The significance of a thrust fault lineation in the Kalak Nappe Complex of Finnmark

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An unusual mineral lineation formed by garnets being gouged into quartzites at the base of a major nappe during late shearing shows that the nappe translation direction did not change significantly during the formation of D2 to D4 folds. This has considerable significance when correlating deformation phases to separate periods within the Caledonian orogenic event.

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The Kalak Nappe Complex (Roberts 1974) is the main metamorphic allochthon in the Caledonides of Finnmark (Fig. 1). Two main rock types have been identified within the complex: (1) a sequence of psammitic and pelitic metasediments with rare carbonate layers (Ramsay 1971), and (2) a suite of dominantly pelitic schists and gneisses thought to be allochthonous basement (Ramsay & Sturt 1977, Ramsay et al. 1980). Both rock types have been intruded by the Caledonian syn-orogenic Seiland Igneous Province (Robins & Gardner 1975) and by pre- or early Finnmarkian tholeiites (Rice 1982, Gayer et al. 1984). Nappe emplacement occurred during the Finnmarkian episode of the Caledonian orogeny (Sturt et al. 1978).

The Porsanger area

In the Porsangerhalvøya area (Fig. 1) a large number of thrust sheets of varying scales and significance have been identified (Rhodes & Gayer 1977, Hayes 1980, Rice 1981, 1982, Ramsay et al. 1984) and these have been grouped into eight main nappes or imbricate stacks by Gayer et al. (in prep., see Table 1). A model for the emplacement of these nappes by a gravity spreading model has been published by Chapman et al. (1984).

Of these eight main structural units, four have been recognized in the Revsbotn-Repparfjord area (Table 1), where all except the Seivika Nappe are composed of Caledonian metasediments. The Seivika Nappe is comprised of a sequence of dark brown to purple coloured pelitic and semi-pelitic schists, with occasional massive quartzite bands. Comparison of these rocks with the Eidvågeid Schists of Worthing (1971), which have recently been re-interpreted as allochthonous basement (Akselsen 1982), suggests that the Seivika Nappe may also be basement.

To the south west of Revsbotn (Fig. 1) the Seivika Nappe overlies the Olderfjord Nappe with a marked structural discordance, but this diminishes to the south. The upper contact with the Brennsvik Nappe is poorly exposed and has generally been cut out by upright normal brittle faulting.

Four main structural events have been distinguished within the basement rocks (Rice 1982), the first of which is recognized solely by a planar fabric (S1) within K-felspar porphyroblasts and some garnets. D2 produced large-scale tight to isoclinal folds with mesoscopic parasitic folds with gently to moderately inclined axial surfaces. Associated with these folds is a penetrative axial planar schistosity (S2). D3 folds have the same style as D2 folds but no associated fabric, whilst D4 folds are upright open periclinal folds similar to those described by Dubey & Cobbold (1977). D2, D3 and D4 axes trend between N–S and NE–SW except where the earlier folds have been rotated into the thrusting direction. At two levels minor thrusts associated with the D2 folding have divided the nappe into three thrust sheets.

The structures observed are similar to the typical deformation sequence in the cover nappes (Rice 1982). The main difference is the smaller interlimb angle and lower dip of the axial surface of the D3 folds in the Seivika Nappe.

Within the Seivika Nappe a relict K-felspar + sillimanite assemblage has been preserved. This indicates a considerably higher peak of metamor-

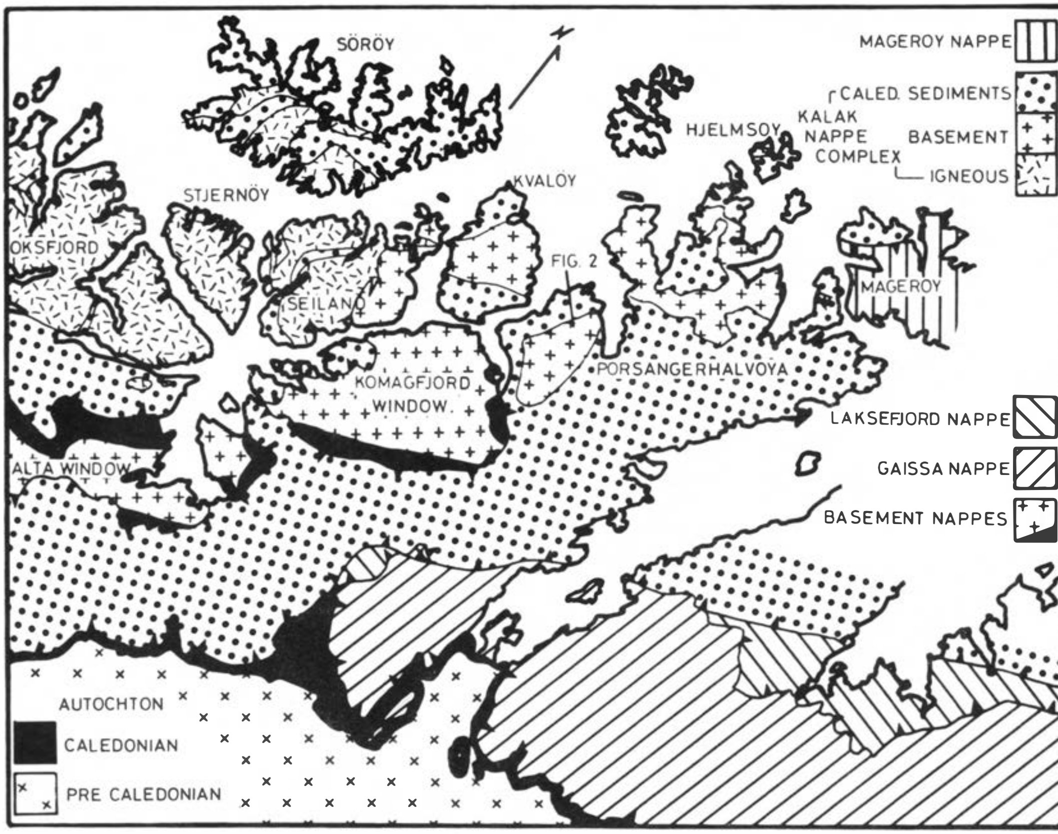

Fig. 1. Simplified geological map of North Norway.

phism than in the adjacent cover nappes; this has been ascribed to pre-Caledonian orogenesis, as on Seiland (Akselsen 1982). Garnet textures and deformation relationships are not fully understood as yet. Akselsen (1982) described two periods of garnet growth within the Eidvågeid Schists – an early pre-Caledonian growth (GI) and a later Caledonian growth (GII) which overgrows the regional fabric wrapped around GI. Although similar relationships are seen in the Seivika Nappe, correlation of growth phases with orogenic events is complicated by the ubiquitous development of two garnet growths in all the cover metasediments on Porsangerhalvøya

Table 1. Correlation of major structural units in the Porsangerhalvøya area, showing previous threefold division and present eightfold division and the local names used in the Revsbotn-Repparfjord area.

Rhodes & Gayer 1977	*Gayer et al. in prep.*	*Rice 1982*
	MOLVIKFJELL NAPPE	
LITLEFJORD NAPPE	SNØFJORD NAPPE	LITLEFJORD NAPPE
	HAVVAVATNET IMBRICATE STACK	BRENNSVIK NAPPE
	GARDEVARRI IMBRICATE STACK	
OLDERFJORD NAPPE	SEIVIKA NAPPE	SEIVIKA NAPPE
	OLDERFJORD NAPPE	OLDERFJORD NAPPE
KOLVIK NAPPE	KOLVIK NAPPE	KOLVIK NAPPE

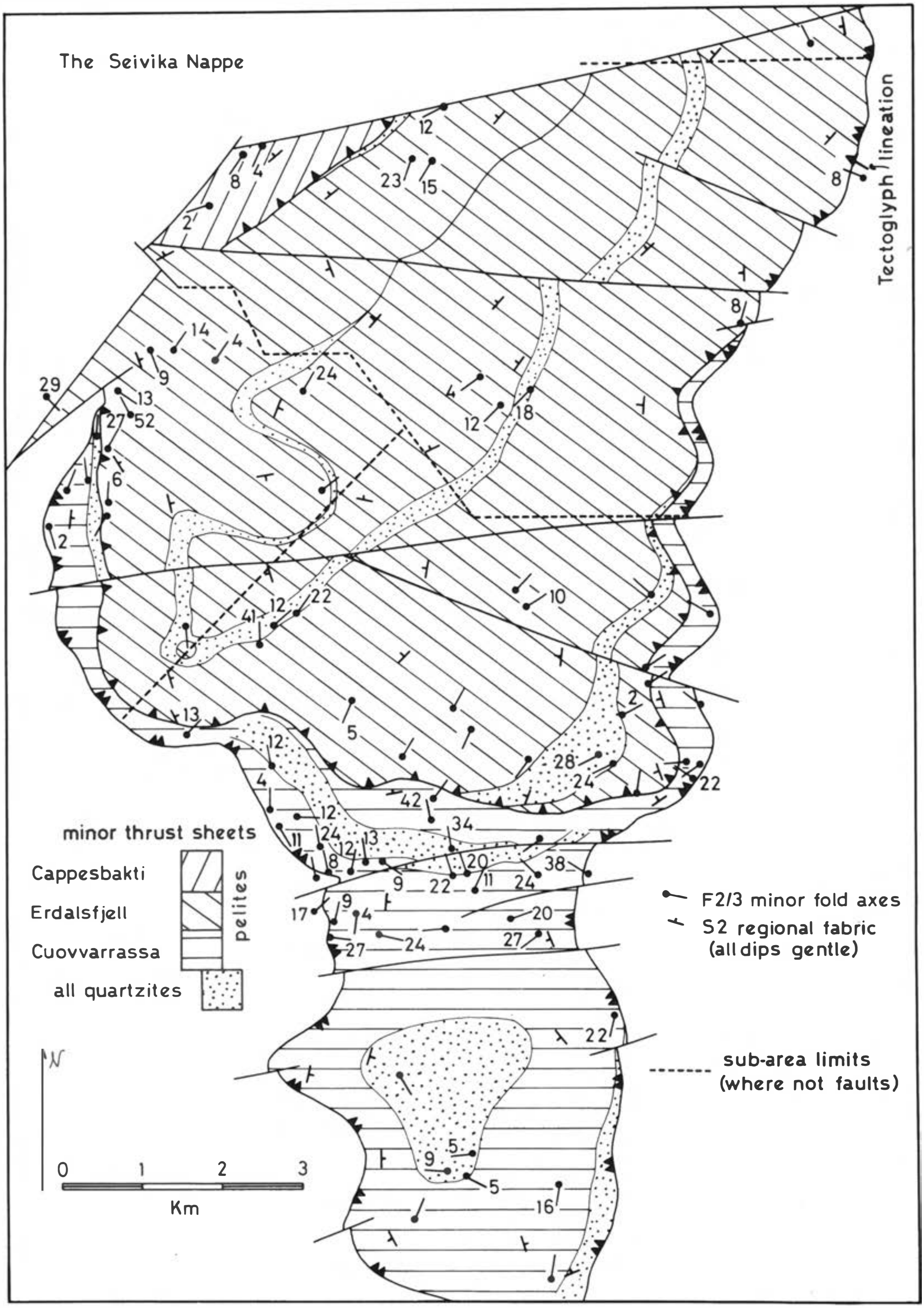

Fig. 2. Geological map of the southern part of the Seivika Nappe, showing the distribution of D2 and D3 folds. Those near the basal thrust have been rotated towards the thrusting direction. Location of tectoglyph lineation shown in north-east.

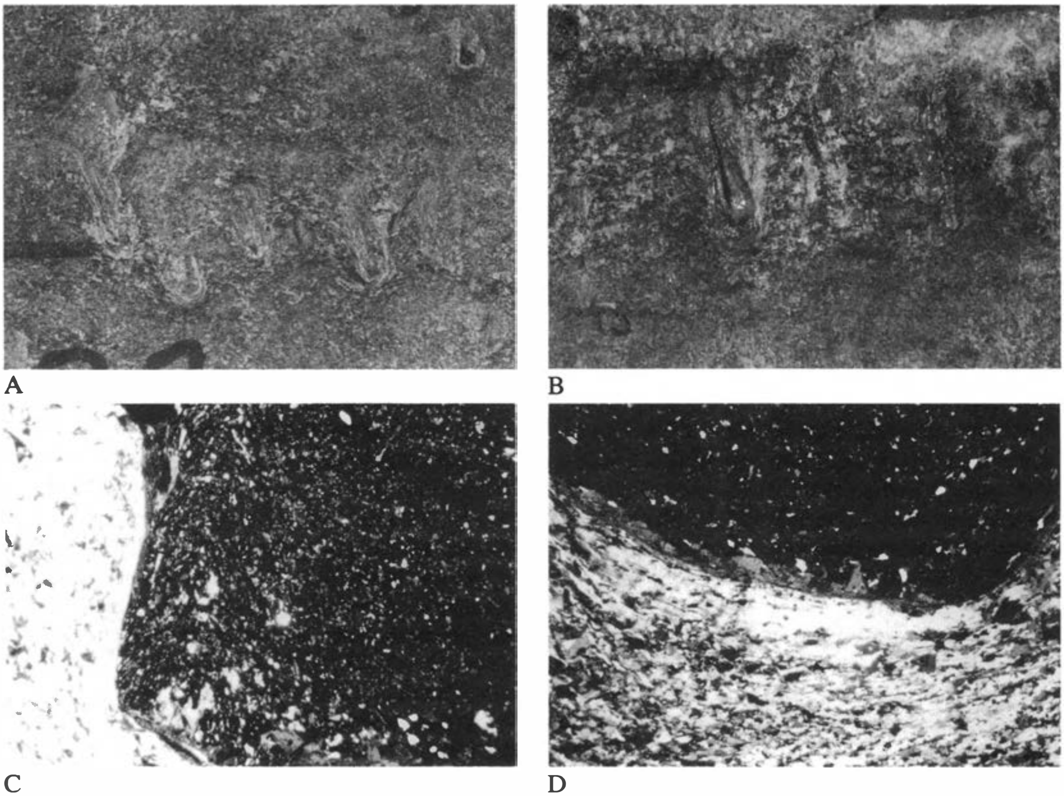

Fig. 3. A & B. Plan photographs of typical gouges in quartzite, formed by garnets. Note 'bow-wave' and folded 'b' lineation. Width photo A 12.5 cm, photo B 12.5 cm. C. Photomicrograph of garnet in a gouge, showing two growth zones – an inner zone with a random inclusion fabric and an outer zone with a planar fabric describing an isoclinal profile. D. Photomicrograph of the mylonite underlying the garnets. Note thin biotite schist layer between garnet and mylonite. Width photo C 4.5 mm, section K21-5, photo D 6 mm, section K21-10.

(Hayes 1980, Rice 1981, 1982). In the cover sequences the first growth (Gt 1) occurred pre- or syn- D2 whilst the second growth occurred inter D2–D3 or early D3, with the actual times of growth varying between nappes (Rice 1982). Comparison of textural and chemical criteria (especially the Fe/Mg ratio and variations in Ca concentration in the outer growths) shows that the second growth in the Seivika Nappe (GtII) is probably equivalent to Gt2 in the cover nappes.

Development of tectoglyph lineation

At one locality at the base of the Seivika Nappe (Fig. 2) garnets have been gouged into quartzite, forming 'elongate prod marks' (Tjia 1968) which are characteristic fault plane markings or 'tectoglyphs' (Dzulynski & Kotlarczyk 1965).

The tectoglyphs, which are exposed on an undersurface in the field, lie between two thin quartzites in a massive pelite unit, within 1m of the basal thrust of the Seivika Nappe. The thrust plane lies at a slight angle to the compositional banding. Three general types of lineations have developed:

1. Scratches or striae up to 3 cm long, with no distinct beginning or termination.
2. Garnets firmly embedded in quartzite, with either a very short (3–5 mm) gouge lineation of essentially uniform depth or no lineation at all.
3. Garnets with prod marks up to 3 cm long, deepening towards the garnet (Fig. 4) with low side ridges and a pronounced 'bow-wave' of quartzite which falls back over the garnet.

In many instances the garnet has weathered out, but a distinct impression of a sub-idiomorphic

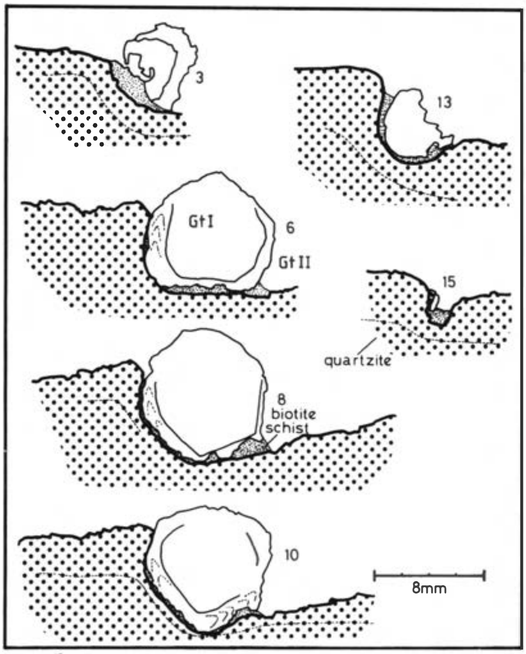

Fig. 4. Drawings of some of 16 evenly spaced serial sections through a 1 cm garnet. Numbers refer to sections in the series of sections K21–1/78 to K21–16/78.

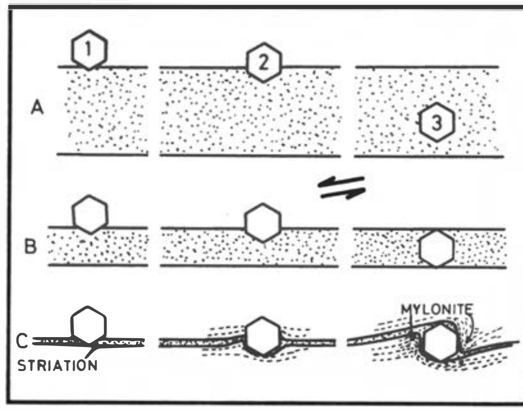

Fig. 5. Model for the development of the lineations. Gouges develop from garnet 3, which rests entirely in the metabasite. Garnets partially embedded in quartzite (garnets 1 & 2) form short gouges or striae on the opposite quartzite.

garnet is preserved. A 'b' mineral lineation, parallel to the minor fold axes, in the quartzites has been rotated into parallelism with the tectoglyph lineation (Fig. 3A & 3 B).

The orangy red colour of the garnets and the occurrence of amphibole and sphene in the inclusion fabric indicate that the garnet grew in a metabasite, probably close to the margin with the metasediments. Two growth zones can be seen in the porphyroblast (Figs. 3C & 4). The age of the earlier growth is unknown because the age of the metabasite is unknown. However, the second growth (GtII) almost certainly grew during early D3 and contains an isoclinal syntectonic inclusion fabric (Figs. 3C & 4). This indicates that gouging occurred during late D3 or after. The possibility that the gouging occurred during GtII growth is discounted by the absence of significant quartz inclusions, although the isoclinal inclusion fabric indicates high shear strains and the improbability of GtII growth remaining a coherent unit if growth had occurred during such high strains.

Shearing oblique to the compositional banding, related to nappe emplacement, thinned the metabasites and probably resulted in it altering to a biotite schist, relicts of which have been preserved between the garnets and the quartzite (Figs. 3D & 4). Garnets near the margin eventually impinged on the quartzites, but probably no tectoglyph developed until both sides of the garnet were held by quartzite (Fig. 5). Gouging then occurred, thinning the layering in the quartzites around the garnet and developing a thin mylonitic fabric adjacent to the porphyroblast (Figs. 3D & 5). Those garnets more or less firmly embedded in the quartzite (1 & 2 Fig. 5) moved only short distances, but produced long striae on the opposite side.

Discussion

The development of tectoglyph groove marks can be accomplished by two mechanisms during fault movement; groove formation by pressure solution, in which grains adjacent to the groove are undeformed, and by plastic deformation, in which adjacent grains are strained and physically pushed aside (Elliot 1976). In the present case the latter mechanism has clearly been dominant, but the presence of a thin veneer of quartz on some parts of the compositional banding around the garnets testifies to a limited amount of pressure solution. That the garnet asperities were not sheared off during tectoglyph formation indicates either a high shear strength for garnet, contrary to the model for elongate garnet formation of Gregg (1978) or to low strain rates.

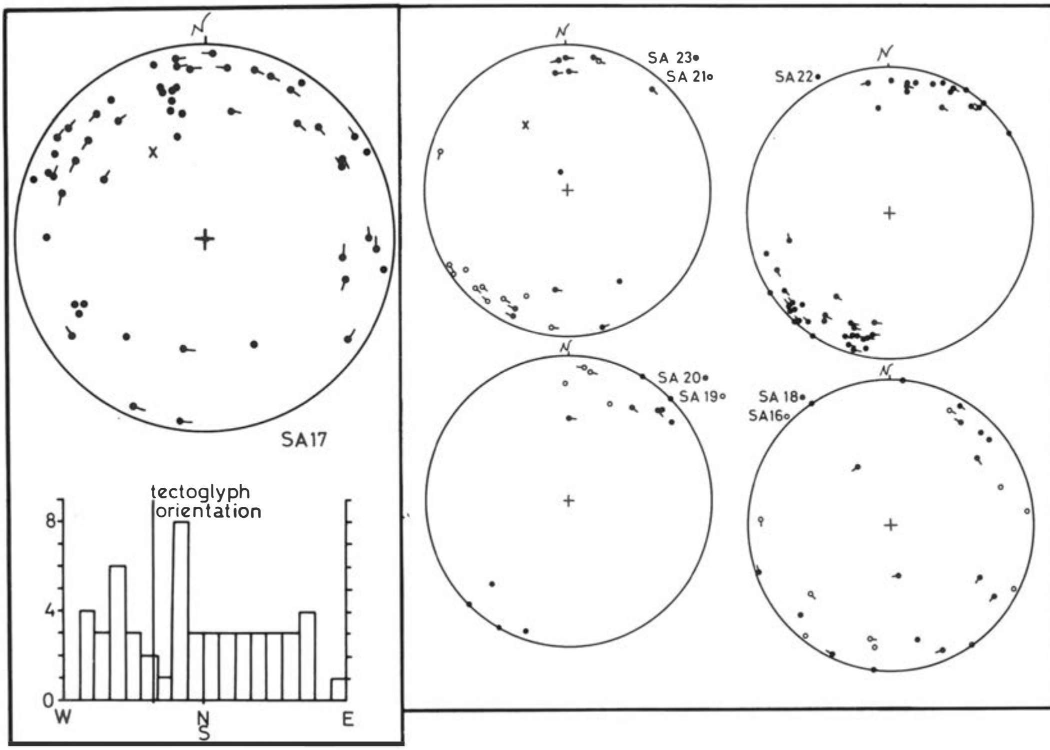

Fig. 6. Orientation of minor folds in the Seivika Nappe, divided into sub-areas. Also shown is the orientation of the garnet tectoglyph lineation.

Within the Kalak Nappe Complex on Porsangerhalvøya, high strain mylonitic fabrics typical of nappes with large ductile translations have not been well preserved. At the base of the Seivika Nappe 'pseudo-psammites' (Ramsay & Sturt 1977) have been found in some areas, but in these quartz grains have almost completely recrystallized. The preservation of the mylonitic fabrics associated with the tectoglyphs suggests a temperature of formation below that at which annealing occurs; that is below the temperature at which the ductile nappe translation occurred during D2 and D3. Further, the absence of mylonitic fabrics in the main part of the quartzites indicates that the system locked after the metabasite had sheared out and that strains were accommodated elsewhere. In the area local to the gouges, extensional crenulation cleavages (Platt & Vissers 1980) with wide spaced axial surfaces (around 1 m) have formed. Development of these shear planes indicates a change from homogenous high strains at the basal thrust to deformation along several narrow discrete planes. The alteration of the metabasite to biotite schist is indicative of strain-induced reaction softening (Williams & Dixon 1982) leading to strain localization.

The tectoglyph lineations have a mean orientation of 07–331° (Fig. 6) which is parallel to the 'a' tectonic axis of the D2, D3 and D4 folds. Typically these folds are slightly non-cylindrical, forming girdle distributions on stereoplots (Fig. 6). Near the Seivika thrust minor folds of D2 and D3 age have been rotated towards the X direction (especially in sub-area 17). Rotation of minor folds has been described from several other parts of the Kalak Nappe Complex, both along the basal thrust (Rhodes & Gayer 1977, Williams 1978) and within the Complex (Hayes 1980, Rice 1981). In the Seivika Nappe, rotation started during D2 and continued into D3, with type II interference patterns (Ramsay 1967) forming. A histogram of fold axes orientation (Fig. 6) shows an essentially symmetrical distribution, suggesting that the same stress regime was responsible for both the D2 and D3 fold formation and their rotation, whilst the overall broad distribution of the orientations confirms that fold formation and rotation overlapped (Sanderson 1972). A minimum in the orientations lies close to the tectoglyph lineation orientation, implying that the nappe translation direction remained constant between early D2 and end D3 or later, and the parallelism of D2, D3 and D4 folds tends to confirm this.

The continuity in thrusting direction within the Seivika Nappe throughout deformation (D2 to D4) has significance in the correlation of deformation events with the different orogenic episodes in the North Norwegian Caledonides. In the Troms-Finnmark border area, where Scandian and Finnmarkian nappes are intercalated, Zwaan & Roberts (1978) have interpreted D3 in the Finnmarkian Nappes as being a result of reactivation during Scandian Orogenesis. Although fossil discoveries by Binns & Gayer (1980) have resulted in reinterpretation of the map of Zwaan & Roberts (1978), the correlation of D3 with Scandian deformation in that area is still thought to be valid (Roberts, pers. comm. 1984). The consistent orientation of minor folds in both the Seivika Nappe and other nappes in the Complex, but differing between nappes (Hayes 1980, Rice 1981, 1982), makes the correlation of D3 with Scandian reactivation difficult to envisage in the Porsangerhalvøya region.

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