7. Tectonic Studies on a Part of the Southern Caledonides of Sweden

by

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The present review is a summary of the following papers, which will also be found in the list of references:

I. ARNE STRÖMBERG, 1952: Om Hedekalken, En petrografisk och tektonisk studie. *Geologiska Föreningens i Stockholm Förhandlingar*, Bd. 74, H.4, pp. 309–316.

II. ARNE STRÖMBERG, 1955: Zum Gebirgsbau der Skanden im mittleren Härjedalen. *Bulletin of the Geological Institution of the University of Upsala*, Vol. XXXV, pp. 199–246, Pl. I–III.

III. ARNE G. B. STRÖMBERG, 1961: On the Tectonics of the Caledonides in the South-Western Part of the County of Jämtland, Sweden. *Bulletin of the Geological Institutions of the University of Uppsala*, Vol. XXXIX, Number 6, pp. 1–92, Pl. I–XII.

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Introduction

The Swedish part of the Scandinavian Caledonides extends from the northernmost part of Sweden to the north-western corner of Dalarna. Thus, the Swedish Caledonides have their southernmost occurrence of appreciable magnitude in western Härjedalen and Jämtland, where the investigations reviewed were made. The area surveyed has an extension of about 800 km² and is situated along the Norwegian border between the latitudes 62°18′ and 63°15′.

In the year 1896 A. E. TÖRNEBOHM finally developed his magnificent hypothesis of large-scale overthrusts in the Caledonides. Although A. G. HÖGBOM (1920) gave his support to this conception, TÖRNEBOHM was contradicted by many contemporary Swedish and Norwegian geologists. Also G. FRÖDIN (1922) denied the existence of large overthrusts, and explained the metamorphism as caused by an extensive injection metamorphism and relatively local movements.

B. ASKLUND and P. THORSLUND (1935), however, distinguished in the Cambro-Silurian of the Central Jämtland area a series of nappes, which together form the floor of the large Seve overthrust presumed by TÖRNEBOHM (1896). Investigations in other parts of the Caledonides have further proved the validity of his ideas.

Apart from studies in certain parts of the present area by HÖGBOM (1920), FRÖDIN (1922), ASKLUND (1933), and G. STÅLHÖS (1937), no regional mapping has been done after the work by TÖRNEBOHM. An extensive regional mapping with special regard to the tectonics of the region therefore had to be made by the present author (STRÖMBERG, 1961).

The main object of the field investigation has been the Särv nappe, the extension of which has been one principal object of the survey. The results of this mapping have in part been reported earlier (STRÖMBERG, 1955) and have also been embodied in the official *Geological Map of Sweden* (N. H. MAGNUSSON *et al.*, 1958).

Within the area surveyed, rather detailed mapping has been performed in some important localities, as N of Mittåfallet in Mittån River and at Ulvberget Mountain (STRÖMBERG, 1955), at Röstberget Mountain near Funäsdalen and at Biskopsån River near the Riksgränsen Anticline (STRÖMBERG, 1961). On the basis of field investigations and measurements, several sections have been drawn through especially instructive parts of the area.

Besides petrological observations, investigations of structural features such as *s*-surfaces, lineations, and folding have been performed everywhere during the mapping work, and especially at exposures with pronounced deformation. Most of the measurements of *s*-surfaces and lineations have been statistically treated according to B. SANDER (1948, I). The main part of about 700 collected hand-specimens was orientated in the field in order to permit further fabric investigations.

Microscopical investigations have been made on about 150 thin-sections from the area investigated. In some cases petrofabric analyses have been performed on deformed rocks. Mainly, the preferred orientations of quartz and micas have been determined (STRÖMBERG, 1955, 1961).

Some chemical analyses have been made: on dolomitic rocks (STRÖMBERG, 1952, 1961), on Ottjäll dolerite (STRÖMBERG, 1955) and on augengneiss (STRÖMBERG, 1961).

Tectonic units

A. E. TÖRNEBOHM (1896) made a distinction between the large Seve nappe, on the one hand, which has been moved independently during the overthrust movements, and lower sub-nappes such as the augengneiss, on the other hand, which have been dragged along more passively with the overthrusting. In essential points I agree with TÖRNEBOHM in this case although I have described the metamorphic rocks underneath the Särv nappe as constituting a separate tectonic unit, the mylonite nappe (STRÖMBERG, 1961). The reason for this is that the mylonite nappe has a regional extension and is separated from its roof and floor by thrust-planes. B. ASKLUND (1938) has found a similar tectonic unit in the Central Jämtland area and has named this unit the granite mylonite nappe.

The mylonite nappe of the present area is mainly composed of mylonites and phyllonites derived from granitic and amphibolitic rocks. Thus, this nappe contains parts of the primary, Precambrian basement of the Särv nappe, mixed up with parts of the parautochtonous basement incorporated during the overthrust movements. The augengneiss seems to have developed by a late porphyroblastesis of microcline in those parts of the mylonite nappe where intense precrystalline deformation and abundance of potassium have facilitated this process (STRÖMBERG, 1961).

The lowermost part of the large Seve nappe is characterized by swarms of dikes of Ottfjäll dolerite which seem to have been only slightly disturbed in relation to rocks of the nappe. I have named this unit the Särv nappe after its occurrence in the Särvfjällen Mountains and other mountains around Särvsjö Village (STRÖMBERG, 1955).

The Helags nappe, named after the Helags Mountain, has been thrust upon the Särv nappe. It contains calcareous phyllites, schists and gneissic rocks in which amphibolites occur. The overthrust zone against the Särv nappe is indicated by mylonitization and shearing of the dolerite dikes.

Stratigraphy of the Särv nappe and its relation to the surroundings

The Särv nappe contains the following rock sequences (STRÖMBERG, 1961).

(1) Parts of the primary basement upon which the sediments of the nappe were deposited. Among these rocks have been observed: light-coloured microcline-granites, red biotite-bearing granite, and the Tännäs complex, composed of felsites and amphibolitic or anorthositic rocks. The rocks of this complex, named after their occurrences in the mountains around Tännäs Village, show a pre-Caledonian deformation, and are very similar to rocks of the Jotun group.

(2) Basal fragmental rocks which contain mainly material from the Tännäs complex, and seem to have been deposited upon a bedrock which must have consisted of rocks of this complex.

(3) The quartzite and greywacke sequences of the Särv nappe proper. Of these the quartzite sequence, containing in its lowermost part banded shales and light-coloured quartzites with scattered quartzite pebbles, predominates in the southern part of the Särv nappe. In the northern part of this nappe the greywacke sequence, which contains biotite-bearing, metamorphic greywackes, siltstones, and sandstones, seems to be situated above the quartzite sequence.

Separated from the Särv nappe proper by a thrust zone the Ulvberg complex, containing dolomite-marble and white quartzite, occurs exclusively between the Särv nappe proper and the mylonite nappe.

Correlation of the rocks of the Särv nappe with rock sequences described from other parts of the Caledonides is difficult to perform with certainty. Dikes of dolerite or amphibolite which occur in the same manner as the Ottfjäll dolerite seem, however, to be rather common in sparagmitic rocks along the margins of the Trondheim area, e.g. to the north of Opdal, as described by O. HOLTEDAHL (1953, p. 279). Intersecting amphibolitic dikes in the lower part of the Seve nappe in Västerbotten may eventually correspond to the Ottfjäll dolerite (cf. STRÖMBERG, 1955).

The occurrence in the Särv nappe of the Tännäs complex, which is compared with the Jotun group, indicates a possible connection between the Lower Jotun nappe and the Särv nappe (STRÖMBERG, 1961). Rocks of this kind seem, however, to have been widely spread in the basement far to the west, and may equally well occur in different tectonic units.

Age of the Ottfjäll dolerite

The dolerite occurring in Ottfjället Mountain was first investigated by P. J. HOLMQUIST (1894), who described closely spaced, parallel dikes outcropping all over Ottfjället and the surrounding mountains.

A. E. TÖRNEBOHM observed that the Ottfjäll dolerite dikes intersect rocks affected by post-Silurian deformation, and for this reason he interpreted the dolerite as being post-Silurian, although simultaneously he stated that the dolerite dikes never occur in Silurian rocks (TÖRNEBOHM, 1896). As I have shown, however, most of the deformation in the sedimentary wall rock of the dolerite dikes is younger than the dolerite (STRÖMBERG, 1961 cf. below). The crystallization which gave the sediments a metamorphic appearance is still later and seems to be essentially post-tectonic.

The large-scale deformation inside the Särv nappe during the overthrust movements can be interpreted as a predominantly external overturning rotation of the stiff and rigid dolerite bodies. This overturning was directed mainly eastwards and was accompanied by an internal rotation in the interposed sedimentary rocks. TÖRNEBOHM's observations of post-Silurian deformation in the rocks intersected by the dolerites are thus no conclusive evidence for a post-Silurian age of the Ottfjäll dolerite.

A. G. HÖGBOM (1920, p. 71) was conscious of some unexpected features concerning the occurrence of the Ottfjäll dolerite. He thus states that the dolerite, although appearing as dikes in the Alsen nappe, has never been found in the Silurian basement underneath this nappe.

G. FRÖDIN (1922) relates some observations of tectonic disturbance in the dolerite dikes, especially at the base of the Särv nappe, but he ascribes the formation of these features to thrust movements of rather limited magnitude.

At some elucidative localities in the bottom of the Särv nappe I found (STRÖMBERG, 1955) signs of intense deformation which, together with the absence of dikes in the basement, proves that appreciable overthrusts must have occurred after the intrusion of the Ottfjäll dolerite. This indicates that the dolerite had been intruded prior to the last overthrust of the Särv nappe.

If considerable schistosity had been present in the nappe at the time of the dolerite intrusion, the formation of dolerite sills would have been favoured. Actually, there are hardly any sills at all and, furthermore, the deformation of the sedimentary rocks is always remarkably weak at the intrusion contacts.

To establish whether or not there was any detectable deformation in the rocks before the dolerite intrusion, I investigated the petrofabrics of some schistose rocks, intersected by dikes of Ottfjäll dolerite (STRÖMBERG, 1961). The results of these investigations indicate that most of the deformation is postintrusive and possibly due to overturning effects connected with overthrust movements of the entire Särv nappe. Only trace indications, especially as to the preferred orientation of mica, may be referable to structures which are older than the Ottfjäll dolerite. Nevertheless some indications of pre-intrusive folding and anisotropy in the Särv nappe suggest that there may have been an early deformation of the rocks before the dolerite intrusion.

The results of the present investigations date the intrusion of the Ottfjäll dolerite back to an early orogenic stage of the Caledonian revolution or to still older times.

One such early orogenic stage is found in the Ordovician, during which epoch there was considerable volcanic activity in the Scandinavian Caledonides (cf. VOGT, 1946 and KAUTSKY, 1949). A comparison of the chemical composition of the Ottfjäll dolerite with that of some Ordovician effusives from the Trondheim area suggests that there is a possibility of some genetic relationship between these rocks (STRÖMBERG, 1961).

Tectonics

The Caledonian deformations have proved to be of different types in the nappes and in the zones of intense translatory movements. In the Särv nappe, axes $b = B$ are orientated mainly in Caledonian directions about NNE or ENE, whereas in the overthrust zone below the same nappe transverse axes $b = B$ always are orientated in about NW (STRÖMBERG, 1961, Pl. III and Pl. IV 36–38). In both these cases, however, the axes of deformation and folding constitute pairs of the type $B \perp B'$ (SANDER, 1948). Contrary to KVALE (1945), I have interpreted a lineation in about NW as $b(=B)$, indicating tectonic transports (mainly compression) of the direction NE–SW (cf. KOARK, 1961).

In 1955 the basal zone of the Särv nappe was investigated (STRÖMBERG, 1955). These studies were complemented by further investigations, the diagrams of which have been given by STRÖMBERG (1961, Pl. IV). There is an interesting effect shown in the deformations of this zone, as lower schists exhibit B-directions in about NW whereas, higher up, near the sheared dolerites in the base of the Särv nappe, the B and β have changed to about NNW (STRÖMBERG, 1961, Pl. IV 33–35; cf. also Pl. IV 29–32).

This effect of changing B-directions with regard to the tectonic position may be interpreted as due to B-axes of different age (cf. LINDSTRÖM, 1958; and STRÖMBERG, 1959) but is more probably effected by a rearrangement of the B-axes due to the anisotropy in the vicinity of the dolerite dikes of the Särv nappe.

In addition to the overturning effects in the Särv nappe, there are indications that certain blocks have been turned horizontally around subvertical axes of rotation during the overthrust movements. This hypothesis (STRÖMBERG, 1961) is based upon the following facts.

(1) In the blocks with supposed rotation the dolerite dikes have a westerly strike instead of the northerly strike which is the rule everywhere else in the nappe.

(2) In the areas surrounding these blocks, where, according to the hypothesis, the most intense shearing stress should have occurred, the rocks of the Särv nappe are more intensely deformed than elsewhere. Since the schistose rocks formed by this deformation are less resistent to weathering than the rocks of less deformed parts of the Särv nappe, the schistosity zones are indicated by valleys. This is the case in the area south of the Åvikberget block (cf. STRÖMBERG, 1961, Pl. I and Fig. 25). South of this mountain the deforma-

tion has resulted in the formation of amphibolitic and quartzitic schists on Gräsmyrberget Mountain. The deformation culminates in the zone, where the Ljungan River has eroded its valley. The same deformation seems to have occurred north of Åvikberget Mountain, where erosion has cut through the Särv nappe and exposed the mylonite nappe.

To the south of the rotated Ottfjället block the schistosity of the Särv nappe is pronounced in the Vålådalen zone (STRÖMBERG, 1961). In the same manner strong deformations, which also may have facilitated the erosion of the Ottsjö Valley, occur in the nappe to the north of Ottsjö Village.

(3) The above blocks are located close to elevated parts of the basement, suggesting that the blocks have been arrested by these elevations during the eastward movement of the nappe.

(4) A comparison of the joint structure in Åvikberget (STRÖMBERG, 1961, Pl. IV, 26) with the joint structures W and N of this mountain (Pl. IV, 27 and 28) shows a late system of joints striking NE in all three diagrams. In Åvikberget, however, the dolerite dikes and the probably older system of joints in the quartzite connected with these form an angle of about 40° to the NE striking joint system. This may be interpreted as the result of an anticlockwise rotation of the Åvikberget block.

Combined, the observations (1)–(4) indicate that rotations *en bloc* have taken place within parts of the Särv nappe during the general overthrust of this nappe.

Summary

Beginning at Hede (1952, 1954) and later extending the investigations further westward and northward (1955), I have mapped and investigated the Caledonides of western Härjedalen and south-western Jämland (1961) with special regard to some structural and tectonic problems.

The Ottfjäll dolerite, which had been considered to be of post-Silurian age by A. E. TÖRNEBOHM (1896) and others, could be shown to have been intruded during an early phase of, or possibly prior to, the Caledonian orogeny. In a certain tectonic unit, the Särv nappe, this dolerite was intruded, mainly as swarms of steep, sub-parallel dikes, striking about N–S. Subsequent overthrusts moved this nappe from an original location far to the west to its present position. Owing to this large-scale overthrusting extensive disturbances developed in the nappe, as for instance a general, eastward overturning of bedding planes and dolerite dikes. Most remarkable are the observations of blockwise horizontal rotation of large parts of the Särv nappe due to local resistance from protruding parts of the basement during the overthrust movements.

Parts of the Precambrian bedrock, consisting of rocks similar to the Bergen–Jotun group and granites, upon which the sediments of the Särv nappe were originally deposited, have been dragged along and embodied in the bottom of the Särv nappe. Another tectonic unit, named the Helags nappe, has been thrust upon the Särv nappe.

References

ASKLUND, B., 1933: Vemdalskvartsitens ålder. *Sv. Geol. Unders.*, Ser. C, No. 377. Stockholm.

— 1938: Hauptzüge der Tektonik und Stratigraphie der mittleren Kaledoniden in Schweden. *Sv. Geol. Unders.*, Ser. C, No. 417. Stockholm.

ASKLUND, B. and THORSLUND, P., 1935: Fjällkedjerandens bergbyggnad i norra Jämtland och Ångermanland. *Sv. Geol. Unders.*, Ser. C, No 382. Stockholm.

FRÖDIN, G., 1922: Über die Geognosie der zentralschwedischen Hochgebirgen. *Bull. Geol. Inst. Upsala.*, Vol. XVIII. Uppsala.

HOLTEDAHL, O., 1953: Norges Geologi. *N. Geol. Unders.*, No. 164. Oslo.

HOLMQUIST, P. J., 1894: Om diabasen på Ottfjället i Jemtland. *Geol. För. Förh.*, Vol. 16. Stockholm.

HÖGBOM, A. G., 1920: Geologisk beskrifning öfver Jemtlands län. *Sv. Geol. Unders.*, Ser. C, No. 140, 2nd, rev. ed. Stockholm.

KAUTSKY, G., 1949: Stratigraphische Grundzüge im westlichen Kambrosilur der skandinavischen Kaledoniden. *Geol. För. Förh.*, Vol. 71, Part 2. Stockholm.

KOARK, H. J., 1961: Zur Deformation des Venna-Konglomerates im Trondheim-Gebietes, Norwegen. Ein Beitrag zur Frage von Formungsrichtung und Streckungs-orienterung an skandischen Konglomerattektoniten. *Bull. Geol. Inst. Uppsala*, Vol. XL. Uppsala.

KVALE, A., 1945: Petrologic and structural studies in the Bergsdalen Quadrangle, Western Norway. *Bergens Mus. Årbok*, 1945–1947. Bergen.

LINDSTRÖM, M., 1958: Toward a further hypothesis on the Scandinavian caledonides. *Geol. För. Förh.*, Vol. 80. Stockholm.

MAGNUSSON, N. H., *et al.*, 1958: Karta över Sveriges Berggrund (Pre-Quaternary rocks of Sweden). *Sv. Geol. Unders.*, Ser. Ba, No. 16. Stockholm.

SANDER, B., 1948: Einführung in die Gefügekunde der geologischen Körper. Teil I u. II. Innsbruck.

STÅHLÖS, G., 1956: The sparagmite series and the Vemdal quartzite of the Hede region, Härjedalen. *Bull. Geol. Inst. Upsala*, Vol. XXXVI. Uppsala.

STRÖMBERG, A., 1952: Om Hedekalken. En petrografisk och tektonisk studie. *Geol. För. Förh.*, Vol. 74, Part 3. Stockholm.

— 1954: Berggrunden inom Hede socken. Part of: Aktuella skandinaviska fjällproblem. *Geol. För. Förh.*, Vol. 76, Part 1. Stockholm.

— 1955: Zum Gebirgsbau der Skanden im mittleren Härjedalen. *Bull. Geol. Inst. Upsala*, Vol. XXXV. Uppsala

— 1959: The Scandinavian Caledonides. A discussion. *Geol. För. Förh.*, Vol. 81, Part 2. Stockholm.

— 1961: On the tectonics of the Caledonides in the south-western part of the county of Jämtland, Sweden. *Bull. Geol. Inst. Uppsala*, Vol. XXXIX, Part 6. Uppsala.

TÖRNEBOHM, A. E., 1986: Grunddragen av det Centrala Skandinaviens bergbyggnad. *K. Sv. Vet. ak. Handl.*, Vol. 28. Stockholm.

VOGT, TH., 1946: Vulkanismens faser i Trondheimsfeltet. *D. K. N. Vid. Selsk. Forh.*, Vol. XIX. Trondheim.