

INTERNATIONAL GEOLOGICAL CONGRESS
XXI SESSION NORDEN 1960

**STUDIES IN THE THRUST REGION OF THE
SOUTHERN PART OF THE SWEDISH
MOUNTAIN CHAIN**

GUIDE TO THE EXCURSIONS NOS A 24 AND C 19

By

BROR ASKLUND



The Swedish geological guide-books

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Excursion no A24: August 2nd—August 10th

Excursion no C19: August 26th—September 3rd

Leader: Professor B. Asklund

Assistants: Dr P. Padget (C19) and

Fil. lic. G. Stålhös (A24). Sveriges geologiska undersökning, Stockholm 50.

Introductory remarks

The excursions A24 and C19 are intended to give a comprehensive review of the thrust regions in their fullest development in a part of the Caledonian Mountain Chain where thrusting was first recognized. Since the time when A. E. Törnebohm established the nature of the great thrust crystalline nappe (1888) — the Seve nappe — and A. G. Högbom on his geological map of Jemtland County (1894) demonstrated the wide extent of this huge nappe, a new aspect of the tectonics of the region has been advanced. This is the discovery that also the wide Cambro-Silurian area of Jemtland, which was previously considered to be autochthonous, is in fact made up of a series allochthonous nappes (Ask-lund and Thorslund 1933—1940). The autochthonous unit to the East of these is only a narrow strip along the boundary with the Archean complex — comprising the Baltic shield.

When Högbom in his guide to the excursion in these highland areas, written for the International Geological Congress in Sweden 1910, (Studies in the post-Silurian thrust Region of Jemtland, p. 53) says: "The geologist who sees the overthrusts of Jemtland for the first time, probably feels doubtful as to the truth of the interpretation to which Törnebohm and the other Swedish geologists have been compelled *par la force des choses*", we are now able to add a lot of convincing examples from the Cambro-Silurian area. When, for instance, a lower nappe, comprising the whole general Cambro-Silurian complex from the Cambrian alum-schist to the very characteristic Silurian *Pentamerus* limestone, is overlain by a flat lying higher situated sheet of rocks with a slice of the mylonitised Archean basement, granite, at its base, and, upon that the sequence of the Cambro-Silurian strata from the Cambrian to a new layer of *Pentamerus* limestone is found, we must be convinced that something has happened. Only the thrust theory is able to explain such a piling up of blocks. The problem is now not if the thrust theory is the truthful theoretical basis for the progress of research, that is now a fact.

In order to get a comprehension of the tectonics of the whole Mountain Chain it is best to start on its eastern side. At Brunflo to the South-east of Östersund, the only town in the Country of Jemtland, there is a good opportunity of studying the autochthonous Cambro-Silurian from the fossil-bearing Lower Cambrian to the Middle Ordovician, represented by the *Orthoceras* limestone of the many limestone-quarries. To the south the sub-Cambrian peneplane, with its outcrops of pre-Cambrian crystalline rocks is exposed and also the elevated Highland of the central Archean "torso", described in the introductory chapter of this guide-book.

After studying the many small traces of the western tectonic elements in the autochthonous beds — small thrust or series of such — the beginning of the great thrust will be seen in the "Lockne field" to the west of Brunflo. There also the facies-variations near the old eastern shore of the Cambro-Silurian seas will be demonstrated together with the several conglomerate series along the old shore.

A tour to the neighbourhood of Åsarna to the South (second day) is made to demonstrate the "Quartzite nappe" resting on the Cambro-Silurian autochthonous unit at Tossåsen and Åsarna etc.

Several days will then be devoted to demonstrations of the thrust areas of the middle part of Jemtland and a short tour made to Åreskutan, a well known highland-mountain and tourist-place, will give us the opportunity to see the "classical" locality where the great Seve nappe is thrust over the Cambro-Silurian. In good weather there is also a chance of seeing the typical Swedish highland-landscape which is more smoothed and gentle than in Norway.

A trip to the north permits us to see the bottom layers of the Cambro-Silurian resting on the Varegian quartzite beds which in turn rest on the Olden granite-core, the whole belonging to the Olden nappe.

Then the excursion returns to the eastern part of the Caledonian in Northern Jemtland, crossing the outlier of the Seve nappe, the flat-lying Offerdal nappe, and passing the Jemtlandian nappes of Cambro-Silurian rocks. At Strömsund in the evening of the fifth excursion day we are again near the eastern border of the Archean, whose rocky hills form a palisade of small summits of granite.

The last two days in Sweden are devoted to the thrust regions of the northernmost parts of Jemtland and that part of the County of Ångermanland which forms the Tåsjö area along the Tåsjö-Lake. There will be a brief opportunity of seeing the autochthonous and allochthonous Cambrian in the Tåsjö-Mountain. At the northernmost part of the Tåsjö-Lake the contact between the Cambrian alum-shales and the Varegian quartzite beneath them will be demonstrated at the Högnäsån rivulet and at the beautiful waterfall called Aborrället on the Sjougdälven river. Then the whole Varegian series will be studied with its different quartzites, red and green slates and bottom-layers of tillite, resting upon the red sparagmite. By means of blasting the contact-surface between the morainic tillite and the underlying red sparagmite has been bared and it shows glacial furrows belonging to the Varegian glacial time. One beautiful outcrop of the whole tillite bed will be demonstrated.

On returning to the western areas along the beautiful Ströms Vattudal (the Water-valley of Ström) there will be an opportunity of seeing the thrust-boundary between the Middle Ordovician graywackes of the Föllinge nappe and the autochthonous horst zone of pre-Cambrian granites. At Storån the Varegian complex rests upon the granite with bottom layers of a beautiful coarse conglomerate. Here the tillite is lacking. At Ringsjön to the south of Ströms Vattudal both the red sparagmite group and the grey sparagmite group are to be seen and the bottom layers of the grey sparagmites resting on the pre-Cambrian granite. In exceptionally well exposed road cuttings situated along the road to Bågede the increasing deformation of the autochthonous granite beneath the great thrust plane of the Seve nappe will be studied and the deepest part of the strongly deformed Seve schists. Then the Seve gneissic schists and amphibolites are to be seen as far as Gäddede.

On the final journey to the Norwegian frontier on the last day in Sweden the central Seve complex is exposed with garnet gneisses, amphibolites and small masses of serpentine. Near the Norwegian boundary the Köli rocks occur with different strata of the Western Cambro-Silurian facies. From the frontier excursion members who are only accompanying the A24—C19 excursions return to Strömsund and Östersund, while the members who are attached to the excursions A4—C1 will continue into Norway.

The Geology of the Caledonian Mountain Chain and of Adjacent Areas in Sweden

The huge area which we call the Mountain Chain forms a geological unit whose history is quite different from that of the rest of Sweden, occupied by the Swedish Archean Platform. If we exclude the southernmost part of Sweden, Scania, which is closely connected with the geological history of Denmark, we find that the Mountain Chain represents a younger phase of geological evolution than the Swedish Archean platform and the different sediments covering it. In this way the geological history of the Swedish Mountain Chain has a very close connection with the main geological history of Norway. The whole Scandinavian Mountain Chain in reality forms a mirror image of the Caledonian Mountain Chain of the Scottish Highlands. Therefore the Scottish name Caledonian Mountain Chain has been adopted. This and other mountain chains of the world formed contemporaneously all belong to the great revolutions of the Devonian period, called the Caledonian orogenesis. During this orogenesis broad coastal zones of the continents became folded and transformed to mountain ridges or broken by faults parallel with the mountain chains already in existence. By lateral orogenic pressure faulted parts of the often very broad shelf-zones were driven as roof-tiles of what geologists call "nappes" over one another and piled up on the subjacent foreland. In this way vast slices of the outer parts of the earth's crust and the geosynclinal sediments resting upon them, were added to the old continent. The coastal zone then moved to a new boundary between the sea and the rising continental block and, indeed, since the time when the Caledonian orogenesis was completed the coastal line along western Scandinavia in general has been the same. Devonian sediments from the geological period when the Caledonian mountain ranges were shaped or from the times nearest to that, do not occur in Sweden. On the other hand, several small areas of Devonian occur along the coast of Norway and also one at Røros in the centre of the Norwegian part of the Scandinavian Mountain Chain. In Sweden the Caledonian rocks are entirely pre-Devonian. The sediments of the Cambro-Silurian systems constitute an essential part of them as do certain late pre-Cambrian formations which almost totally lack signs of organic life. These late pre-Cambrian formations which in some respects seem to be closely connected with the Cambrian, are sometimes made up of tremendous thicknesses of sandstones and argillaceous sediments, now largely transformed to quartzites, slates and the peculiar feldspathic sandstones which have been characterized as sparagmites. For a long time there have been dissensions whether these quartzite-slate complexes and the sparagmites are to be referred to the Cambro-Silurian or not. Norwegian geologists have long been inclined to assume an intimate geological connection between these clastic sediment-formations and the lowest part of the Cambrian strata, the Lower Cambrian, and they also reckoned them as Lower Cambrian or Eocambrian. In Sweden, however, the geologists have for a long time separated the late pre-Cambrian series from the fossiliferous Cambrian. Here we touch upon the familiar international problem, namely pre-Cambrian *contra* Cambrian. New evidence from both Sweden and Norway, however, has persuaded geologists that there exists a dis-

tinguishable difference between fossiliferous Cambro-Silurian and the above mentioned older complexes.

The beginning of the Cambrian period saw a great general change in the evolution of the Baltic shield! Fennoscandia — the vast Archean area of north-western Europe — became, in Lower Cambrian times, widely transgressed by the sea. The course of this dominating event was unmistakably intermittent and interrupted by many advances and withdrawals of the sea. In the advancing or retreating coast-area a mild climate caused the rocks of the Baltic shield to disintegrate slowly, their feldspaths becoming kaolinized. It was then possible for the waves to loosen the quartz grains from the feldspar-rich crystalline rocks. The grains became washed out and rolled until a high degree of roundness was attained. They then accumulated at the bottom of the shallow sea. The argillaceous products were deposited far away and gave rise to the Lower Cambrian clay deposits.

The Lower Cambrian transgression in this way had the power to plane down the earlier, more uneven, coastal platform resulting in a peneplain. This is the sub-Cambrian peneplain and it forms the basement surface on which the Lower Cambrian sediments now rest. It was developed before and during the whole of Lower Cambrian time and the highest level reached by the sea is still recognizable by a marine abrasion terrace. It is evident that the Lower Cambrian sea has not invaded the whole Baltic shield but left a certain part of Fennoscandia free from deposits. This central, higher land mass of Lower Cambrian age is still to be seen and indeed also the old shore line marked by a distinct boundary between the upper terrace of the flat peneplain and an inner higher foreland mass (fig. 1). This extended central "torso" of pre-Cambrian rocks lacks Lower Cambrian and all other Cambrian sediments. It lies to the east of and parallel to the future Caledonian front and separates the "Baltic shallow-water sea" from a western shallow-water sea which at the beginning of the Cambro-Silurian time seems to have formed a broad submerged shelf of the early Paleozoic Atlantic.

In the latter shallow sea the development of the Caledonian geosyncline took place at least as regards this part of the original European shore. In great contrast to the shallow Baltic sea area whose transgressions were from East to West, the transgression of the Caledonian geosyncline sea was from West to East and partially continued over the central mainland "torso" of Scandinavia.

This general view of the Lower Cambrian transgressions is somewhat schematized but they recur at all periods of the Cambro-Silurian. The mainland bridge which separates the Western Sea from the Baltic-Bothnian Sea remains, even though at certain stages in Cambrian, Ordovician and Silurian times it was submerged by the sea much more conspicuously than during the Lower Cambrian. At other times the sea had obviously withdrawn and vast former shelf-zones along the continental bridge were exposed. New transgressions of the sea have often broken down earlier deposited layers of the Cambro-Silurian, sometimes so completely that the old Archean platform, the sub-Cambrian peneplain, was once again bared so that the sea reached the old coast-line and began a new attack on the old continental core. During these intermittent phases of transgression and regression the characteristic Cambro-Silurian strata have been deposited. Along the old shoreland and its shelfzone they show most



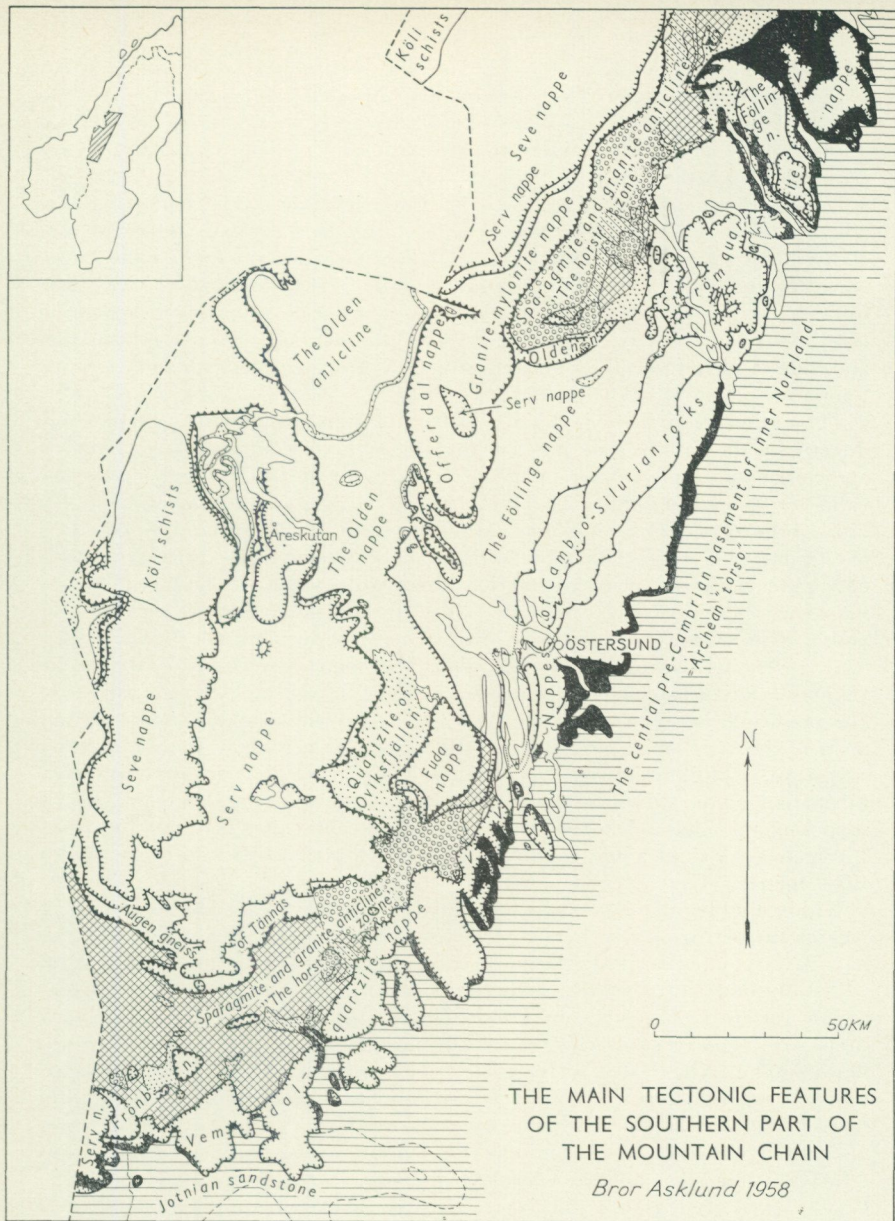
Fig. 1. The principal elements of the Lower Cambrian areas of Fennoscandia. — The thick curves indicate the highest level of the Lower Cambrian sea, coinciding with the limits of the Lower Cambrian peneplean. The thin broken curves indicate the present deformation of this old sea-level surface. The figures indicate the heights of that surface in relation to the present sea-level. This includes the Quaternary deformation by the ice-loading. — From Asklund 1929 and 1938.

clearly the variable distribution of land and sea. The repeated layers of conglomerates between different strata are to be interpreted as coarse sediments of the wave-zone near the shore and include pebbles or blocks and clastic material of sand and gravel from the Archean highland itself or from relatively older fossiliferous strata lying on it. In the eastern autochthonous Cambro-Silurian strata of the County Jemtland we find whole series of conglomeratic beds, separating, *inter alia*, the different zones of the *Orthoceras* limestones or the different well-defined fossiliferous zones of the Cambrian. We can also distinguish breaks or gaps in more continuous sedimentation, or even the total disappearance of older strata. Towards the West, in the broad Cambro-Silurian area of Jemtland, the conglomerate zones disappear and the gaps in the succession grow smaller. Now and then it can happen that there appear certain layers which are not to be found more near the old shoreline.

A detailed review about the many transgressions and regressions occurring during the Cambro-Silurian time cannot be given here but some features of more general importance will be presented. — During the time of the Lower Cambrian transgression the sea reached the foot of the mainland torso of Norrland, the northern part of Sweden. Along the eastern border of the highlands from Dalecarlia in the south to northernmost Lapland there occur sediments, sandstones or slates, which now and then contain Lower Cambrian fossils. The uppermost of the sediments belong to the *Holmia*-zone with *Holmia Kjerulfi* (Linnarsson) as the most characteristic fossil. Where the characteristic trilobites of the Cambrian border are lacking only sparse individuals of the Hyolithidae are found, and therefore the fossiliferous layers have often been called the *Hyolithes*-zone. The lower part of the Middle-Cambrian strata, the *Paradoxides oelandicus* layers of alum-shales are lacking for long stretches of the autochthonous unit, and, if they have ever occurred, they have been completely removed by erosion. The middle part of Middle Cambrian the *Paradoxides Tessini* layers or *Paradoxides paradoxissimus* layers mark a very wide transgression. It seems to have advanced far over the foreland of the maturing geosyncline, and rose considerably higher than the Lower Cambrian. The Upper Cambrian alum-shales are distributed over a good deal of the autochthonous unit, especially in the middle part of it.

The early of the Ordovician period, characterized especially by the *Orthoceras*-limestones, is also a time of wide transgressions. They have temporarily spread over a good deal of the eastern foreland and sometimes have flowed over it. The abundance of limestones still in the south part of Lapland indicates a near connection with the shallow Ordovician sea of the Baltic, and probably free communication with this area. To the north this communication is hardly apparent: here the limestone-facies disappears and is replaced by an argillaceous facies represented by graptolite-bearing argillites. Before the intermittent Ordovician transgressions the Cambrian layers had become partly denuded, sometimes so completely that the Ordovician strata were deposited on different members of the Cambrian or even directly on the Archean basement.







The middle parts of the Ordovician begin with the "*Chasmops* limestone" and indicate a considerable hiatus along the eastern shore. Before the deposition of the limestones a period of strong mechanical weathering prevailed in this



THE MAIN TECTONIC FEATURES OF THE SOUTHERN PART OF THE MOUNTAIN CHAIN

Bror Asklund 1958

The autochthonous borderland

-  Cambro-Silurian
-  Varegite quartzites
-  Varegite tillites
-  Red Sparagmite
-  Gray sparagmite (incl. the Hede limestone)
-  Granites and porphyries of the pre-Cambrian anticline

The nappes






-  Varegite quartzites (V)
-  Sparagmite
-  Thrust boundaries of the "Cambro-Silurian nappes"
-  " " " " Quartzite nappes and sub-nappes of the Seve nappe
-  " " " " "Great Seve nappe"

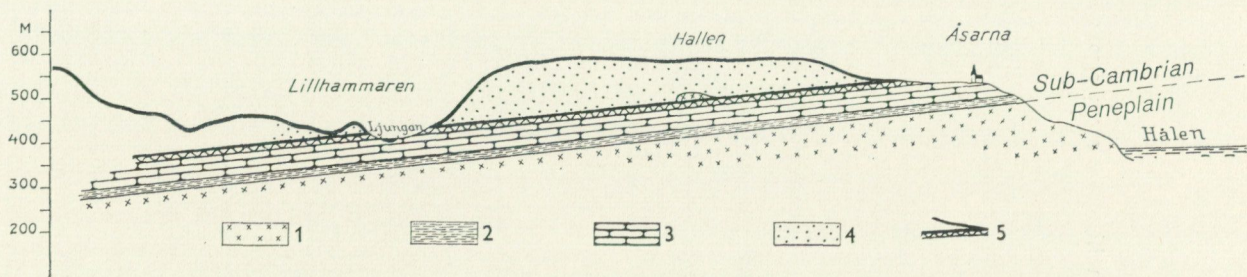
Fig. 2.

area, affecting the Lower Ordovician layers as well as the coast-forming archipelago of Archean hills. The "*Chasmops*" transgression (in the time of the Llanvirnian or Llandeilian sedimentation) extended over a large part of the foreland torso and perhaps inundated it again and thereby established a new connection with the Baltic.

During the transition phase between Ordovician and Silurian a renewed advance of the sea took place after a time of large withdrawals and denudation of the older strata. The flat surfaces of late-Ordovician or older eroded layers were covered by extensive sandstones, partially perhaps sand-dunes, and now forming the Kyrkås and *Phacops* quartzites. They seem to grow thicker to the coast along the old mainland shore. They are followed by deposits of limestone and slate which form the youngest strata of the Swedish highland Cambro-Silurian.

The review given here is mainly for the Cambro-Silurian strata which rest directly on the eastern shore land of the old pre-Cambrian platform, i.e. of the autochthonous Cambro-Silurian complex. To some degree this scheme is also valid for the Cambro-Silurian nappes nearest to the autochthonous unit. The broad area of Cambro-Silurian rocks of the county of Jemtland is especially constituted of a series of nappes which can be separated as different tectonic units, and in the following description their local names will be given (cf. the map, fig. 2). Collectively they are called the "Jemtlandian Nappes" by the author. The westernmost of them, the Föllinge nappe and the Olden nappe, have a very wide geographical extension, and sometimes contain parts of the Cambro-Silurian basement rocks as well as rocks of both the Archean and of the late pre-Cambrian sediment series. As a whole they emanate from more western parts of the Caledonian geosyncline, still formed by a shallow Cambro-Silurian sea or parts of it which have once formed the geosyncline proper with great thicknesses of the different layers (from the eugeosyncline). If we are right in supposing the total thickness of the eastern autochthonous layers to be 200—300 metres, we must admit the thickness of the western nappes to be more than 1,000 metres.

Within the Jemtlandian nappes essential or fundamental changes appear as regards the petrographical nature of the fossiliferous layers. Shales, for the most part dark-coloured argillites, begin to dominate, and the limestone facies of the eastern littoral strata withdraws or diminishes. At the same time the characteristic eastern fauna of trilobites, brachiopods and molluscs diminishes or withdraws, i.e. those groups which form the most essential elements of a littoral fauna most nearly related to those of the Paleo-Baltic area. The pelagic graptolites become dominant and form the typical fossils of the shales. The argillite facies characterizes especially the upper part of the lower Ordovician strata and the lower part of the middle Ordovician, corresponding to the upper *Orthoceras* limestone and the *Chasmops* limestone (*Ogygiocaris* slates etc.). The Cambrian as well as the Silurian strata have preserved more of the eastern autochthonous type of the sediments. — In the larger western Cambro-Silurian nappes, the Föllinge-nappe and the Olden-nappe, the Ordovician slates have been replaced by very widespread greywackes which occur as layers alternating with the slates. They are built up of sandstone-like rocks, mostly with obvious clastic structure. The clastic grains consist of disintegrated and redeposited older



1. Archean 2. Cambrian 3. Ordovician 4. Vemdal-quartzite 5. Thrusted nappe
 Fig. 3. Schematized profile of the Vemdal-quartzite nappe at Åsarna. — B. Asklund
 1933.

or relatively older rocks, significant masses of pre-Cambrian porphyries and granites, fragments of slates and limestones (often with fragments of fossils) from relatively older Cambro-Silurian layers etc. The greywackes indicate a quick disintegration of extensive land areas, which — judging by the fragmentary material, especially of the post-Archean but pre-Cambrian porphyries and granites — are not derived from the eastern mainland torso but from the West. Indeed, old remnants of such highland areas also occur within the nappes themselves, e. g. the large Olden-anticline of western Jemtland consists of very characteristic granites and porphyries. Evidently these land areas have formed isles and island arcs in the Ordovician geosynclinal sea and they may have reached heights of more than 1,000 metres above it. Even if we assume that during the middle Ordovician time intense variations in the sea-level took place as illustrated by repeated cross bedding in the thick units of alternating greywacke and slate, we are not permitted to postulate any great differences in the main geological evolution of these originally far western areas compared with the eastern autochthonous unit. However, it seems that more radical denudation occurred as the Cambrian strata for example were mostly absent, when the early Ordovician transgressions took place. Along the base of the Cambro-Silurian rocks of the Olden nappe the deepest layers are of Ordovician age.

Considering the transition time between Ordovician and Silurian the westernmost nappes demonstrate that the relatively older beds were deeply eroded in some parts, so deeply in fact that the pre-Cambrian basement was laid bare and was able to deliver huge masses of material to the conglomerates of this interval. A very interesting and splendid example is the Offerdals conglomerate of central Jemtland, probably 200 metres thick and containing blocks of porphyry and granite up to 2 metres in size. Distintegrated older quartzites form masses of hard pebbles. They belonged originally to the late-Precambrian, Varegian quartzites. The coarse conglomerates from the transition period between Ordovician and Silurian probably correspond to the fine-grained Kyrkås quartzite and *Phacops* quartzite occurring in the eastern nappes and this type can also be seen in parts of the western nappes farther from the original coast.

The Silurian limestones and slates are represented especially in the Föllinge nappe. The *Pentamerus* limestone is widespread and has a thickness up to 100 metres. The *upper graptolite-slates*, comprising the *Rastrites* and (*Retiolites*) *Cyrtograptus* slates, are distributed in central Jemtland in the Offerdal area. They are partly replaced by greywackes demonstrating that this facies also is to be found in the Silurian rocks. It is of special interest that the *Rastrites* slates have been found to contain thin layers of bentonite from volcanic ashes. Through these occurrences the Jemtlandian nappes show resemblances with those Cambro-Silurian rocks which lie upon the large, more westerly crystalline nappes in the northwestern part of Jemtland, in the Trondhjem area of Norway, and in Swedish Lapland. These upper masses of the great Seve nappe, in Sweden designated as the "Köli schists", enclose several series of volcanic rocks which have been subdivided in an excellent manner in the Trondhjem-field of Norway. However, the very thick layers of volcanics of the Trondhjem-field and the Swedish "Köli schists" on the other hand show a diastrophic evolution of the westernmost Cambro-Silurian which is much more in accordance with the development of the Caledonian syncline in Scotland than with the "eastern

Cambro-Silurian" of the Swedish Highlands. Thus, we also note the quite striking difference between the eastern facies of the Cambro-Silurian compared with the western facies when using the terminology of A. E. Törnebohm, the foremost pioneer of geological exploration in the Swedish Mountain Chain.

In the review hitherto given the Jemtlandian Cambro-Silurian has taken a leading part. It has a richer and more complete development than other boundary areas of the Highlands, through the occurrence of the large nappes or "decken" of Cambro-Silurian rocks. To the south the allochthonous Cambro-Silurian nappes disappear before reaching the valley of the Ljungan River and then only autochthonous Cambro-Silurian is represented through the Counties of Herjedalen and Dalecarlia until the Norwegian boundary is reached in the neighbourhood of the great Lake Femund. Alum-shales and relatively thin layers of Lower Cambrian sandstone occur and now and then also the lowermost part of the Ordovician strata containing *Orthoceras* limestone and *Phyllograptus* shales.

To the north, the Jemtlandian nappes or "decken" can be followed into the southern part of the County of Västerbotten, the southwestern part of Lapland. Here the autochthonous layers of the Cambro-Silurian dominate and are represented by Cambrian alum-shales and Ordovician slates. The *Orthoceras* limestone occurs but only as relatively thin layers among the dominating argillites. As the Cambro-Silurian complex is often very thick it seems probable that remnants of the Jemtlandian nappes may occur. However, more detailed investigations about this subject are lacking. Also in the northernmost County of Norrbotten, the northwestern part of Lapland, there are indications of a "decken-bau" of the Cambro-Silurian complex, e. g. in the section from the big lake Hornavan to the West and from Stora Sjöfallet also westward. Most of the Cambro-Silurian is thought to be autochthonous. It is mainly built up of Cambrian layers, alum-shales and Lower Cambrian sandstones forming the so-called "*Hyalithes* zone".

Some words may be added about the general geological character of the Cambro-Silurian and its history of development before the great Caledonian folding began and the origin of the thrust movements.

The original state of the wide nappes or "decken" of the Cambro-Silurian rocks before thrusting is that of a very broad zone of a shallow sea — i. e. a shelf-zone of the European continent expanding to the west of the old mainland torso (fig. 1). The area considered has obviously had a much greater breadth than the contemporaneous basin of the Baltic to the east of the mainland torso. On this wide shelf of a shallow sea the layers of the Cambro-Silurian were deposited under very quiet conditions just like those prevalent during the deposition of the Baltic Cambro-Silurian. The sedimentation in both areas took place under anorogenic circumstances. A gentle tilting of the strata here and there combined with the development of shallow troughs or doming up of flat ridges, may have occurred but there are no signs of contemporaneous faulting, folding or thrusting. This general picture is important to bear in mind when the great subsequent geotectonics are to be considered. The very small traces of volcanic action — thin layers of volcanic ash in some argillaceous sediments — do not have any greater extension than the thin occurrences of bentonites in the Cambro-Silurian slates of the Baltic and it is fundamental to realize that

neither lava rocks or dikes of igneous rocks have ever been found from Cambro-Silurian beds. Westwards however a deeper sinking of the sea floor seems to have occurred at different times, allowing the accumulations of thicker beds. The clastic material emanates from landmasses to the West. Probably west of these landmasses isles or island arcs of the Caledonian geosyncline proper *i. e.* the eugeosyncline were situated. We can conclude that this area was the place for early geotectonic events, the eruption of volcanoes and the deposition of great thicknesses of Cambro-Silurian. We may reconstruct this picture by inquiring into the problems of the huge crystalline nappes.

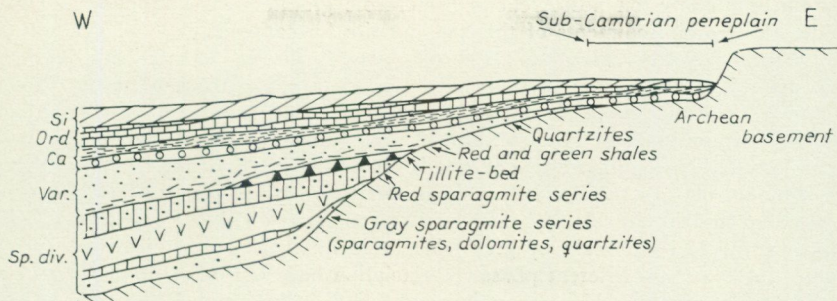
Huge crystalline nappes extend to the west of the Jemtlandian nappes of Cambro-Silurian rocks or to the west of the autochthonous Paleozoic. Formerly they were considered to be a uniform mass of a tremendous slice of the basement block of the geosyncline sea which had been carried along a gigantic flat-lying fault — a thrust-plane, to the east also over the folded Cambro-Silurian beds. This great nappe which we call “the Great Seve nappe” has later been subdivided into several major nappes. These will be named and described in the following pages.

On its back the Great Seve nappe carries a series of stratified rocks belonging to the Cambro-Silurian. The rocks of this series are collectively called the “Köli schists”. They are most conspicuously developed in the Norwegian “Trondhjem Field”. There they have been carefully studied and in this area, with its relatively low degree of metamorphism the different and relatively fossil-rich strata have been stratigraphically fixed in relation to the stratigraphy of the Baltic Cambro-Silurian.

The most characteristic feature of the “Western facies” of the Cambro-Silurian is its richness in extrusive volcanics. These include lavas several thousands of metres in thickness, and volcanic products such as tuffs, ashes and agglomerates, interlayered with the more typical sedimentary rocks of the Cambro-Silurian. The latter rocks have also been invaded by large intrusives, including gabbros and the very peculiar type of granite called “Trondhjemite”. Outside some better preserved core-areas, the sediments are strongly deformed by folding and thrusting. This metamorphism has caused great changes of mineral composition and structure in these rocks, now often making them very difficult to interpret from a general geological point of view. Their geological history is also obscure.

The rocks concerned — “the Köli schists” — occupy a part of middle Jemtland. They belong to the so-called “Tennfors field” which includes a great deal of schist, partially of the “schiste lustré” type. From the northwestern part of Jemtland to the northern part of Lapland there occurs a series of such fields of Köli schists. They include a greater variety of rock types than the Tennfors area of Jemtland, great masses of volcanic rocks, tuffs and agglomerates, limestones, quartzites and conglomerates being present. A couple of successful finds of fossils have admitted at least partial dating of different layers (compare the description by Kulling regarding the northern parts of the Swedish Mountain Chain). Also intrusives occur in the Köli formations, peridotites of different kinds, gabbro and small occurrences of “Trondhjemites”.

Before giving a comprehensive description of the deeper lying complex of crystalline rocks — the Seve complex, which forms the basement of the “Köli”



Si=Silurian Ord=Ordovician Ca=Cambrian
 Var.=Varegian formation Sp. div.=Sparagmite divisions

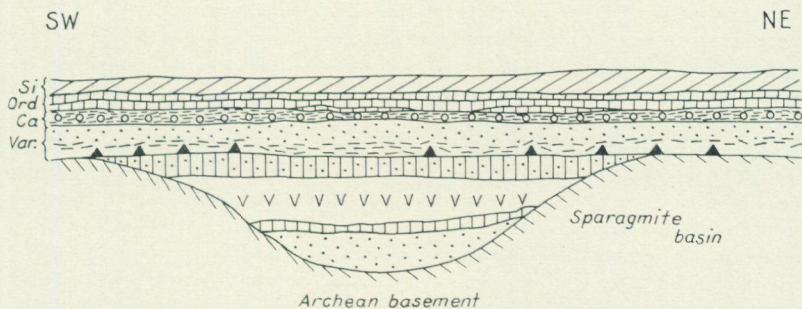


Fig. 4. General scheme for the succession and manner of sedimentation of the late-Precambrian complexes in the Mountain Chain. — The difference between the distribution of the basin-forming sparagmites and the more widely occurring Varegian formation is to be noted. — B. Asklund 1957.

series — a review will be given of the late-Precambrian sedimentary formations which occur especially in the eastern borderland of the Highlands. They are of conspicuous significance in both the autochthonous unit and in the nappes.

Fig. 1 shows how the embryo of the Caledonian geosyncline area appeared in early Cambrian time, when Lower Cambrian deposits were most widespread. The Lower Cambrian beds covered two sedimentary formations which are older than the fossil-bearing strata — with the zone of *Olenellus* in the sense of Walcott — but which, on the other hand, are younger than the Archean basement. The most extended of these Proterozoic formations consists of quartzites and slates, originally very pure quartz-sandstones with intercalations of argillite. Below this upper series there occurs a very characteristic series of red and green slates having the same stratigraphical position and general appearance as the Ekre-slates of the Norwegian Eocambrian. They rest on quartzites or arkoses which sometimes have a high content of feldspar. These rocks, or when they are lacking, the multicoloured red and green slates, may rest on the Archean

basement directly, on post-Archean Proterozoic granites and porphyries, or on older Proterozoic sediments of the "Sparagmite formations".

Often the basal-rocks of the "quartzite slate-formation" consist of a *tillite*, an unambiguous morainic product from this early phase of earth history. The *tillite* is made up of blocks of very variable size and type including granites, gneisses of unmistakable Archean aspect, post-Archean granites and porphyries, especially red sparagmites etc. The matrix consists of grains of different minerals in a mould of very fine fragments. With the tillite layers boulder-clay is often associated and is red-coloured or grayish green-coloured. There also occurs an upper tillite bed underlain by grey feldspathic quartzites or whitish quartzites, indicating that two different phases of glaciation have occurred.

The frequently very thick "quartzite-slate series" including the tillites has been recently (1956) named the *Varegian formation* by the author. This formation corresponds to the upper part of the "Eocambrian", a designation given by W. C. Brögger and also including the sparagmites. The *Varegian* is well limited upwards as well as downwards. The upper limit is marked by the conglomerates which characterize the bottom layers of the fossil-bearing Lower Cambrian beds. They rest on a denudated surface of the upper *Varegian* quartzites. Sometimes there seems to exist a disconformity or discontinuity where the *Varegian* bedded layers are cut at low angles. The lowermost *Varegian* with conglomerates or with the tillite rests on a "mixed" rock-ground consisting of Archean or post-Archean granites and porphyries, or on deeply eroded sparagmites.

The upper quartzites and intercalated slates of the *Varegian* formation are probably deposits of a shallow sea. They represent a transition series between the Proterozoic fossil free formations and beds with a rich and differentiated Cambro-Silurian fauna. It is an interesting fact that the *Varegian* formation is joined to the embryonic Caledonian geosyncline and is rather uniformly distributed along the Highland-boundary from Southern Norway through the Swedish borderland and northwards to Finnmark in northernmost Norway. On the Varanger peninsula the tillites of the formation were detected by Reusch.

The quartzites have had a remarkably wide spread on the floor of the geosyncline and have been thrust from there to form the huge "quartzite-nappe" which extends from southern Norway to northernmost Scandinavia in Norway. This quartzite-nappe is known by several local names in Sweden — the "Vemdalen quartzite-nappe" from the south part of the Mountain Chain (fig. 3) and the "Ström quartzite-nappe" of the northern part of Jemtland and southern Lapland. By studies on the tectonics of Jemtland it was possible to show that the Vemdalen nappe coincides with the Olden nappe of the Cambro-Silurian with its basement of *Varegian* quartzites and underlying crystalline rocks.

In Swedish Lapland the autochthonous *Varegian* quartzites and slates are called the Laisberg series. This forms rather thin beds beneath the Lower Cambrian of the foreland autochthonous unit and have, by some authors, been interpreted as a lowermost part of the Lower Cambrian (Kulling). The direct continuation of the "Laisberg series" into the *Varegian* quartzites of the southern part of Lapland undoubtedly shows that though differently named this series forms a unit of the *Varegian* formation.

The sparagmite divisions occurring beneath the *Varegian* formation have an irregular distribution along the Highland-border; they occur at some places and

are absent at others. The southernmost area is the wide sparagmite area of Herjedalen and Jemtland coming from the Norwegian frontier land round the large lake Femund. It continues to the Storsjö Lake of Jemtland. The lower part of the sparagmites has been designated as the "Grey sparagmite formation". It is made up of conglomerates and arkoses, slates and also limestones, represented by the "Hede limestone" from Herjedalen. It corresponds to the Norwegian "Biri limestone". The "Grey sparagmite formation" is not thick and is discordantly overlain by the Red sparagmite formation, which sometimes also rests on the granitic basement directly. The main red sparagmites are frequently represented by merely coarse conglomerates. Especially the red sparagmites seem to have been formed under arid, continental conditions high above sea-level.

The sparagmite areas of North Jemtland and South Lapland expand from the lake Hotagen in Jemtland into Norrbotten in the northern part of Lapland. They consist of a deep-lying "grey sparagmite formation", which may be very thick or totally lacking. Its lower part consists of quartzites and quartzite conglomerate, sometimes overlain by dark-coloured slaty greywacke. The main mass of the grey sparagmite formation is made up of grey or grey-green-coloured feldspar-rich sandstone or quartzite. Over the lower quartzites there sometimes occur rather thick dolomites. The boundary between the underlying "grey" and overlying "red" sparagmites is a disconformity or sometimes a more prominent discordance with associated conglomerate. At many places along the Ströms Vattudal, the broad valley of the Faxälven river in the northern part of Jemtland, only small remnants of the grey sparagmite formation are found. These are denudation remnants lying in deeply excavated portions of the granitic, i. e. sub-sparagmite, basement. Upon this "mixed" surface the Red sparagmite formation, consisting of red feldspar-rich sandstones and frequently thick beds of conglomerate, was deposited. The pebbles of the latter are made up of different types of granite and porphyry evidently emanating from contemporaneous western highlands, of sandstones, quartzites etc. Sometimes dolomitic beds also occur in the red sparagmites. Even where the red sparagmites reach thicknesses of several hundred metres, they often suddenly disappear, allowing the Vargian sediments to be deposited directly on the old crystalline basement. This is the case, for example at Storån at Ströms Vattudal where a very beautiful basal conglomerate of the Vargian formation rests directly on the old granite. Only 10 or 12 kilometres away, at Harrsjön, the red sparagmites have a thickness of more than 200 metres.

A survey of the general distribution of the sparagmite series indicates that it was originally deposited in basins which now and then appear along the border of the long stretch which later on became the Caledonian geosyncline. For the most part these basins were aligned in a NW—SE direction, perpendicular to the length-direction of the Caledonian geosyncline. This fact is very interesting as no close relationship exists between the formation of those small basins of sparagmite and the overall developments of the geosyncline. Considering this fact as compared with the uniform distribution of the Vargian sediments along the whole geocyncline a profound difference in geological behaviour is evident between the sparagmite-series and the Vargian sediments (cfr fig. 4).

As regards the history of the *great crystalline nappes* it must be emphasized that the possibility of giving a comprehensive scientific explanation for them

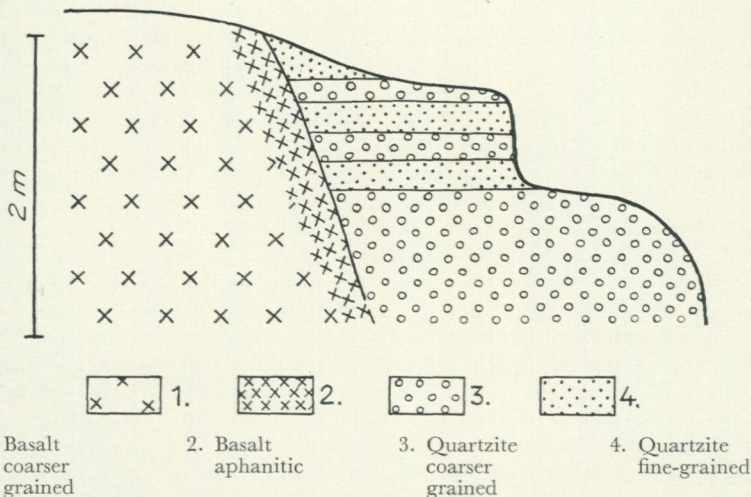


Fig. 5. Basalt dike of the "Ottsjö" diabase type, cutting the bedding of the quartzite of the Serv nappe. Ävikberget, E of Storsjö, Herjedalen. — B. Asklund*1957.

and their rocks, is still very difficult. The rocks of these nappes are for the most part so strongly folded and by different phases of metamorphism so strongly modified from their original state, that severe difficulties arise in giving a generally acceptable explanation. Sedimentary and eruptive rocks alternate in these nappes, the boundaries between the different rocks being frequently obscured. The thrust movements have displaced parts of the initial rock masses from their original coherent state. The circumstances indicated leave full scope for fantasy and subjective opinion which do not contribute to progress in research. Laborious mapping undoubtedly has the best chance of solving the great problems of the chystalline nappes!

Recently a more reliable division of "the Great Seve nappe" into several smaller nappes has been carried out and by this a more definite interpretation of the geological history of the separate units achieved. This is especially the case regarding the vast flat-lying sheet of mainly quartzitic rocks which has its widest extension in Herjedalen and the middle part of Jemtland. During recent years it has been called the "Serv nappe". It corresponds to what previously was named "the quartzite-schists and mica-schists of the Seve group". The main mass of the Serv nappe is made up of quartzites and feldspar-rich quartzites, related to sparagmites but of another type. With the more quartzitic rocks mica-rich schists are associated and at the base of the nappe there occurs a very widely distributed layer of a partly dolomitic limestone. Thousands of basalt-dikes are characteristic for the Serv nappe, both steeply inclined and flat-lying. They belong to the "Ottsjö diabase-type", an olivine-bearing, ophitic basalt when undeformed, and a chloritized greenstone when more strongly deformed.

The steep dikes have obviously cut the sediments and their original bedding structure before the thrusts carried away the nappe to its present position (fig. 5). The metamorphism of the Serv nappe is quite unimportant: its original clastic structure is very distinct as is the primary structure of the "diabases", chilled contacts etc.

Small remnants of the Serv nappe are found also in the northern part of Jemtland, as for example an uppermost layer on the "Offerdal nappe", and also in a streak which enters Sweden at Valsjön to the north of Ströms Vattudal and persists into the southern part of Västerbotten. It is possible that it continues also in the northernmost part of the Swedish Mountain Chain.

The rocks of the Serv nappe have not been dated with any high degree of certainty. They have been compared with the sparagmites, but they are in several respects quite unlike them. They lack the widespread conglomerates of the sparagmites. It is more probable that they are remnants of a much older pre-Cambrian or Proterozoic complex, emanating from unknown areas of the geosyncline and originally lying quite far from the present Scandinavian coast. The rocks bear resemblances to those of the Norwegian Telemark-group and possibly they may have been connected with "the Dal-formation" of southwestern Sweden or with the "Jatulian" of eastern and northern Finland.

Beneath the Serv nappe a big nappe-like sheet of "augen gneiss" occurs in Herjedalen and also as outliers in Dalecarlia. It consists of coarse granite-like rocks with well segregated feldspar augen, often several cms in size, in a deformed and epidotized groundmass. This peculiar rock is called the "augen gneiss of Tennäs" in Herjedalen and the "Frönberg gneiss" in Dalecarlia. To the north it is not so coarse but is replaced by medium-grained deformed granites, still with feldspar augen, or more dense porphyry-like schists. These rocks have been interpreted as originally granites of different kinds with an original porphyry-granite texture. They are in part strongly deformed and altered to real granite-mylonites. The nappe formed by these rocks is designated the "granite-mylonite nappe" and it forms a tectonic unit separated from the Serv nappe. It is situated upon the autochthonous sparagmites or upon the allochthonous Cambro-Silurian rocks. It forms the lowermost unite of the different nappes of the whole Seve complex. There is no question of the granite-mylonite nappe being made up of Archean or Proterozoic granites.

Outliers of the nappe are the "F u d a n a p p e" to the SW of Storsjön in Jemtland, the small "A l s e n n a p p e" to the north of Alsensjön in Central Jemtland and the big "O f f e r d a l n a p p e" to the north, passing the Høtagen Lake and continuing to the Lapland boundary. To the south of Valsjöbyn a lobe of the Offerdal nappe continues into Norway and there, along the river Sandöla, it is directly connected with the wide Archean area of Western Norway, the so-called "Western-Border" (= Vestranden) of Norway.

In the northern part of Lapland an equivalent to the granite-mylonite nappe returns in the form of the so-called "syenite-nappe".

Regarding the different views on the origin of the rocks of the granite-mylonite nappe an earlier generation of Swedish geologists considered them to be thrust Archean rocks, mainly granites or syenites similar to the eastern Archean. Particularly in Norway however, a different view emerged which explained the "augen-gneiss" as emanating from strongly metamorphosed older

rocks which, through processes of palingenesis, feldspathization etc., have become completely altered. A good deal of the complex, according to this concept, has been originally sparagmite. At all events it is certain that parts of this nappe have been subjected to radical transformations though unmetamorphosed parts also occur. This is also a feature of the Serv nappe as mentioned before.

The "real Seve nappe" or the highly metamorphosed part of the chystalline basement of the Kõli schists — the western Cambro-Silurian rocks — is composed of such a multitude of rocks that it is not convenient to attempt a more detailed description here. Only a few general remarks are given below. Evidently the "real" Seve rocks represent a great series of igneous rocks of different kinds as well as a great bulk of different sediments. Garnet-gneisses, garnet-bearing mica-schists and mica-schists are widely distributed. The mineral composition indicates alumina-rich source material, which petrographically resembles corresponding Archean rocks of southern or western Sweden and southeastern Norway, namely, the garnet-gneiss areas with their intercalations of older sediments, comprising mica-rich phyllites, leptites and limestone-bearing, lime-silicate gneisses etc. These Highland schists are sometimes rich in "segregated" material such as aplite and pegmatite which form veins or stripes in the main schistose material. They are very similar to Archean "migmatites" made up of a mixture of old eruptives and sediments of different Archean ages. In some areas the Seve gneisses are made up of rocks which are dominantly of gneiss-granitic type. They show relict structures of originally coarse porphyritic granites. Probably these areas represent deformed masses of granites. Among the garnet-rich gneisses and schists the local type "Åre gneisses" and "Åre schists" may be mentioned. These build up a part of the well-known mountain Åreskutan in Central Jemtland.

Basic rocks are also present. They occur as strongly deformed amphibolites, frequently so abundant that the whole "real" Seve nappe has been called the "amphibolite nappe", in contrast to the north-Laplandian "syenite nappe". Partly there also occur basic rocks which are unmistakable intrusives cutting the garnet-bearing gneisses and schists and also showing primary chystallisation structures such as ophitic structure (diabases, dolerites) or contact-chilling against relatively older rocks of the Seve complex. In some areas these doleritic basic rocks become abundant as invading dikes or stocks in the gneisses and, thus show great resemblance to the numerous intrusions of the "Ottsjö" diabases in the Serv nappe. Perhaps they also are nearly related to the latter. Whether the gabbro intrusions of other areas are expanded intrusions from the magma of the diabase-basalt dykes is not sufficiently known. Connected with these gabbros are greater or smaller occurrences of pyrite and other metalliferous sulphides.

A special group of the basic rocks is composed of peridotite or serpentine. These occur as rounded masses in areas of gneiss and mica-schists. These rounded masses or stocks frequently occur in lines with gaps between the separate bodies. They are interpreted as relatively young intrusives, but have, however, been denuded during the very time when the geosyncline was growing. Also on the Swedish side of the Mountain Chain there occur "serpentine conglomerates", which for the most part were supposed to be of older Ordovician age.

It is an open question as to what age the sedimentation of the crystalline lime-

stones of the "real" Seve masses may be ascribed. Parts of them may represent layers impressed in an older rock complex through the folding processes. Other parts probably belong to older elements of the crystalline masses, perhaps of an old Archean basement.

The youngest rocks of the "real" Seve nappe are the scarce but widely distributed occurrences of granite. They are light-coloured or white rocks invading the others. They correspond to the Norwegian trondhjemites and have been intruded during Cambro-Silurian time.

Interpretations of the nature of the "Seve" complex have changed from time to time. With the presentation of the "thrust theory", a deeper conception of the origin of these huge crystalline masses became possible and the situation of these archaic looking rocks upon the fossiliferous beds of the Paleozoic could be understood. The foremost pioneer of the Swedish Mountain Chain research, Alfred Elis Törnebohm¹ explained the "Seve-schists" as sediments formed far away to the NW, where they became intermingled with volcanic material, especially basaltic lavas. The "Seve-schists" were believed to have been formed during the time of the deposition of the late-Proterozoic sparagmite formation and according to Törnebohm transitions to real sparagmites were considered to exist in the huge nappe — the "clastic *Seve-group*". Through the metamorphic influence of basic lavas the sediments adopted a crystalline habit and by the chemical and mechanical changes combined with sedimentation they became altered to aluminous clayey sediments. These concepts are perhaps somewhat primitive, and, indeed, hide some old Neptunian ideas but they have, however, a very important element of truth. It is a fact that the "Seve schists" have got their highly crystalline habit and the leading structural features of their metamorphism *before* they were moved to the SE by the thrusting. The pure Caledonian metamorphism is thereby to be interpreted as secondary compared with the original and more essential metamorphism. Such a comprehension without any doubt squares very well with the facts: in the "real" Seve nappe there occur over great areas structures and traces of metamorphic processes of several kinds which are older than the deformations which originated contemporaneously with the Caledonian orogeny. This is in full accordance with the facts quoted concerning the Seve nappe and the granite-mylonite nappe or the syenite-nappe of the north. Both show relict structures which of course are easily recognizable when granite structures or clastic structures of sediments are concerned. On the other hand, to determine whether a metamorphic structure is an old one or a new one stamped on the previous one is much more difficult and can lead to serious misinterpretations.

However, both concepts discussed above have been proposed, namely, one in which an older metamorphism is recognised and interpreted as belonging to the old basement of the Caledonian geosynclinal sediments; the other, that the geosynclinal sediments themselves during Caledonian time have been pressed down to a deep level where they *in toto* have become deformed, metamorphosed and subject to palingenic processes with partial melting of the older rocks and formation of migmatites etc.

¹ A. E. Törnebohm (1838—1911). Professor of geology, Director of the Geological Survey of Sweden.

For the author of this review it seems quite clear that the rocks of the "real" Sveve nappe to a considerable extent consist of the basement rocks of the Caledonian geosyncline sediments, an Archean complex and probably also younger pre-Cambrian beds. The widely extending garnet-gneisses and micaschists, and also the amphibolites of unknown extent, seem to represent an Archean basement once situated far from the present Scandinavian western coast. The occurrence of migmatites in the Mountain Chain and other phenomena, indicating plutonic metamorphism at high temperature, are characteristic of this Archean complex as they are in other great gneiss areas of the Scandinavian shield. The occurrence of Archean eruptives within this original gneiss-complex is to be expected and have indeed been found.

Before interpreting these fundamental problems — which are key points of departure for forthcoming research — it is desirable that radioactive age determinations be made from more preserved parts of the nappe rocks. Even if these determinations only give indications within relatively wide limits they should be of great interest for forthcoming scientific research. However, the separation of the highly metamorphic complex under discussion from infolded and transported remnants of the Cambro-Silurian sediments, belong to the regional mapping work.

A general review of the detailed tectonic features of the Swedish Mountain Chain is too intricate for this concentrated description. Such a review is inseparably connected with the geological history of the Norwegian part. But some features may be mentioned. The main view of the moment regarding the most prominent tectonic features has tended to develop in the direction of interpreting the Scandinavian Mountain Chain as being "one-sided". In this respect the present view differs from that of Törnebohm who considered that the Norwegian coastal zone was the centre for the mountain-chain orogeny. There — according to his opinion — a huge down-warping of the bottom of the geosyncline took place and from it the nappes travelled outwards in two directions: to the south-east over the present Mountain Chain and to the north-west over the present narrow zone of the Norwegian coast and sunken parts of the former eastern coast-land of the Paleo-Atlantic.

The picture to-day has changed and attention is now directed more to the west as mentioned in the introduction to this review. All the nappes on the Swedish side demonstrate thrust-movements from NW to SE. Only the narrow slice of autochthonous Cambro-Silurian has remained practically unmoved on its basement. On this slice the "roof-tiles" of the Jemtland nappes with their great thicknesses of Cambro-Silurian beds have piled up, crowned by the huge Olden-nappe with its basement of crystalline pre-Cambrian rocks — the massif of the Olden-granite and a series of anticlines composed of porphyries related to the Olden-granite. This nappe with its basement lacks any equivalent among other "Cambro-Silurian" nappes as regards magnitude. It comprises also the Vemdalen-quartzite nappe to the south and the Ström-quartzite nappe to the north, which earlier have been comprehended as independent tectonic units. A calculation of the distance of transport of this great nappe in relation to the underlying Föllinge nappe indicates a *minimum* of about 130 to 140 kilometres. These figures are relative and the total amount of movement may be much greater.

The leading nappes — the Jemtlandian nappes which principally consist of Cambro-Silurian rocks — have frequently thin slices of their Archean basement still attached: units of the Vargian quartzites occur as more or less thick sheets. These remnants have many times shielded the overlying looser sediment beds from destruction by the forward gliding of the nappes. At other times the soft alum-schists or other schists and shales have formed the basal parts and we may imagine how these rocks have acted as a sort of lubrication-medium, in solid form, for the thrust-planes.

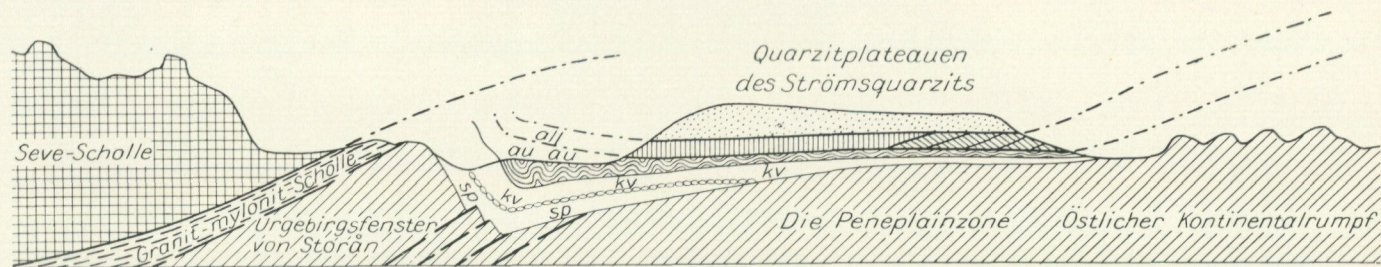
From a tectonic point of view it is very interesting to consider the nature of the horst-like zones of crystalline rocks, mainly granites of post-Archean but also of pre-Cambrian age which occur as broad and long zones to the east of the huge chrystalline nappes. On the top of these horsts there occur sediment beds of different kinds: grey and red sparagmites, Vargian quartzites and slates and even solitary small areas of fossiliferous Cambrian. These horst like zones form two different areas, one stretching from the south of Lake Storsjön in Jemtland to Dalecarlia, the other from Lake Hotagen in Jemtland into the southern part of Lapland.

Along the south-eastern front of these areas they are evidently raised above the surrounding land: sometimes only in the form of an inversion of the sediments resting on the up-domed crystalline basement, as e.g. in the very important profile of Sjougdälven between the Counties of Ängermanland and Jemtland (fig. 6). In most cases their boundary indicates breaks and steep thrusting along a series of smaller faults. Generally these small thrusts are steeper than the flat-lying main thrusts of the great nappes. In the southern part of Lapland wedge-formed blocks of the granitic basement of the northern horst have penetrated the overlying sediment beds and are similar to small nappes set free from their original relationship (fig. 7). The driving up of the horsts has for long stretches also affected the overlying main nappes of Cambro-Silurian rocks and has even been capable of upturning their rear portions. Thus the rear of the Föllinge nappe is inverted for a long stretch from Southern Lapland to Lake Hotagen in Jemtland. The Ordovician greywackes are overturned to form a recumbent fold and the inversion-zone has been penetrated by wedges of the horst, even by thin wedges of fossiliferous Cambrian alum-schist.

From the southern part of Jemtland into the northern part of Dalecarlia the horst-front has inverted the huge thrust-plane of the Vemdals-quartzite nappe. For instance at Hede in Härjedalen the nappe is inverted, twice folded and probably lifted several hundred metres. Here and generally at other similar places the horst-doming by a series of small movements has lifted the granite-sparagmite bottom of the "mio"-geosyncline rather considerable amounts, nearly a thousand metres at some places.

It is evident that the doming up of the horst zones belongs to a younger phase of the tectonic history of the Caledonian Mountain Chain than do the great thrusts of the big nappes bordering the horsts. Indeed, the breaking up of the horst zones may be analogous to the breaking away of the enormous nappes in the eugeosyncline. We can imagine these nappes were loosened from areas lying far from our coasts along zones of dislocation, perhaps more flat-lying than the horst dislocations.

From the horst zones emanate the granite-wedges already mentioned. It is



all = Cambro-Silurian nappe; *au* = autochthonous Cambro-Silurian; *kv* = quartzite-shale formation (Varegian); *sp* = red sparagmite. Between *kv* and *sp* the tillite-layer is indicated.

Fig. 6. Schematic profile from the northernmost part of Jemtland and Ångermanland, Bågede—Storån—Tåsjö valley. — B. Asklund 1938.

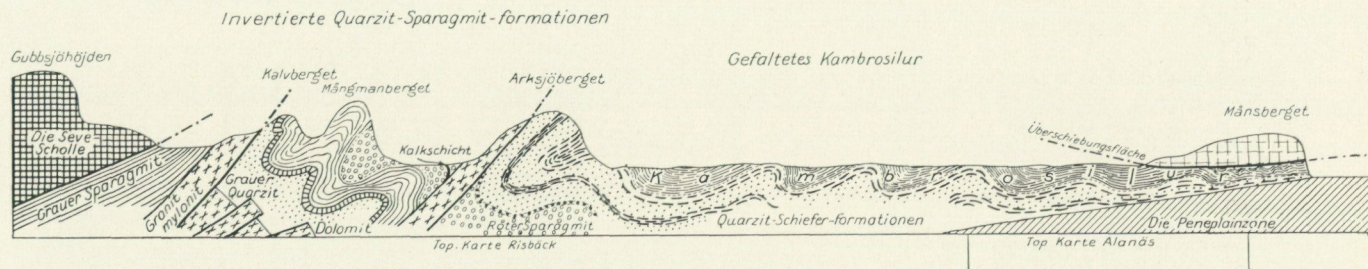


Fig. 7. Schematic profile from southernmost Lapland, Långeleån River and Korpån River. — B. Asklund 1935, 1938.

also evident that even hidden parts of the sediments upon the granite basement sometimes have been torn away and thrust as larger or smaller "nappes" whose amount of transport is insignificant compared with that of the big autochthonous nappes. Such a loosened and thrust small nappe of strongly deformed sparagmite was detected lying upon the raised border of the undeformed horst-zone sparagmite to the south of Lake Storsjön in Jemtland, beneath an outlier of the granite-mylonite nappe. In its lower part there is a slice of the granite-basement attached to deformed red sparagmite.

In an analogous way the much bigger so-called "Stalon nappe" of Southern Lapland also seems to have arisen. It is composed of grey sparagmites with overlying red sparagmites or coarse conglomerates belonging to them. This Stalon nappe may be supposed to have been thrust over wide areas of autochthonous complexes of sparagmite and Vargian quartzite with small remnants of overlying Cambrian alum-shales. The nappe is also thought to have over-ridden outliers of the "quartzite nappe" situated between the lakes Malmogaj and Storvindeln in Lapland. It has a continuation into the southern part of the country of Norrbotten in Lapland and then disappears.

The upheaval and forward movement of the horst-zones have to a large extent caused the western root-zones far to the east of the thrust Jemtlandian nappes and quartzite nappes to be lacking. Otherwise it could have been expected that the western root-zones of the Föllinge nappe and the Olden-nappe would occur between Lake Hotagen and the southern part of Lapland. Likewise the Vemdal-quartzite nappe would have had a root-zone beneath the granite-mylonite nappe. However, this is not the case. In the middle part of Jemtland where, on the other hand, the horst zone is lacking a broad root zone of the Olden nappe exists, composed of the quartzites in the Ovik mountains with remnants of Cambro-Silurian beds in their upper part. In the same way there exists a continuation of the root zone to the north of the Olden nappe represented by the mighty anticline of the Olden granite with overlying Vargian quartzites and Ordovician greywackes and slates. It crosses the Norwegian boundary and at Graessamo in Norway plunges beneath the great mass of the West-Norwegian Archean complex which is thrust over it.

There remain some words to be said about the problems of the movement of the huge crystalline nappes. These are common for the great tectonic problems of the Norwegian mountains. Swedish and Norwegian geologists pursue the work jointly in order to solve them and in this respect the "Mountain Chain" has been the subject of mutual research. The results from recent years indicate that the "big" nappes represent long-transported sheets of a basement situated to the west of the broad shallow sea which the Cambro-Silurian rocks of the easternmost nappes demonstrate to have existed. The different Sveve nappes have superimposed units of this basement in the same way as they have accumulated: nearest to the east there must have occurred a wide complex especially rich in pre-Cambrian areas of eruptives, corresponding to the granite-mylonite-nappe and the syenite nappe. These rocks show, indeed, resemblances with the eruptive rocks of the pre-Cambrian torso of central and northern Sweden, to the east of the autochthonous Cambrian.

Further outwards the quartzite-slate-dolomite floor of the Serv nappe must have been originally situated. Hitherto the original connection between the

Serv nappe and the granite-syenite nappes has not been found. There are great differences between them, *e. g.* no granite rocks have been found in the Serv nappe. On the other hand it contains in some areas numerous dikes or sheets of basalt and in this way the Serv nappe seems to have represented a floor for an upper series of volcanic products of basaltic type which is hitherto unknown in connection with the Serv sediments.

Concerning the "real" Seve nappe the author of this summary thinks it to have originally been situated still further west, the rocks constituting a wide area of Archean gneisses. It may have had some resemblance to the gneiss area of southern Norway, however, apart from the fact that the gneiss floor here was overlain by much greater thicknesses of late pre-Cambrian sediments and Cambro-Silurian beds. Also the Seve floor was invaded on a considerable scale by basalts and other eruptives in the form of dykes or stocks. We may suppose that their extrusive products represent a part of the overlying layered series, to a great extent occurring also in the Cambro-Silurian sediments — in the Köli-schists and in the more well-preserved Cambro-Silurian sediments of the Norwegian "Trondhjem field" (basic and acid lavas and tuffs in the Höllonda-Horg-district and the 2 000 metres thick Stören-group of supposed Tremadocian-Skiddavian age). These westernmost deposits in the Paleozoic are not deep-sea sediments but were lain down on an ocean-bottom which at several times reached sea-level or rose above it. This view is supported by the existence of widespread volcanic ashes and tuffs. The latter probably also reached the contemporaneous eastern areas of the Cambro-Silurian and possibly even the Baltic Cambro-Silurian where thin layers of bentonite occur. These layers are probably records of events occurring in the Caledonian geosyncline area.

A more detailed study of the extent of the crystalline nappes makes it clear that movement has not taken place in a single phase. The deeper lying nappes are often broken or totally lacking over some stretches. This indicates that parts of them have been removed and evidently dragged along in connection with the advance of a higher nappe. From Norway there are examples of an older nappe denuded before the advance of a younger nappe and in this way the new nappe can have overridden the weathering debris of an older nappe. In Sweden the younger thrusting of the horst zones is due to a late phase of movements which have been strong enough to invert the rear, *i. e.* westerly portions, of the older nappes. These facts tally very well with what has been found on the Norwegian west coast. Here small fields of Devonian rocks, younger than the real Caledonian Mountain Chain, have been the subject of small thrust movements with a similar tectonic style (post-Orcadian thrusts of Upper Devonian time).

Compared with other mountain chains of the world the Scandinavian Mountain Chain shows several features of general interest. In consequence of its relatively great geological age it has been deeply denuded. Deep sections to the roots of the nappes are exposed and facilitate study of the tectonics. Compared with the young mountain chain of the Alps the main features are less complicated. This is to a large extent due to the fact that it involves fewer fossiliferous systems. It was also in Scandinavia that thrusts on a gigantic scale were first found (Törnebohm). Without doubt the problems of the Mountain Chain represent one of the most profound and interesting subjects for research which Nature has to offer in Sweden.

Road-log

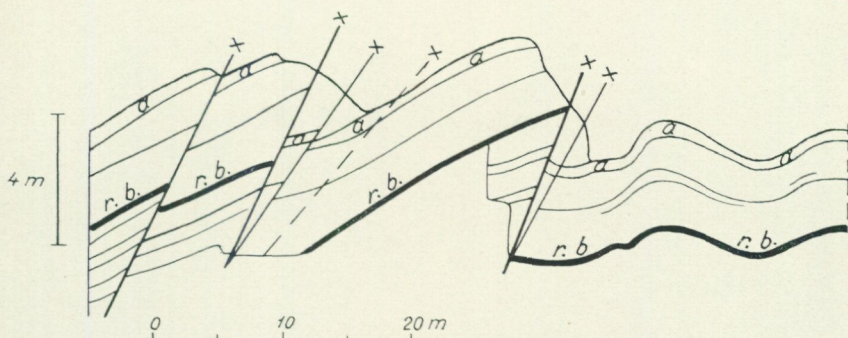
FIRST DAY. BRUNFLO-LOCKNE AREA

1. Arriving at Östersund by train the excursion first takes the road to Brunflo passing the flat or wavy "Cambro-Silurian" landscape: a smooth meadow land with cultivation and a rich settlement. Some outcrops of Ordovician rocks occur along the road. To the south of Brunflo they disappear and are replaced by outcrops of gray Archean Refsund-granite or pre-Cambrian diabase. These occur on a very flat surface — the sub-Cambrian peneplane — which forms a low platform about 325—340 metres above sea-level and just above the level of Lockne-Lake. A short distance from that place we stop on the peneplane and take a short walk to the abrupt rocky hills of the inner and eastern Jemtlandian landscape. The little granite mountain in the front, the *Farskinnet*, is 429 m high and about 100 m above the peneplane surface. It represents an outer part of the inner, eastern Archean areas. Here we also get an excellent impression of the primary boundary between the peneplaned sub-Cambrian basement of the Western Cambro-Silurian area and the old inland "torso" of the pre-Cambrian area. In reality we stand at the highest level which the Lower Cambrian sea reached and hence the limit of the peneplane. This limit is dramatically marked by the steep abrasion cliff. This very characteristic boundary between two geological different areas is still intermittently recognizable over long stretches of the highland Cambro-Silurian, figs. 1 and 2. This old geological boundary permits us to construct also the post-Lower Cambrian deformation of the old 'Baltic' shield and Fennoscandia!

2. Returning to Brunflo the Middle Cambrian alum-shales are to be seen, and also the basal Lower Cambrian conglomerate resting on the Archean Refsund granite. It contains phosphorite pebbles and remains of *Torella laevigata* LINNARSSON in an arkosic coarse-grained mass with fragments of the grayish augen-feldspars of the Refsund granite. Perhaps also some blocks remain showing the contact surface between the glauconitic Lower Ordovician limestone and the Upper Cambrian alum-shale, represented by concretionary limestone. It marks a disconformity with certainly deep erosion of the Cambrian strata.

3. To the North-East of Brunflo church with its defensiv tower from the 12th Century, the Lower Ordovician is represented in the Gråberget quarry by the *Schroeteri* limestone, the uppermost *Orthoceras* limestone of Lower Ordovician age. It shows distinct bedding and signs of tectonism in the form of small thrusts (fig. 8). The latter are more developed in Gustaquarry in the deeper-laying *Platyurus* and *Vaginatium* beds.

4. From the Lunnbomberget, the topmost hill of the Brunflo area consisting of red *Platyurus* limestone and overlying grey *Schroeteri* limestone with a conglomerate between, there is a very wide panorama: to the west the smooth meadows on the Cambro-Silurian, to the south the rather rough palisade of Archean granite hills in a deeply eroded rocky land, to the east the bared sub-Cambrian peneplane zone forming a deep swampy groove between the Cambro-Silurian area and the hilly Archean inner land which reaches 500 to 600 metres and presents an appearance of poverty compared with the agri-



r. b. and *a* mark layers in the limestone series used to deduce the thrust structure. Profile drawn from detailed instrument survey.

Fig. 8. Small thrusts and folds in the *Orthoceras* limestone at Gråberget quarry, Brunflo. — B. Asklund 1944.

cultural land to the west. Farther west the snowy flat highland mountains form a distant background.

5. Leaving the Brunflo-area the very interesting Lockne-area is examined. It represents a rarely exposed part of the old shore-zone of the Cambro-Silurian sea where a couple of transgressions and regressions of the sea have taken place. The area forms a typical archipelago with abrupt hills or monad nocks, of the pre-Cambrian basement separated by deep valleys. In the deepest parts both Cambrian alum-shales and Lower Ordovician shales are to be seen. Middle Ordovician *Chasmops* layers cover them and also form the immediate base layers higher up on the slopes of the Archean hills. These are often covered by a weathering breccia of the disintegrated granite or basalt of the hills, nearly connected with the Middle Ordovician basal layers of conglomerate or conglomeratic calcareous sandstone (so-called 'Loftarsten').

The different *Chasmops* beds will be demonstrated and then, walking to the west along the railway to Skute station, the beginning of more intense thrusting of the dislocated autochthonous Ordovician beds will be studied (fig. 9). The front of the first Jemtlandian nappe with its bottom layers of Cambrian alum-shales is seen before Skute station.

6. On the return to Östersund the contact-surface of the *Chasmops* beds upon *Orthoceras* limestone will be seen. Among the pebbles of the *Chasmops*-conglomerate fossiliferous Cambrian stinkstone is also found.

SECOND DAY. TOSSÅSEN, HALLEN, HOVERBERGET.

1. The rocks underlying the town of Östersund consist of Upper Ordovician *Tretaspis* beds belonging to a second Jemtlandian nappe. Upon them rests the Kyrkås quartzite which is not exposed in the immediate vicinity of the town but at Frösön (etymology: the isle of Frey, the heathen god) opposite the town, it forms a strip along the easternmost and southern shore.



Fig. 9. Overturned fold in front of the Skute Nappe; *Orthoceras* limestone to the right, crushed basal *Chasmops* beds to the left. — At the railway, W. of Lappgrubban. After P. Thorslund 1940.

Seen from Östersund the Hornsberget opposite on Frösön is made up of pre-Cambrian porphyry forming the front of a third Jemtlandian nappe. The road passes through a cutting in this porphyry and higher up on it Cambrian alumshale occurs and a thick bed of *Orthoceras* limestone. At Vallsundet, a ferry-place, the Upper Ordovician Kyrkås quartzite is exposed and upon it rests the thrust Lower Ordovician *Orthoceras* limestone of the third nappe, mentioned above.

The excursion route passes Sunne church with its Varegian quartzite beneath Lower Cambrian beds, now submerged by the raised level of Storsjön-Lake. The road to Hackås passes three poorly exposed Cambro-Silurian nappes. If it is clear weather, however, there will be a good opportunity to admire the wide scenery of the snowy mountains to the west, the Oviksfjällen, made up of thick beds of Varegian quartzite. The road from Hackås to Åsarne is situated on the sub-Cambrian peneplane.

2. At Tossåsen a steep little road from the rather deeply eroded valley in the pre-Cambrian basement leads up to the overlying Cambro-Silurian beds. The profile fig. 10 tells better than words the situation: upon the granite basement rest autochthonous Cambro-Ordovician layers including Cambrian alumshales and Ordovician limestone strata and Lower *Didymograptus* (*Phyllograptus*) shales. Over them a gabbro knob is thrust. It forms a "fossil" cliff of

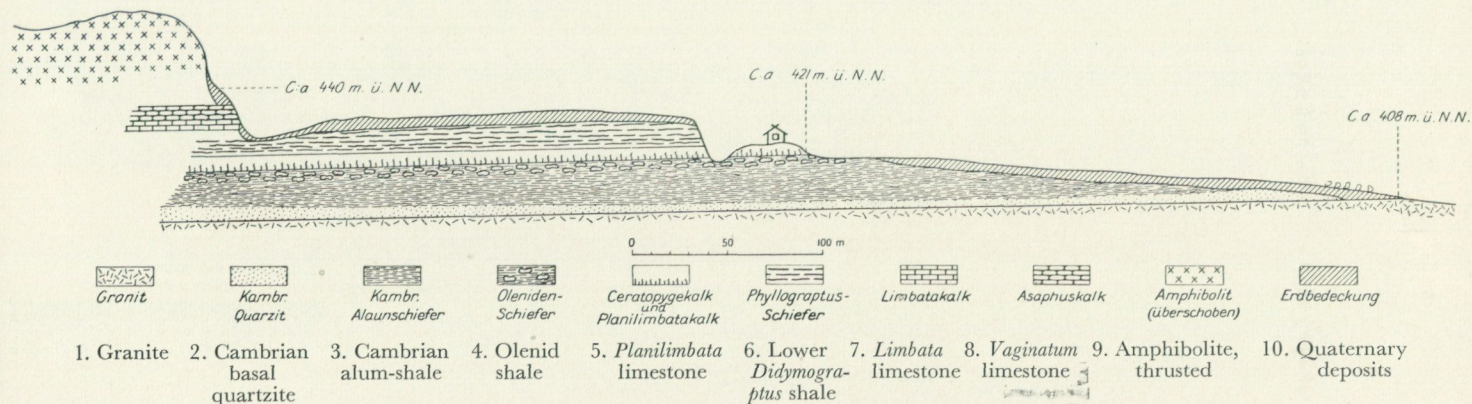
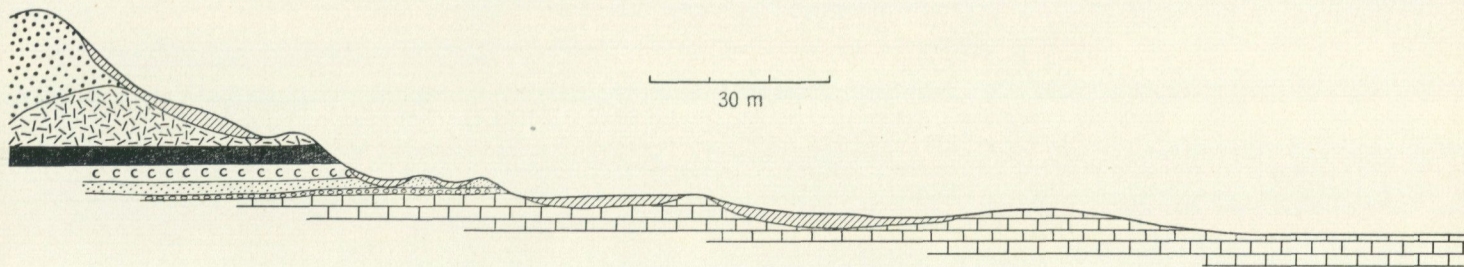



Fig. 10. Profile from Tossåsen (W—E). Shows the Vemdal-quartzite nappe upon the autochthonous Cambro-Silurian. In the front of the quartzite nappe there is a knob of pre-Varegian amphibolite. — From B. Asklund 1938.





Orthoceren-
kalk


1. *Orthoceras*
limestone


Konglomerat


2. Conglomerate


Lofstarstein

3. Basal layer of
the *Chasmops*
beds


Chasmops-
kalk

4. *Chasmops*
limestone


Überschiebungs-
mylonit


5. Mylonite


Granit

6. Granite


Wemdals-
quarzit

7. Wemdals-quartzite


Erdbedeckung

8. Quaternary
deposits

Fig. 11. Profile from Hallen in Åsarna (N—S). — From B. Asklund 1938.

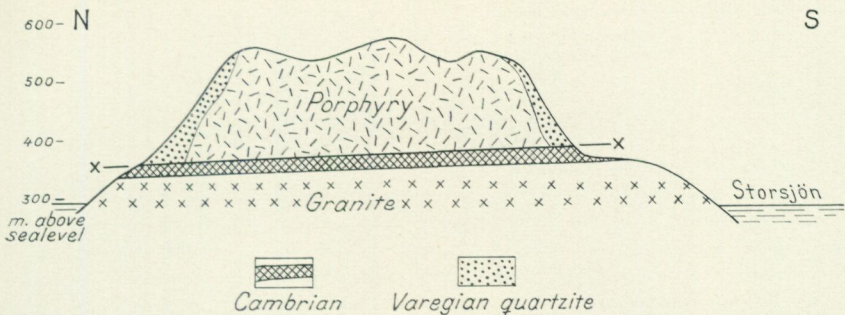


Fig. 12. Hoverberget, profile. A remnant of the Vemdal-quartzite nappe with a central porphyry mountain surrounded by a "collar" of quartzite and resting upon a thin layer of autochthonous Cambrian which lies on the peneplained Archean granite. — B. Asklund. 1958.

the Vargian quartzite nappe. The contact-surface between the glauconitic *Planilimbata* limestones and the basal beds of the Upper Cambrian are exposed beneath a little wooden bridge. The whole thickness of the Cambro-Silurian strata at Tossåsen is about 30 metres.

3. At Hallen in the parish of Åsarna a much thicker part of the Cambro-Silurian remains beneath the thrust-plane of the quartzite nappe. The unexposed Cambrian alum-shale is about 17 metres thick according to a diamond drillhole placed to the East of Skåland Lake situated about 10 kms to the SW of Hallen. Above the Cambrian strata follow Ordovician beds whose lower part is the same as at Tossåsen. Resting on them are the upper parts of the Lower Ordovician *Orthoceras* limestone. The Lower Ordovician has been estimated to have a thickness of about 90 metres and is overlain by a thin bed of the Middle Ordovician *Chasmops* group. It begins with a conglomerate containing pebbles of the eastern Archean granite and a bed of calcareous sandstone very similar to the 'Loftarsten' from Lockne. The fossiliferous *Chasmops* limestone above is a few metres thick. Upon it follows abruptly a mylonitic rock of granitic composition, forming a little cliff or hill at the bottom of the gray Vemdal quartzite of the quartzite nappe. The locality, with its wide lower platform of outcropping *Orthoceras* limestone, is an extremely convincing one for demonstrating the thrust principle (fig. 11). In the vicinity of it the author long ago ordered a digging from the lowermost quartzite-layers. They rested upon an entirely disintegrated mylonite-rock lying on a blue and hard *Chasmops* limestone with very distinct thrust-ripples.

4. Returning to Östersund there is an opportunity of taking a trip round the curious little mountain called Hoverberget. Its central part is made up of porphyry. This is surrounded by an incomplete "collar" of Vargian quartzite which originally must have covered the whole of this small pre-Vargian porphyry mountain. The little remnant of the quartzite nappe and its basement rock rest on a thin layer of Cambrian, the arkosic basal layers of which contain Lower Cambrian fossils (*Torellella laevigata*). They are to be seen on the

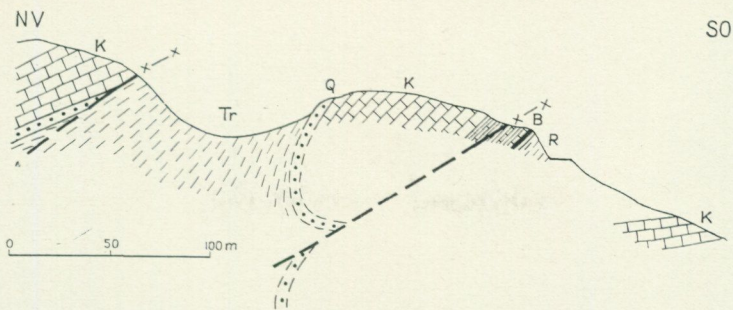
NW-side of the mountain. Beneath them the pre-Cambrian peneplane forms a very flat surface with numerous outcrops (fig. 12).

THIRD DAY. ALSEN—OFFERDAL.

Leaving Östersund the route is taken over Frösön, the old centre of the County Jemtland. An account will then be given of the history of the old "land" called Jemtland. From the Frösö church a panorama will be seen of cultivated and richly settled districts round the Storsjön Lake and the beautiful snow capped mountains to the west. Passing the ferry at Rödösundet the road goes over the great Föllinge nappe of unexposed greywacke and slate.



Fig. 13. Gneissose mica-schists of the Seve nappe at Glösabäcken rivulet, parish of Alsen. — B. Asklund and Th. Lundqvist photo. (1959).



Tr = *Tretaspis* shale; Q = *Phacops* quartzite; K = *Pentamerus* limestone; R = Upper graptolite shales; B = layer of bentonite.

Fig. 14. Schematic section drawn at Berge, parish of Offerdal. — After P. Thorslund 1948.

1. At *V a l n e* the uppermost part of this great Cambro-Silurian area is exposed with the bottom layers of the Silurian present, represented by the *Phacops* quartzite and the *Pentamerus* limestone. Only a short distance to the west the hidden thrust plane of the Olden nappe will be passed, the deepest layers of which are typical greywackes and schists. These may be Lower or Middle Ordovician judging by finds of graptolites in similar rocks farther to the west.

2. On the southern slope of the little hill called *R ö d e b e r g e t* the upper beds of the Olden nappe are exposed. They begin with dark-coloured slates and reddish slates which unfortunately have yielded no fossils but may be supposed to belong to the *Tretaspis* beds. They are overlain by grayish green sandstone or quartzite and on top of them there is a strongly deformed conglomerate with pebbles of granite, porphyry, quartzite etc. This conglomerate has the same stratigraphical position as the Offerdal conglomerate which will be studied in a more complete development later in the day when its stratigraphical position can be more profitably discussed.

Upon the conglomerate follows very abruptly the highly pressed Seve schist capping the little mountain. After some consideration the situation of the thrust-plane may be fixed and by studying the Seve schist on the little summit it will be recognised as a mica-schist, highly deformed and contorted. We may imagine that the original rock of the gneiss was a granite and the deformed product a granite-gneiss mylonite.

3. At the *G l ö s a - r i v u l e t* to the north of the Alsen Lake we find a new, well-exposed locality, where the thrust-plane is to be seen. The upper outcrops at the rivulet are made up of a typically massive gneissose mica-schist whose homogeneous appearance favors an origin from a granite (fig. 13). On well exposed outcrops in the rivulet there are rock-carvings from the "Arctic" Stone Age. These represent elk and reindeer, which were probably attracted to the waterfall and slain by hunting tribes. The thrust plane is to be seen between the mica-schist and the quartzitic sediments beneath it. The thrust-zone itself is characterized by a dense mylonite.

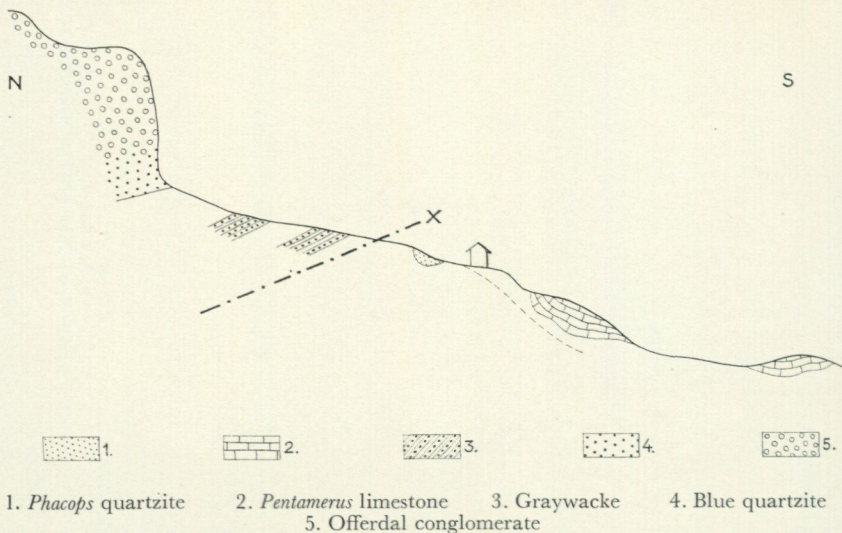


Fig. 15. Profile from Berge, Offerdal, showing the thrust boundary between the Olden nappe and the Föllinge nappe. — From Asklund 1938.

4. Along the road to Offerdal the Olden nappe again is left behind and there are several outcrops of the upper part of the under-lying Föllinge nappe to be seen. They are for the most part made up of the *Pentamerus* limestone which may be about 100 metres thick in this region. There are several good localities for sampling fossils in this area but there is, however, no time for it.

5. Arriving at Offerdal the wooded landscape again thins out. The northern background is dominated by the abrupt thrust-mass of the Seve nappe. Beneath it a somewhat lower terrace of the Olden nappe occurs. Beneath the latter the low-lying meadow land is occupied by the fertilising limestone-rich strata of the Silurian at the top of the Föllinge nappe.

Taking a steep road uphill there is exposed at Berge a very interesting little profile of inverted Silurian layers. At the side of the road occurs black *Rastrites* shale with several graptolites and some thin beds of a grayish slate, recognized as bentonite, overlain by the zone of *Monograptus turriculatus* and its subzone with *Rastrites linnaei*. Behind them stand inverted layers of the *Pentamerus* limestone and the *Phacops* quartzite, lying upon the *Tretaspis* shales of the Ordovician (fig. 14).

The upper surface of the Föllinge nappe is very contorted in detail and shows folding and imbrication beneath the adjacent thrust-plane of the Olden nappe. A little higher the rocks of that nappe are seen to consist of alternating layers of common graywacke and slate. At the foot of the little knob Kläppen black slates are developed and upon them a coarse bluish quartzite or sandstone — a 'blue-quartz' — of about 20 metres thickness. It forms the transition to the uppermost beds of the coarse Offerdal-con-

glomerate (fig. 15). In a feldspar-rich groundmass it holds countless pebbles and rounded blocks of granite and porphyry, quartzite and quartz. The pebbles of igneous rocks are often richly coloured and a dark reddish porphyry is especially noticeable. They are often of head-size and from other parts of the conglomerate blocks of granites are known of up to 1 to 2 metres. Here and there the conglomerate is rather strongly pressed and contains secondary minerals like greenish epidote; other parts are, however, very well preserved.

The stratigraphic position of the conglomerate, which may be estimated to have a thickness of about 200 metres, has been much discussed. Högbom and also Törnebohm considered it to be of pre-Cambrian age and belonging nearest to the sparagmite group. Its superimposition on Cambro-Silurian rocks was recognized as anomalous. A more detailed study of the occurrences of conglomerate made by the author has proved that the conglomerate undoubtedly rests on the Cambro-Silurian strata of the Olden nappe and also contains detritus from these. The question will again be taken up at Rönnöfors (on the 5th day).

6. Returning from Berge a short trip is taken to Ekeberg a few km to the north on the western side of the Offerdal nappe. The thrust plane of the nappe sinks down a good deal and the conglomerate becomes thinner and disappears for a stretch. The front of the Offerdal nappe is seen at Ekeberg where a typical strongly schistose and flat-lying mica-gneiss is exposed. The thrust plane is hidden and we may suppose that at this place the underlying Olden nappe is very thin. Beneath it a very interesting locality shows the topmost part of the Silurian in Jemtland and also of the Swedish part of the Caledonian mountains. In a road-cutting, a greywacke-like sandstone with thin layers of dark-coloured slate is exposed. In an intraformational little conglomerate bank the coral *Favosites gotlandicus* forma *forbesi* has been found. It may belong to the Wenlock beds.

7. At the beautiful little mountain called Kaxås the basal layers of the Olden nappe are exposed. Leaving the Föllinge nappe with its *Pentamerus* limestone and 'upper' graptolitic strata we note that the foot of Kaxås marks the thrust plane beneath the Olden nappe. On the south-eastern slope of Kaxås greywackes and shales of the Middle Ordovician occur and also a limestone bed at their base, probably a part of the Lower Ordovician *Orthoceras* limestones. The complex rests upon a whitish gray quartzite of the main Vargian type. Also the basal member of that sedimentary series is seen as a northernmost knob of porphyry at the summit of the hill. Here we have a good locality where the Vargian Quartzite lies directly on the porphyry, filling up small cavities in it.

8. On the way to the lodgings for the night the road at Nordbyn passes a new little porphyry knob of the Olden nappe. The porphyry-surface has small spots of a quartzite-conglomerate smeared on it and the thin quartzite bed is overlain by strongly deformed slates and also here a limestone bed belonging to the Lower Ordovician. A short distance from that place the strongly deformed and contorted front of the Olden nappe is exposed and also the Silurian series of the uppermost part of the Föllinge nappe beneath it (*Pentamerus* limestone, *Phacops* quartzite etc.).

9. The lodging-place Helleberg is situated upon a little hill of the

Olden greywacke occurring as a diminutive outlier of the Olden nappe. Beneath it we see the flat-lying Silurian limestone. The contact-plane between the upper Olden nappe and the Föllinge nappe has here been penetrated by a boring for water.

The panorama from the Helleberg is very wide: with good visibility the summits of Sylarna in a SW direction on the Norwegian boundary (about 100 km away) can be seen. In a SE-direction a good deal of the cultivated landscape round the Lake Storsjön is visible.

FOURTH DAY. ÅRESKUTAN

1. This day is reserved for a trip to the mountain called Åreskutan, one of the most well-known mountain attractions for tourists in Sweden. The road passes the rather monotonous area of greywackes and slates of the Olden nappe. At several places there have been found graptolites belonging to the Middle Ordovician (*Climacograptus*, *Diplograptus* etc.). At Järpen we will stop to see the typical development of the probably very thick beds with good primary structure. At Hålland there is a beautiful view over a waterfall of the uppermost beds of the Olden nappe, the *Pentamerus* limestone of the Rista falls.

2. Suddenly we leave the flat land and catch sight of the magnificent Åreskutan. A rather hard excursion (about 15 km on foot) lies before us. But this is eased by the mountain-railway and the lift from 400 m to about 850 m height. Then there is a good path to about 1 000 m: s above sea level and after that the highland-mountain heath is fairly flat going.

At the upper lift station there are wide outcrops of the typical Seve rocks. In the lower part of the mountain they mainly consist of "Åre-gneiss", a rather homogeneous schistose grayish rock which may be described as a coarse mica-schist or a garnet-gneiss for the most part. Megascopic *foliae* of muscovite and bronze-brown biotite are abundant in a mixture of quartz and feldspar. Garnet is common and cordierite and sillimanite occur in varying amounts. The feldspars especially the microlite-perthite can form augen-like individuals. The light-coloured components are often separated as pegmatitic or aplitic veins and sometimes occur in separate masses. As a whole the typical Åre-gneiss is very similar to the Archean veined gneisses known from vast districts of southern and northern Sweden and also from south-eastern Norway. Ascending higher on the mountain the Åre-gneiss shows spots or inclusion-like fragments of leptynite-looking, more fine-grained gneiss and pyroxene-garnet-bearing rocks, very like "skarn" *i.e.* reaction products of impure original limestone beds. There also occur spots of fragments of crystalline limestone in connection with "skarn"-rocks. Higher up on the mountain and at Tvärån visited later on the excursion day spots and streaks of amphibolites are to be seen.

Wandering on the mountain heath the sparse outcrops do not show anything else of interest but the major features of the adjacent terrain can be recognized in the panorama view. To the left a flat mountain rises to about 1 100 m, the Mullfjället, with lead-coloured slopes of porphyry rocks forming an anticline. On its eastern slopes the Vargian quartzite rests and forms small conglomeratic zones upon the porphyry. The quartzite is overlain by the slates and

greywackes of the Olden nappe. The whole complex falls beneath the syncline which the Seve nappe forms at Åreskutan.

3. Coming to the valley of the river called the Tvärån on the western side of the mountain we have very good exposures of the Seve rocks along the little river. Upstream there are massive Åre-gneisses of gneiss-granite aspect with recognizable feldspar crystals but also some garnet individuals. They have a certain schistosity falling to the N or NNE. In the outcrops of the river bed there occur several flat-lying dikes of a red-coloured pegmatite with a distinct intrusive appearance. Up the right branch of the rivulet the gneissmass contains "pockets" of more fine-grained rocks and among them occur thin layers of crystalline limestone. "Skarn"-rocks are also visible here as well as amphibolite which partly seems to form flakes of fragments in the gneiss.

There is no opportunity here of discussing the origin of these typical Seve rocks but the author will offer his interpretation of them as found at this locality and similar places elsewhere in Jemtland and Southern Lappland. First there is the profound fact established by Törnebohm that the real metamorphism of the Åre-gneisses in their central part is not related to the main 'Caledonian' metamorphism, involving all rocks of different kinds subject to deformation along the thrust planes and in more or less immediate connection with them. Törnebohm meant that the Åre-gneiss and Seve rocks had a 'primary' metamorphism analogous to that of Archean gneisses. The occurrence of the garnet-gneisses exposed at Tvärån with pegmatite dikes nearly as undeformed as in the Archean gneisses or the remnants of a supracrustal rock complex in them, reaction 'skarns' against siliceous limestone, indicates quite different metamorphic circumstances from the normal deformative metamorphism of the rock masses subjected only to Caledonian stress. The latter only gives the uniform schistosity and foliation of easily deformed material such as slates and other sediments.

Passing along the Tvärån rivulet it is easy to recognize where the undoubtedly Caledonian stress begins. Only some hundred metres along the rivulet and below the gneisses described the Seve rocks become increasingly schistose and suddenly we meet an intense deformation zone marked by a little waterfall where the gneiss loses its previously more evident structure and is transformed into a more massive unit of fine-grained mylonitic rock. It rests upon quite different rocks. These are strongly foliated and contorted and have alternating layers of dark grey schist, light-coloured quartzite and the beds of a dolomitic limestone.

At this locality it may not be easy to appreciate the fact that the boundary between the upper gneiss-series and the lower schist-quartzite-dolomite series is a tectonic plane of major significance. It is in fact a thrust plane between two parts of the Seve rocks. The Lower series represents the Serv nappe and the upper one the 'real' Seve nappe! However, we can recognize a difference between the two complexes: the inner part of the upper one has a more northerly dip of its schistosity whilst the lower one, together with the thrust-zone has a flat, more easterly dip of its strongly developed schistosity. There exists a tectonic "angle discordance" and it is obvious that the Caledonian phase of deformation is younger. The geological significance of these facts is that the more central masses of the 'real' Seve rocks bear evident traces of a pre-Caledonian tectonic metamorphic structure, which is often still dominant and must be kept apart from the real Caledonian metamorphic structural elements. If these facts are

overlooked, there will arise very severe misunderstandings regarding the metamorphic structures as a whole. Törnebohm, with his exceptional field experience of the Seve rocks, undoubtedly founded the right view concerning the problem of double metamorphism when he compared the older metamorphic element of the Åre gneisses with the metamorphism of the Archean gneisses. Högbom also emphasized this similarity between the Åre gneisses and the Archean veined gneisses. He also had much experience of the widely distributed veined gneisses of the Archean complex of Norrland — the northern part of Sweden — or what is named the 'coast-gneiss' on the western side of the Bothnian Gulf. The present author has, during a long period of field work in the Swedish highlands, come to the same view. The main mass of the 'real' Seve rocks is veined gneiss and garnet-gneiss or gneiss-granite, often augen-bearing rocks. The leptite like or calcareous skarn rocks and slaty schists occurring among them seem to be a complex of Archean supracrustal elements and the granitic or basaltic rocks which invaded them. The whole has subjected to a plutono-metamorphism which gave them a characteristic stamp already in Archean time. The Caledonian thrusting has transported these masses almost *en bloc* to new positions at the same time exerting intense (*i.e.* Caledonian) deformation and metamorphism.

The discussion above has only touched upon some of the major problems of the Scandinavian Mountain Chain.

Wandering further along the little Tvärån a steeper zone of small waterfalls is reached. The lowest part of the crystalline rocks adopts a more massive appearance and suddenly ceases with a massive bank of mylonitic rock which can be compared with the granite mylonites of other localities. Beneath it a dark gray Cambro-Silurian schist is exposed in directly connection with the overlying Seve rocks. At this locality we can lay our hand upon the thrust-plane and without any doubt accept the fact that only the thrust-theory is able to explain the abnormal superposition of the Great Seve nappe. The Tvärå-profile has had considerable significance for the 'highland-problem' of the Swedish Mountain Chain since it is one of the places where Törnebohm established the applicability of his thrust-theory to the Mountain Chain.

4. From Tvärån it is a rather long way over swampy terrain to the next localities in the lower part of Ullån. On the slope near Ullån some small outcrops of greywacke belonging to the Olden nappe occur. The lowermost small waterfalls have a stream-bed of Silurian *Pentamerus* limestone. Beneath it the *Phacops* quartzite is also exposed as a thin bed. On the flat outcrops of the strongly stretched limestone small Crinoid stems are recognizable.

5. A short trip is taken to Tegefors, where the porphyry of the Mullfjäll-anticline forms outcrops in the stream-bed.

FIFTH DAY. RÖNNÖFORS-OLDEN

1. The route goes to the north from Helleberg passing the Föllinge and Olden nappes. At Rönnöfors it turns to the NW and passes the greywackes in their fullest development for a stretch of about 10 kms. They will be studied at the bridge over the river Långan where alternating black slates and sandstone-like beds of greywacke are well exposed on the northern side.

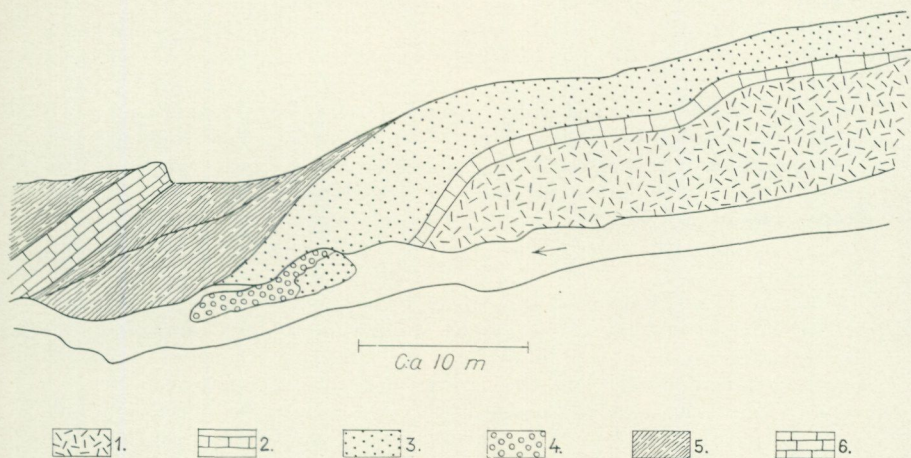


Fig. 16. Schematic section through the basal layers of the Væregian quartzite and the basal beds of the Ordovician resting upon them. Fisklösaån Rivulet, Olden. — From Asklund 1938.

1. Granite. 2. Basal breccia. 3. Væregian quartzite. 4. Phosphorite conglomerate.
5. Ordovician shale. 6. Ordovician limestone.

2. The basal beds of the Olden nappe are visible at the little river Oldån and the rivulet Fisklösaån. At the bridge over Oldån this river forms a canyon about 20 m deep in the grayish white Væregian quartzite which is very similar to the Vemdals-quartzite seen, for example at Hallen (2nd day). Here the Væregian quartzite may have a thickness of about 50 m. At Fisklösaån the basal layers of the Væregian quartzite are found lying upon the Olden granite. They consist of a partly conglomeratic sediment breccia with fragments of the granite, quartz and quartzite in a feldspar-rich matrix. The granite is grayish and somewhat porphyric, indicating a hypabyssic structure.

At a little islet in the stream-bed the Væregian quartzite is exposed and we may estimate its thickness to be about 10 m (fig. 16). It is overlain by small "plates" of a very significant phosphorite conglomerate with small pebbles of phosphorite and phosphoritic sandstone in a sandstone matrix. The conglomerate is only a few cm thick and is overlain by a black, rusty, pyritic slate. This continues on the opposite side of the stream and is overlain by a limestone bed, 10—20 m thick. The limestone in turn is overlain by typical lowermost beds of the Olden nappe, the black slates and alternating grey-wackes.

The limestone bed has a very wide extension as seen from the map of the pre-Quaternary rocks of Sweden. It occurs near the base of the Cambro-Silurian of the Olden nappe, round the large anticline of the Olden granite. For the most part it is separated from the granite by an intermediate layer of Væregian quartzite. However, to the north this layer seems to be denuded and the phosphoritic basal conglomerate of the Cambro-Silurian rests directly

on the granite (at Grubbålsån). There the author has found undeterminable stems of graptolites quite near the basal conglomerate and hence it seems improbable that Cambrian beds occur. The limestone may be supposed to represent a part of the Lower Ordovician *Orthoceras* limestone which it resembles.

From the Olden-area and from a small farm called Frankrike, there is an opportunity of getting a view of the Olden-mountains. Their summits reach 1 300 m and are thus nearly 1 000 m higher than the sediment mantles at their feet. We have stated previously that the Olden nappe has a well exposed thrust-plane at its base. Now we are able to state that this nappe contains basal crystalline elements, "geological cliffs", with a thickness of more than 1 000 m.

3. Returning to Rönnefors the uppermost part of the Olden nappe there will be studied. In a road-cutting strongly folded greywacke and slate is exposed as sharp vertical folds. Near the school at Rönnefors this series is seen in direct contact with an overlying blue-coloured quartzite, which has pebbles of different rocks and passes into a conglomerate, the so-called Rönnefors conglomerate. This is a local representative of the Offerdal conglomerate, at the same position in the stratigraphic sequence and with unevenly spread transition layers of blue quartzite as already observed at Berge in Offerdal. The pebbles of the conglomerate are mostly made up of grayish granite identical with the granite from Fisklösaån at Olden. There also occur pebbles of porphyry and quartzite and fragments of the under-lying black slate. At the next locality, situated some hundred m from the former there are outcrops of the conglomerate on both sides of the road. Only sixty or seventy m from the last outcrops the mica-schist of the Offerdal nappe is exposed. The rock has a strong schistosity falling 30°—40° to the east. Also even if the thrust plane at this locality is not directly exposed the abrupt nature of the tectonic discordance can be appreciated. The mica-schist of the Offerdal nappe here belongs to the granite mylonite-gneiss similar to that seen before at Ekeberg and at Rödeberget. The road then crosses the Offerdal nappe. The Olden nappe here is cut away on the eastern side of the Offerdal cap.

4. If there is time available the route will be taken to the north along the eastern frontier of the Offerdal nappe. It forms a high wooded plateau above the flat land of Cambro-Silurian rocks with a still rather rich settlement. The thrust plane lies upon the *Pentamerus* limestone, which is visible at Skärvången beneath the steep cliff of the Offerdal nappe.

5. Then the road again crosses the Offerdal nappe and there will be opportunity to see its basal members, intensively stretched mica-schists similar to well bedded sediments but formed under the pressure. It is difficult to understand the origin of these peculiar rocks. Most of the evidence speaks for metamorphic differentiation of their material and their geological relationships suggest an origin from granitic rocks.

6. Near Lake Hotagen there is a part of the Offerdal nappe with rocks which are more easily determinable. Originally at a time when the rock-metamorphism was not very advanced they were thought to be a sort of "porphyry-schists". They are in fact granite mylonites, originally augen granites, which under stress have been transformed to porphyry-looking rocks. The

problem is to decide whether the eyes are primary or secondary. The author believes that primary porphyritic feldspars have had layers added to them later. Sometimes the augen individuals have joined with each other and now form bands or streaks.

7. At Rötviiken the road passes a steep anticline of the Cambro-Silurian rocks of the Olden nappe. To the north the Offerdal nappe plunges downwards and develops a very interesting series of deformed granites. Parts of the latter are, however, very little deformed and there can be no doubt as to their primary granitic character. They contain fragments of older rocks (leptites, gabbros etc.). Along the road to Valsjöbyn there are unsurpassable opportunities of studying the very varying development of the deformed nappe: parts of it are pressed to grayish or grayish green mylonites, sometimes with muscovite-porphyroblasts. Other parts have remnant primary granitic structure and even syenitic varieties exist. A third part has the appearance of "porphyry-schists" as described above. The studies of the "granite-mylonite nappe" give the impression that during thrust movements it became divided into a couple of different lenticular or sheet-formed blocks which were subjected to very different degrees of deformation: some parts were intensively crushed and pressed, especially along their boundaries, while at the same time other parts remained mainly intact.

8. At Valsjöbyn quite near the Norwegian frontier, the granite-mylonite nappe is overlain by an upper nappe. It is made up of sediments, quartzites and black slates and contains invading dikes of 'diabase' or basalt. As the base it has a somewhat dolomitic limestone or marble bed. The appearance and stratigraphy of this upper nappe is the same as that of the Serv nappe in Herjedalen, and the outlier of the latter forms an uppermost sheet on the Offerdal nappe (compare the "Pre-Quaternary Rocks of Sweden").

9. Passing the deeper strata of the Föllinge nappe, the locality where Professor Carl Wiman long ago found fossils in the series of greywackes and slates in the vicinity of Föllinge will be shown; also the *Orthoceras* limestone subjacent it.

SIXTH DAY. TÅSJÖ AREA.

1. From Strömsund the road goes over an eastern nappe of the Jemtlandian nappes which here form the boundary with the Archean. At Löverbärga the sub-Cambrian peneplane is reached, here forming a broad shelf with outcrops of the Refsund granite to a height of about 300 metres. The geomorphological boundary against the hilly inner 'main land torso' with heights of more than 400 m is discernible. At Hoting the road has entered the typical hilly inner landscape.

2. From Hoting the road on the eastern side of Tåsjö Lake will be taken. At *Tåsjö Östra* by a rivulet called *Sågbäcken* descends from the Tåsjö Mountain. A flat platform extends along the foot of the mountain, culminating at a height of 320 m. This is the niveau of the sediments upon the basal Archean granite and in the stream bed of the rivulet there occurs a flat-lying conglomerate, made up of pebbles of granite and quartzite in a coarse quartzose mass. This conglomerate is considered by the author to belong to the



Fig. 17. Alum-shale at the road on Tåsjö Mountain. — B. Asklund and Th. Lundqvist photo (1959).

Varegian quartzite-series, not to the Cambrian. Upon it follows a serie of Cambrian alum-shales, comprising the Middle Cambrian *Paradoxides paradoxissimus* beds, a bed only 0.1 m thick of the *Paradoxides Forchhammeri* zone and the lowermost beds of the Upper Cambrian. Upon this autochthonous Cambrian series which is completely undeformed follows a quite different Cambrian series resting on an allochthonous slice of Varegian quartzite. It begins with a contorted alum-schist containing intercalations of a bluish quartzite. The schist includes a thin limestone bed yielding strongly deformed fossils which probably belong to the *Paradoxides oelandicus* beds. The complicated Cambrian stratigraphy in Sågbäcken rivulet has been thoroughly investigated by the author and Professor P. Thorslund. We found that the Cambrian here is made up of two divisions, the upper one being allochthonous. This feature was found to be the key to the understanding of the structure of the very thick Cambrian strata of the whole of Tåsjöberget. On the present excursion we have unfortunately no time for a general demonstration of these interesting circumstances.

2. At Tåsjö Church the Tåsjö Mountain rises 400 m:s above the level of the lake (248 m) to 651 m. It may be supposed that Cambrian beds occur on the unexposed Archean platform. Exposed on the side of the mountain at about 300 m:s height are the *Paradoxides paradoxissimus*-beds which, however, here belong to the allochthonous series. This also outcrops in another rivulet situated 2 km:s to the south of the church where, on an autochthonous (?) series of

alum-shales, occurs a zone of *Paradoxides oelandicus*-shales, containing *Paradoxides Torelli* WESTERGÅRD and *Paradoxides pinus* WESTERGÅRD. These fossils represent the upper zone of the Lower Middle Cambrian over the whole Sweden. The alum-shales show very sharp incompetent folding (fig. 17). They have a "false" thickness of about 350 m:s and reach nearly to the top of the mountain with fossiliferous beds here belonging to the Upper Cambrian (*Olenus* beds). Upon them lies the Vargian Ström quartzite nappe, with a thin basal slice of Archean granite at several places. Its contact with the subjacent alum-schists is exposed at several localities in the rivulet stream bed. Unfortunately there is no time for studying these very interesting circumstances, but a short trip on the road to Granberget will be taken to examine the quartzite nappe.

3. At Brattbäcken along the road to Norråker the autochthonous Vargian quartzite is exposed only a few metres over the level of the lake. In the Tåsjo valley commence the occurrences of autochthonous Vargian quartzite which to the north are seen in every river valley through most of the northern part of the Mountain Chain (the Laisberg series of O. Kulling).

4. At Högnäsån the basal beds of the Cambrian alum-slate upon the Vargian quartzite are visible. At the base there is a layer of calcareous phosphoric conglomerate a few decimetres thick, studded with fragments of *Paradoxides*. The uppermost limestone bed, closely connected with the conglomerate contains *Paradoxides* cf. *paradoxissimus*. Stinkstone-concretions in the alum slate only one metre above the conglomerate contain *Peronopsis fallax* (LINNARSSON) and *Ptychagnostus punctuoculus affinis* (BRÖGGER) according to determinations by Thorslund and Westergård (the latter fossil, by Thorslund was previously supposed to be *Agnostus intermedius* compare fig. 18). Fig. 18 gives a review made by the author including the fossil determinations of Thorslund. By the stratigraphical results from Högnäsån and other localities in the neighbourhood of the Tåsjo Lake it is obvious that the autochthonous series begins with Middle Cambrian, the basal zone being *paradoxissimus*-layers. Whether Lower Cambrian was deposited and then eroded we do not know, but it is represented to the north in the County of Vesterbotten, 40—60 km:s from the Tåsjo Lake.

5. *The Sjougdälven River*. This area gives the best opportunity in the southern part of the Swedish Mountain Chain of getting a comprehensive picture of the autochthonous Cambrian, the subjacent Vargian beds and the Sparagmite formations. At present the Sjougdälven River and adjacent Saxälven River are the subject of imposing hydroelectric investigations and in consequence the rocks of the area have been bared at many places or have been the subject of tunnelling. There are thus excellent opportunities for geological research.

From the bridge over the Sjougdälven River we start a walk on the northern side of the river. On the opposite side we can see some outcrops of Cambro-Ordovician slates forming small isoclinal folds. These slates are Upper Cambrian beds of alum-shale, and the basal part of the Ordovician, the *Dictyonema* slate. Upon them there is a limestone-bed, the *Planilimbata* limestone and upon that a rather thick black argillaceous shale, the *Phyllograptus* shale or Lower *Didymograptus* shale. There is no time to study this whole series (fig. 19). On our side of the river we meet at Abborrfallet a beautiful little waterfall, exposing the Cambrian series represented by fossiliferous *Paradoxides Forchhammeri* beds and subjacent *Paradoxides paradoxissimus* beds.

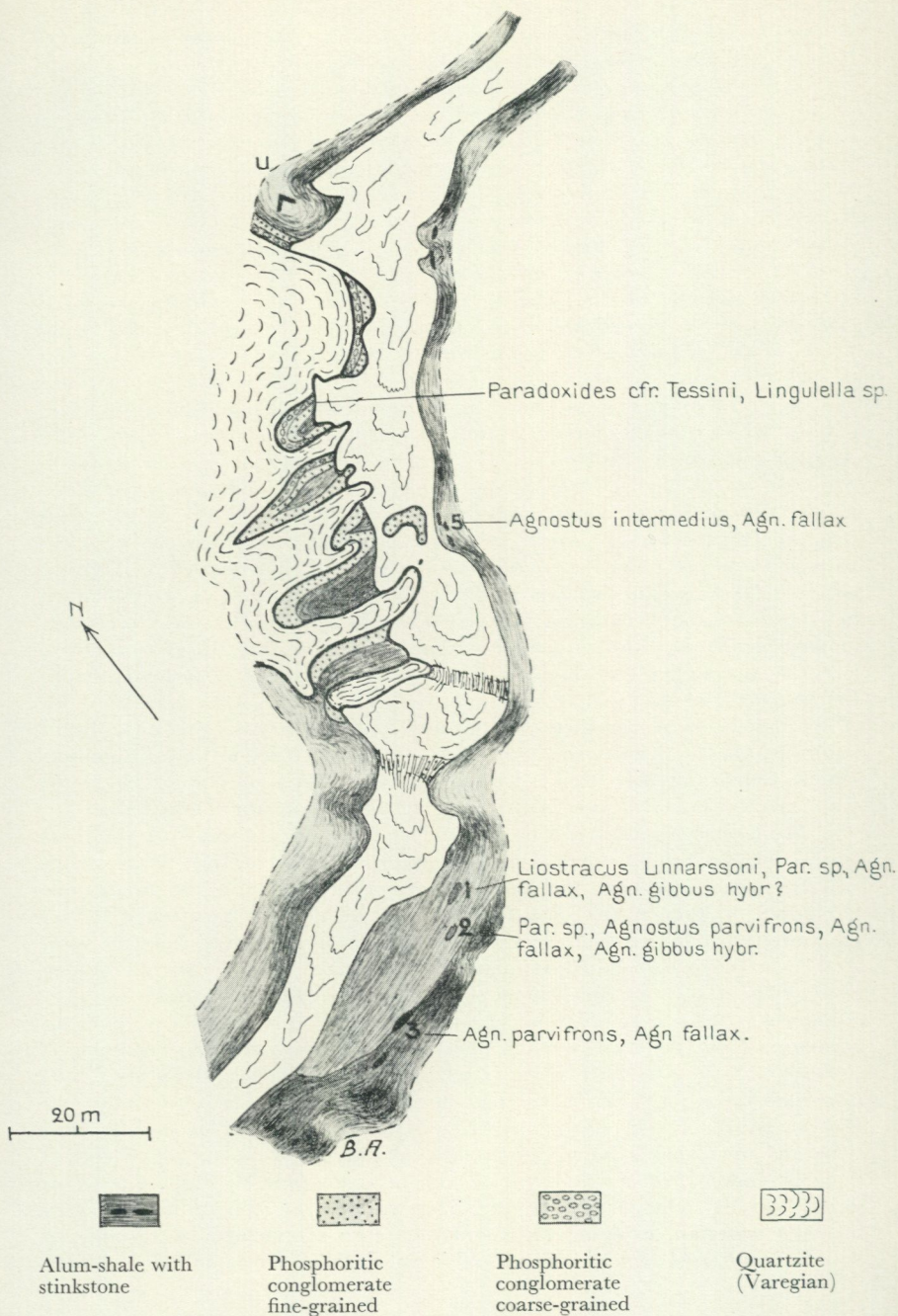


Fig. 18. The contact-zone between Cambrian and Væregian at Höganäsån River, parish of Tåsjö. — After B. Asklund and P. Thorslund 1935.

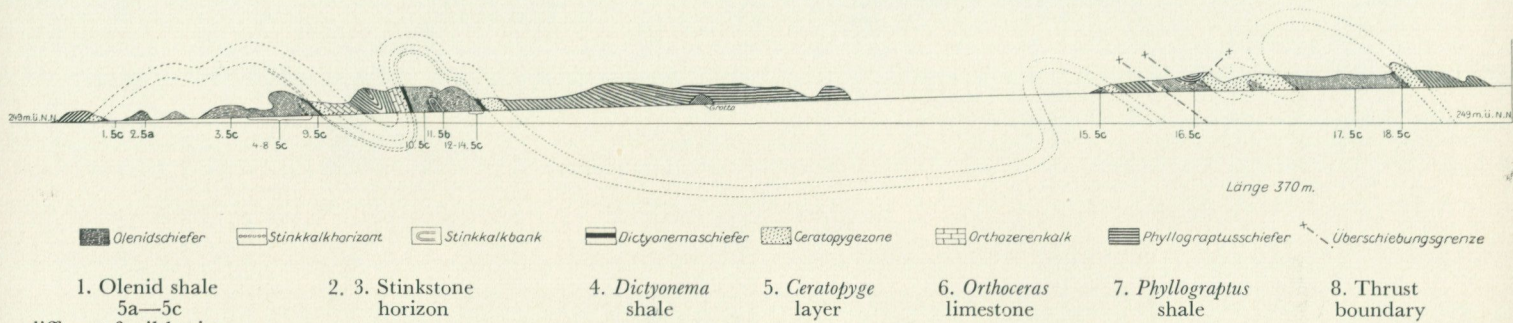


Fig. 19. Profile drawn along the western side of the Sjougdälven River showing the Cambro-Ordovician strata. — B. Asklund 1938.

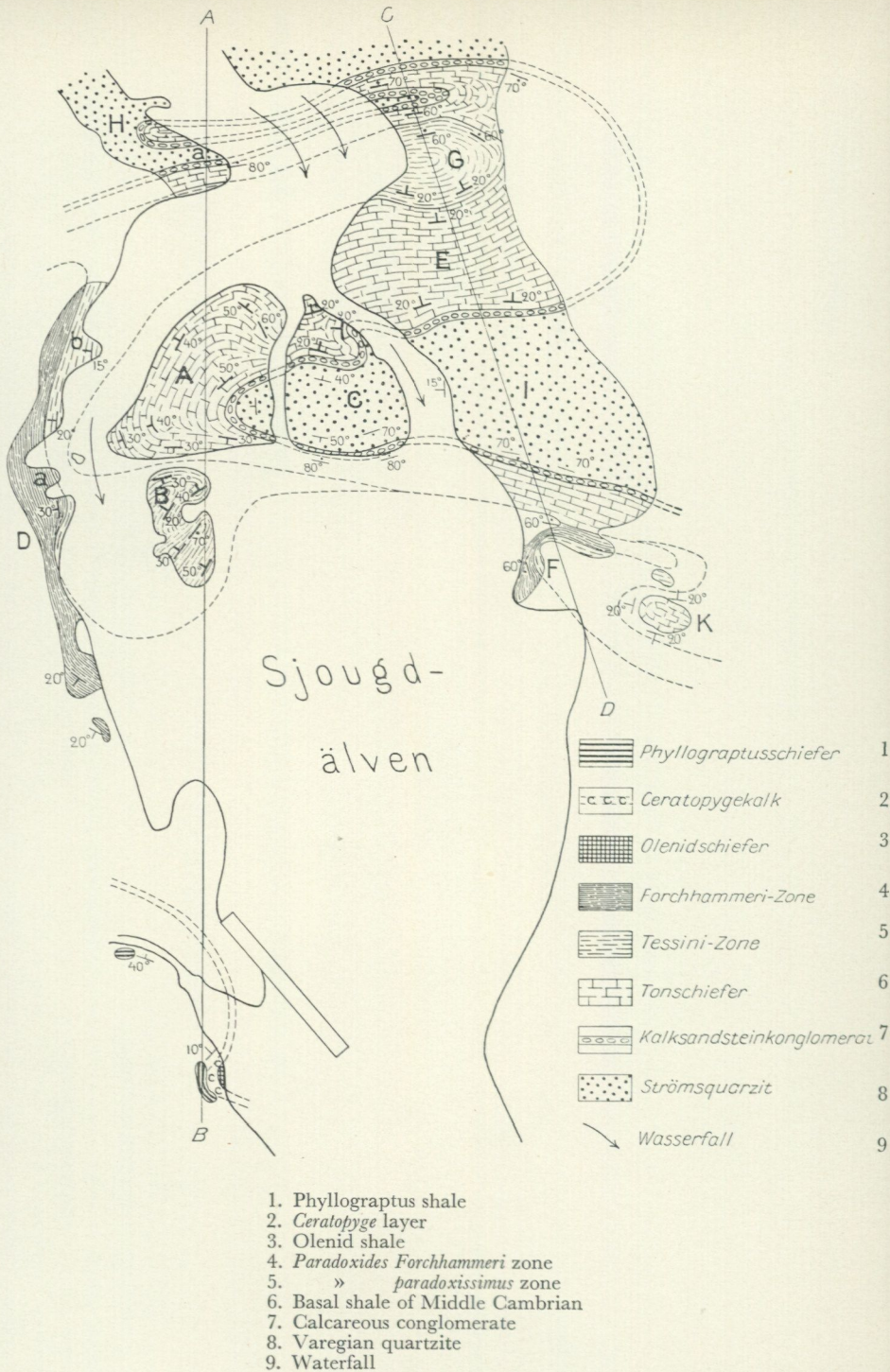


Fig. 20. Map of the contact-zone between the Væregian quartzite and the lower Middle Cambrian beds. Abborrfallet waterfall at Sjøugdälven. 1: 1 000. — B. Asklund 1938.

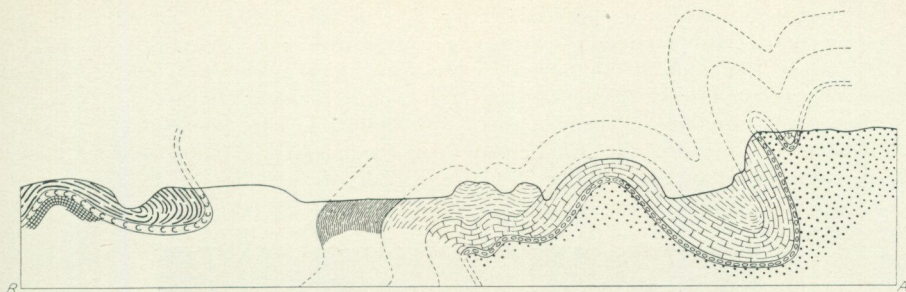


Fig. 21. Section drawn through the Abborrhallet contact zone between Væregian and Middle Cambrian, profile A—B on fig. 20. Signs are the same as in fig. 20.

The latter develop at their base a grayish green slaty rock which rests upon a 1—2 m thick conglomeratic calcareous sandstone. Parts of the latter, especially the uppermost part, are developed as a real dense limestone, similar to the basal Middle Cambrian fossiliferous limestone at Högnäsån. These are the basal layers of the *paradoxissimus*-zone, the lowest occurring zone of the Middle Cambrian. They rest upon typical Væregian quartzite which seems to have been weathered before the subsequent sedimentation and contains small hollows filled with the calcareous sandstone conglomerate.

The superposition of the Middle Cambrian beds on Væregian quartzites is very similar to the superposition by fossiliferous Lower Cambrian beds found by the author in the southern part of Lapland (*Holmia*-beds containing *Hyolithellus* etc.). The basal bed of Cambrian alum-shale sediments is of the same type for different Cambrian zones. — It is interesting to see the complicated folding of the contact zone between the different sediment-groups at Sjougdälven (figs. 20, 21).

Together with Professor P. Thorslund the author has made an estimate of the Cambrian strata of Sjougdälven which can be summarized as follows:

(Ordovician: <i>Dictyonema</i> shale	0.5)
Upper Cambrian (Sub-zones 1—5 c)	21—23 m
Middle Cambrian: <i>Paradoxides Forchhammeri</i> -beds	15—18 m
» <i>paradoxissimus</i> -beds	19 m
Cambrian beds	55—60 m
(Væregian: Gray or bluish quartzite)	

With this succession and the figures in mind it is now convenient to make a comparison with observations from different Cambrian units in the Tåsjöberget to the south. Here no *Dictyonema* shale has been observed in the autochthonous beds. On the contrary, the Ordovician *Planilimbata* limestone (previously considered as *Ceratopyge* limestone) lies directly on sub-zone 4 of the Upper Cambrian and consequently sub-zone 5 is lacking. To the east the Middle Cambrian sub-zones are also thinner, as for instance the *Paradoxides Forchhammeri*-zone in the easternmost rivulet Sågbacken 0.1 m (only *exporrecta* conglomerate).

Thus the Cambrian of the Tåsjö-valley gives the same general picture as the sedimentary beds of the more southern part of Jemtland: the different beds and the whole formation are thinner in the east and thicken westward towards the more central parts of the miogeosyncline. Considering now the upper, allochthonous Cambro-Silurian beds of the Tåsjö Mountain. They commence with a relatively thick bed of the Middle Cambrian *Paradoxides oelandicus*-zone. This is estimated by the author to be 20 to 30 m thick. Above it lies the *Paradoxides*

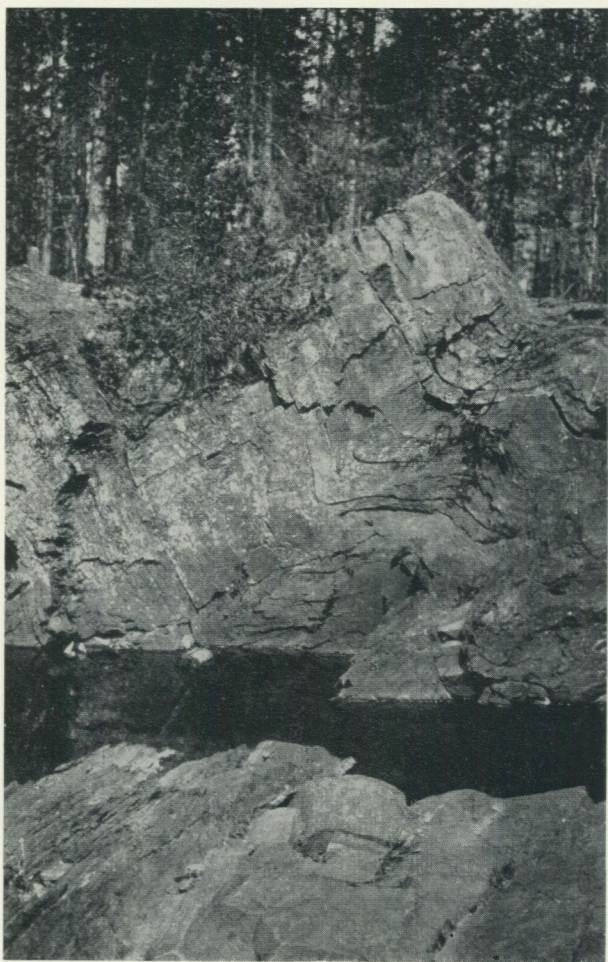


Fig. 22. "Knee-folds" in Værgian shales, to the West of Abborrfallet, Sjougdälven River. Photo P. Thorslund. — From Asklund and Thorslund 1935.

paradoxissimus and *Paradoxides Forchhammeri* beds, which are collectively estimated to be at least 50 m thick. Then 20 m of Upper Cambrian shales. The whole Cambrian series is estimated to be 100—150 m thick and two or three times as thick as the autochthonous series at Sjougdälven. The autochthonous beds at the easternmost locality of the Täsjövalley, Sägbacken, are estimated to be 30 m thick and lie 40 km from the Sjougdälven profile. Assuming the thickness of the whole Cambrian strata has increased proportionally from east to west the quoted figures of their thickness give an opportunity of calculating the distance which the allochthonous Cambrian beds have been thrust. It would be 80—120 kms. Of course such a calculation depends on several uncertain facts, but the order of size is probably about right. It may be added that the allochthonous unit has been supposed to belong to the Föllinge nappe as shown on the general map of the 'Pre-Quaternary Rocks of Sweden' and we may further add some interesting facts concerning the basal parts of the Ordovician. At Sägbacken to the east the allochthonous *Dictyonema* shale is 6 to 8 m thick whilst the *Dictyonema* shale of the autochthonous beds of Sjougdälven 40 km to west is only 1/2 m thick.

After this digression from the vicinity of Sjougdälven we walk farther along the north side of the river. Here a series of different sediments are exposed, including blue or grayish quartzites, grayish green shales and whitish quartzites or conglomeratic quartzites. They are often folded in rather sharp small monoclinical folds with nearly perpendicular angles between the synclinal or anticlinal ("kneefolds", cf. fig. 22). After passing a covered area we finally find at a little waterfall beautiful exposures of a new member of the Væregian strata, the red and green slates. They represent a very characteristic layer of the Væregian and are met with along the whole Scandinavian Mountain Chain (= the Norwegian Ekre slates). They are estimated to be 50 to 75 m thick. From here we return, because the terrain grows more severe along the river. However it may be added that by continuing up the path the whole of the Væregian series may be seen. Beneath the slates mentioned follows a thick layer of a coarse feldspathic quartzite with sparse beds of grayish green slates. They rest upon the tillite which was found here by the author in 1933, the first certain find of this pre-Cambrian tillite in Sweden. It here rests upon the red sparagmite. The stratigraphy of the sedimentary complexes has been summarized in the following way (Asklund, 1935):

Cambrian strata with basal layers of the
Paradoxides paradoxissimus-zone 55 to 60 m
 Major hiatus

Væregian strata:

Alternating quartzites and grayish green slates	— 67 to +87 m
Red and green slates (Ekre slates)	50 to 75 m
Coarse quartzite with grayish green slates	100 to 200 m
Tillite	25 m
	"Boundary"-values 240 to 380 m

Major hiatus

Red sparagmite-sandstone more than



Fig. 23. Tillite with a block of veined garnetiferous gneiss and post-Archean granite (to the left). — Photo B. Asklund and Th. Lundqvist 1959.

6. The profile continues now along the road to Norrsjön. Along parts of the road hydroelectric building-works have exposed wide areas of the rocks. Parts of these areas may be seen. Two km from a little farm *Korsselbränna* a road-cutting is exposed in the tillite and this locality speaks for itself. We recognize among the tillite blocks of granite and porphyry a special kind which is obviously a post-Archean but pre-Cambrian eruptive belonging to the 'Subjotnian' eruptive province of Fennoscandia. It has been transported from the West from unknown basal areas of the miogeosyncline. From the same area numerous gneiss fragments may have come. There are veined garnetiferous gneisses which recall the typical central Seve gneisses of Åreskutan, now in a certain pre-Caledonian environment (fig. 23)! In the greenish gray tillite, which is supposed to represent the deepest tillite-layers the main material is of the Refsund granite from the eastern Archean.

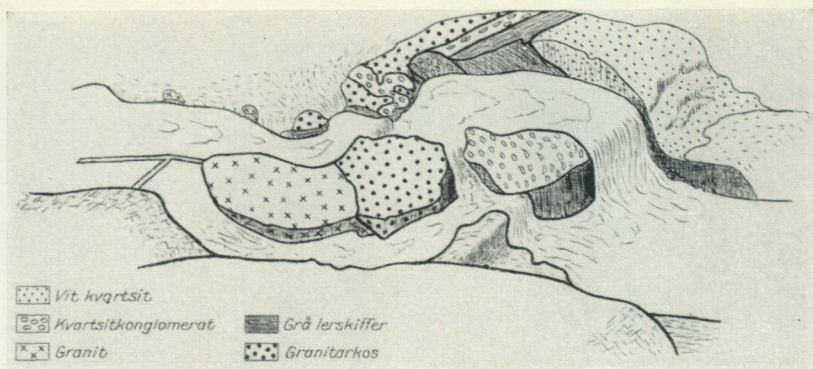
7. To see the next locality at *Erik Mattslet* a short walk is necessary.



Fig. 24. The sub-tillitic surface with ice scratches. Surface exposed by dynamiting. In the upper part of the picture a thin layer of the tillite remains. Erik Mattsselet at the outflow of the Sjougdälven River from the lake. — Photo B. Asklund and Håkan Hopstadius 1959.

Leaving the Vargian, great exposures of the red sparagmite are seen at the outlet of Sjougdälven from the little lake Erik Mattsselet. A small bridge arranged for the excursion members will allow a visit to the southern side of the river where large outcrops of the red sparagmite occur. Along the shore another rock rests on it as a thin plate: we recognize it as the tillite, partly developed as a varved slate of glacial origin. The place is exceptionally good for seeing the contact surface between the tillite and the subjacent red sparagmite. Thanks to the courtesy of the Bålforsen Hydroelectric Power Company (Bålforsens Kraft Aktiebolag) the author was able to arrange for the contact surface to be exposed by dynamiting. An area of about 2 sqm is exposed and reveals ice-scratches and glacial striation. The rock is somewhat elevated and has a westerly dip. The ice-scratches indicate an ice movement from $N20^{\circ}-40^{\circ}W$, quite similar to the Quaternary direction, so we may postulate that the north-pole was situated at its present place! If we are not convinced we can note that at several localities the deepest morainic material with pebbles of the Refsund granite must emanate from the east and this requires an ice movement from the east. Certainly both have taken place (fig. 24).

8. If there is time an excursion to the west will be made to see the north-westernmost part of the Föllinge nappe. At some places it lies on the autochthonous Cambrian; at other places, as for instance in the tunnel to the north of Erik Mattsselet Lake, it lies directly on the Vargian quartzite and the Cambrian is removed.



- | | |
|-----------------|------------------------|
| 1. Quartzite | 4. Gray-coloured shale |
| 2. Conglomerate | 5. Granite arkose |
| 3. Granite | |

Fig. 25. Contact-zone between the Værgian basal layers and the pre-Værgian granite at Storån. — Drawing by B. Asklund 1935.

9. Finally there may be opportunity of seeing the inverted red sparagmite and the gray sparagmite at Norrsjön. The latter becomes very thick and in the next river valley, the Korpån-valley to the north, it is more than 1 000 m.

SEVENTH DAY. THE STRÖM-VALLEY PROFILE.

1. Taking a new road from Korsselbränna (Norråker) the excursion passes the contact zone between the Föllinge nappe and the subjacent autochthonous "horst" zone composed of Cambrian, Værgian and the red sparagmite. In the vicinity of Fånån fossiliferous greywackes and black slates occur with graptolites (*Diplograptus*, *Climacograptus* etc.) indicating a Middle Ordovician age.

2. At the main road along the "Ström Water-valley" between Alanäs and Bågede the greywackes and shales of the Föllinge nappe come very near the Værgian quartzite of the horst-zone represented by a bluish quartzite at Lidsjön. At that place the strata are not inverted but the horst is lifted so that the Föllinge nappe dips at a small angle to the east. Continuing to the west the Værgian series is passed, with bluish or whitish quartzites and then red and green shales.

3. At Storån-river there is an excellent locality for seeing the basal layers of the Værgian formation on the pre-Cambrian granite which form the major part of the horst-zone (fig. 25). At a little hydroelectric station here the Værgian quartzite is well exposed. It is developed as a whitish arkose with a high content of feldspar. Outcrops of the granite are then visible on the right side of the river. Passing an old embankment leading to an islet in the river we are able to see fresh granite with weakly pink-coloured feldspars and bluish quartz. Towards the contact zone it becomes gray or grayish green with a rough surface. It is the weathered and probably kaolinized superficial granite, hardly

separable from the granite arkose. On the eastern side of the islet a coarse conglomerate is developed containing well rounded pebbles of quartz and quartzite etc. in a coarse arkosic matrix of original granite gravel. Looking to the eastern side of the stream we can see the conglomerate overlain by gray argillaceous slate and upon this the white Varegian quartzite.

The Storån locality is interesting as here no tillite occurs. A relatively high part of the Varegian series is here in direct contact with the granite floor. The thick sparagmite divisions occurring only 10 km to the north are absent giving the appearance of a large hiatus between the deposition of the Varegian and the Sparagmite groups.

4. Along the road to Bågede there are exceptionally good possibilities of studying the increasing deformation of the granite horst zone to the west towards the thrust zone of the Seve nappe. The coarse augen-granite becomes more and more schistose and mylonitized. Many interesting details may be observed: boudinage structure of basalt (diabase) dikes in the granite mass, the occurrence of aplitic dikes and masses, obviously primary, without the increasing augen gneiss structure. There will be opportunity of discussing the question of feldspar growth.

5. At Bågede the first of the Seve nappes is met with. The very strongly deformed mica-schist raises the problem of its origin. Following Törnebohm the author is inclined to suppose that this lowest part of the Seve complex is here made up of granite-mylonite analogous to the strongly deformed mica-schists of the Offerdal nappe to the South.

6. From Bågede a new road goes via an embankment over the broad river, and reaching Svanningen the profile of the autochthonous granite horst-zone is repeated. At the eastern end of the Ringsjön Lake the basal zone of the sparagmites has a very unique development. Lying on the weathered and possibly kaolinized granite is an arkosic quartzite conglomerate, several metres thick and containing larger rounded pebbles of the underlying granite. The dip of the contact is to the east but a transverse deformation also occurs with a dip to the west. Upon the conglomerate follows a series of gray or dark gray slates and near the road greywacke like rocks alternating with gray sparagmite containing fragments and pebbles of granitic material. This series has been estimated to have a thickness of about 70 m. It represents a part of the lowermost 'Gray Sparagmite-formation' which is very unusual in Sweden but very similar to the lowest part of the Norwegian Gray Sparagmites, the Bröttum Sparagmite.

Only a short distance from the granite surface the red sparagmite series lies on the gray sparagmite. The contact surface between the two divisions is difficult to find and no coarse conglomerate occurs. However, after thorough examination it is clear that there exists a sharp contact, distinguished by the different colours of the rocks and by somewhat coarser clastic structure in the red sparagmite. To the east the red sparagmite is fully developed with a marked reddish brown colour. Some layers are rich in pebbles of granite and porphyry, sandstone, quartz and feldspar fragments. The brilliant red sparagmitic complex here has been estimated to have a thickness of about 400 metres, beneath the Varegian formation. The latter in this area contains an upper tillite layer, lying on the deepest feldspar rich quartzites of the Varegian. According to this single

observation there seem to exist two different tillite beds of the Væregian similar to the stratigraphy of Finnmark in northernmost Norway.

The landscape of Svaningen gives some idea of the primary sub-Sparagmitian and sub-Væregian land surface of Archean rocks. It has evidently been a hilly landscape with small abrupt knobs of granite and gabbro, submerged beneath a 'Gray Sparagmitian' sea-level and later on regenerated after a period of deep denudation. Then the 'Red Sparagmite' division was deposited, obviously during a period of accentuated aridity, giving rise to the red-coloured deposits with sudden conglomerates. The red sparagmites often lie directly on the Archean surface indicating a pronounced hiatus between the red and gray divisions and complete removal of the latter. Also the red sparagmite group has totally disappeared over certain stretches as we have already seen at Storån. Thus it seems obvious that the Archean of the growing horst zones had already before the sedimentation of the sparagmites a pronounced relief. Combined with up-doming of the horst and related thrusting many complicated smaller tectonic problems have come into existence.

7. Returning to the main road the lowest part of the Seve nappe will be studied in a series of road-cuttings between Bågedede and Sjulåsén. To the east, some outcrops of a mica-schist are to be seen, in part fine-grained and with an obvious layered structure. Some layers recall the quartzite and quartz-rich schists of the Serv nappe and it is an open question if this tectonic element also occurs. On the "Pre-Quaternary Rocks of Sweden" the author has designated this zone as the granite-mylonite nappe only. A short distance to the west these more compact rocks are overlain by coarse mica-schists with large flakes of muscovite and layers or lenses of quartz. These flat-lying or slightly west dipping rocks represent a zone of very strong deformation which the author believes to be the thrust-zone between a subjacent outer nappe of the Seve complex, beneath the huge "real" Seve nappe.

8. The "real" Seve rocks form a marked thrust front a little to the west. There are road-cuttings in the typical garnet-mica-gneiss to the west of the Sjulåsén farm. The really compact Seve gneiss contains layers of garnetiferous amphibolite, the amphibolite forming several characteristic small mountains along the 'Water-valley'. There is no time for more study of the Seve rocks, except at Gäddede, the last lodging place on the journey in Sweden. Here there will be an opportunity of studying the outcrops of the Seve amphibolite with associated pegmatite-dikes near the waterfall at the Gäddede bridge.

EIGHTH DAY. GÄDDEDE TO THE NORWEGIAN BOUNDARY.

If there is an opportunity two localities on the road to Norway with typical veined gneiss with garnet, cordierite etc. will be demonstrated, north of Kvarnbergsvattnet Lake. This coarse type has, according to the author's view, the primary traces of the pre-tectonic metamorphism of the Seve complex similar to the very little deformed cores of the small dunitic peridotites of this area.

Near the Norwegian boundary at Bränna the Köli complex with its soft mica-schist, greenstone etc., and phyllitic beds of the Cambro-Silurian are met with. The strongly deformed Portfjäll conglomerate is the last item of interest on the Swedish side of our Mountain Chain.

Concluding remarks

In order to facilitate the reading of this paper some correlation tables regarding the strata of the Cambro-Silurian and late pre-Cambrian groups are here appended as well as a scheme for the different nappes of the southern part of the Mountain Chain and adjacent areas. The autochthonous series in Table I is essentially a summary given by P. Thorslund. The Olden nappe scheme is by the author as are also schemes II and III.

As a general excursion map "Karta över Sveriges berggrund, skala 1 : 1 000 000, Mellersta bladet, Sveriges Geologiska Undersökning, Ser. Ba 16" (1957) will be used ('Pre-Quaternary Rocks of Sweden'); price 15 Swedish crowns, available in the bookstores and distributed by "Generalstabens Litografiska Anstalts förlag", Stockholms 16, Sweden. The map has a legend in English language.

Only a few works concerning the excursion area may be mentioned here, however these works contain exhaustive lists of the literature published.

Törnebohm, A. E., 1896 — Grunddragen av det centrala Skandinaviens bergbyggnad. Kungl. Svenska Vetenskapsakademiens handlingar, Bd 28, N:o 5 (summary in German language).

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Asklund, B., 1958 — Le problème Cambrien-Éocambrien dans la partie centrale des Calédonides suédoises, Centre national de la recherche scientifique, LXXVI, Les relations entre Précambrien et Cambrien. Paris 1958.

Thorslund, P. 1940 — On the Chasmops Series of Jemtland. Sveriges Geologiska Undersökning, Ser. C, N:o 436.

I. SCHEMATIC TABLE OF THE CAMBRO-SILURIAN OF JEMTLAND

NO YOUNGER LAYERS		AUTOCHTHONOUS SERIES		FÖLLINGE NAPPE		OLDEN NAPPE		
SILURIAN	Wenlock	Black <i>Tretaspis</i> shale Slandrom limestone		Greywacke and shale Shale with bentonite		Offerdal conglomerate		
	Llandovery			Pentamerus limestone				
UPPER	<i>Dalmanitina</i> layers			Quartzite and shale (hiatus)			Quartzite (with dolomite etc) (hiatus?)	
	<i>Tretaspis</i> layers			Shales with sandstone and quartzite layers Dark-coloured shale Limestone			Red and black shales	
ORDOVICIAN	MIDDLE			<i>Chasmops</i> layers	Limestone Shale Limestone "Loftar-stone" Conglomerate Disintegration breccia		Upper <i>Ogygiocaris</i> shale Lower <i>Ogygiocaris</i> shale	Greywacke and shale
	LOWER	<i>Orthoceras</i> limestone	(hiatus) <i>Schroeteri</i> limestone <i>Platyrus</i> limestone <i>Vaginatum</i> limestone <i>Limbata</i> limestone Lower <i>Didymograptus</i> Shale <i>Planilimbata</i> limestone <i>Lycophoria</i> limestone	Upper <i>Didymograptus</i> shale "Orthoceras limestone" (undivided) Shales <i>Lycophoria</i> limestone	<i>Glossograptus</i> shale "Orthoceras limestone" Shale Phosphoritic conglomerate -- hiatus --			
		<i>Ceratopyge</i> layers	hiatus	<i>Ceratopyge</i> shale				
		<i>Dictyonema</i> layers	(<i>Dictyonema</i> shale) at Sjougdälven	<i>Dictyonema</i> shale				
	CAMBRIAN	Upper	hiatus Alum-shale (Olenid shale)	hiatus Alum-shale (Olenid shale)				
Middle		<i>Par. Forchhammeri</i> <i>Par. paradoxissimus</i> <i>Par. oelandicus</i> conglomerate	alum-shale	<i>Forchhammeri paradoxissimus oelandicus</i> (conglomerate)	alum-shale			
Lower		<i>Holmia</i> shale Calcareous sandstone conglomerate (phosphoritic), hiatus	<i>Holmia</i> shale Calcareous sandstone conglomerate (phosphoritic), hiatus					
PRE-CAMBRIAN		Granite		Varegian quartzite		Varegian quartzite		

II. SCHEMATIC TABLE OF THE LATE- PRECAMBRIAN GROUPS

	WESTERN NAPPES (Olden and Seve nappes)	EASTERN NAPPES Eastern Jemtlandian nappes	AUTOCHTHONOUS BEDS
III CAMBRIAN OR ORDOVICIAN fossiliferous layers	Ordovician basal beds of "Ordoceras limestone" or Lower <i>Didymograptus</i> shale; phosphoritic conglomerate	<i>Holmia</i> beds	To THE NORTH: <i>paradoxissimus</i> beds or <i>Holmia</i> beds To THE SOUTH: Lower Cambrian beds (<i>Hyolithes</i> beds) Calcareous sandstone conglomerate
DISCONFORMITY OR DISCORDANCE II VAREGIAN (= Eocambrian, in restricted sense, ASK- LUND 1935 and 1956)	Quartzites, white or blue coloured, with intercalations of gray slates and subordinate layers of red and green shale (Vemdal and Strömquartzite)	Quartzites with in- tercalations of gray slates	5. Quartzites, white or blue-coloured with intercalations of gray slates 4. Red and green shales (3. Upper tillite bed) 2. Quartzite, coarse and conglomeratic, rich in feldspar 1. Lower tillite bed
HIATUS AND DISCORDANCE I SPARAGMITE DIVI- SIONS "Sparagmitian" (TH. VOGT 1924)	Sparagmite groups absent	Sparagmite groups absent	B. RED SPARAGMITE SERIES: red-coloured feldspar-rich sandstones; rare limestone beds A. GRAY SPARAGMITE SERIES: gray-coloured feldspar-rich sandstones, quartzites, gray-wackes and arkoses, dolomites
GREAT DISCORDANCE	Granites and porphyries (pre-Cambrian but post-Archean; sub-Jotnian)	Granites and porphyries (pre-Cambrian but post-Archean; sub-Jotnian)	Archean granites, porphyries, and gneisses

III. SCHEMATIC TABLE OF THE NAPPES IN THE SOUTHERN PART OF THE
SWEDISH MOUNTAIN CHAIN.

III. THE GREAT SEVE NAPPE (ASKLUND 1938)

3. *The "real" Seve nappe*, including the Kõli schists and Seve rocks
 2. *The Serv nappe* (STRÖMBERG 1955)
 1. *The Granite-mylonite nappe*. Outliers: Offerdal nappe, Alsen nappe, Fuda nappe, Frönberg nappe (in Dalecarlia)
-

II. QUARTZITE NAPPES

Vemdal quartzite nappe to the South.

Ström quartzite nappe to the North.

Both quartzite nappes have recently been shown to coincide with the Olden nappe (see below).

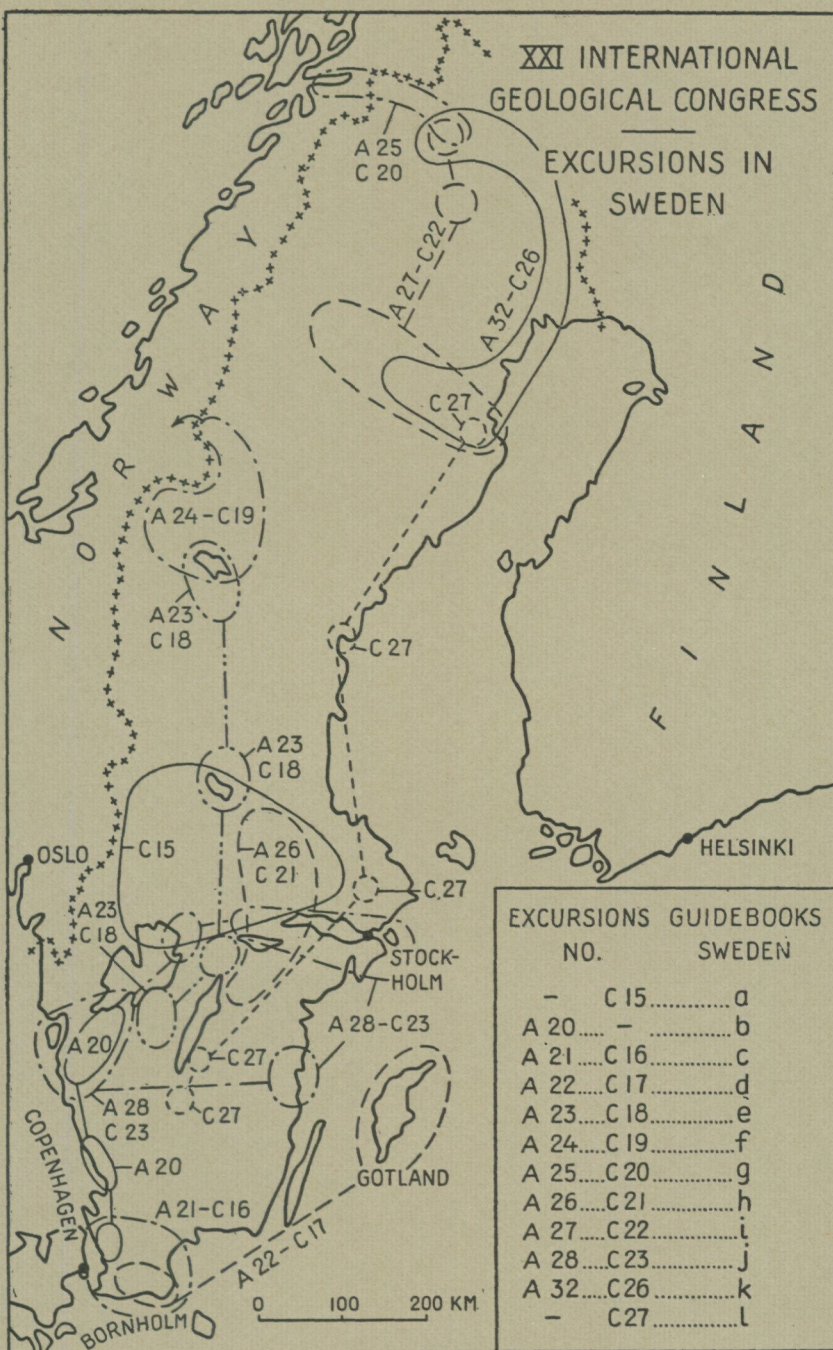
I. JEMTLANDIAN NAPPES (ASKLUND 1938)

5. *Olden nappe*, ASKLUND 1938
 4. *Föllinge nappe*, ASKLUND and THORSLUND 1935
 3. *Sunne nappe*, ASKLUND and THORSLUND, ASKLUND 1938
 2. *Bjärme nappe*, THORSLUND 1940, ASKLUND 1938
 1. *Skute nappe*, ASKLUND and THORSLUND, ASKLUND 1938
-

(BASAL BEDS: Autochthonous Cambro-Silurian or Archean floor to the east.)

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