Journal of Structural Geology, Vol. 6, No. 1/2, pp. 101 to 110, 1984
Printed in Great Britain

0191-8141/84 $03.00 + 0.00
Pergamon Press Ltd

Strain discontinuities within the Seve–Köli Nappe Complex, Scandinavian Caledonides

RICHARD J. LISLE

Department of Structural Geology, Institute of Earth Sciences, Utrecht, Netherlands

(*Accepted in revised form* 29 *June* 1983)

Abstract—This paper utilizes the results of a regional survey of the state of finite strain carried out in an area built up of stacked thrust sheets to draw conclusions about the relative timing of penetrative deformation and thrust motion, and to place constraints on the deformation models devised to explain the geometry of the individual thrust sheets. A strain survey within the Seve–Köli Nappe Complex reveals abrupt changes which represent discontinuities in the strain pattern. One of these discontinuities coincides with the boundary between the Seve and Köli Nappes and separates intense transversal stretching strain within the Seve Nappe from the longitudinal strains of lower intensity within the Köli Nappe. The weight of geological evidence favours the interpretation of this strain discontinuity as a unconformity with significant deformation of the Seve Nappe occurring before rocks of the overlying Köli Nappe were deposited (? Middle Ordovician). A second discontinuity marks the junction between the Krutfjell Nappe and the underlying lower grade Köli rocks. The strain distribution is incompatible with a previous interpretation of the discontinuous Krutfjell Nappe as a string of mega-boudins—an interpretation which implies considerable post-thrust flattening of the nappe pile. The strain results and other evidence favour earlier deformation of the Krutfjell Nappe before these rocks were thrust over the underlying tectonic units. The lens-shaped outcrop configuration of the Krutfjell Nappe is explicable in some cases if the geometry of this nappe is a westerly thinning wedge. Within the low grade Köli Nappe rocks north of the Grong Culmination the longitudinal stretching is difficult to explain in terms of easterly directed nappe movements whereas the clear transverse strains in other tectonic units appear to predate the main Silurian thrusting event.

INTRODUCTION

THE MOST obvious and impressive result of the Caledonian orogeny in Scandinavia is the development of large-scale thrust faults. These thrusts, which throw allochthonous units eastwards over the Baltic Shield, dominate the large-scale tectonic pattern and form the bounding surfaces between adjacent units of distinct lithological and metamorphic characteristics. The latter are the consequences of the fact that the development of the thrusts postdates the establishment of the regional metamorphic sequences in the rocks. It is the amount of disruption of the metamorphic pattern which has allowed minimum distances of displacement along the thrusts to be estimated. Such estimates suggest that the summed displacement for visible thrusts in the Scandinavian Caledonides could exceed 500 km (Gee 1975).

In contrast to the sedimentary and metamorphic patterns, the regional pattern of deformation and its relationship to thrusting is less clear and is the subject of this paper. To analyse the deformation pattern it was decided not to concentrate on the episodic nature of the deformation, which has been demonstrated in many areas, but instead to assess the total deformation suffered by the rocks. This approach, which involves a regional analysis of the finite strain, was attempted in a part of the Seve–Köli Nappe Complex where sufficient strain markers are available to give a reasonable picture of the finite strain distribution.

THE SEVE–KÖLI NAPPE COMPLEX

The Seve–Köli Nappe Complex forms a major component of the Caledonides in Central Scandinavia. It is an allochthonous unit belonging to the upper part of the exposed nappe pile and comprises rocks of variable metamorphic character. The lower part of the complex, the Seve Nappe, is largely made up of amphibolite facies meta-sediments and basic meta-igneous rocks with a core of gneisses and migmatites locally at granulite facies. Recent dating work suggests the presence of Precambrian rocks within the nappe (Reymer *et al.* 1980, Koark *et al.* 1980, Claesson 1982). The Köli Nappe, itself a composite of thrusted slices, contains Ordovician and Silurian rocks and is generally of lower grade (greenschist facies). For details of the Seve and Köli thrust units the reader is referred to Zwart (1974) and Zachrisson (1969), respectively.

A pronounced feature of the Seve–Köli Nappe is its wedge-like geometry (Zachrisson 1969). The basal Seve thrust with its gentle westerly dip produces a large number of windows where lower nappes or basement become exposed (Fig. 1). The upper contact of the Seve–Köli Nappe complex formed by the basal thrust of the Rödingsfjell Nappe crops out with a straighter course suggesting a steeper angle of dip. This explains why no klippes of the Rödingsfjell nappe were produced. The resulting wedge-shaped Seve–Köli Complex thins westwards (Fig. 7).

As I intend below to compare fabric patterns to the thrust geometry it is desirable to determine the direction of thrusting from evidence other than that derived from fabric data. The wedge geometry can be used for the purpose if we assume that the symmetry of the wedge structures is related to the symmetry of the thrusting motion (Clough's method using thrust imbrications, see Ramsay 1969, p. 74). Lines of outwedging, or branch-lines (Boyer & Elliot 1982) corresponding to the lines of

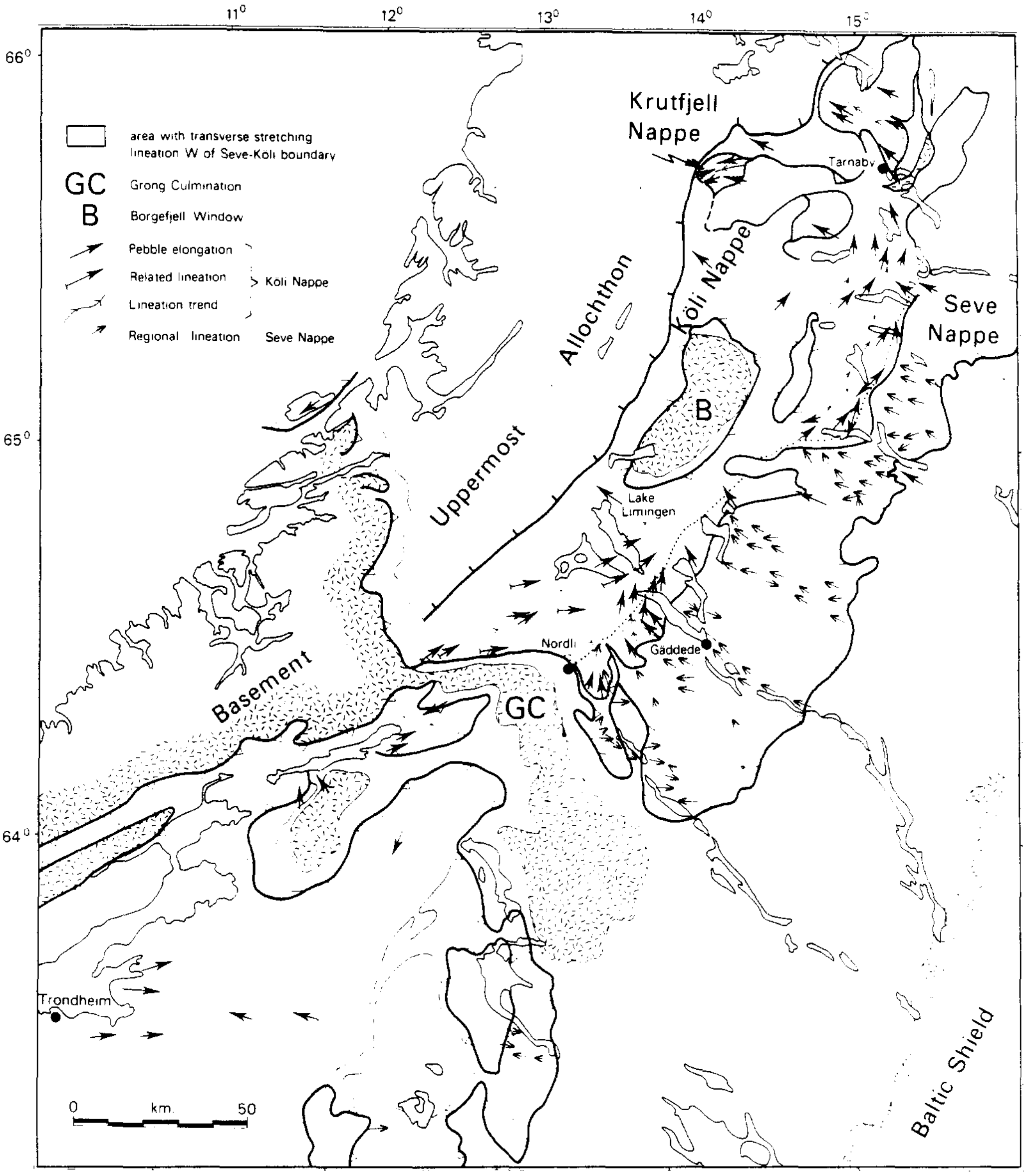

Fig. 1. Pebble extension lineations in the Köli Nappe and stretching lineations in the Seve Nappe (see Appendix A).

intersection of thrust planes which bound the wedges, can be readily constructed in a number of places on the geological map. An example of the branch-line is obtained by joining the points of disappearance of the Seve Nappe at the Grong Culmination and Akkajaura Culmination (Zachrisson 1973). The average direction of these lines is 030° N which is close to the average trend of the Caledonian front (020° N). The deduced direction of thrusting is perpendicular to this direction (110–120°N). Hossack (1983) gives additional examples from the Scandinavian Caledonides of the type of information to be gained by the construction of branch-lines.

STRAIN PATTERNS

The Seve Unit

The polyphase nature of the deformation of the Seve rocks has been repeatedly described (Trouw 1973, Zwart 1974, Biermann 1979, Ghosh *et al.* 1979, Van Roermund 1982) and the discovery of Precambrian age for these rocks means that we can place only very broad limits on the timing of deformation. In view of these complexities, it is convenient to adopt the classification proposed by Williams & Zwart (1977), which for this general area, distinguishes a group of structures, overlapping in time with the main metamorphism and which contributed to the production of the pronounced fabric in the rocks, from a group of structures which postdate the fabric and deform it. The fabric produced by the first group of structures is of regional distribution and is of plano-linear (*LS*) type. The linear component of the fabric is parallel to mineral lineations, rodding and fold axes. Williams & Zwart (1977) and Calon (1979, p. 82) list characteristics of this fabric which suggest that it is the result of extremely intense deformation. The associated folds have highly flattened shapes. Also sheath folds, assumed to have developed by extreme strain modification of non-cylindrical fold forms, are drawn out parallel to the lineation. Strongly rotated garnets are common and large angles of rotation have been recorded (Schoneveld 1977). These angles are probably functions not only of the amount of strain but also of the vorticity (the degree of non-coaxiality) associated with the deformation history. However, if geological flow with high vorticity is exceptional, as Pfiffner & Ramsay (1982) argue, then these rotational angles must be the result of high strains. If simple shear is assumed, some garnet inclusion spirals indicate shortening in excess of 90% (Williams & Zwart 1977). Calon (1979, p. 82) uses boudinage to estimate minimum strain of 80% shortening.

Data on orientation of this lineation have been compiled from student theses of the universities of Leiden and Utrecht and are shown in Fig. 1. The average plunge direction of this lineation is around 290°, the direction estimated for motion of the thrusts from branch-line information. Similar lineation orientation has been observed in other areas in the Scandinavian Caledonides (e.g. Kvale 1953, Lindström 1958, Hooper 1968), and suggests a straightforward genetic connection between the lineation and the thrusting. However, it appears that lineations of different ages share this direction. Calon (1979, p. 84) records lineations defined by kyanites and Ghosh *et al.* (1979) record high-grade minerals in the necks of boudins indicating extension during metamorphism whilst elsewhere strong mylonitic lineations are developed along thrust planes which clearly post-date the metamorphism (Zwart 1974). I conclude therefore that a transversal fabric in some of the Seve rocks existed before the thrusting.

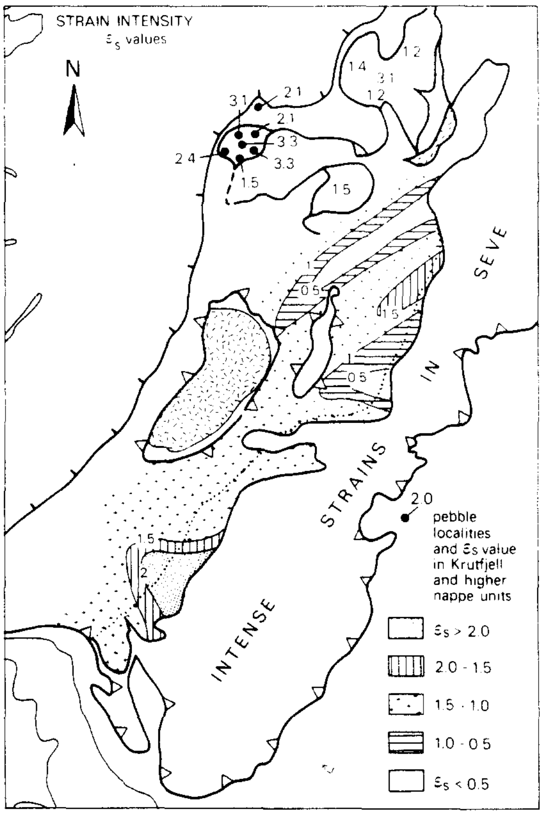

Fig. 2. Distribution of strain magnitudes (expressed in ϵ_s units) within a part of the Seve–Köli complex. ϵ_s is a function of the axial ratios of the strain ellipsoid

$$\left(a = \frac{1+e_1}{1+e_2},\ b = \frac{1+e_2}{1+e_3}\right).$$

and is calculated from

$$\epsilon_s = \frac{1}{\sqrt{3}}\left[(\ln a)^2 + (\ln b)^2 + (\ln ab)^2\right]^{1/2}.$$

The Köli Unit

A survey of the strain within the Köli Nappe is made possible by the widespread occurrence of deformed conglomerates. Strain estimates have been made at some 50 localities. Details about these localities are given in Appendix B. Although for comparison, some data from the south of the Grong Culmination are shown, the following discussion concentrates on localities north of the Grong Culmination.

The strain estimates are based on the average orientation and axial ratios of the pebbles. This method of analysis ignores the effects of competence contrasts between the pebbles and matrix and initial pebble fabrics. As most of the conglomerates are composed of quartzite pebbles in a schistose matrix, ignoring the first of these effects leads to an underestimate of the strain amount. The initial fabric effect is to overestimate because the plane of pebble flattening is usually nearly parallel to the bedding in the conglomerates. These considerations together suggest that the estimation of the strain magnitude (in terms of axial ratio) are too low by a factor of between 1 and 1.5. The pebble stretching lineations (X axes of the strain ellipsoids) are shown in Fig. 1. In relation to the trend of the thrusts, these lineations can be described as longitudinal with the exception of: (a) the area (shaded in Fig. 1) in northern Jämtland, just west of the Seve–Köli contact; (b) some higher grade regions within the Köli distinguished as the Krutfjell Nappe (Fig. 1) and (c) possibly some high structural units in the Köli Nappe, which crop out further west than the Borgefjell Window. In these exceptional areas with a transversal stretching as well as in the normal longitudinal strain areas, the plunge of the stretching axes (X) is generally gentle whilst the planes of foliation defined by the flattening of the pebbles (XY plane) have variable angles of dips. This variability is due to late folding on axes parallel to the stretching direction. This folding, which is often developed on a large scale, corresponds to that described by Zachrisson (1969).

Figure 2 summarises the intensity of the estimated strains. Values of the strain magnitude, in terms of expressed ϵ_s, are less than 1.5 (corresponding to $X/Z < 8.3$ for a $K = 1$ strain). Higher strains occur in the Nordli–Blasjön area and the highest strains were recorded in the Krutfjell Nappe (see Fig. 2). The regional variation of K values for the strain show a similar pattern (Fig. 3). Low strains tend to be oblate and longitudinal; high strains are prolate and transverse. This is clear from Fig. 5 (discussed below).

Notable too is the correlation between the amount of

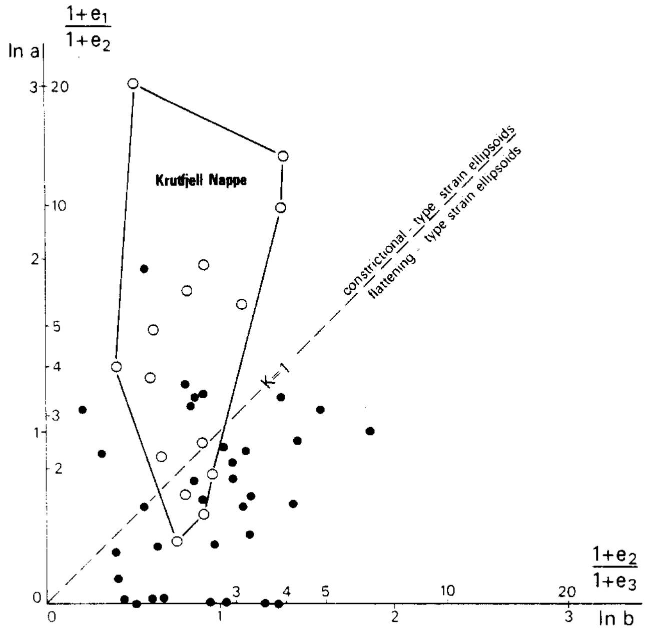

Fig. 3. A Flinn strain diagram showing strain ellipsoids from the normal low-grade Köli Nappe (filled circles) and from the Krutfjell Nappe (open circles).

strain and the mode of pebble deformation. The contributions made by pressure solution (Fig. 4a) and fracturing (Fig. 4b) are more marked in low strain areas (cf. Roberts 1979, in Lake Limingen area), whereas macroscopic ductile and homogeneous deformation of pebbles characterizes the higher strain areas (Figs. 4c & d). In the strongly deformed pebbles of the Krutfjell Nappe, well-developed quartz crystallographic fabrics were produced (Lisle, in preparation).

Besides the fact that the Krutfjell Nappe conglomerates show higher strains, the rest of the pattern is difficult to relate to the thrusts, although the intense transverse strains in the eastern Köli Nappe in northern Jämtland may have to do with their proximity to the Seve–Köli contact which is locally interpreted as a thrust (Sjöstrand 1978).

LARGE-SCALE SHAPE CHANGES DEDUCED FROM MEASURED STRAINS

When, as is the case in this area, strains are fairly constant in the orientation of their principal axes but λ_1, λ_2 and λ_3 axes interchange between localities, the Nadai diagram is useful for representing strain ellipsoids (Owens 1974). On such a diagram (Fig. 5) principal strains are plotted along axes associated with three perpendicular geographic reference axes: the normal to the thrust planes ('vertical'), the strike of the thrust planes ('Caledonian trend') and the dip direction of the thrusts ('transverse') in this case. On this diagram (Fig. 5) we can distinguish between strains with longitudinal and tranverse stretching directions (x axes). We can also see how much of the variability of strains can be accounted for by folding. Folding about one of the geographic reference axes which postdates the pebble deformation, has the effect of moving the plotted point representing the strain to a mirror-image position with repect to that axis of the diagram corresponding to the fold axis. In other words, the point moves to the position it would assume if the diagram itself were 'folded-over' about that particular axis. Once this property of the Nadai diagram is appreciated, we can see a number of strains with outlying positions (such as those with X directions in a vertical orientation which plot on the bottom right of the diagram) can be accounted for by late folding on axes parallel to the Caledonian trend (the folds evident on the maps of Zachrisson 1969).

The ellipsoids in the low-grade Köli Nappe (as opposed to the Krutfjell Nappe) on average show an extension in the direction of the Caledonian trend of around 80%. However, because the axes of the strain ellipsoid are not exactly parallel either to each other or to the strike of the chain we cannot conclude that the Caledonides have been extended longitudinally by that amount. Schwerdtner (1976) explains the difficulties involved in drawing this sort of conclusion which is also hindered by a lack of knowledge of the volume change involved in the deformation.

For many of the same reasons, it is impossible to know what the change in total stratigraphic thickness as a result of deformation has been. For individual localities the calculation is possible, so we make an estimate for a typical locality which indicates a minimum two-fold reduction of the stratigraphic thickness. It is important to note that bed thickness changes are not given by the stretch associated with the line now perpendicular to bedding but should be calculated by the method given by Schwerdtner (1978).

DISCONTINUITIES IN THE STRAIN PATTERN

The Seve–Köli boundary

A pronounced change in strain state occurs at the contact of the Seve and Köli units. Intense transversal strains in the Seve Nappe give way to relatively weak, usually longitudinal strains in the Köli. It is of interest to know if these two strain states are compatible. If they are compatible they must meet the requirements that both ellipsoids yield a common sectional strain on the plane of contact of the strain domains (the Seve–Köli boundary). Taking into account the constraints based upon our knowledge of strains and the orientation of this Seve–Köli boundary plane, the above requirement is not met and the boundary plane is thought to represent a discontinuity in the finite strain pattern.

A number of authors (Sjöstrand 1978, Zachrisson 1969) propose that the Seve–Köli boundary is a thrust. Trouw (1973) favours a low-angle normal fault. Faulting would then provide an explanation for the strain discontinuity. Others (Stephens 1979, Gee 1975) suggest that movement on this contact has been of a minor and local

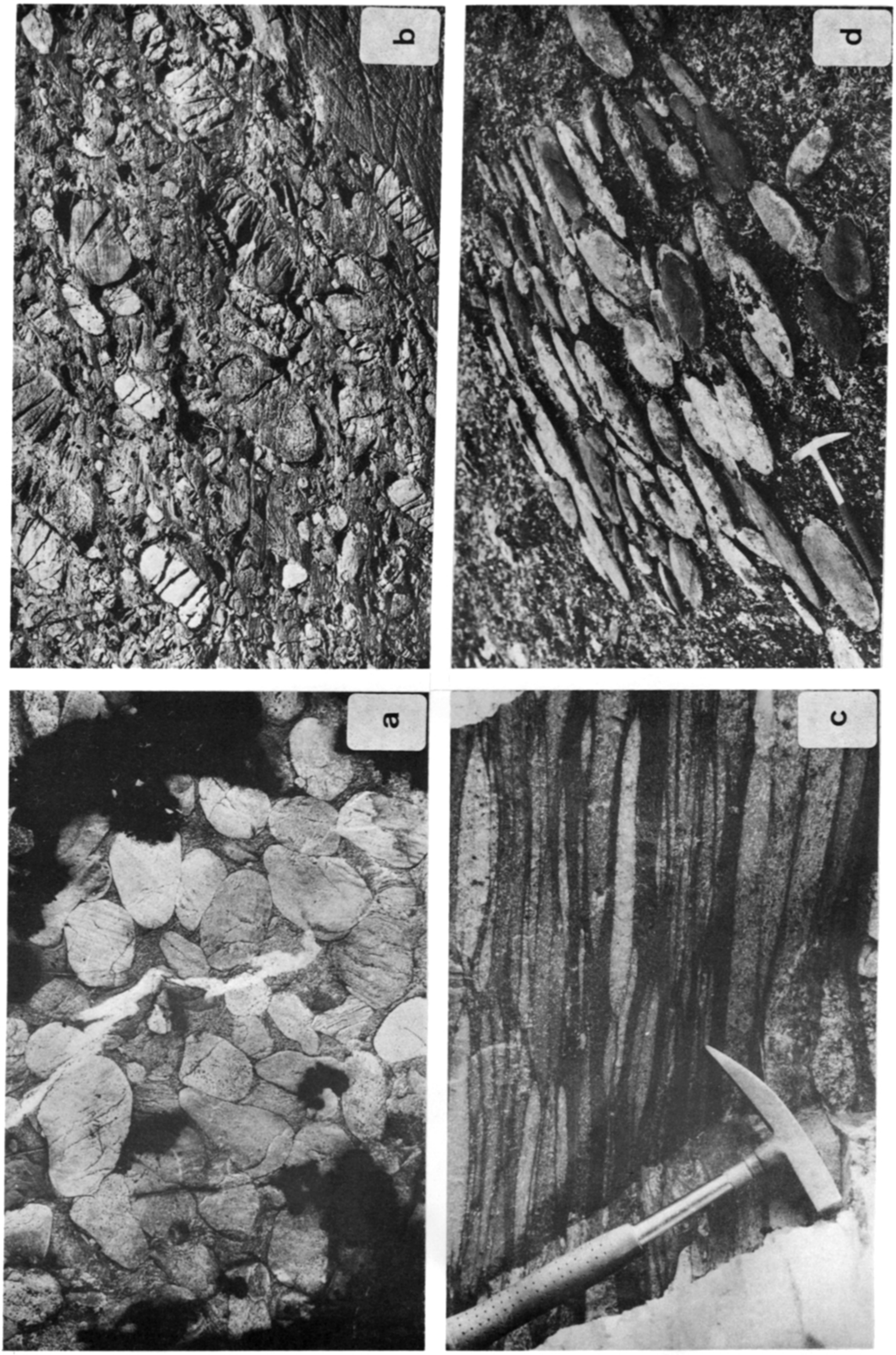

Fig. 4. Modes of pebble deformation. (a) Pressure solution effects in area of low deformation, Vojtja conglomerate, Vallnas, Stor-Bjorkvattnet. (b) Fractured pebbles, Storvika, Stjördal, Norway. (c) Large ductile strains, Portfjell conglomerate, Locality 9003 (see Appendix). (d) Large ductile strains shown by pebbles extracted from their matrix, Krutfjell Nappe, locality 9108 (see Appendix).

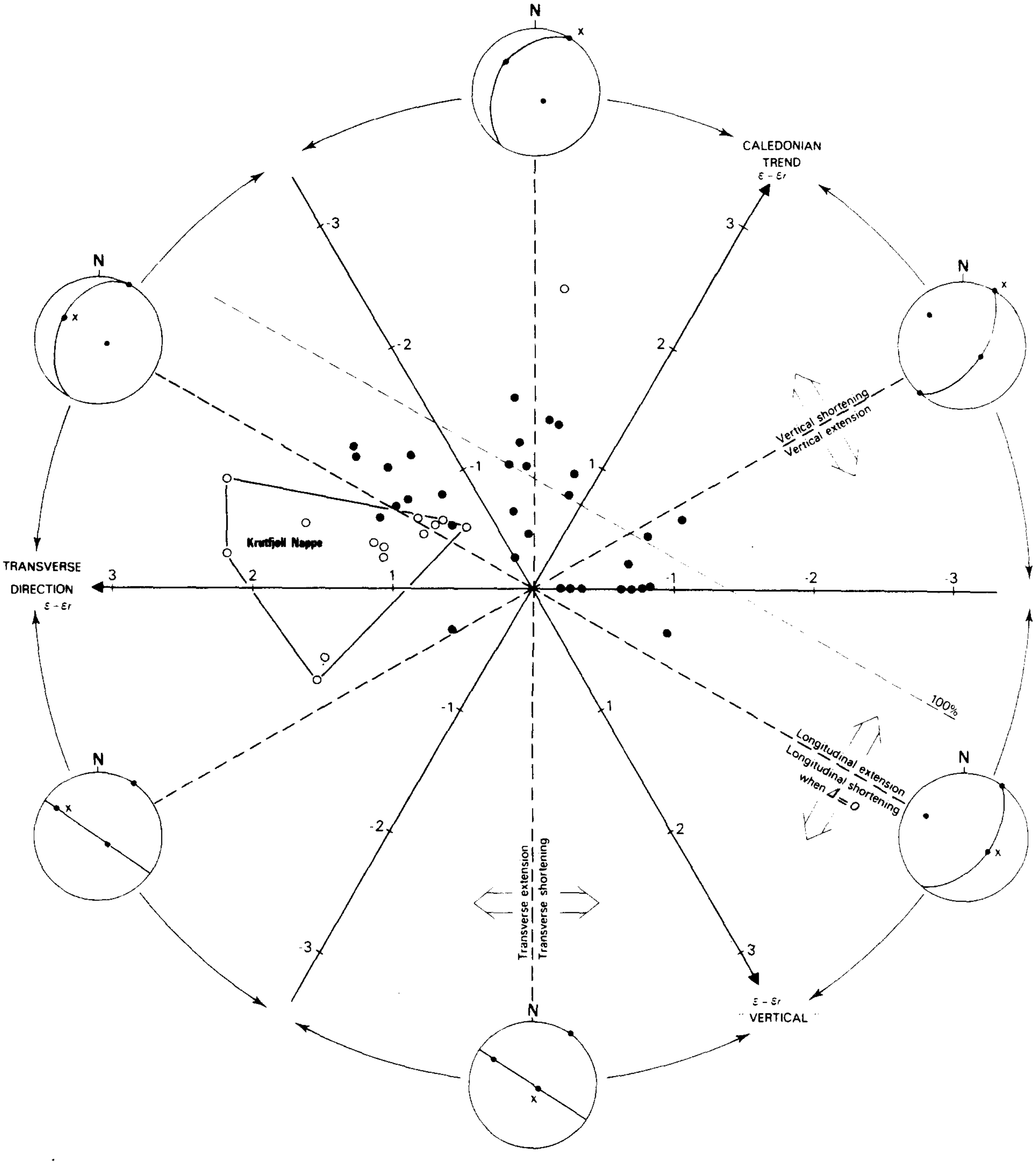

Fig. 5. The orientation and shape of strain ellipsoids from the low-grade Köli and Krutfjell tectonic units expressed by means of a Nadai diagram. For interpretation of this diagram see text.

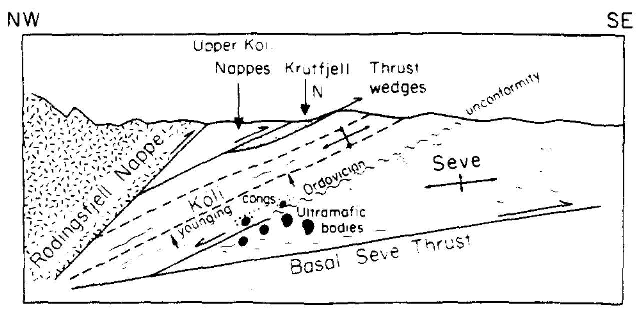

Fig. 6. Highly schematic profile summarizing the important geometrical features of the Seve–Köli Nappe Complex.

character. Important in this respect is the distribution of a group of ultramafic bodies which are clearly concentrated in a zone which straddles the Seve–Köli boundary from the Grong Culmination to Tärnaby (Zachrisson 1969, Stigh 1979). The intrusions indicate that any movement on this plane after the emplacement of the bodies has been slight. The time available for possible thrust movement before their emplacement is severely restricted since the occurrence of serpentinite conglomerate in the lower part of the Köli (Zachrisson 1969) implies the intrusion of these bodies more or less simultaneously with the deposition of the Köli Nappe sediments. Another explanation of the strain incompatibility would seem to be required and we are left only with the possibility that the Seve–Köli contact is essentially an unconformity. The following points, summarized in Fig. 6, are in keeping with this idea: (a) stratigraphic units within the Köli, although cut off by the basal Seve thrust, run parallel to the junction with the Seve; (b) the Köli rocks young, in general terms, upwards away from the contact and (c) the Seve is made up, at least partly, of Precambrian rocks. This accounts for the contrasting strains in the Seve and Köli units by allowing substantial traversal stretching of the Seve rocks to occur before the deposition of the lowest Köli, that is before, at least the Middle Ordovician (Fig. 6). Although the transversal orientation of this early Seve strain suggests a relationship to Caledonian deformation, there is no other evidence favouring early Caledonian (for instance, the Finnmarkian of Sturt & Roberts 1978) above a still older deformation event.

The main (Silurian) deformation in the area produced longitudinal stretching as seen in the Köli Nappe, and, presumably, modified the earlier transversal fabrics in the Seve Nappe.

The Krutfjell Nappe contacts

The Krutfjell Nappe (Fig. 1) is the name given to several areas of rocks which show lithological similarities with Köli rocks but are metamorphosed at upper amphibolite facies. The steep metamorphic transition to the surrounding greenschist-facies Köli requires that the lens-shaped areas occupied by these rocks on the map are bounded by tectonic contacts.

Häggbom (1978) and I. Ramberg (1981) describe the nappe as an example of mega-boundinage structure produced by the heterogeneous stretching of a once-continuous nappe. According to Häggbom (1978) this stretching which postdates the thrusting has given rise to pronounced transversal lineations within the nappe.

This boudinage model for the Krutfjell Nappe does not explain the strain pattern. According to the normal interpretation of boudinage structure, the tectonic lenses ('swells' or boudins) develop within a competent layer and are regions where average strain magnitude is low compared with that for the rest of the system. The strains measured in the Krutfjell lenses, however, are the highest recorded in this study and contrast strongly with the low strains in the low-grade Köli underlying these lenses.

The boudinage model alone cannot explain the strain distribution within and around the lenses. If the model is adhered to, we are forced to conclude that high transverse strains had accumulated in the Krutfjell Nappe before it was thrust onto the normal Köli rocks. This is thus an example of deformation giving rise to transverse fabrics which predate thrusting. Similar conclusions have been drawn by Reymer (1979) based on isotopic dating and Claesson (1979) who argues for an Ordovician age of the deformation in these rocks.

Certain features of the map pattern of the Krutfjell Nappe suggest that its lens-shaped outcrop may result from a cause other than boudinage. If the point of westerly disappearance of the lower Laxfjallet Unit below the Norra Storfjallet lens and the Södra Storfjallet lens are located on the map (Fig. 7) these points are found to lie on a straight line, suggesting that this is a line of outwedging of the unit. This branch-line (trend 040°N) is also parallel to the branch-line constructed in a similar fashion for the Tärnaby basement wedge (Fig. 7). The author believes that open folding and erosion of wedge-shaped nappe units could yield some of the mapped lenses of Krutfjell Nappe.

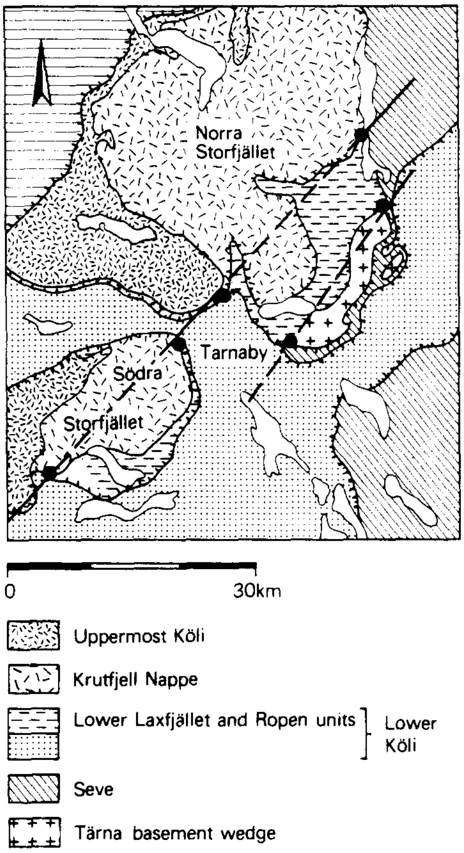

Fig. 7. Lines of nappe disappearance ('branch-lines') constructed for the unit underlying the Norra Storfjället and Södra Storfjället 'lenses' of the Krutfjell Nappe. Geology taken from Sandwall (1981, fig. 1).

DISCUSSION

The recognition of discontinuities in a regional strain patern can reveal important faults or sedimentary breaks. Conversely, these structural or sedimentary breaks associated with strain discontinuities provide information about the relative timing of deformation with respect to faulting or unconformities, respectively.

In the Seve–Köli Nappe Complex, a strain survey suggests that much of the transversal deformation occurred earlier than previously thought and certainly earlier than the main Silurian thrusting event. The strains in the low grade Köli Nappe could possibly date from the period of thrusting but the longitudinal orientation, oblateness (low K values) and intensity distribution of the strain ellipse in these rocks are not easy to relate to proposed nappe displacement models including the transversal nappe spreading model of H. Ramberg (1980). Estimates of nappe translation are critically dependant on the relative timing of deformation of the nappes and thrusting. If the pre-thrust stretching deduced here can be detected in wider areas the displacement estimates of 500 km based on nappe overlap distances (Gee 1975) can be accounted for largely by translation and have not, as Gee (1978) suggested, been exaggerated by significant post-thrusting attenuation.

Acknowledgements—David Roberts, Herman van Roermund, Tony Senior and Harm Stel are thanked for helpful discussions.

REFERENCES

Biermann, C. 1979. Investigations into the development of microstructures in amphibole-bearing rocks from the Seve–Köli Nappe Complex. Doctoral thesis, University of Leiden.

Boyer, S. M. & Elliott, D. 1982. Thrust systems. *Bull. Am. Ass. Petrol. Geol.* **66**, 1196–1230.

Calon, T. J. 1979. A study of the alpine-type peridotites in the Seve–Köli Nappe Complex, Central Swedish Caledonides with special reference to the Kittelfjäll Peridotite. Doctoral thesis, University of Leiden.

Claesson, S. 1979. Pre-Silurian orogenic deformation in the north-central Scandinavian Caledonides. *Geol. För. Stockh. Förh.* **101**, 353–356.

Claesson, S. 1982. Caledonian metamorphism of Proterozoic Seve rocks on Mt. Aveskutan, southern Swedish Caledonides. *Geol. För. Stockh. Förh.* **103**, 291–304.

Curet, E. A. 1979. De geologie van het zuidelijk deel van de Norra Storfjäll in de omgeving van Laisholm. Master's thesis, University of Leiden.

Gee, D. G. 1975. A tectonic model for the central part of the Scandinavian Caledonides. *Am. J. Sci.* **275**, 468–515.

Gee, D. C. 1978. The Swedish Caledonides—A short synthesis. *Geol. Surv. Pap. Can.* **78–13**, 63–73.

Ghosh, S. K., Roy, A. B. & Troëng, B. 1979. Superposed folding and metamorphism in the Seve nappe around Areskutan in the Swedish Caledonides. *Geol. För. Stockh. Förh.* **101**, 85–103.

Häggbom, O. 1978. Polyphase deformation of a discontinuous nappe in the Central Scandinavian Caledonides. *Geol. För. Stockh. Förh.* **100**, 349–354.

Halls, C., Reinsbacken, A., Ferriday, I., Haugen, A. & Rankin, A. 1977. Geological setting of the Skorovas orebody within the allochthonous volcanic stratigraphy of the Gjersvik Nappe, Central Norway. *Bull. Inst. Min. Metall.* **00**, 128–151.

Hooper, P. R. 1968. The 'a'-lineation and the trend of the Caledonides of Northern Norway. *Norsk. geol. Tidsskr.* **48**, 261–268.

Hossack, J. R. 1968. Pebble deformation in the Bygdin area (southern Norway). *Tectonophysics* **5**, 315–39.

Hossack, J. R. 1983. A cross-section through the Scandinavian Caledonides constructed with the aid of branch-line maps. *J. Struct. Geol.* **5**, 103–111.

Koark, H. J., Märk, T. D., Pahl, M., Purtscheller, F. & Vartanian, R. 1980. Precambrian fission-track ages of sphene from the Caledonides of Mount Areskutan, Sweden. *Bull. geol. Instn Univ. Upsala* **9**, 5–12.

Kvale, A. 1953. Linear structures and their relation to movement in the Caledonides of Scandinavia and Scotland. *Q. Jl. geol. Soc. Lond.* **109**, 51–73.

Lindström, M. 1958. Tectonic transports in three small areas in the Caledonides of Swedish Lapland. *Lunds Universitets Arsskrift. N.F. Ard 2* **54**, 5–85.

Lutro, O. 1979. The geology of the Gjersvik area, Nord-Trøndelag, Central Norway. *Norg. geol. Unders.* **354**, 53–100.

Owens, W. H. 1974. Representation of finite strain state by three-axis planar diagrams. *Bull. geol. Soc. Am.* **85**, 307–310.

Peacey, J. C. 1964. Reconnaissance of the Tømmeras Anticline. *Norg. geol. Unders.* **223**, 275–293.

Pfiffner, O. A. & Ramsay, J. G. 1982. Constraints on geological strain rates: arguments from finite strain states of naturally deformed rocks. *J. geophys. Res.* **87**, 311–322.

Prestwick, T. 1974. Supracrustal rocks of Leka, Nord-Trøndelag. *Norg. geol. Unders.* **311**, 65–88.

Ramberg, H. 1980. Diapirism and gravity collapse in the Scandinavian Caledonides. *J. geol. Soc. Lond.* **137**, 261–270.

Ramburg, I. B. 1981. The Brakfjellet tectonic lens: evidence of pinch-and-swell in the Caledonides of Nordland, north Central Norway. *Norsk geol. Tidsskr.* **61**, 87–92.

Ramsay, J. G. 1969. The measurement of strain and displacement in orogenic belts. In: *Time and Place in Orogeny* (edited by Kent, P. E. *et al.*) *Spec. Publs geol. Soc. Lond.* **3**, 43–79.

Reymer, A. P. S. 1979. Investigations into the metamorphic nappes of the Central Scandinavian Caledonides on the basis of Rb–Sr and K–Ar age determinations. Thesis, University of Leiden.

Reymer, A. P. S., Boelrijk, N. A., Hebeda, E. H., Priem, H. N. A., Verdurmen, E. A. T. & Verschure, R. H. 1980. A note on Rb–Sr whole-rock ages in the Seve Nappe of the Central Scandinavian Caledonides. *Norsk geol. Tidsskr.* **60**, 139–147.

Roberts, D. 1967. Geological investigations in the Snasa–Lurudal area, Nord-Trøndelag. *Norg. geol. Unders.* **247** 18–38.

Roberts, D. 1979. Structural sequence in the Limingen–Tunnsjøen area of the Grong district, Nord-Trøndelag. *Norg. geol. Unders.* **345**, 101–114.

Sandwall, J. 1981. Caledonian Geology of the Jofjället area, Västerbotten County, Sweden. *Sver. geol. Unders.* **C778**, 1–105.

Schoneveld, C. 1977. A study of some typical inclusion patterns in strongly paracrystalline rotated garnets. *Tectonophysics* **39**, 453–471.

Schwerdtner, W. M. 1976. A principal difficulty of proving crustal shortening in Precambrian shields. *Tectonophysics* **30**, T19–T23.

Schwerdtner, W. M. 1978. Determination of stratigraphic thickness of strained units. *Can. J. Earth Sci.* **15**, 1379–1380.

Sjöstrand, X. X. 1978. Caledonian geology of the Kvärnbergsvattnet area, northern Jämtland, central Sweden. *Sver. geol. Unders.* **C735**.

Stephens, M. B. 1975. Pebble strain analysis in the Vojtja conglomerate of central Västerbotten, Sweden. *Geol. För. Stockh. Förh.* **97**, 74–82.

Stephens, M. B. 1979. Occurrence, nature and tectonic significance of volcanic and high-level intrusive rocks within the Swedish Caledonides. In: *Caledonides in the U.S.A. Proceedings of Symposium I.G.C.P.*, Blacksburg, Virginia.

Stigh, J. 1979. Ultramafites and detrital serpentinites in the central and southern parts of the Caledonian Allochthon in Scandinavia. Thesis, Chalmers University of Technology, Göteborg, Sweden.

Sturt, B. A. & Roberts, D. 1978. Caledonides of northernmost Norway (Finnmark). *Geol. Surv. Pap. Can.* **78–13**, 17–24.

Trouw, R. A. J. 1973. Structural Geology of the Marsfjällen area, Caledonides of Västerbotten, Sweden. *Sver. geol. Unders.* **C689**, 1–115.

Van Gijlswijk, M. 1979. De geologie van het noordwestelijke Norra Storfjäll gebied, Provincie Västerbotten, Sweden. Master's thesis, University of Leiden.

Van Roermund, H. L. M. 1982. On eclogites from the Seve Nappe, Jämtland, Central Scandinavian Caledonides. Doctoral thesis, University of Utrecht.

Williams, P. F. & Zwart, H. J. 1977. A model for the development of the Seve–Köli Caledonian Nappe Complex. In: *Energetics of Geological Process* (edited by Saxena, S. K. & Bhattacharji, S.) Springer, Berlin, 169–187.

Wolff, F. C. 1960. Foreløpige meddelelser fra Kartbladet Verdal. *Norg. geol. Unders.* **211**, 212–230.

Wolff, F. C. 1967. Geology of the Meraker area as a key to the eastern part of the Trondheim region. *Norg. geol. Unders.* **245**, 123–146.

Zachrisson, E. 1969. Caledonian geology of northern Jämtland–southern Västerbotten. *Sver. geol. Unders.* **C644**, 1–33.

Zachrisson, E. 1973. The westerly extension of Seve rocks within the Seve–Köli Nappe Complex in the Scandinavian Caledonides. *Geol. För. Stockh. Förh.* **95**, 243–251.

Zwart, H. J. 1974. Structure and metamorphism in the Seve–Köli Nappe Complex (Scandinavian Caledonides) and its implications concerning the formation of metamorphic nappes. *Centenaire de la Soc. Géol. Belgique Geologie de domains cristallins.* Liege, 124–144.

APPENDIX A

Some of the pebble strain data plotted in Figs. 1, 2, 3 and 5 were taken from the work of Curet (1979), Halls *et al.* (1977), Roberts (1967, 1979), Stephens (1975), Lutro (1979), Peacey (1964), Prestwick (1974), Trouw (1973), Van Gijlswijk (1979) and Wolff (1960, 1967).

APPENDIX B: *Deformed conglomerate data*

	Locality	Map Reference		Axial Ratios		Orientation	
		Lat(N)	Long(E)	$a = \frac{x}{y}$	$b = \frac{y}{z}$	x axis	z axis
301	S. Artfjället	65°53′	14°53′	2.1	2.6	298–10	173–53
336	S. Artfjället	65°54′	14°52′	3.6	1.8		
20	S. Artfjället	65°53′	14°57′	20.7	1.7	295–02	200–10
199	S. Artfjället	65°53′	14°54′	2.4	1.9	313–16	161–64
133	S. Artfjället	65°54′	14°53′	6.2	2.3	109–02	146–28
180	S. Artfjället	65°53′	14°55′	1.4	2.1	296–6	196–46
21	S. Artfjället	65°53′	14°57′	3.6	1.8	300–22	028–06
9001A	Nordli	64°23′	13°31′	1.0	3.8	$k = 0$	148–52
9001B	Nordli	64°23′	13°21′	3.2	2.3	018–38	
9001C	Nordli	64°23′	13°31′	2.6	2.8	350–06	095–70
9002	Kveli, Nordli	64°32′	13°41′	1.8	4.1	332–18	052–66
9003	Vagen	64°38′	13°46′	2:7	4.2	002–44	162–31
9004	Jormlien	64°45′	13°52′	1.8	3.2	324–62	132–32
9005	Vojtjajaure	65°33	15°18′	1.4	1.9	017–08	127–54
9006	Vojtjajaure	65°34′	15°19′	1.3	1.5	weak fabric	
9007	Fättjaur	65°20′	15°15′	3.4	2.5	033–14	168–65
9009	Ankarvattnet	64°51′	14°16′	1.5	3.2	324–32	142–56
9010	Ransarn	65°10′	15° 5′	1.0	2.6	$k = 0$	309–06
9100A	Kvesjoën	64°13′	13°56′	3.1	4.9	315– 0	104–82
9100B	Kvesjoën	64°30′	13°56′	2.7	6.4		
9101	Grundfors	65° 8′	15° 4′	1.0	1.7	$k = 0$	282–15
9102A	Klimpfjäll	65° 5′	14°41′	2.0	2.3	050–20	200–70
9102B	Klimpfjäll	65° 5′	14°41′	2.1	2.9	252–06	140–66
9103	Sannaran	64°54′	14°43′	2.3	2.9	292–08	210–75
9105	S. Storfjället	65°37′	14°41′	4.0	1.5	296–33	110–50
9106	Lill-Bjorkvattnet	65°29′	15°26′	3.4	2.4	295–36	100–48
9107	Krutfjell	65°44′	14° 5′	7.1	2.5	280–23	042–38
9108	Krutfjell	65°43′	14°16′	2.6	2.5	240–06	340–56
9110	N. Krutfjell	65°47′	14°18′	13.4	4.0	090–16	284–58
9111	N. Krutfjell	65°47′	14°12′	10.0	4.0	056–14	274–75
9204	N. Fättjaure	65°18′	15°19′	1.8	1.8	352–37	098–20
9205	Ransarn	65°10′	15° 5′	1.0	2.8		
9206	Ransarn	65°10′	15° 5′	1.9	2.5		
9207	N. Storfjället	65°56′	15° 7′	1.7	2.5	292–05	112–85
9207A	N. Storfjället	65°56′	15° 7′	1.8	2.3	292–05	112–85
9208	Björkvattnet	65°35′	15°12′	1.2	1.5	weak fabric	
9230	Forsbäck	65°40′	15°26′	1.0	1.8	$k = 1$	129–10
9232	Favnvandet	65°49′	14°22′	3.2	4.0	290–00	200–50
9233	Virisen	65°26′	15°19′	2.3	1.3	040–10	140–30
9234	Unkervatnet	65°35′	14°11′	4.2	1.8	310–40	116–50
9235	Gränssjo	65°25′	14°50′	1.0	1.5	$k = 1$	080–40
9236	Slätdalbacken	65°26′	15° 2′	3.1	1.3	360–15	261–37
9237	Skalmodal	65°25′	14°34′	1.6	3.3	040–43	232–42
9241	Limingen	64°45′	13°43′	1.0	3.6	$k = 1$	322–58
9242	Limingen	64°44′	13°46′	1.4	2.6	065–10	284–54
9243	Limingen	64°41′	13°42′	2.5	3.2	056–30	326–10
9244	Seterhaugen	64°40′	13°40′	7.3	2.2	050–06	144–05