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Spherically arranged inclusions in post-tectonic garnet porphyroblasts

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SUMMARY. Garnet porphyroblasts, containing elongate ilmenite inclusions arranged in an essentially spherical pattern, are described. The garnets are post-tectonic, and the inclusion pattern is the result of deformation and simultaneous replacement of the matrix by the growing porphyroblast.

THIN sections of a quartz–muscovite–chlorite–chloritoid–garnet schist from Connemara, Ireland, reveal a distinctive inclusion pattern within the garnet porphyroblasts. The inclusions are arranged in a spherical manner more or less about the centre of the porphyroblasts, and it can be demonstrated that this pattern developed during static growth of the garnets. The samples were collected from a coastal exposure due north of Bunnahowna, Renvyle Point, Connemara; the regional geology of this area has been described by Cruse and Leake (1968).

The matrix of the rock consists of small ($< 0{\cdot}2$ mm) flakes of chlorite and muscovite, which, together with elongate grains of ilmenite (usually $< 0{\cdot}1$ mm in length), define the schistosity of the rock. Xenoblastic quartz grains (*ca* 0·1 mm diameter) occur, mainly in quartz and chlorite-rich layers resulting in microscopic inhomogeneity of the matrix. Post-tectonic porphyroblasts of mimetically grown lamellar twinned chloritoid ($< 1{\cdot}5 \times 0{\cdot}4 \times 0{\cdot}4$ mm) and round to sub-idioblastic (rarely idioblastic) garnet (up to 2·5 mm diameter) are abundant, whilst accessory tourmaline, apatite, and porphyroblastic plagioclase (probably albite) also occur. The chloritoid porphyroblasts cut across the schistosity, occasionally at high angles, and contain trails of ilmenite inclusions continuous with the matrix fabric, thus providing clear evidence of the post-tectonic growth of the chloritoid. The garnet porphyroblasts occur as inhomogeneities in the rock, with the schistosity closely bowed around them. A weak crenulation cleavage puckers the rock and marks the last event observable on a microscopic scale, except for minor late-stage alteration.

Inclusions in the garnets are almost entirely elongate ilmenite grains, identical in appearance and composition to those in the matrix. The similarity of composition was verified by microprobe analysis. In thin section these inclusions are arranged more or less concentrically about the core of the porphyroblasts. Thin sections cut at varying orientations with respect to the schistosity all show this pattern, implying that the three-dimensional geometry defined by the inclusions is essentially spherical. Figs. 1 and 2 show such garnets. Fig. 2, with the coarse ilmenite inclusions, is not

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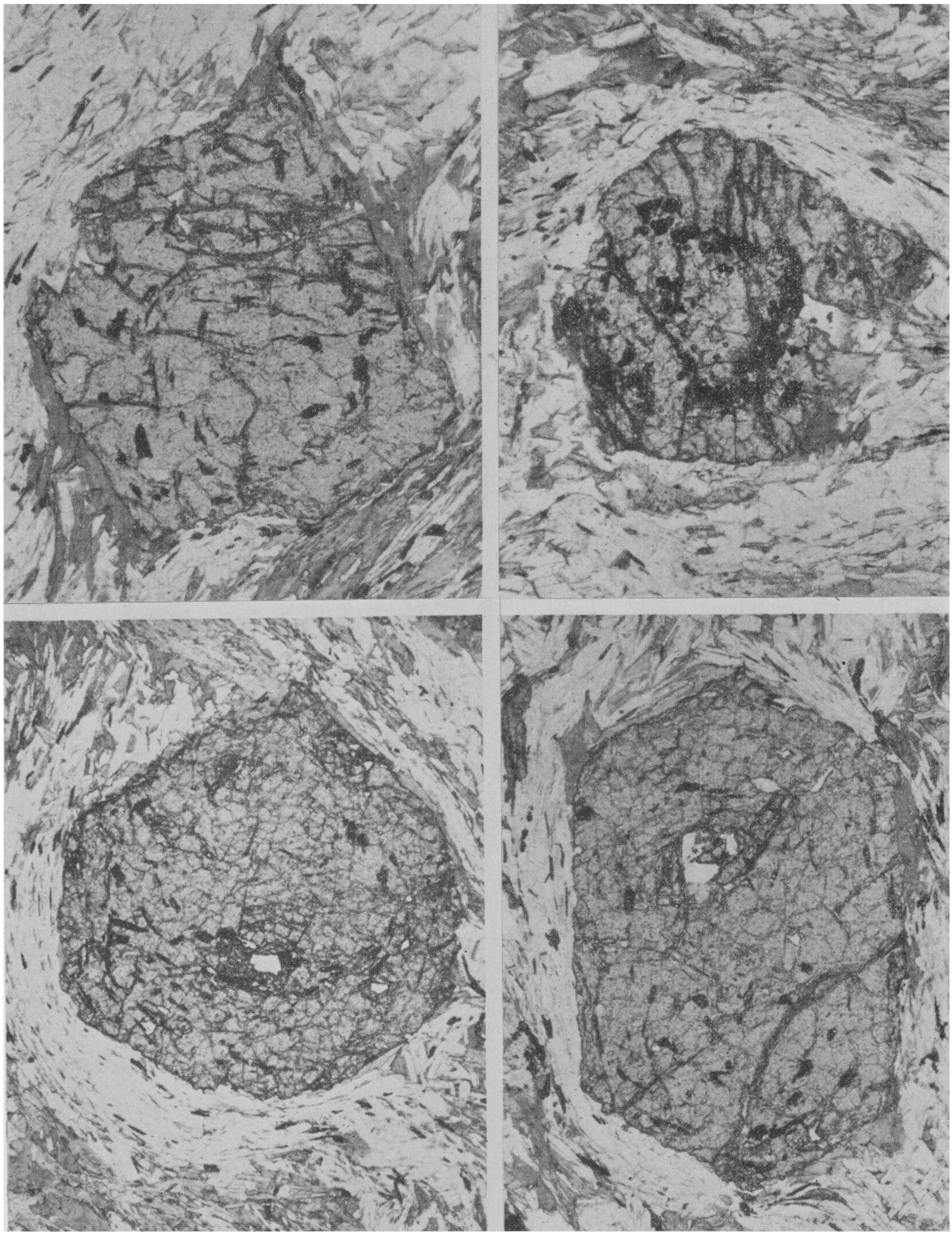

FIGS. 1 to 4: FIG. 1 (top left). Discontinuous rings of ilmenite plates in garnet. Note ilmenite continuous between garnet and matrix. FIG. 2 (top right). Similar to 1, but coarse ilmenite inclusions. FIG. 3 (bottom left). As 1 but inclusion pattern asymmetric. FIG. 4 (bottom right). Idioblastic garnet showing inclusions parallel to the garnet form. All figures: ×50, plane polarized light; low relief minerals: grey, chlorite; colourless, muscovite; black, ilmenite.

typical, but does show an almost complete ring. In most garnets the rings are incomplete due to the low abundance of inclusions. Fig. 3 shows a similar garnet in which the inclusion pattern is asymmetrically disposed with respect to the core of the garnet: in this case this asymmetry is reflected in the matrix deformation, the matrix being more strongly deformed on the side furthest from the centre of the inclusion pattern. Fig. 4 shows an idioblastic garnet in which it is apparent that the inclusions are actually orientated parallel to the faces of the porphyroblast. Clearly the roughly spherical inclusion pattern in most of the garnets simply reflects the approximately spherical shape of the garnets. Some idioblastic garnets show a circular arrangement of inclusions towards their centres, with inclusions mimicking the idioblastic outlines towards their edges, suggesting that the idioblastic shape was only gained late in their development. The cores of the garnets are frequently free of inclusions.

Several lines of evidence show that the garnets grew post-tectonically, and probably finished growing after chloritoid growth had ceased:

The phyllosilicates of the matrix are frequently truncated by the garnets; due to the fine grain-size of the matrix this is not easy to demonstrate but is shown locally in fig. 1. Ilmenite plates, continuous with the external schistosity, are occasionally partly enclosed in a garnet; two examples of this occur in fig. 1. Chloritoid porphyroblasts may, together with the matrix phyllosilicates, be moulded around the garnets; such crystals exhibit strain extinction, a feature absent from the chloritoid in the body of the rock. The schistose matrix in contact with the garnets is commonly depleted in chlorite and enriched in muscovite, indicating an antipathetic chemistry between the porphyroblast and its matrix; this is shown clearly in fig. 3. In one instance chloritoid was observed partly enclosed by garnet, the texture strongly suggesting later overgrowth by the garnet.

It is not possible to reconcile these observations with tectonic deformation of the matrix around the garnets. Similarly, there is no possibility that these inclusion patterns are spirals due to syntectonic growth of the garnets. Fig. 4 demonstrates that the inclusions are essentially parallel to the crystal faces of the garnet. In addition, Powell and Treagus (1970) have shown that there is no section of a porphyroblast grown during rotation that shows essentially circular patterns of inclusions. Furthermore the garnets are demonstrably post-tectonic. Hypotheses treating the inclusions as exsolved phases in the garnets are also untenable due to the continuity of ilmenites observed between the garnets and their matrices, and the similarity in composition and appearance between the included ilmenites and those in the matrix. Later flattening of matrix around the post-tectonic garnets also seems unimportant. In particular, chloritoids growing away from garnets show no strain extinction or microboudinage (Misch, 1969) and even where they cross the schistosity at a high angle are undeformed (Misch, 1972, p. 922). The textural relationships are, however, compatible with a mechanism whereby the garnets both displaced the matrix around them, and replaced the matrix as they grew, in a manner similar to that envisaged by Misch (1971). It is suggested that as the garnets grew, the matrix, with its elongate ilmenite plates, was moulded around the garnets and brought into parallelism with the developing garnet form. With subsequent or simultaneous overgrowth and replacement of the matrix, the ilmenite plates were retained as inclusions parallel to the growing surfaces. Figs. 1, 3, and 4 all show ilmenite plates in the matrix already aligned parallel to the garnet margins.

It must be concluded that the garnets have simultaneously both displaced and replaced the pre-existing schistose matrix during their growth. Thus, although the criteria which Misch (1971) proposes for the recognition of such porphyroblasts are insufficient (Ferguson and Harvey, 1972), this example strongly supports Misch's general conclusion, and may be considered as a diagnostic inclusion pattern for post-tectonic crystals around which a schistosity has been moulded during their growth.

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