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Some new Petrofabric Diagrams of the Garnet Peridotite at Alpe Arami (Ticino, Switzerland)

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Abstract

Petrofabrics of olivine in the garnet peridotite of Alpe Arami were investigated in order to check transitions in preferred orientations as a result of deformation. The starting fabric [100] normal to a compositional layering S_L and [001] together with [010] in S_L, known as the [100] fabric (Möckel, 1969) represents a rotationally unstable orientation during deformation. In various specimens natural deformation caused significant changes in preferred orientation and recrystallized grains also possess the new orientation. The new fabric developed, the [010] fabric ([010] normal to the S-plane and [001] together with [100] in the S-plane) is suggested to represent a rotationally stable end orientation, which could not be changed by further deformation on {0kl} [100] slip systems, in respect to the strain axes. It is suggested that in some cases both [100] and [010] fabrics are developed in separate regions in fold hinges depending on respectively locally extension or shortening conditions within a fold.

INTRODUCTION

In this paper another explanation is discussed for the assumed tectonic character of a [100] preferred olivine orientation in some fold hinges and the relation of local strain with determined glide systems.

The structural petrology of the garnet peridotite body of Alpe Arami near Bellinzona (Ticino, Switzerland) was investigated by Möckel (1969), while the crystallographic fabric and the microstructural development of a mylonite rim around the body was discussed by Buiskool Toxopeus (1976, 1977^a). Möckel (1969) concluded that the oldest preserved plane in the garnet peridotite is S_L, a tectonic or magmatic layering defined by compositional variation. The principal preferred orientation pattern of the olivine is the $\gamma - 01. = [100]$ fabric (i.e. $\gamma - 01. = [100]$ is normal to the layering S_L and $\beta - 01. = [001]$ together with $\alpha - 01. = [010]$ are parallel to the layering S_L).

In a locally developed, later tectonic phase the garnet peridotite was altered

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to spinel amphibole peridotite. This deformation phase (F_O) produced folds in S_L and a schistosity (S_O) parallel to their axial surfaces; since these folds are rather tight, S_O is almost parallel to S_L, except in the hinge regions. Fold axes of S_L folds are parallel to olivine grain shape lineations.

In the spinel amphibole peridotite there is again a [100] fabric normal to S_O, developed during F_O (i.e. [100] is normal to S_O and [001] together with [010] are parallel to S_O) (MÖCKEL, 1969). Although in the limbs of the folds S_L is almost parallel to S_O, difference can be made between the oldest developed fabrics in the garnet peridotite related to S_L, and the subsequent, overprinted fabrics related to S_O. Two mineral lineations, and preferred orientation patterns of clinopyroxene, orthopyroxene and amphibole developed in a different way for these two events support this hypothesis (MÖCKEL, 1969, p. 120).

A tectonic origin for this new [100] olivine fabric, developed during F_O, was proposed by MÖCKEL (1969) because of its relationship to folding viz. in S_L folds a [100] fabric is present in the limbs ([100] normal to S_L), while in the hinges the [100] preferred orientation is normal to the fold axial plane. Electron microscope observations (BUISKOOL TOXOPEUS, 1976, 1977^b) of dislocation substructures indicate that the active glide system was {Okl} [100] in the porphyroclasts as well as in the matrix grains. Since the major slip direction is parallel to [100], no preferred orientations of [100] parallel to the direction of shortening (Z) are to be expected after deformation (AVÉ LALLEMANT, 1975; BUISKOOL TOXOPEUS, 1976; SHELLEY, 1976). It is therefore difficult to explain an overall [100] fabric perpendicular to S_O as a tectonic fabric formed by a {Okl} [100] dislocation glide mechanism, because glide normal to the fold axial plane is an unrealistic model for folding. The orientation [100] parallel to the shortening axis (Z) is undeformable according the condition of VON MISES (1928), unless deformation is achieved by kinking or some other mechanism (PATERSON, 1969).

Another fabric type, the [010] fabric ([010] is normal to the S-plane, [100] together with [001] are in the S-plane), is more consistent with the electron microscope observations (BUISKOOL TOXOPEUS, 1976, 1977^b). This fabric type is developed in heavily deformed and recrystallized matrix grains in the mylonite rim around the peridotite body. Therefore some more petrofabric work was carried out to check the tectonic origin of the [100] fabric orientation in deformed parts of the peridotite; especially fold hinges of F_O folds were selected.

RESULTS

Petrofabric analysis was carried out on samples from three F_O folds (two tightly folded spinel amphibole peridotites AR 41, AR 42, and one open folded chlorite peridotite AR 29). Although MÖCKEL (1969, p. 109–112) has

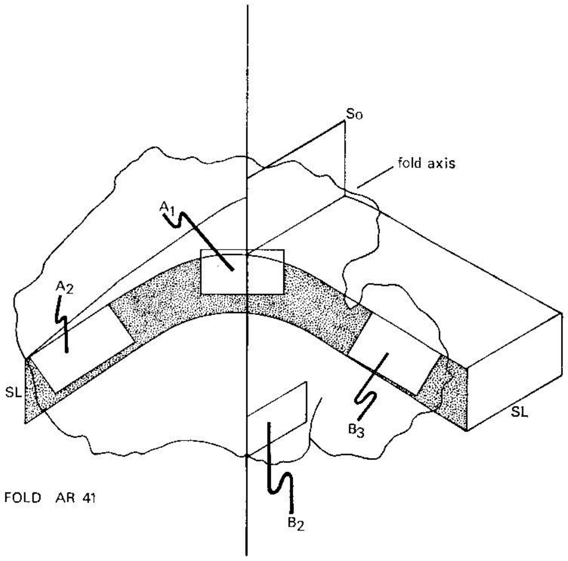

Fig. 1. Drawing of the folded handspecimen AR 41, showing the locations of thin sections AR 41A1, A2, B2 and B3. Sample normal to the fold axis.

already described two of these specimens (AR 41, AR 42), some new results were obtained.

AR 41. Four thin sections of this fold were investigated (Fig. 1). The fabrics of AR 41A2 and AR 41B3 were in general representative of the [100] fabric in the limbs of the fold ([100] normal to S_L, [001] and [010] forming girdle patterns in S_L, Möckel, 1969, p. 110). Two sections (AR 41A1, AR 41B2) from the fold hinge, however, yielded different preferred orientation patterns. Specimen AR 41A1 gave similar results as observed by Möckel (1969, p. 110) and points to a development of a strong [100] fabric normal to S_O instead of S_L. Specimen AR 41B2 (Fig. 2) resulted in a strong [010] pointmaximum at 45° to S_L, situated approximately in S_O, while [001] and [100] define broad girdle patterns with submaxima at 45° to S_L and S_O. Although both thin sections were taken only 5 cm apart in the fold hinge (Fig. 1), the fabric in the hinge is very inconsistent. The grains are elongated parallel to the fold axis, but no preferrred crystallographic orientation of olivine parallel to this elongation is observed.

AR 42. In spite of the heavy serpentinitization (Möckel, 1969, p. 111) one section was investigated. The thin section was covering the inner part of the fold hinge. The grains again are elongated parallel to the fold axis, but there is no preferred crystallographic orientation parallel to this direction. In general the preferred orientations of olivine are weak. [100] is oriented mainly in the S_L plane showing some pointmaxima at large angles to S_O, but a girdle of [100] pointmaxima is also present parallel to S_O. [001] is randomly oriented with some preference for S_O and S_L. [010] is mainly oriented in S_O in two point-maxima, but orientations at large angles to S_O in S_L also occur.

AR 29. The chlorite peridotite possesses strong deformation features in larger crystals (porphyroclasts) surrounded by some equiaxed matrix grains, exhibiting foam structures with triple point junctions (Fig. 3). The rock shows a slightly folded layering S_{01} (S_L, S_O?). Thin sections from limbs and fold hinge were investigated, but no distinction was observed between them other than a slight folding of the fabric related to the fold geometry; porphyroclasts and matrix grains also exhibited similar preferred orientations (Fig. 2).

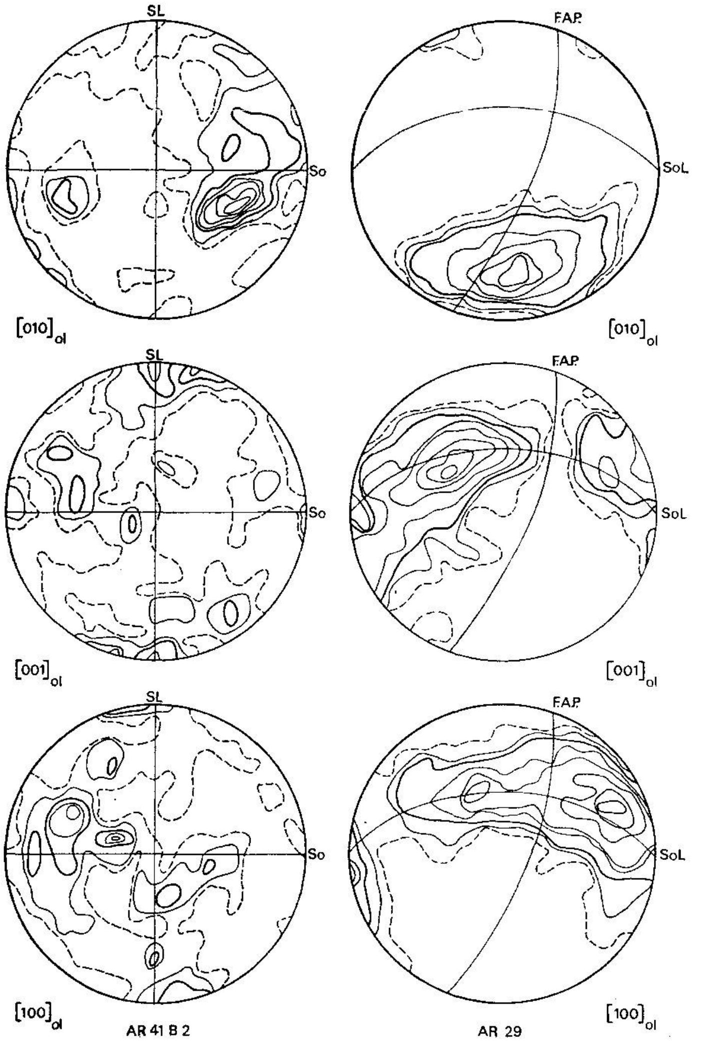

Fig. 2. Folded spinel amphibole peridotite AR 41B2, section parallel to the fold axis, diagrams rotated normal to the fold axis, 200 olivines, counting circle 2%, contours at 3, 5, 7, 9, 11, 13, 15. Chlorite peridotite AR 29, section normal to the fold axis (FAP = fold axial plane), 300 olivines (matrix and porphyroclasts), counting circle 2%, contours at 3, 5, 7, 11 ([100], [001]), 15 ([100]), 19, 23 ([100], [001]), 29 ([100], [001]), 37 ([010], [001]), 47 ([010]), 57 ([010]). Density 3: dashed line, density 7: bold contour.

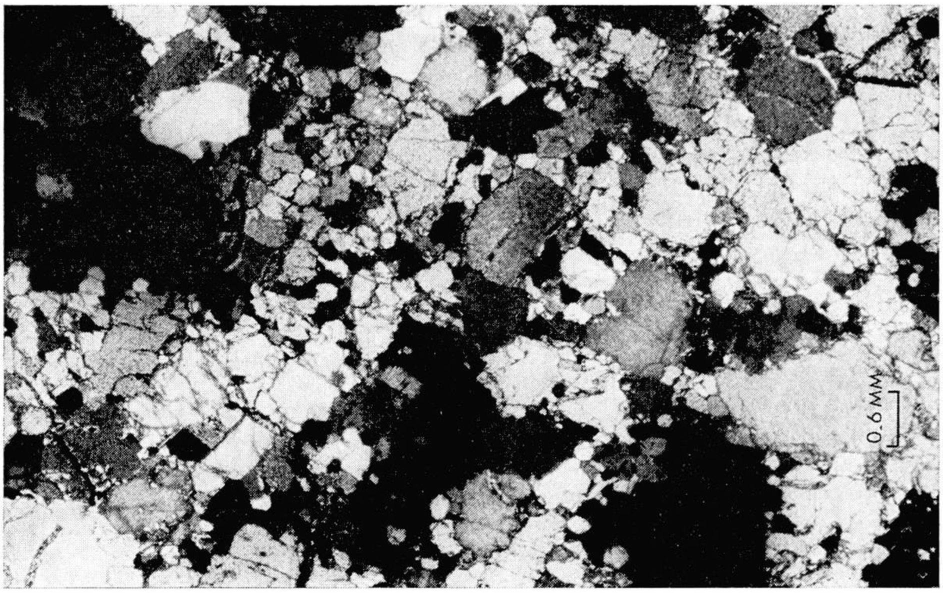

Fig. 3. The chlorite peridotite AR 29, strained olivine porphyroclasts embedded in recrystallized matrix grains. The slightly folded layering S_{01} is difficult to recognize in this part of the thin section.

The preferred orientation is extremely strong, showing a [010] pointmaximum normal to S_{01}, while [001] and [100] formed pointmaxima within the S_{01} plane (Fig. 2). No crystallographic preferred orientation was found parallel to the fold axis. The deformation features and the preferred orientation patterns visible in this rock are concluded to predate the slight folding.

DISCUSSION AND CONCLUSIONS

The existence of the [100] fabric normal to the layering S_L was indisputably proved by Möckel (1969), but the tectonic character of the [100] fabric is still an open question (Möckel, 1969; Avé Lallemant and Carter, 1970). As already mentioned the observed slip systems {Okl} [100] (Buiskool Toxopeus, 1976) can not explain the [100] fabric orientation, but is consistent with the observed [010] fabric. The possibility exists, that the [100] fabric was generated by dislocation glide systems completely vanished now by overprinting of subsequent deformation phases with other dislocation systems. Experimental results determining, P, T, $\dot{\epsilon}$ fields of the various slip systems known to be operative in olivines so far, however, do not support this explanation (Raleigh, 1968; Carter and Avé Lallemant, 1970; Carter, 1971; Phakey et al., 1972; Avé Lallemant, 1976; Green, 1976).

Although the number of folds studied is too small to draw definite conclusions about the overall fabric development during the various deformation phases in Alpe Arami, three types of patterns are observed:

1. [100] fabric normal to S_L (AR 41B3, AR 41A2); this fabric type was also observed by MÖCKEL (1969) as the oldest fabric development of possibly tectonic or magmatic origin;
2. weak to random preferred orientations in fold hinges, sometimes pointing to a [100] fabric normal to S_O (AR 41A1), in other cases (AR 41B2, AR 42) indicating transitions to a [010] fabric type;
3. strong preferred orientations featuring the [010] fabric normal to a layering S_{01} in strongly deformed and recrystallized specimens.

It is proposed that in highly deformed zones in the peridotite the [100] fabric is transformed into a [010] fabric, this in contradiction with the interpretation of MÖCKEL (1969).

In the tight folds (AR 41, AR 42) the S_O plane is not developed as a new schistosity plane; olivine crystals are not flattened (or recrystallized) in this plane, although, they are elongated parallel to the fold axis. The S_O plane in AR 41, AR 42, therefore has no meaning as a new tectonic reference plane in which flattening or recrystallization occurred. The fold hinge can be better described as a zone of more intense deformation compared with the limbs. As a result of the folding a strong mineral lineation is developed in the fold hinge parallel to the fold axis, pointing to some flow in direction of the fold axis. The number of different preferred orientation patterns, the inhomogeneity of fabric, also may point to the fold hinge as a zone of intense deformation with variable local strain conditions. This hypothesis is in contrast to shear or flexural slip fold models, assuming strong deformation in the fold limbs.

In the lims the [100] fabric normal to S_L was well developed (AR 41A2, AR 41B3); there was no need to change this orientation, because here only slight deformation took place. In addition to this a [100] fabric is difficult to deform in cases when S_L is parallel to S_O. The orientation [100] normal to a shear or flattening plane is almost undeformable and may give [100] relict fabrics (BUISKOOL TOXOPEUS, 1976; SHELLEY, 1976).

In regions in the limbs, but near to the fold hinge, with an increasing angular relationship between S_L and S_O, the original fabric [100] normal to S_L is still preserved. This feature shows that deformation in the limbs was comparatively small because strong deformation should cause fabric rotations from [100] normal to S_L to [100] in S_O.

In the hinges, however, the orientation [100] normal to S_L has disappeared completely (AR 41A1) or to a large extent (AR 41B2, AR 42), as a result of deformation (BUISKOOL TOXOPEUS, 1976).

Competent and incompetent layers, developed in the peridotite parallel to the mineralogical layering, would deform in a different manner in the fold hinge. In the competent olivine bearing layers extension and compression occurred normal to the fold axial plane in the fold hinge in respectively the outer and inner arc of the fold. In specimen AR 41 these two areas are studied, represented by AR 41A1 (the extension side) and AR 41B2 (the compression side). Petrofabric analysis results show in these two sections different preferred orientations. In the extension side of the fold hinge a [100] fabric was developed normal to S_O, in agreement with the hypothesis. Extension normal to S_O in this part will result in slip on {Okl} [100] giving a new preferred orientation of [100] parallel to the extension axis. This is in agreement with the observed fabric [100] normal to S_O.

In the inner part of the fold compression normal to S_O makes it impossible to develop new [100] preferred orientations normal to S_O. In the thin section covering this area transitional fabrics from [100] into [010] normal to S_O are developed, giving rise to complicated patterns. Depending on the degree of strain in this part of the fold hinge, a new fabric developed from random orientations to orientations with [100] in S_L; some similarity with the [010] fabric therefore is present. This fabric development is clearly visible in AR 29, a strongly deformed and partially recrystallized rock (AR 41, AR 42 do not show these deformation features). A completely new [010] fabric has developed here, showing a strong preferrred orientation as a final stage which could not be changed by further deformation on {Okl} [100] in respect to the strain axes (AVÉ LALLEMANT, 1975; BUISKOOL TOXOPEUS, 1976; SHELLEY, 1976). A similar development can also be seen in AR 18 (MÖCKEL, 1969, p. 113). Here [100] has rotated into S_O, while [010] shows a pointmaximum normal to S_O. Although in other specimens described by MÖCKEL (1969) [100] was concentrated normal to S_L or S_O, in most cases a tendency can be recognized for [100] to form weak girdle patterns towards the S-planes. This fabric development may also indicate a tendency to transform [100] fabrics into [010] fabrics during deformation.

Although the preferred orientations compared may have been formed during different deformation phases and in different strain regimes, there is evidence at least in some cases that the [100] fabric is transformed as a result of deformation into a more favourable preferred orientation: the [010] fabric. In some cases a new tectonic [100] fabric normal to S_O has developed locally in fold hinges in regions of extension normal to S_O. In the studied rocks no preferred orientations of [100] parallel to the shortening axis are found. These results are in agreement with fabrics observed in the mylonite rim around the peridotite body, showing a similar tendency (BUISKOOL TOXOPEUS, 1976, 1977^a, 1977^b).

The above described explanation of the [100] fabric only locally developed in fold hinges, can by no means explain why the [100] fabric was extensively formed in the garnet peridotite normal to S_L. However, its tectonic origin is very much open to question.

Storage

The samples are stored under numbers RGM 249747 (AR 29), 249760 (AR 41), and 249761 (AR 42) together with other Alpe Arami samples described by MÖCKEL (1969) and BUISKOOL TOXOPEUS (1976) at the Rijksmuseum van Geologie en Mineralogie in Leiden, The Netherlands.

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References

AVÉ LALLEMANT, H. G. (1975): Mechanisms of preferred orientations of olivine in tectonite peridotite. Geology, *3*, 653–656.

AVÉ LALLEMANT, H. G. and N. L. CARTER (1970): Syntectonic recrystallization of olivine and modes of flow in the upper mantle. Geol. Soc. Am. Bull., *81*, 2203–2220.

BUISKOOL TOXOPEUS, J. M. A. (1976): Petrofabrics, microtextures and dislocation substructures of olivine in a peridotite mylonite (Alpe Arami, Switzerland). Leidse Geol. Med., *51*, 1–36.

— (1977^{a}): Fabric development of olivine in a peridotite mylonite. Tectonophysics, *39*, 55–72.

— (1977^{b}): Deformation and recrystallization of olivine during mono- and poly-phase deformation, a transmission electron microscope study. Neues Jahrb. Min. Abh. *129*, 233–268.

CARTER, N. L. (1971): Static deformation of silica and silicates. Jour. Geophys. Res., *76*, 5514–5540.

CARTER, N. L. and H. G. AVÉ LALLEMANT (1970): High temperature flow of dunite and peridotite. Geol. Soc. Am. Bull., *81*, 2181–2202.

GREEN, H. W. (1976): Plasticity of olivine in peridotites. In: Electron Microscopy in Mineralogy. Ed. H.-R. Wenk. Springer Verlag, Berlin, 443–464.

MISES, R. VON (1928): Mechanik der plastischen Formänderung von Kristallen. Zeitschr. angew. Math. Mech., *8*, 161–185.

MÖCKEL, J. R. (1969): Structural petrology of the garnet peridotite of Alpe Arami (Ticino, Switzerland). Leidse Geol. Med., *42*, 61–130.

PATERSON, M. S. (1969): The ductility of rocks. In: Physics of Strength and Plasticity. Ed. A. S. Argon. The M.I.T. Press, London, 377–392.

PHAKEY, P., G. DOLLINGER and J. CHRISTIE (1972): Transmission electron microscopy of experimentally deformed olivine crystals. Geophys. Mon., *16*, 117–138.

RALEIGH, C. B. (1968): Mechanisms of plastic deformation of olivine. Jour. Geophys. Res., *73*, 5391–5406.

SHELLEY, D. (1976): Mechanisms of preferrred orientations of olivine in tectonite peridotite: Comment and Reply. Geology, *4*, 518–520.

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