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Albite porphyroblasts with sigmoidal inclusion trails and their kinematic implications: an example from the Taconic Allochthon, west-central Vermont

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Abstract

Microstructural analyses of albite porphyroblasts in phyllite of the Taconic Allochthon were conducted in order to determine the origin of the sigmoidal inclusion trails within the porphyroblasts and to evaluate if and when the porphyroblasts rotated during the deformation history. Three cleavages (S_2, S_3, and S_4) with similar strike are present in the phyllite. The albite porphyroblasts are characterized by inclusion-rich cores and inclusion-free rims, and the boundary between the cores and overgrowths is characterized by relatively straight and parallel zones of concentrated rutile. The sigmoidal inclusion trails within the cores are inferred to be trapped microfolds. The zones of concentrated rutile are interpreted to be truncation planes that formed during the development of S_3. In contrast to the tight orientation distribution of S_3, the truncation planes show a wide distribution pattern. The mean orientations of S_3 and the truncation planes also differ. These orientation data indicate that the porphyroblasts have not only rotated with respect to S_3 but also to the geographic reference frame. In addition, the growth of the porphyroblasts was influenced by differentiation associated with S_3 crenulation cleavage formation; the porphyroblasts grew preferentially within microlithon domains where chlorite, a reactant mineral for the porphyroblasts, is abundant.

1. Introduction

Porphyroblasts are widely observed in metamorphic rocks and provide both structural and metamorphic information for regional tectonic analysis. Information retrieved from porphyroblasts includes metamorphic facies from index minerals, pressure–temperature paths from zoned crystals, and overprinted structural fabrics from inclusion trails. In terms of structural significance, porphyroblasts with inclusion trails potentially record several deformation stages and the characteristics of the flow field. Porphyroblasts provide more geologic information than, for example, shear indicators in higher-grade rocks where several generations of cleavages may be present and incremental strain markers, such as fibrous veins and strain shadows, are rarely preserved.

In spite of the wide occurrence and usefulness of porphyroblasts, workers disagree on the growth interpretation of synkinematic porphyroblast inclusion patterns (e.g. Bell et al., 1992a, b; Passchier et al., 1992; Gray and Busa, 1994). A long debated issue is whether inclusion trails have a rotational or non-rotational origin, particularly for spiral and sigmoidal inclusion trails. Understanding the origin of inclusion trails is important because it affects the determination of sense of shear (Bell et al., 1992a; Wallis, 1992). Moreover, understanding if and when natural populations of porphyroblasts rotate during their growth history is important in light of previous theoretical and experimental work. This work indicates that rigid objects in a viscous matrix undergoing non-coaxial flow will, in general, rotate with respect to a kinematic

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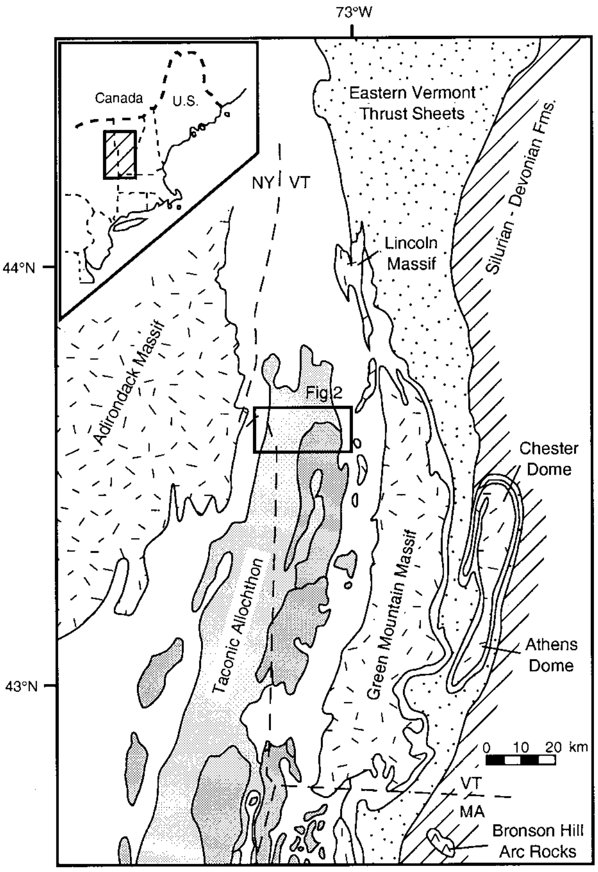

Fig. 1. Regional geologic map of major lithotectonic units in western New England. Redrawn from Stanley and Ratcliffe (1985). Inset shows location of map.

reference frame such as the instantaneous stretching axes of a flow field (Jeffery, 1922; Ghosh and Ramberg, 1976).

Albite porphyroblasts from phyllites of the northern Taconic Allochthon in west-central Vermont provide an opportunity for better understanding the growth of porphyroblasts with inclusion trails. The albite porphyroblasts commonly contain well defined sigmoidal inclusion trails. In addition the porphyroblasts are abundant, a standard-size thin section in some cases containing hundreds of porphyroblasts. The abundance and clarity of the inclusion trails allow a statistical study of the behavior of a population of porphyroblasts within single thin sections. Data from different samples were treated separately, which results in a better data set because there is no need to assume that samples experienced the same strain.

2. Geologic background

The Taconic Allochthon in western New England (Fig. 1) consists mainly of slate, phyllite and meta-siltstone, with subsidiary metamorphosed graywacke, limestone, and quartz sandstone. These rocks, ranging from late Proterozoic to middle Ordovician in age, are continental slope-rise deposits of the Taconic sequence. In New England, the Taconic Allochthon is interpreted to have been emplaced toward the west-northwest onto mostly coeval continental shelf deposits during a mid Ordovician arc-continent collision (Zen, 1967; Rowley and Kidd, 1981; Stanley and Ratcliffe, 1985; Karabinos et al., 1998). The phyllite samples used in this study are from the eastern part of the northern Taconic Allochthon in west-central Vermont (Fig. 2).

The northern Taconic Allochthon contains mineral assemblages that are consistent with lower greenschist facies conditions (e.g. muscovite + chlorite + quartz $\pm$-albite $\pm$ chloritoid) (Zen, 1960). The appearance of albite and chloritoid porphyroblasts in the eastern part of the northern Taconic Allochthon and the increase in grain size from west to east across the Allochthon indicate increasing metamorphic grade from west to east. The presence of paragonite and an association of albite and chloritoid suggest that the mineral reaction to produce the albite porphyroblasts in the greenish phyllites is most likely paragonite + chlorite + quartz = albite + chloritoid + water (Zen, 1960).

Field studies and structural analyses have resulted in the subdivision of the northern Taconic Allochthon across strike into three structural domains (Chan, 1998). These structural domains are delineated on the basis of the distribution and intensity of three regionally developed cleavages: S_2, a slaty cleavage; S_3, a crenulation cleavage and S_4, a spaced phyllitic cleavage. S_1 is only locally recognized and is typically a bedding-parallel fabric. The structural domains have gradational boundaries and are defined from west to east as follows (Fig. 2). Domain A contains a well developed S_2 and a weakly developed S_3. Domain B contains an overprinted S_2, a well developed S_3, and in the eastern part a very weakly developed S_4. Domain C contains overprinted S_2 and S_3, and a well developed S_4. A lineation (L_2, L_3, or L_4) defined by the preferred orientation of phyllosilicates on the cleavage surface is associated with each cleavage. The long axes of strain shadows associated with L_2 (Chan, 1998) and L_4 (see below) are on average parallel to the respective mineral lineations.

3. Microstructural observations

Thin-section analysis of rock samples collected across the northern Taconic Allochthon indicates that albite porphyroblasts are present only in Domain C. Not all samples collected in Domain C, however, contain albite porphyroblasts with distinct and well defined inclusion trails. Among more than a dozen samples from Domain C, two samples were selected

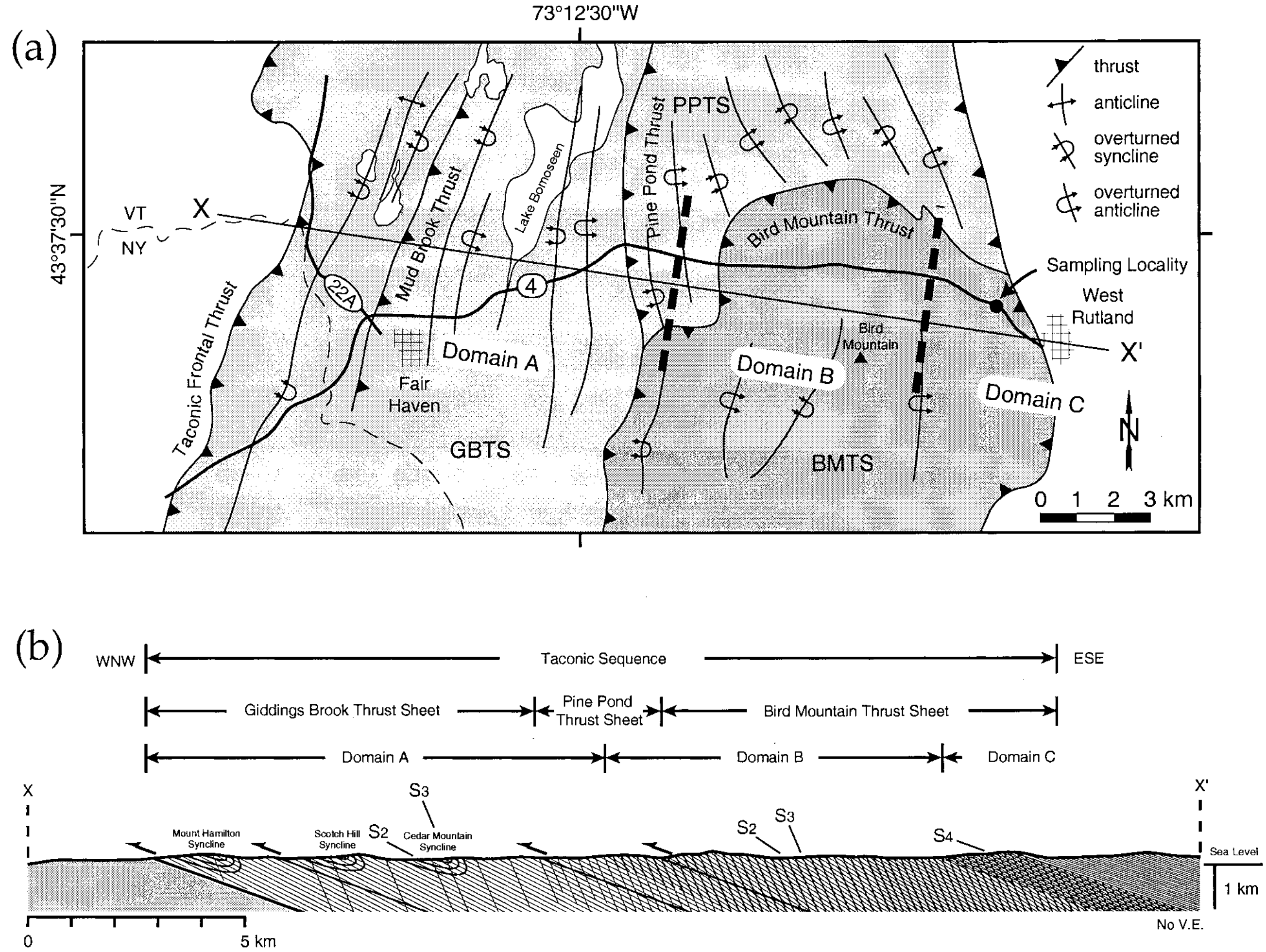

Fig. 2. (a) Simplified geologic map of northern Taconic Allochthon compiled from Zen (1961) and Fisher et al. (1970). Structural domains A, B, and C are delineated by dashed lines. Sampling locality is shown by solid circle. GBTS = Giddings Brook thrust sheet; PPTS = Pine Pond thrust sheet; and BMTS = Bird Mountain thrust sheet. (b) Schematic cross-section highlighting spatial distribution of three regionally developed cleavages (S_2, S_3, and S_4) in northern Taconic Allochthon. Cross-section line XX′ is shown in (a).

for a detailed study of porphyroblast microstructure, because they contain abundant albite porphyroblasts, about 200–300 per thin section, and well defined inclusion trails. In addition, S_3 is not strongly overprinted by S_4, allowing characterization and measurement of the orientation of S_3 in the matrix.

Thin sections were prepared in two orientations, one parallel to S_4 and the other perpendicular to S_4 and parallel to L_4. Thin sections in these two orientations are considered sufficient for studying the inclusion trails for the following reasons. First, the spatial association of S_4 and the albite porphyroblasts suggests that the growth of the porphyroblasts was primarily during the development of S_4. Second, the S_2, S_3, and S_4 cleavages have similar, approximately north-trending strikes. Although L_2, L_3, and L_4 have different plunges, they have similar east-southeast trends. The similarity in strike of the S_2, S_3, and S_4 cleavages, the similarity in trend of the associated lineations, and the approximately orthogonal relation between the strike of the cleavages and the trend of the lineations indicate that sections perpendicular to S_4 and parallel to L_4 are suitable for analyzing both cleavage patterns and inclusion trail patterns.

3.1. General characteristics of the albite porphyroblasts

The albite porphyroblasts generally have a long dimension of less than 0.25 mm and a short dimension of less than 0.12 mm. Although the grain size is small, the porphyroblasts show well defined shape and optical characteristics under the petrographic microscope. The porphyroblasts are characterized by inclusion-rich cores and inclusion-free overgrowths. Optical extinction angles are similar in both the core and overgrowth areas, indicating the overgrowths inherited the crystallographic orientation of the albite cores. However, the extinction in the cores is less sharp than the extinction

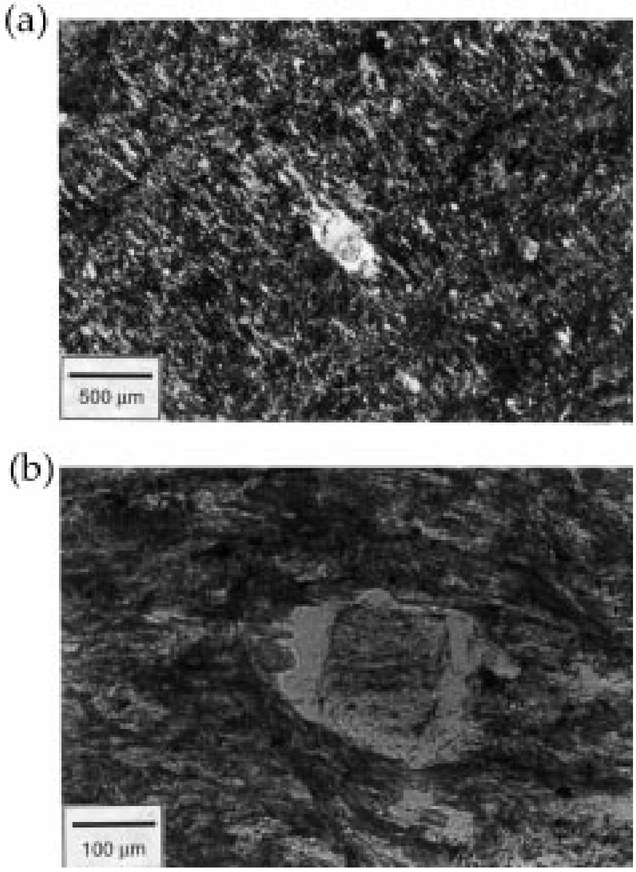

Fig. 3. (a) Photomicrograph of preferred orientation of phyllosilicates defining L_4 and elongate albite porphyroblast with long dimension subparallel to L_4. Dark chlorite-rich bands running from upper right to lower left are trace of S_3. S_4-parallel section. Cross polarized light. (b) Photomicrograph of a typical albite porphyroblast characterized by an inclusion-rich core and inclusion-free overgrowths. Inclusion-rich core shows two straight edges (truncation planes) and inclusion trails display counterclockwise curvature from center to edge. Long dimension of porphyroblast is subparallel to trace of S_4. S_4-perpendicular and L_4-parallel section. View is to north-northeast. Plane polarized light.

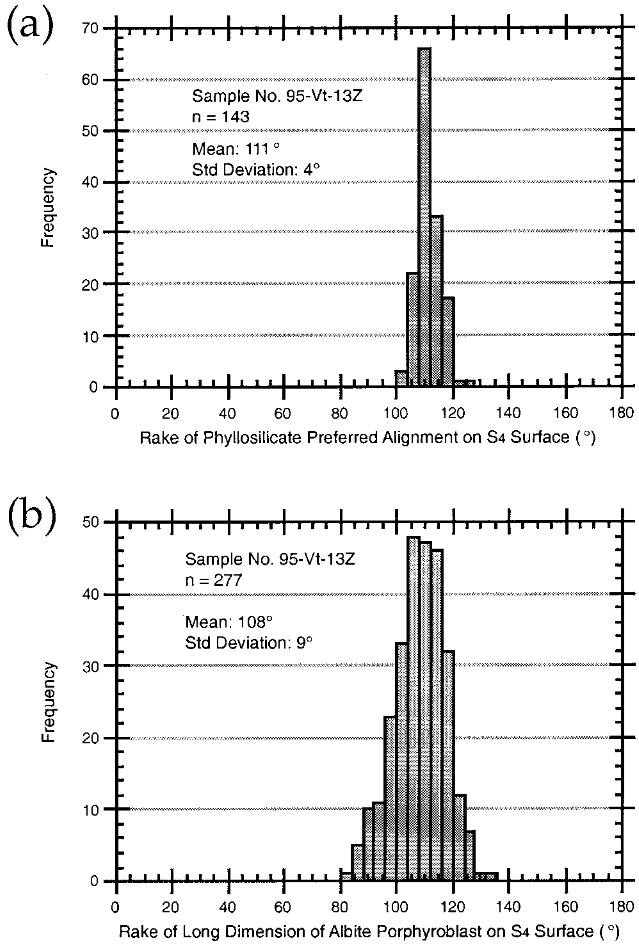

Fig. 4. Histograms of orientations of (a) long axes of phyllosilicates defining L_4 and (b) long dimensions of albite porphyroblasts. Measurements on S_4-parallel section and given as rake with respect to strike of S_4 in sample.

in the clear overgrowths. The cores in optical extinction are characterized by bright speckles, which are probably related to the dispersion of light by the inclusions.

The inclusion-rich albite cores are approximately equidimensional and have a diameter generally smaller than 0.15 mm. The inclusions are mainly composed of rutile, which is needle-shaped and has a length of from one to a few microns. Alternating narrow rutile-rich and rutile-poor zones, which have a spacing of several microns, define the inclusion trails and inclusion patterns observed in the cores of the porphyroblasts. Rutile is also widely distributed in the surrounding matrix.

Because the albite cores are surrounded by clear albite overgrowths, the internal inclusion trails and external foliations are discontinuous. Nevertheless, several lines of evidence suggest that the inclusion trails represent trapped slaty cleavage (S_2): (1) the grain size of the rutile needles is similar in both the albite cores and the matrix; (2) rutile is not involved in the albite-forming mineral reaction; and (3) the micron-scale spacing of the inclusion trails is similar to the spacing of S_2.

The contacts between the albite porphyroblasts and the matrix of the phyllite are relatively distinct and smooth. Less commonly, the albite interfingers with the phyllosilicates in the matrix. Although there is some variation, the shape of individual albite porphyroblasts approximates a prolate ellipsoid, the ratio of the longest to shortest dimension generally being less than two. The albite cores are present in the central part of the ellipsoidally shaped porphyroblasts. In S_4-parallel sections, the inclusion-free overgrowths bracket the albite cores, and the long dimension of the porphyroblasts (core plus overgrowth) lies parallel to the phyllosilicate preferred orientation in the matrix (Figs. 3a and 4). In addition, on the two sides of the

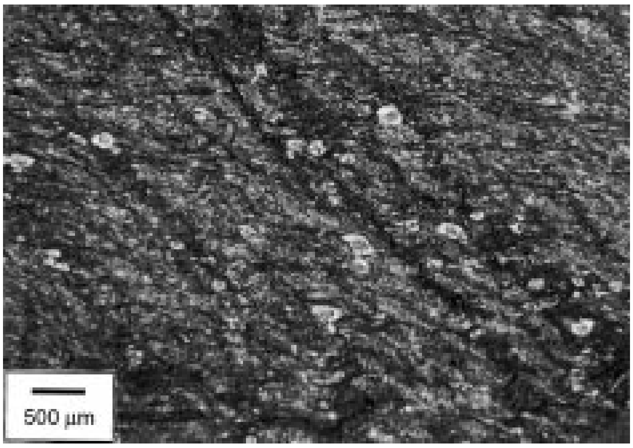

Fig. 5. Photomicrograph of differentiated S_3 cleavage characterized by chlorite-rich and chlorite-poor bands. Many albite porphyroblasts are present within photomicrograph. S_4-perpendicular and L_4-parallel section. View is to north-northeast. Plane polarized light.

albite cores where inclusion-free overgrowths are present, zones of concentrated rutile lie along the core–overgrowth boundaries (Fig. 3a). In S_4-perpendicular and L_4-parallel sections the inclusion-rich cores are, in general, totally surrounded by inclusion-free overgrowths, and the long dimension of the porphyroblasts is approximately parallel to the trace of S_4 (Fig. 3b). In many of the porphyroblasts, the overgrowths are slightly asymmetrically disposed, stepping up to the left when viewed to the north-northeast.

3.2. Geometry of the inclusion trails

In S_4-parallel sections, the rutile needles in the albite cores appear randomly distributed in most cases and do not display clear inclusion trails. In contrast, in S_4-perpendicular and L_4-parallel sections, the inclusion-rich cores show distinct inclusion trails (Fig. 3b). Generally, the inclusion trails are relatively straight in the central part of the albite core, although some show

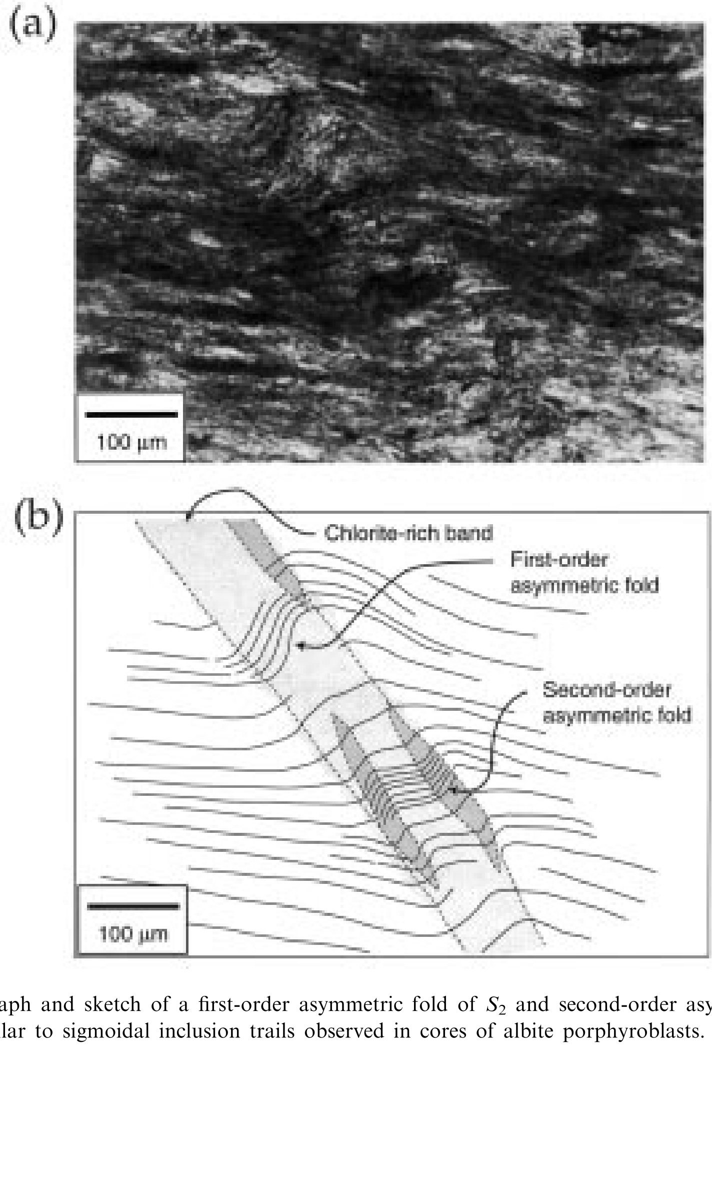

Fig. 6. (a) and (b) Photomicrograph and sketch of a first-order asymmetric fold of S_2 and second-order asymmetric fold of S_2. Geometry of folded S_2 in chlorite-band is similar to sigmoidal inclusion trails observed in cores of albite porphyroblasts. View is to north-northeast. Plane polarized light.

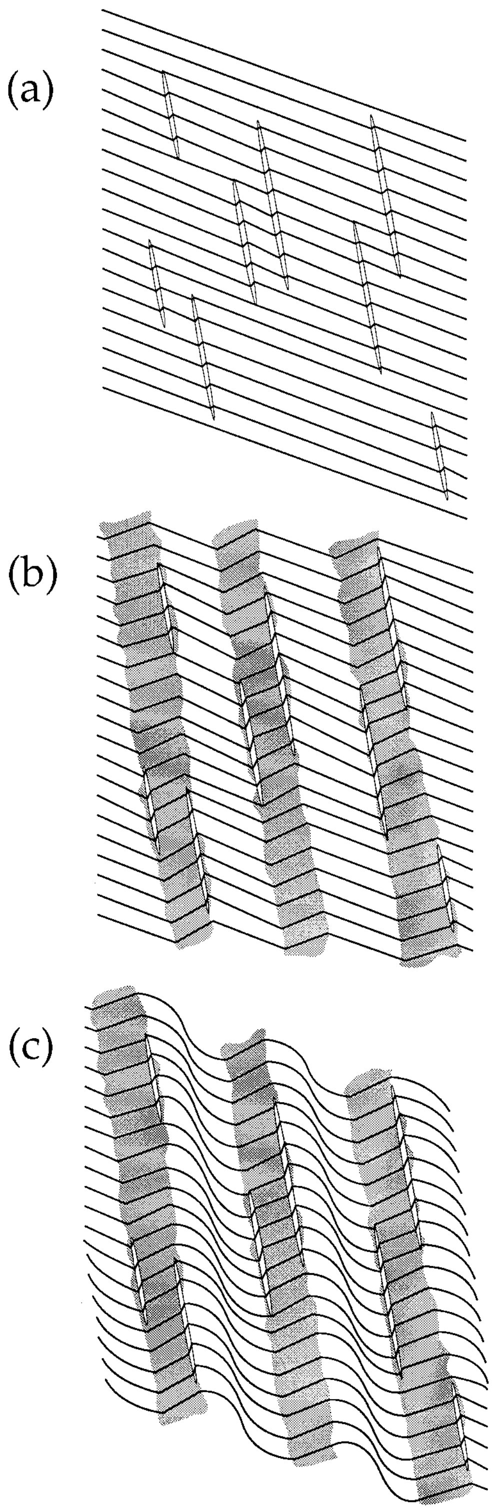

Fig. 7. (a) Schematic diagram of slaty cleavage (S_2) and second-order microfolds. (b) Same as (a) with addition of first-order microfolds and S_3-parallel chlorite bands. (c) Same as (b) with addition of S_3 zonal crenulation cleavage. Diagrams are drawn only for illustrative purposes because timing relations are unknown.

a slightly wavy shape. Relatively abrupt bends in the inclusion trails are present at the edges of the albite cores. In almost all the observed porphyroblasts, the inclusion trails display a sigmoidal shape. The shape of the sigmoidal inclusion trails typically shows counterclockwise curvature from the center to the edge of the core when viewed toward the north-northeast (Fig. 3b). Only a very small portion of the albite porphyroblasts (less than 5%) have sigmoidal trails with the opposite curvature. In addition, a few porphyroblasts have inclusion trails with a concave shape that is similar to the millipede structure of Johnson and Bell (1996).

As observed in the S_4-parallel sections, two relatively straight edges at the boundaries of the albite cores are a prominent feature of the porphyroblasts. These two straight edges are defined by zones of concentrated rutile, and they form abrupt contacts between the inclusion-rich cores and the inclusion-free overgrowths (Fig. 3b).

3.3. S_3 and S_3-parallel chlorite bands

The S_3 cleavage is a zonal to discrete crenulation cleavage which was superimposed on the penetrative slaty cleavage (S_2). The S_3 cleavage dips moderately to steeply to the east within the northern Taconic Allochthon. Mineral differentiation is locally associated with S_3. In greenish phyllites of Domains B and C, well organized S_3-parallel chlorite bands are commonly observed (Fig. 5). These chlorite bands generally lie along short limbs of first-order asymmetric microfolds, which display an S-shape when viewed to the north-northeast; the chlorite bands are parallel to the axial planes of these microfolds. Most of the albite porphyroblasts are present in the chlorite bands. Samples from Domain B, which contain a well developed S_3 but no albite porphyroblasts, locally show second-order S-shaped asymmetric microfolds along the edges of the chlorite bands (Fig. 6). The width of the chlorite bands is comparable to the width of the albite cores, and the geometry produced by the first- and second-order microfolds within the chlorite bands is comparable to the geometry of the most commonly observed inclusion trail type in the albite porphyroblasts. The second-order microfolds were not observed in the matrix of the samples from Domain C. Schematic diagrams in Fig. 7 illustrate the relations among the S_3 zonal crenulation cleavage, the S_3-parallel chlorite bands, and the first- and second-order microfolds.

3.4. S_4

The S_4 cleavage is a spaced phyllitic cleavage that dips gently to the east. In hand sample, the S_4 surface

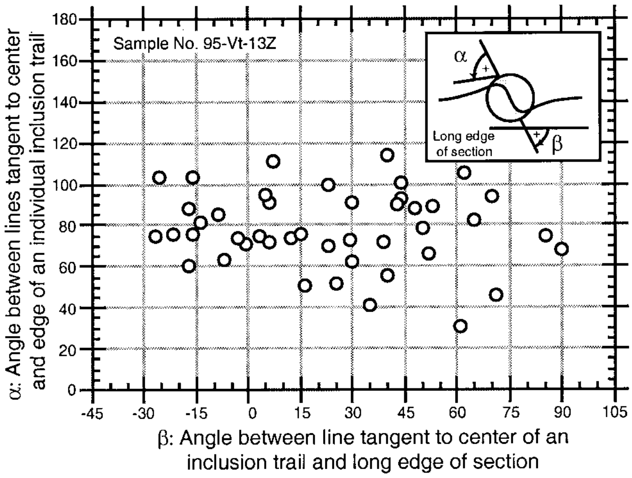

Fig. 8. Plot of angle between line tangent to center of an inclusion trail and a given reference line (β) vs angle between lines tangent to center and edge of an individual inclusion trail (α). Measurements on S_4-perpendicular and L_4-parallel section. Inset shows definition of angles α and β.

is lustrous and has a strong mineral lineation (L_4) defined by the alignment of phyllosilicates. The S_4 cleavage is characterized by larger cleavage-defining white micas than S_2 and S_3, and the thickness of S_4 cleavage domains is greater than that of S_2 and S_3. The albite porphyroblasts typically lie within the microlithon domains of S_4.

4. Evidence for inclusion trails being trapped microfolds

A set of criteria has been developed to determine whether curved inclusion trails are trapped microfolds or formed as a result of rotation of the porphyroblasts; these are summarized by Passchier and Trouw (1995, p. 182). Generally, six criteria support a rotational origin for curved inclusion trails: (1) continuous internal foliation (Si) spirals that are connected with the external foliation, especially when the sense of shear is confirmed by other shear indicators; (2) in elongate crystals, a symmetry axis of the Si spirals that is parallel to the long axis of the crystal; (3) included 'folds' in Si with a strongly curved axial surface trace; (4) Si spirals that appear to be included strain shadows; (5) a relative rotation angle indicated by Si curvature that is greater than 180°; and (6) Si spirals that decrease in amplitude from the center to the rim of the porphyroblast along the symmetry axis of the spiral. The first two criteria are not applicable to the albite porphyroblasts in the Taconic phyllites, because the inclusion-rich albite cores are surrounded by clear albite overgrowths and the cores are approximately equidimensional. The third to fifth criteria, which imply rotation of porphyroblasts only if the features are present, are not observed in the albite porphyroblasts.

Application of the sixth criterion usually requires serial sections of single porphyroblasts for geometric analysis of the shape of the inclusion trails. The inclusion trails of the albite porphyroblast population provide similar information, however, because the thin sections intersect each porphyroblast at varying distances from the porphyroblast center. The geometric analysis involves establishing the relation between two angles determined from the sigmoidal inclusion trails (see inset in Fig. 8). If the inclusion trails formed as a result of synkinematic rotation of the porphyroblasts, the angle (α) between the lines tangent to the center and edge of an individual inclusion trail should vary as the angle (β) between the line tangent to the center of an inclusion trail and a given reference line varies (Gray and Busa, 1994). For the albite porphyroblasts, the angle α displays relatively similar values regardless of the angle β, which varies up to about 120° (Fig. 8). The geometric analysis implies that the sigmoidal inclusion trails did not form as a result of synkinematic rotation of the porphyroblasts.

Two criteria are recognized in the literature to demonstrate that the Si inclusion patterns are trapped microfolds: (1) the inclusion of more than one fold wavelength and (2) similarity in size and geometry of included and matrix folds (Passchier and Trouw, 1995, p. 182). Superficially, neither criteria applies to the observed albite porphyroblasts, because the inclusion trails are sigmoidal in shape and the wavelength is not comparable to the spacing of the S_3 zonal crenulation cleavage. However, if it is assumed that second-order microfolds like those observed in samples from Domain B were also present in samples from Domain C but were strongly overprinted during the development of S_4, the sigmoidal inclusion trails are readily interpreted as trapped microfolds. The first criterion applies, the sigmoidal character of the inclusion trails resulting from the cores trapping two short limbs of the second-order microfolds. The second criterion also applies, the albite cores being of comparable width to the chlorite bands and to the trapped parts of the first- and second-order microfolds. Other supporting evidence for the interpretation of trapped microfolds is the presence of abrupt bends, a variable sense of curvature at the edges of the cores, and oppositely concave trails. In addition, trapping of folded layers is suggested by slightly wavy central inclusion trails in some of the large porphyroblasts.

5. Evidence for rigid-body rotation of the albite cores

Although the inclusion trails are interpreted as trapped microfolds, the porphyroblasts may nevertheless have rotated during deformation. The albite porphyroblasts provide the markers necessary for

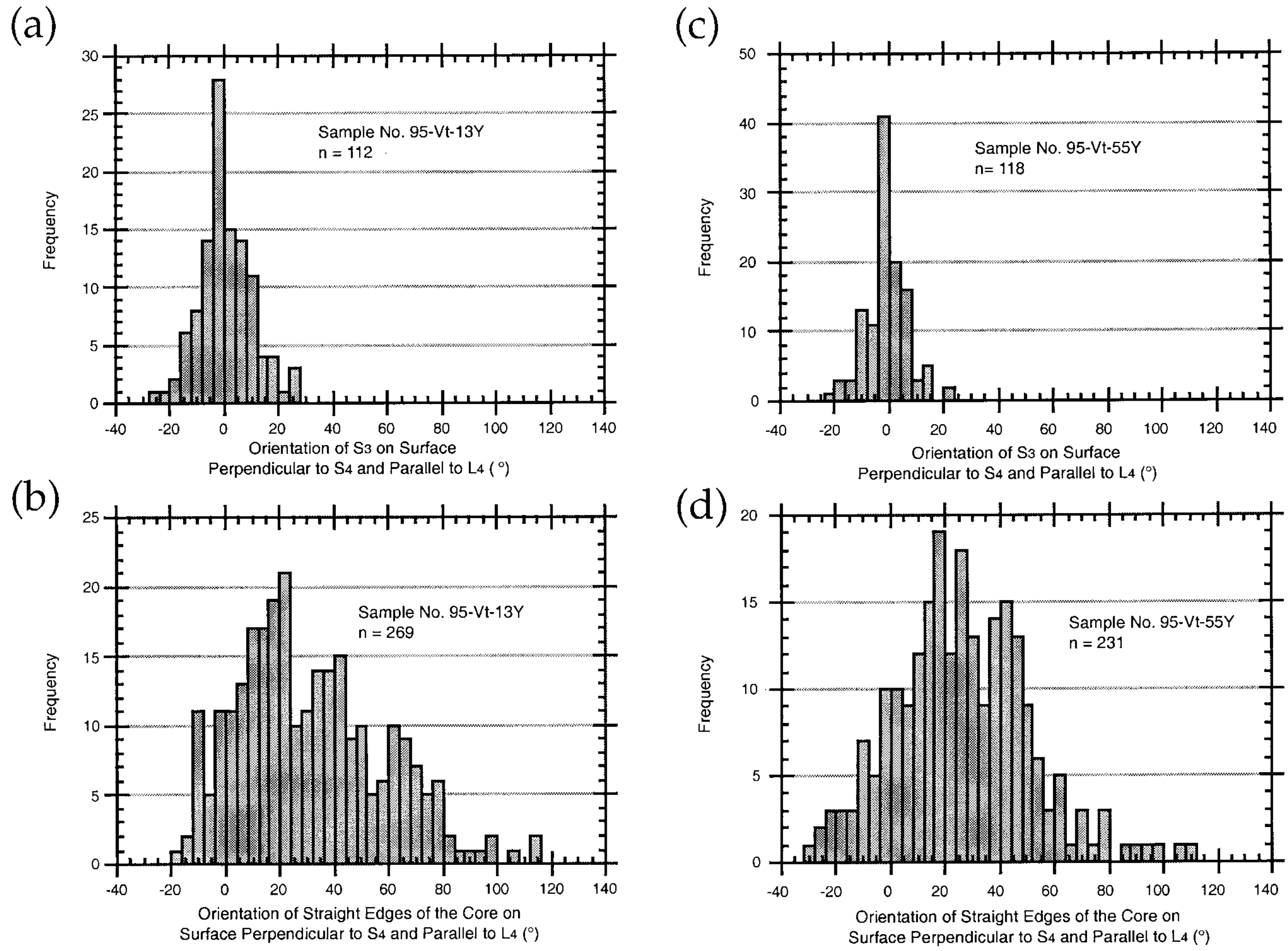

Fig. 9. Histograms of (a) and (c) orientation of S_3-parallel chlorite bands and (b) and (d) truncation planes along albite cores. Measurements on S_4-perpendicular and L_4-parallel sections. Thin sections view to north-northeast. Positive angles represent clockwise direction from a given reference line on thin sections.

determining whether they rotated with respect to a chosen reference frame. Because the axial plane of the trapped microfolds is parallel to the two straight edges of the cores, the two edges are interpreted as preserved cleavage domains of S_3. The two edges are referred to as truncation planes (cf. Passchier and Trouw, 1995). A marker that indicates the orientation before deformation is present in the form of the truncation planes in the porphyroblasts. Because the albite porphyroblasts show almost no sign of internal deformation such as wavy extinction and cracks, the truncation planes are considered to be unstrained. A passive marker in the deforming phyllite matrix is also present in the form of S_3-parallel chlorite bands. The initial positions of both markers should be statistically parallel before deformation because the truncation planes developed along S_3 cleavage domains.

Measurements of the orientations of the truncation planes and the S_3-parallel chlorite bands were made on the S_4-perpendicular and L_4-parallel sections. Because the two truncation planes in an albite core are about parallel, only one truncation plane was measured for an individual porphyroblast. The measurements show that the mean orientation of the S_3-parallel chlorite bands differs from the mean orientation of the truncation planes (Fig. 9). The difference in orientation indicates that the albite cores have rotated on average clockwise with respect to S_3 when viewed toward the north-northeast. The mean orientations are consistent with the top-to-the-west-northwest sense of shear for S_4 implied by the asymmetry of the inclusion-free overgrowths, S_3 rotating counterclockwise at a faster rate than the porphyroblasts on average.

The orientation of the truncation planes, which ranges from about $-20°$ to $80°$, is much more disperse than the orientation of the S_3-parallel chlorite bands, which ranges from about $-20°$ to $20°$ (Fig. 9). The fairly wide distribution of the orientation of the truncation planes indicates different amounts of rotation of the albite porphyroblasts with respect to S_3 as well as rotation of the porphyroblasts with respect to each other. Because the porphyroblasts rotated with respect

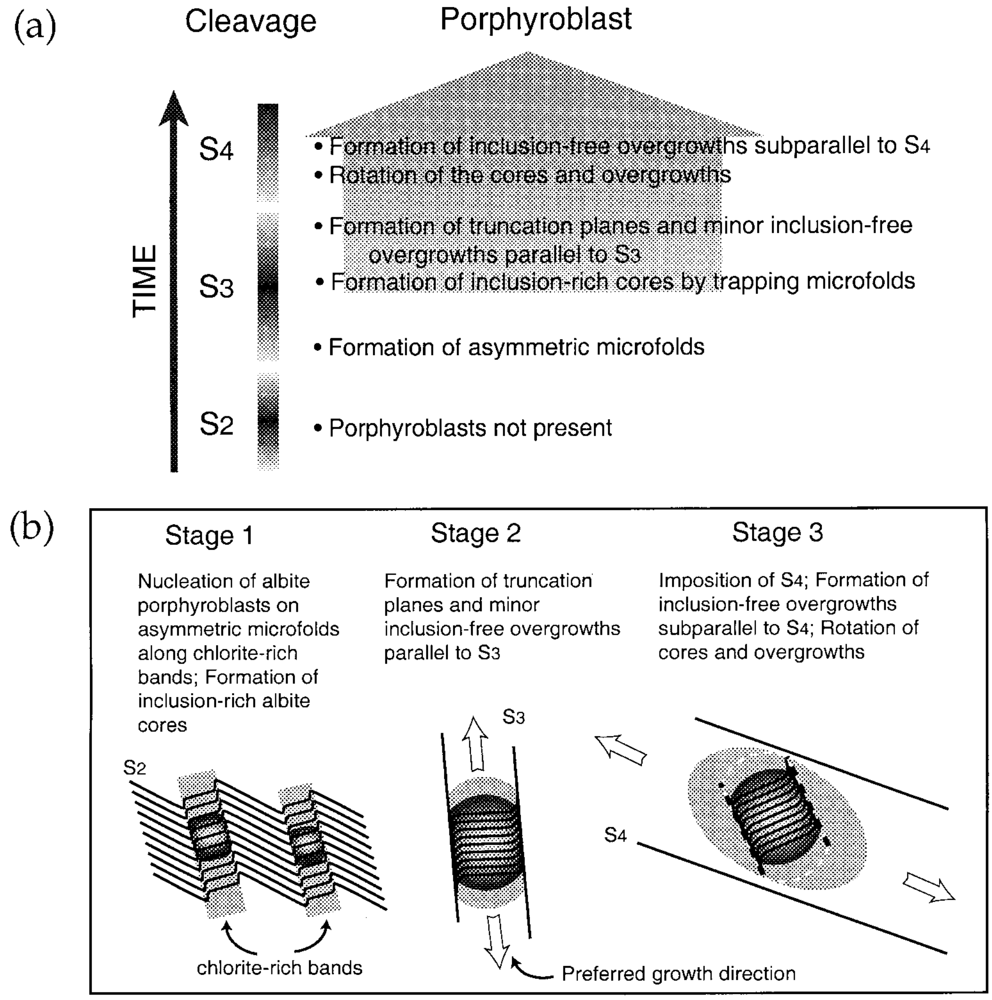

Fig. 10. (a) Timing relation between development of cleavages (S_2, S_3, and S_4) and growth of albite porphyroblasts. (b) Growth sequence for development of albite porphyroblast with sigmoidal inclusion trails that show counterclockwise curvature from center to edge.

to each other, most porphyroblasts must have rotated with respect to the geographic reference frame.

6. Discussion

The timing and spatial relations between the development of the cleavages and the growth of the albite porphyroblasts are inferred from the described microstructural features and summarized in Fig. 10. Porphyroblasts were not present during the development of S_2 and most of the history of S_3. They began to develop late in the history of S_3. The first growth stage involved preferential nucleation of albite porphyroblasts in chlorite-rich bands which contained sigmoidally shaped S_2 resulting from the geometry of first- and second-order microfolds. During this stage, the inclusion-rich cores formed and trapped the folded S_2 within the chlorite bands. The second growth stage, which also occurred late in the history of S_3, is characterized by the formation of inclusion-free albite overgrowths that result in the porphyroblasts having minor clear overgrowth parallel to S_3. This stage appears to have been accompanied by pressure solution, which contributed to the development of the well defined truncation planes along the edges of the albite cores. The growth of the porphyroblasts continued during the development of S_4. This third growth stage is characterized by the addition of inclusion-free overgrowths and the rotation of the inclusion-rich cores plus overgrowths as it was added. The accretion of overgrowths resulted in the porphyroblasts being elongate subparallel to S_4.

The association of the chlorite bands with the short limbs of the first-order S-shaped asymmetric microfolds indicates that the process of mineral differentiation in the phyllites is structurally controlled. Assuming constant length of folded layers, the formation of short limbs involves an increase in area during the initial stages (Suppe, 1985). This process creates void space which may facilitate fluid flow and the deposition of chlorite in the short limbs during deformation. Because chlorite is an important reactant to produce albite, the width of a chlorite band probably limits albite growth to single microlithon domains. This is evidenced by the albite porphyroblasts developing mostly along the chlorite bands.

Unlike many porphyroblasts which exhibit approximately idiomorphic crystal forms, such as those composed of garnet and staurolite, the shape of the albite porphyroblasts reflects the strain experienced by the rocks. In particular, the elongate shape of the porphyroblasts results from the inclusion-rich cores acting as relatively rigid objects that formed strain shadows for the directional growth of inclusion-free overgrowths. The geometry in S_4-parallel sections of the inclusion-free albite, which brackets the albite cores and lies parallel to the mineral lineation, is probably a reflection of plane strain deformation. Similar observations have also been reported in the Sanbagawa Belt in Japan, where large albite porphyroblasts in schists also exhibit clear albite overgrowths related to strain (Wallis, 1998).

Previous theoretical and experimental work has shown that rigid objects generally rotate with respect to a kinematic reference frame in a deforming viscous matrix (Jeffery, 1922; Ghosh and Ramberg, 1976). This work also shows that the rate of rotation of the rigid objects depends on the kinematic vorticity of the deformation flow and the initial orientation and aspect ratio of the objects. The albite porphyroblasts in the Taconic phyllites provide microstructural and geometric evidence supporting rotation of porphyroblasts in a deforming matrix. The evidence for rotation, however, does not involve the curvature of the sigmoidal inclusion trails, which are interpreted to be trapped microfolds. In principle, given a kinematic vorticity number for a deforming viscous matrix, the angle of rotation of a rigid ellipsoidal object varies systematically, depending on the initial orientation and the aspect ratio of the object (Ghosh and Ramberg, 1976). However, constant modification of the aspect ratio of the albite porphyroblasts during the development of S_4 makes it difficult to apply the theory to determine the kinematic vorticity number for S_4.

7. Conclusions

Microstructural observations and geometric analyses indicate that sigmoidal inclusion trails in albite porphyroblasts of the northern Taconic Allochthon do not reflect synkinematic rotation of porphyroblasts with simultaneous trapping of the external foliation. Instead, the inclusion trails represent trapped microfold geometries that were developed during the formation of S_3. Mineral differentiation is commonly associated with S_3 as shown by well aligned chlorite-rich bands. This structurally controlled differentiation explains why sigmoidal inclusion trails are present in the albite porphyroblasts: porphyroblast nucleation was localized in the bands where the reactant mineral, chlorite, was abundant and parts of the first- and second-order microfolds characteristic of the chlorite bands were accordingly trapped.

In contrast, geometric evidence other than the shape of the inclusion trails demonstrates that the albite porphyroblasts have rotated with respect to each other. This implies that most of the porphyroblasts must also have rotated with respect to the geographic reference frame. Although the rheology of the phyllite is not known, the geometric data support theoretical and experimental work indicating that rigid objects will rotate with respect to a chosen kinematic axis in a viscous fluid during homogeneous non-coaxial flow (Jeffery, 1922; Ghosh and Ramberg, 1976).

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