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Heterogeneous strain of a phyllite as revealed by porphyroblast–matrix relationships

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Abstract—Garnet porphyroblasts in a homogeneous phyllite specimen from the central Norwegian Caledonides provide insight into the distribution and type of strain which followed the garnet growth. Matrix schistosity is traceable through the porphyroblasts in the form of inclusions which allow the measurement of two parameters: the flattening of the matrix schistosity around the porphyroblasts, and an angle of rotation of the porphyroblasts relative to the matrix schistosity. Both parameters vary considerably as studied in a large thin section cut parallel to mineral lineation and perpendicular to schistosity. Accepting some simplifications and assumptions, it seems necessary to consider the strain as composed of two components: a noncoaxial strain component of a simple-shear type, and an approximately coaxial strain component, both of which are heterogeneously developed on the scale of the thin section. The shear planes of the simple-shear-type strain are likely to lie parallel, or at a very small angle, to the matrix schistosity. The linear fabric of the phyllite seems to be a material expression of the coaxial strain component. The $\lambda_1\lambda_2$ plane of the finite strain ellipsoid most probably varies in orientation across the thin section and is only, by coincidence, parallel to the almost constantly oriented matrix schistosity.

INTRODUCTION

THIS paper investigates the strain variation in a phyllite specimen through analysis of porphyroblast–matrix relationships and seeks to explore the role of the schistosity during a particular event of deformation.

The significance of schistosity, i.e. penetrative planes of splitting defined by a preferred dimensional orientation of metamorphic minerals in tectonites, has been a subject of discussion for many years. Some investigators hold that the schistosity plane is parallel to the $\lambda_1\lambda_2$ plane of the strain ellipsoid and was so during its formation, while others seem to favour the interpretation that the schistosity plane, at least in some cases, is parallel to a plane of high shear strain (see discussion in Hobbs *et al.* 1976, p.231).

This investigation indicates that in the phyllite specimen studied, despite a homogeneous appearance on handspecimen and outcrop scales, the $\lambda_1\lambda_2$ plane of the finite strain ellipsoid varies in orientation throughout the specimen and only by coincidence is parallel to the schistosity plane.

The local geological context of the sample is described in Olesen *et al.* (1973) and Olesen (1974).

SAMPLE DESCRIPTION

Field occurrence

The sample is a porphyroblastic grey–green phyllite of Early Palaeozoic age from a locality a few km north of Tydal, in the Trondheim region of Norway (11°40′40″ E/63°04′42″ N). It has homogeneously developed schistosity, and a mineral lineation is visible on the schistosity planes (Fig. 1). Regional considerations suggest that the schistosity and mineral lineation were formed during the second regional deformation episode (D_2), although there is no direct indication of this at or near the sample locality. Only one *S*-surface is visible in the hand specimen studied, although thin section observations indicate that a thin and discontinuous compositional layering lies at a very small angle to the schistosity (Fig. 2). But at surrounding localities similar phyllites display an older folded compositional layering to which the schistosity is axial planar.

Microstructure

The matrix of the phyllite consists of about equal amounts of lath-shaped phyllosilicates (white mica and chlorite) and generally elongate quartzes with a grain size (long axis) of 0.05–0.1 mm. Minor amounts of biotite and opaque phases are also present. The rock is homogeneous on the scale of the hand specimen, except for a few layers of mm thickness which consist of about 75% quartz, equidimensional grain size 0.1–0.2 mm, and about 25% lath-shaped chlorites, 0.1 mm size. In general, the quartz grains have straight to slightly curved grain boundaries and no, or only weak, undulose extinction.

The phyllosilicates and the elongate quartzes both have good, preferred dimensional orientation, which provides the rock with its schistosity. This is also lineated, again defined by the dimensional orientation of the constituent minerals, particularly the phyllosilicates. Contributing to this mineral lineation is a good preferred dimensional orientation of numerous elongate biotite porphyroblasts with an average dimension of about 0.25 × 1 × 2 mm with the smallest dimension perpendicular to the schistosity. Many of the biotite

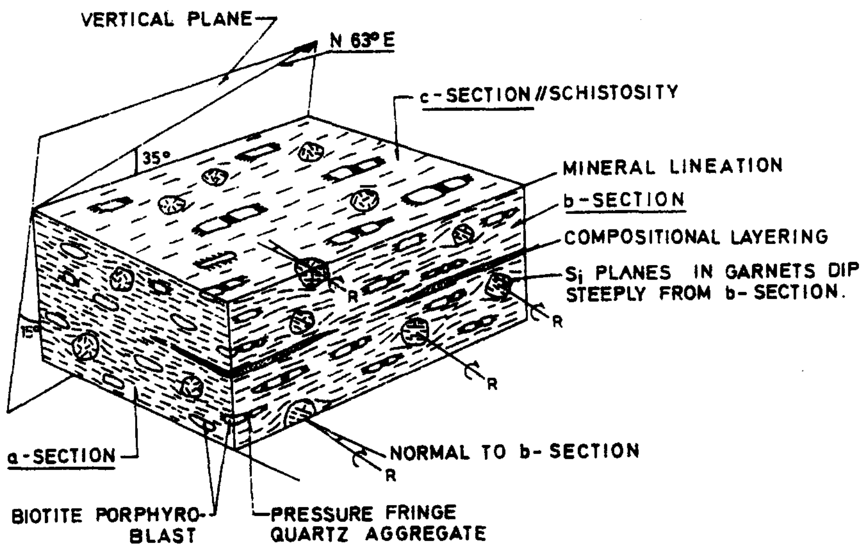

Fig. 1. Block sketch demonstrating the geometrical relationships of the structural and microstructural features of the sample, and defining the a-, b- and c-sections.

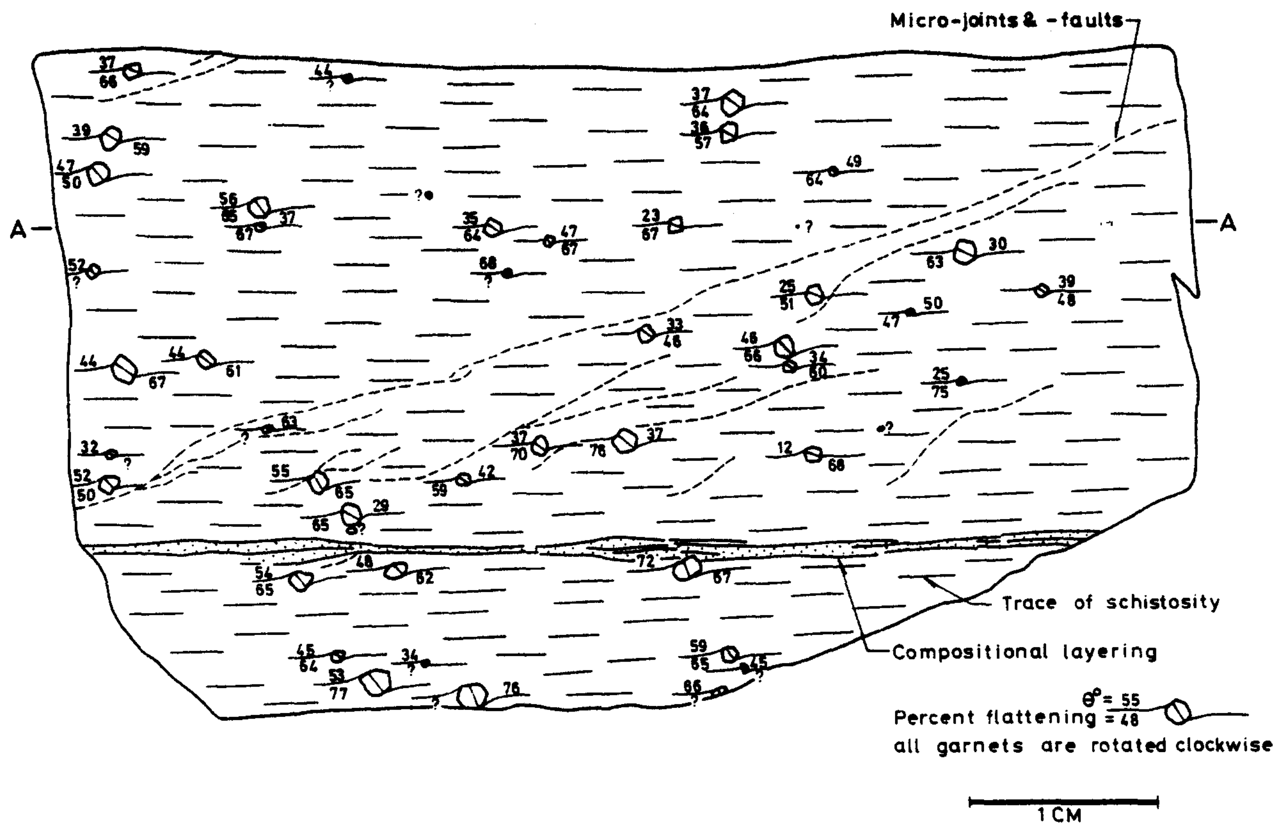

Fig. 2. Sketch of large thin section of b-section orientation. The garnet porphyroblast shown in Fig. 3(a) is at the upper right, denoted 30/63. Further explanation in text. In an absolute sense the rotation of garnets is clockwise, when observed toward the NW. The geometry of the micro-joints and micro-faults indicates that the slip direction on these surfaces lies at a large angle to the b-section.

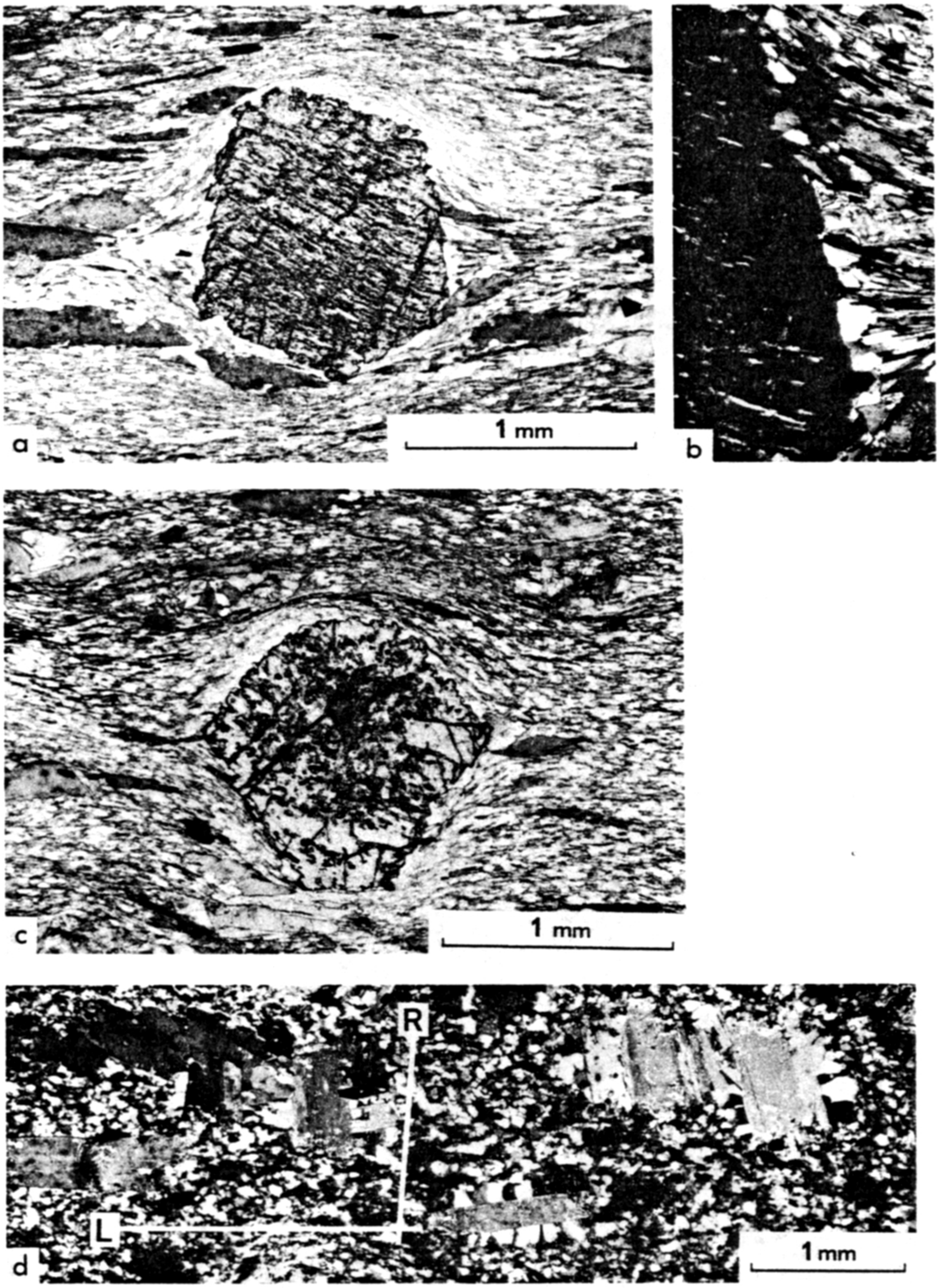

Fig. 3. (a) One garnet and several biotite porphyroblasts, observed in a thin section cut perpendicular to schistosity and parallel to mineral lineation (the b-section). The arrow points to a pressure fringe quartz aggregate on a biotite porphyroblast. One nicol. (b) Close-up of garnet porphyroblast in (a) demonstrating perfect continuity and parallelism of the included planar fabric and the matrix schistosity in the upper part of the figure, and incipient pressure fringe quartz growth in the lower part. Two nicols. (c) Similar to (a), but observed in the a-section. One nicol. (d) Biotite porphyroblasts with pressure fringe quartz aggregates, observed in the c-section. Two nicols. L indicates the orientation of the mineral lineation, while R shows the approx. orientation of the garnet porphyroblasts rotation axes.

porphyroblasts are in fact segmented, tied together by pressure-fringe quartz aggregates (see Fig. 1). The biotites are all deformed, showing undulous extinction and frequent kinking of the (001) cleavage, which in most cases lies at an intermediate to high angle to the schistosity. The schistosity curves around the biotites, although some biotites show discordant relationships (Figs. 3a & c). They have no internal fabric.

Garnet porphyroblasts are less abundant. They tend towards idioblastic and equant shape, are generally between 1 and 1.5 mm in diameter, and are fairly evenly distributed in the rock, although they lie close together in pairs at several places (Fig. 2). A few very small garnets (small as observed in thin section; most size variation in this case is probably due to the cut effect) contain no internal fabric. All the other garnets contain a planar or only slightly curved (S-shaped) internal fabric (S_i) in their centres, defined by elongate grains of quartz and opaque phases, which can be traced continuously across the garnet grain boundary into the matrix schistosity (S_e) with a varying angle between S_i and S_e (Fig. 3b). Most garnets show a distinct S-shaped curving of the internal fabric along the margin of the porphyroblasts. The schistosity also curves around the garnet porphyroblasts (Figs. 3a & c). Thus, the garnet and biotite porphyroblasts postdate a schistosity which was deformed after the porphyroblast growth ceased, but in the case of the garnets there was some overlap in time (e.g. Zwart 1962).

The planar inclusions in the garnets (S_i) suggest a time period of no (or very slow) deformation during which most of these porphyroblasts grew. It is not possible to recognize whether this static period was a true interkinematic period between D_1 and D_2 (Olesen *et al.* 1973) or if it reflects rapid growth of the garnets during D_2 (Olesen 1978). The garnets may, thus, be interkinematic or synkinematic. This paper is concerned with that part of the D_2 deformation which postdates this static period, whether it comprises all or only part of the D_2 deformation.

The homogeneity and type of strain were investigated by microscopic study of the geometry of S_i of the garnets and S_e of the matrix.

GEOMETRY OF S_i/S_e

Three thin sections were studied (Fig. 1): one perpendicular to the schistosity and almost parallel to the mineral lineation (referred to below as the b-section); one perpendicular to the schistosity and almost perpendicular to the mineral lineation (the a-section); and one section parallel to the schistosity (the c-section).

Where possible, two parameters were measured in the b-section: the flattening of the schistosity, and the angle between S_i and S_e (Fig. 4). S_i was traced through the garnets, across the garnet grain boundaries and into the corresponding schistosity planes of the matrix, using photomicrographs (an improvement on the method of Trouw (1973, p. 111)). In a few garnets it was not possible to trace S_i into S_e accurately enough, due either to an inclusion-free garnet margin, or to a partial loss of continuity between S_i and S_e in garnets with high angles between S_i and S_e, and no figure is indicated. In the remaining garnets, the percentage figure of flattening is believed to be accurate to within ± 10% in the figure.

The angle between S_i and S_e (θ) was measured in almost all garnets and the only difficulty was to find the orientation of S_e at an 'undisturbed' distance from porphyroblasts. θ is believed to be accurate within ±3°, and as S_i is planar, it is free from any cut effect as opposed to garnets with spiral inclusions (e.g. Powell & Treagus 1970; Schoneveld 1979).

Figure 2 is a sketch of the thin section of b-section orientation. The positions and orientations of compositional layering, the matrix schistosity, and the garnet porphyroblasts are indicated, as are the measured flattening and θ. Micro-joints and micro-faults related to late kink bands are also shown; these are non-penetrative retrogressive features and will not be considered further.

Figure 5(a) is a plot of the flattening percentages against θ's from those garnets where both figures could be measured. The flattening lies between 46 and 77% with a mean of 63%, while θ varies between 12 and 76°. There is no obvious relationship between the variation of the two parameters, between θ and the distance to the nearest neighbour garnet (N.N.D.) (Fig. 5b), or between θ and the garnet grain size as observed in the b-section.

The garnet porphyroblasts observed in the a- and c-sections contain an isotropic inclusion pattern, in one case with a diffuse linearity. In the a-section the matrix schistosity curves around the porphyroblasts in a symmetrical pattern and the garnet grain boundaries cut S_e discordantly (Fig. 3b).

The angle between S_i of the garnets and the plane of the thin section of b-section orientation was measured using the method of Powell (1966). The orientation of the dominant quartz–garnet grain boundaries of the quartz inclusions within the garnet porphyroblasts was measured on a universal stage. The result was a remark-

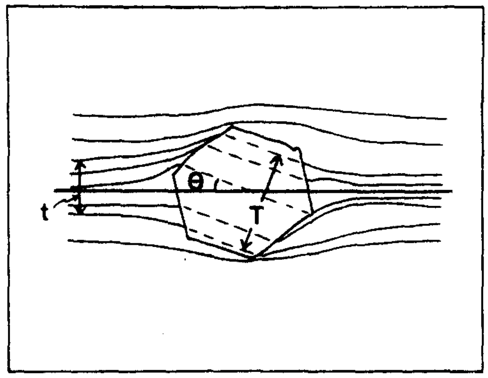

Fig. 4. θ is the angle between S_i and S_e. The flattening is indicated in per cent: $(T-t) \times 100/T$, where T is the distance between two clearly recognizable S_i planes, while t is the distance between the two corresponding matrix schistosity planes. In cases of S-shaped S_i along margin of porphyroblast, θ is the angle between S_e and the central planar part of S_i.

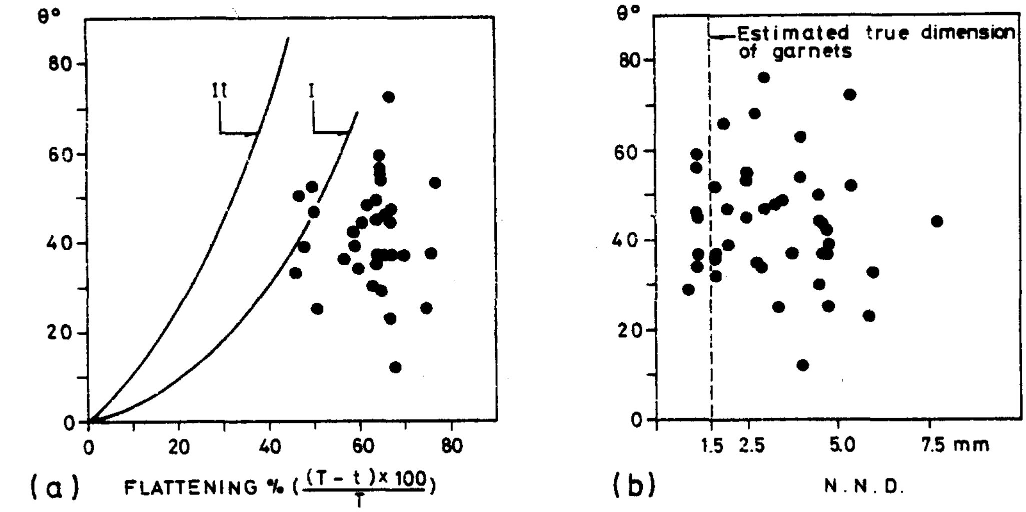

Fig. 5. (a) Plot of flattening against garnet rotation θ. A linear regression calculation results in a correlation coefficient R of −0.01. The graphs emanating from (0,0) refer to Fig. 6. Further explanation in text. (b) Plot of garnet rotation θ against the distance to the nearest-neighbour (N.N.D.) in the b-thin-section. The true centre-to-centre distance will in almost all cases be greater than the measured N.N.D.

ably constant orientation of S_i. The measurements within individual garnets are, in some cases, constant from one side to the other; in other cases the dip varies up to 9°. The average dip of S_i in the porphyroblasts relative to the plane of the b-section varies only slightly, from 75 to 90° with a mean of 83°, without any obvious relation to variation in θ, or the distance to the nearest neighbour garnet, and all dips are towards the NE quadrant (Fig. 2). These observations indicate that the axes (R) of relative rotation of the garnet porphyroblasts are fairly constant in orientation, that they lie in the schistosity plane (S_e) and are almost perpendicular to the b-section, irrespective of the amount of relative rotation. As the angle between the b-section and the mesoscopic mineral lineation is 3° at the most, it follows that the R's display a significant departure of a few degrees from being perpendicular to this lineation (Fig. 1).

THREE-DIMENSIONAL SHAPE OF GARNETS

A fundamental problem in the interpretation of the described microstructural–geometric relationships is the 3-D shape of the garnet porphyroblasts. Six- and five-sided polygons are by far the most common outline of the garnets in the three sections, supplemented by a few four- and seven-sided polygons, which indicate that the fundamental garnet shape is the dodecahedron.

Length to breadth ratios of the garnets have been measured in the three thin sections, and the results are compared with similar measurements on an absolutely equant model dodecahedron (Table 1). The highest L/B ratios in the thin sections are all from small garnets with irregular or three- or four-sided outlines, suggesting that they are actually marginal cuts through larger garnets. The comparison with the model dodecahedron demonstrates that the garnet porphyroblasts of this study are equant, statistically speaking. Therefore, as a first approximation, they will be treated in the following section as rigid spherical objects, unless otherwise stated.

INTERPRETATION

The recognition of θ's departing from 0° raises several questions. (1) Did the matrix schistosity rotate and the porphyroblasts remain fixed in orientation as visualized by, e.g. Ramsay (1962)? (2) Did the garnets rotate and the schistosity remain fixed in orientation? (3) Was it a combination of these two possibilities as modelled by, e.g. Ghosh (1975)? If (1) is the explanation, θ should be almost constant since the garnet elongation is very small or nonexistent and the schistosity has a constant orientation. This is not the case; θ varies through more than 60°. Furthermore θ-values greater than ~45° are probably inconsistent with (1) as initial angles between the direction of shortening and the matrix schistosity of less than 45° would more likely result in folding (crenulation) than passive rotation, as the matrix has a strong mechanical anisotropy. Therefore, possibilities (2) and (3) remain, and the strain pattern must contain at least a component of noncoaxial strain to explain the observed geometry.

Table 1. Garnet shape (L/B ratios)

	N	X	σ	Min.	Max.
a-section	17	1.34	0.23	1.04	1.86
b-section	44	1.31	0.23	1.00	2.13
c-section	33	1.26	0.18	1.00	1.87
equant model*	40	1.26	0.20	1.10	2.13

L = longest dimension of grain measured in (thin) section.
B = dimension of grain perpendicular to L, measured from the midpoint of L.
* Random sections through an equant model dodecahedron are produced by generating (pseudo) random points on the surface, each three points repesenting a section.
N = number of measurements; X = mean; σ = standard deviation; Min. and Max. = lowest and highest values of L/B ratios, respectively.

Taking the component of noncoaxial strain, as a first approximation, to be a heterogeneous simple-shear type of strain, two questions are raised. What is the relationship between shear strain and garnet rotation and what is the orientation of the shear plane of the heterogeneous simple shear?

Two equations have been used to describe the relationship between amount of rotation (Ω in radians) of rigid spherical objects in simple shear (shear strain γ):

$\gamma = \Omega$ (Schmidt 1918)

and $\gamma = 2\Omega$ (Rosenfeld 1970).

However, both equations are based on an unrealistic mechanical situation. In the case of the Rosenfeld equation the spherical object is rotating in a flowing homogeneous matrix with isotropic mechanical properties. The Rosenfeld equation is also valid for a rigid sphere rotating in a Newtonian fluid undergoing simple shear (Jeffery 1922), but phyllites hardly behave as a Newtonian fluid, being more likely to follow a power creep law similar to some other geological materials (e.g. Carter 1976). Whether the creep is Newtonian or follows a power law, the difference in the rotational behaviour of rigid spheres is probably small (Ferguson 1979). More serious is the fact that phyllites are mechanically anisotropic. Schoneveld (1979, p.54) discussed the possible effect on garnet rotation caused by the usually strong preferred dimensional orientation of micas in schists and phyllites. In short, he considered accumulation of micas 'above' and 'below' a rotating garnet to impose an additional torque on it, and concluded that the valid equation may lie anywhere between the Schmidt and Rosenfeld equations, and that variations in the mica content of the matrix may cause the equation to vary between these two extremes. This subject is clearly a matter of much speculation, and it will be assumed in the following discussion that one equation is valid for all garnet rotations of this study, with the equation lying somewhere between the Schmidt and Rosenfeld equations.

The approximate orientation of the shear plane of heterogeneous simple shear may be found by inspection of Fig. 2. If the shear plane is non-material and lies at an appreciable angle to the schistosity of the specimen, a higher shear strain would result in greater flattening and a higher angle of rotation (θ), as well as wavy schistosity due to the heterogeneity of shear strain (Fig. 6). Neither this nor such a simple relationship between θ and the flattening is recorded (Fig. 5a). Furthermore, inspection of Fig. 2 does not reveal any obvious cross-cutting zones with constant θ's. On the contrary there is a tendency for porphyroblasts to lie with roughly similar values of θ in rows (sub-)parallel to the schistosity (e.g. line A–A in Fig. 2 with three garnets with relatively low values of θ, surrounded by garnets with θ's around 50°), suggesting that the trace of the shear plane in the b-section is identical to, or lies very close to, the trace of the schistosity in the b-section.

It is concluded above that the rotation axes of the garnets lie in the schistosity plane. Therefore, it is tempting to state that the shear plane is actually parallel to the schistosity plane of the specimen, with the direction of translation lying a few degrees from the direction of the mesoscopic mineral lineation. However, it is not possible to make this definite statement, as one cannot exclude the possibility of a small angle between the schistosity and the shear plane.

The above conclusion is critically dependent on the variation in θ-measurements reliably reflecting comparable variations in shear strain. It may be argued that variations in θ in the range of 20°, as is the case at line A–A in Fig. 2, are too small on which to base any firm conclusion, as garnets are not spheres but have edges and corners which may influence the angle of rotation, other factors being equal. Clearly the stress pattern around a dodecahedron embedded in a flowing matrix will be different from the stress pattern around a sphere, but a theoretical quantification of this effect is beyond the scope of this paper. An indication of the magnitude of this corner-edge effect is gathered from a number of

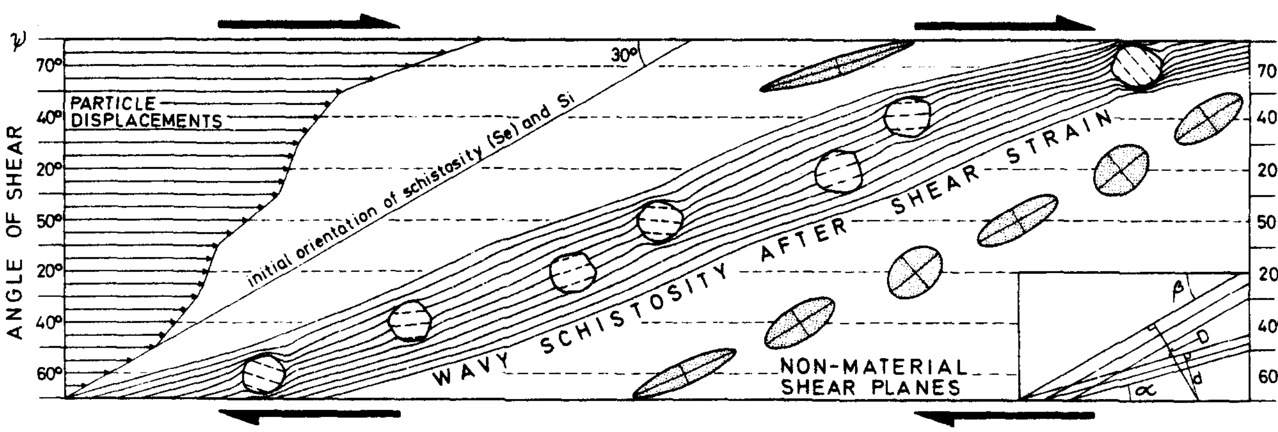

Fig. 6. Analysis of geometry of schistosity, flattening around rigid porphyroblasts, and rotation of porphyroblasts, during heterogeneous simple shear with non-material shear planes (lying at an angle to this schistosity). The analysis assumes that the trace of schistosity acts as passive marker lines during strain, and that the angle of porphyroblast rotation (Ω) is ½γ (Rosenfeld 1970, Dixon 1976). The relationship between θ and flattening of this particular model is shown with graph I in Fig. 5(a). The flattening is calculated as $(D-d)/D$ of the inset figure. The relationship between θ and flattening for a similar model based on the Schmidt-equation ($\gamma = \Omega$) is shown with graph II in Fig. 5(a).

tests of polygonal rigid bodies rotating in a simple shear box similar to that of Schoneveld (1979) and comparable to those of Ghosh (1975) and Ghosh & Ramberg (1976), using silicone putty as matrix (realizing that this again is an unrealistic matrix, mechanically speaking). The effective shape (i.e. the shape of the section through the centre of the body) of the dodecahedron is a four, six or eight sided polygon. The rotation behaviour of rigid bodies with equant four sided (F), six sided (S) and circular (C) cross sections has been studied through a shear strain (γ) of 3, during which all bodies rotated almost 90°. The S and C bodies rotated indiscernibly within the experimental eror, very closely following the Rosenfeld equation; the F body also followed the Rosenfeld equation after almost 90° of rotation but the experiments suggested that there are slight variations in the angular velocity on the way, other factors being equal. The F body rotated slightly less than the S and C bodies in the orientations with the body sides almost parallel and perpendicular to the shear plane, possibly taking up the loss again at a later stage. The maximum differences in body rotation for identical shear strains do not exceed 3° and, taking experimental error into consideration, the maximum possible difference after almost 90° rotation cannot exceed 6°. A few relevant experimental results of Ghosh & Ramberg (1976, fig. 5) and Willis (1977) are in accordance with this suggestion, but it would seem hazardous to extrapolate these results to nature in view of the mechanically unrealistic experimental matrix. As no experimental results using a mechanically more realistic matrix are known to the author, and as a theoretical quantification of this possible corner-edge effect still remains to be performed, it will be assumed here to be insignificant.

Another possible source of error in interpretation is suggested by the fact that several garnets lie in pairs. It is known from viscous theory and experiments (e.g. Darabaner & Mason 1967) that particles embedded in a flowing matrix may aggregate and rotate as units, two or more together. In the case of garnet porphyroblasts rotating in a (heterogeneous) simple shear, the distance between most garnets will change during the progressive deformation, and two (or more) garnets may get so close to each other that they aggregate, or they may already have aggregated during the preceding growth stage. Two aggregated equant and equal-size garnets will probably rotate as a rigid body with a shape of almost 2:1 (Wakiya 1971), which has a rotational behaviour known from theory (Jeffery 1922) and experiments (e.g. Ghosh & Ramberg 1976). The crucial feature is the orientation of the long axis of this doublet relative to the shear plane and shear direction. A doublet with its long axis lying in the shear plane and perpendicular to the shear direction will rotate as a single garnet, while a doublet with the long axis lying perpendicular to the shear plane will show a significantly larger rotation than a single garnet for identical shear strain increments. In the general case, the long axis will rotate along a pair of elliptical cones (Jeffrey 1922), which means that the orientation of a fixed plane within the garnets such as S_i is bound to change dip relative to the plane containing the shear direction and perpendicular to the shear plane. In this study this plane, as a first approximation, is taken to be the b-section.

It will be recalled that the average dip of the S_i in the garnet porphyroblasts relative to the plane of the b-section only varies between 75 and 90° and that there is no indication that the dip is related to the distance to the nearest neighbour garnet. It is clear from Fig. 5(b) that several garnet pairs are so close together that they may actually touch each other. If we consider, for example, the garnet pair denoted 46/66 and 34/60 in Fig. 2 and we assume that they are both 1.5 mm in diameter (estimated from the size variation in the thin sections) then they just touch each other to form a doublet with a long axis inclined ~45° to the schistosity plane. This is the doublet orientation which is expected to yield the greatest variations in S_i dip and yet the S_i dips of the two garnets are quite close to the mean of 83°. This suggests that aggregation is not an important factor in the interpretation of garnet rotation. It may explain some of the variation in S_i dips and in θ, but a closer study of the actual mechanism of doublet formation suggests that the influence on θ may be very small indeed (Fig. 7), insufficient to invalidate the above conclusions.

It is interesting to note that the second highest value of θ occurs in a garnet lying immediately adjacent to the slightly discordant quartz-rich layer (Fig. 2). Gregg (1978, 1980) described schistosity-parallel shearing which is apparently concentrated in or at quartz-rich layers; a comparable situation is possibly encountered here. Hobbs *et al.* (1976), in their discussion of the development of schistosity-parallel compositional layering, suggested that strain discontinuities play a role in this process. The phyllite specimen studied here may support this suggestion.

Figure 5(a) demonstrates a non-interdependence of θ to flattening. Most values of flattening lie around 60–70%, and it is not possible to detect an areal grouping of values in the b-section, except that two of the highest values (70 and 76%) were measured in two garnets lying close to each other in the same schistosity plane (in the centre of the b-section, Fig. 2).

It appears necessary to consider the total strain as a result of the interaction of two strain components: heterogeneous simple shear, as discussed above, and a component of an approximately coaxial strain, also heterogeneous, with no obvious relationship between these two components. Theoretically they could be of different ages, although the simplest explanation obviously would be to assume contemporaneity.

The direction of preferred dimensional orientation of micas in the specimen is clearly a direction of extension, as pressure-fringe quartz aggregates commonly lie at the short edges of the biotite porphyroblasts and also on the sides of garnets as observed in the b-section (Figs. 3a & b), and this is also the case where θ is low (i.e. where the simple shear strain is low). In the c-section similar pressure-fringe quartz aggregates are observed extending from many biotite porphyroblasts in the direction of

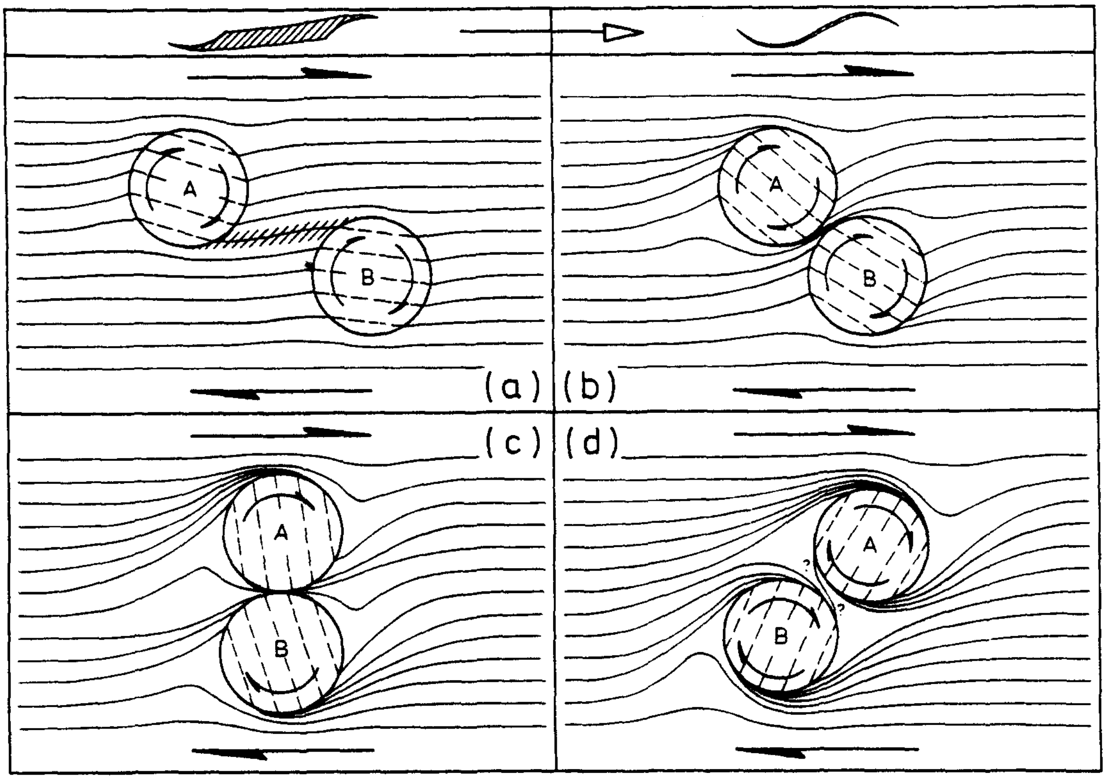

Fig. 7. (a) Two garnets are rotating according to the imposed shear strain with no mutual interference. Mica-rich domains develop 'above' and 'below' the garnets (see e,.g. Schoneveld 1979). (b) The two garnets approach each other and start to interfere. The mica-rich domain 'below' garnet A coalesces with the one 'above' garnet B, and this domain is bound to take up a very high strain of a non coaxial type including a large volume reduction. This is illustrated by way of hatching an area of identical material points. It is suggested here that in fact this domain works as a 'brake' on the angular velocity of the garnets. (c) Garnets A and B are (almost) in contact, rotating as a doublet. This implies, in analogy with fluid mechanics, that the body experiences an acceleration in the bulk angular velocity. However, it should be noted that the effective cross-section of the doublet is increasing, which calls for an additional diffusive transport of matrix material, such as quartz. (d) The garnets recede from each other and start to rotate as individuals, but the mica-rich domain between them still works as a 'brake'. The recession process involves a volume increase of the mica-rich domain, which is presumably accommodated by growth of pressure fringe minerals. It is suggested that these opposing effects to a large degree cancel each other out.

the lineation, but there are also a few examples of pressure-fringe quartz aggregates growing on biotite porphyroblasts in a direction at high angles to the lineation (Figs. 1 and 3d). Thus, both the flattening of the schistosity and the preferred dimensional orientation of micas appear to be material expressions of the coaxial strain component, where the principal extension λ_1 is parallel to the linear fabric (and different from the λ_1 of the simple shear component), and the intermediate direction λ_2 also lies in the schistosity plane (because of the symmetrical flattening around the garnets in the a-section), and is $\geqq 1$.

It is important to know the temporal relationship between the two components of strain discussed above for two reasons. (1) If the coaxial strain component postdates the simple shear type of strain, the possibility remains that there was originally an angle between the shear plane and schistosity up to ~20° (as judged from the present configuration of garnets in Fig. 2) which was subsequently diminished during the coaxial strain. (2) To be able to calculate the variation of combined strain across the b-section (i.e. the variation in orientation and axial ratios of λ_1 and λ_3), it is necessary to know the sequence of events (Rosenfeld 1970, Ramberg 1974). Assuming contemporaneity introduces similar problems, as it is necessary to know ($d\varepsilon/dt$) and ($d\gamma/dt$) to solve the problem of strain calculation and these parameters are completely unknown (Ramberg op. cit.).

One can state, however, that the $\lambda_1\lambda_2$ plane of the finite strain ellipsoid only by coincidence can equal the schistosity plane of the specimen, as it will vary in orientation throughout the specimen. The $\lambda_1\lambda_2$ plane of the combined post-porphyroblast strain ellipsoid will probably not lie in the schistosity plane, and the finite strain ellipsoid is a superposition of this post-porphyroblast ellipsoid on a pre-porphyroblast ellipsoid, the orientation of which is unknown.

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