THE 'A' LINEATION AND THE TREND OF THE CALEDONIDES OF NORTHERN NORWAY

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Attention is drawn to the consistently large angular discordance between the trend of the major (F_1) nappe folds of West Finnmark and North Troms and the outcrop of the Caledonian thrust front. It is suggested that the tight early folds in layered rocks of variable competency produced a regional lineation which became a preferred direction of transport for subsequent deformations.

In the second half of the paper an example from Olderfjord, North Troms, is described inwhich the 'a' direction of F_2 folds lies parallel to the axis of the F_1 folds. In the more competent contact aureole of the Olderfjord norite the F_2 deformation takes the form of shear planes, parallel to the planes of the F_2 folds outside and on which is developed a strong 'a_2' lineation. Thus the F_1 microfold lineation and the F_2 'a' lineation are coincident.

REGIONAL TRENDS

The conspicous lineation that is developed in the apparent direction of tectonic transport along the marginal thrust zones of the Caledonian orogenic belt, both in Scotland and in Norway, is well known. The early controversy in the literature (Phillips 1937, Anderson 1948, Kvale 1953, Turner 1957, Lindström 1958), to which it gave rise, was concerned primarily with whether this lineation lay parallel to the 'a' or the 'b' tectonic axis. The subsequent demonstration in both areas that the lineation lies parallel to fold axes which are earlier than the main thrust movements, and an appreciation that fold axes and their associated lineations may lie anywhere in the 'ab' tectonic plane (Weiss 1959, Ramsay 1960), has altered, but not entirely explained the problem.

It is becoming evident that the same pattern is present in the Caledonian structures of Northern Norway. On the island of Söröy in West Finnmark (Ramsay & Sturt 1963, Sturt & Ramsay 1965) and in the Loppa-Kvænangen area of West Finnmark and North Troms (Hooper & Gronow, in press; Ash, in press) the earliest structures (F_1) are large nappe folds with which is associated a strong rib-like lineation, best developed in the psammitic lithologies (Fig. 1). The trend of this lineation is N-S on a regional scale, although locally variable due both to its original sinuous nature and to subsequent folding. It bears slightly to the east of north on Söröy and in the Loppa district then swings to NNW-SSE in the Kvænangen area. In Reisadalen (Skjerlie & Tek Hong Tan 1961) and the Birtavarre area (Padget 1955) a similar strong lineation has been described and mapped into the thrust zone at an angle of approximately 90°. In this area the lineation is described as an 'a' lineation following Kvale (1953), but recent reconnaissance work by the writer and his colleagues leaves no doubt that it is parallel to the axes of early tight to isoclinal folds (Fleuty 1964) and is a continuation of the F_1 lineation mapped in detail on Skjervöy (Ash, in press) and the Kvænangan area. West of Porsangerfjord, Gayer (Dr. R. A. Gayer, pers. comm.) has mapped early overturned folds trending approximately N-S immediately north of the Kolvik Thrust. In the south of Troms, Kalsbeek & Olesen (in press) describe two early sets of folds with axes WNW-ESE while across the border in northern Sweden Lindström (Lindström 1955, 1956, 1957, 1958) makes it clear that the predominant lineation at the thrust front is parallel to the axes of tight overturned folds trending NW-SE, perpendicular to the trace of the thrusts.

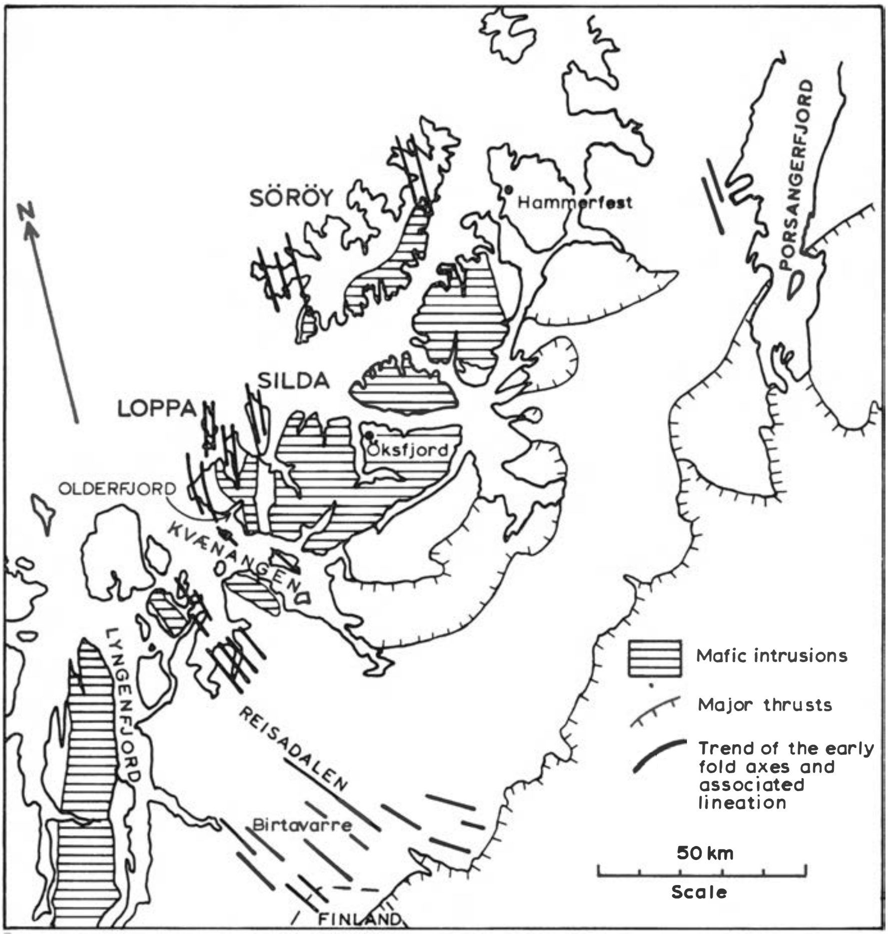

Fig. 1. The trend of the early fold axes and the associated lineation in the Caledonian rocks of West Finnmark and North Troms.

Wherever adequate descriptions of the structures of the Caledonian rocks in Northern Scandinavia are available, therefore, the same pattern emerges. The trend of the thrust plane is perpendicular to the axes of an earlier set of overturned folds (Fig. 1). To the writer's knowledge no satisfactory explanation for this is available. Clearly the possibility that some fold axes may lie in the direction of tectonic transport (Weiss 1959, Ramsay 1960) does not explain the frequency of this particular orientation in Northern Norway. Johnson (1965) has tentatively suggested that earlier structures may be swung into the direction of transport by the thrust movement. On this hypothesis, fold axes normally running approximately parallel to the thrust outcrop on a regional scale should swing into the direction of transport as the thrust zone is approached and there is some evidence for this in the F_2 lineation in the Moines of Scotland. A swing of this kind is apparent in Northern Norway and the concept of the early lineation being turned into the direction of tectonic transport by the thrust movement might go some way to explain the orientation of the F_1 structures in the thrust zone.

However, in West Finnmark the F_1 forms major fold nappes facing east and west away from an anticlinal rise trending N-S between the islands of Silda and Söröy (Hooper & Gronow, in press). It seems unlikely that this regional structure, extending as it does for some 100 kms from the thrust front has been twisted bodily through a large angle during the thrust movement. Yet it lies at an angle of between 45° and 90° to the thrust front.

It is generally assumed that the thrust front reflects the regional trend of the orogenic belt. This is clearly true on a continental scale. It need not be true on a more limited scale. In Norway it is suggested that the original trend of the F_1 structure approximates to the true trend of the orogenic belt and that the thrust front cuts across this trend. With this in mind, it may be more than coincidence that the trend of the strongly developed early structures in West Spitsbergen (Dr. R. A. Gayer, pers. comm.), 250 kms due north of West Finnmark, is also N-S and that the N-S line joining these two portions of the Caledonian fold belt runs parallel to and just inside the continental shelf. The curved nature of the marginal thrusts in West and Central Finnmark and the report (Strand 1960) that they die out to the east could also be explained on this hypothesis.

Following this line of argument it is necessary to consider why the thrusts should locally transgress the 'true' trend of the orogenic belt. It is suggested that the linear grain of a tightly folded succession of rocks would constitute a preferred direction of transport for a later deformation. This could occur without altering the direction of principle stress by interchanging the 'a' and 'b' tectonic axes between the two deformations. Under conditions of low hydrostatic pressure, in which the differences in the competency of the various lithological units would be relatively large, this reorientation of the tectonic axis would be favoured. These are the same conditions of brittle deformation which lead to thrusting.

This concept might explain some of the cross folding commonly found in orogenic belts. In the initial stages of marginal thrusting any tendency of the orogenic belt to relieve the stress by moving parallel to the earlier fold axes would be subordinate to movement westwards over the stable blocks. During this initial movement, however, the angle between these two preferred directions of tectonic transport would be decreased. At some stage a compromise direction would become possible, lying parallel to the earlier fold axis, but at some oblique angle to the true margin of the orogenic belt. Marginal thrusts developed in this way would lie oblique to the general trend and would probably form a series of arcuate thrusts, dying out along their length away from the orogenic belt and being replaced by further thrusts, in echelon, so that the true continental trend of the orogenic belt would be maintained.

AN EXAMPLE OF a_2 COINCIDING WITH THE F_1 FOLD AXES

This explanation has been suggested by the structures in the metasediments on the southern shore of Olderfjord (Fig. 1). Here the 'a' axis of the F_2 deformation approximates to the regional trend and plunge of the F_1 folds. Furthermore, a strong F_2 lineation is locally developed in the 'a_2' direction.

The metasediments at Olderfjord carry the imprint of three phases of deformation — F_1, F_2 and F_3 — which may be correlated with those on the Sandland peninsula to the north (Hooper & Gronow, in press). They are intruded by a syn-F_1 norite, the contacts of which now lie parallel to the foliation of the garnet gneiss forming a contact aureole between the norite and the metasediments. F_3 takes the form of gentle folds with steep axial planes

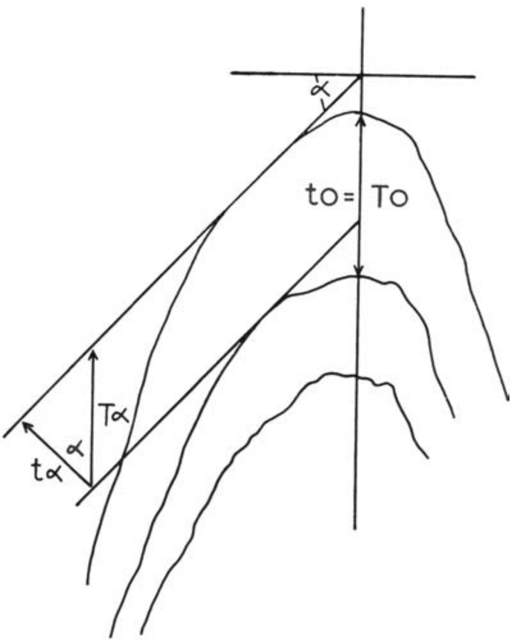

Fig. 2. Profile of an F_2 fold, Olderfjord, illustrating the parameters t and T used in Figs. 3 & 4.

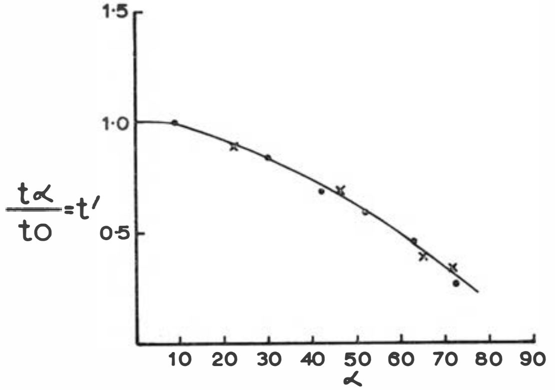

Fig. 3. Plot of t' around the fold of Fig. 2.

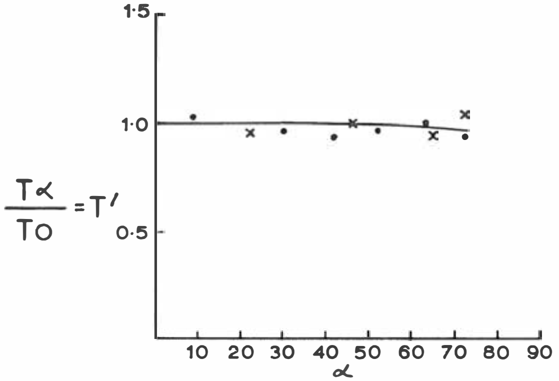

Fig. 4. Plot of T' around the fold of Fig. 2.

parallel to a series of joints and fractures striking N60. Their effect on the earlier structures (F_1 and F_2) may be ignored in the present context.

F_1 and F_2 are both well represented by minor folds and lineations. Refolded folds and folded F_1 lineations are well displayed. As in other parts of West Finnmark and North Troms the F_1 folds are usually tight or isoclinal with a rib-like lineation parallel to the axes of the folds in the dominant psammitic and semi-pelitic lithologies. Folds of the second deformation have close to tight interlimb angles (Fleuty 1964) with an axial plane dipping gently east, parallel to the contact with the norite. Hooper & Gronow (in press) have correlated these with folds on Loppa of the same style and orientation and they have suggested that these represent one of a set of three fold styles associated with the regional F_2 stress field, the group of three possessing orthorhombic symmetry on a regional scale. As in all other folds ascribed to the F_2 deformation in the area, those at Olderfjord are associated with a mild crenulation parallel to the fold axes which contrasts markedly with the coarser lineation of F_1 in the same lithologies.

The F_2 folds at Olderfjord conform to the similar-fold model, class 2 of Ramsay's classification (Ramsay 1965), as seen in Figs. 2, 3 and 4. In addition the locus of the F_1 lineation around the F_2 folds lies in a plane (Figs. 5 and

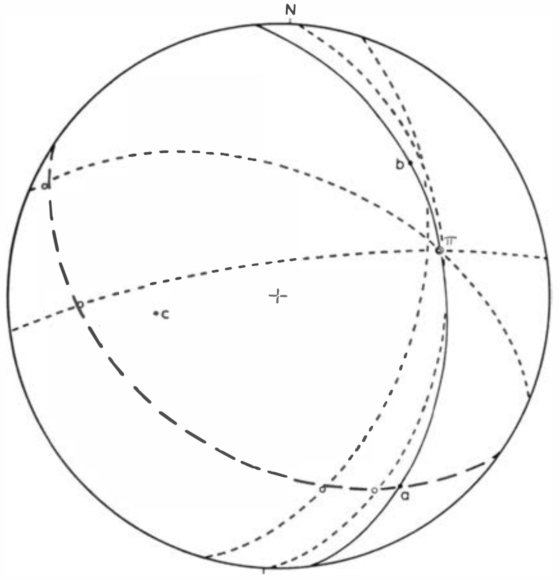

Fig. 5. Plot of the foliation plane around an F_2 fold (small dashes), the axial plane of the F_2 fold (fulline) and the locus of the F_1 lineation (big dashes).
$\odot\pi = F_2$ fold axis
$\oplus$ $= F_1$ lineation
a, b and c are the tectonic axes derived from the diagram. Schmidt net.

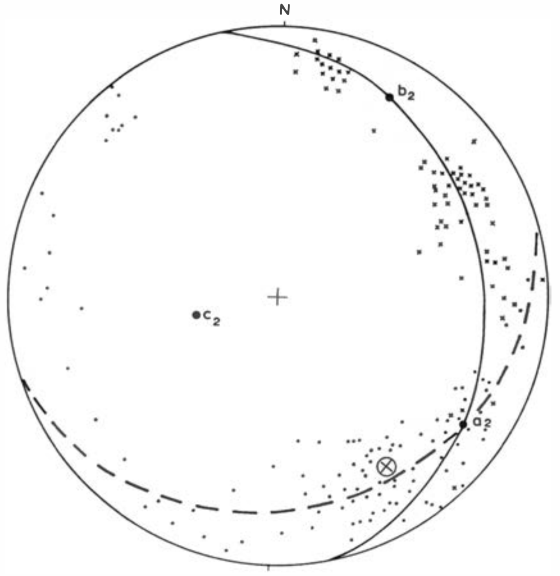

Fig. 6. Plot of F_1 lineations (·), F_2 lineations (x), the average F_2 axial plane (full line) from the South shore of Olderfjord. The dashed line is the great circle through the F_1 lineation and a_2, b_2 and c_2 are the F_2 tectonic axes derived from the diagram. (x) is the maximum of the F_1 lineation at Narsok. Schmidt net.

6) and it may be concluded with reasonable certainty that these folds are the result of axial planar flow. The direction of tectonic transport derived from the stereograms (Figs. 5 and 6, Ramsay 1960) lies close to the maximum of the F_1 lineation, derived chiefly from measurements on the hill of Narsok half a mile to the west, where the F_2 deformation is relatively mild.

In the garnet gneiss adjacent to the norite the F_1 folds have been sealed during the contact metamorphism and the characteristic F_1 lineation can no longer be detected except on the fold closures. The foliation of the gneiss lies parallel to the axial plane of the F_1 folds. It is also parallel to the axial plane of the F_2 folds in the surrounding metasediments. During the F_2 deformation some of these planes were reactivated as shear planes which now form topographic benches in the gneiss parallel to the norite contact. Along the shear planes the foliation becomes very intense and the planes have developed a strong lineation parallel to the 'a' axes of the F_2 folds outside the aureole. A similar lineation occurs on shear planes within the norite. It is an 'a' lineation of F_2 age.

It has previously been suggested (Hooper & Gronow, in press) that the axial plane of F_2 at Olderfjord developed with a gently easterly dip because this plane approximates to the plane of contact between the massive norite and the metasediments on the one hand and to one of the potential shear planes of the F_2 regional stress field on the other. It is now further suggested that the direction of movement within that plane was controlled by the linear grain imposed in the metasediments by the severe F_1 folding.

A correlation of the thrusts marginal to the orogenic belt with the F_2 folds at Olderfjord is not suggested. Both are post F_1, but evidence of their relative age is not yet available. The important point is that the direction of transport of both the marginal thrusting and the F_2 deformation at Olderfjord, near the centre of the orogen, is parallel to the axes of the earlier (F_1) isoclinal folding.

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REFERENCES

ANDERSON, E. M. 1948: On lineation and petrofabric structure and the shearing movement by which they have been produced. *Quart. J. Geol. Soc. 104*, 99-132.

ASH, R. P. (*In press*): The geology of Skjervöy, North Troms, Norway. *Norges Geol. Undersök.* Årbok. 1967.

FLEUTY, M. J. 1964: The description of folds. *Geol. Assoc. Proc. 75*, 461-492.

HOOPER, P. R. & GRONOW, C. W. (*In press*): The regional significance of the Caledonian structures of Sandland Peninsula, West Finnmark. *Quart. J. Geol. Soc.*

JOHNSON, M. R. W. 1965: In: *Geology of Scotland*, ed. G. Y. CRAIG, Oliver and Boyd. Edinburgh.

KALSBEEK, F. & OLESEN, N. Ö. (*In press*): *Norges Geol. Undersök.*

KVALE, A. 1953: Linear structures and their relation to movement in the Caledonides of Scandinavia. *Quart. J. Geol. Soc. 109*, 51-74.

LINDSTRÖM, M. 1955: Structural geology of a small area in the Caledonides of Arctic Sweden. *Lunds Univ. Årsskr., N. F. Avd.* 2, 51, *No.* 15.

LINDSTRÖM, M. 1956: A tectonic study of Mt. Nuolja, Swedish Lapland. *Geol. Fören. Förhandl. 77*, 557-566. Stockholm.

LINDSTRÖM, M. 1957: Tectonics of the area between the Keron and Lake Allesjaune in the Caledonides of Swedish Lapland. *Lunds Univ. Årsskr., N. F., Avd. 2, 53, No. 11.*

LINDSTRÖM, M. 1958: Tectonic transports in three small areas in the Caledonides of Swedish Lapland. *Lunds Univ. Årsskr., N. F., Avd. 2, 54, No. 3.*

PADGET, P. 1955: The geology of the Caledonides of the Birtavarre region, Troms, Northern Norway. *Norges Geol. Undersök. 192*, 107 pp.

PHILLIPS, F. C. 1937: A fabric study of some Moine schists and associated rocks. *Quart. J. Geol. Soc. 43*, 581-620.

RAMSAY, D. M. & STURT, B. A. 1963: A study of fold styles, their associations and symmetry relationships from Söröy, Northern Norway. *Norsk Geol. Tidsskr. 43*, 411-431.

RAMSAY, J. G. 1960: The deformation of early linear structures in areas of repeated folding. *J. Geol. 68*, 75-93.

RAMSAY, J. G. 1967: *Folding and Fracturing of Rocks*. McGraw-Hill. New York and London.

SKJERLIE, F. J. & TEK HONG TAN 1961: The geology of the Caledonides of the Reisa Valley area, Troms-Finnmark, Northern Norway. *Norges Geol. Undersök. 213*, 175-196.

STRAND, T. 1960: *In*: Geology of Norway, ed. O. HOLTEDAHL. *Norges Geol. Undersök. 208*, p. 272.

STURT, B. A. & RAMSAY, D. A. 1965: The Alkaline complex of the Breivikbotn area, Söröy, Northern Norway. *Norges Geol. Undersök. 231*, 164 pp.

SUTTON, J. 1960: Some cross folds and related structures in Northern Scotland. *Geol. Mijnbouw. 39*, 149-162.

TURNER, F. J. 1957: Lineation, symmetry and internal movement in monoclinic tectonite fabrics. *Geol. Soc. Amer. Bull. 68*, 1-18.

WEISS, L. E. 1959: Geometry of superimposed folding. *Geol. Soc. Amer. Bull. 70*, 91-106.