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TECTONIC CONDITIONS IN THE FRONT RANGE OF THE SWEDISH CALEDONIAN IN CENTRAL NORRLAND

BY

TORSTEN DU RIETZ

WITH FOUR PLATES

STOCKHOLM 1960

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Professor P. THORSLUND has greatly facilitated the description of the Cambrian shale complex by his numerous fossil determinations and studies of many of the limestone horizons which occur in the shales of the Lövstrand region.

Boliden, September 1957.

Torsten Du Rietz.

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CONTENTS

†1—*601185. SGU. Ser. C 568. Du Rietz*

Abstract. This paper presents the tectonic conditions and general petrology of a large part of the eastern border of the Caledonian range of the northern part of central Sweden.

The region around Lake Ormsjö in southern Lapland was investigated in detail and the rock complexes were followed toward the south, the west and the north. The large Strömquartzite nappe of the Ormsjö region was surveyed by detailed mapping and many diamond drillings. The nappe is almost horizontal, but it is nevertheless dissected by many small thrust planes and often displays many imbrications. The autochthonous shales below the Quartzite nappe chiefly belong to the Cambrian. The fossils indicate that the middle and upper Cambrian stratigraphy is fairly complete. The lower part of the shale complex has no recognizable fossils. The upper part of the complex has been moved by the thrusting of the superimposed nappe and parts of the shales have been thrust upward into the overlying Quartzite. In other parts of the investigated region overthrust shale complexes also occur. To the west of the Ormsjö region allochthonous Ordovician rocks outcrop frequently.

To the west the Ström quartzite nappe is superimposed by the Oxfjäll or Sparagmite nappe which, like the former, often exhibits an imbricated structure. Further westward toward the huge Seve nappe the tectonic conditions are more intricate. In front of and underneath the Seve nappe mylonitic rocks occur which originally belonged to the Archean basement or the "Eo-Cambrian" Sparagmite or Strömquartzite formations.

In the northern part of the Lake Tåsjö district a window in the Cambro-Ordovician shale complex appears showing an autochthonous or para-autochthonous Ström quartzite series downward passing over into sparagmite with a tillitic rock complex at the contact between the two formations. Tillites have also been observed at several places in the nappes. The contact between the sparagmite formation and the Archean basement is tectonically disturbed; a disturbance probably caused by the pushing of the great Seve nappe.

The "autochthonous" basement of quartzite, sparagmite, and granite shows increasing para-autochthonous development toward the south and southwest. Imbrications also become evident to an ever increasing degree.

In the southernmost part of the investigated region the Offerdal nappe appears which in the tectonic pattern corresponds to the Seve nappe, though it is an isolated unit with another stratigraphic development.

A series of 13 sections through the mapped region along with some figures in the text show a general conception of the tectonic development.

Introduction

The general tectonic conditions of the Caledonian Range of Central Scandinavia were fairly well established by A. E. Törnebohm as early as 1896 in his excellent paper "Grunddragen av det centrala Skandinaviens bergbyggnad", while the general geology of the rocks of the Caledonian border of Jämtland was shown with reasonable clarity in A. G. Högbom's map of 1894 drawn to a scale of 1: 500 000. Later Törnebohm's general concept of great overthrusts was much criticized both in Norway and in Sweden. In the middle of the thirties, however, investigations made by B. Asklund and P. Thorslund in northern Jämtland and the neighbouring regions showed that the general principles of nappes which have been carried a long way was in accordance with facts and this was demonstrated by some detailed mapping. Thus fossil-bearing older strata were superimposed on younger rocks. They distinguished more or less the same main nappes as were shown by Törnebohm and, in addition, some overthrusting of Cambro-Ordovician complexes beneath the large nappes.

In 1939 the writer of this paper started a survey of the eastern part ~~of~~ the Caledonian Range of Västerbottens län (Lapland) and Ångermanland for the Boliden Mining Company. Most of the investigation dealt with the Eo-Cambrian Ström quartzite nappe of that region. A preliminary paper was published in 1942. Somewhat earlier a paper on the region to the south of this area, was brought out by E. Grip. An extensive report on the border of the Västerbotten Caledonian was published by O. Kulling in 1942. Kulling's paper has since been summarized in his account of all of the Caledonian rocks of Västerbottens län (1955).

The author has continued his investigation of the region and proceeded further to the southwest toward the lakes Laxsjön, Hotagen, Häggsjön and Valsjön in Jämtland in the S, and the big Seve nappe to the W. The survey is mainly concerned with the big nappes. Westward, toward the Seve nappe (the mountain complex), the investigation is of a more regional nature and is only detailed in some places where the tectonic conditions are intricate. As the author has not made any paleontologic-stratigraphic investigations of the Cambro-Ordovician shales, these complexes have been dealt with as one complex where possible. On the large map of the district, Plate I, the rocks indicated, are mostly coherent units.

Within the most thoroughly investigated area, *i.e.* the region around Lake Ormsjön in southernmost Lapland, the stratigraphic succession of the shales is well known thanks to drillings which have been made down to the pre-Cambrian basement through the Ström quartzite nappe and the younger sedimentary complex underneath. As was pointed out earlier by Asklund and Thorslund, the shale complex (including limestones, calcareous and arenaceous shales, etc.) partly consists of autochthonous Cambro-Ordovician and partly of shale-complex nappes which have been transported above the autochthone. To the S and SW of Ormsjön this is more evident, though the overthrust complexes may vary within different regions. In the region W of L. Ormsjön a shale complex of another facies is exposed consisting of alternating calcareous sandstones, graywacke-shales, and dark shales.

The different types of shales and calcareous rocks of the Cambro-Ordovician have all been designated in the same way on the large map, Pl. I.

Within the easternmost Caledonian range there occur displaced or overthrust masses of Archean complexes which will generally be called granite complexes or nappes as granite is the dominant rock within these complexes. In some of them gabbroic rocks are prominent, *e.g.* in the western part of the largest complex, S of the River Sjougdälven. In the southern part of the same complex, *e.g.* between the Lakes Lakavattnet and Hotagen, red porphyries also occur. Because of the frequent mylonitization of the "Granite complex", granulated, porphyritic granites may be difficult to distinguish from regular porphyries. Leptites and Archean schists were only observed quite locally.

The large map is based on the investigations and mapping of the present author who has also made use of the maps of the authors referred to above. The following geologists and assistants have, on occasion, taken part in recent mapping work for the Boliden Mining Company: O. Brotzen, T. Forsvall, H. Lindström, A. Stenlund, U. Svensson, F. and O. Theolin, U. Svensson also assisted in the drawing of the large sections. F. Theolin has been particularly helpful in the mapping of the southernmost region.

In the mapping of the different tectonic complexes, some of the characteristic rocks have been traced as far as possible in order to ascertain which rock complexes belong to the same rock unit. This is especially true of the quartzite complexes.

As far as the general nomenclature of the rock groups is concerned the author has mostly used the same names as in the earlier paper. The well-known name of the Ström quartzite nappe as a synonym for the northern part of the Vemdal quartzite nappe is thus still used. Kulling has introduced a new name, the Blaik nappe, for the same complex, but as this designation also includes what is here referred to as the Sparagmite or Oxfjäll nappe, which is pushed over the quartzite nappe, it is not appropriate to use it when referring to the Ström quartzite nappe alone.

The autochthonous Ström quartzite at the northern end of Lake Tåsjön, as well as the underlying sparagmite complex,[1] shows in its continuation towards the SW that it has been thrust over the originally superimposed Ordovician shales. These thrust complexes will generally be called para-autochthonous (nappes) in this paper as the displacement covers a shorter distance than the true allochthonous nappes, *e.g.* the Ström quartzite nappe. Further toward the SW the tectonics of the thrusting become more and more intricate with several

[1] The Ström quartzite and Sparagmite formations, both older than the lowermost fossiliferous Cambrian, have generally been designated either as Eo-Cambrian or Sparagmitian by Swedish and Norwegian geologists working with these complexes.

Schuppen as well as mylonitization of some of the rocks. Further toward the W, beneath the large mountain complex of the Seve nappe, there appear complexes or slices of rocks which have been thrust passively by the large overriding nappe. These complexes have been much fractured, becoming schistose and mylonitized, but generally with some cores of quite recognizable original rock types. This zone of rocks or complexes has been designated the Mylonite zone or Mylonite nappe zone. It may consist of very different rocks depending upon whether the material is taken from quartzite or sparagmite complexes, or overthrust Archean rocks, *etc*. When the conditions are intricate *e.g.* in the southwestern part of the mapped area where most of the "para-autochthonous" nappes have been imbricated or partly mylonitized by the thrusting of the superimposed Seve nappe, it will be a matter of personal judgement which parts are to be considered as para-autochthonous and which may be included in the mylonite zone.

Detailed investigations, especially within the Ström quartzite nappe, have shown that the tectonic complexes, despite the fact that they are continuous, may be imbricated or tectonically shattered. The big Ström quartzite nappe is thus often disrupted by thrusting combined with faulting and the crushing of the rock complex. The undermost slipping surface of the Quartzite complex above the black shales may be rather smooth or horizontal as a unit, but when examined in detail the plain is often found to be split by local thrust plains, which may cause material from the underlying Cambro-Ordovician shales to be brought up into the quartzite nappe, sometimes all the way to the surface of the nappe, thanks to the dragging of the quartzite.

In order to demonstrate the tectonic conditions within the whole region, thirteen parallel sections have been drawn in a northwesterly direction, starting with the section through the area SW of Lake Malgomaj and ending with the section along Lake Hotagen in the southern part of the region investigated. They may be taken to be simplified as the thrust planes are generally more complex and intricate than it is possible to show. As is revealed by the more detailed investigation in the Ormsjö area, a very detailed investigation of all the areas would be necessary to get even a fairly correct picture of the tectonic evolution. The thrust lines in the profiles may sometimes represent systems of overthrusts. Some of the short thrust lines drawn in the sections may be symbolic indications of thrust in order to show that disturbances occur.

The thrusting of the large overriding Seve complex probably caused the "para-autochthonous" anticlinal Archean complex, S of the river Sjougdälven (the Svaningen complex) in its turn to thrust the superincumbent sparagmite and quartzite into recumbent folds or a formation resembling overlapping tiles above the overlying shale complex. Under further thrusting these elements behaved more or less like allochthonous tiles or nappes as to be seen in the southwestern region. Detailed sections have shown that conditions may be very different in neighbouring areas. At one place several slabs may have been thrust above each other and sometimes some of them are not to be found in the vicinity. An autochthonous Quartzite formation may still be lying above the granite while slabs of the same quartzite are to be seen in the lower front of the thrust granite mass.

The Sparagmite formation originally occurred as thick sediments in local basins, but it is often missing between the Ström quartzite formation and the Archean basement. Thus the Sparagmite formation is often missing within the thrust complexes too. The Sparagmite formation, containing interstratified shales may be found *in situ* above an Archean complex while another granite mass has been pushed above it and has crushed and metamorphosed the sparagmites as well as the granite itself.

Within the southwestern part of the mapped area two schistose zones have been indicated beneath the Seve nappe. This is, however, only a general sketch of the area, as there are in reality several subthrust slabs or nappes beneath the Seve nappe. Within the underlying Archean on the southeastern side, too, there are more or less local overthrusts and mylonitic zones. A great tectonic plane of this kind has been indicated on the map.

As the total area of the map is large, the original map drawn to a scale of 1 : 100 000 had to be diminished to 1 : 300 000, but as certain areas in the region have formations which are too intricate to be indicated on this map, parts of it should have been reproduced on a larger scale.

In order to give a tectonic illustration of the best known area, *i.e.* the Ström quartzite nappe of the Ormsjö area, detailed sections of the Lövstrand area on the southern side of Lake Ormsjön are given (Pls 3 and 4). In this area hundreds of diamond drillings have cut vertically through the quartzite nappe and penetrated the shales underneath. Some drillings have also passed down into the Archean basement. One section through a small area is drawn to a scale of about 1 : 3 000 for both horizontal and vertical distances, while the other, which cuts right across the nappe in the same section, has a vertical scale 5 times the horizontal. Other detailed investigations have shown that the tectonic appearance of the overthrusting, which is shown in these sections, is at least to some extent typical of other regions too. Also the overthrust Archean complexes have in some places shown rather similar imbricated thrusts.

An Outline of Rock Formations

Within the eastern border of the mountain range of Västerbotten the lower part of the autochthonous rocks (the "Hyolithes zone") consists of sandstone or quartzite which generally passes into an arkose or quartz conglomerate next to the Archean basement. The quartzite sandstone is overlain by Cambrian shales and often also by Ordovician rocks below overthrust quartzite corresponding to the Ström quartzite nappe. Toward the S the autochthonous quartzitic sandstone thins out and vanishes at Lake Vojmsjön. Further S the Archean is almost directly overlain by shale units. A thin bed of arkose or conglomerate is, however, generally found next to the basement. In the uppermost part of the shales a thick limestone, generally belonging to the Ordovician Ortoceras limestone, sometimes occurs, *e.g.* at Djupdal, NE of L. Ormsjön.

Further to the W, at the northern end of Lake Tåsjön, the quartzitic sandstone reappears below the shale complex but there are no outcrops of autochthonous Archean. The Quartzite formation is underlain by the upper part of the Sparagmite formation. Toward the W this large Sparagmite complex comes in a steep contact to a granite or Archean complex which is presumably the original basement of the Sparagmite formation. This basement has been thrust upward and forward against its primary cover. The quartzite at the northern end of L. Tåsjön also shows indications of fracturing, although to a less degree than is the case with the Quartzite nappe. In view of the fact that the quartzite dips slightly toward the SE and is overlain by a thick series of sediments, which, in its turn, is overlain by the Quartzite nappe, everything indicates that the lowermost quartzitic sandstone corresponds to the autochthonous sandstone of the northern part of Västerbotten (the central part of Lapland). The Quartzite complex is also curved upward at the NNW part of Lake Tåsjön, due probably to the push of the underlying Sparagmite complex situated to the W, a push initiated by a thrusting movement of the Archean basement. In the northern part of the quartzite area local overthrusts were observed near the river Saxälven. Toward the SW the thrusting of the quartzite and sparagmite complexes becomes more and more manifest.

The allochthonous complex, the Ström quartzite nappe, has been traced in continuous or isolated units from the northern end of Lake Malgomaj in the N to Henningskälen in northern Jämtland (between Strömsund and Laxsjö) in the S. The widest part of the nappe (in NW to SE), is to be found in southern Västerbotten, from the neighbourhood of Fjälltuna, N of Dorotea, northwestward to the region of Risbäck, so it is at least 50 km wide. Part of the nappe, E of L. Arksjön, however, is eroded. A large part of Blaikfjället, as well as the region between the rivers Långseleån and Saxälven, constitutes a window in the Quartzite nappe, with Cambro-Ordovician shales outcropping. Further toward the W, in the region of Karlsborg and at Lake Mesjön, quartzite again appears, probably as upward curved or thrust anticlines of the same nappe. Adding this we arrive at a total width for this part of the nappe of at least 60 km. The total width of the overthrust is probably much larger.

In its northwestern part the Ström quartzite nappe is overlain with a thrust contact by a sparagmite complex, at Mt. Arksjöberget, Mt. Blekevare, Sörfors and L. Norrsjö. This nappe may conveniently be called the Oxfjäll nappe as the mountain Oxfjället lies in the middle of the sparagmite area. Westward both the Ström quartzite nappe and the Oxfjäll nappe disappear beneath the Seve nappe, which, however, has a nearest substratum consisting of mylonitized units of sparagmite, granitic slices and to some extent quartzite, too.

The Sparagmite or Oxfjäll nappe is, in its southernmost part at St. Sjougden —River Sjougdälven, thrust over the northern part of the large para-autochthonous Archean complex, here called the Svaningen complex. The undermost part of the Sparagmite complex is strongly schistose.

Within the eastern, lower, part of the Oxfjäll nappe there often are thin stripes of pure quartzite which probably represent infolded and thrust parts of Ström quartzite. Between Sörfors and L. St. Raijan a window in the Oxfjäll nappe discloses Ström quartzite associated with a wedge or mass of Archean rocks (Revsund granite). Further to the N, *i.e.* at Risbäck and between the lakes Rissjöarna and L. St. Gittsjön, there are two large sheets of Archean rocks, for the most part Revsund granite. These complexes actually lie underneath the Sparagmite nappe and above the Quartzite nappe, but their southeastern parts have been thrust upwards, thus creating steep contacts. Whether the granite complexes were the original substratum of the sparagmite or whether they are horizontal wedges of Archean material pulled along in the overthrusting of the Oxfjäll nappe is not possible to say.

There are also some lesser granite complexes at the western end of the Oxfjäll nappe around L. Dabbsjön. They are probably wedges of Archean pulled along beneath the Seve nappe, in the same way as the schistose granite slices to the E of L. St. Sjougden. Within the "Mylonite zone" to the S of L. St. Sjougden toward Bågede and L. Dunnervattnet, Archean rock material predominates, but schistose sparagmite and quartzite have also been observed in places. The long stripe of whitish quartzite, about 200 m wide, beneath the Seve nappe at Valsjöby, probably represents original Ström quartzite, now recrystallized.

In the northernmost part of the region shown on the map, at the northwestern end of Lake Malgomaj, there is an area with more or less mylonitized Archean rocks, consisting of granite and greenstone sometimes with arkoses above. This complex is considered by Kulling to belong to the lowest part of his "Stalon nappe". The author has as yet not been in a position to resolve the problem of whether this complex is to be considered as belonging to an upper nappe, thus corresponding to the Mylonite zone, or if it is another Archean sheet, roughly corresponding to the granitic area N of the lakes Rissjöarna. It should be noted, however, that the large Archean units generally move separately in the overthrusting. The eastern contact against the quartzite in the direction of Lake Malgomaj shows a steep contact, which indicates that the Archean complex might have been thrust from the underlying side.

The autochthonous Ström quartzite in the lower part of the river Sjougdälven develops into a para-autochthonous to allochthonous unit running past L. Harrsjö to L. Gärdsjön, where it occurs as autochthone on the granite complex of R. Storån, as tiles of quartzite to the E of it. At Mt. Strömberget by Lidsjöberg the quartzite forms an inverted complex in the eastern front of the granite mass, so that arkose-conglomerate occurs next to the granite (cf. Grip, 1941). To the S the quartzite has been traced by way of Bränna, L. Svanavattnet to R. Renån. At the eastern end of L. Yttre Renåflyn the quartzite and a small granite mass form a continuous band. The continuation of the quartzite toward L. Lakavattnet is to a great extent covered by moraine and bog. From L. Lakavattnet it has been traced past L. Tjänafjällsjön to the middle of Lake Hotagen. By L. Hökvattnet and L. Laxsjön there are two isolated, upward curving pieces of the same unit. The quartzite and arkose-conglomerate are partly involved in the underlying shales. At the northwestern limit of L. Hotagen the quartzite has been traced at the foot of the front of the overthrust granite as a para-autochthonous band running in a WNW direction through the southwesternmost part of the map area.

The autochthonous sparagmite on the southern side of R. Sjougdälven, which further toward the SW is thrust over the quartzite, disappears S of Lake Fånsjön but appears again thrust over the quartzite of Mt. Ögelhättan. It can be traced southward to R. Renån, where it disappears again. In the region around L. St. Byvattnet sparagmite occurs above the Archean complex, partly as isolated areas, which toward the W are overthrust by granite wedges. To the W of Mt. Erfjället, the sparagmite, as well as the interstratified, grayish sparagmitic shale, becomes more and more schistose toward L. St. Brinnsjön. It is evidently overthrust.

The schistose, conglomeratic to arkosic shale which runs toward the W from the northern part of L. Hotagen is similar in appearance to the sparagmite W of Mt. Erfjället but its position indicates that it represents the basal part of the Offerdal nappe.

In the W, the base of the Seve nappe is generally distinguished by a strong schistosity or micaceousness. This zone of mobility, generally characterized by large, thin plates of muscovite, or less frequently chlorite, is generally not thick, but it may be developed as several parallel surfaces. The superincumbent complex generally consists of slates or schists, often with inliers of more or less metamorphic, basic volcanics. A common development is thus phyllites or mica-schists with varying amounts of interstratified amphibolites. Phyllites and quartzites may also predominate. The degree of metamorphism may thus vary considerably. Calcareous or arenaceous phyllites as well as dark phyllites, sericite phyllites, garbenschiefer or schists occur. Amphibolitic rocks are generally frequent at a somewhat higher level, where peridotites may also appear. Where the degree of metamorphism is low the phyllitic rocks may be quite similar to the "Köli" rocks of the Cambro-Silurian of "westerly" facies. Sparagmitic rocks do not appear in this association but they may appear as a unit beneath the Seve nappe proper, as is the case in the Offerdal nappe. Gneissic rocks and pegmatitic or granitic intrusions generally occur further westward in the Seve nappe.

The base of the Seve nappe has a somewhat undulating appearance, similar to that of the Ström quartzite nappe, but somewhat more pronounced. Both longitudinal and perpendicular folding can be observed.

The Archean Basement

The Archean rocks just to the E of the Caledonian border mainly consist of Revsund granite. Basic igneous rocks and Archean sedimentary rocks, as well as other granitic rocks, appear here and there. Drillings within the Ormsjö region which have reached the Archean basement have encountered Revsund granite, quartz-monzonite, greenstone, and Archean schists. Among the para-autochthonous Archean rocks of the Svaningen complex in northern Jämtland, younger granites of the Rätan type, or even of the Olden granite type, may predominate in some regions. In the region around L. St. Byvattnet, however, Revsund granite predominates. Within the southern part of the Svaningen complex the bedrock varies greatly, from mylonitized rocks to igneous rocks in very varying states of preservation.

Detailed mapping and diamond drillings within the Ormsjö—Lövstrand region have shown that the Archean basement dips uniformly about 1° towards the NW.[1] This figure has been used for the drawing of the sections in other parts of the mapped region also, although the slope of the basement surface may be somewhat different in the areas to the S, where the thrusting of the Svaningen Archean complex toward the SE may have affected the dip of the basement. It is quite probable that it was the load of the nappes or overthrusts which caused the downward dip of the Archean surface toward the Caledonian range as E. Ljungner (1950) has pointed out.

The Cambro-Ordovician Sediments

A stratigraphic table of the Cambro-Ordovician sediments containing fossils known to belong to the eastern part of the Caledonian of Västerbotten has been collocated by Kulling (1955). Asklund and Thorslund have supplied stratigraphic sections and lists of fossils from several areas (1935).

In this paper the author will describe the stratigraphy of the Ormsjö—Lövstrand region, which has been investigated by diamond drillings. Some drillings have penetrated right down into the Archean basement. The borings within the Lövstrand area have shown that the Quartzite nappe is always underlain by alum shale or black shale on which the nappe has glided and part of which has been brought along in the thrusting.

A normal section below the Quartzite nappe in the central region of the Lövstrand area is about as follows:

Alum shale with calcareous layers (dark limestone)	6— 8 m,
Dark, argillaceous shale with calcareous layers	8—13 m,
Layer of gray limestone	0.3 m,
Dark shale, slightly graphitic or carbonaceous	21—61 m,
Shale conglomerate, calcareous or arenaceous	about 0.1 m,
Arkose-conglomerate, often substituted by siltstone	0— 2 m.

Then Archean bedrock follows.

The lowermost layer, which consists of arkose and siltstone, corresponds to the lowest layer in the Laisvall area according to Ljungner, Grip, and Marklund. The "Eo-Cambrian" sandstone of Laisvall fails here. The thin shale

[1] In an earlier report it was erroneously reported to be 2° toward the NNW (Du Rietz 1954).

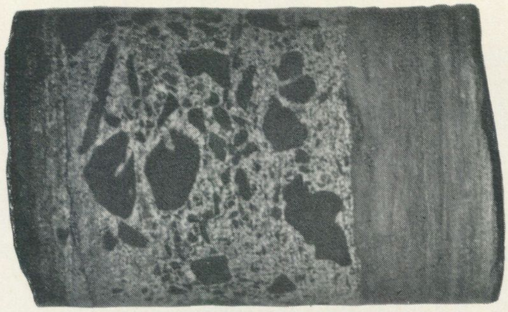

Fig. 1. Shale (siltstone) conglomerate with arenaceous calcareous matrix. From drill core. Lövstrand. About natural size.

conglomerate with about 1 cm large fragments of shale in a somewhat calcareous and arenaceous matrix is also similar to what is considered as the bottom conglomerate of the fossiliferous Cambrian in Laisvall. It is followed by a few metres of dense, argillaceous shale or claystone above which comes a typical calcareous shale and siltstone conglomerate, about 10 cm thick (cf. the photo, fig. 1). The fragments of dark claystone are about 1 cm in diameter, though they are irregular and generally rather flat. The matrix is almost white and calcareous. It is overlain by a thick, dark shale. This is followed by a layer of limestone which according to its fossils belongs to the lower part of the Middle Cambrian. In the dark argillaceous shale that follows there are several calcareous layers in which fossils of the middle part of Middle Cambrian have been observed.[1]

The highest layer of alum shale and interstratified calcareous layers belong, at least partly, to the Upper Cambrian judging by the discovery of the trilobite *Agnostus pisiformis* in a limestone layer in the lower part of the alum shale in one drill hole. The alum shale partly passes over into Lower Ordovician in the western section. The upper part of the shale horizon has often been moved by the thrusting of the superposed nappe. Part of the complex has often been thrust upward into the overlying quartzite. It is generally the uppermost alum shale complex that has so been thrust, but even the dark shale of Middle Cambrian age has been observed within the overlying complex.

In the deep boring at R. Ormbäcken the alum shale is of a very great thickness. This is due to a large extent to overthrusting and involving. But it may to some extent also represent a wider stratigraphic column. A deep boring to the N of V. Ormsjö also shows a great depth of alum shale (61 m), but these shales show distinct disturbances in the bore column.

A detailed description of the shale complex of the central Lövstrand area will now be given with the aid of deep borings Nos. 247 and 415. The stratigraphy in the northwestern part of the area will be demonstrated with the aid of the section of drill hole No. 465 (cf. Pl. 3).

[1] Fossils have been determined by P. Thorslund and T. Tjernvik.

In the central area the weathered Archean basement is overlain by siltstone and dense argillitic shale. The shale has a grain size of about 0.01 mm but shows arenaceous layers in which the quartz grains are up to 1 mm. The arenaceous siltstone passes over into a conglomeratic sandstone which has flat pebbles of siltstone with a diameter of about 1 cm while the rounded quartz grains attain a size of about 4 mm in an arenaceous matrix with a grain size of 0.1 to 0.2 mm. The conglomerate becomes calcareous higher up, *i.e.* the groundmass is a calcareous sandstone. There are pebbles of both dark and pale shale. The whole complex has a thickness of 1 to 2 m.

Above it follows a banded, grayish shale and siltstone. The shale layers have a grain size of about 0.02 mm while the siltstone layers have a grain size around 0.1 mm. Besides quartz grains there are altered feldspars and sericite flakes. The thickness of this complex is about 2 m. The shale conglomerate which follows is about 6 cm thick. There are pebbles of a size of 0.3 to 2 cm of dark shale or light-coloured siltstone. Besides quartz, there may also be pebbles of phosphorite and possibly also of glauconite. The groundmass consists of white calcareous sandstone. This conglomerate is very characteristic. A photo of the rock is shown in fig. 1.

Above the conglomerate a grayish-dark shale follows which has small arenaceous or calcareous lenses or layers. The lenses are more plentiful in the western area. This horizon is rather variable in both grain size and material. It probably corresponds to the Lower Cambrian. The thickness is about 8 m.

In bore hole 415 there follows another shale conglomerate of a thickness of 15 cm. The pebbles consist of dark shale and quartz grains in a groundmass of calcareous sandstone with glauconite.

This is followed by the *Paradoxides oelandicus* zone judging by fossils in drill core 247. It consists of a dark, argillitic shale and alum shale with layers of dark limestone generally some dm thick. The alum shale is almost quite black without discernible minerals apart from calcite veins and grains of pyrite. The black, argillitic shale in thin slices shows a brownish black mass with fragments of quartz 0.01 or 0.02 mm in diameter. It may also be possible to discern sericite and chlorite as well as large veins of calcite. Pyrite grains occur irregularly but sometimes plentifully.

Photo C. Burlin

Fig. 2. Clay siltstone with arenaceous and calcareous pebbles. About 8/10 of nat. size.

The dark gray limestone is granular with an intermediate grain size of 0.2 mm. It is dotted with powder of carbon or fine veins of it. There are scattered crystals of pyrite.

Judging by fossils in other drill cores, most of the black shale belongs to the *Paradoxides paradoxissimus* beds. *P. paradoxissimus* and *Hypagnostus parvifrons* have been determined from several drill cores by P. Thorslund. Above follows the *Paradoxides forchhammeri* beds which here have a lower part containing *Ptychagnostus lundgreni* and *Acrotreta sagittalis* and an upper part with *Goniagnostus nathorsti* according to fossils found in boring No. 415.

The upper part of the shale complex belongs to the Upper Cambrian according to Uran determinations and the occurrence of *Agnostus pisiformis* and *Parabolina spinulosa* found in several cores, *e.g.* three layers in core 361. *Protopeltura præcursor* was found in drill core 379. In the westerly drill holes the zone of *Dictyonema* is found judging by badly preserved fossils in the upper part of the sections.

In the central part of the Lövstrand area, the succession of the layers is relatively intact, though disturbances occur in the upper part of the sections. In the lower part of the shale complex, above the bottom conglomerate, no recognizable fossils have been observed. Very likely Lower Cambrian occurs in the shale complex above the typical shale conglomerate.

To judge by the conglomerate horizons changes of sea-level have occurred in the lowermost complex.

In the area of the westernmost borings, close to R. Ormbäcken, the conditions of the shales are different. Great displacement within the shale complex are to be seen except within the lowermost part. Above the weathered Archean granite lies a quartz-sandstone conglomerate with calcareous groundmass. Quartz pebbles are most common, but there are also grains of microcline and, further up, shale pebbles and some phosphorite in a calcareous or shaly matrix between the sandstone grains. The thickness of the arkose and conglomerate is about 1.7 m.

This is succeeded by siltstone-shale with pebbles or layers of calcareous sandstone. A rock section relatively rich in light-coloured pebbles has been photographed in fig. 2 from the core of another bore hole. The thickness of this zone is about 8 m.

It is covered by a 25 cm thick shaly limestone which is overlain by a calcareous siltstone or sandstone which above passes into siltstone (the size of the quartz grains is of an order of 0.1 mm). This rock is often brecciated by calcite veins. The whole zone is about 8 m thick.

Above this a 7 m thick dark shale comes with calcareous layers. It is tectonically disturbed and shows thrust surfaces in its upper layers.

About 29 m above the Archean the alum shale appears. It probably represents the lower part of the Upper Cambrian. As compared with more easterly bore records a large part of the Middle Cambrian is lacking, and this part has probably been overthrust toward the SE.

This is succeeded by siltstone and shale of the same type as is found in the lower section. Above this comes middle Middle Cambrian in the form of alum shale and black shale of great thickness (with interstratified thin beds of limestone). It is overlain by lowermost Middle Cambrian. This is succeeded by *Dictyonema* shale and then Upper Cambrian. Above the alum shale black shale or dark argillitic shale comes with layers of dark limestone. Disturbances are to be seen in several places. The bottom of the above-lying quartzite nappe is tectonized.

In the bore section of 465, (Pl. 3), there are several overthrusts. The alum shale complex shows several repetitions. Some of the overthrust shale horizons toward the SE, above the quartzite nappe, probably come from this area. It is chiefly the middle Middle Cambrian (zone of *Ptychagnostus gibbus* and *Hypagnostus parvifrons*) which is found in one of these overthrust complexes and it seems to be this overthrust part which fails in the bore section of No. 465.

The deep borings 1 to 2 km SE of 465 are less tectonically disturbed but there are some overthrusts within these shale sections too.

The fossils found in the Lövstrand drill cores by P. Thorslund are listed in a descending stratigraphical order:

Dictyonema sp.,
Protopeltura precursor,
Parabolina spinulosa,
Agnostus pisiformis (abundant),
Goniagnostus nathorsti,
Acrotreta sagittalis,
Ptychagnostus lundgreni,
Hypagnostus parvifrons (abundant),
Paradoxides paradoxissimus (abundant),
Ptychagnostus gibbus,
Paradoxides sp., (*oelandicus* group).

The Ström Quartzite Series

The composition and stratigraphy of the Ström quartzite series is best known in the large nappe, particularly in the region around Lake Ormsjön. In the first place a description will be given of its composition in the Lövstrand area. It must be pointed out that the Ström quartzite varies in composition and thickness from the eastern part of the nappe toward the NW. The original thickness thus increases toward the mountain range and the interstratified shales also get much thicker in the NW.

A normal section through the Ström quartzite nappe in its eastern part will be about as follows: uppermost a white or pale gray quartzite which has sometimes preserved the texture of quartzite sandstone (cf. figs 3 & 4). In this rock a couple of very thin layers occur of greenish siltstone or quartzitic schist (cf. fig. 9). In the lower part the quartzite often passes over into a medium grained quartzite sandstone which further down passes over into an arkosic quartzite sandstone (cf. fig. 5). The latter sometimes has a layer of quartzite conglomerate (cf. fig. 6). The arkose may have layers of fragmentary siltstone, cf. the photos, figs. 8 and 9.

At the Tåsjö side of the area it has been observed that the arkose (cf. fig. 7) at the bottom of the nappe turns into a granitic arkose, just as it does at Järvsand and Havsnäs. A lenticular mass of schistose granite has often been observed

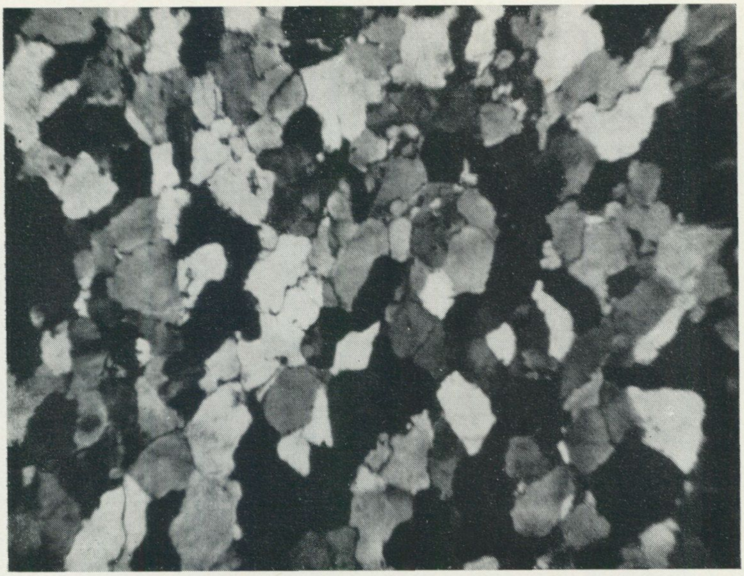

Fig. 3. Pure quartzite. Bredsele, N of Ormsjö. 30 ×, crossed nicols.

at the bottom of the nappe, though it is often separated from the nappe by enveloping shale. But it has also been observed attached to the arkose. In the large nappe of Ström quartzite no real sparagmitic rock has been observed in the bottom of the nappe.

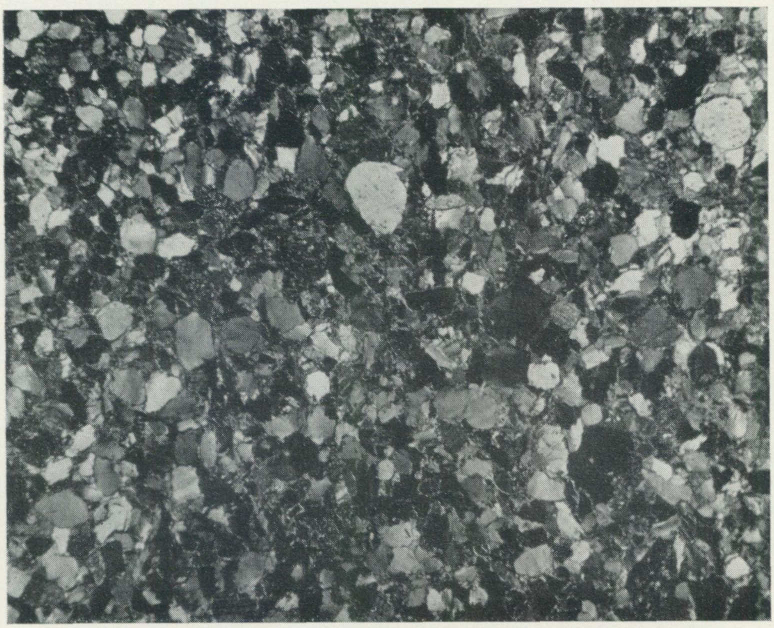

Fig. 4. Quartzite sandstone. Ormsjö. 9 ×, crossed nicols.

As demonstrated by the two large, detailed sections through the Ström quartzite nappe at Lövstrand (Plates 3 and 4) the Quartzite series is often duplicated by overthrusting or imbrication. In this process the whole quartzite complex may have been pushed over its eastern part (toward the SE) at several places. Sometimes the whole overthrust complex is almost complete. It has been possible to follow a layer of the bottom arkose up through the nappe toward the surface. Often some part of the overlying shale has also been brought all the way to the surface, but this is usually not the case as the shale generally tapers out in the lower part of the Quartzite nappe. But in a few instances a thick layer of the underlying shale has been brought all the way to the present surface and preserved thanks to the folding in the Quartzite complex.

Generally the overthrust Quartzite complex is not complete owing to its having been divided and crushed in the overthrusting. The lower arkosic part may have failed in the nappe in the first place or it may have been separated from the main quartzite complex. Overthrustings diagonally through the quartzite nappe also occur. Slightly oblique thrust surfaces parallel to the general dip of the layers of the quartzite have also been observed. In the central part of the Lövstrand nappe the dip of the overthrust surfaces often shows an angle of about 25° toward the NW, though they undulate markedly. Undulating and folding of the thrust surfaces both occur in the direction of the pushing, and to a lesser degree perpendicularly. In addition there are several other displacements, faults, and crush zones of a less range. Fractures parallel to the direction of the thrusting seem to be marked displacements. The crush zones may be combined with *en echelon* displacements.

The layers of arenaceous shale or siltstone of the central Lövstrand area are generally less than one foot thick.[1] But already at the northern end of Lake Ormsjön the arenaceous shales are much thicker, a few metres in thickness, and there are more of them too. As we travel further to the NW, *e.g.* to Mt. Arksjöberget or L. St. Raijan, the thickness of the shales increases. But the thickness is often tectonically increased. There are grayish, reddish, and greenish shales. The thickness of the shales may be as much as 30 m, but it varies greatly due to imbrication and folding.

In the base of the eastern part of the nappe a thick series of arkosic and fragmentary shale also occurs as a substitute for or alternating with the bottom arkose. This rock type is reminiscent of a boulder clay but it is evidently, at least partly, a development of crushing caused by the thrusting.

Evidently the thick bundles of shale within or above the Quartzite complex of the Ormsjö region are chiefly overthrust layers from beneath, as their composition is the same as that of the shale underneath the Quartzite nappe and as they contain similar fossils. It is often possible to trace this overthrusting of the shale in the cores from the diamond drill holes from the base of the nappe upward. Of course there is also liable to be some shale above the quartzite in the Quartzite nappe, just as there is above the autochthonous quartzite N of

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[1] According to Grip, greenish, thin layers of shale also occur in the autochthonous sandstone series of Laisvall in southern Norrbotten.

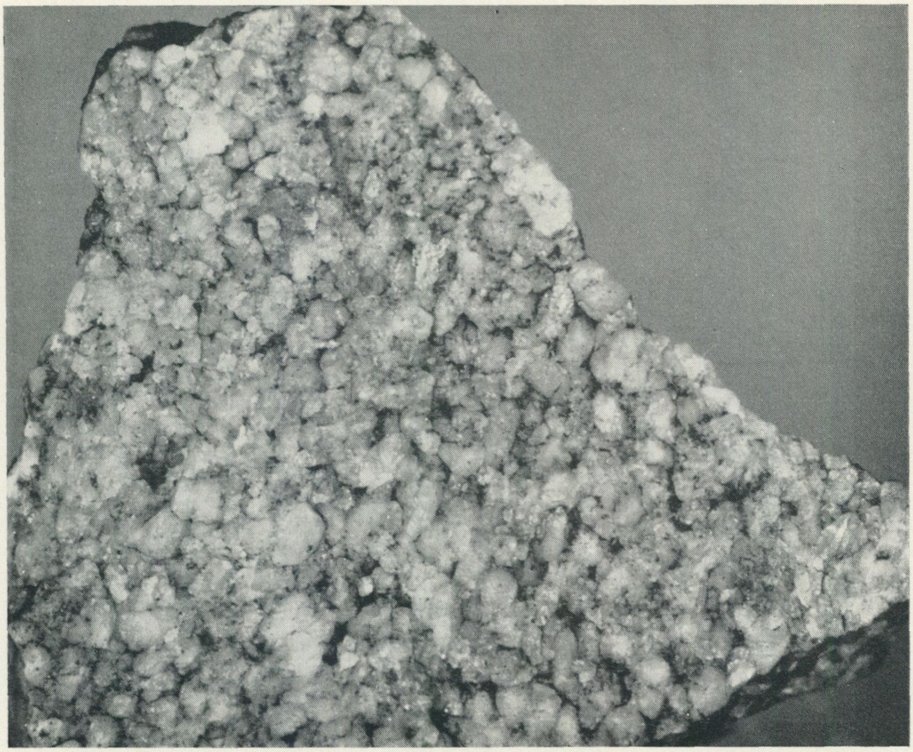

Photo C. Burlin

Fig. 5. Coarse-grained quartz-sandstone. About nat. size.

Lake Tåsjön, but no place where this occurs is known in the area, and probably this shale has, in the majority of cases, been brought off by the thrust movement and then easily eroded at the surface.

In order to show the mineralogic composition of the Quartzite series in the eastern part of the nappe a vertical series of rock samples from a diamond drilling is given in Table 1. In the Table pure quartzite is quantitatively under-represented while siltstone is overrepresented.

Secondary enrichments with calcite, pyrite, galena, sphalerite, fluorite, barite, and chalcopyrite are rather local occurrences which generally appear separately, though galena and sphalerite often appear together. The order of frequency of their appearance is about the same as the order in which they are named above. Calcite is thus most frequent, followed by pyrite. Chalcopyrite is the least usual. The fluorite is usually strongly violet in colour and it may be plentiful in places. Calcite also occurs as an alteration product of arkosic rock types and it is thus far more frequent than the other above mentioned minerals. Pyrite is relatively common in some regions, *e.g.* to the S of the Ströms vattudal valley. Sphalerite is about as common as galena, but it occurs in lesser quantities. It is

Table 1. Samples of a cut through the Ström

Table 1. Samples of a cut through the Strömquartzite nappe at Lövstrand. Numbered from top to

No.	1	2	3	4	5	6
Colour	Pale gray	Pale gray	Gray	Pale gray	Pale gray	Pale green
Grain size in mm	0.5	0.3—0.02	0.5	0.3	0.4	about 0.02
Type of rock	Fine-grained quart-zite	Dense quart-zite	Fine-grained quart-zite	Fine-grained quart-zite	Fine-grained quart-zite	Seri-citic slate
Quartz	94	53	95	94	97	2
Sericitic mineral	0.5	38	0.3	1	1	82
Opaque minerals	2.5	2	3.2	1	1	2.6
Calcite	3	Tr.	1.5	4	1	
Microcline (perthite)		2				
Plagioclase						
Quartzitic groundmass		4.8				12
Feldspar groundmass						
Zircon	Tr.	Tr.				0.2
Chlorite (Biotite)		0.1				
Titanite		0.1				1
Tourmaline		Tr.			Tr.	0.1
Epidote						0.1
Apatite						
Barite						
Flourite						
Quartzite (Chert)						

pale in colour and thus poor in iron. It is considered to be tele-magmatic in origin. The lead ores of the Ormsjö region always show a very low content of sphalerite. In the relatively small occurrences to the SW, however, the content of sphalerite may be considerable.

The lead mineralization has at first followed the fracturing in the quartzite but it often occurs as impregnations or disseminations between the quartz grains too, in which case an ore body may have been formed. Due to its occurrence in fractures and because of the tectonization of the rocks, the grain size of the galena of the Ormsjö region is less than that of the Laisvall mine,

[1] Where streaks have been crushed finer, grained zones have been formed. Calcite occurs in the crushed zones.
[2] Quartzitic dark sandstone with rounded quartz grains in siltstone groundmass.
[3] Pyrite and calcite occur in schistose zones.
[4] Unsorted quartzitic sandstone with some crushed zones.
[5] Run through by crushed zones with streaks of sulphide and calcite.
[6] Quartz and sulphides about 0.03 in size. The mineral size of the sericitic groundmass is about 0.01 mm.
[7] The large quartz grains are about 1 mm in size. The grains of the groundmass are about 0.1—0.2 mm. Sulphide-grains occur between the other grains and as streaks.
[8] The rock is partly crushed. Sericitic minerals appear around the quartz grains.
[9] Slightly porphyritic quartz grains about 0.2 mm in size in a dense sericitic sandstone. Calcite appears as veins.

quartzite nappe at Lövstrand. Per cent by volume

bottom. Per cent by volume.

7	8	9	10	11	12	13	14	15	16
Pale gray	Pale gray	Gray	Grayish white	Dark gray	Dark gray	Gray	Pale gray	Dark gray	
about 0.5	about 0.3	0.02 (0.2)	0.15	about 0.1	0.3	about 1	0.5	about 0.5	about 2
Uneven grained quartzite	Fine-grained quartzite	Siltstone	Fine-grained to dense quartzite	Siltstone	Fine-grained quartzite	Medium grained quartzite	Fine-grained quartzite	Arkose-sandstone	Coarse-grained quartzite
95	97.5	46	94	54	90	87	89	55	88
1.4	1.7	11	2.3	43		0.1	0.2	17.5	9.4
2.6	0.4	2	0.9	1	8	3.5	1.7	0.2	1.5
0.9	0.3	9	2.6		1.9	1.3	6	3	0.9
		1		} 1.6	} 0.1			21	
								2.3	
		24							
Tr.	Tr.	0.1	Tr.	0.1				0.1	Tr.
0.1	0.1	6.5		0.1				0.7	
		0.1		0.1				0.1	
	Tr.	0.2	0.2	0.1	Tr.				0.2
		0.1							
						4.3	1.3		
						3.8	1.8		
								0.1	

where it occurs in an autochthonous, less metamorphosed, quartzite sandstone.

Table 2 shows the composition of some bottom arkoses of the Ström quartzite nappe from different regions. As is seen in the table, microcline or microcline-perthite is infinitely more common than the plagioclase. The composition of the rocks is rather like that of the sparagmites but the outward appearance is quite different. The quartzite arkose is thus of a normal, pale or white coloured type. The two types from the south-western side of Lake Flåsjön referred to in Table 2 are, however, of an extreme type which is very dark in colour. However, arkoses in the vicinity which pass over into granite arkoses reveal that

[10] Crushed zones appear in several directions.
[11] A fine-grained fragmentary sandstone with dense sericitic groundmass grain-size about 0.05 mm. Opaque grains are partly sulphides, partly dense minerals.
[12] Ore grains appear around the borders of the other grains. Calcite appears as veins.
[13] Quartzite sandstone with crushed zones and secondary infiltration of barite, flourite, pyrite and calcite.
[14] Calcite, sulphides, barite and flourite around the quartz grains and as veins.
[15] Grain size is very uneven. Sericite and calcite appear as matrix. Calcite partly replaces the larger grains.
[16] Occurs in the bottom of the nappe. The rock has crushed zones. Carbon has infiltrated from the black shale underneath.

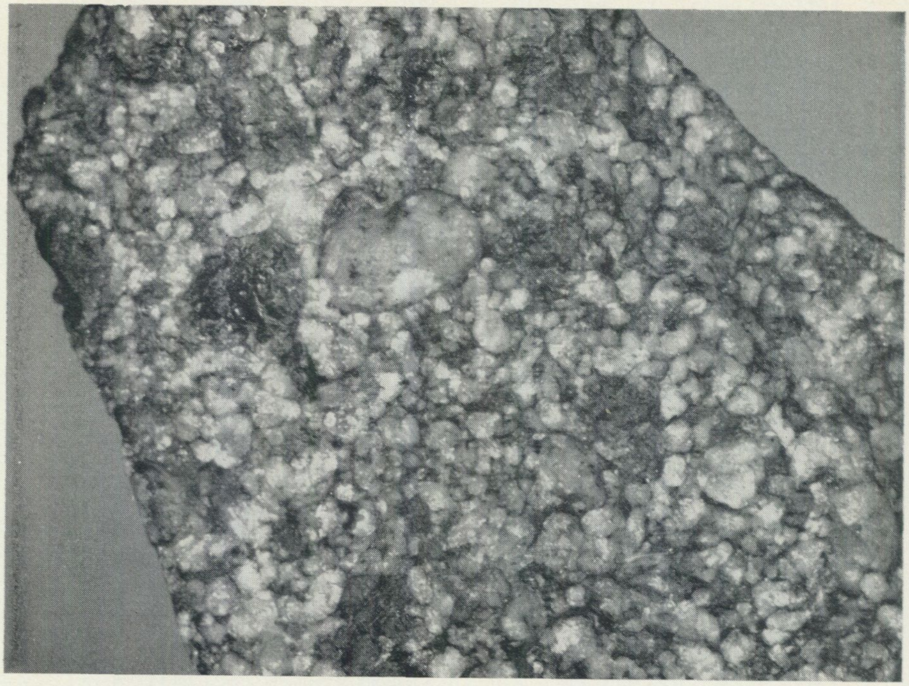

Photo C. Burlin

Fig. 6. Quartzite conglomerate, Alaviken. About nat. size.

sparagmite hardly could have been formed at the basal part of the nappe in that region.

Some angular conglomerates associated with layered, fragmentary siltstone at the bottom of the nappe may correspond to tillite. This is more evident when it is remembered that these layers at the bottom of the nappe resemble the varved arenaceous shales above the tillite and below the quartzite at the top of the sparagmite formation to the N of L. Tåsjön.

Table 3 shows the composition of shales within the Ström quartzite formation both in the nappe and in the para-autochthonous series. Compared with the Cambrian shales they are more quartzitic and differently coloured.

The para-autochthonous Ström quartzite series that occurs at the northern end of L. Tåsjön and further toward the SW, is quite analogous in composition and appearance to that of the allochthonous nappe. The thickness is generally less and the lowermost arkose sometimes fails. Its appearance and relation to the Cambrian shales at the lower end of the river Sjougdälven has previously been described by Asklund and Thorslund (1935). It is often in contact with the uppermost part of the sparagmite formation, the tillite. NW of Korselbränna, as well as at the lower end of L. Erik Matsselet, there occurs a varved arenaceous shale, close to the tillite, followed above by quartzite with subordinate quartzitic shale and, on the top, pure quartzite. At the river Saxälven the thickness of the quartzite complex is great. Where it comes in contact with

Table 2. Bottom arkose or conglomerate. Within the Ström quartzite Fine-grained varieties. Per cent by volume

No.	17	18	19	20	21	22	23	24	25
Locality	Fjälltuna	Mt Månsberget	Eastern Tåsjö		Ala-viken	W of L. Flåsjön		Southern Tåsjö	L. Gärdsjön
Rock type	White arkose-conglomerate	Greenish bottom arkose	Granite arkose	Quartzite conglomerates		Arkose conglomerate	Dark arkose sandstone	Arkose	Quartzite conglomerate
Grain size m/m	2	3	5	3	3	3	0.5	0.5	varying greatly
Quartz	59	62	55	49	81	52	74	54	65
Microcline (perthite)	38	19	42	30	5	38	17	44	25
Plagioclase	0.3	0.2	0.5	2	0.5		0.2		
Altered feldspar	0.6	5		4		0.3	0.2	0.1	
Sericite	2	5.5	1	8	Matrix: 2	8.5	7.4	1.2	3.5
Chlorite-biotite			0.7	2	10.5	0.3	0.6	0.4	0.3
Calcite		7	0.2	4.5	1			0.1	5.3
Ore grains	0.1	1.3	0.1		Tr.	0.2	0.3	0.1	0.9
Zircon	Tr.	Tr.	0.1	0.1	Tr.			Tr.	Tr.
Tourmaline	Tr.		0.1	Tr.		0.1		Tr.	
Epidote									Tr.
Titanite			0.1						
Barite		Tr.							
Shale (slate)								0.1	
Quartzite-chert				0.2		0.5	0.3		
Granophyr, Porphyrite			0.2			0.1			

[17] Grain size is uneven. The rock is crush-brecciated.
[18] Grains are slightly rounded. Grain size varied. Sericite and some calcite as matrix. Calcite generally as veins.
[19] The rock is slightly crush-brecciated.
[20] Pebbles about 3 mm in size in dark-gray dense matrix.
[21] Beautiful conglomerate with pebbles up to 15 mm in size.
[22] Dark gray bottom arkose very uneven in grain size. Pebbles of microcline-perthite up to 1 cm in diameter. The rock is somewhat like a sparagmite conglomerate.
[23] Bottom arkose. The colour of the rock is dark because of pigmenting and biotite-chlorite in the groundmass. Slightly reminiscent of a sparagmite.
[24] Varying grain size. Slightly crush-brecciated.
[25] Bottom of the para-autochthonous Ström quartzite.

Table 3. Quartzitic or arenaceous shales in the Ström quartzite series. Per cent by volume

	Allochthonous rocks			Para-autochthonous rocks		
No.	26	27	28	29	30	31
Type of rock	Finely laminated quartzite sandstone	Banded quartzitic slate	Red siltstone	Laminated arenaceous siltstone	Laminated fine-grained quartzite sandstone to siltstone	
Locality	Ormsjö	Mt Arksjöberget		Korselbränna	Harrsjö	
Colour	Pale yellowish green	Grayish red	Dark brick red	Pale yellowish gray	Pale yellowish gray	Yellowish gray
Grain size m/m	0.1—0.2	0.1	0.02	0.05—0.1	0.05	0.05—0.1
Quartz	29	61	7	52	29	47
Microcline	9	8	} 1.5	8	} 7	3.5
Plagioclase	1	} 10	}	2	}	1.5
Altered feldspar	1.7	}				
Quartzitic matrix	10		about 67		55	43
Sericitic minerals	42	18	4	31	2	2
Calcite	6	0.1		3	2.3	
Chlorite-biotite	0.2	1.5	0.3	1.3	3.5	1.5
Zircon		0.1	Tr.	0.1	0.2	0.1
Tourmaline	0.1	0.2		0.4	Tr.	0.2
Ore grains	} 1	} 1	0.2	0.5	} 0.8	} 1
Pigment	}	}	about 20	1.7	}	}
Titanite, rutile	Tr.	0.1			0.2	0.2
Apatite					Tr.	

[26] Laminated siltstone to very fine-grained sandstone with sericite-quartzitic groundmass. Tectonized rock. Calcite occurs as veins.
[27] Banding of arenaceous layers and layers rich in groundmass. Somewhat tectonized.
[28] Alternating dark and pale layers. Mineral fragments are about 0.02—0.04 in diameter. The groundmass does not permit of detailed calculation.
[29] Occurs at the base of the quartzite above the tillite.
[30] The groundmass consists of disintegrated feldspar with sericite, quartz and a little chlorite. The banding is caused principally by layers richer in quartz or in sericite.
[31] The layering is caused partly by pigmenting, partly by different grain size. Fragments are partly fractured partly rounded.

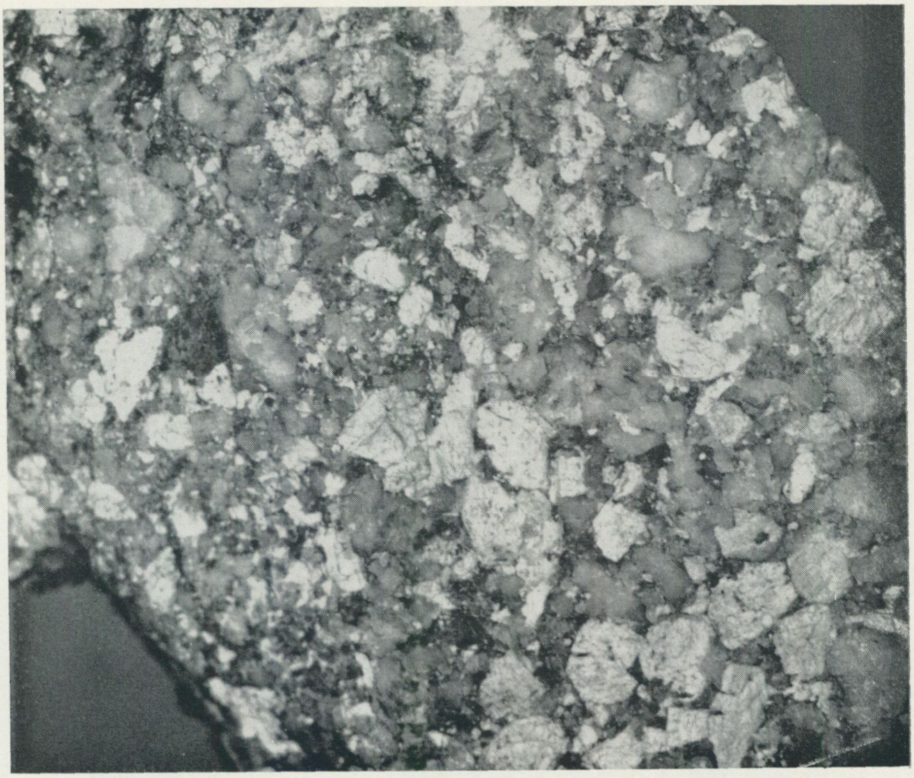

Photo C. Burlin

Fig. 7. Arkose. Bottom layer of quartzite. N. Tåsjö. About nat. size.

the overlying Cambrian shale, overfolding and overthrusting is to be seen. The quartzite also shows crush-fracturing.

In the para-autochthonous quartzite of L. Harrsjön the following stratigraphy is to be seen at one locality S of L. Harrsjön:

Uppermost thick quartzite	
Quartzitic shale	0.2 m,
Quartzite conglomerate and arkose	2 m,
Grayish green, laminated siltstone	0.5 m,
Red shale	1 m.

The base is not outcropping. At another locality in the neighbourhood a thin layer of dolomite was seen at the bottom of the quartzite.

At River Storån, close to L. Gärdsjön, approximately the following stratigraphy was observed (cf. Asklund, 1935):

Uppermost quartzite	several metres,
Quartzite conglomerate	0.1 m,
Quartzitic shale	about 7 m,
Arkose and some conglomerate Granitic arkose }	about 15 m.
The substratum is red, cataclastic granite.	

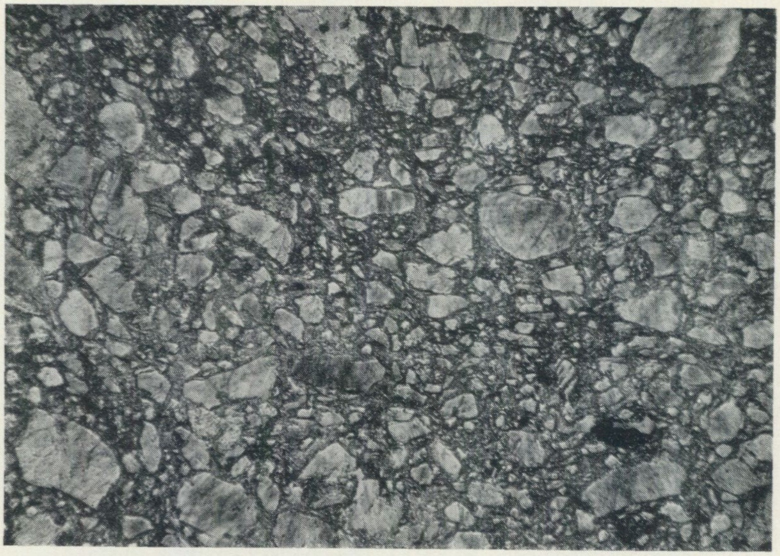

Fig. 8. Fragment-rich siltstone, Brattbäcken. 40 ×.

Toward the SE this autochthonous complex is overthrust above wedges of alternating granite and quartzite (including quartzite conglomerate, etc.). Toward the SW at Mt. Strömberget quartzite conglomerate occurs at the front

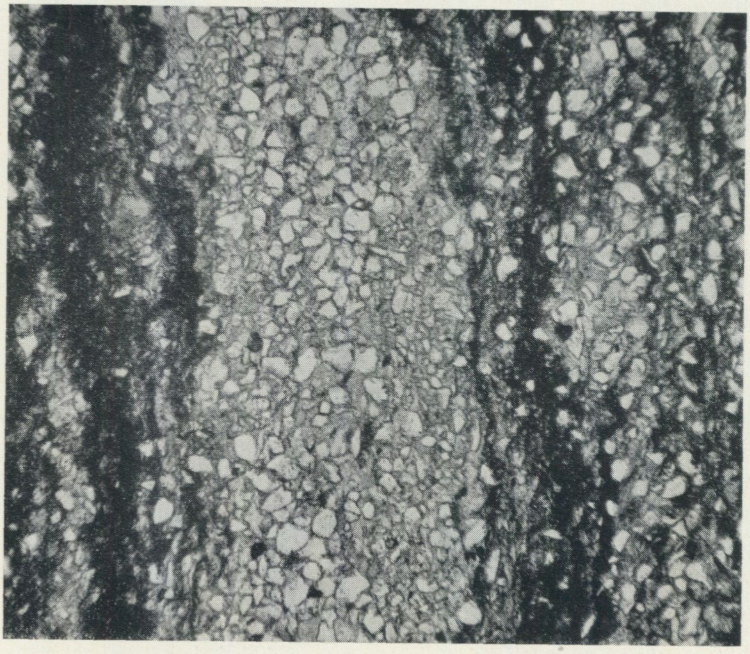

Fig. 9. Layered siltstone. Knaften. 35 ×.

of the overthrust granite and follows below by quartzite and Ordovician shales toward the SE, where they probably form overlapping tiles.

Further southward, near R. Renån, the lower part of the quartzite is seen to be split where it comes in contact with the underlying shales. At the eastern end of Lake Y. Renåflyn granite occurs directly below the arkose and the quartzite. Overthrust tillite-like sparagmite is to be found above.

The quartzite complex continues toward the S, but outcrops are few and only brecciated quartzite was observed.

As mentioned above the shales within the Ström quartzite series are rather quartzitic or arenaceous in composition, with transitions to siltstone or sericitic shale. The shales in the lowermost part of the complex are rather rich in fragments. Two such types are shown in figs. 8 and 9. In the western part of the Ström quartzite nappe, where the shales get thicker, some more regular argillaceous shales have also been observed.

The Sparagmite Formation

The sparagmites are petrographically arkosic to conglomeratic rocks with transitions to quartzitic sandstones. The typical sparagmite is, however, a strongly coloured feldspar-rich sandstone with varying grain size. Small grained conglomerates with pebbles up to 1 cm in diameter are rather abundant. To the sparagmite formation there also belong arenaceous shales, generally feldspar-bearing, sometimes also dolomite or limestone, and moraine-like rocks, tillites. This latter rock type occurs rather frequently within the mapped region.

Among the sparagmites a distinction has usually been made between reddish and gray, or dark, sparagmites. The former type as a rule consists of reddish brown to brownish violet rocks, often with a strong colour caused by iron oxide pigmentation (cf. figs. 10 and 11). The conglomeratic layers may also have a reddish appearance caused by an occurrence of pebbles of jasper or red chert and red porphyries. There are also faintly coloured sparagmites of a violet tinge.

The gray sparagmites may be lighter or darker gray or greenish gray. The dark gray or greenish gray sparagmites generally seem to have arisen by way of metamorphism of reddish sparagmites. The appearance has also been commented upon by Kulling (1942).

The light-coloured sparagmites (pale to whitish) seem to be washed out or sorted by water. They often vary in colour from pale gray to faintly pink or violet and to almost white. They may thus be quite quartzitic in appearance, but they are of about the same composition as the reddish or grayish sparagmites. The rock combination indicates that we are dealing with rocks of the sparagmite formation and not with a representative of the Ström quartzite formation.

From what the author has seen, it is not possible to divide the sparagmites stratigraphically in accordance with the colour of the rocks, in a lower division of gray and an upper one of red sparagmites. The reddish sparagmites seem

Fig. 10. Red, layered sparagmite. W of Sjougdälven. 1/2 of nat. size.

originally to have predominated within the region investigated. In a few cases it has been observed that an interstratification of red and gray sparagmites may occur, as has earlier been reported by Kulling (1942). Grayish sparagmitic shales may also occur together with reddish sparagmites. The light-coloured sparagmites which occur here and there, *e.g.* in the region of Lake Norrsjön, seem to belong to an upper part of the sparagmite series.

The sparagmitic areas are generally distinguished by an abundance of boulders of sparagmite due to which outcrops often are difficult to find except in steep mountain slopes. Contacts with other rocks are very rare. The sparagmite is often quite even-grained and the layering is then difficult to discern.

It is only on the southwestern side of the river Sjougdälven that the sparagmite occurs in a direct autochthonous position, though only the upper part of it is to be seen. The base is not to be seen as the contact with the granite in the NW is tectonically affected. The position of the sparagmite mass and the dip in the layers shows that the whole sparagmite complex has been somewhat bent up by the push of the granite complex from the SW.

The red sparagmite of this large complex is generally well preserved. The rock is sometimes distinctly bedded and also shows cross-lamination. Fig. 10 shows a distinct laminated sparagmite. The lamination is often made more distinct by grains of iron oxide. The rock often contains scattered pebbles. Fine-grained conglomeratic layers occur here and there. Mylonitic brecciations were observed, causing bands of grayish sparagmite. Next to the overturned granite contact light-coloured sparagmites dominated.

Tables 4—6 are intended to show the mineral composition of both sparagmites and sparagmitic shales. Coarse-grained and conglomeratic types have not

Table 4. Para-autochthonous sparagmites. Mineral comp. Per cent volume

No.	32	33	34	35	36	37	38	39	40
Locality	L. Tomas Hansselet	R. Sjougd-älven	Mt Bod-berget	Mt Ögel-hättan	Mt Hiberget	L. Djup-vattnet	Mt Erfjället	Mt Lilla Erfjället	L. N Häggsjön, Offerdal Nappe For comparison
Type of rock	Coarse-grained conglomeratic	Arenaceous	Even-grained	Arkose-conglomerate		Schistose	Schistose	Schistose	Granulated-schistose
Colour	Gray	Grayish red	Pale red	Gray	Light-coloured	Gray	Pale gray	Dark gray	Pale gray
Average grain size	3 mm	0.4 mm	0.6 mm	0.6 mm	Varying	0.5 mm	0.3 mm	0.4 mm	Varying
Quartz	41	35	71.5	49	59	38	52	53	51
Microcline (perthite)	41	30	26	33	25	17	23	20	20
Plagioclase	3.4	6	0.3	7	1.5	0.6	2		4
Altered feldspar		9	0.5		2.5	0.5	0.4		
Quartzite, chert (jasper)		2	0.2	5	3.2	2			
Sericite	13	5	0.3	0.1	3	24	20	20	21
Chlorite and biotite	0.3	0.1	0.7	3	1		0.1	0.7	1
Calcite	1	5				0.2			
Ore grains	0.3	1.3	0.3	0.6	0.3	0.5	0.3	1.3	Tr.
Titanite, rutile	Tr.	0.7	0.1	0.4		0.2	0.2	1	2
Zircon		0.4	Tr.			Tr.			Tr.
Tourmaline		0.1	0.1						Tr.
Epidote and allanite		2.7				3	2	4	1
Apatite		0.2							Tr.
Groundmass					4.5	14			
Rock fragments		2.5		2					

[32] Subrounded grains.
[33] Subrounded grains.
[34] Rounded grains. Slightly mylonitic.
[35] Angular to rounded grains.
[36] Greatly varying grain-size and grain texture.
[37] Partly mylonitized.
[38] Partly mylonitized.
[40] Residual parts in granulated or recrystallized and discoloured sparagmitic sandstone. Microcline occurs as small augen.

Table 5. Sparagmites of the Oxfjäll nappe. Mineral comp. Per cent by volume

No.	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Locality	L. Gubbsjön	N of L. Svansele	S of Brännåker	L. St. Arksjön					Mt Arksjöberget			Mt Oxfjället		L. Rajtasjön
Type of rock	Schistose	Schistose	Schistose	Quartzitic			Granular	Tectonized	Quartzitic	Laminated	Arenaceous	Uneven granularity	Conglomeratic	Uneven granularity
Colour	Red	Pale	Pale	Pale	Reddish		Red	Grayish red	Dark	Gray	Dark	Brownish violet	Gray	Pale
Average grain size	1 mm	0.6	0.4	0.4	1 mm	0.5	2 mm	0.5	0.4	0.2	0.3	0.4	1.5	1 mm
Quartz	52	69	44	70	77	80	62	62	73	74	73	69	67	79
Microcline (perthite)	35	17	37	14	13	13	24.5	23	17	19	17	12	9	18
Plagioclase			2	3	1		0.4			0.2		0.5	0.4	
Altered feldspar	0.6			0.8	2	2.5		1	1	4	4.4	3	5	
Chert, quartzite		0.1	1	0.1	1	0.4	1	1	1		1	0.2	1	
Sericite	12	10.3	12	12	5.5	4	12	8	3.4	1.3	2	11	16	2.6
Chlorite + biotite			1					Tr.	2.6		1		0.4	
Ore grains	0.2	0.5	0.3	0.1	} 0.5	0.1	0.1	1	2	1.2	0.1	4.3	0.1	0.3
Titanite, rutile			1.4	Tr.	} 0.5				Tr.	0.1				0.1
Zircon	0.1	0.1	0.1	Tr.	Tr.		Tr.	Tr.	Tr.	0.2		Tr.		Tr.
Tourmaline									Tr.	Tr.				
Epidote, allanite			1.2											
Apatite	0.1		Tr.							Tr.			0.1	Tr.
Rock fragments											1.5		1	
Groundmass								5						

[42] Sericite occurs in crushed streaks.
[43] Some grains are porphyritic. Some grains are granulated.
[44] Strongly schistose. Quartz is rather granulated.
[45] Sericite occurs enveloping the larger minerals.
[46] Granular.
[47] Arenaceous.
[48] Irregular grain size.
[49] A groundmass has been formed by mylonitization.
[50] Sericite and chlorite occur as a coating round the grains.
[51] Ore grains and zircon occur in rows or layers.
[52] Even grained. Arenaceous texture apparent due to pigmentation around the grains.
[53] Sericite and ore pigments around the grains. Microcline is strongly sericitized.
[54] Rock fragments of sparagmite occur. Also a little granite and chert.
[55] Grain-size varies between 0.2 and 3 mm.

Fig. 11. Red sparagmite. St. Arksjön. 9 ×, crossed nicols.

been included in the tables as it would require many rock slices in order to obtain a strict composition.

Besides mineral fragments, the coarse conglomerates contain pebbles of sparagmite, quartzite, granite, porphyry, and jasper or chert. Fig. 12 is a photo of a coarse-grained, red sparagmite with pebbles of dark, red porphyry. The fine-grained conglomerates occur intraformationally within the sparagmite formation, but the thickest conglomerates observed in outcrops are those occurring in connection with or below the tillites. The tillite conglomerates themselves are still more polymict and inhomogenous than the sparagmite conglomerates.

A rock type which has yet to be closely investigated is the dolomite or limestone within the sparagmite formation. The largest occurrence of this rock type is the dolomite of Kalvberget, to the W of Risbäck. This occurrence has been described previously by both Asklund (1935) and Kulling (1942).

The sparagmites further to the SW, especially those on Mt. Erfjället and further westward become more and more schistose. They show abundant, secondary formation of epidote, titanite, and biotite (chlorite). This mineral development is analogous to a description by Kulling of sparagmites from the Stalon region in the N. The sparagmites are markedly schistose and also contain sparagmitic shales. In view of the schistosity of the sparagmites in the Mt. Erfjället—L. Brinnsjön region and of the fact that they lie above more or less mylonitic granites and are overthrust by another mass of granite, it is

Photo C. Burlin

Fig. 12. Coarse-grained, red sparagmite. W of Sjougdälven. About 1/2 natural size.

possible that the sparagmitic rocks of this region may have formed a far transported nappe.

The striped, feldspar-rich schist, that appears running in almost the same direction toward the W along the northern half of L. Hotagen and further westward, has about the same composition as a whole as the Erfjället sparagmitic complex, *i.e.* it is composed of sparagmitic shale with interstratified sparagmite though it is more metamorphosed. It seems to represent Klippen of the northernmost and basal part of the Offerdal nappe.

The sandstone or sparagmite of the lower part of the Offerdal nappe is generally a quartzitic, layered, grayish rock which, due to strong mylonitization, changes into dense banded rocks or sericite schists. Relatively well preserved rocks show transitions between sandstone, arkose, conglomerate, and shale.[1] The schistose rocks show porphyritic grains of microcline in a quartzitic groundmass. The sericite is often gathered in stripes or layers. The schistose rocks always have some secondary epidote and titanite. The composition of a rock type to the N of Lake Häggsjön is seen in No. 40, Table 4. The sandstone varieties generally contain about 50 % quartz, and 20 % each of microcline and sericite, though these amounts vary greatly, and a few per cent of epidote, titanite, plagioclase, often also biotite-chlorite, and calcite.

Another area with a large expanse of grayish, sparagmitic shales lies beside Lake St. Bergvattnet within the south-western part of the large Oxfjäll nappe. In the region Tvärsele—Storfallet there is also a fairly large expanse of sparagmitic shales. Pictures of dense sparagmite and sparagmitic shale from that region are given in Figs. 13 and 14. Red sparagmitic shales also occur but they

[1] Well preserved sparagmitic arkose is often to be seen in the groundmass of the Offerdal conglomerate to the S.

Table 6. Sparagmitic shales. Per cent by volume

No.	56	57	58	59	60	61
Locality	L. Mesjön—Risbäck			Korselbränna	Mt Erfjället	
Type of rock	Sparagmitic shale		Red shale	Fragmental shale	Schistose Sparagmite	Sparagmitic shale
Colour	Dark gray	Pale gray	Dark red	Variegated	Gray	Dark gray
Grain size m/m	0.2—0.02	0.2—0.02	0.1—0.02	0.2—0.01	0.5—0.05	0.2—0.03
Quartz	30	35	2	37	49	53
Microcline	19	5	1	14	14	22
Plagioclase	0.3			1	1.5	0.5
Altered feldspar . . .				2		
Quartz-feldspar matrix	21	30	29			4
Sericitic matrix . . .	29	29.5	60	37	27	10
Biotite-chlorite . . .	0.4			5	0.2	8
Calcite	0.2					0.7
Ore grains	0.1	0.5	8	0.5	4	0.5
Zircon				Tr.	Tr.	0.1
Titanite					2.3	0.2
Epidote					2	Tr.
Apatite						1
Tourmaline						Tr.
Quartzite, chert . .				2.5		
Sparagmite grains . .				1		

are not abundant in this part of the map area.

The mylonitized sparagmites appear in two main types. One rock type has a granulated appearance with augen of microcline in a schistose, granulated groundmass. The other rock type, which is more common, shows much sericitization, indicating a stronger metasomatic alteration. It still contains augen of microcline, but they are often somewhat altered. There are also transitionary rock types, *e.g.* laminated or striped rocks with bands of both rock types. Both rock types may show secondary formation of epidote, titanite, biotite, chlorite, and possibly garnet. These minerals are, however, more common in the alteration of the sparagmitic shales, and the dark dense sparagmites. Transitions between all stages of metamorphism may be studied in the rock complex at the base of the Offerdal nappe. The lowermost part of this complex is, however, composed of mylonites of Archean rocks and sparagmite conglomerates.

The Tillites

Tillitic conglomerates or boulder clay have been observed within or in contact with sparagmites in the autochthonous or para-autochthonous zone in the following localities: The southern side of L. Hansselet, W of L. Tomas

[56] A thick complex of shale with interstratified sparagmite.
[58] Shale layer in sparagmite.
[59] Probably a boulder clay.
[60] Interstratified with sparagmite.

Fig. 13. Dense sparagmite. Storfallet.

Hansselet, at L. Erik Matsselet and SE of it, NW of Korselbränna, at the river Sjougdälven (two localities), NW of Mt. Bodberget, E and SE of L. St. Byvattnet, at and E of L. Y. Renåflyn.

In the Oxfjäll nappe tillites have been observed *e.g.* SW of L. St. Dabbsjön, Between L. St. Dabbsjön and L. L. Dabbsjön, at several places near Sörfors and L. L. Raijan, W of L. Sörsjön, in many places on Mt. Långmarksberg and SW of it, in the rivulet between L. Bergvattnet and L. Sörsjön, S of L. Bergvattnet,

Fig. 14. Folded and schistose sparagmite shale. Storfallet, W of Risbäck.

N and NW of L. Hansselet, in the rivulet between the lakes Nåsjön and Nyselet, and SW of this locality. Tillites have also been observed as erratics in many places.

The tillite conglomerate is generally dark in colour, often dark gray to almost black when it is schistose. It may sometimes be rather similar to a strongly schistose granite, but its fragmentary nature can be recognized. When the rock is well preserved the fragmentary appearance of the boulders is discernible. They are angular and uneven in size and form.

The composition of the conglomerate can be very polymict, but the groundmass is often more or less sparagmitic, though dark in colour. At a few places both tillite conglomerate and boulder clay, *i.e.* laminated or varved arenaceous shale or siltstone with stray pebbles, have been observed at the same locality. The boulder clay is not frequent, however.

The general mineral composition of the tillites is seen in Table 7, which refers to relatively fine-grained varieties. The tillite generally has a denser and more plentiful groundmass than the sparagmite conglomerates. The groundmass is very dark thanks to a relatively high content of biotite, chlorite, and ore-mineral pigments.

The tillite NW of Korselbränna is best exposed. The author has previously given a picture from this area, and two others are reproduced here, figs 15 and 16. The following boulders or pebbles were observed: Revsund granite, aplitic granite, coarser-grained granite, plagioclase-rich granite, granophyre, pegmatite, feldspar gneiss, schistose gneiss, porphyry, greenstone, diabase, many pebbles of red, gray, and violet sparagmites, arkose, light-coloured sandstone,

Fig. 15. Tillite conglomerate. NW of Korselbränna. About 1/7 nat. size.

Table 7. **Tillites, allochtonous and para-autochthonous. Small-grained types. Per cent by volume**

No.	62	63	64	65	66	67	68	69	70	71
Locality	Mt Långmarksberg			Sörfors	R. Sjougdälven		NW of Korselbränna			NW Mt Bodberget
Type of rock	Boulder clay	Fragmentary sandstone	Conglomerate breccia	Tillite conglomerate			Fragmentary rock			Laminated boulder clay
Quartz	12	29	67	32	28	36	25	42	33	24
Microcline (perthite)	14	19	20	5	15	37	10	19	23	7.5
Plagioclase	3.4	2	4	12	4	14	3.5	8	12	2
Altered feldspar		6		11	1	2	3.5		1.7	7
Sericite	1.2	5.6	3.9			0.4		1.9	0.8	15
Sericite groundmass				17	33		37			27
Biotite	0.2	4.5		10	3.5	Tr.	1	0.1	1	1.4
Chlorite	2.5	3.4		7.5		2.3	2	1.9	1.5	0.5
Calcite, dolomite	26	0.2	4		5.6	5.4	15	0.3	3	
Ore grains	0.7	1	0.1	2	1.5	0.2	2	0.8	0.8	0.4
Quartzite, jasper		0.2		0.5	0.4	2	1	1.4		
Dense, dark groundmass	40	28			8			24	21	15
Zircon						Tr.		Tr.	Tr.	0.1
Apatite						Tr.		0.1	0.2	Tr.
Tourmaline	Tr.	0.1							Tr.	Tr.
Zoisite, Epidote				1				Tr.		
Titanite, rutile						0.1		Tr.		0.1
Porphyry, porphyrite		1		2		0.6		0.5	2	

[62] Laminated rock with fragments and pebbles.
[64] Pebbles about 1 cm in size. Sandstone about 1 mm in grain size.
[65] Many pebbles of Archean rocks.
[66] Washed moraine. Pebbles of sparagmite, granite, greenstone, etc.
[67] Pebbles of granite, porphyry, greenstone, sparagmite.
[68] Dark red, fragmentary rock.
[69] Sparagmite, and Archean rock fragments in a dense groundmass.
[70] Pebbles of granites, gneiss, granophyr, porphyry, sparagmite, quartzite.
[71] Matrix of sericitized grains and dark pigmented bands.

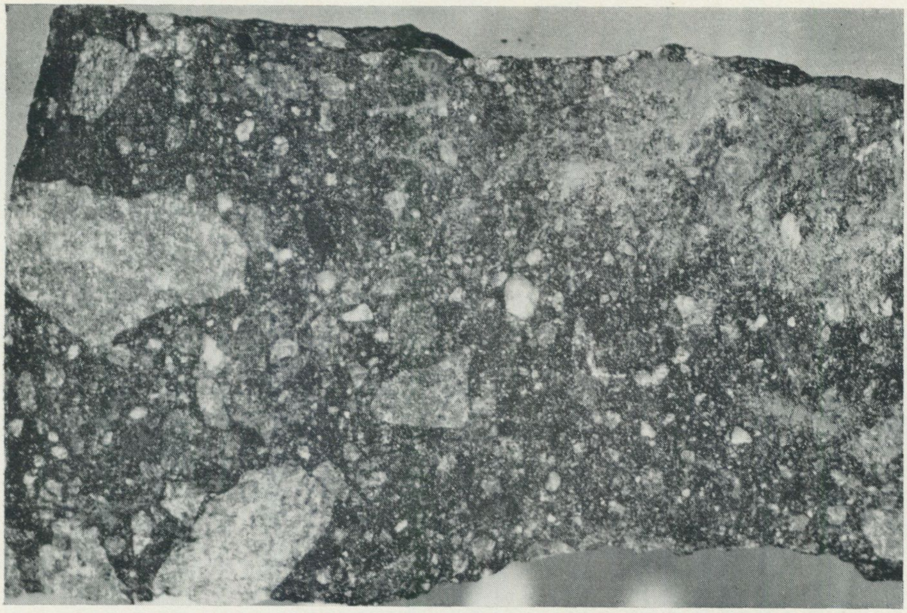

Fig. 16. Tillite conglomerate. NW of Korselbränna. About 2/3 nat. size.

quartzite, quartz, chert or jasper, *etc*. Granite, sparagmite, quartzite, and quartz are the most common boulders. The size of the boulders varies greatly, boulders more than 1 m in diameter having been observed. — The tillite may also be very fine-grained, showing transitions to boulder clay.

Kulling has described some tillite localities in this region, particularly at Mt. Långmarksberg, reproducing several photos (1942, 1955).

The very polymict conglomerate at the base of the southern end of the Offerdal nappe is very similar in part to the sparagmite conglomerate of Garbmadak in the Laisvall region which, according to Marklund, is to be regarded as a tillite conglomerate. In another area the Offerdal conglomerate is reminiscent of the sparagmite conglomerate NW of Korselbränna.

The sparagmite and tillite beside the river Sjougdälven corresponds to the Moelv sparagmite, Moelv conglomerate and the Moelv tillite of the L. Mjösen region in Norway. The shales, siltstones and red shales which often occur between the sparagmite formation and the Ström quartzite formation correspond to the Ekre shales of Norway, where the Quartzite-sandstone formation also follows above them.

The tillites in the para-autochthonous unit SW of the river Sjougdälven evidently also correspond to the Moelv tillite.

Above the tillite to the NW of L. St. Byvattnet follow gray shales, which may correspond to the Ekre shales. The sparagmites above the Svaningen complex in the south-western region, which as a rule have disturbed tectonic contacts with the granite, probably all correspond to the upper section of the

Sparagmite formation of L. Mjösen. The association of light-coloured sparagmites and red ones is also analogous to the condition in the Mjösen region where such an association characterizes the upper part of the sparagmite formation. The tillites within the Oxfjäll nappe in most cases belong to the upper tillite (the Moelv tillite of Norway). But it is always more difficult to determine the stratigraphic position in involved nappes.

The tillites of western L. Hansselet and those on the southern side of L. St. Dabbsjön may be examples of tillites which are directly overlying Archean bedrock. They are thus analogous to some of the bottom sparagmites of southern Norway which are supposed to correspond to the Moelv tillite. The shale complex of L. St. Bergvattnet probably corresponds to the Ekre shales too, as tillite-like conglomerates are associated with such shales.

A detailed mapping of the sparagmite complexes should reveal additional localities of tillite. Sparagmite conglomerates of a type similar to that underlying the tillite of the river Sjougdälven have been observed in several places.

In northern Norway there are two separate layers of tillite, according to Holtedahl and Föyn, a lower one often associated with dolomite as in Härjedalen and southern Norway, and an upper one associated with sandstone and shale which probably corresponds stratigraphically to the Moelv tillite but has another petrographic association. The Garbmadakk conglomerate in the overthrust complex of the Laisvall region in Norrbotten (F. Kautsky, Marklund) evidently also corresponds to the sparagmite conglomerate and tillite of the river Sjougdälven. The tillites further N in Norrbotten often seem to lie directly upon or close to the Archean basement. They are not connected with sparagmites according to G. Kautsky (1949) and Kulling (1951).

The Archean Complexes

The two Archean nappes E and N of Risbäck are partly schistose or mylonitized, but partly show well-preserved relics of Revsund granite, too. Their position indicates that they might have been the basement of the sparagmite nappe, but they may, just as well, have been isolated complexes, which as flat wedges, were broken away from the basement in the overthrusting of the sparagmite. Furthermore they were thrust into the overlying sparagmite complex at their southeastern margins. As the contact relationship is tectonic it is not possible to ascertain the primary circumstances. The smaller Archean rock or granite complex at Sörfors presents another appearance and it seems to be associated with the Ström quartzite nappe and may have been its primary basement. Its direction and position as a continuation of the Risbäck granite complexes may, however, indicate, that it, too, can have been a tectonic wedge-like intrusion in the Quartzite nappe at the thrusting.

THE LARGE PARA-AUTOCHTHONOUS ARCHEAN WINDOW, THE SVANINGEN COMPLEX

The great Archean rock mass extending from L. St. Sjougden southward through northern Jämtland constitutes a large window in the Caledonian border region. It has been thrust upward in varying degrees toward the SE. It is not possible to say whether it is strictly para-autochthonous or whether it has been torn from its basement. However, it seems to get more overthrust and mylonitized toward the south. Its raised altitude and the fact that it is fractured into several wedge-like thrusts, revealed particularly by the study of the originally overlying quartzite and sparagmite, indicate that these thrusts are relatively late, later than the original overthrust of the large, flat Ström quartzite nappe. To some degree the tectonic disturbances in this nappe, as well as the mylonitization and frequent overthrusts, are probably due to late deformation by the Archean upheaval. This warping and thrusting of the Archean complex is probably the result of the thrusting of the great Seve nappe. The Archean anticline seems to represent several units pushed over each other with disruption in the overlying complexes. As the different thrust horizons are impossible to follow except where they are revealed in outcrops, some thrust-lines within the Archean complex marked on the map and sections are more or less symbolical. The conditions are far more complex than it has been possible to ascertain.

The Svaningen complex is bounded on the S by another overthrust of Rätan granite with superincumbent schistose or mylonitized arkoses or sparagmites with interstratified slates belonging to the lowest part of the Offerdal nappe. This forms a high nappe complex which in its lowermost part consists of formations of "Eo-Cambrian" rock type and is superimposed by more or less schistose or metamorphosed Cambro-Silurian rocks corresponding to the "Seve-Köli" rocks or Cambro-Silurian rocks of "westerly facies".

When we approach the Seve nappe from the Svaningen complex, the thrusts or imbrications of the complex become more and more evident showing mylonitization or dragging of the rocks. The original rock type may be hard to recognize.

As has been mentioned above, there appear, in some parts of the eastern "Mylonitic zone", complexes of quartzite or sparagmite which have been dragged above the western part of the Svaningen complex. At Valsjöby, N of Hotagen, there occurs, beneath the Seve nappe, a long stripe of white quartzite with underlying phyllitic shales which may represent a nappe of Ström quartzite which has pulled some Cambro-Ordovician shales along with it. Otherwise the mylonitic zone generally consists of Archean rocks, and, in the northern part, generally of Archean rocks and sparagmite of more or less wedge-like appearance. Granitic and sparagmitic rocks may, when mylonitized, be hard to discern. Tillite-like rocks have also been observed in this part of the Mylonitic zone. Ström quartzite appearing here and there are easier to recognize, though they occur in both whitish and very dark varieties.

The Seve nappe (the Mountain Complex)

The complexes which have been dragged along by the Seve nappe do not really belong to it. The lowermost zone of the nappe itself generally consists of micaceous slates which upwards may be metamorphic to a greater or lesser degree, consisting of phyllitic rocks, micaschists or gneisses. The complex is often interspersed with layers of amphibolites and calcareous or arenaceous rocks (or quartzites).

Thus the complex generally consists of more or less metamorphic Cambro-Ordovician rocks of "westerly facies". The lower part of it may be in a phyllitic facies (including quartzites or calcareous rocks) or it may consist of micaschists, quartzites and gneisses with interstratified amphibolites. The latter rock association is often called "Åre-schists" in Jämtland.[1] The whole complex is generally strongly micaceous in the lowermost thrust zone.

In the higher parts of the overthrust complex the degree of metamorphism is often greater so that gneissic rocks predominate. Conditions vary, however, from region to region. The tectonic bottom of the Seve nappe does not constitute a definite stratigraphic layer. The dislocation of the complex may have occurred at different levels within the westerly Cambro-Silurian or beneath it. Thus the basement of the Cambro-Silurian complex may also have been pulled along in the overthrusting. But in most cases this part became separated in the overthrusting and appears as wedges or separate nappes. Micaceous slates or schists generally constitute the "typical" base of the complex as the shales were the best gliding plane.

Thrust planes occur also within the Seve nappe. When the thrusts occur, complexes with the same degree of metamorphism probably glide easily over complexes of another homogeneity. The author was already aware that several notable overthrusts also exist in the interior of the great Seve nappe (Seve-Köli complex). In a section drawn right through the Caledonian from Storuman in Västerbotten to Mo in Rana in Norway in 1946 for the Boliden Company the author indicated a few great overthrusts within the interior of the Seve-Köli complex.

This description is not meant to be a detailed one of the rocks of the Seve nappe[2] since the present investigation deals chiefly with the border region of the Caledonian ridge. The configuration of the Seve nappe of northern Jämtland may be discussed in a later paper.

The Sections

A series of 13 parallel sections, Pl. 2, has been drawn through the mapped region from SE to NW. The scale of height is double that of length. The sections may be taken to be relatively schematic as the number of thrusts in many instances should be greater than indicated. There may sometimes be a series of thrusts when only one has been shown, as thrust surfaces that pass through similar rock complexes are difficult to discover. The thickness and the position

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[1] In the higher part of the Åreskutan complex the degree of metamorphism is higher. The feldspar-bearing or micaceous quartzite, with or without amphibolites, is thus overlain by garnet-bearing quartzites, micaschists and amphibolites. These rocks are in their turn overlain by migmatitic gneisses and migmatitic amphibolites. Solitary pegmatitic intrusions may, however, appear not far above the overthrust of the Åre nappe.

[2] The westerly, uppermost part of the Seve nappe is often called the "Köli" nappe.

of the lower surface of the rock complexes are more difficult to determine the farther we go toward the NW in the sections as no deep borings have been done there and there may be several complexes on top of each other. Deformation and mylonitization are also likely to be greater in the NW than in the SE.

The sections begin with No. 1 right across Mt. Blaikfjället toward Mt. Gittsfjället in the northern part of the map region and ends with No. 13, which is a section near Lake Hotagen in Jämtland. Additional sketches will be given in the text.

Section No. 1 shows the almost horizontal position of the Ström quartzite nappe. It is eroded to a great extent on the low anticline of Mt. Blaikfjället, which runs in a north-westerly direction. In the NW the Quartzite passes beneath the Sparagmite nappe, but it was buckled up by the thrusting of the Archean nappe or wedge at the SE end of Mt. Gittsfjället. The contact Quartzite—Sparagmite was also steepened by the same thrust. Above the Archean mass the sparagmite appears again, and further toward the NW there are imbrications of Ström quartzite, sparagmite, and granite within the Gittsfjället region. As this part of the area was not very well investigated it has not been included in the map.

The underlying shale, chiefly of Cambrian age, forms a large part of Mt. Blaikfjället where the Quartzite nappe has been eroded, though it is generally only visible in close connection with Klippen of quartzite.

Section No. 2 shows a broad cut through the flat, allochthonous Ström quartzite which to the E of Risbäck dips underneath the Sparagmite and the Archean block. The basement below the Quartzite nappe has generally proved to be alum shale or black shale of Cambrian age. This shale beneath the nappe has proved a good lubricant for the flat overthrusting of the Quartzite nappe. The uppermost shale generally moved along some distance as the Quartzite glided over it. When the Quartzite nappe was broken up causing imbrication of the layers, a little black shale generally followed some way up at the basal part of the quartzite tiles. The shale generally wedged out, but in some instances it followed all the way up, thinning out but getting thicker again. In a few instances the lowermost part of the Quartzite nappe was a quartzitic siltstone; this was probably very much brecciated in the overthrusts within the nappe. Quartzite at the contact with the shale basement may be brecciated with infiltrations of some carbon into the bottom part of the nappe, and the quartzite may thus become a bluish black rock. This condition is, however, more usual in the westerly parts of the Quartzite complexes. This appearance was also evident in the bottom part of the overthrust quartzite at the south-eastern contact of the Mt. Oviksfjäll quartzite in southern Jämtland.

The lowermost part of the Quartzite nappe is generally quite smooth, and on the whole the lower surface of the nappe is almost horizontal notwithstanding local imbrications.

The profile of Mt. Arksjöberget in the western part of the Quartzite nappe, shown in fig. 16 in the paper of 1942, show the extensive development of interlayering shales in this part of the Quartzite nappe. The shales were somewhat overrepresented in the drawing.

The Oxfjäll nappe in the Risbäck region lies above the quartzite and is rather flat lying. Approaching Risbäck the Archean sheet, originally lying below the Sparagmite, turned upward against it on its south-eastern side, but it still lies beneath the Sparagmite on the western side. The Archean nappe is a dragged and broken complex at the base of the Sparagmite nappe, and it is less plastic.

The Sparagmite complex to the N of Risbäck (*e.g.* in Mts. Mångmanbergen) is a thick mass of gray, schistose sparagmite above the well preserved, red sparagmite of the Risbäck region. In the buckled up part to the W the dolomite mass of Mt. Kalvberget appears. Dolomite is a relatively rare element in the mapped areas. Further to the NW in the second section, in the region of Stenbäck—L. Gubbsjön, the sparagmite is gray to reddish, very schistose and often traversed by quartz veins (cf. Harst and Asklund). The sparagmite is foliated and imbricated by the overlying complexes. The Mylonitic zone is rather thin here. The bottom of the Seve nappe has one or two surfaces of micaceous schist (sericite-schist, sericite-chlorite-schist, and sericite biotite-schist) superimposed by quartzitic to phyllitic micaschists, and a superincumbent complex of micaschists and amphibolites. There are several thrust horizons of a minor range.

Section No. 3 passes in its eastern part the region from L. Bellviksjön to R. Ormbäcken which has been investigated with diamond drillings and mapped in detail and proceeds through the window of Ordovician shale around Mt. Harrsjöhöjden. Outcropping shales in this part are generally of Föllinge-Holmsjö facies according to Asklund and Thorslund. They generally consist of graywacke shales, argillitic shales, and calcareous-arenaceous shales.

SE of Sörfors the Ström quartzite nappe reappears but dips beneath the Oxfjäll nappe. At Lake L. Raijan there appears a window in the complex due to the occurrence of a granite wedge. The position of the granite indicates that it is the base of the Quartzite complex, but was torn away and thrust obliquely toward the SE, analogous with the granite wedge at Risbäck, though the granite there indicates that it once lay beneath the Sparagmite. The sketch, fig. 17, suggests a development of the situation.

The Sparagmite complex of Mt. Oxfjället is very thick. Besides the normal, even-grained, brownish to violet red sparagmite, there are layers of arenaceous and conglomeratic sparagmite and also of whitish, quartzite-like sparagmite

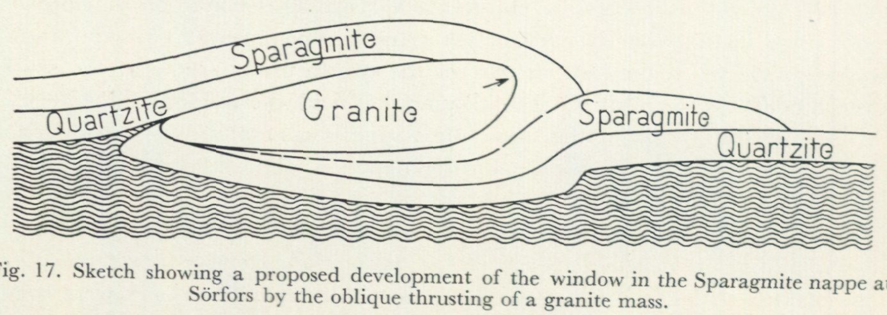


Fig. 17. Sketch showing a proposed development of the window in the Sparagmite nappe at Sörfors by the oblique thrusting of a granite mass.

and grayish ones. The relationship shows that these different layers are a development within the red sparagmite complex.

At Lake L. Dabbsjön the Ström quartzite appears again, probably due to an upward curving in front of the Seve nappe. The north-western part of this quartzite complex is tectonically disturbed by wedge-like units of sparagmite containing tillite, an overthrust wedge of quartzite and above this, granite again, followed by tillite-like sparagmite. Above the latter follows a quite schistose complex named the Mylonitic zone. The Seve nappe follows above this complex in the northern part of Lake St. Dabbsjön.

Section No. 4 shows, in its eastern part across Mt. Tåsjöberget, the Ström quartzite nappe with underlying complex of Cambro-Ordovician shales which, according to the investigation by Asklund and Thorslund, is composed of both autochthonous and allochthonous shales of at least the same thickness as the shale complex bored through at R. Ormbäcken. There the autochthonous shales are overlain by an overthrust shale complex, with predominant alum shale, 65 m thick.

The Quartzite nappe in the region of Kyrktåsjö is often fairly complete, *i.e.* besides the thick upper quartzite, the lower part of the nappe contains arkosic quartzite, arkose with fragmentary siltstone layers passing over into granitic arkose, which may have some granite in the base. The granite may also be completely separated from the Quartzite complex.

At the northern end of Lake Tåsjön there appears a new element below the Cambro-Ordovician shales. That is the basal quartzite sandstone which is probably autochthonous. Its petrographic character and mode of development is very like that of the Ström quartzite in the nappe. This basal quartzite thins out to the E, and it first appears at the easternmost part of the front range to the N of Lake Vojmsjön. The outcropping of this lower part of the autochthonous at northern Tåsjö is due partly to the dome-like upheaval of the basement and partly also to the presence of a huge sedimentation area of the "Eo-Cambrian". The conditions further to the SW show that the Archean basement itself has been forced upward, probably due to the advance and push of the great Seve nappe toward raised irregularities of the underlying complex. To the N the contact of the Quartzite series with the overlying shales is also disturbed. Several small thrusts have been observed.

Further toward the NW, in the region of Långmarksberg—Norrsjön, the Quartzite nappe again appears above the shales. Above the Quartzite comes the Oxfjäll nappe, the eastern margin of which shows some imbrications of quartzite and sparagmite. The Sparagmite complex to the NW is rather schistose. The pale sparagmites are rich in sericite and the dark red sparagmites pass over into greenish gray, schistose ones. The northwestern border toward the Seve nappe has not been much investigated.

In the eastern part of section No. 5 but little of the Ström quartzite nappe remains. Already in this section the autochthonous Quartzite of the northern part of L. Tåsjön shows a thrust over the shales to the SE. The Sparagmite on the other hand has glided above the Quartzite in Mt. Bodberget. The profile further passes the broadest part of the red sparagmite complex of great thickness. The contact between the sparagmite unit and its primary basement of granite shows a slight overthrust. The Oxfjäll nappe to the NW of the granite-gabbro area is strongly schistose at its base. Tillite was observed in several places. The Quartzite at the base of the Sparagmite nappe is squeezed out in this section. All the complexes between the Seve nappe and the Archean mass in this region are strongly pressed, foliated, or mylonitized. The rocks immediately below the Seve nappe are alternating slices of Archean rocks, sparagmites, and sometimes quartzites. This appearance has been observed particularly between the two lakes St. Sjougden and Nåsjön. The tiles may correspond to those masses which have been observed in the region between the lakes Saxvattnet and Mesjön to the N. The schistose rocks on the SE side of L. St. Sjougden have all been included in the mylonitic zone beneath the Seve nappe.

Section No. 6 passes through the flat Ström quartzite nappe of the Alanäs region. At the bottom of the nappe, allochthonous granite has been observed in several places. Sometimes there is a granitic arkose in the bottom of the nappe and sometimes only quartzite. Granite has also been observed, broken away from the quartzite with some shale between. The bottom arkose of the nappe is sometimes rather dark.

The Quartzite nappe has a large extension between the lakes Flåsjön and Strömsvattudal, but it is rather thin and there are several windows showing the underlying alum shale or limestone. At two places, due to thrusting, imbrication of the underlying Ordovician limestone are visible. At Havsnäs (Kalkberget) the thickness of the limestone is considerable.

Passing the gentle shale anticline to the NW one arrives at the para-autochthonous quartzite SW of L. Harrsjön where there is a series of imbrications in the front of the Svaningen Archean complex, which are simplified in the drawing. It is to be noticed that the thick sparagmite to the N has already dwindled out. The quartzite of this area originally lay directly on the granite, as has earlier been described in the case of the quartzite of Storån.

At Lake Yttre Långvattnet quartzite has been observed above the granite-gabbro complex at the margin of the Mylonite zone which is here composed of several different rocks. To the N of L. Klumpvattnet a Klippe of quartzite has been observed above the granite. There are several small thrust planes dissecting both the granite and the quartzite. At the NW end of L. Y. Långvattnet comes the Seve nappe.

Section No. 7 passes in the E through a fairly continuous Ström quartzite nappe. It passes the para-autochthonous complex at Mt. Strömberget where quartzite is thrust over graywacke shale, but higher up toward the front of the granite complex quartzite-conglomerate or arkose comes next to the granite. It is not possible to say whether this is to be regarded as a continuous inverted series of quartzite, or several tiles of the Quartzite complex, but the later relationship seems more probable.

The Mylonite zone and the Seve nappe of Mt. Stormyrhöjden—Knäppen has not been investigated in this section.

In section No. 8 the Ström quartzite nappe of Västerkälen, Lilla Allvattnet, Dragan, Hillsand thins out in several places. Its basal part is either arkosic or quartzitic above the shale basement. At the lake L. Allvattnet it is possible to see imbrications of the nappe with wedges of limestone sqeezed into the Quartzite complex.

To the NW of the shale-window lies the overthrust para-autochthonous quartzite S of Linjeviken. The overthrust sparagmite is thick and imbricated. Tillite has also been observed. In the NW part of the sparagmite follows an overthrust granite but in its base a mylonitic quartzite occurs in places which indicates that part of a para-autochthonous quartzite has been hauled along in the thrusting of the Svaningen complex. This quartzite also reappears in a window in the Archean nappe at Lake Hemvattnet. The Archean complex consists to a great extent of Revsund granite. To the S of L. St. Ringsjön leptitic rocks have also been observed and further to the N gabbroic rocks are represented.

The degree of foliation or mylonitization increases toward the NW and several overthrusts occur. It is thus a matter of personal judgement where the eastern limit of the Mylonite zone to the S of the region between Torsfjärden and Bågede should be drawn. In the Bågede-Sjulsåsen area there are several tiles of schistose Archean rocks, mostly gabbroic in composition. Micaceous schists appear near Sjulsåsen. The lowermost part of the Seve nappe consists of micaschists and amphibolites.

In section No. 9 the para-autochthonous quartzite near R. Renån shows an imbrication in its lower part with intercalations of the underlying shales. The Sparagmite complex to the W is both folded and imbricated. The E—W sections sketched of the para-autochthonous quartzite-sparagmite-granite complexes from Mt. Ögelhättan in the N to Mt. Hiberget in the S are drawn

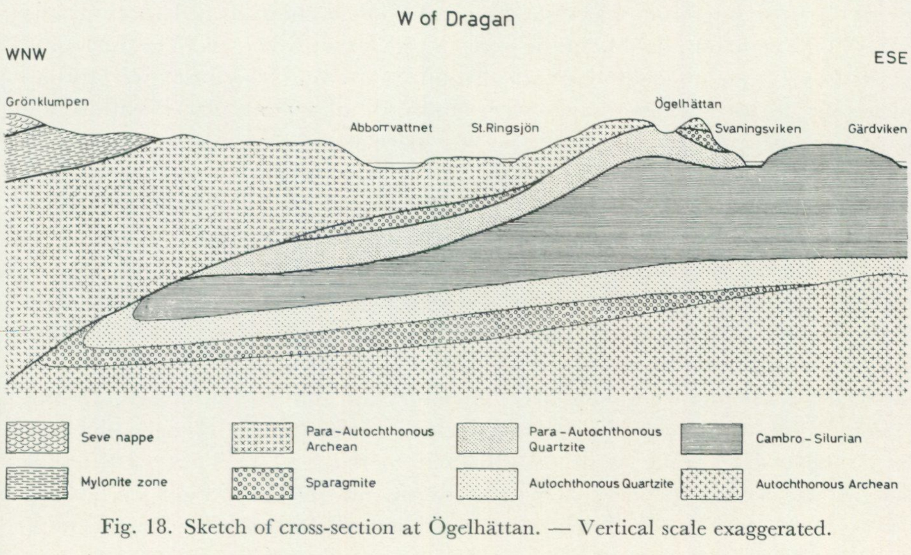


Fig. 18. Sketch of cross-section at Ögelhättan. — Vertical scale exaggerated.

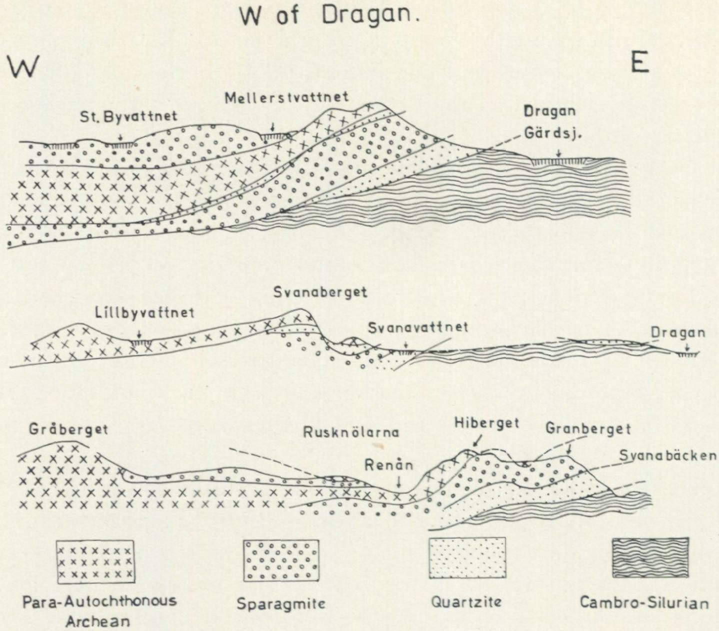


Fig. 19. Sections to the West of Ströms vattudal. — Vertical scale exaggerated.

in order to give an impression of the nature of the overthrusts and local foldings in the imbricated zone, figs. 18 and 19.

Above the Svaningen complex in the St. Byvattnet region there occurs a sparagmite which may be para-autochthonous as the contact with the granite is disturbed. There are also tillite-like conglomerates above the sparagmite and to the W gray sparagmitic shales predominate. These show disturbances in the NW. The extent of the Mylonitic zone is not exactly known. The mylonitic schists have been divided schematically into two zones, because two distinct micaceous thrust surfaces have been observed in several places within the Mylonite zone, one beneath the undermost part of the Seve nappe proper and one almost as evident beneath the upper one, but separated from it by a complex of to some extent well-preserved rocks, at least partly of Archean origin. It is thus a kind of imbrication of the undermost part of the great nappe.

Section No. 10 passes through the southernmost part of the Ström quartzite nappe. To the NW, in the region between the lakes Finnvattnet and Klumpvattnet, no outcrops of para-autochthonous Quartzite have been found. But it is probable that a narrow strip of it occurs. There is a large expanse of overthrust sparagmite between Mt. Öjarsklumpen and L. Lillfulvarn. In this section it is drawn as overriding the eastern granite, because it has been observed thrust above the granite at its eastern limit to the S of L. Y. Renåflyn. But there is also a granite thrust above the sparagmite on Mts. Finnsjöhöjderna. The tectonics of this region are rather complicated. Between the Lakes Djupsjön and Klingervattnet to the N there occur local tillite-like imbrications which vary greatly from one place to another. The tectonic condition of this area can only be determined after very detailed mapping.

At L. Lillfulvarn the granite basement is elevated, but further westward a granite overthrust, probably of great magnitude, appears. The Archean region to the SW shows much foliation and mylonitization, indicating imbrications of thrusts. The Mylonitic zone in the northwestern part of the profile has not been investigated. The limits of the zones are thus tentative.

Section No. 11 passes through the Cambro-Ordovician of the region between Hallviken and Henningskälen. The shales show local overthrusts even in their easternmost part. There are probably several para-autochthonous to allochthonous thrusts, though the overthrust surfaces are hard to find. It is thus mainly by means of stratigraphic-paleontologic investigations of the shales and limestones, such as those made by P. Thorslund in Central Jämtland, that the thrust lines within the sedimentary complexes may be ascertained.

At Henningskälen there remains a Klippe of Ström quartzite. The limestone at the base shows several imbrications.

The extension of the para-autochthonous Quartzite around Storån, NW of Henningskälen, is not definitely known. Here and there granite, or granite tiles, which have glided over from the Mt. Stakafjäll area appear. Below the overthrust granite of Mt. Skalfjället there appears a rim of sparagmite that may indicate a connection between the "para-autochthonous" sparagmites of L. Sjättvattnet in the NE and the "para-autochthonous" ones of Mt. Erfjället in the SW.

In section No. 12 an isolated Quartzite occurs in the Laxsjö region. It is both underlain and overlain or overfolded by limestone and shale. This quartzite seems to be a thrust and overfolded continuation of the Ström quartzite of L. Hökvattnet and the southern part of Mt. Tjänafjället. In both these places it is possible to see the connection between the folded Quartzites, which in their northwestern parts have been traversed by the granite complex. To the W quartzite is visible again in a window in the the overthrust granite. The bottom surfaces of both granite and quartzite show corrugated folding-thrusting. At Laxsjö, however, the overfolding of the shale complex is noticeable.

Besides granite the Archean mass to the N has many mylonitic rocks. Some of the porphyritic rocks are true porphyries, but most of them are certainly mylonitized porphyritic granites.

To the W of Mt. Erfjället and N and S of L. St. Foskvattnet a Sparagmite complex lies above the granite. It is strongly schistose and partly consists of sparagmitic shales. The sparagmite may be hard to recognize. It is either para-autochthonous or allochthonous. Little is known about the Archean rocks to the NW.

The Seve nappe has been thrust over Cambro-Ordovician shales which are now often slate-like or schistose. The whitish gray quartzite within the phyllitic complex beneath the Seve nappe probably corresponds to Ström quartzite formation, though it is completely recrystallized. These rocks beneath the Seve nappe have been dragged or moved below the great nappe and are considered to be a part of the Mylonitic zone.

The rocks within the Seve nappe are for the most part slightly micaceous phyllites with subordinate intercalations of amphibolites. Part of the phyllites is calcareous, and part arenaceous.

Section No. 13 passes through Cambro-Silurian rocks. It meets the narrow zone of para-autochthonous Quartzite NE of Ålviken. This band of quartzite turns aside at Lake Hotagen following the lake. It is encountered at three places along the side of L. Hotagen below overthrust granite. It is met with again further to the NW at Rötviken, and it then follows a more westerly direction, later deviating to the WNW.

Above the overlying granite at Lake Hotagen quite foliated sparagmite-like rocks occur on the northeastern side of L. Hotagen. In the northern and northwestern parts of L. Hotagen similar rocks also occur. These rocks are reminiscent of the foliated sparagmites of Mt. Erfjället region as well as those of the lower part of the Offerdal nappe. Their position as flat remnants above the granites or mylonites at the border of the Offerdal nappe indicates that they are probably outliers of that nappe. They are schistose and mylonitic, often looking like stripe-like schists with lenses of sandstone or feldspar-quartzite between. They occur at several places in the north-eastern part of Lake Hotagen, at Hotagen church and W of Rötviken. Here they are underlain by granite, Föllinge-Holmsjö shales, and quartzite.

The rocks overlying the granite on the NE and N side of Lake Hotagen show that the granite dips toward the SW and S indicating a flexure which may have caused the origin of the waterway. This subsidence of the basement at the edge of the Offerdal nappe has probably been caused by the pressure of that nappe.

The quartzite unit running WNW of Rötviken has an outlier on the southern side of Lake Bergsjön. This quartzite occurs around a dome of granite, but at the same time it seems to be thrust over the Föllinge-Holmsjö shales. It is thus probable that this complex may be allochthonous.

The granite mass of Botelnäset consists, in its southwestern part, of porphyritic granite, but its northeastern part is relatively mylonitic. It is run through by thrust horizons. The southwestern part runs toward the NW to the S of Rötviken and westward to L. Rörvattnet.

The region between church of Hotagen and the southern end of Lake Valsjön consists to a great extent of granite-mylonites, but the high parts of the region are less metamorphic. A thrust surface occurs at the southern end of Lake Valsjön and it may correspond to the foliated mylonites in the lower part of the River Hasslingsån. The region close to the Seve nappe at the northern limit of L. Valsjön consists of remnants of often well preserved Archean rocks between mylonitic and foliated rocks. Detailed mapping would be necessary to distinguish the units. The double Mylonitic zone is thus only a temporary solution.

The rocks in the Seve nappe to the NW of the white quartzite consist of micaceous phyllites, amphibolites, dark schists, green-schists, quartzites, calcareous phyllites, garnet-bearing phyllites, calcareous sericite-phyllites, etc.

The Offerdal nappe

The Offerdal nappe was described by A. G. Högbom, and by Törnebohm in 1896 (Ansätten nappe). Asklund (1951) refers to the nappe by the name "Offerdal".

It is an upper nappe which in its higher part carries some Cambro-Silurian of "westerly" or "Köli" facies with transitions into micaschists just as in the Seve nappe. At its northeastern border the sparagmite- or sandstone-like lower part is underlain by a granite mylonite zone. This is most probably a complex which has been dragged along underneath the nappe.

The thick complex of sandstone and interstratified shale above the granite mylonite is now more or less metamorphic. They are foliated and more or less granulated. They contain a high content of microcline, and slightly metamorphosed relicts show arkosic rocks with large microclines. They are very much like the schistose complex of the western part of the Erfjället Sparagmite, consisting of sparagmites and shales. The undermost thrust surface of the Offerdal nappe is micaceous or micaschist-like. In the upper part of the complex a strongly micaceous thrust surface has also been observed. The complex above this thrust to a great extent consists of phyllites such as dark phyllites, quartz-phyllites, calcareous phyllites, sericite-phyllites, etc. In some areas amphibolites, micaschists, and quartzites also occur. The highest complex in the Ansätten mountain consists predominantly of phyllites with subordinate garbenschiefer, amphibolite, and quartzite.

An outlier or Klippe of the Offerdal nappe on Mt. Tuttaberg shows a quartzite complex below sparagmitic rocks. It may correspond to the Ström quartzite formation.

It may be convenient to divide the Offerdal nappe into two complexes, a lower Offerdal nappe proper and a higher Ansätten nappe, according to Törnebohm, though he used the name Ansätten for both complexes. The extent of the higher rock complex is somewhat greater in the northern part than was indicated in the Törnebohm map. It seems as if both complexes moved about the same time from the W to the E.

The author has sketched two sections from the northern part of the Offerdal nappe showing the distribution of the rock complexes. Fig. 20 (upper section) shows an imbrication or overfolding of the lower Offerdal nappe with a wedge of red, porphyritic granite between. The upper Offerdal nappe or the Ansätten nappe shows, at least in some places, a foliate micaschist surface underneath, though the contact to the lower nappe is generally not visible. Fig. 20, lower section shows that the quartzite below the overthrust granite of the Svaningen complex on the northeastern shore of Lake Hotagen is thrust into the underlying shale complex on the southwestern shore of L. Hotagen. The uppermost

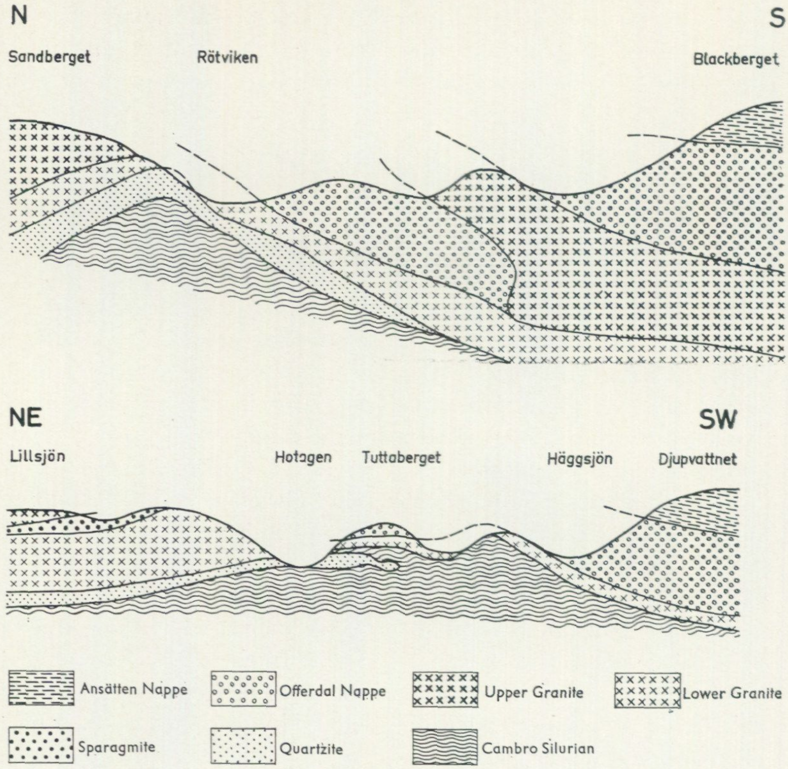


Fig. 20. Sections across the northern border of the Offerdal nappe. — Vertical scale exaggerated.

Tuttaberg unit is a Klippe of the Offerdal nappe above the mylonitic granite which occurs above Cambro-Ordovician rocks of the Föllinge-Holmsjö facies.

The basal part of the eastern border of the Offerdal nappe, from Lake Häggsjön toward the S, becomes more and more mylonitic and consequently the granite-mylonite may be difficult to distinguish from the mylonitic sparagmite which is often banded or sericitized (cf. fig. 21). It seems as if the granite-mylonite dwindles out before reaching the eastern end of L. Landsjön, but it is visible in places to the S.

The Offerdal conglomerate in the southern part of the nappe is very polymict and varies much from one place to another. Sometimes granitic pebbles dominate, sometimes sparagmitic or quartzitic ones, and sometimes dense porphyries. The conglomerate is reminiscent of the sparagmite-tillite conglomerates but it is generally paler in colour. The sparagmite pebbles, too, are generally of the pale type. In places the conglomerate passes over into arkose or sandstone of a sparagmitic type. The conglomerate lies at the very bottom of the nappe and its lower part is generally quite schistose. It is overlain by a foliated, mylonitic sparagmite-like schist. As the conglomerate conforms with the Offerdal nappe, and appears at the base of the nappe in several places, it must be

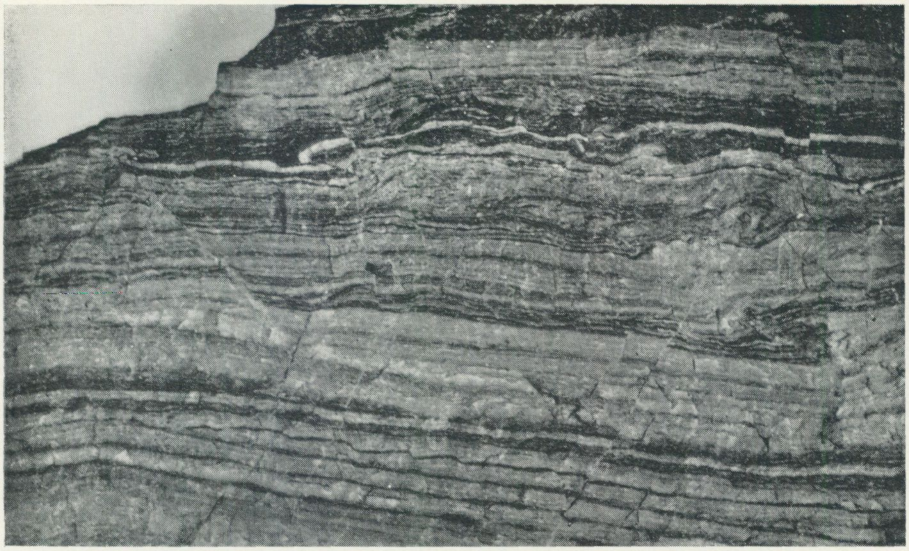


Photo C. Burlin

Fig. 21. Banded, granulated sparagmitic quartzite. Skärvången. About 3/4 nat. size.

either a part of the nappe or a complex which has been dragged along at the base of it like the granite mylonite.

The Rönnefors conglomerate at the western border of the Offerdal nappe, which is reminiscent of one type of the Offerdal conglomerate, is strongly folded syntectonically with the basement shale and quartzite. It is thus tectonically separated from the Offerdal nappe.

Conclusions

A simplified picture of the tectonic units or complexes, which have been described above, is given in fig. 22.

The Quartzite and Sparagmite nappes, as well as the Archean which have been carried along, have been designated as the "Eo-Cambrian" unit **C**.

The highest nappes, *i.e.* the great Seve nappe and the Offerdal nappe, with its upper unit, the Ansätten nappe, have been designated with the letters **I** and **K**.

The Cambro-Ordovician (or Cambro-Silurian) shales have been divided into two units: **A** designates the shale border to the **E** of or below the Ström quartzite nappe. It indicates a chiefly autochthonous shale complex (with interstratified limestone) which lies on the Archean basement and para-autochthonous parts of this complex which have been somewhat pushed. **B** designates the interior and southern parts of the shale complexes. It consists of both allochthonous and para-autochthonous parts. The western part of it consists chiefly of Ordovician rocks of graywacke-shales intermingled with layers of argillites and calcareous sandstones (Föllinge-Holmsjö facies).

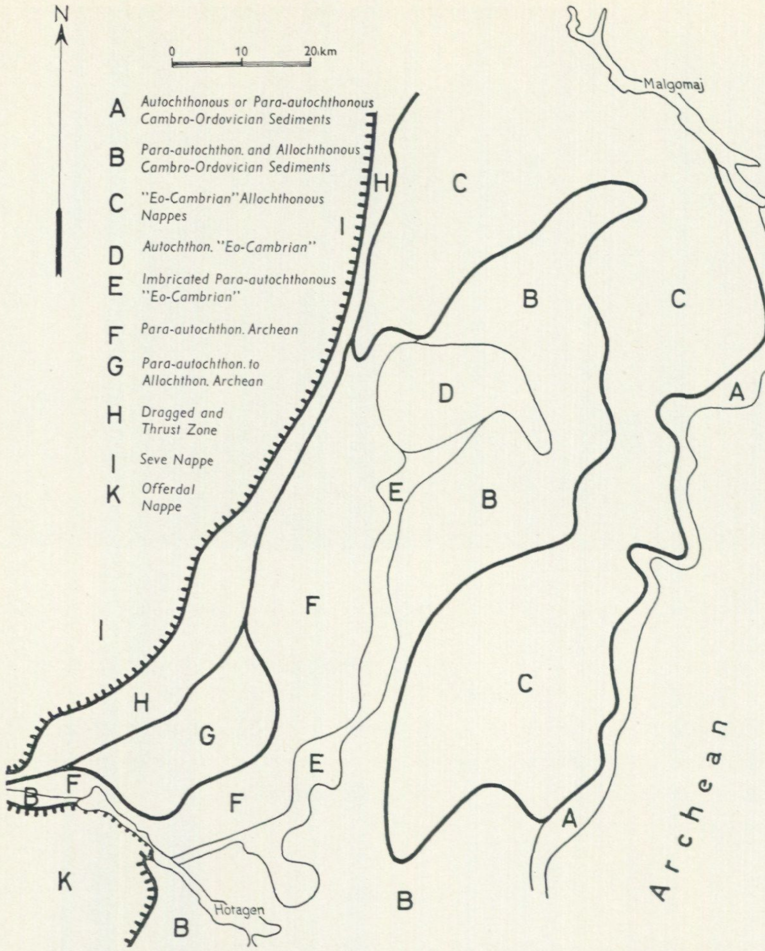


Fig. 22. Tectonic units of the Caledonian border of northern Central Sweden.

F designates the great Archean window within the Caledonian border, which was thrust more or less upward toward the SE owing to the pressure exerted by the late Caledonian movements and the large thrusts.

G designates a stronger thrust part of the same Archean window or anticline.

E designates the "Eo-Cambrian" sandstones with interstratified shales, *i.e.* the Sparagmites and Ström quartzites which originally lay on the Archean basement but have been pushed from the original position by the thrusting of the "granite" mass. Imbricated and other thrusts have resulted from these movements and some of the complexes have been inverted. The Sparagmite complex has generally been thrust above the Quartzite series. Another variation in the appearance of the rock complexes is caused by the fact that the original sedimentation of the sparagmite is highly localized. In some places, especially within the eastern border, it has not been deposited at all; instead the Ström quartzite series has been laid down directly on the Archean basement.

D is a relatively unmoved part of the "Eo-Cambrian", and it has been classified as autochthonous. Minor displacements have, however, occurred here, too.

The complex **H** is a pushed zone beneath the great Seve nappe. It consists of different rocks which have been pushed and thrust longer or shorter distances, more or less passively, below or in front of the large nappe. This zone is very heterogenous and its composition varies greatly from one region to another. It may thus be wide or narrow and consist of few or many rock units, the one above the other. Some parts of it may thus be conceived as belonging to the Seve nappe by one geologist or to the displaced basement by another.

G occupies an intermediate position. It could have been referred to the **F** unit or even to the **H** complex. Distinct thrusts have also been observed in the **F** mass but they are hard to follow up. Within the southern part of the main map two separate units of the **H** complex have been schematically indicated in order to show that these complexes may be divided into different units. The author has not had any opportunity to continue the investigation of this part of the region.

In order to give a conception of the evolution of the overthrusting five sketches are given in fig. 23, A—E, A representing a relatively quiet stage in the foreland, E being the final complex situation. It has been assumed in section A that the "Eo-Cambrian" and Cambro-Ordovician sediments were deposited on a flat foreland of the Caledonian with a large distribution of the Quartz-sandstone series (the Ström quartzites). The Sparagmite formation is assumed to have been the lowest sandstone formation, which formed in local depressions in the foreland but laid down more extensively further toward the Caledonian geosyncline. The two sandstone series are covered by Cambrian and higher shaly complexes.

In the late Caledonian movements, the overthrusts, the author has assumed that the sandstone complexes with superincumbent shales were thrust, in at least two different places, before or in front of the Seve nappe. The Middle Cambrian to Upper Cambrian black shale or alum shale were convenient layers to glide upon. The large Seve nappe was later overthrust behind and above the Quartzite- and Sparagmite nappes. Owing to its weight, and the violence of the thrust, the Seve nappe disrupted the pre-Cambrian basement. Due to irregularities in the Archean basement, or in the sedimentary basins above it, some parts of the pre-Cambrian were pushed beneath the great nappe.

The two thrusts, shown schematically through the "Eo-Cambrian" in section B, resulted in the flat lying nappes of section C. The western overthrust could just as well have been drawn as a recumbent fold with a following overthrust. This may have pushed the eastern nappe forward. The eastern nappe, the Ström quartzite nappe, has proved to be in a normal position, but it is often multipled by imbrication. The western overthrust produced the Oxfjäll or Sparagmite nappe. This nappe is complex.

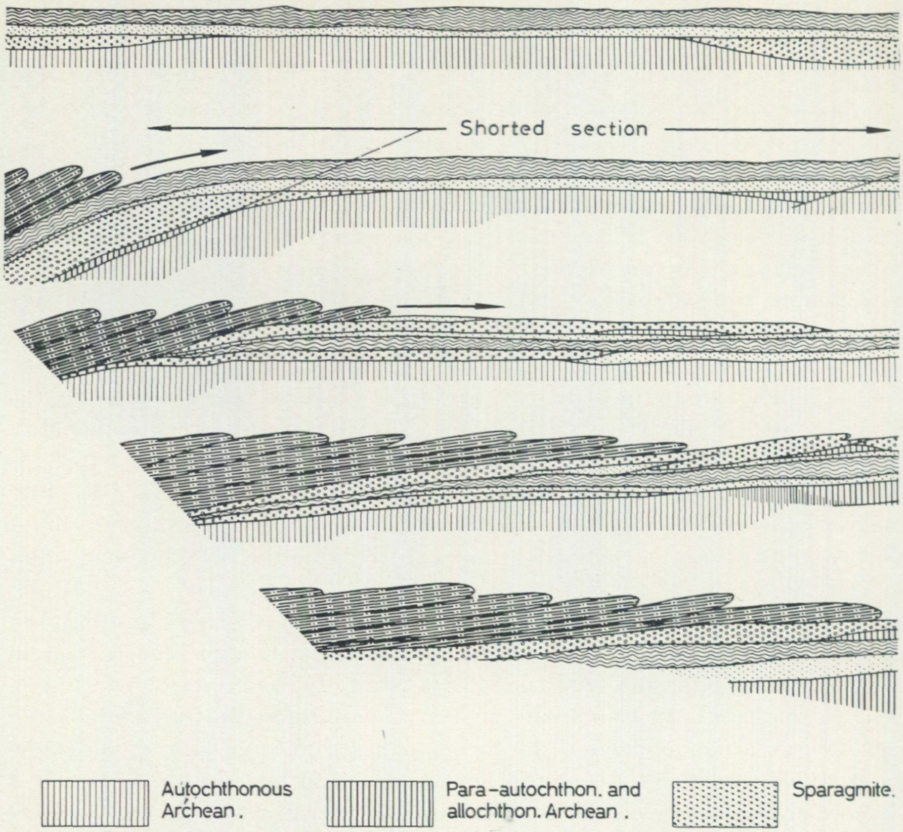


Fig. 23. Five sketches showing the development of the thrust complexes within a central cut through the mapped region.

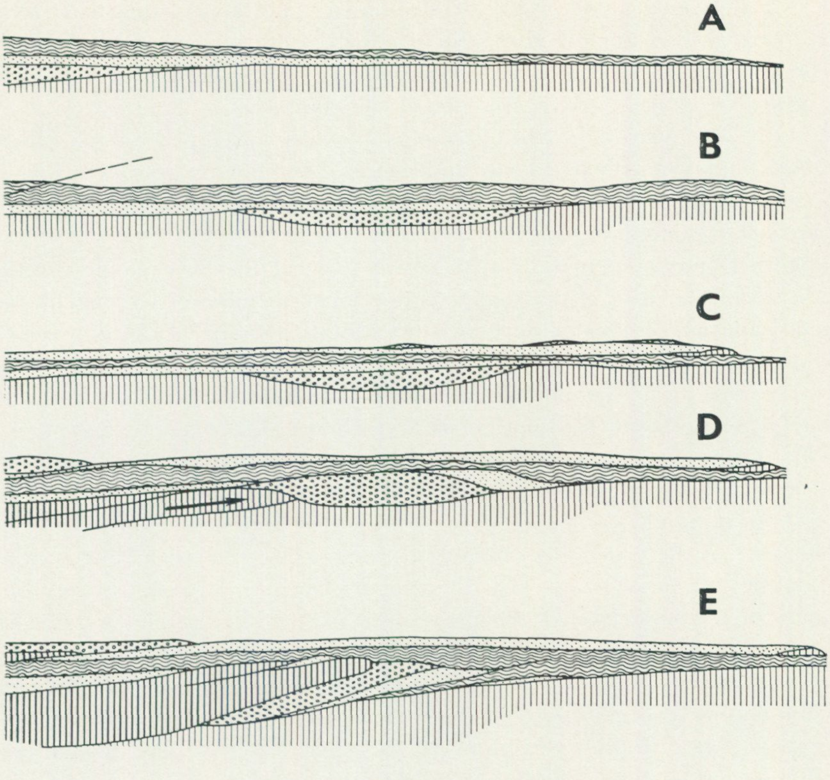
The Oxfjäll nappe shows that the sparagmite sediments may be assumed to have been more extensive in westerly regions than in the foreland. It is often hard to see, within the Oxfjäll nappe, which part is inverted and which part is unturned. In the western part of it conditions are complicated by the thrusting of the Seve nappe. The original position of the quartzites appearing there is not really ascertainable.

Section D shows the forward thrusting of the Seve nappe. Its structure is drawn to be complex. The thrusting caused displacement in the basement.

Lastly section E reproduces a late stage of development in the thrusts, the forward thrusting of the granite anticline.

These sketches only show the development within the central part of the region.

In the S, the development was not quite the same in the formation of the Offerdal overthrust. The Offerdal nappe is supposed to be a broken-off continuation of the Seve nappe in the N. The Offerdal nappe chiefly consists of two parts, of which the upper one, the Ansätten nappe, corresponds strati-



graphically to the Seve nappe, as it is composed of more or less altered Cambro-Silurian rocks of westerly facies, though without the highest metamorphic development. The lower part, the Offerdal nappe proper, is composed of strongly schistose or granulated, partly recrystallized "Eo-Cambrian". It was already recognized by Törnebohm being chiefly of sparagmitic origin. Petrographically this complex is predominately composed of microcline-quartzite and schist, its composition corresponding fairly closely to the Sparagmite formation. Due to a strong metamorphism it is partially recrystallized. It is often discoloured and may not be easily recognized as a sparagmite by its colour. Pure quartzite, which may correspond to the Ström quartzite, is rather unusual within this region.

Part of the granite or granite-mylonite complex which underlies the Offerdal nappe in the N was pulled along as a basal mylonite within the eastern part of the Offerdal nappe but dwindles away toward the S.

Within the Åre nappe, the nappe southwest of the Offerdal nappe, there are also feldspar-bearing quartzites in the basal part, which may correspond to the Sparagmite series. There is also a rim of Archean rocks in the lowest part of it, on the western side of R. Järpströmmen. The banded quartzite gneisses with interstratified amphibolites which follow higher up are, however, harder to correlate stratigraphically. The occurrence of typical peridotite lenses points to a lower Ordovician age in one part of the complex.

A study of the stratigraphic development of the lower part of the Offerdal and Åre nappes makes it easy to understand Törnebohm's interpretation that the Seve rocks, *i.e.* the lower, metamorphic part of the Seve nappe, are metamorphic sparagmite or "Eo-Cambrian".

This rock development fails in the lower part of the Seve nappe proper in the N. The lower part of that nappe is developed as more or less metamorphic Cambro-Silurian sediments, and volcanics. "Eo-Cambrian" rock complexes are only to be found in the lower nappes. The metamorphic zone with garnet-mica-gneisses, garnet amphibolites, injection gneisses and migmatites, which occur higher up in the Seve nappe and which the author has described earlier (1938) on the basis of two sections through the Seve nappe in northern Jämtland and in Västerbotten, seem to correspond to the high metamorphic complex of Åreskutan.[1]

Our part of the Caledonian mountain range is not rectilinear but somewhat undulating, almost zig-zag. This is evidently due to different degrees of resistance in the basement of the great overthrusts. It is visible or not visible anticlines and intermediate depressions chiefly in the Archean basement which have more or less impeded the movement of the overthrusts as can be seen in the undulating configuration of the Caledonian of Northern Jämtland and Lappland. The different directions of the overthrusts caused the nappes to break in places, dividing the nappes in different units.

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[1] The nappe to the W of the Åre nappe (W of the Mt. Mullfjäll anticline) has a stratigraphic-tectonic development other than that of the Åre nappe. In this section it is rather low metamorphic, consisting of westerly Cambro-Silurian rocks, but they partly appear in the garbenschiefer facies.

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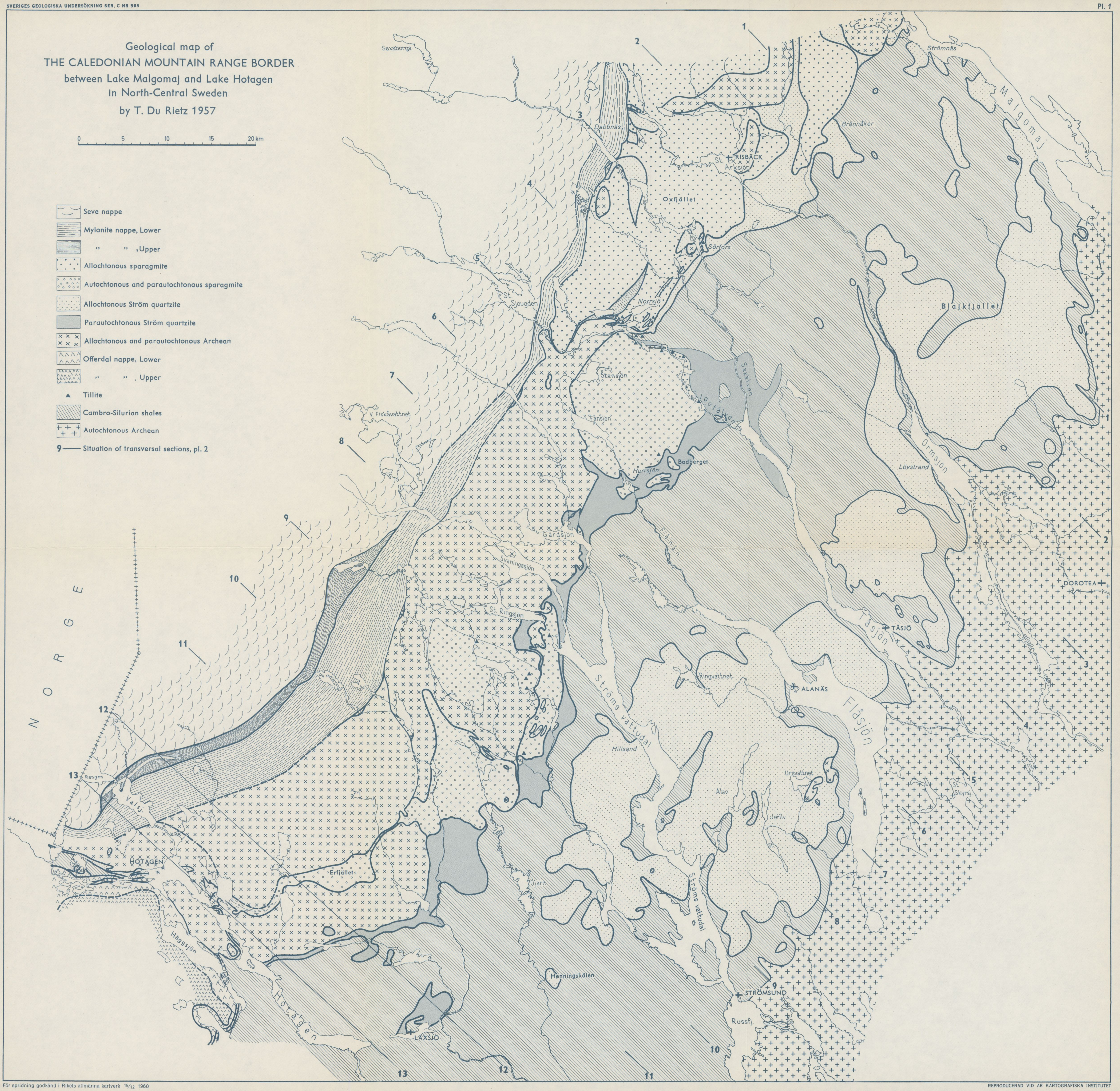
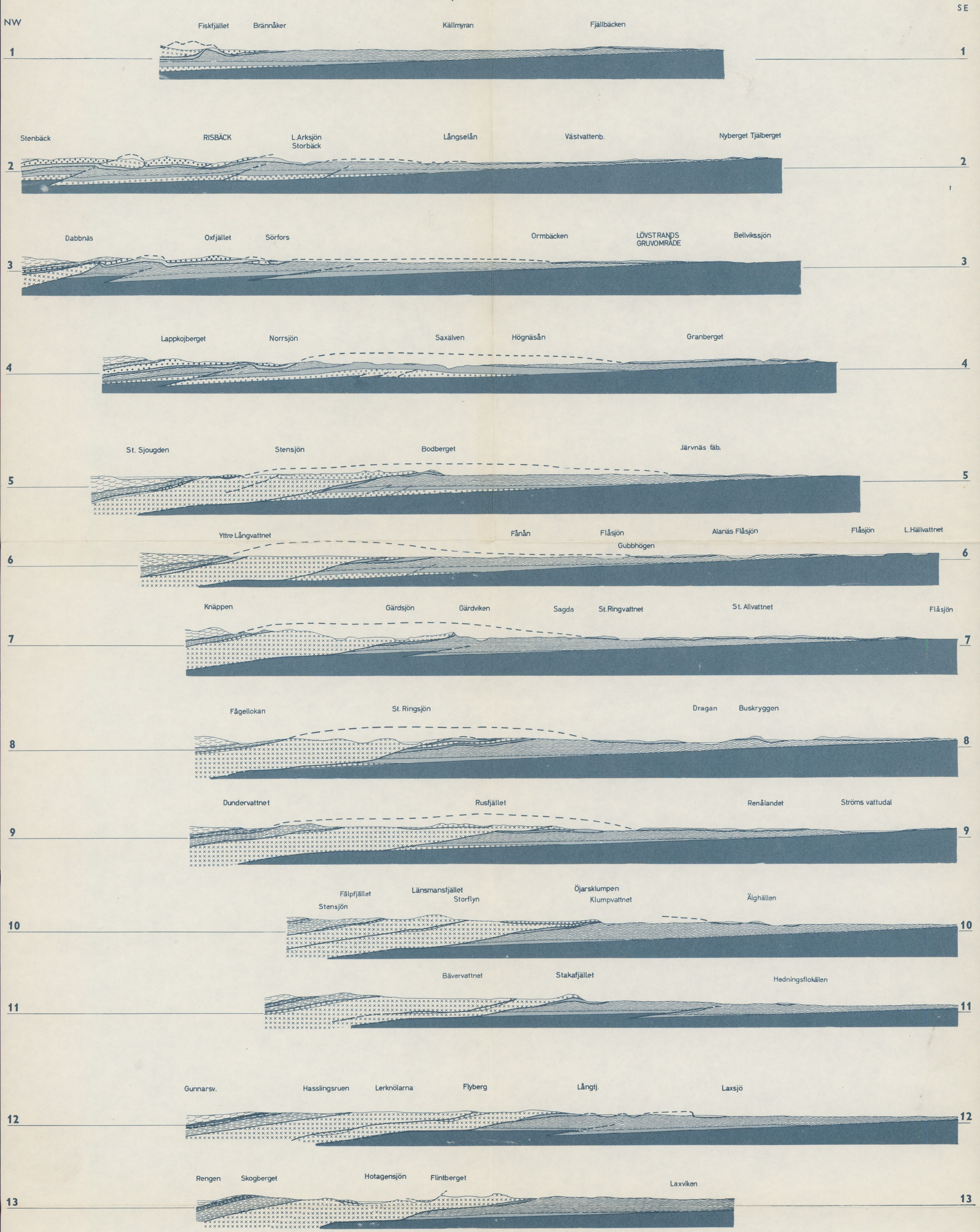
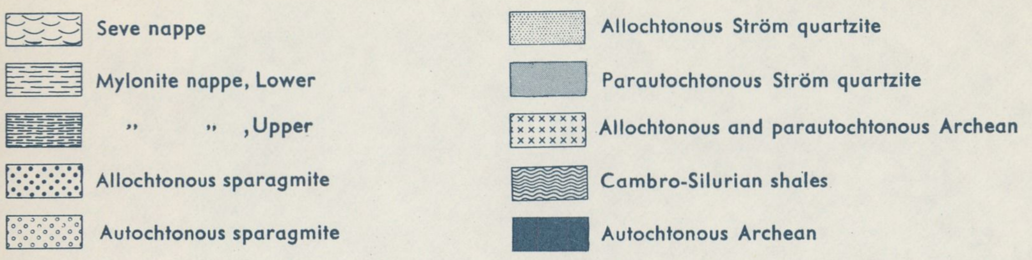
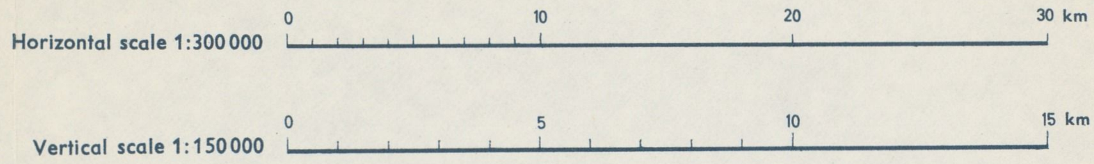

Geological map of
THE CALEDONIAN MOUNTAIN RANGE BORDER
between Lake Malgomaj and Lake Hotagen
in North-Central Sweden
by T. Du Rietz 1957
0 5 10 15 20 km
Seve nappe
Mylonite nappe, Lower
" " , Upper
Allochtonous sparagmite
Autochtonous and parautochtonous sparagmite
Allochtonous Ström quartzite
Parautochtonous Ström quartzite
Allochtonous and parautochtonous Archean
Offerdal nappe, Lower
" " , Upper
Tillite
Cambro-Silurian shales
Autochtonous Archean
9 Situation of transversal sections, pl. 2
NORGE
Saxaborga
Dabbnäs
Strömnäs
Brännåker
Malgomaj
RISBÄCK
Arksjön
Oxfjället
Sörfors
Blajkfjället
St. Sjougden
Norrsjö
Stensjön
Fänsjön
Saxälven
Joutalven
Harrsjön
Bodberget
V. Fiskåvattnet
Ormsjön
Lövstrand
Gärdsjön
Svaningssjön
St. Ringsjön
DOROTEA
TÅSJÖ
Tåsjön
Ringvattnet
ALANÄS
Ströms vattudal
Flåsjön
Hillsand
Ursvattnet
Alav.
Jorliv.
Rengen
Valsjö
HOTAGEN
Erfjället
Häggsjön
Hotagen
Henningskälen
STRÖMSUND
Russfj.
LAXSJÖ
1
2
3
4
5
6
7
8
9
10
11
12
13

TRANSVERSAL SECTIONS THROUGH THE CALEDONIAN MOUNTAIN RANGE BORDER
between Lake Malgomaj (North) and Lake Hotagen (South).

by T. Du Rietz 1956







REPRODUCERAD VID AB KARTOGRAFISKA INSTITUTET

SECTION THROUGH THE LÖVSTRAND REGION. Southern Lappland, Sweden

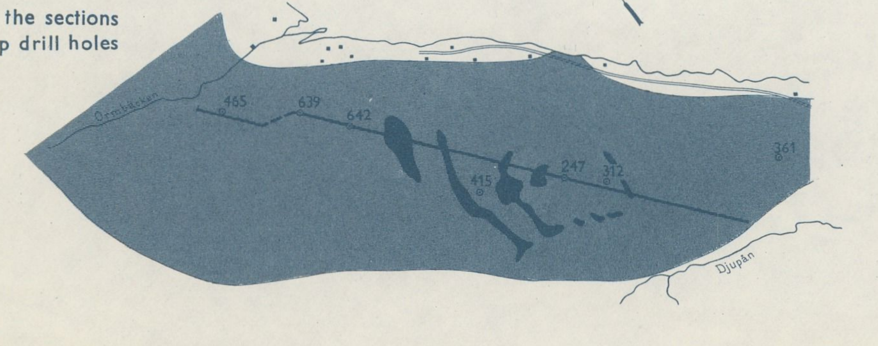
Surveyed in 1956 by T. Du Rietz

Horizontal scale 1:12000
0 200 400 600 m

Vertical scale 1:2400
0 20 40 60 80 100 m

- Shales (incl. limestone)
- Tectonized shales
- Alum shales
- Ström quartzite
- Arkose in Ström quartzite
- Lowermost shale with conglomerates
- Archean schists
- Granite
- Drill hole

Situation of the sections and deep drill holes



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SECTION THROUGH THE MIDDLE PART OF THE LÖVSTRAND REGION

Detail of Section Plate 3

Surveyed in 1956 by T. Du Rietz

Vertical and horizontal scale 1: 2400

0 20 40 60 80 100 m

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Ser. Ca.

N:o 38 LUNDQVIST, J., Beskrivning till jordartskarta över Värmlands län. (Quaternary deposits of the county of Värmland.) Karta i skala 1:200000. 1958.
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Karta i två blad (Map in two sheets) 30,00

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Meddelanden i stencil.

N:o 4 STÅLHÖS, G., Bidrag till kännedomen om den radioaktiva strålningens fördelning inom den svenska berggrunden. Summary: Contribution to the knowledge of the distribution of the radioactivity in the bedrock of Sweden. 3,00

21. International Geological Congress Excursions in Sweden.

Excursion nr	Guide-book	Price	Excursion nr	Guide-book	Price
C 15	a	5.00	A25-C20	g	6.00
A 20	b	6.00	A26-C21	h	6.00
A21-C16	c	2.00	A27 C22	i	5.00
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