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EBBE ZACHRISSON

CALEDONIAN GEOLOGY
OF NORTHERN JÄMTLAND
— SOUTHERN VÄSTERBOTTEN

KÖLI STRATIGRAPHY AND MAIN
TECTONIC OUTLINES

WITH 1 PLATE



STOCKHOLM 1969

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C DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1969

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ABSTRACT

The stratigraphic and tectonic results of several years' prospecting work for sulphide ores in a central part of the Swedish Caledonides have been compiled into a regional map covering an area of about 5 000 sq. km and with a north-south extension of nearly 150 km.

Four major north-trending folds, referred to as the Riksgränsen Antiform, the Western Synform, the Fjällfjäll Antiform and the Eastern Synform dominate the structure of the area, folding the compositional banding, the regional schistosity and the thrust-sheets. The lithologies described here are of low metamorphic grade and referred to as Köli in Swedish literature. Some comment is also included on the high grade Seve rocks and on arkoses and quartzites in lower tectonic units.

Local lithostratigraphy in carefully investigated areas within the Western Synform have been correlated to form the basis of a regional subdivision of the low-grade Köli rocks into three major groups. The Eastern Synform contains the fossil-bearing units, which Kulling (1933) used for his stratigraphic subdivision. Although many correlations have earlier been made and discussed, this compilation is apparently the first attempt to represent for the whole map area a lithostratigraphic grouping of all Köli rocks.

Deformation occurred during several phases. The first phase(s) F_1 , produced isoclinal, generally minor folds and a strong schistosity, sub-parallel to bedding. It is likely that at least in some areas the sequence was laid in quite large, recumbent folds (pre- F_1) prior to the formation of this schistosity. Associated with F_1 or slightly younger are local and possibly also more regional low angle thrusts, e. g. the Gellvernokko and Leipik Nappes, described for the first time in this paper. These Köli nappes as well as the whole Seve-Köli Nappe Complex were transported eastwards prior to the next phase, F_2 , which produced more open folds with a generally steep-dipping axial surface. Apart from the production of ubiquitous parasitic minor folds, this phase was also responsible for the formation of the Riksgränsen and Fjällfjäll Antiforms and the Western and Eastern Synforms.

Sections have been drawn across the area, which clearly demonstrate regionally very flat-lying structures, and a marked tendency for all tectonic units and their internal stratigraphic sequences to thin or even wedge out completely westwards. This is most clearly visible for the Seve rocks, which are quite thin or even missing around the Hehtajaure and Fjällfjäll Windows and never impinge on Norwegian territory in this part of the Caledonides.

I. INTRODUCTION

1. General remarks

The present paper and accompanying map is intended in broad terms to present the geological results of the prospecting work, carried out by the Ore Prospecting Department of the Geological Survey of Sweden in the Caledonides during the years of 1962–1968. Economic aspects have led to a certain unevenness in the distribution of the data, more intense work being concentrated in mineralized areas. However, to control the regional correlation, areas in between have also been investigated from a stratigraphic and structural point of view. This summary presents the more general conclusions, which can now be drawn, the main results being presented in the geological map Plate I. In many places stratigraphic and tectonic problems have had to be left unsolved, sometimes due to the lack of detailed work, sometimes due to the fact that new information from other parts has made reinterpretation necessary, which can not always be done without additional field checking. It is hoped that this summary will serve as a general background and a basis for more detailed descriptions of restricted areas and geological map-sheets. The area under consideration covers completely or partly the map-sheets 22 E Frostviken, 23 E Sipmeke, 23 F Fatmomack, 24 E Joesjö and 24 F Tärna.

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I am also indebted to Mrs S Järnefors, who drew the maps and diagrams, and especially to D G Gee, Ph. D., for constructive criticism and correcting the English of the manuscript.

2. Regional setting

The area dealt with lies within the Jämtland-Västerbotten Caledonides and belongs to the Sve-Köli Nappe Complex (Kulling 1960, 1964). The front of the thrust appears in the easternmost part of the map (see insert map, Plate I), where it rests on Eocambrian sparagmites and quartzites (Lower Caledonian Bedrock, Kulling 1960). More centrally similar rocks outcrop in the Hehtajaure

and Fjällfjäll areas and on the north-eastern corner of the Børgefjell Window. Probably all these rocks are late Pre-Cambrian, belonging to the same basal tectonic unit.

The main part of the Børgefjell Window is composed of coarse-grained granites, interpreted as autochthonous, Pre-Cambrian basement (Kautsky 1948). Preliminary whole-rock Rb-Sr age-determinations of 1 670 m. y. (Priem 1967) confirm this view.

The Seve-Köli Nappe itself contains rocks of higher metamorphic grade (gneisses/mica-schists, amphibolites and ultrabasic rocks) in its lower part, outcropping in the eastern and south-eastern part and fringing the Hehtajaure area. Locally they occur around the southern hinge of the Fjällfjäll Antiform but further west, against the Børgefjell Massif, they seem to be completely missing. Apparently the lower part (Seve) of the Seve-Köli Nappe Complex wedges out westwards.

The upper Köli part of the Seve-Köli Nappe Complex forms the main subject of this paper, the stratigraphic and tectonic outlines being described and discussed. The succession is characterized by sediments and volcanic rocks of an eugeosynclinal sequence, metamorphosed in greenschist facies or, towards the Seve base, appearing in a higher grade condition ("*Garbenschiefer*"; "*kärvskiffer*" in Swedish). Some evidence of a tectonic contact between the Köli and the Seve units exists.

3. Previous work

To avoid making this description too voluminous very little by way of historic review will be given here.

In his description accompanying the county map of Västerbotten (1955), Kulling summarized all work up to 1954. He made minor changes in his stratigraphic nomenclature in 1958. Two years later Quensel (1960) published a description to a county map of Västerbotten, printed already in 1929, and the same year Kulling (1960) dealt with the Caledonides of Swedish Lapland in the "Description to accompany the map of the pre-Quaternary rocks of Sweden". The present author published an account of a part of southern Västerbotten – the "Remdalen Syncline" – in 1964. Preliminary results from the Arefjället Synform were presented by Gee (1968).

The latest contribution to the geology of northern Jämtland was made by Nilsson (1964) with a detailed investigation of the Blåsjö area. His bibliography gives a complete list of all earlier investigations.

Regional stratigraphic correlation with Norway and with northern Norrbotten was discussed by Strand (1963) and Kulling (1964). An abstract to a paper over the same topic as the present publication was printed in GFF (Zachrisson 1968).

II. STRATIGRAPHY OF THE KÖLI ROCKS

1. Introduction

The Köli sequence is composed of layered supracrustal rocks, originally marine sediments, now occurring as phyllites, intercalated with volcanic rocks (greenschists and quartz-keratophyres) and tuffites. The primary sedimentary bedding is still visible as a distinct compositional banding due to variations in sedimentary facies, presence of varying amounts of organic matter or intercalations and admixture of volcanic material. Amongst Swedish Caledonian geologists the name Köli is generally used for these low-grade rocks, within which it is not difficult to make a regional stratigraphy.

Table I

Stratigraphic correlation and proposed subdivision into groups based on revised, local, stratigraphic columns

| Blåsjö area | Remdalen area | Björkvattnet-Virisen | N. Jämtland-S. Västerbotten |
|---|--|---|-----------------------------|
| G. Nilsson 1964 | E. Zachrisson 1964 (revised) | O. Kulling (1933) 1958 | This paper |
| Graphitic phyllites, quartzites, greenstones and greenschists Portfjäll conglomerate | Frems Phyllite Remdalen Greenschist with porphyry-limestone horizon Graphitic Phyllite with thin greenschist horizons Remdalen Quartzite-Conglomerate-bearing Formation | | Remdalen Group |
| Basalt - quartz keratophyre formation Blåsjö phyllite | Stekenjokk Quartz-Keratophyre & Lasterfjäll Quartz-Keratophyre-bearing Formation Lasterfjäll Calcareous Phyllite Bellovare Formation | Viris Quartzite Lövfjäll Phyllite Broken "Series" Slättdal-Voitja "Series" | Lasterfjäll Group |
| | Tjopasi Formation | Gilliks "Series" (Mesket) Seima "Series" (Rotik) Ro "Series" | Tjopasi Group |

The basis for Västerbotten Köli stratigraphy was established by Kulling, (1933, amended in 1955, 1960) in the least metamorphosed sequences, outcropping in the Eastern Synform. In the upper part of Kulling's succession sedimentary structures are common. The Lövfjäll Phyllite (see Table I), a mixed calcareous sequence of sandstones and phyllites, shows well-preserved bedding with rhythmic sedimentation of psammitic-pelitic material, often in graded units of less than a decimetre up to a metre. Flow casts and other bottom structures are also known. In the Viris Quartzite, current bedding has been used locally to demonstrate the way-up. The transitional zone between these two formations is particularly rich in greywackes, which often pass into very coarse units (sedimentary breccias and polymict conglomerates).

The sequence of the Eastern Synform (Björkvattnet-Virisen) contains well defined macrofossils of Upper Ordovician and Lower Silurian age (Kulling 1933, 1960).

On the map, Plate I (see also Table I), all Kulling's lower stratigraphic units (the Rotik, Mesket and Gilliks "Series") are taken together and shown as one major unit, the upper part of his sequence (the Voitja-Slättdal, Broken, Lövfjäll and Viris "Series") forming another. On the same map the lithologic boundaries in some cases have been modified according to photogeological interpretation and to some additional field work, mainly in the western limb. For the southern part of the trough, maps were presented by Högbom (1925, 1937) and Du Rietz (1941). Some observations have also been taken from notebooks in the SGU archive (unpublished material).

Due to the more intense folding and schistosity in the Western Synform sedimentary structures are only locally preserved. Graded bedding is quite common, however, south-east of Stekenjokk, where a number of drillholes penetrate calcareous phyllites of the Gellvernokko Nappe. It has also been observed by G Kautsky north of Qvarnbergsvattnet, and by the author in V. Vardofjäll and in the Skalmodal valley. Current bedding is known from a few localities at Durjenjokk (not on the map) in Beskow's (1929) Upper quartzite. Of coarser sediments, greywackes have been described by Nilsson (1964) south of Leipikvattnet. Conglomerates occur at various levels. The acid volcanic rocks sometimes (as in V. Vardofjäll) show pyroclastic or agglomeratic structures similar to those described by Beskow from S. Storfjället (1929). No pillow lavas have so far been identified within the area (cf. Zachrisson 1966). Most basic and acid volcanic rocks seem to have been laid down as tuffs.

Apart from crinoid stems (fragments) in some localities of the Bjuräly, Raukasjö, Bellovare and Remdalen limestones (Du Rietz 1936, A. G. Högbom 1920, A. Högbom 1925, Du Rietz 1941) no macrofossils have been found within the Western Synform. In 1964 well preserved microfossils were discovered by the author in thin sections of a dark, bituminous limestone from a drill-hole penetrating the Gellvernokko Nappe, south-east of Stekenjokk. Material is under

examination, and up to now many limestones and phyllites have yielded various acritarchs.

In the Western Synform, local lithostratigraphic columns were described in the Blåsjö area by Nilsson (1964) and in the Remdalen area by the author (1964). Correlation of the successions in these two areas was proposed by Zachrisson, based on the marked similarity in both areas of gabbro-intruded calcareous phyllite formations and on overlying association of quartz-keratophyre and quartzite conglomerate. A reservation was then expressed with regard to further correlation southwards. Recent mapping has justified the original correlation and at the same time shown that the uppermost parts of the successions in both Remdalen and Leipikvattnet areas are tectonically disturbed. The revised stratigraphic columns are shown in Table I.

Based on the mapping of formations around the southern and northern ends of Fjällfjället and the pass over Raukasjö-Autjojaure-Kultsjön, it is now possible to correlate the stratigraphic sequences in the Eastern and Western Synforms. A thick, calcareous phyllite, in the Western Synform heavily gabbro-intruded, forms a major mappable unit. It provides the basis for a threefold lithostratigraphic subdivision of the whole sequence, with underlying and overlying much more varied units, mainly composed of non-calcareous, dark, quartz-rich, graphitic phyllites with intercalations of volcanic rocks and containing several quartzite conglomerate horizons. In the "Remdalen Syncline" the conglomerates were chosen as the base of the middle and upper units, the Lasterfjäll and Remdalen Groups respectively. Although they are generally monomikt, the boulder content not being indicative of any major unconformities, locally minor unconformities can be demonstrated. Over very long distances they are without doubt the very best key horizons for lithostratigraphic work. Their use for subdividing the sequence, however, does lead to some difficulties especially in areas where the conglomerate horizons are impersistent. An alternative might be to use just the calcareous phyllite lithology as representative of the middle group but in this case it would be very hard to define its boundaries because the changes to grey, graphitic or quartz-rich phyllites are often transitional or occurring with repeated intercalations of different lithologies.

It is doubtful whether at present, or in the future, well-defined formal lithostratigraphic units could be extended over such wide areas as are dealt with in this paper. A system correlating local, lithostratigraphic sequences with the aid of tables and diagrams is perhaps to be preferred. However, the main intention of the present paper is to show the regional distribution of major rock units. The author thinks that this is best done according to the proposed subdivision into major groups, as shown in Table I, based on well-known conglomerates used in a rather conventional way (cf. Kautsky 1949).

It should be mentioned here that the Fjällfjäll Arkose (Zachrisson 1964) is no longer included in the Köli stratigraphy. Consequently it is not dealt with in this chapter; its position is discussed in more detail on p. 19.

Based on the regional correlations presented in this paper and on the fossil dating of the Slättdal Limestone and the Broken graphitic phyllites, the lowest major unit, the Tjopasi Group, should be of Cambrian (?) – upper Ordovician age, the Lasterfjäll and Remdalen Groups being uppermost Ordovician – Silurian. Finally it should be mentioned here that the "series" of Kulling's nomenclature are principally treated as formations.

2. Tjopasi Group

Originally defined in the Remdalen area as the Tjopasi Formation, this unit includes the graphitic rocks with volcanic intercalations, overlying the Fjällfjäll Arkose. The key sections and its characteristics were described by the author in 1964. In this paper the Tjopasi rocks are referred to as a group, despite their rather restricted thickness in both limbs of the Remdalen Synform, and include all units below the Bellovare Conglomerate down to the base of the Köli sequence.

Going southwards from the Fjällfjäll area, to southernmost Västerbotten and northern Jämtland, there is a marked increase in thickness of this part of the sequence. Where most complete it generally contains the stratigraphic units shown in the left part of Table II.

Table II

Comparative successions of the Tjopasi Group

| Southernmost Västerbotten – northern Jämtland (this paper) | Björkvattnet–Virisen | |
|--|------------------------------------|------------------|
| | Kulling 1933 | Kulling 1958 |
| Graphitic phyllites with quartzitic, conglomeratic and limestone horizons | Gilliks "Series" | Gilliks "Series" |
| Volcanic rocks (basic and acid) Grey and graphitic phyllites | Mesket "Series" | Seima "Series" |
| | | Ro "Series" |
| Serpentinite conglomerate Quartzite conglomerate | Rotik "Series" = = Rotik Congl. | Ro Conglomerates |
| Varied sedimentary, tuffitic and volcanic rocks | Not present or not distinguished | |

The degree of metamorphism increases downwards, biotite, garnet and hornblende starting to grow, so that in the south-eastern part of the map area the rocks of the Tjopasi Group are represented by often dark-coloured mica-schists in the Garbenschiefer ("*kärvskiffer*") zone. In contrast with the Seve rocks, the Köli sequence is characterized by the presence of graphitic rocks as well as conglomerates and volcanics, all of which are generally absent in the Seve assemblage. In some areas they show a tectonic disconformity towards the Seve rocks.

Both on the western side of the Fjällfjäll Antiform and on the westernmost corner of the Hehtajaure Window the Tjopasi Group is remarkably thin. It is not sure whether this thinning is depositional or tectonic.

Northwards the zone of Tjopasi rocks widens very markedly on the eastern slope of V. Vardofjäll. Still further north, between Vapstsjön and Abelvattnet, the lithology becomes more varied. It is mainly the sedimentary members which start to show new facies with an increasing amount of coarser, clastic rock-types, including greywackes and conglomerates of "Gilliks type" (see Kulling 1933); the volume of volcanic rocks also increases.

Within the Tjopasi unit, when tracing its lower and upper limits northwards, are included the Rotik, Mesket and Gilliks "Series" of Kulling (1933), renamed Ro, Seima and Gilliks "Series" in 1958. The same conclusion is reached when correlating the rocks of the Western and Eastern Synforms at the southern end of Fjällfjället, tracing them northwards in both limbs of the Björkvattnet-Virisen - Ransaren Synform.

North of Abelvattnet this zone has been mapped into contact with the belt of dark phyllites and volcanic rocks on the northern slope of Södra Storfjället (Beskow 1929). From there it extends westwards into Norway but could also be followed on the northern side of the Joesjö valley (just north of the map area) to encircle the Joesjö Dome.

In the Skalmodal region the Tjopasi rocks are extensively exposed, but in Rainesfjället, on the north-eastern corner of the Børgefjell Window, these beds are again extremely thin.

One of the most characteristic features of the upper part of the Seve and the lower part of the Köli are the numerous ultrabasic rocks. The concentration in this zone is very pronounced, more than a hundred different bodies or massifs being proved within the map area. In the Seve part they generally occur as dunites; in the Köli, strongly or completely altered to serpentinites or locally even to soapstones.

The Ro Conglomerate (Kulling 1955, 1958) is generally a serpentinite conglomerate, as it is in the type localities (the Rotik Conglomerate, Kulling 1933). Regional mapping of the present area strongly suggest that all serpentinite conglomerates occur at a well-defined stratigraphic level. From many parts of the Caledonides they have been reported in association with a quartzite conglom-

merate (Du Rietz 1935, Kautsky 1949, Kulling 1955, 1958). At the boundary between Jämtland and Västerbotten, both these conglomerates are well-developed on each side of the Slipsik-Hehtajaure culmination, and in Jämtland this zone is represented by the easternmost, lower conglomerate horizon (not shown on the map) near the base of the Köli rocks. In many localities it has been demonstrated that the serpentinite conglomerate lies immediately on top of the quartzite conglomerate, the latter often being intruded by serpentinite bodies, the intrusion being the source of the detritus for the ultrabasic conglomerates. This generation of ultrabasic rocks consequently must have been intruded at an early stage and already brought into position of erosion at the time of formation of the serpentinite conglomerate. The conglomerates generally occur as two nearly monomict units, but Backlund (1925) observed scattered serpentinite or hornblendite boulders in quartzite conglomerates and Kulling (1958) used this evidence for relating them to the Ro Conglomerates.

The Tjopasi Group also contains ultrabasic intrusions at higher levels, and the number of localities known from the middle or upper part of the Köli sequence (the Lasterfjäll and Remdalen Groups) has increased as a result of detailed mapping (localities 2 km north of Stekenjokk, in northern Remdalen, in V. Vardofjäll and in Arefjället may be mentioned). The big serpentinite body in Rotfjellet (north-west of Remdalen in Norway) has certainly a similar position. The author has never met serpentinite conglomerates in association with these latter, younger intrusions.

Despite higher-level intrusions these results mainly agree with the general view that the peridotites occur in the older part of the stratigraphic sequence (Kulling 1933, 1960, Strand 1960). A conflicting opinion has been expressed by Wolff (1967) concerning the Trondheim area.

The Tjopasi Group also contains the polymict conglomerates of Gilliks type. They seem to have a maximum development in the Björkvattnet-Virisen area, wedging out southwards in both limbs of the Fjällfjäll Antiform.

Between the Ro (serpentinite and quartzite) Conglomerate and the polymict conglomerates occur the main part of the volcanic rocks. These, together with intercalated sediments, were divided by Kulling (1955) into two units: the lower Ro "Series" with the Ro Conglomerate at the base, and the Mesket "Series" (renamed to Seima "Series" in 1958) with locally developed conglomerates or coarse clastic members as a basal part. His suggestion that this subdivision might be difficult to fulfil in other areas was justified. The author thinks that this part of the sequence, containing the volcanic rocks (basic as well as acid) has to be treated as one formation. On the other hand there seems to exist in northern Jämtland (the Raukasjö area) another mixed sequence with sediments and acid/basic volcanic rocks (generally in Garbenschiefer facies) below the serpentinite/quartzite conglomerate. This unit is apparently not present or preserved in Kulling's type area. The correlations are shown in Table II.

3. Lasterfjäll Group

Basal conglomerates

Within the type area in Remdalen the base of the Lasterfjäll Group was placed below a thin, impersistent limestone and quartzite conglomerate/quartzite-bearing unit, the Bellovare Formation (Zachrisson 1964) with type section on a small hill at the south-western corner of the Fjällfjäll Antiform. Southwards this characteristic rock association can be followed nearly continuously along the eastern slope of Preunttjåkko (Högbom 1925), over the Västerbotten/Jämtland boundary, west of the Hehtajaure Window, via the Raukasjö limestone to join up with a conglomerate immediately below the calcareous Blåsjö Phyllite in northern Jämtland.

As already mentioned this unit is impersistently developed along the western side of the Fjällfjäll Antiform. In the Ö. Vardofjäll and Arefjället areas the conglomerate is partly replaced by more or less continuous quartzite horizons (Voitja quartzite, see below). Further north, quartzite conglomerates are again met with on the eastern slope of S. Storfjället, where they disappear in Nierjentjåkko beneath the S. Storfjäll Nappe.

The Skalmodal Dome of Tjopasi rocks is fringed by a quite persistent, thin quartzite/quartzite conglomerate on its northern and eastern sides. In the south the same level is represented by a quartzite conglomerate in Gemsäive (not to be confused with the Gemsäive Quartzite, see below, p. 14).

Based on detailed mapping of the Köli sequence, the conglomerates and limestones at Bellovare and Preunttjåkko can be stratigraphically correlated with similar rocks around Rafsensjöarna in the south-western end of the Ransaren Synform, south-east of V. Fjällfjället. From here northwards, scattered conglomerate/limestone occurrences can be used to trace this zone into the western limb of the Björkvattnet–Virisen Synform, as well as eastwards and northwards into the eastern limb of the same major structure.

In Jämtland and southernmost Västerbotten the conglomerate/limestone association generally comes directly below the calcareous phyllite. North of the Fjällfjäll Antiform conditions are more complex due to the fact that dark graphitic phyllites occur between the calcareous phyllites and the Bellovare Formation. Both in this graphitic unit (the Broken "Series") and in the Gilliks "Series" below, quartzite horizons are common. In many cases it is thus difficult without detailed mapping to say which quartzite horizon represents the Voitja level. There seems, however, only to be one quartzite conglomerate in these "Series", indicating the boundary between the two groups.

In both limbs of the "Remdalen Syncline" (Zachrisson 1964) thin green-schist horizons were observed at the top of the Bellovare Formation, immediately below the calcareous phyllite. Basic volcanic rocks at this level are not uncommon in the Western Synform, and in some places also the Lövfjäll Phyllite

is very chloritic in its lower part, in part a real greenschist (see Högbom 1925, p. 39). These members show a gradational transition to the overlying rocks and are therefore included in this formation.

Gabbro-intruded calcareous phyllite

Large areas of low-grade Köli rocks in southern Västerbotten–northern Jämtland are occupied by calcareous phyllites, in some horizons heavily intruded by saussuritic hornblende gabbros. They form a major formation and a fundamental part of the Lasterfjäll Group (Zachrisson 1964). In Remdalen they were given the name of Lasterfjäll Calcareous Phyllite, and further south they were described by Nilsson (1964) as the Blåsjö Phyllite. Du Rietz' map (1936) shows their continuation southwards (described as "fyllit, kvartsfyllit, kalkfyllit"), passing the western part of Qvarnbergsvattnet into Norway.

In the western limb of the Western Synform the same unit outcrops in a belt from Sippmikkjaure south-westwards on the south-eastern side of the Børgefjell Window, forming the lowermost part of the Köli sequence. In the Stekenjokk region, from just north of Sippmikkjaure to Ransarån, they are cut by the thrust at the base of the Seve-Köli Nappe, but at Ransarån they reappear and can be traced north-westwards into Norway.

On the southern side of the Skalmodal–Ö. Vardofjäll culmination the gabbro-intruded calcareous phyllites cover large areas. North of the culmination the formation strikes into Norway on both sides of Arevattnet, whereas in the eastern limb of the Arefjället Synform it can be traced to disappear beneath the S. Storfjäll Nappe. West and north-west of Abelvattnet they once again appear in a dome-shaped structure (Kroarjokk).

Rather low in the calcareous phyllites of the Western Synform (and well below the gabbro-intruded horizons) a quartzitic facies is developed in the Gemsåive area and locally in Ö. Vardofjäll. When passing Nedre Vapstsjön they attain their maximum thickness in the eastern limb and the most southerly occurrences of this facies are known to exist in V. Vardofjäll.

Du Rietz (1941) has emphasized the petrographic similarities between the Gemsåive and Viris Quartzites. These quartzites occupy a higher stratigraphic position than those mentioned earlier (p. 13) at the base of the group, and should most likely be correlated with Kulling's Viris Quartzite in the Björkvattnet–Virisen area and restricted outliers further south (Du Rietz 1941, Plate 3 and Tab. 3). According to Kulling (1933) the Viris Quartzite is the youngest rock unit in Björkvattnet–Virisen, but recent mapping (Gee 1968, unpublished material) has shown that, south of Virisen, greywackes, conglomerates and phyllites of Lövfjäll type containing good way-up evidence also occur on top of the Viris Quartzite. This supports the author's interpretation in Table I, that the Blåsjö, Lasterfjäll and Lövfjäll Phyllites represent the same lithostratigraphic unit, the Viris Quartzite corresponding to thinner quartzite units oc-

curing as intercalations in the lower part of the calcareous phyllite sequence of the Western Synform.

A very characteristic feature of the calcareous phyllite formation are the intrusions of meta-gabbro. The regional mapping has shown most of them to be remarkably limited stratigraphically, being concentrated in the upper part of the formation. It is most likely that they were intruded as sills, once forming even more continuous sheets, now partly tectonically deformed into lens-shaped bodies. They are of pre- or syntectonic age and have suffered from all registered tectonic phases. No such gabbros are known from the Eastern Synform, apparently due to the fact that this higher stratigraphic level is no longer preserved.

Volcanic and associated rocks

As will be seen from Table I the upper part of the Lasterfjäll Group also contains non-calcareous, grey or generally graphitic phyllites with intercalations of basic and acid volcanic rocks, the latter generally the dominating member. In the Blåsö area this part was referred to as the Basalt – quartz-keratophyre formation, three rather detailed sections being described by Nilsson. Further northwards this unit can be followed as a thin horizon just below and east of the Gellvernokko thrust until it disappears beneath the nappe in the southern part of the mountain Gellvernokko. In the west it reappears likewise just beneath the Gellvernokko thrust in Rörsjöfjället and Baima up to Sippmikkjåure; around Stekenjokk it attains a maximum thickness of more than 500 metres, being known in detail from a large number of drill-holes through the Stekenjokk and Levi ore bodies. It can then be followed into both limbs of the Remdalen Synform. As a consequence of the repetition of the Calcareous Phyllite in the Remdalen Synform (see page 21 and Fig. 1) the Lasterfjäll Quartz-Keratophyre-bearing Formation should be stratigraphically correlated with the Stekenjokk Quartz-Keratophyre. The Lasterfjäll Greenschist, having a position below the acid volcanics, then corresponds to a basic volcanism, documented over very large areas (cf. Nilsson's (1964) schematic sections, p. 10, where the lowest members are described as green tuffites). The quartz-keratophyres in Remdalen can be traced northwards to V. Vardofjäll. They are not preserved in the Skalmodal-Ö. Vardofjäll culmination but turn westwards into Norway on its southern side.

In central Arefjället the upper part of the Lasterfjäll Group also contains acid volcanic rocks, very likely of a similar stratigraphic position, but conditions are too complicated to be discussed in this more regional work.

This upper part of the Lasterfjäll Group, on top of the Calcareous Phyllite, is apparently not preserved at all in the Eastern Synform.

taining limestone layers in the Remdalen area, widens northwards to become an important formation. The volcanism of this group is markedly basic. The quartz-keratophyres, being quite common in the lower groups, are completely missing.

In the Arefjället Synform rocks of a similar appearance occur on top of mixed volcanic rocks and graphitic phyllites. They are supposed to be stratigraphically equivalent to the Remdalen Group. It is very probable that these rocks continue from the Arefjället Synform north-westwards to cover areas west and south-west of the S. Storfjäll Nappe, as well as restricted parts north of Abelvattnet.

Looking southwards into Jämtland the implications of the relationships further north require that the Portfjäll Conglomerate should be correlated with the Remdalen Conglomerate and be placed as the base of the Remdalen Group. This view is supported by the similarities shown by the superimposed sequence of dark graphitic phyllites with intercalations of basic volcanic rocks (greenschists with a total absence of quartz-keratophyres).

In northernmost Jämtland, the Gellvernokko thrust is generally located approximately at the Lasterfjäll-Remdalen Group boundary. Both on its eastern and western side the quartzite conglomerate is locally preserved, and exactly at the boundary to Västerbotten (at Tjokkola, 2 km west of Stekenjokk) occur the northernmost localities of the Portfjäll Conglomerate, represented by just a few thin conglomeratic layers or pseudo-conglomeratic, quartzitic horizons. Consequently the rocks in the area between the Børgefjell Window and the Gellvernokko Nappe from Stekenjokk down to Sippmikkjaure have been included in the Remdalen Group.

North of the Stekenjokk culmination, and as isolated outliers in the Stekenjokk area, dark phyllites occur on top of the volcanic rocks. In the transitional zone conglomerates are absent but "thin layers of a light-coloured quartzite, sometimes with a pseudo-conglomeratic appearance" (Zachrisson 1964, p. 16) occur. They form the base of the Kosaåive Phyllites and this formation and the overlying greenschist should be placed in the Remdalen Group (cf. Fig. 1).

The overall picture is that rocks of the Remdalen Group are preserved in several depressions along the western synformal axis.

5. Comment on the stratigraphy of the upper Köli nappes

Within the Gellvernokko Nappe the stratigraphy and its correlation to the above-mentioned units has not been finally worked out, and the structures are too complicated to be discussed on the basis of a map in the scale of 1:200 000. It might, however, be stated, as roughly shown on Plate I, that the area north of Leipikvattnet and most of the eastern part of the nappe is built up of rocks of the Lasterfjäll Group, calcareous phyllites (but without gabbro

intrusions) and quartz-keratophyres being the main rock-types. The rocks of its western part show strong similarities with those of the Remdalen Group, and a great many occurrences of quartzite conglomerates on top of quartz-keratophyres are correlated with the Portfjäll and Remdalen Conglomerates.

In the Leipikvattnet area the rock sequence, described by Nilsson (1964), belongs to two different tectonic units. According to the present author the upper part forms the Leipik Nappe, on Nilsson's map starting with a unit of undifferentiated rocks and passing upwards into units containing the Bjurälvs Limestone, polymict conglomerates and greywackes – a somewhat uncommon facies of the Köli rocks of northern Jämtland. In some respects the rocks are reminiscent of the Liming facies of the Grong area (Strand 1963, Foslie 1926, Oftedahl 1958). The metamorphic grade does not differ from that of the underlying units.

The rocks of the Södra Storfjäll Nappe were described by Beskow in 1929. Many attempts have since been made to correlate the stratigraphy with adjoining parts of Västerbotten, especially by Kulling (1955, 1958). For the present, the author will not comment on these because a reinvestigation of both the stratigraphy and the structures has just started. The metamorphism is slightly higher, rocks in upper amphibolite facies being quite common.

III. STRUCTURES

The following main tectonic units could be discerned within the map area:

| | | | |
|-------------------------------|-------------------------------------|--|---------|
| Seve-Köli Nappe Complex | Köli part | Köli nappes (S. Storfjäll Nappe Leipik Nappe Gellvernokko Nappe) | Thrust |
| | | Lower Köli unit (incl. minor nappes and repetitions) | Thrust? |
| | Seve part | | Thrust |
| Lower Nappes | (quartzites and sparagmites) | | Thrust |
| Basement | (autochthonous or parautochthonous) | | Thrust |

1. Basement

The basement is commented on in the beginning of the paper.

2. Lower Nappes — areas with quartzitic and arkosic rocks

For very long distances in Sweden and Norway part of the Caledonian front is formed by sparagmites and quartzites in low tectonic units. They are overlain

by high-grade rocks of the Seve part of the Seve-Köli Nappe Complex. On the map Plate I quartzites and sparagmites occur east of the easternmost part of Kultsjön, where they belong to the Gittsfjäll Nappe of Kulling (1942) or to the parautochthonous "Horst zone" of Asklund (1960).

Similar rocks also occur as inliers or windows much further to the west. In northern Jämtland, the Hehtajaure Window was first recognized and mapped by G. Kautsky. On the geological map of Sweden, 1:1 milj (1958), it was subsequently marked as an area of Caledonian granite. If present at all, granite forms a very subordinate part. Quartzites and arkoses appear below typical, high-grade Seve rocks protruding westwards from the main eastern zone. The basal Seve part of the Seve-Köli Nappe Complex apparently becomes thinner westwards, and on the western side of the Hehtajaure Window it is sometimes nearly completely missing. It is quite clear, however, that the low-grade arkoses and quartzites cannot be stratigraphically tied to the overlying high-grade Seve rocks (or to the tectonically overlying Köli rocks) but must be separated as a lower tectonic unit.

Based on local evidence on the western side of the Fjällfjäll Antiform and in Rainesfjället, the author, in 1964, placed the Fjällfjäll Arkose as the lowest unit of the Köli sequence. Wider regional investigations have revealed conditions which are difficult to fit into this view. On the southern and eastern side of the Fjällfjäll Antiform, thin slices of Seve rocks are present, composed mainly of mica-schists and grey, garnetiferous gneisses, granitic gneisses and a few amphibolite horizons. These critical rocks take a position between the arkoses and the well-defined Köli rocks, just as they do around the Hehtajaure Window. The Seve part thus is apparently even thinner around the Fjällfjäll Antiform and on the western side it is completely missing. When revisiting the type sections east of Lasterfjället (Zachrisson 1964, pp. 9–10) it is hard to demonstrate a tectonic contact, but it is likely that a zone of sericite/chlorite-rich phyllites has to be reinterpreted as such. This seems to be a special problem where the low-grade quartzites and arkoses are directly overridden by low-grade Köli rocks, without Seve rocks being represented. From this point of view the tectonic problems at the eastern side and northern end of the Fjällfjäll Antiform (the Gottern area) deserve further investigation, and the area on the north-eastern side of Børgefjellet has to be reinterpreted. Kulling (1955, pp. 168, 281), Du Rietz (1941, pp. 67–68) and others have been aware of the tectonic problem but no conclusive evidence has been presented. Based on similarities and continuous changes from the eastern front, via the Hehtajaure Window to the Fjällfjäll Antiform, the author thinks that a logical explanation and correlation between these areas could be achieved by placing them in corresponding tectonic positions (Plate I, sections).

3. The Seve rocks

The Seve rocks are referred to on p. 6. In connection with the prospecting for ore bodies little detailed work has so far been done within this unit.

According to the present author the Seve rocks are supposed to form a separate tectonic unit with tectonic contacts separating it from the underlying quartzites and arkoses and the overlying Köli rocks. In the latter case it is demonstrated by a slight tectonic disconformity at the base of the *Käruskifferzone*, e. g. on both sides of the Seve ridge towards the Hehtajaure Window.

4. Major folds

In the following chapter the major antiforms and synforms are described. The latest small scale compilation of the whole region is the 1:1 milj map of the pre-Quaternary rocks of Sweden, based mainly on Kulling's Västerbotten county map of 1955. In the description to the latter (p. 274) Kulling gives a sketch map of fold axes, tectonic boundaries and axial traces of some major folds.

On the map (Plate I, insert map) the following major fold structures could be recognized (from west to east):

The Riksgränsen Antiform

The Western Synform (or the Arefjället–Remdalen–Leipikvattnet Synform)

The Fjällfjäll Antiform

The Eastern Synform (or the Björkvattnet–Virisen–Ransaren Synform).

By way of comment on the terminology used above, it should be mentioned that in the Björkvattnet–Virisen area way-up structures could partly be used to demonstrate quite large, first-phase (pre- F_1) sideways closing folds, older than the formation of the synform (F_2). In the Western Synform only scattered way-up evidence could be presented. Furthermore the rocks are complicatedly folded during several tectonic phases, even the earliest of these probably disturbing the normal stratigraphic relationships. The Köli nappes existed prior to that folding phase, which produced the major antiforms and synforms, listed above. Thus these younger structures were superimposed on such a complex suite of rocks that the words syncline and anticline are no longer relevant.

Riksgränsen Antiform

The westerly limitation of the Western Synform is not a continuous antiformal ridge. In the same way as the "Riksgränsen Anticline" on a broad scale contains isolated, dome-shaped culminations (as e. g. the Sjängeli, Nasafjäll, Børgefjell, Grong, Sylarna Windows etc.) so, within the area discussed in this paper, it is represented by three isolated domes of which the Børgefjell Window has a notable elongation in a NNE–SSW direction whilst the Skalmodal and Joesjö Domes have WNW–ESE or E–W elongations.

The Børgefjell Window forms the southerly dome of this antiformal zone. A Pre-Cambrian basement, (supracrustal rocks, microcline-rich augen-gneisses, and granites of Revsund type) and a younger sequence of sediments of the "Hyolithus zone" type (Kautsky 1948, Zachrisson 1964) are separated from the overlying units by a clean-cut thrust, against which the rocks in the window show an easily demonstrated disconformity. The Fjällfjäll Arkoses on the north-eastern corner apparently belong to a separate tectonic unit below the Seve-Köli Nappe Complex. Seve rocks are not known from the area (but might exist on the south-eastern side of Børgefjellet). At the base of the overlying (Seve-)Köli Nappe the thrust is clearly disjunctive (Rutland and Nicholson, 1965).

In the Skalmodal area the eastern part of a dome-shaped inlier of Tjopasi rocks extends into Sweden. This structure has been investigated on the Norwegian side by L. A. Barkey (pers. comm.).

The dome in the Joesjö area could partly be inferred from data by Murriss (1957) and Beskow (1929), and additional field observations have been added by the geologists of the Boliden Company. On the Norwegian side a preliminary map by I. Ramberg (1967) gives information about the westerly continuation of this major structure.

The Western Synform

The synformal structure of Remdalen was described by the present author in 1964 under the name of "Remdalen Syncline". The axial trace of this major synformal zone can be followed to the north and south over a distance of more than 120 km. Along the synformal axis culminations and depressions occur.

The most conspicuous axial depression is the one centered in the Remdalen area. Stratigraphic and structural evidence from adjoining areas has forced the author to amend the stratigraphy as it was described in 1964. This provides an acceptable explanation for the disappearance of the Stekenjokk Quartz-Keratophyre, Kosaåive Phyllites and the Greenschist in both limbs of the synform, a low-angle thrust being placed at the base of the overlying Fasovardo Phyllite (cf. Fig. 1); northwards this thrust cuts down through the volcanic unit into the Lasterfjäll Calcareous Phyllite. In the western limb some tectonic disturbances were recognized east of Fremsjön (cf. geological map in Zachrisson, 1964), and in the eastern limb a very strong mylonitisation occurs in the greenschist/grey phyllite horizon, which could be followed to the north-easternmost corner of Lasterfjället. Apparently this zone can be traced into contact with Du Rietz' (1941) thrust at the top of the dark phyllites in V. Vardofjäll. In Arefjället this zone is characterized by very strong isoclinal folding (D. G. Gee, in preparation). It is thus possible that what appears as a thrust in the south passes into isoclinal folds in the north, suggesting that this nappe structure originated from

accentuated, isoclinal F_1 folds where the lower limb has been completely sheared out. These circumstances do not influence the stratigraphy of the upper unit (the Remdalen Group), as described in 1964.

Going northwards the culmination zone is passed between Gemsåive and Ö. Vardofjäll in the gabbro-intruded Lasterfjäll Calcareous Phyllite. Some difficulties arise in placing the major axial trace, because several subordinate synforms are present.

When passing north over the above-mentioned culmination, a consistent NNE plunge leads into another major depression. In its southern part it contains the well-defined Arefjället Synform, a structure widening further northwards into a big trough between the Skalmodal and Joesjö Domes in the west and bordered to the east by the northerly continuation of the Fjällfjäll anti-formal zone. Based on Beskow's map (1929) it is very likely that the central part of this broad depression is occupied by a thrust and infolded unit, the Södra Storfjäll Nappe (*Södra Storfjällsskällan*). (The name "Storfjäll Nappe" (*Storfjällsskällan*) has been proposed by Kulling (1964) for all more high-grade rocks in this part of Västerbotten in a tectonic position between the Rödingsfjäll Nappe and the low-grade Köli sensu stricto. Whilst this appears acceptable for Södra Storfjället its application to Norra Storfjället is less certain.) To the north, east and south the Södra Storfjäll Nappe shows a slight tectonic unconformity towards the underlying Tjopasi and Lasterfjäll Groups. On the western side detailed mapping is lacking and the boundary of the nappe undefined. However, from short visits to this ground it seems likely that the rocks along the national boundary belong to the lower unit. The Södra Storfjäll Nappe should thus comprise a klippe of slightly more high-grade rocks, resting on lower-grade Köli rocks.

To the south of Remdalen, an undulating culmination is present in the Stekenjokk region, with a continuous but gentle plunge to the SSW. As was the case in the north, this southern part of the synform also contains infolded nappes in its central part. The Gellvernokko Nappe has its northerly termination in the mountain Stekevare, showing a very pronounced discontinuity, which is also clearly visible on the regional electromagnetic maps. Its eastern limit has been traced down to the area southeast of Leipikvattnet, where it disappears below the Leipik Nappe. Its western boundary is sometimes difficult to establish, especially south of Sippmikljaure where the thrust starts to become conjunctive (Rutland and Nicholson, 1965). Towards Huddingdalen (Norway) the thinning must be extreme, both the Gellvernokko Nappe and the lower Köli unit being contained in the thin zone between the Bjurälv (Huddingdal) Limestone and the Borgefjell Massif.

With strong support from both structural and geophysical observations an important tectonic boundary has to be drawn to delineate the Leipik Nappe as an even higher tectonic unit. It rests on the Gellvernokko Nappe in the west,

north and north-east, whereas it seems to be resting directly on the lower Köli unit in its south-eastern part. Where this important thrust should be placed further south is still an unsolved problem.

The axial trace of the Western Synform could be extended into the Grong area in Norway, where the excellent maps by Foslie show a major synform in the Jomafjell area. The boundaries shown in the insert map of Plate I represent the lower and upper limit of the Jomafjell greenstone and the lower limit of the Liming Group (Foslie 1926, Strand 1956).

Fjällfjäll Antiform

In the Västerbotten part of the area the Fjällfjäll Antiform forms a central ridge, separating the Eastern and Western Synforms. The core of this structure contains the Fjällfjäll Arkose, forming a window in the Seve-Köli Nappe. The southern end of the antiform plunges abruptly to the SSW and is slightly overturned to the east (Eklund in Högbom 1925). Northwards the internal structures within the Fjällfjäll Arkose do not always seem to be conformable with overlying rocks but are influenced by more or less NW-trending folds. Especially in the eastern limb from Grasansjön northwards complications occur, and as yet no satisfactory explanation can be given of the conditions within the crest of the antiform where it plunges to the NNE north of lake Gottern.

From Ö. Vardofjäll northwards, the Tjopasi Group of dark phyllites with volcanic rocks, below the Lasterfjäll Calcareous Phyllite in the west and the Lövfjäll Phyllite to the east, can be traced to about 10 km west-south-west of Tärna, forming the continuation of this antiformal zone.

The Hehtajaure Window is a dome-shaped structure apparently more or less in the southerly continuation of the Fjällfjäll antiformal zone. Its relationship to this major structure, however, remains uncertain.

The Eastern Synform

In his classical paper of 1933, Kulling came to the conclusion that around Vesken the Viris Quartzite forms the core of a large, westwards closing recumbent syncline. Detailed investigations during the last few years (D. G. Gee) have strongly favoured Kulling's interpretation, and demonstrated that the Björkvattnet–Virisen–Ransaren Synform refolds these older structures and the regional schistosity.

Further north, on the western side of Björkvattnet, Kulling's map shows another strip of Viris Quartzite, forming the core of a smaller, eastwards overturned syncline. Numerous field observations of graded bedding and flow casts indicate complicated, isoclinal folding. Whether the axial trace of the major synform should be placed in the above-mentioned syncline or further to the east (possibly in the middle of Björkvattnet) is not for the moment possible to decide on.

Southwards the eastern synformal trough comes to a sudden termination north of Kultsjön. Högbom (1925, p. 38) described some conglomerate localities in Borgafjällen as being located in its continuation southwards, and on the county maps by Quensel (1929), Högbom (1937) and Kulling (1955) an area of low-grade rocks (Köli resp. Garbenschiefer) is shown around Autojaure, preserved in a local, flat depression in the antiformal, EW-trending Seve ridge, which extends westwards towards the Hehtajaure Window. Still further south-westwards this sequence can be stratigraphically correlated with that of the synformal structure passing over the eastern part of the lake Raukasjö. If the Autojaure area is taken as a link, the axial trace could be drawn from the southern part of the Ransaren Synform into the Raukasjö area and from there westwards. The Eastern and Western Synforms would then merge in the Leipikvattnet region.

5. Structural sequence

Most of the axial traces shown in Plate I belong to folds which are the result of rather late phases, younger than the emplacement of the Seve-Köli Nappe itself. This is clearly demonstrated by the folding of the thrust planes. The rocks show, however, the imprint of older, very important phases which generally neither appear on small scale maps nor in Plate I. In the following chapter the fold phases are given the symbols F_1 , F_2 and F_3 , adherent schistosity or cleavage S_1 , S_2 and S_3 , the subdivision being based on fold characteristics and interrelationships.

F_1 phase

In most incompetent, phyllitic rocks a very strong schistosity, parallel or sub-parallel to the compositional banding or bedding, could be observed. Generally it is very difficult to relate this schistosity to any visible fold structures. In some cases, however, small folds can be detected, and based on such observations it has been possible to prove that this structure cuts through the hinges of these minor folds, acting as an axial surface schistosity (Fig. 2). In incompetent rock-types, these earliest folds are isoclinal or nearly isoclinal. In drill-cores from the Gellvernokko Nappe south of Stekenjokk numerous observations of graded bedding disclose the intensity of this folding. As a contrast to these repeated, local inversions, it is essential to point out that regional, major inversions are difficult to prove. It seems as if most isoclinal folds of this phase are restricted to limited stratigraphic units and generally occur within these, not affecting two or more mappable units or formations.

In the more competent rocks, mainly quartz-keratophyres, arkoses and quartzites and in some coarser beds amongst the phyllites, the F_1 folds may not be truly isoclinal and the schistosity can often be observed to form a small

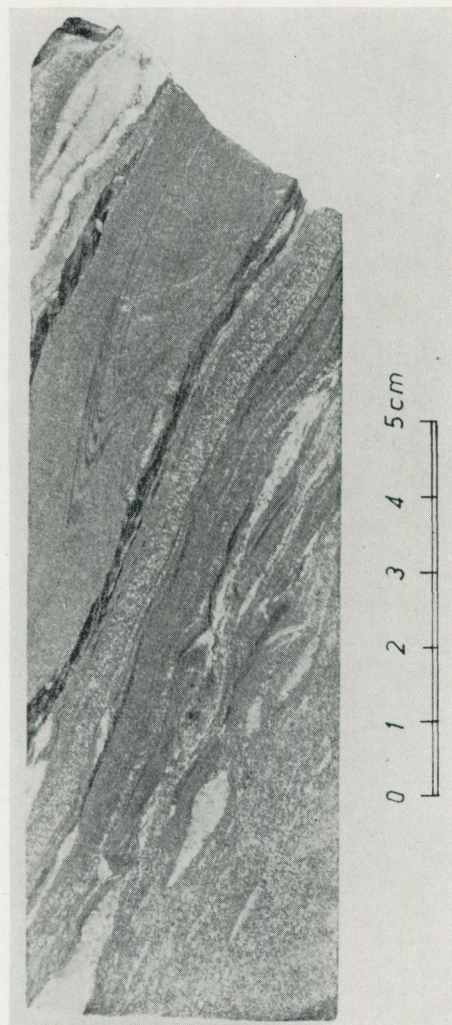


Fig. 2. Hinge of tight F_1 fold in drillcore of grey, slightly calcareous phyllite. Quartz veins and segregations occur parallel to the S_1 schistosity. The core is cut perpendicular to the flat-lying F_1 fold axis. In the dark graphitic layers on both sides of the fold a weak imprint of the S_2 cleavage can be observed, parallel to the core. From Dbh 67002 through the Gellvernokko Nappe, south of Stekenjokk. Photo. I. Signorelli.



Fig. 3a. Quartz-rich phyllite with thin, calcareous layers (more deeply weathered), indicating the bedding (S). The S_1 schistosity forms an angle of a few up to about twenty degrees with the bedding. The visible folds are of F_2 age and deform both S and S_1 .

but clearly visible angle to the bedding in the fold limbs (see Fig. 3). The folds are then sometimes of a style not so very different from that of the F_2 folds. Such an open F_1 fold is shown in Fig. 4. In these lithologies intersection of schistosity and bedding has often produced a pronounced F_1 lineation (Fig. 4b).

The early F_1 folds can be distinguished in general by

- a) their characteristic style, being, tight or isoclinal,
- b) their relation to the oldest schistosity, this being axial planar,
- c) their relation to other fold-phases, being deformed by F_2 and later phases.

Generally they have a transverse orientation in relation to the later folds and much of what has earlier been described and discussed as cross-folding has been demonstrated or is very likely to be interpreted as the result of F_1 folding. As a rule it has a NW-SE orientation; in the northern part of the map area it is generally more or less E-W, but variations are rather large.

Concerning criterion b) above it should be mentioned that some F_1 folds show a schistosity which is already deformed around the hinges of the folds. Because these folds are themselves deformed by typical F_2 folding and generally



Fig. 3b. Detail of F_2 fold hinge zone. In the lower left corner the S_2 axial surface cleavage could be observed, dipping 50° WNW. Photos taken looking north-north east on vertical ac-joint surface, perpendicular to F_2 fold axis. Locality 400 m north of Rösjön (Gellvernokko Nappe).

have the same orientation as other undisputable F_1 folds, they have been included in this first group.

The F_1 folding is of the similar type, but in many cases the limbs are relatively well preserved even in very accentuated, isoclinal folds. In some phyllites, on the other hand, only the sheared-off, isolated hinges of slightly more competent layers are left.

The F_1 folding and schistosity affects rocks of all stratigraphic levels. Also the hornblende gabbro lenses are strongly sheared and schistose and the intrusion probably occurred prior to the F_1 phase.

In Jämtland and in the Western Synform, the Köli rocks are strongly affected by S_1 , but they are also generally intensively crenulated by younger folding. Eastwards, towards the base of the Köli, the rocks in the Garbenschiefer zone show a more regular, gently undulating schistosity, which seems to be parallel to the foliation in the Seve gneisses and mica-schists.

In the Björkvattnet-Virisen area, Gee (unpublished SGU-material) has demonstrated that the S_1 schistosity cuts across even older fold structures which must be classified as of pre- F_1 age (e. g. the Vesken fold).

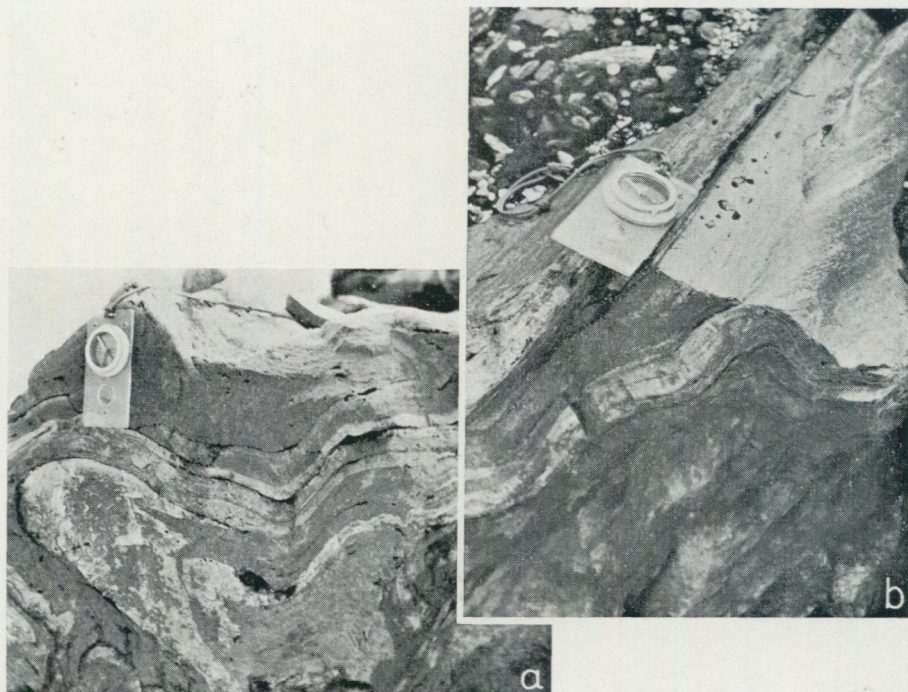


Fig. 4. Greenschist with thin quartz-keratophytic layers. Gellvernokko, south of Stekenjokk (Gellvernokko Nappe). Photos taken looking south.

a) Thickened, partly sheared-off hinge of eastwards-closing F_1 fold with the flat-lying axial surface, slightly deformed by F_2 with subvertical axial surface.

b) On the top of the same exposure, F_2 fold with the F_1 lineation deformed over the hinge.

F_2 phase

Most of the major and minor fold structures within the Köli rocks belong to the F_2 generation. Compared with the early folds they are more open in style. On the deformed S_1 surfaces the F_1 lineations are bent around the hinges of the F_2 folds (Fig. 4 b) whereas the F_2 folding itself often produced a new lineation due to the intersection of the S_2 cleavage and the S_1 schistosity, present as a crenulation of the phyllosilicates. Typical F_2 folds are shown in Högbom 1925, Fig. 10; Du Rietz 1941, Fig. 4–6; Nilsson 1964, Fig. 20; Zachrisson 1964, Fig. 7 and 13. The axial surface cleavage is often sub-vertical (Fig. 5), sometimes with a fan-shaped arrangement of the cleavages (Zachrisson 1964, Fig. 20). Local variations, however, to nearly flat-lying positions have also been observed.

The F_2 phase is responsible for nearly all synforms and antiforms visible on the map Plate I, including the major ones described previously in chapter III:4. Due to pre- F_2 deformation and to younger disturbances the axes are slightly



Fig. 5. Calcareous phyllite with S_2 axial surface cleavage $N 40^\circ E/70^\circ NW$, related to visible F_2 folds, deforming nearly flat-lying S_1 schistosity. Gellvernokko, 4 km south of Stekenjokk. Photo taken looking north-north-east on a vertical ac-surface.

variable but generally they have a NE–SW or NNE–SSW orientation, with a fairly low plunge, as a rule between 0 – 30° . The thrust planes of the Köli nappes as well as the basal Seve–Köli thrust (around the Hehtajaure, Fjällfjäll and Børgfjell Windows) are conformably deformed with the S_1 schistosity in the major F_2 structures and are consequently of pre- F_2 age.

F_3 phase

It is possible that a third phase, F_3 , could be recognized as of regional importance. Its position in the structural sequence is fixed by the fact that it is deforming the F_2 axial surface cleavage. Whereas this latter is often sub-vertical, the axial surface of the F_3 folds is generally flat-lying or sub-horizontal. Folds are of the zig-zag or chevron type with straight limbs and sharp hinges, and have so far been observed in the Western Synform in the area between the Hehtajaure and Børgfjell Windows, both in the Gellvernokko Nappe and in the lower Köli unit. In both limbs vergence is down-dip (cf. Roberts 1967).

IV. CONCLUDING REMARKS

Discussion of regional stratigraphic correlation outside the area described here is deferred for the present. There is a hope that within the not too distant future both micropaleontology and isotopic age-determinations will contribute towards a more firmly established chronostratigraphy.

With regard to the structure of the area described, some general aspects deserve comment. Three important geometrical features appear to be established beyond reasonable doubt. These can be seen from the map (Plate I) and from the schematic cross-sections (see also Fig. 6).

- a) The structures are regionally flat-lying.
- b) There is a marked tendency for all the units to become thinner westwards or even wedge out completely.
- c) The highest tectonic units occur in the west, the lowest in the east.

With regard to b) above, the relationship for the lower quartzite nappes is uncertain. However, the general level of erosion in the central part of the map area, east of the Børgefjell Window (see Sections III and IV), gives excellent possibilities to study the variations within the Seve part of the Seve-Köli Nappe Complex. From a maximum thickness in the eastern part of the map (and in its north-south continuation outside the map area) it shows a continuous decrease and apparently dies out completely without impinging on Norwegian territory in this part of the Caledonides. Seve rocks are also absent on the western part of the Grong culmination and around windows in the Riksgränsen Antiform further northwards along the Norwegian-Swedish border. This means that Seve rocks (referred to as high-grade Caledonian rocks of this specific tectonic

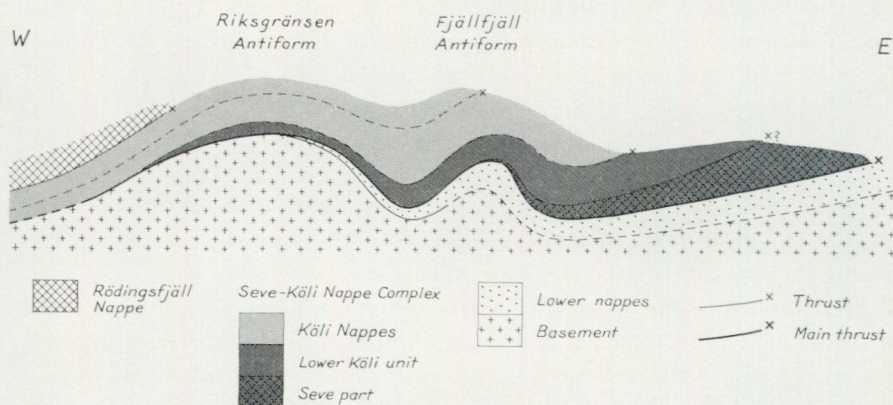


Fig. 6. Schematic west-east section, illustrating the structural pattern.

level) have their main extension in Sweden and are not to be expected below the low-grade Köli rocks or higher tectonic units in the central or northern Caledonides of Norway.

A similar westerly thinning can be proved for the low-grade rocks, with regard both to each tectonic unit (the Köli nappes) and their internal stratigraphy. The latter phenomenon can be illustrated by the Tjopasi Group as shown in Section III. In the Western Synform several tectonic units are present within the Köli. On the south-eastern corner of Børgfjellet both the lower Köli unit and the Gellvernokko Nappe have to be squeezed in between the basement and the Leipik Nappe. Further west, part of the Grong sequence has been separated as a still higher tectonic unit, the Gjersvik Nappe (Oftedahl 1956).

What has been said above also serves to illustrate within the map area the superposition of higher tectonic units when going westwards. The Gjersvik Nappe and the Hattfjelldal Nappe (north-west of Børgfjellet, mainly limestones) are the highest Köli nappes in the area. Both are overlain by the Rödingsfjäll Nappe, composed of high-grade rocks.

For all these units of a very regional extension, it is hard not to assume a transport roughly eastwards along nearly horizontal, low-angle thrust-planes. If gravity was the dominant agent in producing these structures, it has to be evoked on a very large scale, not only radiating from local domes (Ramberg 1967). Although the F_2 folding shows some deviation around the basement areas, it is characterized by a rather constant orientation (NE/SW) of the generally steep-dipping S_2 axial surface cleavage.

Finally, the author wants to emphasize that a similar flat-lying Caledonian pattern, is also apparent from regional work in the northern Caledonides of Sweden and Norway (Kautsky 1953, Kulling 1964, Gustavson 1966, to mention some of the contributors). In the southern Caledonides, the Jotunheimen and Bergsdalen areas are examples of flat-lying Caledonian structures (Holtedahl 1936, Strand 1951, Kvale 1948). From the Trondheim area results of detailed and regional investigations have lately been presented by Wolff (1967), and Roberts (1967, 1968). At present it is somewhat difficult to see how their interpretation can be fitted into a wider regional context.

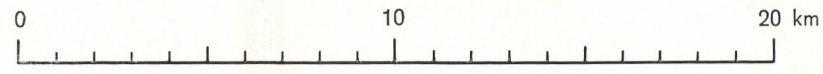
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GEOLOGICAL MAP OF NORTHERN JÄMTLAND — SOUTHERN VÄSTERBOTTEN

Ebbe Zachrisson 1969
Scale 1:200,000



SEVE-KÖLI NAPPE COMPLEX

S. Storfjäll and Leipik Nappes

Undifferentiated

Gellvernokko Nappe

Not divided

Remdalen Group

Lasterfjäll Group

Lower Köli unit

Remdalen Group

Lasterfjäll Group with Viris Quartzite facies

Tjopasi Group

Rocks of uncertain stratigraphic position

Seve rocks

Gneisses, mica-schists, amphibolites

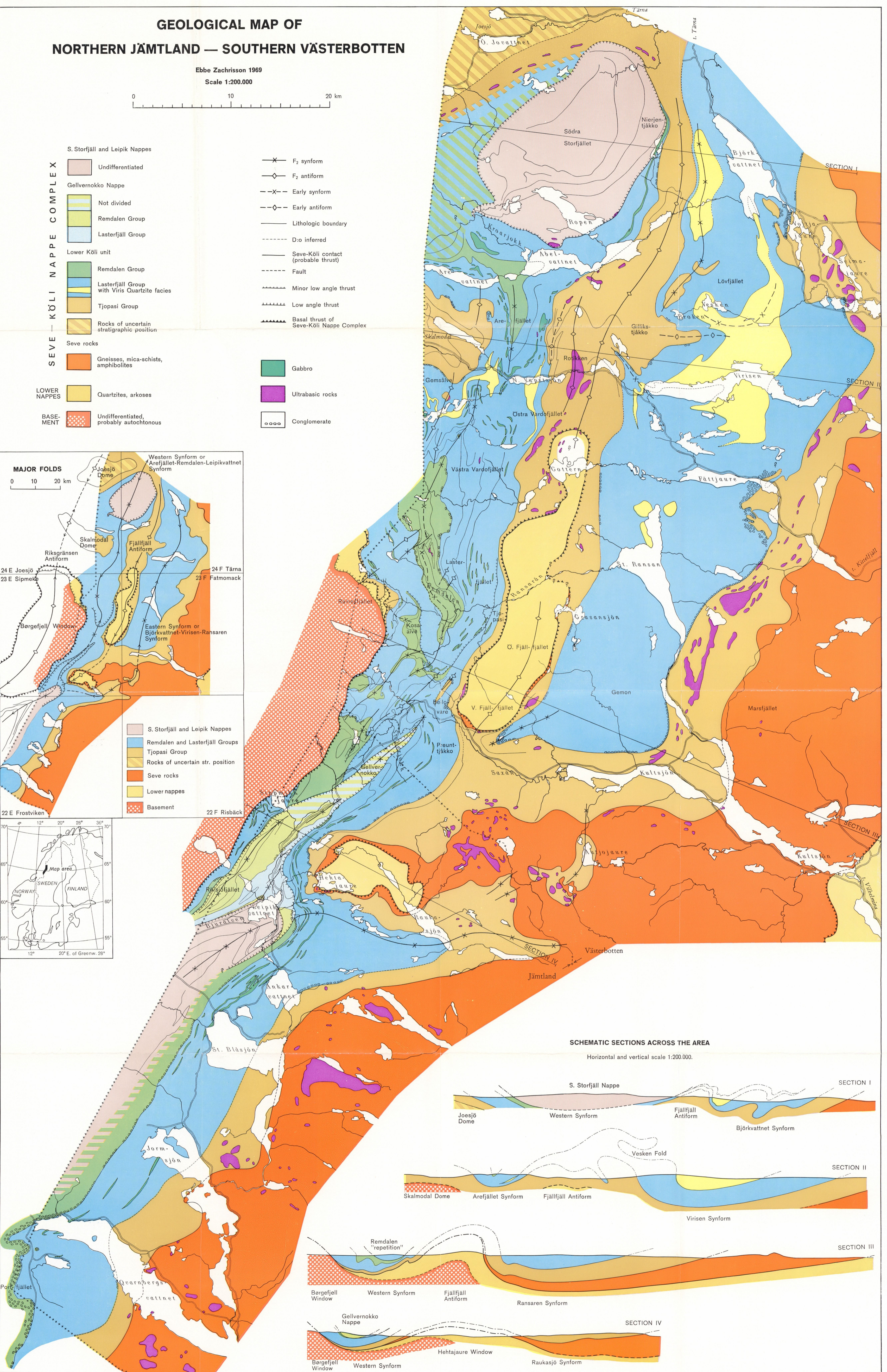
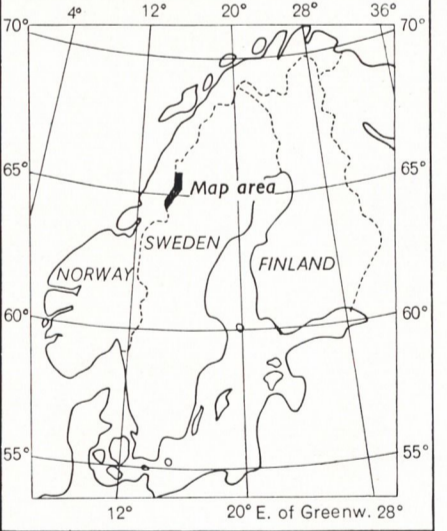
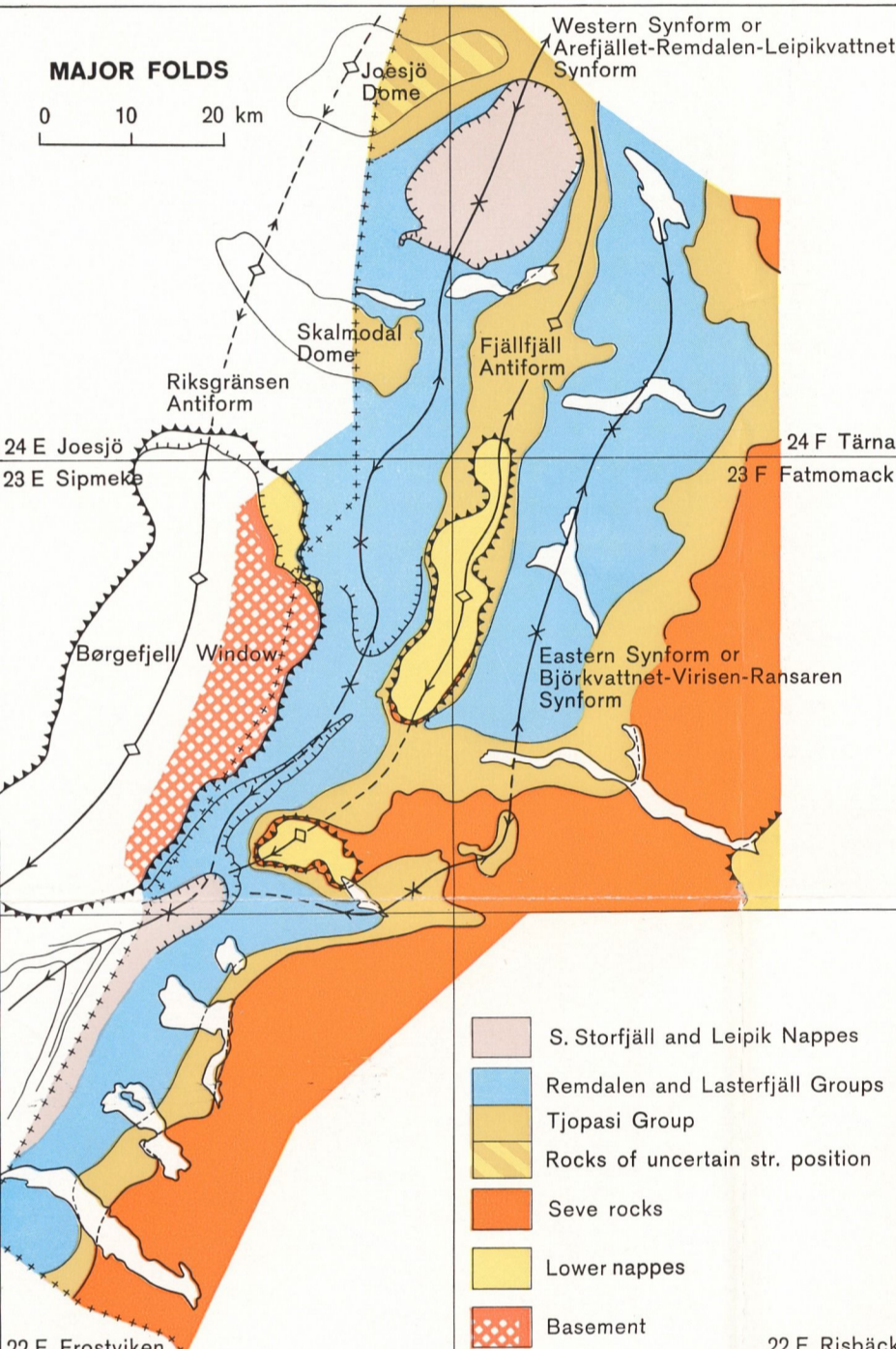
LOWER NAPPE

Quartzites, arkoses

BASEMENT

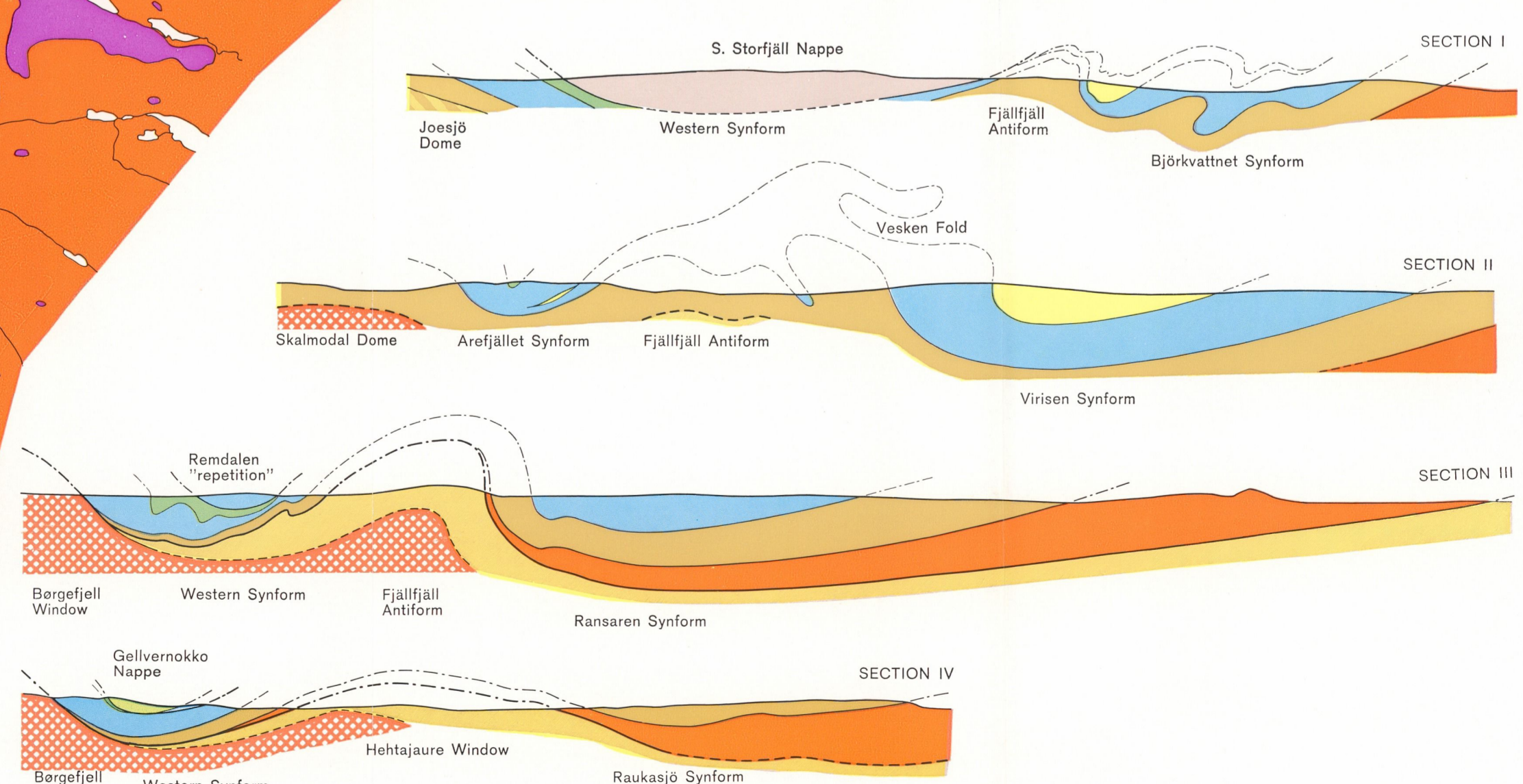
Undifferentiated, probably autochthonous

- X F₂ synform
- ◊ F₂ antiform
- X- Early synform
- ◊- Early antiform
- Lithologic boundary
- - - D: inferred
- Seve-Köli contact (probable thrust)
- - - Fault
- ▴▴▴ Minor low angle thrust
- ▴▴▴ Low angle thrust
- ▴▴▴ Basal thrust of Seve-Köli Nappe Complex
- Gabbro
- Ultrabasic rocks
- Conglomerate



SCHEMATIC SECTIONS ACROSS THE AREA

Horizontal and vertical scale 1:200,000.



PRISKLASS E

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