulitic lower crust. The eastern margin of the massif presents a transition to the granulitic gabbros through a layered sequence including pyroxenites and dunites.

A chronological evolution of textures in the peridotite is established, showing a continuous evolution from mantle-derived textures (porphyroclastic) located in the southwestern domain to recovered textures (equigranular) developed to the northeast along the preserved transition with the granulites. This recovery process is considered to be enhanced by fluid circulation, it would occur in granulite facies temperature conditions. The map of penetrative structures confirms this chronology : the foliation and lineation attitude follows a progressive evolution with a steep lineation associated with mantle textures and a flat one associated with crustal textures, this last orientation being concordant with that of the surrounding granulites. The structural analysis is consistent with a diapiric emplacement model of the Balmuccia lherzolite developed in asthenospheric mantle conditions and ending in the granulite facies conditions of the lower crust.

INTRODUCTION

Among the ultramafic bodies included in the western part of the Ivrea zone, referenced in LENSCH (1968, 1971); LENSCH & ROST (1972); SCHMID (1967); NICOLAS (1974); ERNST (1978, 1981); GARUTI & FRIOLO (1979), a distinction in two groups has been proposed by LENSCH (1968, 1971) and by NICOLAS (1984): 1 – the Finero body and small ultramafic lenses of the Val d'Ossola area which present the same paragenetic evolution as the surrounding granulitic rocks (LENSCH & ROST, 1972; LENSCH, 1976) and 2 – the Baldissero and Balmuccia bodies which constitute spinel lherzolites that exhibit mantle textures. Information on the primary relationships between upper mantle and continental lower crust is expected from the study of these two lherzolite bodies. The primary mantle textures are better preserved in the Baldissero massif, but this massif is separated with a tectonic contact from the Ivrea zone granulites. The Balmuccia massif shows a more complex textural evolution, but its relationships with the basic granulites of the Ivrea zone are exceptionally well exposed along the eastern margin of the massif. The present paper discusses field structures, microstructures and fabrics in the Balmuccia peridotite and surrounding granulitic gabbros, brings new insights in the relationships between these two units and discusses the previous models proposed by SHERVAIS (1979); JACKSON (1979); RIVALENTI ET AL. (1979); and NICOLAS (1984).

Geological setting

Over a horizontal distance of 15 km, the Ivrea zone presents an E-W cross section from upper mantle lherzolites at Baldissero and Balmuccia to lower crust metabasites and metasediments (Fig. 1). The metamorphic grade decreases through the Ivrea zone southeastward from granulite to amphibolite facies (BERTOLANI, 1973; SCHMID, 1967). Rb/Sr data give a Caledonian age (478 Ma) for this metamorphism (HUNZIKER & ZINGG, 1980). This fragment of lower crust belonging to the South Alpine plate was upthrust against the Austro Alpine and Pennine units along the Insubric line. Based on independent lines of evidence, the age of this upthrusting is now considered as Hercynian (GIESE, 1979; HUNZIKER & ZINGG, 1980), although the Insubric line is an Alpine feature.

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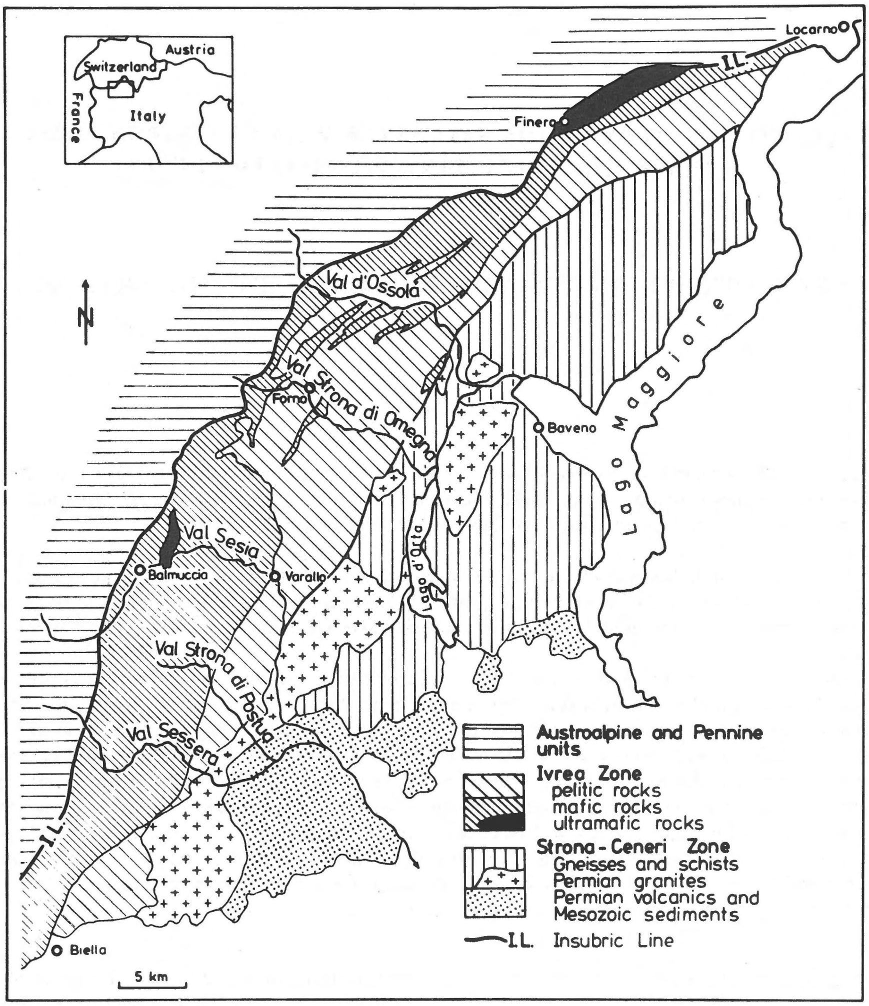

Fig. 1
Map of the Ivrea zone. The Balmuccia and Finero ultramafic bodies are marked in black in the W and N part of the region respectively. After Hunziker & Zingg (1980).

FIELD STRUCTURES

The Balmuccia massif has a N-S elongate shape (5 km × 1 km) with a strong E-W asymmetry. The western contact is sharp and sheared, whereas the eastern one exhibits a progressive transition from peridotites to the garnet bearing granulitic gabbros of the Ivrea zone. This transition is marked by the interlayering of dunites, pyroxenites and granulitic gabbros (layered sequence of Garuti, 1977) over a distance of one to two kilometers (Figs 2 and 3).

Penetrative structures in the lherzolite

The foliation in the peridotites (Figs 3 and 5a) is dipping steeply to the west. Its trend varies progressively from N 5° in the southwestern part to N 170° in the northeastern part. Simultaneously the spinel lineation (Figs 4 and 5b) changes from a N 5° trend, 65-45° norward plunge to a N 170° trend and 15-10° northward plunge. This change in attitude coincides remarkably well with textural type one (see under TEXTURE) as shown in Fig. 4, where a dividing line can be traced, which is based on the geographical distribution of porphyroclastic and annealed facies.

Foliations and lineations in the northeastern domain are concordant with those measured in the granulitic gabbros of the eastern contact (Figs 3 and 4).

Dikes

The peridotite of the Balmuccia body is cross-cut by several generations of ultramafic and mafic dikes whose emplacement chronology has been established by Lensch (1971), Shervais (1978) and Jackson (1979). Jackson (1979) showed that Cr-diopside websterites crop out as bands concordant or sub-concordant with the foliation (Fig. 5d); they are sometimes branching. A distinct generation of Opx-rich Cr-diopside dikes cross-cut the more Cr-diopside rich websterites and can make a higher angle with the foliation (Fig. 5e).

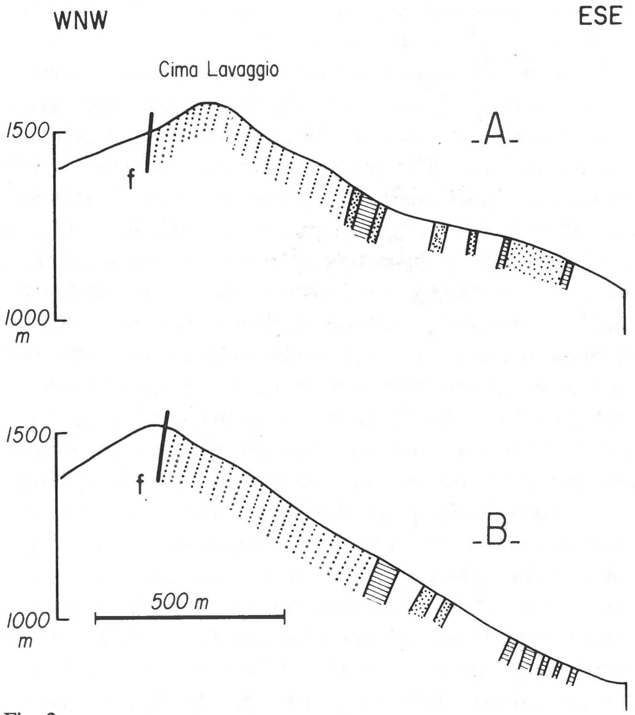

Fig. 2
Cross sections through the Balmuccia body (localized on Fig. 3). Legend: dotted lines, lherzolites with trace of the foliation; dots, dunite satellites; hatches, pyroxenite; white, granulitic gabbro.

Al-augite ariegites cross-cut websterite dikes and may be oriented at any angle to the foliation and lineation, although they are dominantly subconcordant (Fig. 5f). Spinel-rich Al-augite ariegites are cross-cut by younger plagioclase-rich ariegites.

In conclusion, younger dikes which tend to be oriented perpendicular to the lineation (Fig. 5f) have been interpreted as produced by magma injection perpendicular to the extension direction (spinel lineation), whereas older dikes are parallel to the foliation due to progressive deformation (JACKSON, 1979; NICOLAS & JACKSON, 1983). Folding of all types of dikes is ubiquitous in the massif, with tighter folds in websterites, and more open folds in ariegites. All fold axes are parallel to the spinel lineation (Fig. 5c), thus following its rotation from a northward to a northeastward trend.

In the granulites of the eastern contact (layered sequence) the bands of pyroxenites and dunites interlayered with gabbros are concordant with the foliation in the granulites. As for the central peridotite body, this concordance is interpreted as a tectonic transposition.

TEXTURES

The study of textural types in the present paper follows MERCIER & NICOLAS' (1975) classification. It is based on a complete survey of the Balmuccia peridotites and surrounding granulites, and their geographical distribution is taken

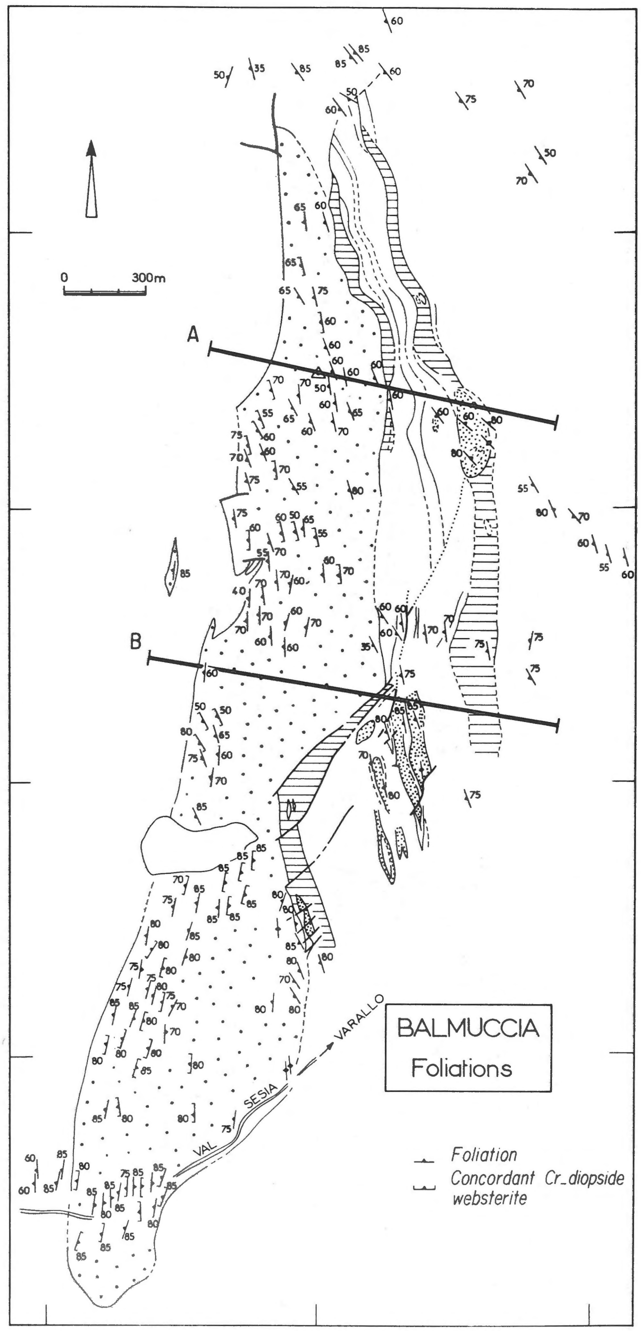

Fig. 3
Foliation map. Numbers indicate the dip. Legend: widely spaced dots, lherzolite; closely spaced dots, dunite; hatches, pyroxenite; white, granulitic gabbro.

into account. It differs somewhat from GARUTI'S (1977) classification; the relevant comparison will be presented.

Within the central part of the Balmuccia massif, fertile lherzolites are predominant, with only local occurrence of harzburgites and dunites in lenses 0.5 to a few metres thick. In the eastern part of the massif, dunite lenses, tens of metres thick are frequently interlayered with pyroxenite and gabbro bands.

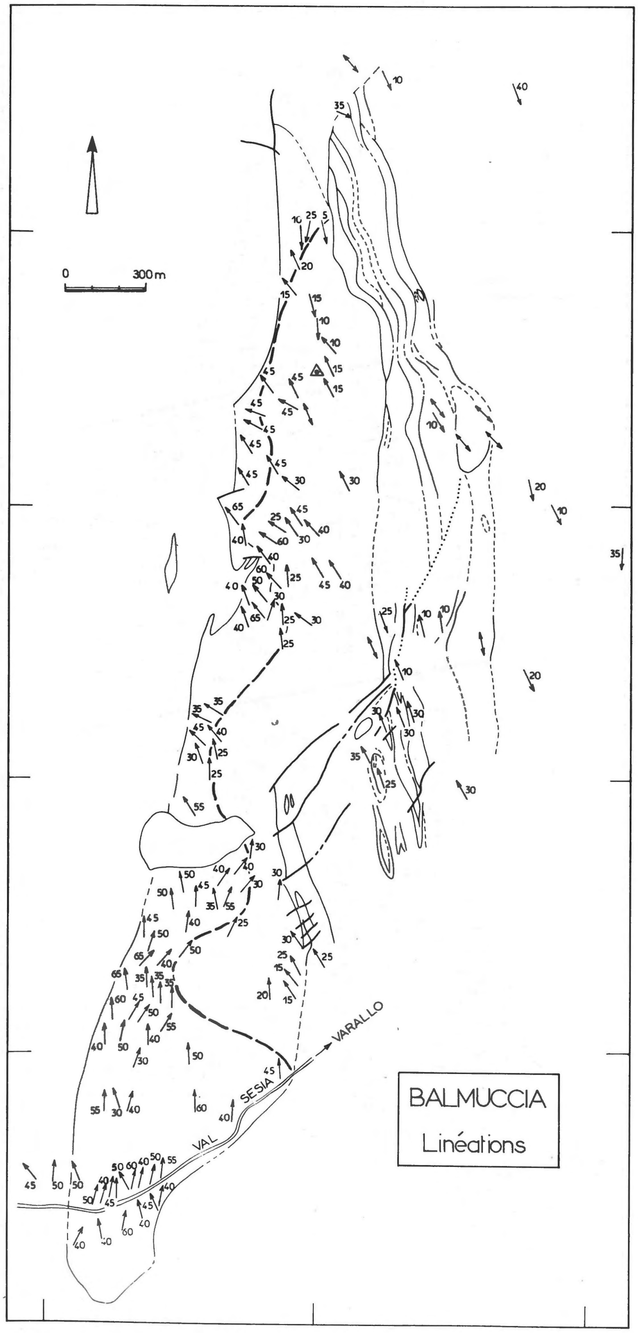

Fig. 4
Lineation map. Numbers indicate the dip. Heavy dashed line in the peridotite: approximative divide between porphyroclastic textures to the SW and equigranular tabular to the NE.

Lherzolites

The lherzolitic part of the massif can be divided into two textural domains. Equigranular tabular textures (MERCIER & NICOLAS, 1975) defining a strong foliation are observed in the northeastern part of the massif. Porphyroclastic textures are confined to the southwestern part of the massif (Fig. 4). It is a key point to decipher the primary or secondary character of the porphyroclastic texture and to establish the porphyroclastic/equigranular chronology.

In the *porphyroclastic texture* (Fig. 6a) olivine porphyroclasts (5 mm × 1,5 mm) have a lozenge or elongated shape with irregular boundaries. Deformation substructures in olivine are tight. The general association of lobed and/or vermicular spinel grains with pyroxenes suggests that this texture evolved from the protogranular one that is well known in mantle rocks: primary porphyroclastic of MERCIER & NICOLAS (1975), and represented in the Baldissero massif (Figs 8a and b). Normally this texture excludes a close association of spinel with olivine and, in particular inclusions of small spinel in olivine, as this results from scattering spinel-pyroxene clusters followed by olivine grain growth enclosing the spinel grains. However, counting of spinel inclusions in primary porphyroclastic textures has yielded 17% spinel included into the olivine for a lherzolite nodule from a basalt and 2% for a Baldissero lherzolite. The same counting in secondary porphyroclastic texture from the Finero body gives 31% spinel inclusions in olivine. Based on this criterium, the Balmuccia porphyroclastic texture (Figs 6a and 8c), with 9% spinel inclusions in olivine is primary, and has been derived from a normal protogranular one. This porphyroclastic texture would correspond to the foliated texture of GARUTI (1977).

The lattice preferred orientation of olivine (Fig. 7a) is indicative of comparatively high temperature intracrystalline slip on the (0kl) [100] slip system. The obliquity of this fabric, which is due to shear flow regime (NICOLAS et al., 1973), does not give a consistent sense of shear at the scale of the massif. GARUTI's (1977) fasbrics indicate a dominant (010) [100] slip system.

Locally (Fig.6b), trails of recrystallized neoblasts (0,04 mm × 0,1 mm) along olivine porphyroclast grain boundaries represent the imprint of a continuing high stress deformation, which perhaps is also responsible for the tight porphyroclasts substructure. This texture is called porphyroclastic by GARUTI (1977) and the recrystallized trails and associated fabrics are assigned to shear planes symmetrically inclined to the foliation. In the most recrystallized specimens we observe that one shear plane parallel to the maximum orientation of olivine slip planes is dominant. This plane could be interpreted as a Sc shear plane (BERTHÉ ET AL., 1979), where the strain concentrates during the ultimate stage of a shear deformation.

The *equigranular tabular texture* (Fig. 6C) is distinguished by a more regular shape of olivine crystals (2 to 4 mm). Recrystallized polygonal olivine grains (3 mm) are developed in olivine rich zones. Spinel grains with globular shape predominate over lobed and embayed ones (Fig. 8e). They are interstitial and more frequently included in olivine (15%) or orthopyroxene and not restricted to pyroxene clusters. As mentioned earlier this suggests that a continuing deformation dismembered and scattered the spinel aggregates and that deformation was accompanied or followed by olivine grain growth allowing the inclusion of spinel in olivine. Olivine

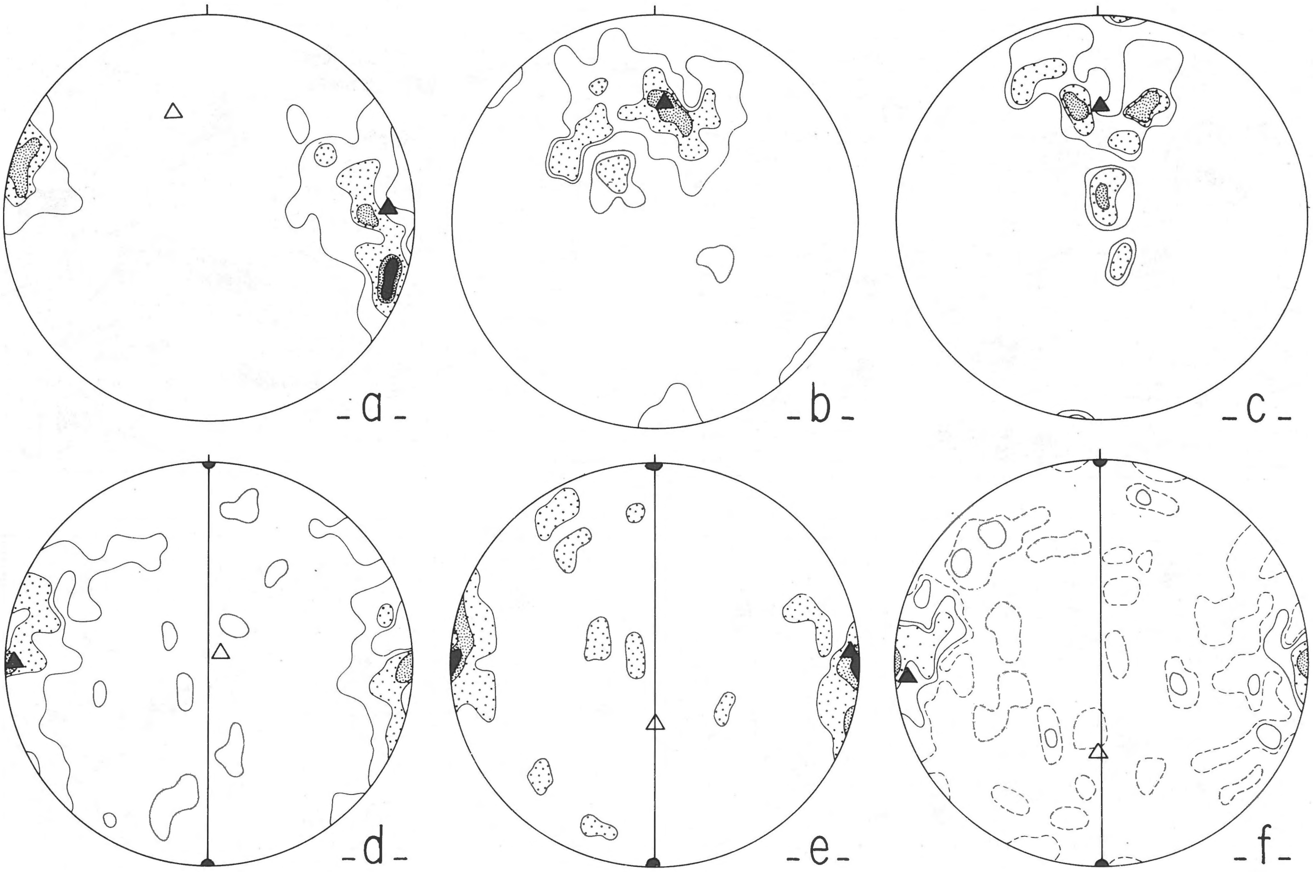

Fig. 5
Field structures in peridotite and surrounding granulites, lower hemisphere projection a, b and c, geographical reference system; a, poles of foliation, 93 measurements; b, lineations, 80 measurements; c, fold axes, 46 measurements. Structural reference system with foliation and lineation for d, e and f; d, poles of Cr-diopside websterite dikes, 71 measurements; e, poles of OpxCr-diopside websterite dikes, 30 measurements; f, Al-augite ariegite dikes, 85 measurements. Contours, 2, 4, 8% per 0,45% area. Black triangle, computed maximum; open triangle computed pole of best plane.

lattice-preferred orientation with a good [010] maximum perpendicular to the foliation (Fig. 7b) reflects the strong development of foliation by anisotropic grain boundary migration ([010] being a direction of slower growth), in keeping with other fabric data obtained in this textural type (CORDELLIER ET AL., 1981). The equigranular tabular type would correspond to the strongly foliated textures of GARUTI (1977).

Transitional textures between the porphyroclastic and equigranular ones are frequently observed (Fig. 6d). They are characterized by progressive annealing involving grain boundary migration. In particular polygonal olivine neoblasts with planar (010) grain boundaries develop from porphyroclasts.

There is a tendency for the equigranular tabular or transitional textures to characterize depleted peridotite (with lower amount of pyroxene).

Dunites

In the Balmuccia lherzolite, dunite forms thick bands, half a metre wide, concordant with the lherzolite foliation. They contain thin spinel layers parallel to the foliation, and locally streaks of elongate pyroxene grains. Lenses of dunite or depleted peridotite occur also as inclusions in the enclosing granulitic rocks (layered sequence).

Coarse *equigranular mosaic textures* are sometimes observed in dunite bands enclosed in lherzolites with a equigranular tabular texture and in the dunite lenses from the layered sequence (Figs 6e and f). The dunites with equigranular mosaic textures, contain alignments of fluid inclusions indicative of a fluid percolation. The lattice fabric associated with this equigranular mosaic texture (Fig. 7c) shows the [010] maximum normal to the foliation. We interpret this equigranular mosaic texture and the associated fabrics as the result of annealing during or after deformation, under the influence of fluids which may lower the temperature of annealing (CORDELLIER ET AL., 1981, CHOPRA & PATERSON, 1981). Plastic strain and/or annealing have obliterated any previous texture either of magmatic or deformational origin. GARUTI (1977) used the term equigranular to characterize the textural type corresponding only to the harzburgite or dunite lenses of the layered

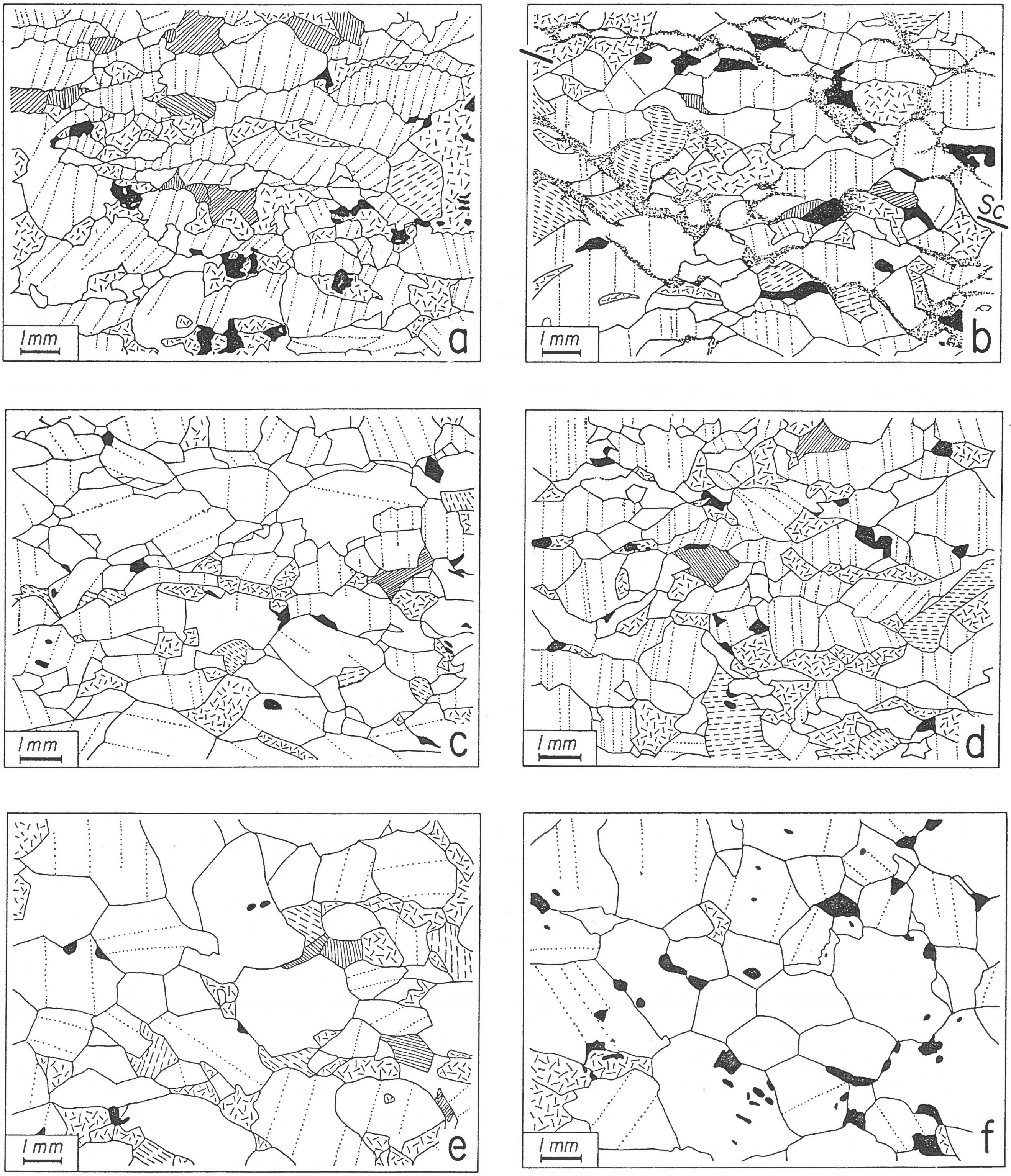

Fig. 6
Drawing of textures from thin sections parallel to the XZ plane of finite strain. a, porphyroclastic lherzolite 76 VS 22; b, porphyroclastic recrystallized lherzolite 79 BLA 1; c, equigranular tabular lherzolite 78 BLA 44; d, transitional porphyroclastic/equigranular tabular lherzolite 78 BLA1; e, equigranular mosaic depleted peridotite 75 VS 20; f, equigranular mosaic depleted periodotite of the layered sequence 75 VS 8. Legend: white, olivine with trace of subboundaries; widely spaced hatches, orthopyroxene; closely spaced hatches, clinopyroxene; black, spinel.

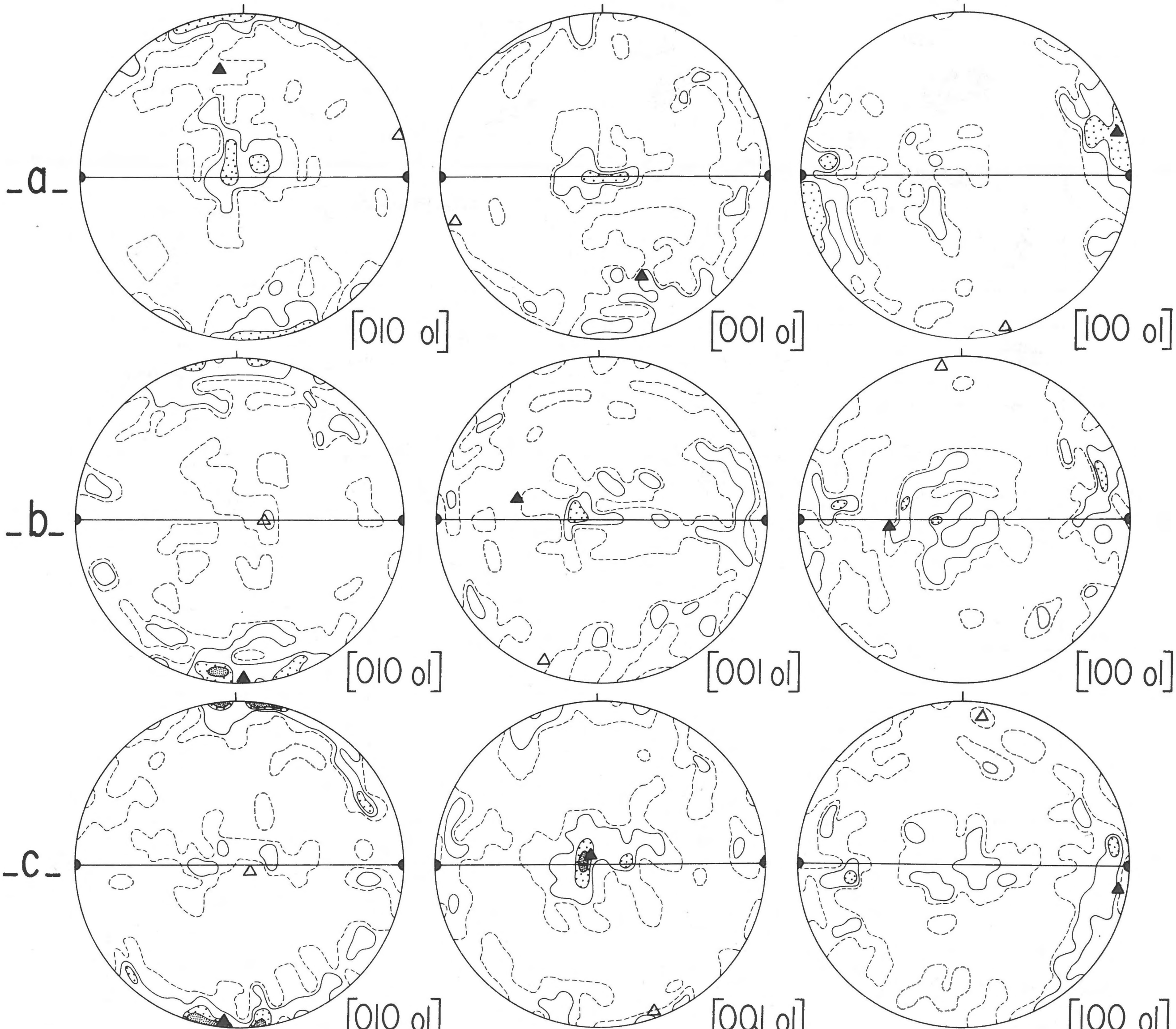

Fig. 7
Olivine lattice preferred orientations. Lower hemisphere projection. Contours 1, 2, 4, 8% per 0.45% area. Solid line, foliation; dots, lineation. Black triangle, computed maximum; open triangle, computed pole of best plane. a, porphyroclastic lherzolite; b, equigranular tabular lherzolite; c, equigranular mosaic dunite from the layered sequence.

sequence. He assigned to them a cumulatic origin. The corresponding fabrics are either random or of the same type as in our Fig. 7c. The textures of dunites included in the lherzolitic body are termed secondary protogranular.

Dikes

Textures in the websterite dikes are generally coarser grained than in the enclosing lherzolite. Olivine grains are strained, orthopyroxene crystals are strongly kinked, clinopyroxene grains are more equant.

In Al-augite dikes, minerals usually have a weaker shape fabric than in the earlier dikes. Deformation microstructures are however common in olivine and orthopyroxene crystals.

Granulitic gabbros

The surrounding metamorphic gabbros exhibit a typical granulitic texture in which the elongated pyroxene (marking the lineation) is generally unstrained whereas the plagioclase is mechanically twinned. For this reason, their deformation is assumed to occur during the granulite facies metamorphism. Temperature conditions of this metamorphism are fixed around 800°C by SCHMID & WOOD (1976); this is compatible with the occurrence of mechanical twinning in plagioclase which occurs at temperatures as high as 800°C (BORG & HEARD, 1970).

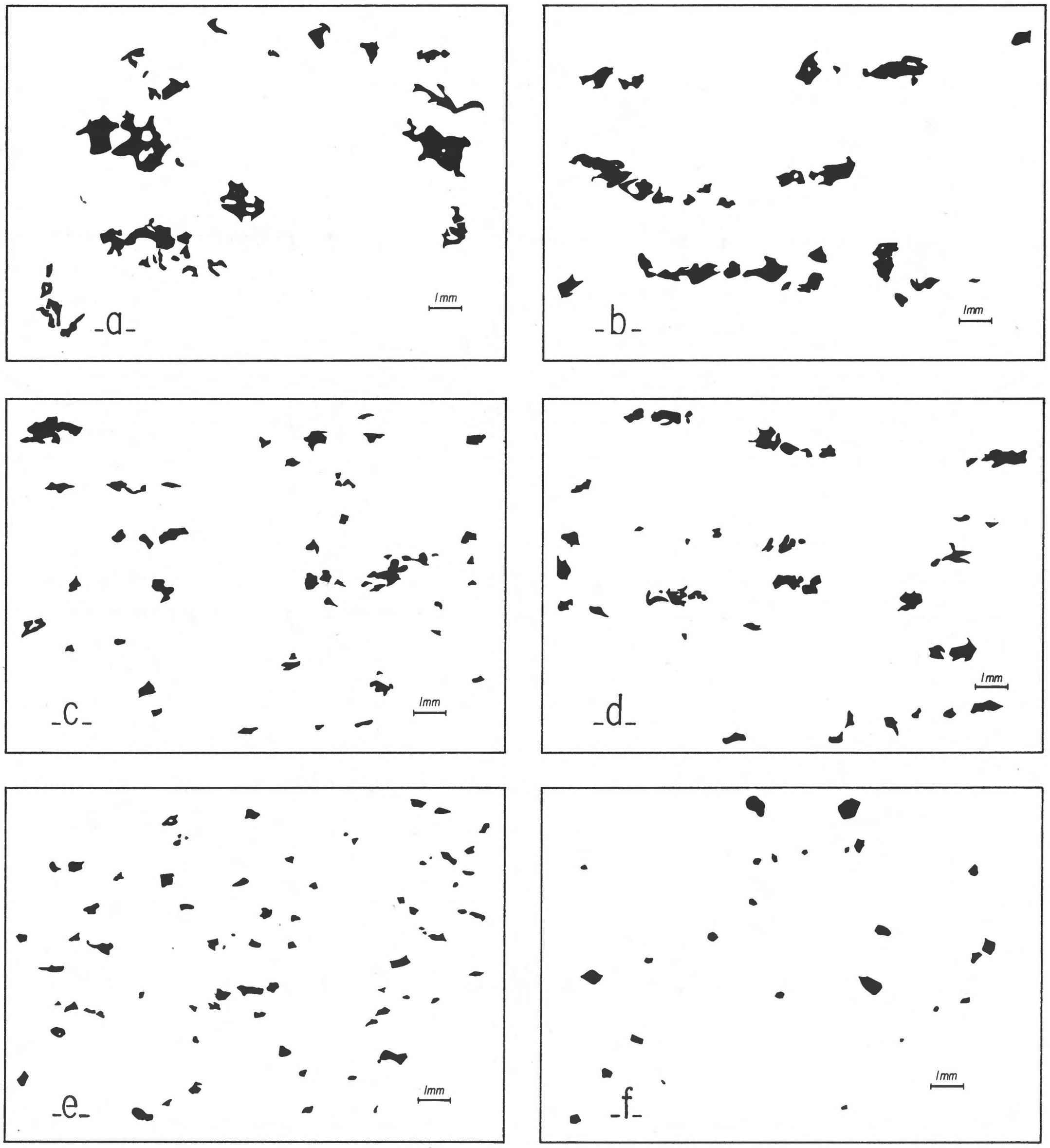

Fig. 8
Evolution of shape and size of spinel grains from protogranular to porphyroclastic and equigranular textures. Drawing after this sections cut along the XZ plane of the finite strain. a, protogranular texture, Baldissero lherzolite, Ba 3A; b, porphyroclastic texture, Baldissero lherzolite Ba 4A; c, porphyroclastic texture, Balmuccia lherzolite with dynamic recrystallization 79 BLA 1; d, porphyroclastic texture, Balmuccia lherzolite 76 VS 22; e, équigranular tabular texture, Balmuccia lherzolite 78 BLA 1; f, équigranular mosaic texture, Balmuccia dunite 76 VS 18.

DISCUSSION

Mantle history

The chronological relationship between the various periodite textural types allows an interpretation of the Balmuccia history. The sequence proposed in this paper is based on the textural interpretation of MERCIER & NICOLAS (1975) and more specifically on the shapes and types of association of spinel. In this séquence, the porphyroclastic textures developed in the western part of the massif predate the equigranular textures of the eastern part. This conclusion is deduced from the fact that the porphyroclastic textures are directly superimposed on a mantle type protogranular texture and is not of secondary type. The evidence provided in favour of this interpretation is the close association of lobed and embayed spinel grains with ortho-clinopyroxene clusters like in mantle lherzolite nodules and in the Baldissero massif, rather than with olivine (Figs 8a, b, c, d).

The deformation is imprinted in a fertile lherzolite rich in websteritic and ariegitic dikes. The mineralogy of the lherzolite and of the dikes and the emplacement sequence of the dikes reflect also a mantle history of successive partial melting events.

The thermal history of the massif (SHERVAIS, 1979) indicates a slow cooling between 1200°C/12-20 kbar (equilibration temperature of the system Ol-Px-Sp) and 860°C/10-13 kbar

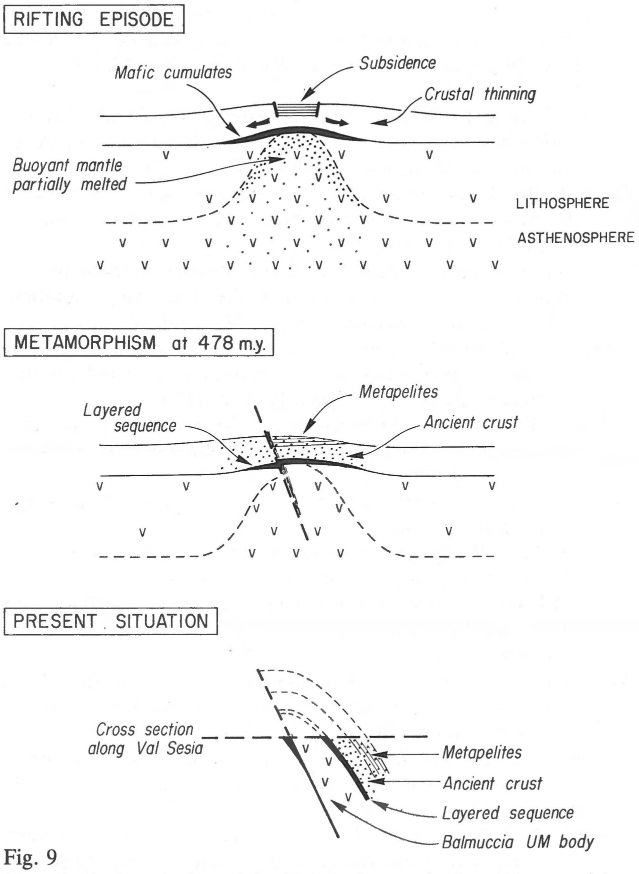

Fig. 9
Hypothetical evolution of the Val Sesia area in the rifting model.

(equilibration temperature of the pair Opx-Cpx) in the peridotites and surrounding granulitic gabbros. This cooling episode took place while the mantle rose which also produced, by partial melting, parental magmas of the Al-augite dikes suite (SHERVAIS, 1979; SINIGOI ET AL., 1983). The 860°C temperature equilibria in the peridotite and in the granulites are assumed to be contemporaneous.

The structural sequence proposed here fits the temperature constraints of a rising mantle model. The mantle deformation recorded by the porphyroclastic textures preserved in the southwestern part of the lherzolite body was produced during plastic flow under relatively dry conditions at temperatures sufficiently high to activate the high-T slip systems in olivine (CARTER & AVE LALLEMANT, 1970). Continued plastic flow at temperatures down to 800°C (see next section) was responsible for the superimposition of a tight substructure and high stress local dynamic recrystallization (see under TEXTURES, Lherzolites). From the foliation/lineation attitudes and corresponding fabrics in peridotites (NICOLAS ET AL., 1973), the orientation of the flow can be accurately defined. The flow plane is oriented N-S dipping steeply westward, and the flow line is oriented N-S dipping 45 to 65° northward. This represents the present day orientation.

Crustal history

The equigranular tabular texture in the eastern part of the massif is derived from the porphyroclastic texture by continuing strain, responsible for the scattering of spinel grains (Figs 8e and f) and by syn-tectonic or post-tectonic olivine grain boundary migration, responsible for the inclusion of spinel grains in olivine. The equigranular mosaic texture occasionally met in the dunite bands within the lherzolites and in the dunite lenses of the layered sequence is due to a stronger recrystallization which has obliterated any previous texture.

The fine grained recrystallization textures observed at olivine grain boundaries of some porphyroclastic lherzolites, and the associated tight substructure in olivine porphyroclasts are assigned to a local shear strain concentration during a final stage of plastic deformation. By comparison with similar textures developed at the sole of ophiolites, temperatures around 700°-900°C and deviatoric stress as high as 1 kbar are ascribed to this deformation (NICOLAS ET AL., 1980).

The equigranular textures with evidence of an important recovery are regarded as evolving at lower temperature from the porphyroclastic textures. This is paradoxal as recovery is a thermally activated process and should be more important at higher temperatures. It is proposed to explain this paradox by taking the role of fluids into account, whose effects on recovery have already been documented in peridotites. The fluid inclusions in olivine and the occurrence of a pargasitic amphibole indicate that fluids were more abundant in the eastern peridotites than in the western ones and thus could be responsible for their recovered character.

Eventually, the high stress deformation superimposed on the porphyroclastic texture in the western lherzolites could have developed under drier conditions concurrent with wet recovery in the eastern peridotites. It could correspond to shear flow concentrated in a narrow zone during the cooling of the massif with a possible relation to the sheared character of the western contact of Balmuccia massif.

The equigranular textures are thought to have developed in the peridotites at the same time as the surrounding gabbros were deforming and recrystallizing in granulite facies conditions as suggested by SHERVAIS (1979). It is shown by the fact that the foliation and lineation in the peridotites displaying equigranular textures have the same attitude as those in the granulitic gabbros. Radiogenic ages of 478 Ma (HUNZIKER & ZINGG, 1980) for this metamorphism suggest that the intrusion of the Balmuccia lherzolite was a Caledonian event.

CONCLUSION

The data presented in this paper are consistent with the model of a diapiric intrusion of the Balmuccia lherzolite massif at solidus temperatures, producing the partial melting still recorded by the dikes. This intrusion is followed by a granulitic metamorphism in the peridotite and surrounding gabbros (SHERVAIS, 1979; RIVALENTI ET AL., 1979; NICOLAS, 1984). This Caledonian metamorphism could have been triggered by the heat released by the mantle intrusion.

The granulitic metamorphism is more pronounced in the eastern part of the massif which was probably the top of the intrusion in contact with the overlying mafic crust. A release of water during crustal metamorphism could explain the stronger recrystallization in the peridotites and possibly, through hydrous partial melting, their more depleted character (NICOLAS, 1984). The peridotites from the western part would preserve a fertile mantle mineralogy and texture.

The structural continuity between mantle-derived porphyroclastic texture in lherzolites and crustal equigranular texture in peridotites or dynamical recrystallization in lherzolites agrees with a continuous tectonic process, initiated at high T in the mantle and ending in granulite facies in the lower crust.

A model of Caledonian rifting has been proposed by SHERVAIS (1979) and NICOLAS (1984). Our conclusions support this hypothesis and allow us to specify a few characters of this mantle diapir and to suggest some consequences of its intrusion.

1 – A limited residual character of the mantle rocks, compared to mantle from ophiolites; 2 – high density of dikes representing trapped magmas of evolutive compositions (SHERVAIS, 1979; SINIGOI ET AL., 1983); 3 – production of the greater part of the magma during the deformation resulting in tectonic transposition of dikes; 4 – development of granulite facies metamorphism in mafic formations during the final stage of diapirism; 5 – development of amphibolite facies metamorphism in the overlying pelitic sequence (HUNZIKER & ZINGG, 1980).

In such a model, the layered mafic sequence (a few km thick) of the Ivrea zone could have originated, at least partly, in magma chambers located at the base of the crust in present rifts. A hypothetical evolution of the Val Sesia area in the rifting model is presented in Fig. 9.

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