SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ba ÖVERSIKTSKARTOR MED BESKRIVNINGAR N:O 16

DESCRIPTION TO ACCOMPANY THE MAP OF THE PRE-QUATERNARY ROCKS OF SWEDEN

BY

N. H. MAGNUSSON, P. THORSLUND, F. BROTZEN,

B. ASKLUND AND O. KULLING

With one map in three separate sheets

in the scale 1:1000000

STOCKHOLM 1960

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PREFACE

The Geological Survey of Sweden could the fourth of Juli 1958 celebrate the first century of its existance. As director (1951—1958) I decided upon publishing a new map of the Prequaternary rocks of Sweden in 1 : 1 million. I am naturally myself in the first instance responsible for this map. Many geologists within and outside the Survey have, however, cooperated in putting together the material for the map. It has been real teamwork.

For the southern part of the Caledonian Mountains B. Asklund has been the leader and for the northern part O. Kulling. G. Kautsky has made important contributions. Among the assistants for the southern part of the Caledonian may be mentioned A. Strömberg and G. Stålhös and for the northern part G. Bexell, N. Marklund and H. Johansson.

For the Cambro-Silurian, Mesozoic and Tertiary sediments outside the Caledonides J. Eklund has assembled the relevant material.

For the pre-Gothian, Gothian and Dalslandian of southwestern Sweden W. Larsson and P. H. Lundegårdh have left important contributions and I have during several excursions discussed the problems of this region with them. P. H. Lundegårdh has drawn the map of the Precambrian region north of Gävle as far as Sundsvall and made some corrections for the region north of Sundsvall. The map of the Precambrian of the county of Västerbotten is taken from the map of S. Gavelin with the corrections necessary as a consequence of the investigations of G. Kautsky in the Skellefte field. For the Norrbotten county the newly published map of O. Ödman has been used.

The colours and symbols outside the Caledonian Mountains have been chosen by myself in consultation with M. Lundqvist. For the Caledonian B. Asklund has taken part in the consultations and the colours are in this region essentially those he has proposed. E. Björk, M. Ekman and B. Lindeberg have done the drawings. M. Lundqvist and O. Hedbom at the Institute of Cartography have supervised the printing.

I much regret that the discription of the map has been delayed. I have myself written the description of the Precambrian rocks outside the Caledonian Mountains. P. Thorslund has written about the Cambro-Silurian, F. Brotzen about the Mesozoic and the Tertiary, B. Asklund about "The geology of the Caledonian Mountain-Chain and of the Adjacent Areas in Sweden", and O. Kulling "On the Caledonides of Swedish Lapland".

To all persons mentioned above and to the many whose names have not been included but who have cooperated in various ways in the production of the map I wish to express my deepest gratitude.

Stockholm in May 1960.

Nils H. Magnusson

To my predecessor as Director of the Geological Survey of Sweden, Professor Nils H. Magnusson, I wish to express my gratitude for the energetic and purposeful work, which he after his retirement has bestowed in order to bring to an end the description of the new petrological map of Sweden. I am also very obliged to professor P. Thorslund, University of Uppsala, for his account concerning the Cambro-Silurian areas and its stratigraphy.

I hope that the description of the map will be a contribution of considerable value to a wider information of the Prequaternary geology of Sweden.

Stockholm in May 1960.

K. A. Lindbergson

CONTENTS

The Swedish Precambrian outside the Caledonian Mountain Chain

By

Nils H. Magnusson

On the new map of the Pre-Quaternary rocks of Sweden younger and older Precambrian rocks are distinguished. For the younger Precambrian, Swedish geologists have long used the term *Algonkian* and for the older Precambrian the term *Archean*. The former term has been used on the new map but not the latter, because the upper limit of the Archean in different countries has been placed at different ages in schemes of age relations. Some countries only use the term for much older rocks than those dominating the older Precambrian of Sweden.

In the scheme on the map therefore these older Precambrian rocks have been divided into Karelian, Svionian, Dalslandian, Gothian and pre-Gothian rocks, belonging to as many cycles or periods. The order in the scheme is not the order of age. The Karelian and Svionian cycles dominate in Norrland, that is Sweden north of Gävle, and in the eastern part of Central Sweden. The Dalslandian, Gothian and pre-Gothian cycles on the contrary dominate in southwestern and southeastern Sweden.

The age relations found through field observations and through absolute age determinations have shown that the order of the cycles from the oldest to the youngest is: pre-Gothian ⟶ Svionian ⟶ Karelian ⟶ Gothian ⟶ Dalslandian. In the following the cycles and their rocks will be described in this order.

The pre-Gothian Cycle

The rocks of this cycle appear only in southwestern Sweden where they form a broad belt from Scania to the Norwegian frontier, north of Lake Vänern. For large parts of this belt there are no modern geological maps. To get a uniform picture the rocks are divided into grey gneisses, augen-gneisses in the grey gneisses, red gneisses, augen-gneisses in the red gneisses, hyperites in the red gneisses, and amphibolites. Because in the northern part of the grey gneiss-region a division of the gneisses into red and grey gneisses has been impossible in the absence of geological maps the rocks have been designated as alternating grey and red gneisses. Supracrustal remnants in the gneisses have been given a special designation as also the charnockites of the Varberg district.

The homogeneous grey gneisses contain quartz, plagioclase (oligoclase or andesine), biotite, and often also hornblende. In some types muscovite, too, appears in essential amounts. In the more intermediate gneisses microcline ap-

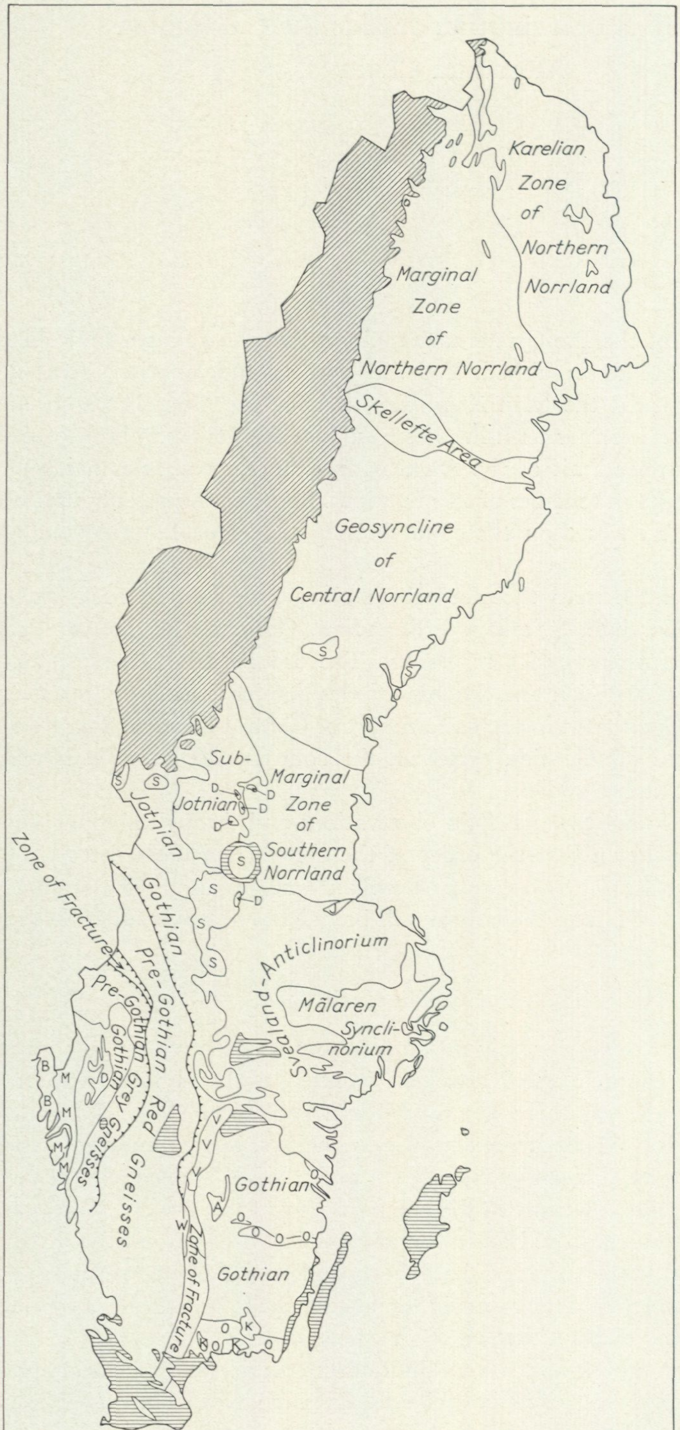


Fig. 1. Map of the tectonic zones and regions of the Precambrian of Sweden (B = Bohus granite, M = Stora Le-Marstrand series. D = Dalslandian sediments, K = Karlshamn granite, O = Older Gothian rocks, A = Almesåkra series, V = Visingsö series, S = Subjotnian rocks).

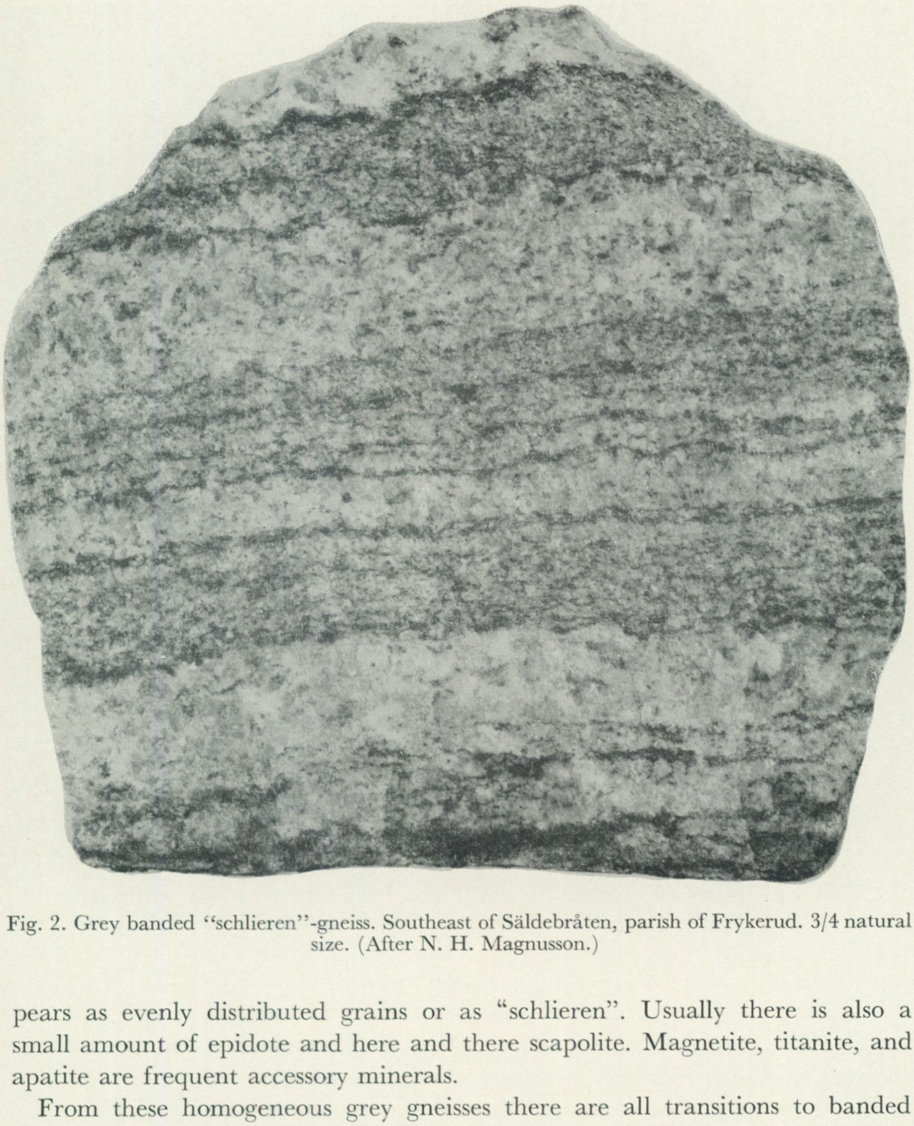


Fig. 2. Grey banded "schlieren"-gneiss. Southeast of Säldebråten, parish of Frykerud. 3/4 natural size. (After N. H. Magnusson.)

pears as evenly distributed grains or as "schlieren". Usually there is also a small amount of epidote and here and there scapolite. Magnetite, titanite, and apatite are frequent accessory minerals.

From these homogeneous grey gneisses there are all transitions to banded types and "schlieren" gneisses in which red gneisses and amphibolites also appear as bands or "schlieren".

In the transitional types to the banded grey gneisses there is a more and more marked tendency for the plagioclases to gather together in white bands alternating with dark bands rich in biotite and hornblende, often together with garnet.

The amphibolite-bearing zones are even more complicated as a result of the exchange of material between the amphibolites and the gneisses. The amphibolites are then often replaced by hornblende-rich transition types often with small concentrations of such minerals as garnet, hornblende and augite.

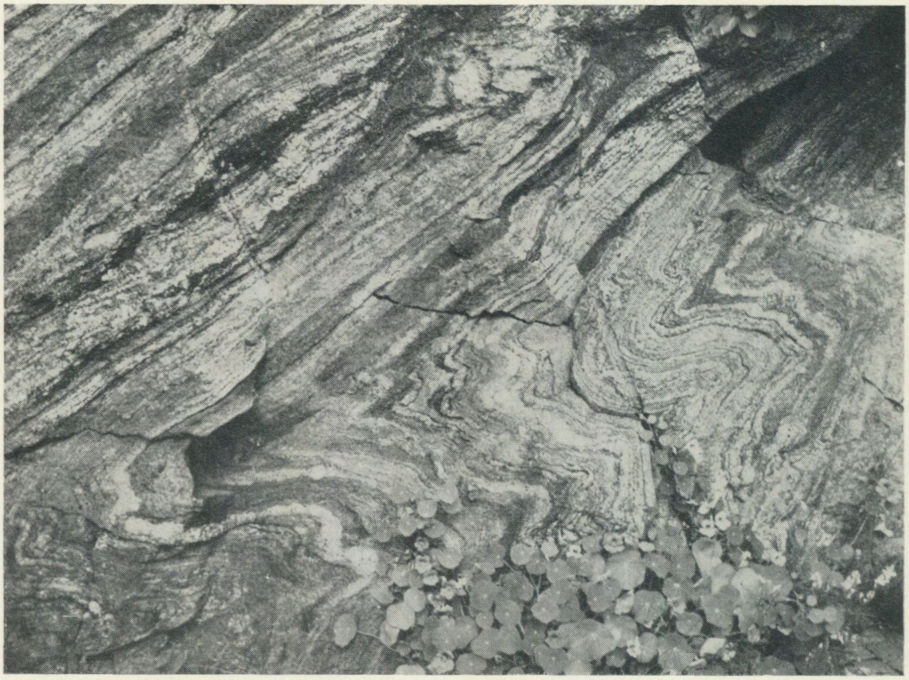


Fig. 3. Folded pre-Gothian banded gneiss. Trollhättan. (After P. H. Lundegårdh.)

Some grey gneisses contain smaller or larger red "augen". These "augen" sometimes have increased in size. The author has found augen with more than 2 dm diameter. Together with feldspars these augen often also contain quartz. Frequently there are also all transitions between augen gneisses and grey gneisses with red schlieren rich in microcline.

In the large amphibolites there have often been found kernels of norite and gabbros going over to uralite-norite, uralite-gabbros, hornblende-gabbros, amphibolites and garnet-bearing amphibolites towards the contacts.

Quartzites and limestones have been found as small remnants only in a few places. The original quartzite and limestone layers have otherwise disappeared through exchange of material during the gneissification processes.

The transformation of the original rocks into the banded gneisses, "schlieren"-gneisses and "augen"-gneisses described above must be due to a metamorphic differentiation inside the different rocks combined with a more or less intensive exchange of material between the layers. Smaller layers have therefore often totally lost the original composition. In other cases small isolated kernels give ideas of the original material.

The red quartz-feldspar material rich in microcline has been the most movable as the red "schlieren" and the red "augen" clearly indicate.

South of Lake Vänern where the gneissification is weaker the dominating grey gneisses have been described as supracrustal rocks with band- or lens-shaped intrusions of gneissic intermediate granites, often rich in basic inclusions, gneissic augen granites and larger and smaller intrusions of amphibolites often with gabbroic kernels.

The grey gneisses dominate the smaller western part of the pre-Gothian region from the Norwegian frontier to the east of Göteborg (Gothenburg) and is to the east bounded by a thrust zone dipping towards the west. East of this thrust zone and in the region south of Göteborg the dominating pre-Gothian gneisses are red gneisses, rich in microcline or with about the same amount of microcline and acid plagioclase. The latter gneisses are usually called *intermediate*. The red gneisses rich in microcline vary from types very poor in other minerals than quartz and feldspars to types with biotite, often also muscovite. A characteristic accessory mineral is magnetite. The types poor in femic minerals have been called red *salic*, the types somewhat richer in such minerals are called red *semisalic*. The *intermediate* gneisses have larger amounts of plagioclase, and the plagioclase is somewhat more basic. Besides, there are larger amounts of biotite, and hornblende often also appears as an essential component. In the intermediate gneisses there often have been found granitic kernels. Some alkaline types characterized by low amounts of quartz have probably been quartz-syenites. The grey plagioclase-gneisses poor in femic minerals have been called *grey salic* and the same gneisses rich in femic minerals (biotite and hornblende) have been called *grey basic*. These granitic and syenitic rocks form a very fine differentiation series. Gabbros and diorites more or less altered to amphibolites are also connected with this intrusive series.

Together with the gneisses named above there appear here and there more fine-grained gneisses, which probably are supracrustal rocks, lavas and tuffs. The latter often show a distinct bedding. These volcanic rocks vary from red over intermediate to grey types. Associated with them are also quartzitic layers and layers rich in calcite and skarn minerals such as garnet, pyroxene, epidote and hornblende. Even magnetite and hematite have locally been found as spots or as distinct layers. It is often difficult to separate layers rich in hornblende skarn from amphibolites rich in hornblende. In other places beds rich in quartz alternate with beds poor in quartz and beds rich in micas (muscovite and biotite) with beds poor in micas.

In the region of Karlstad the gneisses have been studied in more detail. Those explained as original granites are called the *Karlstad granites*. The original supracrustal rocks have been grouped together in the *Hammarö series*.

North of the Karlstad region there appears in Horrsjöberget a quartzite rich in kyanite together with a relatively well preserved porphyritic rock. Comparatively well preserved calciferous tuffs have also been found in Östmark, near the Norwegian frontier. Certainly futural investigations will come across several now unknown areas with supracrustal rocks.

Towards the Norwegian frontier the granitic gneisses over a great area pass into well-preserved granites.

In the region north of Lake Vänern there appear in the red gneisses a great many occurrences of *hyperites*. These are dark brown-violet rocks in which with the naked eye plagioclases with about 55 % anorthite and ophitic texture can

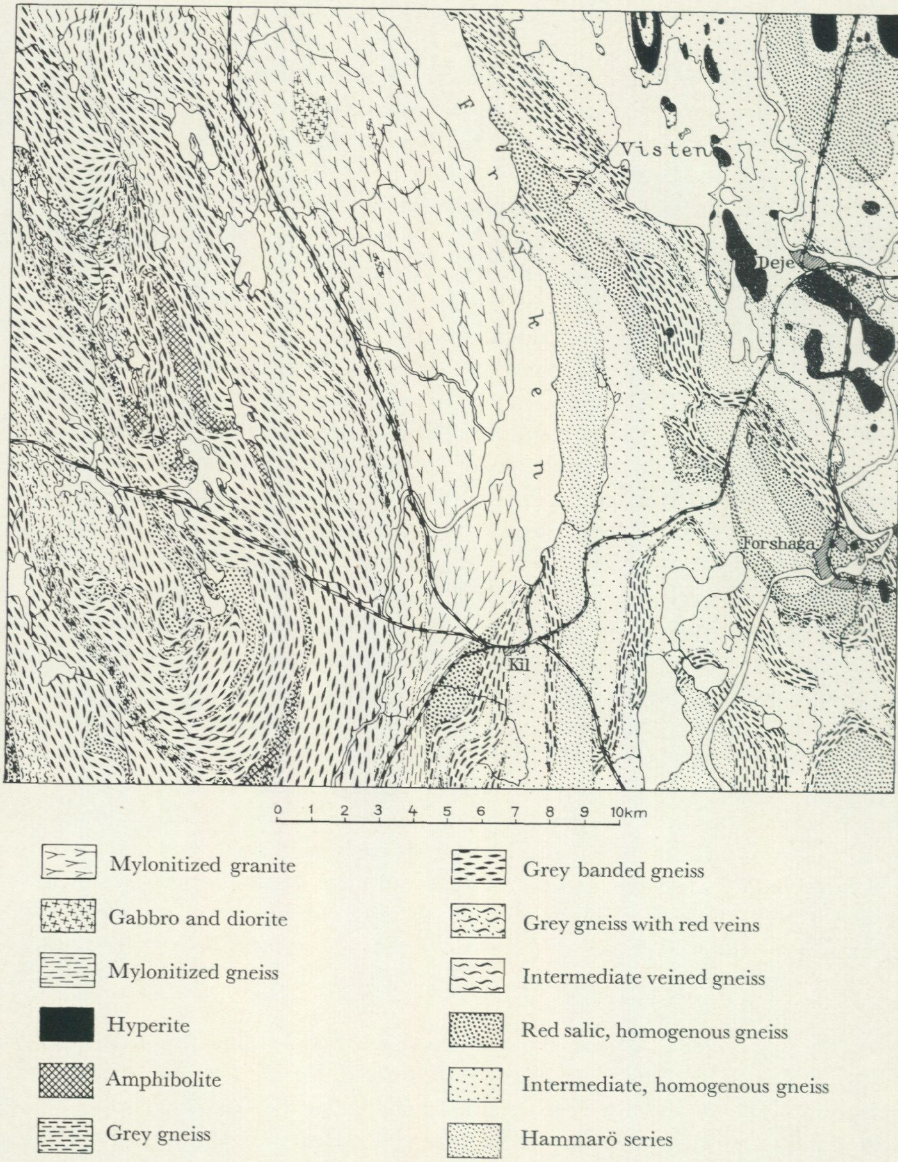


Fig. 4. Map of the Kil region northwest of the town of Karlstad. In the western part of the map a complex belonging to the pre-Gothian grey gneisses, in the easthern part a complex belonging to the pre-Gothian red gneisses and between them mylonitized Gothian granites, gabbros and diorites and mylonitized pre-Gothian gneisses pressed down in late Gothian time between the two blocks. (After N. H. Magnusson.)

be seen. Between the plagioclase abundant dark minerals (olivine, augite, hypersthene-augite and hypersthene) occur. Besides, there is a large amount of titanomagnetite and apatite.

Outwards the hyperites pass into *hyperite-diorite,* the colour becoming more

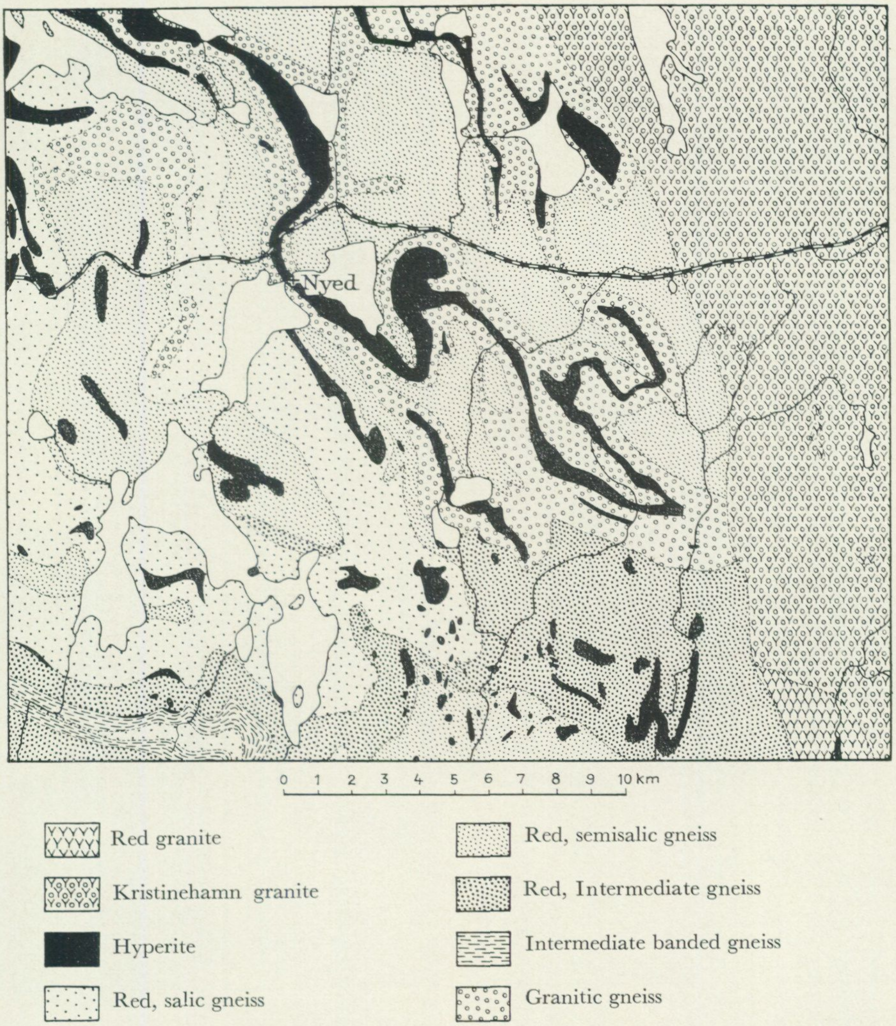


Fig. 5. Map of the pre-Gothian Nyed region northeast of the town of Karlstad. In the eastern par the red granites and the Kristinehamn granites which both are of Gothian age. (After N. H Magnusson.)

green because the pyroxenes and olivine have been replaced by hornblende and the outer parts of the plagioclases enriched in the albite-component. Garnet and biotite begin to appear in this zone.

The hyperite-diorites pass into *hyperite-amphibolites* towards the contact with the surrounding gneisses. These amphibolites are schistose, dark green rocks with grey-white plagioclases and dark green hornblende and usually also red garnet in often large grains. The amounts of biotite and quartz are higher than in the diorites.

Field observations have shown that the gneisses usually dip beneath the hyperites. At only a few smaller occurrences do the latter lie between two

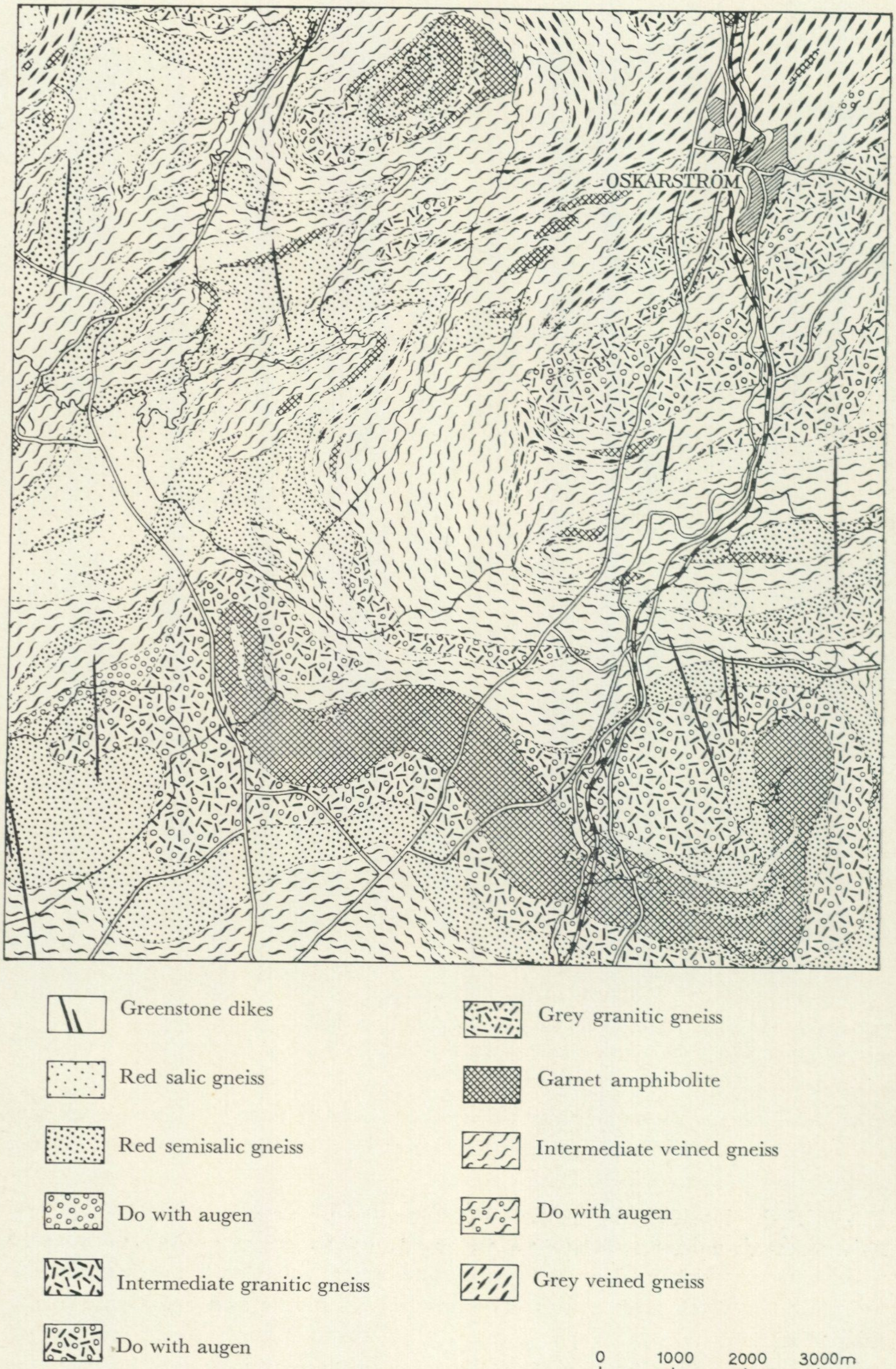


Fig. 6. Map of the pre-Gothian region north of the town of Halmstad. (After W. Larsson.)

gneiss-layers. Especially in the Molkom region most occurrences of hyperite are parts of one and the same large layer. The hyperite is younger than the original surrounding rocks but older than the regional gneissification. It is during this process that the hyperite was altered to hyperite-diorites and amphibolites.

A few hyperite occurrences of the same type appear also south of Lake Vänern as far as the town of Tidaholm.

The red gneisses south of Lake Vänern as far as the province of Scania vary in the same way as in the region north of this lake, and where modern investigations have been undertaken it has been possible to distinguish a series of intrusive rocks varying from basic rocks (originally gabbros and diorites) through plagioclase gneisses to dominantly red intermediate and acid gneisses. The intermediate gneisses have the granitic appearance best preserved.

In the Halmstad region the granitic rocks and the basic rocks connected with them appear as longish lense-formed bodies in a mass of more fine-grained, veined intermediate or grey gneisses, which have been explained as original supracrustal rocks, among which volcanics seem to play a great role. The gneiss-complex south of Halmstad and Ljungby and in northern Scania seems to have a similar construction.

Together with the red gneisses there is, especially in the region from the town of Lidköping (in the north) via Borås to Varberg (in the south), a good deal of grey gneiss. This rock is usually extremely well banded like the grey gneiss in the western pre-Gothian region where these rocks predominate. Even the red gneisses sometimes show a banded texture.

In a broad zone from the coast between Varberg and Halmstad in an easterly direction there appear a great many occurrences of *amphibolites*. These rocks are usually characterized by a large amount of garnet and often pyroxene rich in iron appears together with hornblende and a basic plagioclase. These amphibolites have been called *garnet-pyroxenolites*.

In the same zone charnockitic rocks have been found, especially in the region of Varberg. The *Varberg charnockite* consists of antiperthitic oligoclase, orthoclase, diopside, hypersthene, hornblende, garnet and some ore minerals in varying proportions. In some basic charnockites the hornblende dominates over the pyroxene. The charnockites have originated through material exchange during a metamorphism at great depth, high temperature, hydrostatic pressure and very dry conditions.

Traces of this ultrametamorphism have also been found in northern Scania.

The Svionian Cycle

The term Svionian was introduced by J. J. Sederholm for part of the oldest Archean rocks of Southern Finland including quartzites, schists and limestones corresponding to part of the leptite system of Central Sweden. Sederholm, however, in his table showing the subdivisions and correlation of the Precambrian rocks of Fennoscandia (1932) paralleled his Svionian quartzites with a number

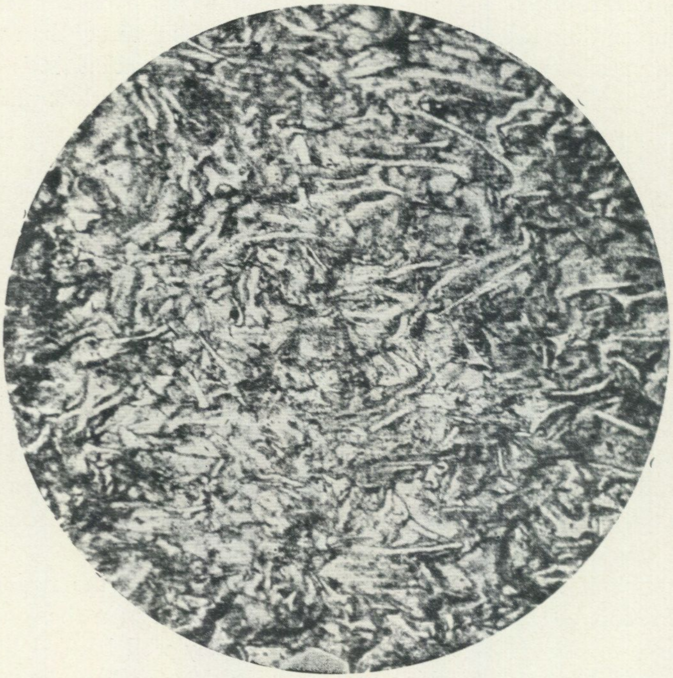


Fig. 7. Tuffitic hälleflinta, south of Brevik, parish of Grythyttan. Microfoto × 33. Small fragments of finely splintered pumice, recrystallized to an allotriomorphic mixture of quartz and felspar in a dense slaty mass. (After N. Sundius.)

of Swedish quartzites which have later been interpreted as much younger, namely Gothian.

In 1936 the author redefined Svionian so as to comprise a complete petrological cycle. The Finnish geologists use instead the term Svecofennian for this cycle. This term was originally proposed by W. Ramsay (1909) for the old orogenic belt stretching from southeastern Finland to eastern Värmland. W. Wahl and H. G. Backlund (1936) widened Svecofennian so as to comprise the whole orogenic cycle including the mentioned folding. The author has preferred to use the term Svionian for the whole cycle also in the scheme for the new map. The reader must always remember that the Svionian cycle in Sweden is the same as the Svecofennian in Finland.

THE SVIONIAN ROCKS OF SVEALAND

The most thorough investigations within the large region of this cycle have been made in the iron ore bearing region of Central Sweden. The supracrustal rocks are here acid volcanics (so-called leptites and hälleflintas), very subordinate basic volcanics, slates, greywackes, quartzites, and conglomerates. Together with the acid volcanics the iron ores, the limestones, and the dolomites appear.

Nearly all iron ores poor in phosphorus in Central Sweden are originally

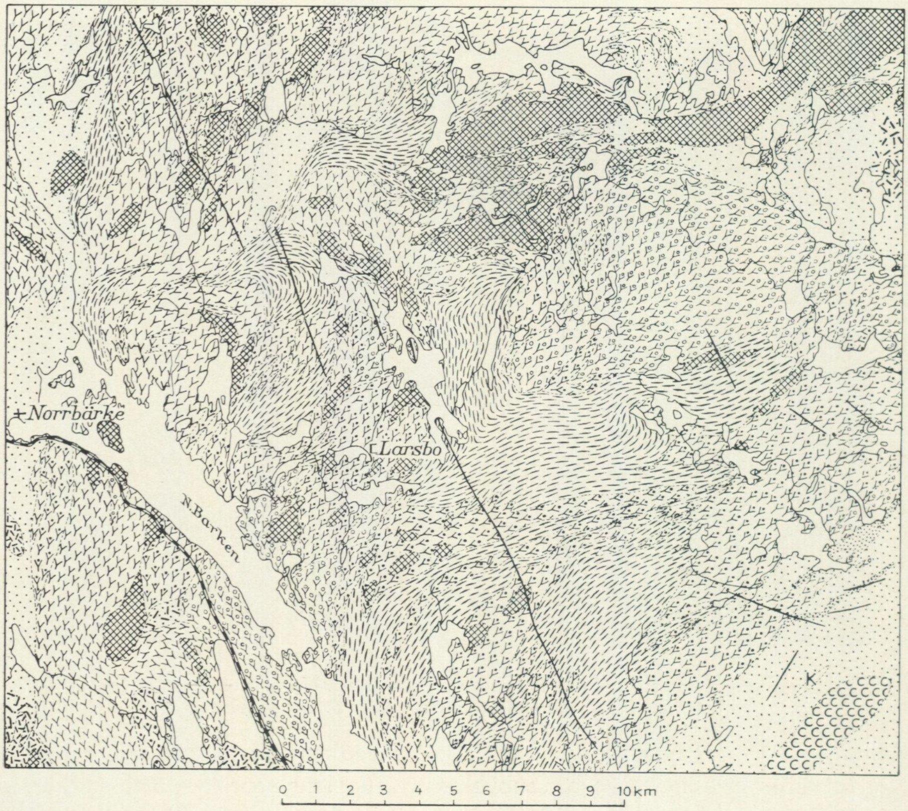
Fig. 8. Quartzitic mica schist from the shore of lake Stora Norn, northeast of Smedjebacken. Belongs to the Larsbo series. (After S. Hjelmqvist.)

sedimentary with limonite, perhaps also siderite as primary ore minerals. The apatite iron ores, however, are subvolcanic intrusions near the earth surface.

The supracrustal rocks are best preserved in the Grythytte field. At the bottom of the series there are hälleflintas rich in sodium and with intercalated layers of limestone and iron ore poor in manganese. Then follow hälleflintas with potassium dominating over sodium and with intercalated layers of limestones and manganiferous iron ores. Microscopic investigations have shown that some of the hälleflintas are lavas, others are tuffs. In the lavas there appear phenocrysts of quartz and feldspars, micropoikilitic, granophyric, spherulitic and fluidal structures. The tuffs often show good vitroclastic structure and a distinct bedding. Coarse agglomeratic layers are frequent.

The sediment series above the volcanic rocks have usually been called the *Grythytte series*. It begins with conglomeratic greywackes followed by a black slate with intercalations of scoriaceous, spilitic greenstones and above this black slate a grey slate and at the top a thick conglomerate.

The conglomerate is not found outside the Grythytte field. The other rocks named above have been found in large parts of the ore-bearing region of Central Sweden. Great differences have, however, been found regarding the details of the stratigraphic scheme. The black slate may be lacking. The scoriaceous greenstones can appear even in the greywacke and hälleflinta layers. The sodic volcanic rocks may be intercalated with more potassic ones and the latter can sometimes be dominant even in the lower part of the volcanic etage.



Dolerite-diabase
Younger granite
Dikes of granite and pegmatite
Red, microcline granite
Intermediate granite
Grey, plagioclase granite
Gabbro and diorite
Quartzite
Larsbo series
K Limestone
Leptite
Cordierite-mica-schist

Fig. 9. Map of the Svionian Larsbo region northwest of the town of Fagersta. The dolerites are of Jotnian age. (After S. Hjelmqvist.)

Dacitic and andesitic volcanics have also been found here and there, especially in the upper part of the volcanic stage.

The slates are in some regions replaced by quartzites and arkoses as in the *Larsbo series* (between Norberg and Smedjebacken).

The slate and greywacke sediments are very extensive around Lake Mälaren, in what the author has called the *Mälaren synclinorium*. Around this synclinorium the volcanics are the dominant rocks, and the sediments appear

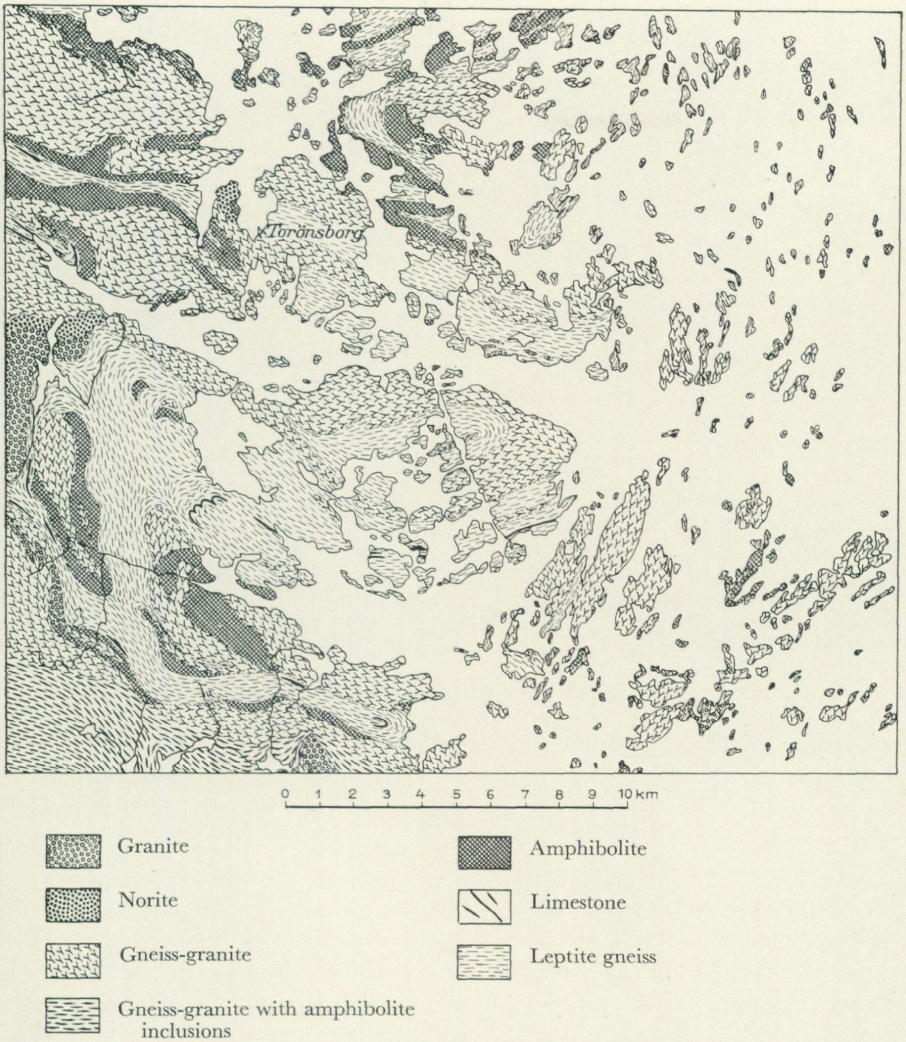


Fig. 10. Map of the Svionian region of Torönsborg southeast of the town of Söderköping. The granites and norites are Gothian intrusions. (After B. Asklund.)

preserved in larger and smaller synclines in this anticlinorium which the author has called the *Svealand anticlinorium*. The structure forms a well-developed horseshoe-shaped old mountain chain, which the Finnish geologist W. Ramsay once called the Svecofennian mountains.

Through the Svecofennian folding processes the layers became more or less elevated and steeply dipping as a rule. The synclines and anticlines often show isoclinal dips. Some regions, however, show more moderate dips and more open synclines and anticlines.

In connection with the folding the earliest Svionian granites appeared. These form a differentiated series preceded by gabbros and diorites and beginning

Fig. 11. Veined leptite gneiss. 2 km east of Valla, Sköldinge. (After N. H. Magnusson.)

with grey oligoclase granites followed by intermediate granites usually with augen-granite texture, and terminated by red granites rich in microcline. In the region of Norrtälje anorthite gabbros have been found which are somewhat younger.

Where these synkinematic granites dominate over the supracrustal rocks the latter appear as larger and smaller remnants and often the original stratigraphy can be followed in the granites as the remnants are still in their original positions. In the central parts of the granite bodies, where the temperature was higher, homogeneization processes were predominant and the remnants disappeared.

Through more or less intensive folding and higher temperature in the regions where the volume of synkinematic granites was larger, the supracrustal rocks were pressed and recrystallized. The hälleflintas, that is the best preserved acid volcanic rocks with dense ground masses, became altered to leptites. The leptites have granoblastic structures. In the leptites and especially in the transitional types phenocrysts can often be seen in the original lavas and bedding and agglomeratic structure in the tuffs. In the gneissic leptites even these structures have disappeared and it is only transitions to better preserved leptites in the field that can be the proof of the volcanic origin.

The slates which in the Grythytte field are quartz-chlorite-sericite rocks often with some felspar, have been altered to mica schists with biotite and such minerals as cordierite, almandite and andalusite in varying proportions. The black

Fig. 12. Veined granite gneiss. 1.5 km NNE of Eriksberg, St. Malm. (After N. H. Magnusson.)

slates contain 1—2 % graphite. The original, very small graphite grains have been replaced by larger and larger grains. The same minerals originate as in the grey slates but the recrystallization seems to be somewhat delayed. The clastic structure of the greywackes disappears where the recrystallization is strong enough. The limestones and dolomites turned into crystalline rocks and the impurities have, through reactions with the carbonates, given rise to skarn minerals. Where limestones and dolomites appear together with "jaspilite" ores skarn minerals such as garnet, pyroxene and amphibole have originated through reaction between existing materials. Such skarns are called *reaction skarns*.

Solutions driven before the granite front have been the cause of the metasomatic alterations which have been summarized as *magnesia metasomatism*, by which the leptites have been altered to mica schists usually characterized by such minerals as cordierite, gedrite, andalusite, and almandite in varying proportions. Where these alterations have been stronger the mica schists have gone over to quartzites characterized by the minerals named above. The limestones and dolomites reached by the solutions have been more or less replaced by skarn minerals (tremolite, diopside, humite minerals, serpentine and so on) and impregnated by pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. The sulphide ores of this type are in Sweden called *sulphide ores of the Falun type*. Older skarn-iron ores have had their mineralogical composition altered. Besides the minerals named above such minerals as anthophyllite and talc occur. Along the limestone, skarn, and iron ore boundaries mica-chlorite-talc "sköls" have originated.

The supracrustal rocks as well as the intrusive rocks mentioned above became during an intraorogenic period intersected by greenstone dikes. Most of them are now plagioclase-hornblende rocks with the ophitic texture preserved here and there. These greenstones are without doubt old diabases.

In late Svionian time a sinking of a large part of Central Sweden occurred, causing intense metamorphic processes. In the regions with the highest temperature during this metamorphism the supracrustal rocks and above all the slate sediments were altered to veined gneisses. Not only the supracrustal rocks but in some degree also the older granites and the greenstone dikes named above have been altered more or less. From small veins there are all transitions to larger elongated concentrations of pegmatitic and granitic material. This granitic material shows all transitions between types with gneissic texture and types with granitic texture. That the alteration of the rocks to veined gneisses took place in connection with transports of material on a large scale is quite clear from the investigation of the limestones and iron ores within the area of the veined gneisses. The limestones have been altered to coarse crystalline rocks with abundant irregular spots and schlieren of skarn minerals formed through reactions between the wandering solutions and the carbonates. The iron ores have been impregnated with feldspar and altered in several other respects in connection with internal material transport.

Outwards from the central part of the region of the veined gneisses, pegmatites and granites have a more and more independent and intrusive appearance. These granites are called *Stockholm granites* (the even-grained types) and *Fellingsbro granites* (the porphyritic types). These late-orogenic granites are, even where they appear far from the veined gneisses, accompanied by a great quantity of pegmatite. These granites are in the author's opinion dome-shaped diapiric superstructures with veined gneisses at depth. Much of the material in these late orogenic granites has passed through the zone of the veined gneisses. In its passage some material was removed from this zone and some was retained. The zone of veined gneisses has thus acted as a kind of filter. The material having passed through is that necessary for the development of the pegmatites and the accompanying granites, i.e. above all silica and alkalis. The veined gneisses on the contrary have been enriched in iron, magnesia and alumina, causing the development of such minerals as almandite, cordierite, andalusite, and sillimanite. These occur not only in the original slates but also in the quartz-feldspar rocks, the original leptites and granites.

In the pegmatites, especially south and southwest of the Mälaren synclinorium, tourmaline, beryl, orthite, apatite, and fluorite are often found. Also uranium minerals have been found associated with the late Svionian pegmatites and granites. The iron ores of regions rich in such pegmatites and granites have often been enriched in one or several of the minerals named above.

Scheelite and molybdenite are also found in the late Svionian granites and pegmatites at some distance from the region of the veined gneisses. The only

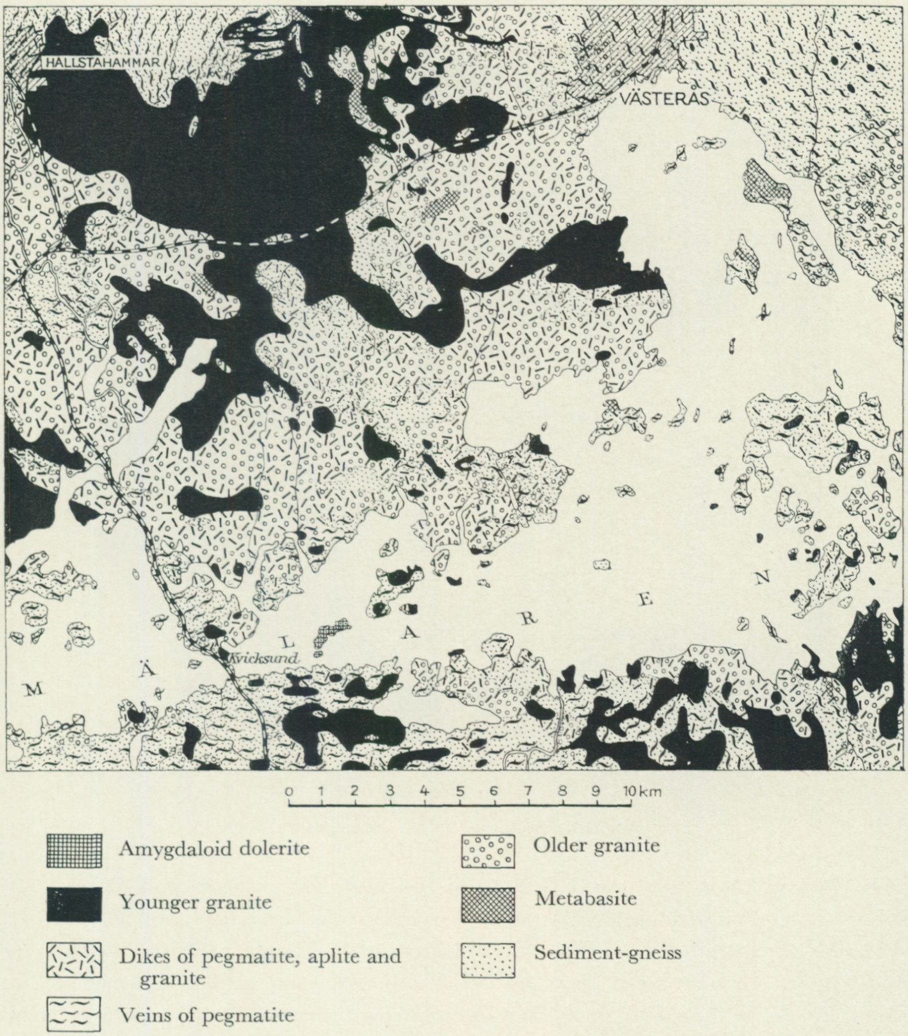


Fig. 13. Map of the Svionian Västerås region. The most interesting feature is the irregular forms of the late Svionian granites. The amygdaloid dolerite is of Jotnian age. (After P. H. Lundegårdh.)

scheelite occurrence worth mining is Yxsjö, near Grängesberg, where scheelite occurs in an old limestone together with pegmatite material, garnet-hedenbergite-amphibole skarn and fluorite.

South and southwest of the region of the veined gneisses there are fahlband-impregnations of different sulphides: pyrite, pyrrhotite, sphalerite, and galena. The largest of these occurrences is the sphalerite-galena ore in the *Åmmeberg field* which have been explained as impregnations along a local migmatite front.

Fig. 14. Revsund granite. Natural size. From the vicinity of the Revsund church.

THE SVIONIAN ROCKS OF CENTRAL NORRLAND

In Central Norrland the supracrustal rocks are greywackes and slates with subordinate quartzitic intercalations. Volcanic rocks are very rare as also are synkinematic granites. Late Svionian granites on the contrary occupy large areas and appear outside these areas as isolated larger and smaller diapiric intrusions. In connection with these late-kinematic granites the sediments have been altered to veined gneisses. Often there are all transitions between the granites and the veined gneisses and it is quite clear that both are products of the same palingenic processes caused by a regional sinking of the geosynclinal sediments in this broad belt in which the layers strike in general from westnorthwest to eastsoutheast. This geosyncline has its continuation in Central Finland on the other side of the Gulf of Bothnia.

The sediments of this geosynclinal belt of Central Norrland are best preserved along the coast between the towns of Härnösand and Örnsköldsvik and about 100 km from the coast in westerly direction. In this region the sediments often have well-preserved bedding. Clastic grains are clearly visible in the greywackes and quartzites. It was these relatively well preserved sediments the author had in mind when he proposed the term *Härnö series*.

The sediments of this series towards the north, west and south and also in a

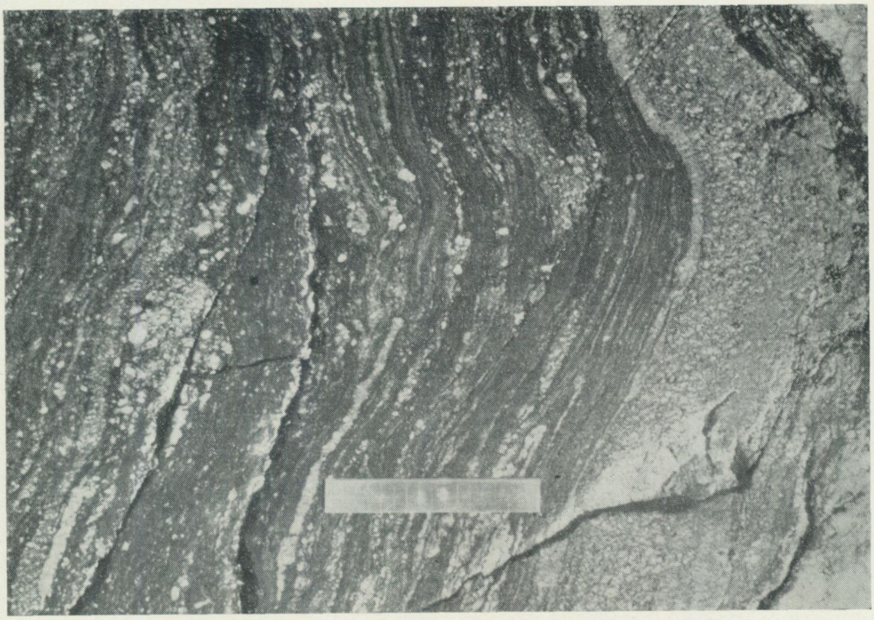


Fig. 15. Feldspathized and veined gneiss, derived from banded sediments W. Järnäs, Nordmaling (After S. Gavelin.)

broad belt along the Ångerman river pass into veined gneisses. These gneisses must also be designated as Härnö sediments. The veins consist of quartz-feldspar material that has been more mobile than the darker micaceous mass around them. Together with biotite the veined gneisses and the relatively well preserved sediment often contain muscovite. The amount of muscovite is especially remarkable in the region of the better preserved sediments. The late Svionian diapiric granites within this region and in the regions around it are even-grained rocks rich in microcline and muscovite. These granites have long been called *Härnö granites*. It is a fact that the granites are rich in muscovite when the surrounding sediments are rich in this mineral.

In the veined gneisses almandite, cordierite and andalusite have often been found together with the micas, quartz and feldspars.

Towards the west and north the supracrustal rocks have been more and more attacked by granitization and pass into granitic rocks rich in dark micaceous "schlieren" which must be considered as remnants of the Härnö sediments. Successively these transition rocks pass into typical *Revsund granites*. These granites are characterized of usually 2—5 cm large phenocrysts of microcline in a groundmass of microcline, oligoclase, quartz and biotite, sometimes also hornblende and garnet.

The Revsund granite has its largest extension in the northwestern part of the geosyncline enclosing larger and smaller areas of sediments. Among the sediments there are also some occurrences of basic volcanics. Towards the east the Revsund granite grades into a large region of veined sediment gneisses intruded by a great many smaller granites. The latter vary from typical Revsund granite to even-grained types which have been called *Skellefte granites*. They differ from the Härnö granites in their low content of muscovite.

In good outcrops at the coast south-east of Nordmaling it has been possible to study in detail the relation betwen the mica schist sediments, the veined gneisses and the granites. The conclusion is that the Revsund granites originated through alteration and mobilization of the sediments and that the veined gneisses with their abundant pegmatitic veins and biotite-plagioclase-rich material imply a metamorphic differentiation during which the more mobile quartz-feldspar material separated and even could intrude into the surrounding rocks and form hybrids.

If the veined gneisses have been formed through metamorphic differentiation, the granites have been formed through homogeneization processes at higher temperatures.

The Revsund granites and their even-grained and more fine-grained varieties are associated with the geosyncline in Central Norrland and have, together with the veined gneisses, been formed in connection with the sinking of the geosyncline in late Svionian time.

THE SVIONIAN ROCKS OF SOUTHERN NORRLAND

The region between the geosyncline of Central Norrland and the Svealand anticlinorium can be called the *marginal zone of Southern Norrland*. This zone is, contrary to the geosyncline in the north, rich in volcanic rocks and in old synkinematic granites. It seems quite clear that these rocks are older than the sediments of the Härnö series. The map also shows how different the region of this series is in comparison with the region of the marginal zone. The boundary between them can be followed from Jättendal on the coast north of the town of Hudiksvall via Hassela and Mellansjö. Near north of this line an arkosic quartzite, the *Naggen quartzite*, has its northern limit. In the eastern environs of Mellansjö the clastic structure is well preserved. Towards the east the rock is also more and more strongly metamorphosed by metasomatic alterations in connection with the palingenic processes that have occurred in this region in late Svionian time. Through such alterations garnet, sillimanite, and cordierite have been formed.

The Naggen quartzite has been interpreted as the basal sediments of the Härnö series. There is much in favour of this interpretation. It is also possible that some smaller synclines found along the coast south of Harmånger can be filled with Härnö sediments and that quartzites corresponding to the Naggen quartzite can be basal layers in the Härnö series also in these smaller synclines. Large parts of the sediments in this marginal zone in southern Norrland must, however, be older than the Härnö series, especially the sediments appearing together with the acid volcanic rocks.

The sediments have in the whole marginal zone been altered more or less

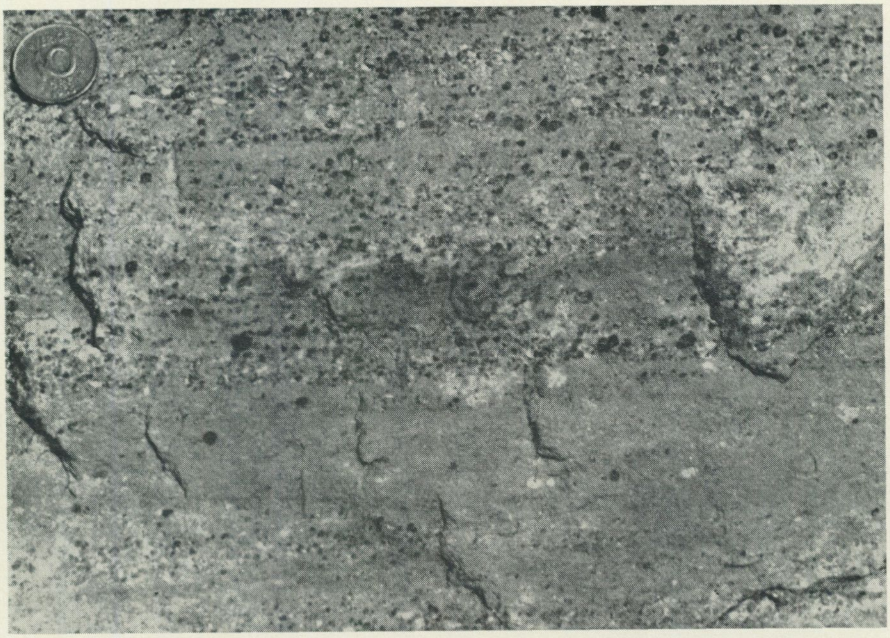


Fig. 16. Arkosic quartzite with extremely well preserved bedding. Naggen. (After P. H. Lundegårdh.)

to veined gneisses. Only locally have better preserved sediments been found, as in the Hamrånge and Los-Hamra regions. The dominating volcanic rocks are acid and to be considered as more or less strongly altered leptites. Even the latter are here usually developed as veined gneisses. In the leptite gneisses there also occur limestones and iron ores of the same types as in the anticlinorium of Svealand. The sediment and leptite gneisses have been intruded by elongated synkinematic granites of the same types as in this anticlinorium south of the marginal zone but here usually altered to gneisses. In subordinate amounts even basic volcanics appear together with the acid leptites.

Late Svionian palingenic granites are nearly connected with the alteration of the supracrustal rocks and the synkinematic granites to veined gneisses. They appear as larger and smaller diapiric bodies especially in the southern part of the marginal zone. Sometimes, as for instance around Bingsjö and Ljugaren, the leptites and the synkinematic granites have been recrystallized and are so coarse-grained that it is often very difficult to separate them from the palingenic granites.

In the northern part of the marginal zone the older granites have an extensive distribution and dominate over the other rocks. These granites have been called red and grey *Ljusne granites.* Most often they are augen granites. There are several field observations that support the opinion that this structure is a palingenic one formed during the regeneration process in late Svionian time. The even-grained old granites are also usually strongly recrystallized.

In two regions better preserved rocks have been found, as mentioned above.

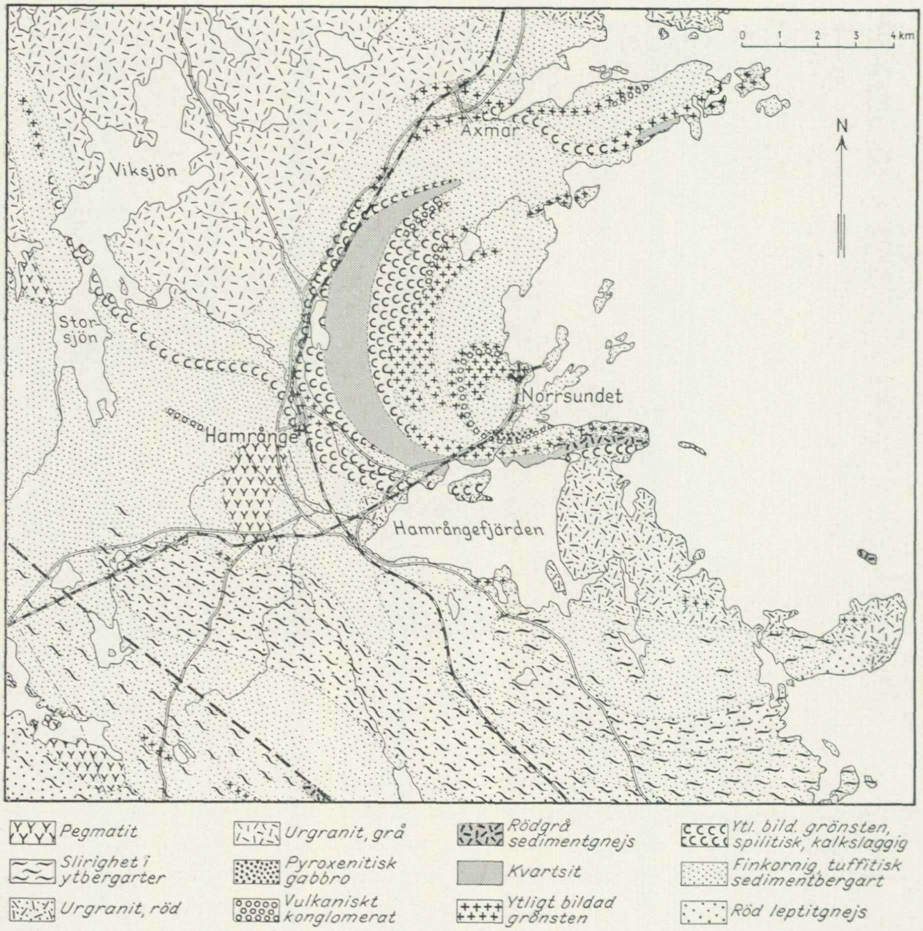


Fig. 17. The central and southern parts of the Hamrånge syncline. Scale 1: 200 000. Terms contained at the four columns of the legend, from the left to the right: Pegmatite — Migmatitization in supracrustal rocks. — Primorogenic granite, red. — Do, grey. — Pyroxenitic gabbro. — Volcanic conglomerate. — Sedimentary gneiss, red grey. — Quartzite. — Supracrustal greenstone. — Do, spilitic, calcite-bearing. — Tuffitic-argillitic rock. — Leptite gneiss, red. (After P. H. Lundegårdh.)

In the *Hamrånge region* the supracrustal rocks form an open syncline. Old granites and gneissic leptites form the floor. Above follows a nearly dense dark-grey tuffitic volcanite and an effusive, most often scoriaceous and spilitic greenstone. Then follows a dark-grey tuffite again. Together with the effusive greenstones occur layers of quartzite and volcanic conglomerates.

In the *Los-Hamra region* four series have been separated, namely *Sub-Los, Lower Los, Upper Los* and *Noppi series.* All these series have been considered to be younger than the Svionian cycle. New investigations have, however, shown that the two lower series are older than the late Svionian alterations and therefore must belong to the Svionian. They have now with their effusive green-

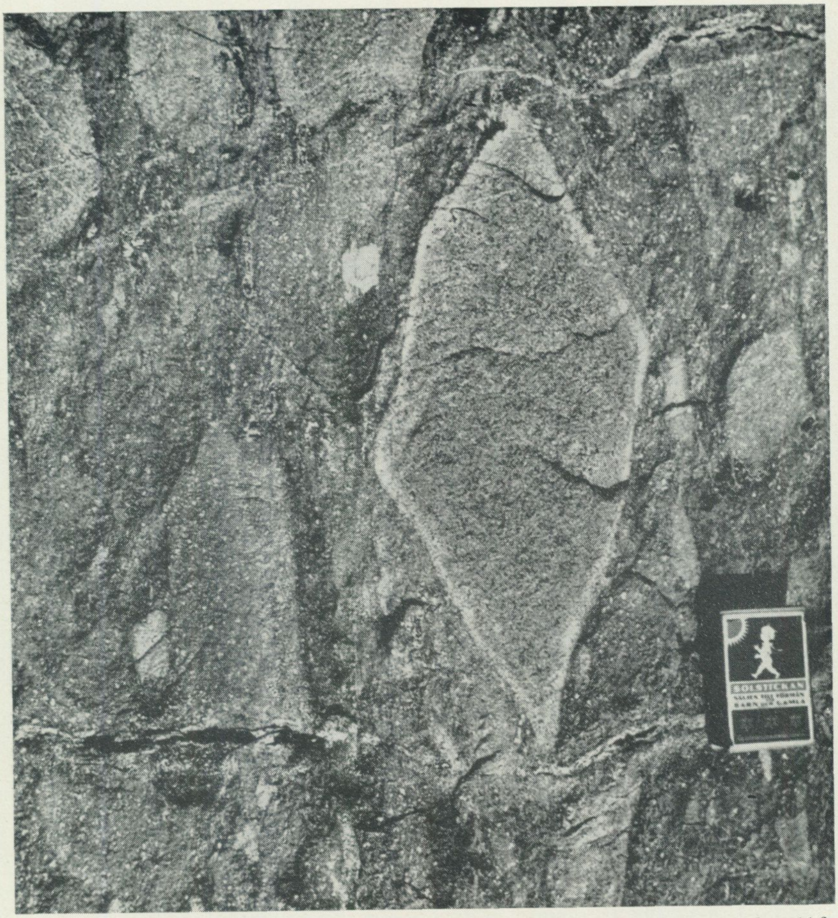


Fig. 18. Volcanic conglomerate from the Hamrånge syncline. Southwest of Norrsundet. (After P. H. Lundegårdh.)

stones, acid volcanics and sediments been placed side by side with the Hamrånge rocks described above.

The boundary between the veined gneisses in the southern part of the marginal zone and the relatively well preserved leptite—old granite complex in the south is unusually sharp. The problem is if this boundary can be explained as a limit for the palingenic processes only or if in addition it is the limit for a nappe from the north. Another interesting problem must be mentioned. The map shows clearly that the general strike from east-west north of Sandviken bends towards the north-west and then follows this direction up to the Los-region. In the anticlinorium of Svealand south of the gneisses the general strike turns instead from east-west to south-west and then to south. The author has therefore suggested that we have here two mountain ranges of which the northern one is the younger.

P. H. Lundegårdh has described the *Naggen quartzite group* as composed of

Fig. 19. Polymict Vargfors conglomerate with large boulder of a porphyritic granite. W. Levattnet, Malå. (After S. Gavelin.)

arkoses, arkosic quartzites, subgraywacke, mica schists very rich in silica, and rare volcanics (mainly basic). In contrast to this miogeosynclinal facies in the marginal zone the eugeosynclinal rocks north of the basal quartzite layers are schists (metamorphic greywackes and clayey slates) with intercalations and intermixings of rudaceous—arenaceous and basic volcanic rocks.

The serorogenic alterations are by Lundegårdh summarized as recrystallization of older microcline and sometimes of other minerals, migrations of potassium and formation of new microcline granoblasts, intergrowths and porphyroblasts locally assembled to veins (migmatitization), mobilizations in the first instance of silica and feldspar, either as veins and small dikes of pegmatite and sometimes aplite or masses, in part real intrusions, of pegmatite and fine medium- to fine-grained granite (serorogenic palingenic rocks).

THE SVIONIAN ROCKS OF NORTHERN NORRLAND

At the northern boundary of the geosyncline of Central Norrland the *Skellefte field* is situated. Owing to the many sulphide ores found there since the first world war this region has been thoroughly mapped. The uppermost supracrustal rocks are slates and greywackes belonging to the *Elvaberg series* supposed to be equivalent to the *Härnö series*. These two terms can hence be interpreted as local names for the same geosynclinal series.

The bottom layers in the Elvaberg series are marine felsite conglomerates and sedimentary breccias with calcite cementation and pebbles of Jörn granite as well as intercalations of psammites and slates. A fluviatile facies consisting of polymict greyish conglomerates with numerous pebbles of Jörn granite also occurs. Overlying this conglomerate occur above an angular unconformity polymikt motley conglomerates and sandstones with current bedding and rare granite pebbles. These fluviatile conglomerates are the *Vargfors conglomerates.* In these as well as in the marine conglomerates, the *Mensträsk conglomerates,* there appear andesitic lavas.

The bottom layers just described are to be considered as equivalent to the Naggen quartzite along the southern boundary of the central geosyncline.

Beneath the conglomeratic bottom layers of the Elvaberg series there is a great unconformity and hiatus. The older layers have been strongly folded in connection with the intrusion of the synkinematic Jörn granites.

The rock complex of these older layers has been called the *Maurliden series.* New investigations have for this series resulted in the following stratigraphy from above downwards.

4. Skogsheden volcanics: Porphyrites and amygdaloidal basic lavas
3. Petikträsk slate: Graphite slates interstratified with quartz-porphyry (about 50 %)
2. Maurliden volcanics: Felsites, quartz-porphyries, feldspar porphyries, and acid tuffs
1. Maurliden slate: Grey and black slates, psammites, greywackes and conglomerates. Sedimentary cycles and graded bedding are common. Intercalations of acid and intermediate volcanics likewise.

The folding of the supracrustal rocks of the Elvaberg and Maurliden series has given synclines and anticlines orientated westnorthwest—eastsoutheast. Both north and south of the Skellefte field the orientation of the folds are more variable.

The *Jörn granites,* named above, are usually sodium-rich granites with a marked tendency to go over to granodioritic types. Sometimes, however, there also appear potassium-rich types. Diorites and gabbros, too, seem to be connected with these granites.

The slates and greywackes of the Elvaberg series pass southwards into the veined sediment-gneisses of the central geosyncline, the origin of which, as pointed out above, was nearly related in time with the development of the Revsund granites.

The Revsund granites have intruded also the supracrustal rocks of the Skellefte field and the Jörn granites outside the region of the veined gneisses. Outside the front of these gneisses, the migmatite front, the sulphide ores of the Skellefte field appear in a narrow zone stretching from Boliden more than 100 km via Maurliden to Kristineberg. They are all characterized by intensive metasomatic alterations which have resulted in the development of sericite-chlorite schists. Towards the migmatite front in the south sericite and chlorite have been replaced by biotite and cordierite and the most plausible is that the sulphide-bearing solutions came from this front. The tectonic circumstances in the supracrustal series close to the front have also played a great role in localizing the deposits. The ores consist of pyrite with varying amounts of Cu, Zn,

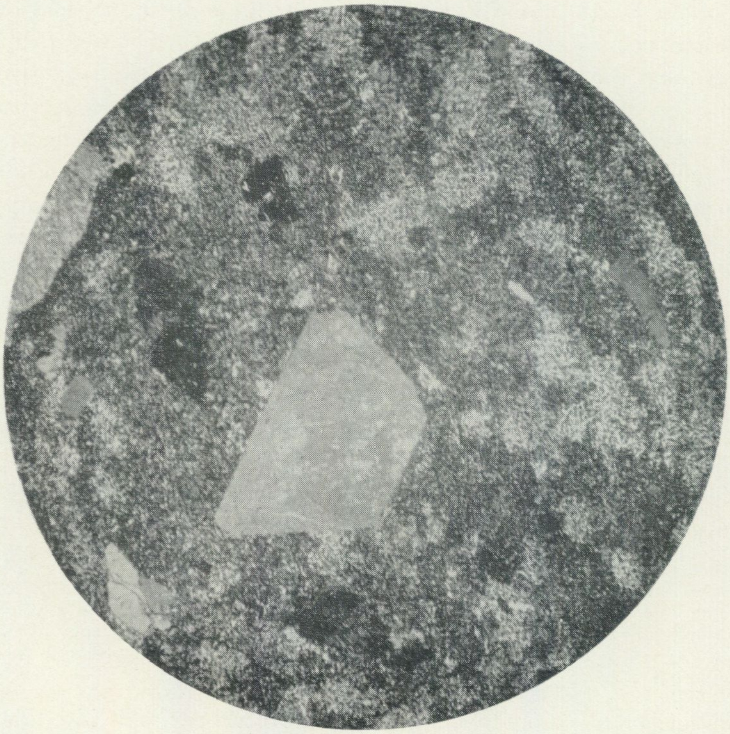


Fig. 20. Quartz-bearing porphyry, Ekströmsberg iron ore field, microphoto, + nicols × 16. Phenocryst of microcline with perthitic intergrowths of albite, poikilitic groundmass. (After P. Geijer.)

As, Ag, and Au. In Boliden, where the amount of Zn is very low, Co, Se, Te, Bi, Hg, and Pt metals have also been found in workable amounts.

The Skellefte field is to be considered as the southernmost part of the *marginal zone of Northern Norrland*. After a gap at the town of Skellefteå the slates and greywackes continue along the coast in a zone about 60 km broad northwards to Älvsbyn. In this outlier of the geosynclinal sediments Revsund and Skellefte granites appear as larger and smaller diapiric massifs and the sediments have to a large extent been altered to veined gneisses in the usual way. Conglomerates are also found in this region, as for instance in the vicinity of Piteå. The Pite conglomerate has been correlated with the Vargfors conglomerates.

The dominating rocks in the marginal, Svionian zone of Northern Norrland are the volcanic rocks and the old, synkinematic granites. The volcanic rocks are usually called the *Kiruna—Arvidsjaur porphyries*. They have been mapped and examined in more detail especially in the iron ore region around Kiruna and in the Arvidsjaur region immediately north of the Skellefte field.

The well-known apatite iron ore body in Kiirunavaara is a 4,000 m long and 20—200 m broad intrusion along the upper boundary of a syenite porphyry grading downwards into a syenite. Above the iron ore is a complex of quartz-porphyry beds intercalated with tuff- and agglomerate-layers. Ore dikes have been found in both the hanging and the foot walls. The compact ores in the Tuolluvaara mines in the neighbourhood of Kiruna are surrounded by broad zones of ore breccias with pieces of porphyry in the ore and ore-dikes in the porphyries. There can be no doubt about the intrusive character of the ores of the Kiruna type. The iron ores in the Gällivare field are often surrounded by impregnation zones with magnetite, hematite, apatite, and skarn minerals showing that the ore melts were rich in gases. There are many occurrences of the Kiruna type known in northernmost Sweden and all appear in near connection with the Kiruna porphyries.

In the Arvidsjaur region the oldest volcanics were basaltic andesites and andesites upwards followed by dacites, keratophyres and quartz-keratophyres. Above these volcanics liparites are found. The evolution has thus followed a clear line from basic differentiates to more and more acid. At one place, however, the liparites are overlain by an andesite. The total thickness of the lava beds including the very subordinate pyroclastic layers amounts to about 1,500 m.

In the volcanic region between the Kiruna porphyries in the north and the Arvidsjaur porphyries in the south it has not been possible to establish a regional stratigraphic succession among the lavas. The division of the volcanics in this region into basic and acid types shown on the map must be regarded as schematic. The rapid and very irregular fluctuations between basic and acid types formed in the field indicate a rapid variation in the chemical composition of the lavas.

Along the boundary of the Caledonian mountains from Sjöfallet in the north and lake Hornavan 160 km to the south, a sediment complex called the *Snavva-Sjöfall series,* is intercalated between two volcanic complexes, which both have been referred to the Kiruna-Arvidsjaur porphyries. The lower volcanics are in the main acid lavas with intercalations of basic lavas. The upper volcanics are acid lavas with corresponding tuffitic sediments.

In the tuffitic sediments on Ultevis appear thin layers of manganese minerals such as hollandite, bixbyite and braunite, manganiferous garnet and epidote. Layers of hematite and jaspilite have also been found.

The Snavva-Sjöfall series consists essentially of sandstones and quartzites intercalated with basic lavas, sometimes developed as pillow lavas. The uppermost layer on Ultevis is a limestone.

In the *Jokkmokk region* a sediment-series has been found, consisting of quartzites rich in feldspar and mica, arkoses, black slates, and limestones. These rocks occupy, however, only small areas.

The old synkinematic granites of Svionian age in the marginal zone of Northern Norrland are usually known collectively as *Arvidsjaur granites.* This intrusive granite series begins with gabbro and diorite and then goes over via granodiorites to acid quartz-microcline granites. They correspond with the Jörn granites of the Skellefte field and have been followed from the Arvidsjaur region to Råstojaure in northernmost Sweden.

Our present knowledge concerning the Svionian cycle of Norrland indicates that we have a broad central geosynclinal belt, including the regions of the Härnö series in the south and the Elvaberg series in the north and that the Mensträsk and Vargfors conglomerates are to be considered as the bottom layers of the latter, the Naggen quartzite group the bottom layers of the former, and that there is a great unconformity between these basal sediments and the underlying rocks.

The author has, therefore, in 1957 used the term Svionian for the basement of the Härnö and Elvaberg series and the term Late Svionian for these series themselves. In a paper now in press P. H. Lundegårdh has proposed the term *Bothnian* for these younger Svionian series.

The Karelian Cycle

Some years ago a new map of the Precambrian geology of Norrbotten County was published by the Geological Survey. On this map the rocks within a more than 100 km broad zone along the Swedish-Finnish frontier are classified as younger than the rocks of the Svionian cycle described above. They are correlated with the Karelian rocks on the Finnish side of the frontier. The zone in question is here called the *Karelian zone of Northern Norrland*. Within this zone there are a few windows where the Svionian rocks are exposed. On the other hand there have been found isolated Karelian supracrustal rocks above the Svionian rocks in small areas outside the zone.

The first series included in the Karelian cycle was the *Vakko series* north of Kiruna, whereas the *Pajala* and the *Kalix series* for a long time were considered to be Svionian. Now they are all assigned to the Karelian cycle and are considered to be equivalent to the *Lapponian* rocks in northern Finland.

The Lapponian is built up of alternating sediments and basic volcanic rocks. In addition there occur dikes of hypabyssal basic rocks.

The sediments are in part clastic rocks and in part chemical precipitates. Among the clastic rocks we particularly note quartzites and phyllites. The former are often feldspathic. The phyllites are either grey or black. In the latter case they carry an appreciable content of graphite and pyrrhotite and generally occur in close association with the basic volcanics. Conglomerates occur as intraformational beds in the other sediments. A basal conglomerate has been found only in the Pajala area.

The chemical sediments display a variety of types. Limestones and dolomites are widely distributed, occasionally in large bodies, and may be considered as characteristic of the series. They are often closely associated with the volcanics. In the Kalix archipelago algal structures are found in the dolomite. Chert, sometimes ferruginous and jaspilitic, is also a characteristic component in the Lapponian sediments. It is usually fine-grained or dense and does not exhibit any clastic structures. Quartz, in a microscopically fine-grained mosaic, is the predominating mineral but sulphides, magnetite, pyroxene, and amphibole are also noted. The ferruginous types may occasionally contain fayalite. From Pajala a mineral in the chert has been described which probably is a pseudo-

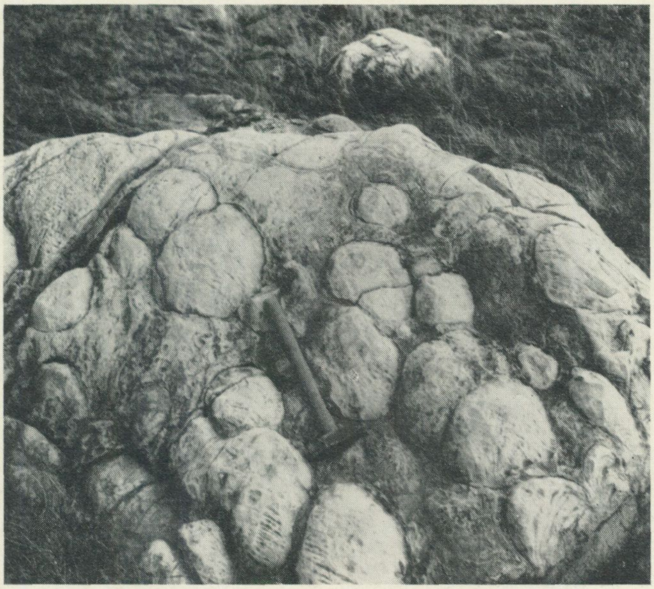


Fig. 21. Algal structures in dolomite. Vitgrundet, Kalix. (After O. Ödman.)

morph after greenalite. In some cases quartz-banded iron ores of sedimentary origin are associated with the chert.

The Lapponian volcanic rocks are exclusively of basic composition. Extremely well preserved pillow lavas are typical; amygdaloidal and fine-grained lavas also occur. Tuffaceous rocks and agglomerates are found alternating with the lavas. The former are sometimes banded and give the impression of having been deposited in water.

The hypabyssal dike rocks associated with the volcanics vary in composition from ultrabasic types to diabases. The former now appear in the form of serpentine or soapstone. The so-called leuko-diabase is a special type of dike rock. It is composed of albite as a dominant component and varying amounts of amphibole, chlorite, ankerite, and quartz. The leuko-diabase is interpreted as a sodic differentiate of the diabase magma.

The stratigraphy varies considerably from one area to another and it is not possible to give a stratigraphic sequence for the whole series. In Pajala, one of the best known areas, the stratigraphy found is from below: arkoses and conglomerates ⟶ phyllites and gneisses ⟶ quartzites with conglomerates ⟶ limestones, dolomites, and chert ⟶ agglomeratic and tuffitic greenstones ⟶ quartzitic sediments and gneisses. There is a great unconformity between this series and the underlying Kiruna porphyries with their apatite iron ores.

In the Kalix region the lower part of the Lapponian sediments is mainly composed of basic volcanics, with intercalations of limestones and dolomites often appearing together with layers of quartzite and calcareous phyllite. Above the volcanics follow sediments, especially slates and greywackes. Carbonate rocks are rare in this stage.

The Svartlå outlier of Lapponian rocks in the Svionian zone on the Lule river, south of Harads, consists of quartzites, greywackes, and grey slates with intercalations of basic volcanics and black slates. In this outlier there is also a conglomerate with pebbles of the underlying Svionian rocks: Arvidsjaur porphyries and granites and also veined gneisses of Late Svionian age.

In the Svappavaara region the Lapponian is built up of graphite schists with jaspilitic quartzite, tuffitic greenstones, limestone, quartzite, and conglomerate. There is here as in the Pajala region a great unconformity between the Lapponian and underlying Kiruna porphyries with their apatite iron ores (Svappavaara and Leveäniemi).

The *Vakko series,* north of the town of Kiruna, was, as mentioned before, the first series, which was separated from the Svionian and correlated with the Karelian in Finland. Now the Vakko series is also considered to be Lapponian. Its sediments are phyllites, quartzitic sandstones, and conglomerates as well as intercalations of limestones and dolomites. In the basal conglomerates there are pebbles of the underlying Svionian granites. Together with the sediments there also appear, as usual in the Lapponian, a thick series of greenstone. A well exposed profile at *Vittangivaara* north-north-east of Kiruna has given the following stratigraphy, from below: 320 m amphibolitic greenstone — 238 m basic tuffs and tuffites — 24 m basalt — 12 m bedded greenstone — 18 m crystal tuff — 16 m tuffite with layers of iron ore — 96 m basalt — 16 m bedded tuff and limestone — 202 m pillow lava — 16 m greenstone tuffs with quartz-banded iron ore — 40 m pillow lava.

The well-known profile through the rock complex of the Kiirunavaara and Luossavaara apatite iron ore field shows from the east Kiruna greenstones — Kurravaara conglomerate — syenite, upwards grading into syenite porphyry — the iron ore body — the quartz porphyry complex (lavas and intercalated tuffs as well as agglomerate layers) — Lower Hauki series (tuff layers altered by hydrothermal solutions) — Upper Hauki series.

The Kiruna greenstones must now be included in the Lapponian volcanics and they show the same complex stratigraphy as in Vittangivaara. The Kurravaara conglomerates are rich in pebbles but layers free from pebbles can also be seen. The pebbles consist especially of keratophyres and syenite-porphyries belonging to the Kiruna porphyries. There have also been found pebbles of magnetite-syenite porphyry and apatite iron ore, greenstones from the Kiruna greenstone complex, ferruginous quartz, quartz, and varying sediments. It seems therefore quite clear that even the Kurravaara conglomerate must be Lapponian.

The Upper Hauki series consist of quartzitic sandstones showing great unconformity with the Kiruna porphyries, and the Lower Hauki series. It has long been correlated with the Vakko series and is Lapponian. The only Svionian rocks are the ores themselves and the surrounding Kiruna porphyries as well as the Lower Hauki series.

The Lapponian supracrustal rocks have been intruded by the *Haparanda granites* which are to be considered as the Lapponian synkinematic granites. The intrusions began with gabbros and diorites. Granodiorites and plagioclase granites dominate. Also monzonites and syenites have locally been found. Pegmatites are lacking.

After the Lapponian stage, and after intrusion of the Haparanda plutonics, there followed a period of intense erosion of the early Karelian mountain chains, which even exposed the deep-seated Haparanda intrusives. Pebbles of these intrusives have been found in the conglomerates of the *Bälinge series*.

The Bälinge conglomerates are polymikt and contain a great variety of pebbles of older rocks. Pebbles of Haparanda granites prevail in all localities but Lapponian supracrustal rocks are also common. In some conglomerate occurences pebbles of Svionian volcanics, Revsund granites, aplites, pegmatites, and migmatites have been observed. Only seldom have arkosic and quartzitic sediments been found associated with the conglomerates. In one case a grey phyllite was found.

Andesitic lavas of Bälinge age with phenocrysts of plagioclase and uralite and sometimes amygdaloidal texture have a much larger extension than the sediments of the Bälinge series which only appear in small scattered areas from Piteå in the south to the vicinity of Gällivare in the north. Together with the andesitic lavas pyroclastic rocks appear, but only in a few localities. A common feature in all Bälinge conglomerates is the basic composition of the matrix which contains abundant plagioclase, hornblende and biotite. It is believed that this basic material consists of volcanic debris which was intermixed with the sediments during their deposition.

Both the Svionian and the Karelian rocks have been intruded by *late Karelian granites and syenites*. On the new map these rocks are divided into the Lina granite group, Sorsele and Edefors granites, perthite granites, and syenites.

The *syenites* have been classified into plagioclase-perthite-syenites, perthite--syenites and quartz-perthite-syenites. They are usually developed as coarse- to medium-grained massive rocks, varying from brown to brownish red in colour. Transitional varieties such as quartz-syenites or granitic types with higher content of quartz and microcline have a distinct red colour. Plagioclase and microcline, as a rule intimately intergrown, are the predominating components. The plagioclase is generally oligoclase or albite. A characteristic feature of many syenites is the development of feldspar grains measuring $1 \times 2 — 5$ cm. These are composed of rhomb-shaped or rectangular kernels of plagioclase with surrounding rims of perthite.

Quartz is usually present in a few scattered grains. An increase of free quartz changes the syenite to normal granite or where microcline perthite dominates to *perthite granite*. The major components in this rock are perthite and quartz. Its colour is red, often with a brownish-red or greyish-brown tinge. The perthite is composed of approximately equal amounts of microcline and albite. The quartz has a characteristic bluish-grey colour and has a strong tendency to

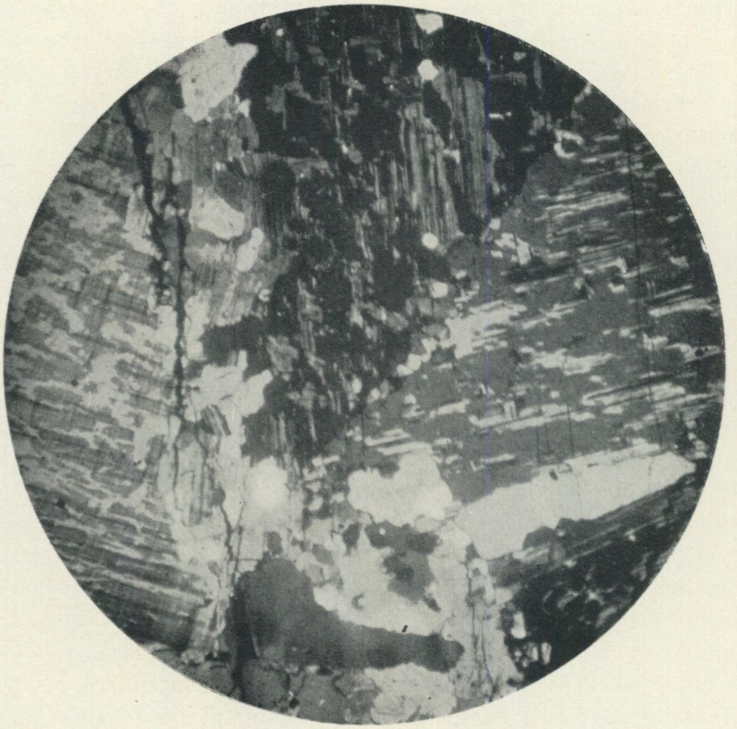


Fig. 22. Feldspar in quartz-perthite-syenite, Sjaungatuottar, microphoto, + nicols × 16. (After P. Geijer.)

develop euhedral grains. Mafic minerals are practically absent. In the marginal parts of some areas with perthite granite an albite granite has developed.

As seen from the map the syenites and the perthite granites are often nearly connected and occur in a 100 km broad belt from the Finnish frontier in the east to the Caledonian mountains in the west, that is the region of the iron ores in northernmost Sweden. A certain chemical and mineralogical relationship also exist between the perthite syenites and granites and the Kiruna porphyries. The porphyries are looked upon as the source material of the syenite-granite series.

The *Edefors granite* is a bright red or brownish medium-grained rock characterized by small aggregations of dark minerals. The predominant constituents are quartz, microcline, plagioclase, hornblende, and biotite. Pyroxene is only sparsely distributed. The syenitic forms of this granite are greyish green or brownish, coarse to medium-grained rocks. The major constituent is microcline perthitically intergrown with oligoclase or albite. Quartz is present only as occasional grains. The mafic minerals are the same as in the granite. To these syenites belong also the *Boden syenites*.

The *Sorsele granites* north of the Skellefte field display a great variation in mineralogical composition and appearance. Coarse- to medium-grained red or grey hornblende granites are common types. The red type is similar to the Edefors granite and the grey variety resembles the grey Arvidsjaur granites (of Svionian age). Porphyritic granites with phenocrysts of feldspar are common in some localities. A characteristic feature of these granites is the occurrence of small fragments of fine-grained basic rock. In other cases the Sorsele granite may be a coarse grey or red granite with biotite as a prominent constituent. It then strongly resembles the Revsund granite. Syenitic forms are identical with the Edefors and Boden syenites. Granophyric intergrowths of quartz and feldspar are common structural features in the Sorsele granites. Otherwise the texture is distinctly granitic, the feldspar often being well crystallized. Quartz, microcline, acid plagioclase and hornblende are the major constituents. Sometimes hornblende is substituted by biotite or pyroxene. In the syenitic types, however, pyroxene is more common.

The Edefors and Sorsele granites as well as the perthite syenites and perthite granites must be assigned to the anorogenic or intraorogenic granites. The *Lina granites* on the contrary are typical late-orogenic granites accompanied by aplites and pegmatites and nearly related in time with the late Karelian veined gneisses. In many cases the Lina granites are believed to have passed through a magmatic stage and are unquestionably intrusive into their wall rocks but on the other hand, there often occur gradual transitions from sediments to granites containing ghost-like remnants of the former. In such case the granite does not show any intrusive features and is considered to have been formed by granitization *in situ*.

The Lina granite proper is a medium-grained, homogeneous rock of reddish colour. The comparatively sparse biotite is the only mafic mineral. Quartz, microcline and albite-oligoclase are the major constituents. In some areas the granite has a porphyritic texture and carries large phenocrysts of red microcline. Graphic types are common.

Very extensive areas within the Karelian zone of Northern Norrland are represented by *late Karelian gneisses,* usually developed as veined gneisses. The main components of these rocks are quartz, feldspar, muscovite and biotite. The more basic members carry in addition amphiboles and pyroxenes. Of accessory nature are minerals like sillimanite, andalusite, cordierite, garnet, graphite, and chrome-bearing mica. Not only sediments have been identified among the veined gneisses but also basic volcanic rocks and the Haparanda granites.

The late Karelian granites and especially the late orogenic Lina granites have also a very wide extension in the Svionian marginal zone of Northern Norrland. Svionian rocks metamorphosed during the late Karelian phase are therefore widespread in this zone. The Arvidsjaur and Kiruna porphyries for instance have been altered to leptites and leptite gneisses or, if the grain is larger, to granitic rocks which are difficult to distinguish from true granites. The basic volcanics have been altered to amphibolites and sometimes also to real veined gneisses.

The Svionian granites in this zone have also been strongly influenced by the same metamorphic processes. Thus, for instance, in some places late Karelian

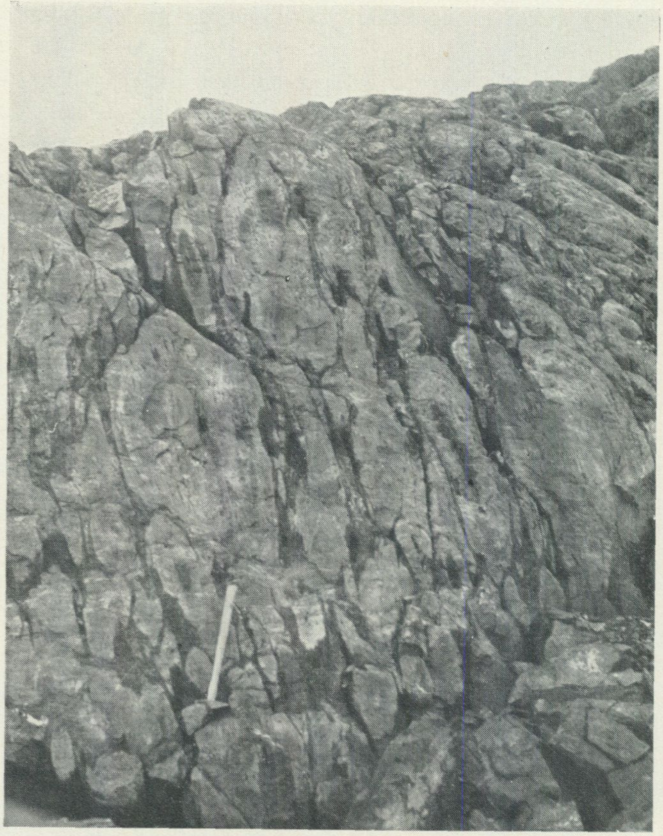


Fig. 23. Pressed Lapponian pillow lava. Sjangeli. (After O. Ödman.)

granitic material has invaded the Arvidsjaur granite to such an extent that hybrid forms have developed which are difficult to classify.

Within a roughly triangular area with its apex in the Pajala region and extending from there west-south-west and north-west to the border of the Caledonian mountains, scapolite has a regional distribution. Not all rock members of the Precambrian series have been scapolitized but basic rocks in particular, volcanics as well as intrusives have fallen victim to this special form of metamorphism. Acid rocks are more rarely scapolitized. The scapolitization process implies an addition of considerable amounts of chlorine and carbon dioxide to the host rock. The mineral assemblage of the scapolitized rocks shows also that sulphur, boron, phosphorus, titanium, iron, copper, and molybdenum have been added. Of especial interest is the close relationship between scapolitization and copper mineralization (chalcopyrite, bornite and chalcocite). The solutions bringing about this transfer of material must have been very mobile. They ought to have emanated from a deep-seated magmatic source. The most probable is that the scapolitization was caused by the Lina granite.

Karelian rocks occur also within the Caledonian mountains in the window between the eastern end of Torneträsk and Sitasjaure. Basic volcanic rocks, mica schists, conglomerates, and dolomites build up the supracrustal rock series, which is considered to be of Lapponian age. The *Vassijaure granite* has been correlated with the Lina granites. There is also a copper mineralization of the type described above.

Within the Karelian orogenic zone proper the general strike of the formations is north—south, often with a slight deviation to the east. An exception from this rule is found in the coastal regions between Luleå and Kalix and at Karungi where the trend of the Lapponian series is east—west. This is the same direction as the corresponding Lapponian rocks in adjoining parts of Finland.

The tectonic features in the Svionian orogeny in the marginal zone of Northern Norrland are usually strongly influenced by the late Karelian folding and they are consequently as a rule difficult to recognize. It is only in the southernmost parts, adjacent to the Skellefte field, that with some degree of certainty we still may find the older structural zones preserved. In the northern parts of the marginal zone it is doubtful whether any Svionian structural zones can be recognized at all.

The folding during the Karelian cycle occurred in two stages. During the earlier the Lapponian series was folded and the Haparanda granite series intruded. After an erosional interval, with the formation of the Bälinge series, a renewal of the diastrophic forces occurred in late Karelian time. This later stage is by far the most revolutionary. Not only the Karelian rocks but also the older Svionian basement was involved in the folding process. The bed-rock was regionally metamorphosed, and granitization and migmatitization took place on a grand scale.

Absolute age determinations made during the last years on rocks from Sweden, Finland, and the Soviet union have given about 1800 millions of years for both the Karelian and the Svionian rocks. The investigations in northernmost Sweden have, however, clearly indicated the existence of two cycles different in time, the younger Karelian cycle and the older Svionian. There are essentially two explanations for these apparently contradictory facts. The first is that these cycles have been very near each other in time. The palingenic processes in late Karelian time in such a case must have followed upon the palingenic processes in the Late Svionian so nearly that the time that elapsed between the two must have been smaller than the errors of the methods used. The second, the most probable is that a widespread regeneration has occurred both in the Karelian and in the Svionian rocks in connection with a regional sinking of both regions in late Karelian time. Most determinations have been made on micas by means of the potassium-argon method. The rise of the temperature might have been high enough to drive out the argon. Then the disintegration could start again.

The Gothian Cycle

THE GOTHIAN ROCKS OF SOUTHEASTERN SWEDEN

The dominating rocks in Southeastern Sweden are granites which have been collectively named the *Småland granites.* These constitute a differentiated series beginning with gabbros and diorites. Then follow grey plagioclase granites, so-called *grey Växjö granites,* intermediate augen granites, often called *Filipstad granites,* and red granites rich in microcline and quartz, so-called *red Växjö granites.*

The gabbros often show anorthositic and monzonitic differentiates, and in some massifs nickeliferous pyrrhotite and chalcopyrite have been found in concentrations rich enough for mining before the discovery of the Sudbury ores.

The red Växjö granites are composed of quartz, perthitic microcline, acid plagioclase in varying amounts, and subordinate biotite. Locally also hornblende has been found in small amounts. Characteristic for the intermediate granites are the 2—5 cm large, more or less rounded, red or red-violet phenocrysts of microcline-perthite often surrounded by rims of plagioclase. Sometimes a good zonal structure can be seen in the microcline augen. The amount of quartz is lower than in the red Växjö granites, the amount of biotite and hornblende higher. Augite has locally been found. The plagioclase is usually a basic oligoclase. Where the amount of quartz is low the granites pass into quartz-syenitic types. The grey basic granites have a greater amount of plagioclase than microcline and more hornblende and biotite than the types mentioned above. Together with hornblende also augite is a usual component, often occurring as kernels in the amphibole.

Supracrustal rocks occur often as very irregular remnants enclosed in the large granite mass. There are both sediments and volcanic rocks of Gothian age. The sediments seem to be older than the volcanics and build up three series: The *Västervik series* in the environs of the town of Västervik, the *Vetlanda series* in the environs of the town of Vetlanda, and the *Västanå series* northwest of the town of Sölvesborg.

The *Västervik series* occupies a large area around Västervik and Gamleby and builds up a great many smaller remnants in the surrounding granites. The dominating rocks in this series are quartzites, often showing cross-bedding and sometimes ripple marks. All transitions exist from pure quartzites (orthoquartzites) to feldspar-quartzites as well as to mica schists with andalusite and sillimanite. Small layers of hematite and magnetite have been found in several places.

Towards the north the large quartzite body is limited by the Loftahammar granite, which is developed as a gneissic augen-granite. The age relations between this granite and the Västervik quartzite is not quite cleared up. The geologist who first mapped this region in more detail came to the conclusion that the Loftahammar granite was the basement for the quartzite series. Other geologists are of the opinion that the granite is intrusive into the quartzites. It is, however, clear that the granite cannot be Svionian as the late Svionian

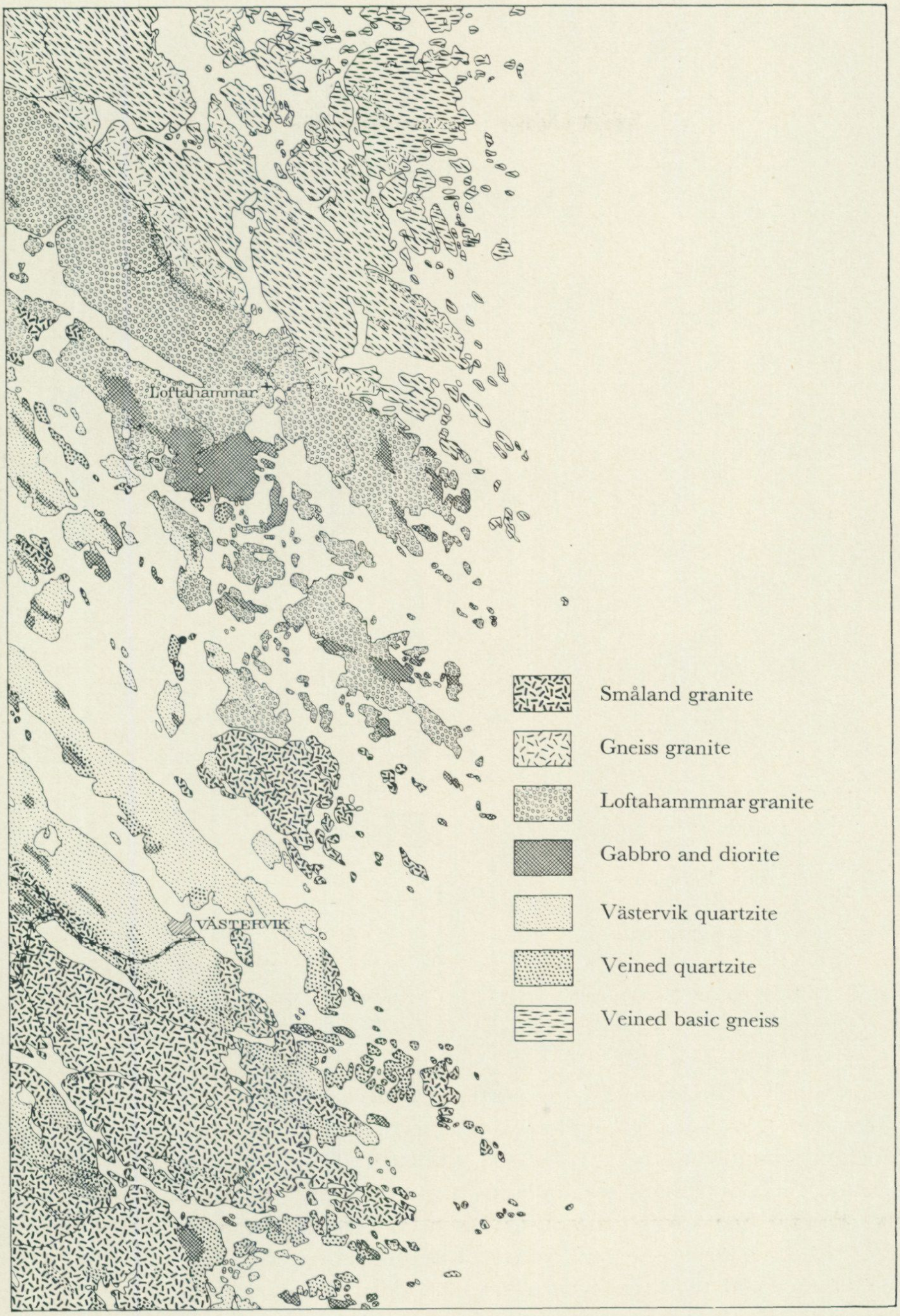


Fig. 24. Map of the Loftahammar-Västervik region. In the northernmost part the Svionian veined gneisses and gneiss-granites. In the Gothian region south of these rocks the Loftahammar granite is of old Gothian age and probably older than the Västervik quartzites which are intruded by gabbros and diorites and by the Småland granites. (After A. Gavelin and F. Svenonius.)

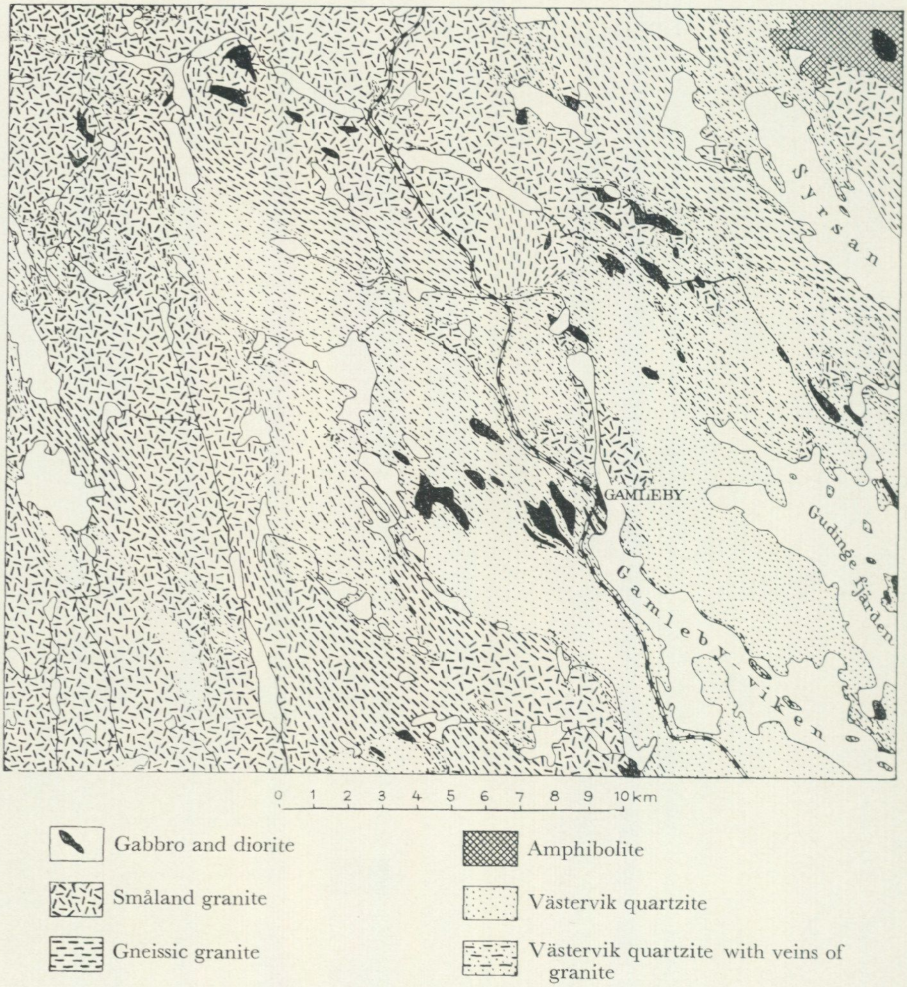


Fig. 25. Map of the Gothian Gamleby region northwest of the town of Västervik. (After F. Svenonius.)

veined gneisses disappear at the northern boundary. Of great interest are the alterations that have taken place in connection with the development of the Småland granites. Large parts of the supracrustal series contain a great many granitic veins and dikes accumulating towards the fronts of the granites, and the granites themselves contain, as has been pointed out above, diffuse remnants of the quartzite series. It is according to most geologists quite clear that the supracrustal rocks have been assimilated in the granites on a large scale. Some geologists think instead that material for the granites has been taken from the supracrustal formation at great depth and high temperature. The author thinks that these two explanations can be very well combined. The amount of feldspar in the quartzite is not high enough for an alteration *in situ* of the quartzite to granite. A large supply of material from outside has been necessary.

The *Vetlanda series* seems also to be dominated by original sandstones intercalated with conglomerates and slates. Besides there are also found limestones, basic, often scoriaceous lavas, and corresponding tuffs. In the latter, poor, bedded iron ores have been found locally. The sandstones are altered to quartzites. The bedding is, however, often wonderfully well preserved. The slates have been altered to mica schists.

In the vicinity of the Malmbäck railway station the conglomerate contains pebbles of granite. The granite that has been the source of the material in these pebbles must be older than the Småland granites surrounding and intersecting the Vetlanda series. From the Vetlanda region a zone with older gneissic granites of varying composition can be followed to the town of Oskarshamn on the east coast. The granite pebbles in the Malmbäck conglomerate probably are of the same age as these gneissic granites, which should belong to the basement of the Vetlanda series.

The *Västanå series* consists of mica schists, mica quartzites, quartzite-conglomerates and volcanic rocks which seem to be dacite tuffs. The mica in the quartzitic layers is essentially muscovite. Together with this mineral there are also kyanite, manganiferous andalusite, and otrellite. Occasionally tourmaline, rutile, and hematite are present in the quartzite, the hematite together with muscovite, forming thin layers. The conglomerate layers contain well rounded but deformed quartzitic pebbles. Underneath the quartzite beds there lies a bed of amphibolite interpreted as a metamorphosed diabase or diabase-tuff. The dacite tuffs appear as intercalations in the quartzites.

The immediate basement of the Västanå series is a relatively fine-grained gneiss which has been designated as hälleflinta or hälleflint-gneiss. These rocks seem to be volcanic and mostly tuffs. Towards the east these rocks grade structurally into the more strongly metamorphosed rock series called the *Blekinge coastal gneisses*. These gneisses are usually even-grained, medium- or fine-grained rocks poor in mica and characterized by a distinct parallel structure. The usual colour is grey. The mineral components are quartz, plagioclase, and microcline-perthite. The proportions between these minerals vary within wide limits. The amount of plagioclase is usually high. Quartz lies usually between 30 and 40 % but increases in some places so much that the rocks become quartzitic. Hornblende has sometimes been found in subordinate amounts. The parallel structure has been considered as original bedding in a supracrustal series.

The volcanic rocks appearing within the Gothian Småland granite area are usually known as the *Småland porphyries*. They have a large extension in this region forming elongated bodies with predominant east-west strike and being enclosed by the granites. The greatest part of these volcanic rocks is quartz-porphyry and subordinate associated tuffs. The colour is usually red, red-brown or brown but also dark grey and black types appear. As phenocrysts both quartz and feldspar occur. The groundmass is often glassy. Occasionally many primary features have been preserved in the lavas as for instance fluidal struc-

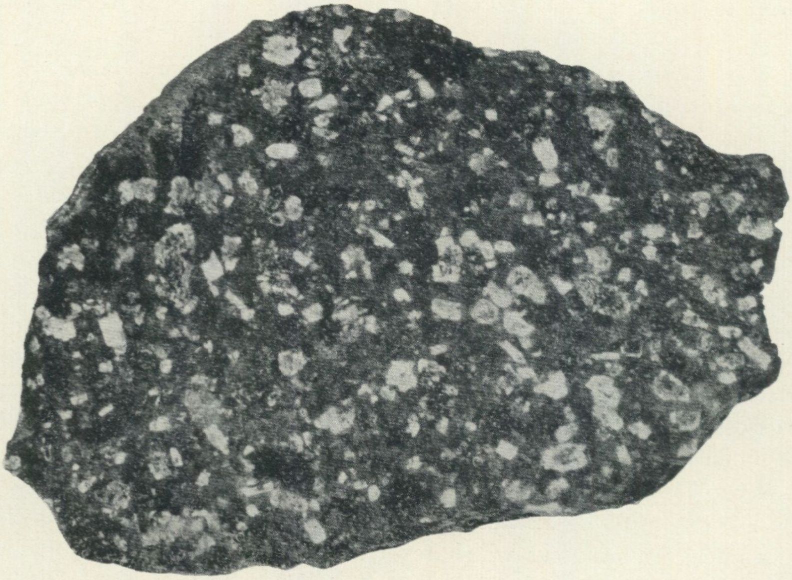


Fig. 26. Porphyry, southeast of Boxholm. Natural size. Belongs to the Gothian Småland porphyries. (After N. H. Magnusson.)

tures, spheroliths, perlitic cracks, lithophyses, and in the tuffs ash structures. Agglomerates and volcanic breccias have also been found.

The primary features, however, are mostly obliterated by metamorphism and the rocks have often acquired a more or less distinct schistosity. The relations of the porphyries to the surrounding granites offer much of interest. Towards the granites the porphyries often grade into granite porphyries with relatively large phenocrysts of quartz and with granophyre structure of the groundmass. This happens above all towards the more basic granites. In other cases aplitic rocks with granophyre structure have been formed. Granite dikes often intersect the porphyries in such amounts that they dominate over them. The transitional types mentioned above may have been partly developed by the contact-metamorphic influence of the granite upon the volcanic rocks but may partly be interpreted as a fine-grained porphyritic structure in the marginal zone of the granite itself.

The Småland porphyries have been considered as the effusives of the Småland granite magma. Several observations indicate that the granite intrusions are relatively thin and flat-lying.

The Gothian granites can be followed over to the western shore of Lake Vättern and from there in a north-north-western direction to Långflon on the Norwegian frontier in the northernmost part of the province of Värmland, after which the granites have been called *Värmland granites*. These vary in the same way as the Småland granites. The intermediate augen-granites dominate, and the more acid are called *Filipstad granites* and the more basic, often quartz-syenitic types, are called *Kristinehamn granites*. The more subordinate *red bio-*

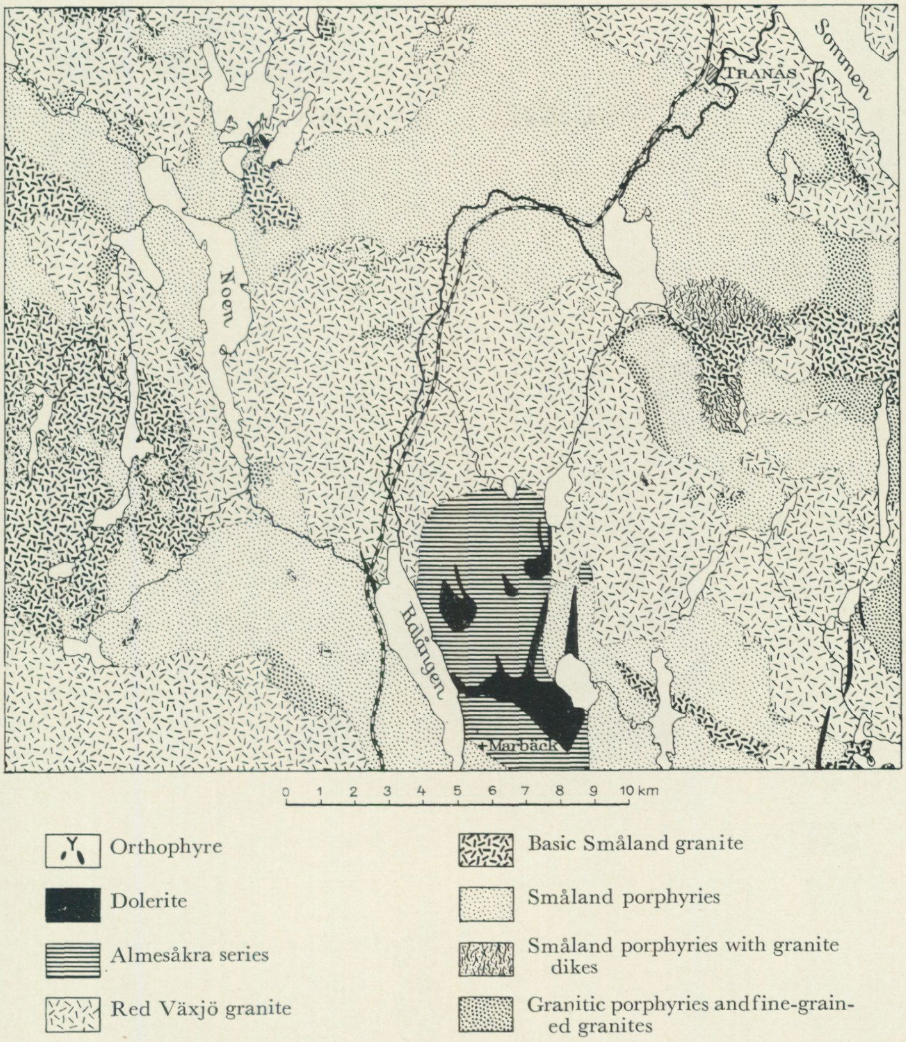


Fig. 27. Map of the Gothian region of the town of Tranås. The Almesåkra series and the dolerites are of Jotnian age. The orthophyres are also Algonkian. (After A. Gavelin.)

tite granites correspond to the red Växjö granites among the Småland granites. Remnants of porphyries have been found in the region between Hagfors and the Norwegian frontier. Together with the volcanics Gothian sediments also appear. Among them the sediments of the *Rämsberg series* are the best known. They consist of a coarse quartzite conglomerate, arkoses with intercalations of conglomerates with pebbles of hälleflinta, a bedded quartzite with intercalations of mica schists, and poor iron ores.

The relations of the Gothian granites to the older Svionian rocks in the boundary zone from Lake Vänern to the Baltic Sea offer much of interest. As a rule the boundaries are sharp. Between Lake Skagern and the town of Norr-

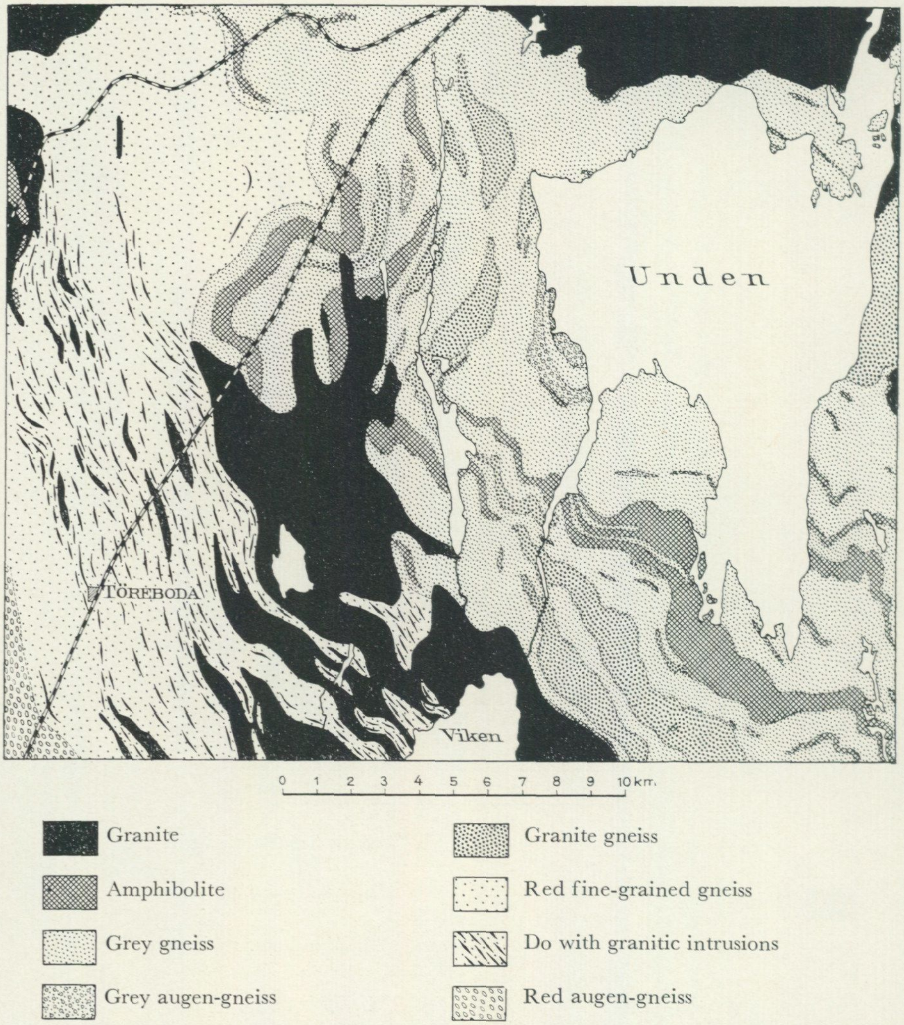


Fig. 28. Map of the region of Töreboda east of the town of Mariestad showing pre-Gothian fine-grained gneisses and red augen-gneisses in the western part and the Svionian amphibolites, grey gneisses, grey augen-and-granite-gneisses in the eastern part. The Gothian granites have intruded both the pre-Gothian and the Svionian rocks. (After H. E. Johansson.)

köping the Gothian augen-granites often pass into gneissic rocks with augen quite similar to those in the real granites. The augen successively disappear in the surrounding gneissic Svionian rocks. Such isolated gneissic augen granites have been found also in the Svionian region south of Norrköping. The author has explained these rocks as roots beneath the Gothian granites for material seeking its way upward.

In the northern part of the Småland granites there are larger and smaller remnants of Svionian rocks. The southern limit for such remnants passes through Boxholm and Rimforsa. Outside the northern boundary zone there are only a few isolated massifs of Gothian granites.

The southern boundary has puzzled geologists a good deal. What has been called Tving granite on the map and has been given a special colour has by some geologists been considered as grey Växjö granite, mostly more or less tectonized and altered to often strongly schistose, gneissic rocks. The well-preserved granite in the northwestern part of the area is also very similar to some Småland granites in the large Gothian granite area in the north. In the eastern part of the Tving granite area the rock has on the other hand developed as a coarse augen gneiss. The boundary between it and the Småland granites in the north is sharp.

Younger than the Coast gneisses in the Blekinge region, the Tving granites and the Gothian granites north of them are the coarse-grained porphyritic *Karlshamn granite* and the fine-grained and usually even grained *Spinkemåla* — and *Halen granites.* The former dominate in the larger massifs, the two latter in the smaller massifs. These young granites enclose remnants of older rocks, often in large amounts, and are connected with migmatites showing varying proportions of granitic material and of the old rock material.

Some of these young palingenic granites are very similar to the Bohus granite and on the new map they have been grouped together with them as Dalslandian.

New age determinations indicate, however, that the Karlshamn granite is about 1420 million years and that a regeneration has gone over southeasternmost Sweden at that time, as both the Småland granites of that region, the Tving granites, and the Coast gneisses all give figures between 1560 and 1460 million years. If we consider the figures for the whole Gothian area in the eastern part of southern Sweden, we find that they fall between 1660 and 1420 million years. The age determinations thus seem to indicate that the Karlshamn granite series may be the youngest granites in the Gothian cycle.

From the southern end of Lake Vättern a broad *zone of fracture,* 20 km wide, has been followed southwards into Scania, the southernmost province of Sweden. In this zone the rocks are cut by steeply dipping, usually nearly vertical schistosity planes characterized by sericite, biotite and epidote. Often the rocks have been completely altered to schistose types rich in these minerals. Quartz and feldspar grains are more or less cracked and smashed. Real mylonites have also been found in the zone.

From Vättern to Lake Rusken the zone passes through the Barnarp granite which is a Gothian granite originally of the same type as the granites east of the zone but deformed to a rock rich in schistosity planes. In this granite there occur several hyperite bodies. One of them forms Mount Taberg, where a large concentration of *titanomagnetite-olivinite* occurs. This deposit is Sweden's largest supply of titanium and vanadium. The boundary between this ore and the surrounding hyperite is always sharp, and the ore contains fragments of hyperite. The ore must therefore be intrusive into the hyperite, that is in its mother rock.

South of Lake Rusken the zone of fracture goes through pre-Gothian gneisses of varying types. Orientated along the schistosity planes there appear in this part of the zone a great many dikes of *hyperite-diabase*. The main constituents are labradorite and hypersthene-augite together with titano-magnetite, biotite and hornblende. These hyperite-diabases always show sharp contacts and fine-grained to dense marginal facies.

Hyperite-diabases also occur on *Romeleåsen,* a longitudinal horst of Pre-cambrian rocks surrounded by Cambro-Silurian and Mesozoic layers. The dominant rocks of Romeleåsen are old gneissic granites in which remnants of supracrustal rocks (volcanics and sediments) have been found. These rocks have been intruded by hornblende granites and biotite granites possibly of Gothian age.

Lastly there appears in the zone of fracture, along its western boundary, a very interesting rock known as the *Vaggeryd syenite.* Quite new investigations have shown that this rock was originally a fairly normal augite-syenite composed of oligoclase, orthoclase with some sodium, augite, and perhaps hornblende. During a later phase an autometasomatism has affected the syenite, especially its central part, and altered the mineral composition so that plagioclase richer in sodium, ægerite-augite, and hastingsite were formed. This alteration took place essentially in the central part of the massif, owing to the later consolidation.

The schistosity planes made the intrusion of the syenite possible. This intrusion was at least somewhat younger than the hyperites, as syenite dikes have been found intersecting a hyperite occurrence in the Taberg region.

The possibility of other occurrences of alkaline syenites and granites of the same age as the Vaggeryd syenite has been brought up *(Glimåkra syenite* and *Vånga granite).* It is also a possibility worth considering that the metasomatic alteration that formed the Varberg charnockites out of older material could have taken place in the same time.

The Gothian granites west of Lake Vättern are also passed through by a great many schistosity planes, which however don't lie so close as in the zone south of Vättern. The granites between the schistosity planes usually show several features of crushing. That is the case also with the Värmland granites from the eastern shore of Lake Vänern to the Norwegian frontier in northern Värmland. In this often schistose granite zone and in the schistosity zone south of Vättern the age determinations fall between 1380 and 1240 million years.

The Vaggeryd syenite has given 1270 million years, which probably is the age of its origin. The Västanå sediment series on the contrary is probably Gothian but has been influenced by the movements in the schistosity zone and has given 1240 million years. The slates in the Grythytte and Saxå fields in eastern Värmland have given 1380 and 1280 million years respectively. These slates are no doubt early Svionian and should have given about 1800 million years. Influenced by the Gothian granites and by the still later movements that gave the rocks there schistose appearance they have given such low figures. A strongly schistose Gothian Värmland granite has given 1060 million years. This can be explained so that the movements in the schistosity or fracture zone south of Lake Vättern and its continuation in Västergötland and Värmland began about 1380—1240 million years ago and continued during the Dalslandian regeneration for about 1000 million years.

At the very granite front against the pre-Gothian gneisses in the west there have been found in many places that the gneiss complex dips with moderate angles beneath the granites, which seem to have been pressed towards the west over the pre-Gothian gneisses, except where still younger faults exist. This thrust plane zone has been followed from the Norwegian frontier to the region west of the southern end of Lake Vättern.

The thrust and mylonite zone limiting the pre-Gothian grey gneisses to the east has been considered to be of the same age as the folding of the Dal series. The author now think it more probable that it is of the same age as the thrust plane zone limiting the red pre-Gothian gneisses to the east but that it has been influenced by the later Dalslandian regeneration.

Special mention must be made of the relations between the pre-Gothian gneisses and the Gothian granites in the region of Töreboda. The gneisses are there relatively fine-grained and probably belong to old supracrustal rocks within the pre-Gothian complex. They show here moderate dips to the east and have been intruded along the schistosity planes by a great many thin intrusions of Gothian granite. To the east, these fine-grained pre-Gothian gneisses meet with the Svionian rocks which on the map have been designated as old granite with some amphibolites. In the granites there are fine-grained leptites, and often the latter dominate. The fine-grained pre-Gothian gneisses according to several field observations dip under leptite rocks belonging to the Svionian cycle.

THE GOTHIAN ROCKS OF SOUTHWESTERN SWEDEN

Gothian rocks, both granitic and supracrustal, occupy an elongated syncline in the gneiss-area of southwestern Sweden. Beginning at Lake Glafsfjorden south of the town of Arvika it has been followed to the Onsala peninsula, south of Göteborg (Gothenburg).

The granite series is typically anorogenic. It begins with gabbros and diorites followed by the *Åmål granite,* which is rich in plagioclase and corresponds to the grey Växjö granite. Then comes intermediate granites, often developed as augen granites and, lastly, the red *Kroppefjäll granite,* which is rich in quartz and microcline and corresponds to the red Växjö granite. The intermediate granites have often been reckoned to the Åmål granites, and the whole series has been called the *Åmål-Kroppefjäll granite series.*

The supracrustal rocks have been summarized in what has been called the *Åmål series,* because they were mapped in more detail around the town of Åmål. Volcanic rocks dominate in this region. Quartz-porphyries, dacites, and andesites occur among the lavas, which are accompanied by ash tuffs, crystal

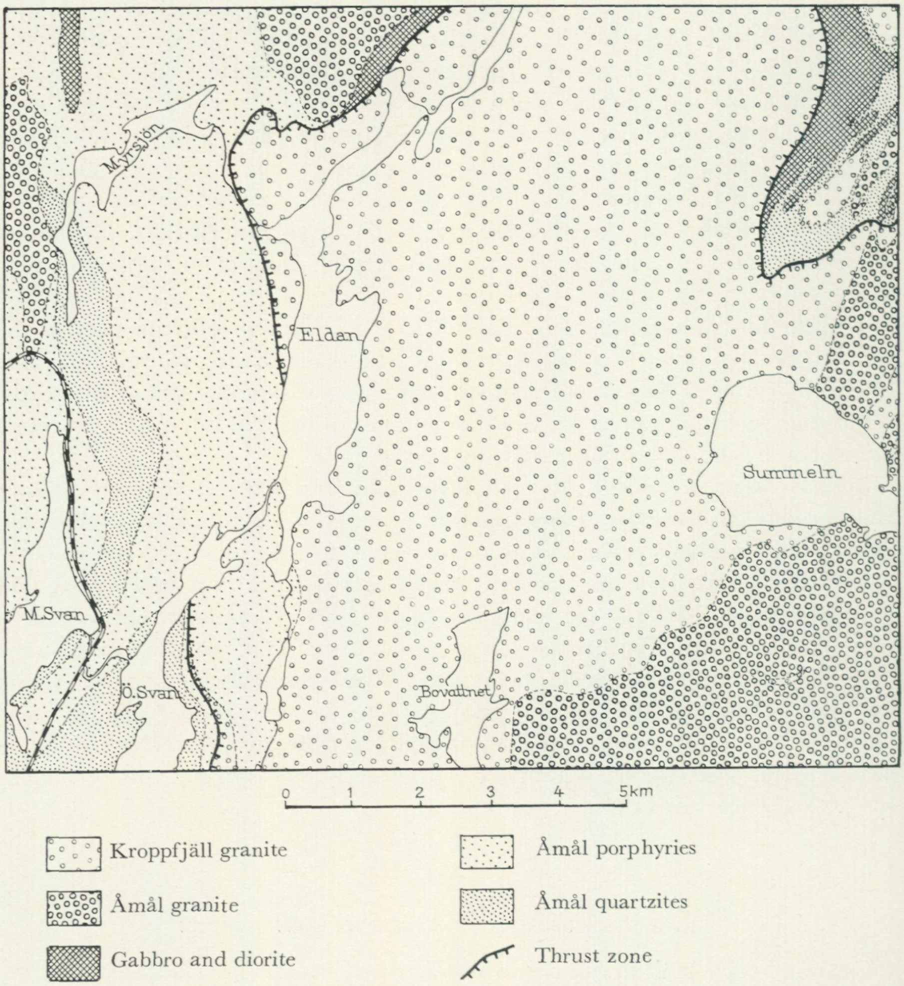


Fig. 29. Map of the Gothian region northwest of the town of Säffle. (After N. H. Magnusson.)

tuffs, agglomerates and volcanic breccias. Intercalated are in some places polymikt conglomerates. These contain mainly pebbles of the volcanic rocks, but sometimes pebbles of quartzites and even of granites occur.

Together with the volcanics occur quartzites in which sometimes good bedding, cross-bedding well marked by small layers of hematite, ripple marks, and conglomeratic layers have been found. There are thus great similarities between the Åmål series and the Västervik series and the Småland porphyries described before.

Well preserved quartzites have a relatively large extension in the region of Svanskog. Even here the volcanic rocks dominate, and among them the quartz-porphyries. The dacites and andesites, however, disappear immediately north of Svanskog.

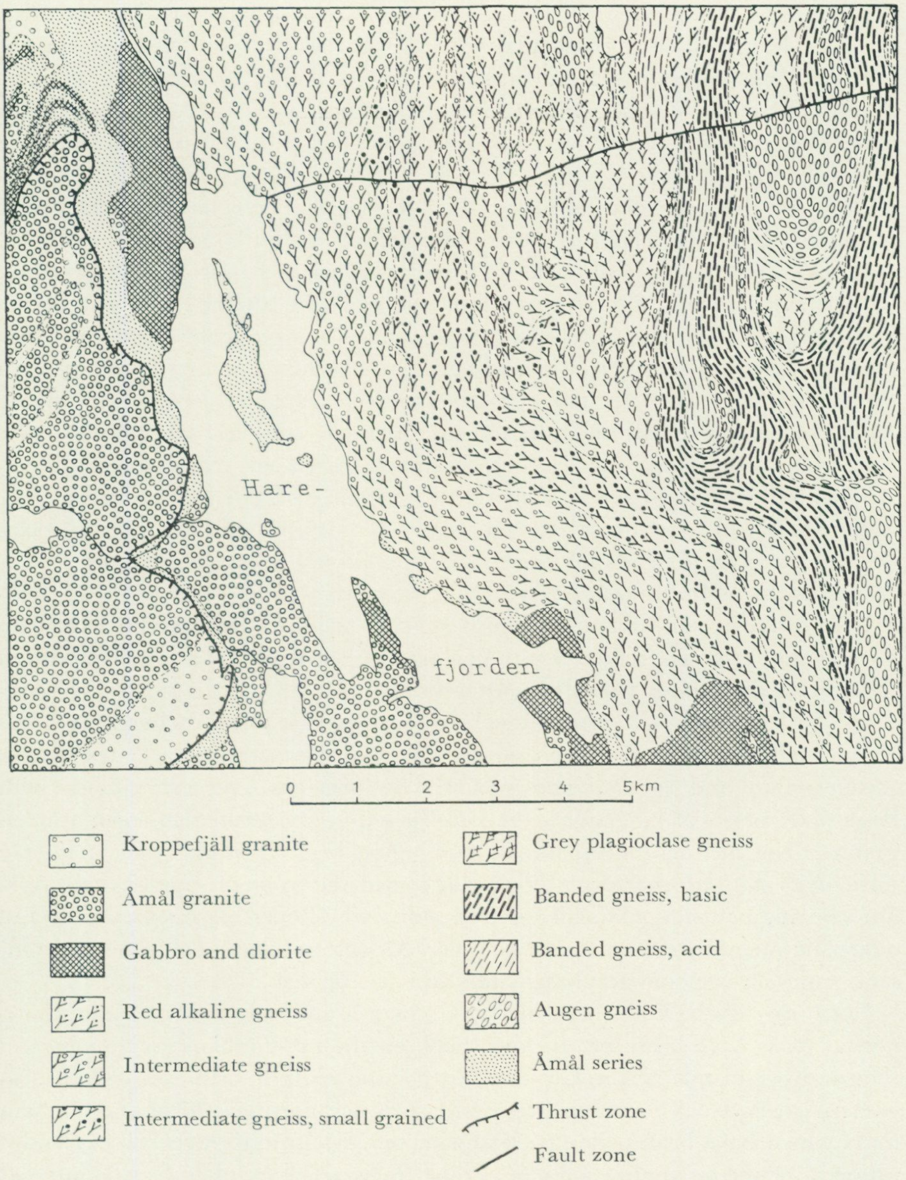


Fig. 30. Map showing the region north of the town of Säffle with the Gothian rocks in the western part and the pre-Gothian gneisses in the eastern. (After N. H. Magnusson.)

The quartzites have in both the Svanskog and the Åmål regions often a large amount of feldspar. Such feldspar-quartzites alternating with pure quartzites and with volcanic quartz-porphyry layers build up the Åmål series north of Svanskog in what has been called the *Gillberga syncline*. This is the northernmost part of the Gothian syncline in southwestern Sweden. The Åmål series here lies directly upon the pre-Gothian gneisses. As far as can be judged we have here an old land-surface, which had been thoroughly weathered. The kaolinite has later been altered to muscovite. It is in this region clear that the basement for the Åmål series had been gneissified before the weathering and the formation of the Åmål series, which form the bottom layers in the Gillberga syncline. The granites and their accompanying gabbros and diorites form flat-lying intrusions higher up.

Probably the large granite mass filling the Gothian syncline from Gillberga to the Göteborg (Gothenburg) region also consists of flat-lying intrusions which enclose a great many remnants of supracrustal rocks besides the larger remnants named above. The remnants have first been altered through contact metamorphism which caused a recrystallization. A large-scale assimilation has naturally taken place in connection with the development of the granites. In connection with later tectonic processes and in some regions where higher temperatures prevailed, the supracrustal rocks as well as the granites have undergone deformations and recrystallizations. In this way cataclastic schistose, gneissic schistose and gneissic schlieric types originated. All transitions exist between these rock types and between them and surprisingly little altered rocks.

In the region of Rådanefors there is a relatively large remnant of supracrustal rocks in the granites. This remnant consists of strongly schistose feldspathic quartzite and quartz-porphyry together with an amphibolite altered to hornblende schist. Even the surrounding granites are strongly schistose and often difficult to distinguish from the supracrustal rocks.

In the southernmost part of the large syncline around Göteborg the rocks have usually got a gneissic appearance. The most characteristic granites are the *Askim granite* and the *Frölunda granite*. The former is a red-grey granite with large phenocrysts of microcline, the latter a red-grey intermediate even-grained granite. The metamorphism has in this region been so strong that it is very difficult to state to what extent the rocks considered to be of supracrustal origin are volcanic or metasomatically altered sediments. Relics of conglomeratic and quartzitic rocks have been found however. Among the amphibolites on the Onsala peninsula agglomeratic basalt tuffs can also be seen.

North-east of the Gillberga syncline Gothian granites and subordinate supracrustal rocks have been forced down between the pre-Gothian grey gneisses in the south-west and the pre-Gothian red gneisses in the north-east. The south-western gneiss block has been pressed towards the north-east over the Gothian rocks which have been mylonitized and rendered schistose. A feeble recrystallization after the mylonitization can also be traced. The granites are the same as in the Gillberga syncline and the supracrustal rocks the same as in the Åmål series of this syncline. Both volcanics and quartzites have been found. The Gothian complex in this *mylonite zone* tapers out south of St. Kil. The thrust zone can then be followed towards the south along the eastern shore of Värmlandsnäs and Kållandsö and then via Lake Anten and Lake Mjörn down to Lake Lygnern, east of the town of Kungsbacka, where it fades way. From St. Kil to Lake Lygnern the thrust zone passes between the western block of grey gneisses and the eastern block of essentially red gneisses.

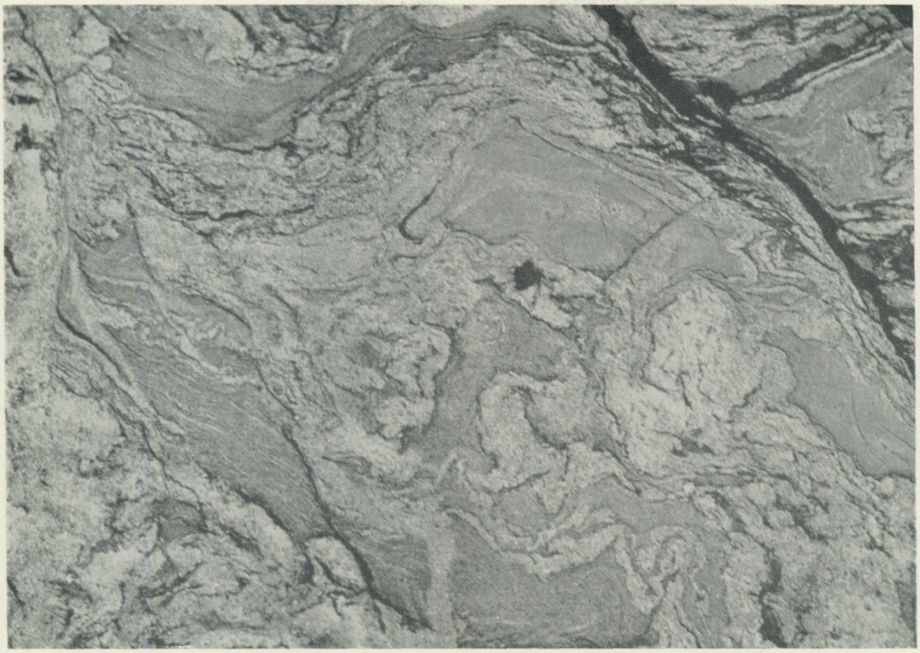


Fig. 31. Veined and folded slate or greywacke gneiss. Isle of Vrångö, parish of Styrsö. Belongs to the Stora Le-Marstrand series. (After P. H. Lundegårdh.)

West of the Gothian syncline just described the gneisses are quite different from the pre-Gothian ones east of the syncline. The dominating rocks are grey sedimentary gneisses with veins or schlieren of pegmatitic or aplitic composition. These rocks are, from a regional point of view, very monotonous. However, in detail variations occur, depending on the amount of mica, and give lighter and darker grey colours to the usually fine-grained schistose mass. Parallel with the schistosity there are lighter veins of quartz and feldspar. These veins vary in frequency, width and extension along the schistosity. The veins are always more coarse-grained than the rest of the rock, and more coarse-grained in the broad than in the thin veins. If the rock is plastically folded the veins always follow the folds. The amount of quartz is often high, often over 50 %. The amount of mica is also high, often exceeding the amount of feldspar. Such types ought to be called mica schists. Of the micas muscovite usually dominates over biotite. In some regions microcline is rare or absent, the plagioclase being an oligoclase. In other regions, as for instance around and south of the town of Marstrand, the amount of microcline is higher, and beds rich in this feldspar alternate with beds poor in it. Impregnations of pyrite and pyrrhotite have been found. These sediments are transitional types between sandstones and slates metamorphosed to gneissic mica schists with aplitic and pegmatitic veins. Small quartzitic intercalations and even relatively thick pure quartzites have been found here and there in these gneisses.

As intercalations in the sedimentary gneisses described above occur layers of red-grey veined gneisses with a significant amount of microcline but a low amount of mica. These layers may be volcanic rocks. Amphibolitic veined gneisses may be basic volcanics. Some ultrabasic intrusions have been altered to soapstones. The occurrence in a few places of such minerals as clinozoisite, tremolite, calcite, and grossularite seems to indicate the presence of carbonate rocks in the original sediments.

The sediment series described above has been called the *Stora Le-Marstrand series*. It is apparently older than the Åmål series, judging by field observations east of Lake Stora Le. Observations north of Göteborg, where gneisses quite similar to the sedimentary mica gneisses of the Le-Marstrand series also appear east of the Gothian syncline, indicate that this series is younger than the pre-Gothian gneisses which have undergone a much more deep-seated gneissification. On the map it has been assigned to an older part of the Gothian. There is, however, also the possibility that we are here concerned with a Svionian series.

On the Koster islands west of the town of Strömstad there occurs a supracrustal series of fine-grained gneisses, the main type of which has a laminated structure due to close alternation of more or less micaceous layers. This structure may be that of an original volcanic tuff. This rock is rich in plagioclase (oligoclase or oligoclase-andesine), but more or less microcline-rich rocks also occur.

The greater part of the area is occupied by the gneiss-granites which include a variety of igneous rocks belonging to a differentation series ranging from highly basic amphibolites to plagioclasic gneiss-granites, intermediate gneiss-granites, and acid gneiss-granites. Very often the intermediate granites exhibit a weakly developed porphyritic texture with diffuse "augen" of microcline perthite. Younger than this gneiss-granite series are coarse-grained porphyritic gneiss-granites with 3—5 cm long, rounded eyes of microcline perthite evenly distributed in the medium-grained groundmass.

Distinctly younger than the gneiss-granites is a rather common group of dikes, mainly of metabasitic composition. These are rich in hornblende and basic plagioclase and have a varying content of quartz.

Still younger is an eruptive series, the most typical geological significance of which is its extremely abrupt manner of intrusion against the older rocks. The series form a long differentation series from typical gabbros and norites (including smaller differentiates of monomineralic composition, such as anorthosite) through diorites and quartz-diorites to real acid granites.

All the rocks named above are traversed by several hundreds of diabase dikes. These are *the Koster diabases* and they strike mainly north—south. The width of the dikes varies from some few centimetres to a maximum of 50—70 metres. Similarly their texture varies from aphanitic or glassy to typical coarse-grained texture of real dolerites. Together with augite there are varying amounts of olivine and hypersthene. Sometimes the dolerites have been transformed to hornblende-rich diabases. Distinctly younger than the Koster diabases are coarse-grained pegmatites intimately related to the Bohus granite.

Of all these rocks the supracrustal rocks and the gneiss-granites must be included in the Stora Le-Marstrand series. The others are essentially younger.

In the Göteborg region the sedimentary gneisses of the Stora Le-Marstrand series appear, over large areas, as remnants enclosed in granites which have been considered to be of Gothian age.

There are many problems left for futural investigations in the interesting area of the Stora Le-Marstrand series. Only small parts of this area are mapped in detail.

The Dalslandian Cycle

Within the Gothian syncline in southwestern Sweden the *Dal series* appears as an essentially younger supracrustal series. West of Mellerud there have been found remnants of a somewhat older supracrustal series called the *Kappebo series*. Between both series and the underlying Gothian rocks among which granites dominate, there is a great unconformity showing that there must have been a long period of intensive weathering and erosion in the interval between the Gothian and the *Dalslandian cycle* to which the Dal and Kappebo series belong.

The Kappebo series has a very restricted distribution and has therefore the same colour as the Dal series on the map. The stratigraphy of the Kappebo series is, from below, quartz-porphyry with layers of greywackes, then eroded and redeposited acid volcanics, then a conglomerate with pebbles of Kroppefjäll granite, then arkoses and greywackes, the so-called Kappebo greywackes, and at the top of the series a quartzitic sandstone. A clear discordance separates this series and the Dal series above.

The bottom layers of the Dal series are built up of arkoses and conglomerates passing upwards into a *quartzitic sandstone*.

Above these bottom layers follow dark slates with intercalated impure and sometimes bituminous limestone and subordinate beds of reddish sandstones. Two or three sheets of metamorphosed basic effusives are often met with in this division. They are partly tuffaceous, partly amygdaloidal, but generally their original structures have been destroyed by metamorphism, and the rocks have been transformed into schistose greenstones mainly composed of chlorite, epidote, albite, quartz, titanite and magnetite. Also in the underlying quartzitic sandstone such spilitic chlorite rocks have been found.

Above the slates there follows a white quartzite about 480 m thick with subordinate layers of red slates and impure limestone.

Then follow gritty schists, the *Liane schists*. These grade into light-coloured mica-schists. Sometimes they are less metamorphosed and can then be called impure feldspar-bearing sandstones, or sparagmites. Small layers of conglomerate and slates are interstratified in this division, which seems to be separated from the former by an unconformity.

In several places there have been found small occurrences of a breccia composed of the rocks of the former division and of Gothian rocks from the basement of the Dal and Kappebo series. This peculiar rock is at least for the most part a product of the thrust movements which have taken place in this complex. In several places it is possible to trace overthrusts carrying Gothian rock masses above folded Dalslandian layers.

The tectonic movements have caused more or less prominent metamorphic features in which mechanical effects generally prevail over chemical transformations. The Gothian rocks which have taken part in the movements have had this metamorphism impressed on older metamorphic characters. Besides the cataclastic structures the development of epidote and sericite are characteristic for large parts of the Gothian rocks surrounding the Dal series.

West of the Gothian syncline and the Dal series area the large *Bohus granite* massif is situated along the coast between the town of Lysekil and the Norwegian frontier, north of the town of Strömstad. The Bohus granite is, in spite of colour and structure variations, always an acid rock rich in potassium. It is never connected with more basic differentiates. Structurally it varies from dominantly even-grained to porphyric types and is over large areas rich in diffuse remnants of rocks belonging to the Stora Le-Marstrand series. It is accompanied by a great many pegmatites, which have intruded the surrounding rocks, and in some degree also the granite itself. The granite massif has as far as can be judged the form of a flat-lying, relatively thin plate.

Small massifs of Bohus granite appear also west of Årjäng. These are very irregular, and dikes from one of them have intruded the rocks in an outlier of the Dal series.

The alterations in connection with the intrusion of the Bohus granite were naturally most intensive in the region nearest the largest massif, that is in the rocks belonging to the Stora Le-Marstrand series. In connection with the intrusion of these late orogenic (palingenic) granites there must have been a considerable sinking of both the Dalslandian and Gothian regions along the coast and also of the pre-Gothian basement. The absolute age determinations indicate such a regional sinking as they all have given 1130 to 920 million years for the whole Precambrian area west of the thrust and fracture zone which divides Southern Sweden into two halves with very differing geological histories.

There have been three intensive sinking periods in the history of southwestern Sweden. During the first the pre-Gothian rocks were altered to gneisses.

During the second the Gothian anorogenic granites were intruded and the Gothian rocks altered for the first time. At the same time the existing gneissic pre-Gothian rocks were extensively recrystallized. Gothian and pre-Gothian complexes have, therefore, in many regions where they border on each other similar structures and grain size.

During the third period of sinking the Bohus granite developed, preceded by intense tectonic movements. The Dal series was folded. This folding was caused by a division of the Gothian basement into flat blocks which moved relatively to each other. It was in connection with these movements that nappes of Gothian rocks were thrusted over the Dalslandian. The Dalslandian Dal series and the neighbouring rocks were at this time in the zone of fracture. The rocks at some distance to the north of the Dal series seem on the contrary to have been in the zone of flow, since the fracturing and displacement of thin sheet-like blocks disappear in this direction. In these outer zones, therefore, new palingenic processes took place and similar processes have surely taken place here and there in the Gothian and pre-Gothian rocks of Southern Sweden. Most of these processes must have been of a metasomatic nature but have effected changes in detail only. The main features were already established.

The Koster diabases, named before, appear along schistosity planes on the whole parallel and were surely intruded at the time of the folding of the Dal series. These diabases are therefore considered to be Dalslandian.

To sum up the age determinations according to the Potassium 40/Argon 40 method have given:

2100—1680 million years for the Karelian and the Svionian rocks. The average of 25 determinations is very near 1750 million years.

1660—1420 million years for the Gothian rocks east of Lake Vättern and east of the schistosity and fracture zone south of this lake.

1380—1240 million years for the schistosity zone south of Lake Vättern and the continuation of this zone west of Vättern and from this area over the Värmland granites up to the Norwegian frontier.

1130—920 million years for the Dalslandian, Gothian and pre-Gothian rocks west of the schistosity zone named above. All these rocks are influenced by the Dalslandian regeneration.

In the American Journal of Science Gordon Gastil has in January 1960 published a paper about "The Distribution of Mineral Dates in Time and Space". Among the intervals of date abundance the following are of special interest for Sweden namely 1860 to 1650 million years, 1480 to 1300 million years and 1100 to 930 million years. The first correspond to the Karelian and Svionian in Sweden, the second fall between the Gothian cycle proper and the time of the movements that caused the schistosity in the schistosity zone and its continuation towards the north, the third correspond very near with the Dalslandian regeneration. In a table Gastil has given the "peaks of mineral date abundance". For the Potassium/Argon method he has found the peaks of 970, 1330 and 1790 million years. 970 million years correspond very near with the age, 920 million years, of the Bohus granite in Sweden, 1790 million years correspond near with the average for the Karelian and Svionian rocks. 1330 is somewhat younger than the age of the Karlshamn granite.

Jotnian and Sub-Jotnian

In the northern part of the province of Dalarna (Dalecarlia) and in neighbouring parts of the province of Härjedalen volcanic rocks, the *Dala porphyries,* occur over an extensive area. They are separated from the overlying Jotnian sandstones by a period of denudation, which is well accentuated and therefore called *sub-Jotnian.*

Among the Dala porphyries lavas dominate. They show great variations from one lava bed to another. Often they have been intercalated with beds of clastic material such as tuff, agglomerate, volcanic conglomerate sometimes of great thickness, and sandstones. For these clastic beds the term *Digerberg sandstones* has been used.

The Dala porphyries have originated through repeated volcanic eruptions over a long period. Several lava types have been distinguished. In the Älvdalen region north-west of Lake Siljan the following stratigraphy has been established. At the bottom a lower porphyrite, overlain by the Digerberg sandstone, then an upper porphyrite, sometimes developed as a uralite-porphyrite. Then follows a porphyry rich in phenocrysts and then porphyries with extremely marked fluidal structures including the well-known dark brown *Blyberg porphyry.* At the top of the porphyry series in the Älvdalen region lies the *Bredvad porphyry* which, with its brick-red groundmass and scattered small phenocrysts of the same colour, can easily be separated from other porphyric rocks and has thus in glacial geology been much used for the determination of the directions of the ice movement.

The stratigraphy of the Älvdalen region cannot be followed over the whole Dala porphyry area because the individual lava beds are of restricted extent.

Microscopic investigations have shown that the quartz-porphyries are composed of orthoclase, sometimes also some microcline, an albitic plagioclase, quartz, and subordinate amounts of such minerals as chlorite, muscovite, epidote, diopsidic augite, ores, and apatite. Phenocrysts of idiomorphic feldspar crystals are usual. Around orthoclase phenocrysts oligoclase shells occur. Here and there quartz phenocrysts have also been found and among them phenocrysts with tridymitic habit. Dense, often glassy, groundmasses with lithophysis and perlitic cracks occur in felsitic types. Granophyric structure is usual. Locally an antigranophyric structure with radiating orthoclase crystals in predominating quartz has been found. Poikilitic and spherulitic structures are also frequent, as well as fluidal structure.

The porphyries proper are composed of the same minerals as the quartz-porphyries but the amount of quartz is very low.

In the porphyrites the plagioclase is an andesine and makes up 40—50 % of the whole. The amount of orthoclase is low, about 10—30 %, the amount of quartz 0—15 %, the amount of diopsidic augite, pseudomorphs of this mineral, epidote, and chlorite 15—35 %. Instead of augite sometimes amphibole has been found and also a small amount of olivine. Ore minerals are often about 5 %.

The lavas are unusually well preserved. No regional metamorphic processes have reached them. Within their area appear, however, red granites of rapakivi type, including the *Garberg granite* in the Älvdalen region. White oligoclase shells often appear as rings around the red orthoclase phenocrysts. In other cases this characteristic rapakivi texture is mostly absent. The dominating minerals are then red phenocrysts of feldspar, partly orthoclase and partly minutely twinned microcline and albite. The orthoclase is generally strongly pigmented by iron-oxide, even to the extent of making optic determinations almost impossible. Porphyritically, it appears in a fine-grained groundmass, surrounded by micropegmatite or granophyric zones of feldspar and quartz. The quartz-feldspar base always includes minor percentages of chloritized green hornblende together with some biotite and muscovite, titanite, magnetite, fluorite, and apatite. Femic minerals occur only as accessories.

Outside the volcanic area the *Rätan granite* occupies a very large area from the Los-Hamra region to the southern end of Lake Storsjön. It is a rather coarse-grained syenitic, somewhat porphyritic rock, containing up to 3—4 cm large, pink, perthitic Carlsbad twins of microcline and some white oligoclase phenocrysts. The equigranular groundmass consists of these two feldspars together with greyish violet, vitreous quartz, brown biotite, titanite, and green hornblende. The latter sometimes contains cores of pyroxene. Common accessories are magnetite, apatite, and fluorite. The microcline crystals are sometimes rectangular, but are mostly rounded and occasionally surrounded by myrmekitic or homogeneous zones of plagioclase. This rapakivi-like textural development seems to be bound to the more acid marginal phases.

The *Järna granites*, in the region around Lake Siljan and south of Fredriksberg, has an extremely well preserved granitic structure. It is composed of a relatively basic plagioclase (andesine), subordinate microcline-perthite, quartz and biotite, usually together with hornblende often with kernels of pyroxene. Accessory minerals are magnetite, apatite, titanite, and zircon. The plagioclases are idiomorphic against quartz and in a somewhat lesser degree against microcline.

Both the Rätan and the Järna granites were long considered to be older than the sub-Jotnian volcanics. Recent investigations have, however, shown that they have intruded into these volcanics and therefore are younger. Together with the rapakivi granites they are now called *Dala granites*. There is a clear consanguinity between them and the Dala porphyries, and they are therefore thought to have come from the same source.

As has been mentioned before the supracrustal rocks in the Los-Hamra region were divided into four series. The two lower of these (Sub-Los and Lower Los) have recently been shown to belong to the Svionian cycle. The *Upper Los* and *Noppi series* are essentially younger, and recent investigations have made it probable that they are nearly related in time to, but somewhat older than the volcanic series, the Dala porphyry series, described above.

The stratigraphy of the Upper Los series is, from below, arkoses — white, grey or green quartzites — slates and graywackes, and violet grey quartzites. After an unconformity marked by a conglomerate follows the Noppi series. From below the sequence is quartzites — quartz-porphyries — tuffitic sediments — quartz-banded slates and greywackes, and at the top a sandstone-quartzite. The primary features of the Noppi sediments are generally much better preserved than those of the Los sediments, and their metamorphic grade is less.

It has recently been proposed that these two series should be given the name *Lower Dala series* and the Dala porphyry series the name *Upper Dala series*.

The rocks belonging to the Lower Dala series have, on the map, been given

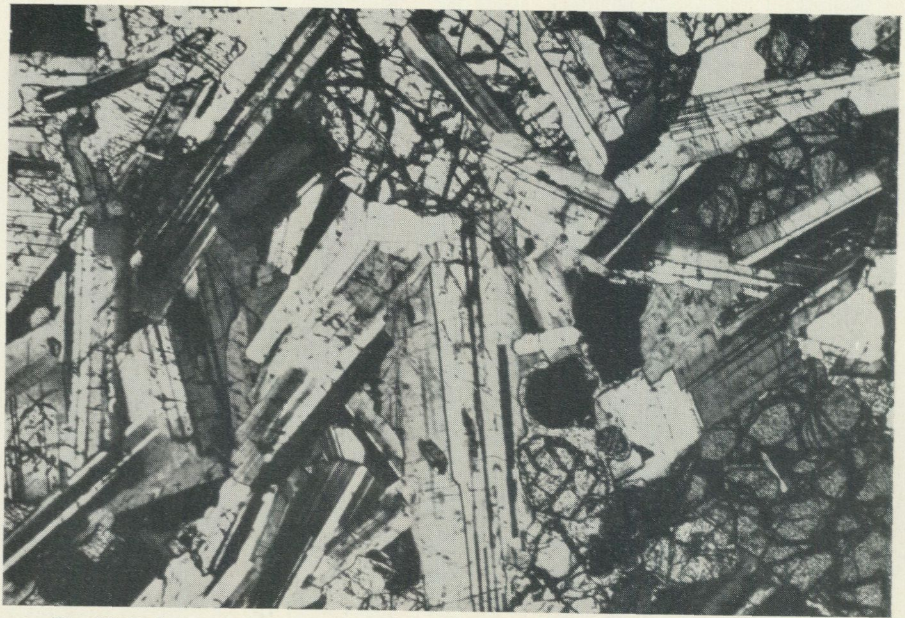


Fig. 32. Doleritic diabase (so-called Åsby diabase). Thin section, magnification 30 x. (After P. H. Lundegårdh.)

the colour of the Dalslandian sediments, according to the author's opinion at that time. As seen on the map there occur between the eastern end of Lake Siljan and the Sågen region in the south-east eight small areas of rocks that now also must be reckoned to the Lower Dala series. The most characteristic rocks in these small areas are coarse quartzite-conglomerates. In the conglomerates, for instance south-west of Leksand, there have been found pebbles of leptite, quartz-porphyry, old granite, quartzite, quartz, pegmatite, and hematite ore.

The sub-Jotnian in Dalecarlia and neighbouring provinces can thus be divided into Lower Dala series, Upper Dala series and Dala granites. Between these rocks and the Jotnian sandstones there is a great unconformity as mentioned above. The sandstones must have been deposited on a well developed peneplane, the *sub-Jotnian peneplane.*

The sandstone series reaches a maximum thickness of 800 metres in the south and thins out towards the north. In the same direction the material also becomes less coarse. From these circumstances it has been concluded that the material was derived from a land area lying in the south. The bulk of the series consists of a reddish brown sandstone, but yellowish and white varieties also occur. Thin intercalations of chocolate-coloured shales are frequently met with in the upper horizons, and conglomerates or arkoses are constantly present as bottom-layers. Their pebbles are mainly porphyries and quartzites, the latter of a characteristic orange colour. Feldspar, fresh or kaolinized, is a prominent constituent, particularly in the lower horizons. Calcareous layers have been found only occasionally at some localities in the northern part of the area.

Cross-bedding and ripple marks are very common in the sandstones and so are mud cracks and fossilized rain drops in the slates. Sometimes typical "*dreikanter*" have been found. No sure organic remains have been found. The sandstone material must have been deposited in shallow water during a warm and dry climate. The possibility has also been propounded that the tides may morphologically have co-operated in the sedimentation of the Dalecarlian Jotnian, which cannot be explained by aeolian or fluviatile erosion and sedimentation only.

Diabase beds of different ages and petrographic characters have been intercalated in the Jotnian sandstone series. One type is a rather coarse ophitic olivine diabase, the *Åsby diabase*. It forms an intrusive sheet in the sandstone. Another olivine diabase, the *Särna diabase,* is fine-grained and is also intrusive. These doleritic diabases also appear as dikes not only in the sandstone area but also outside it in the large area of the Dala series and the Dala granites. Occasionally both diabases lack olivine but contain quartz, because of the resorbtion of silica from the sandstone. The doleritic Åsby diabase often passes into monzonitic types with about 15 % orthoclase. Albitic types have also been found.

A third type, the *Öje diabase,* is porphyritic with often large phenocrysts of plagioclase and often amygdaloidal with vesicular cavities filled with such minerals as agate, chlorite, and antigorite. Nearly connected with these beds is a conglomerate with small pebbles of agate, which may have been derived from the amygdules of the underlying Öje diabase. The building up of the sandstone series must thus have been interrupted by a time during which the vesicles of the diabase were first filled with agate, and subsequently the amygdules, by the weathering of the rock, loosened and gave material to the conglomerate.

The intrusive sheets of diabase named above appear in the uppermost part of the sandstone series and must belong to a younger period of eruption than the effusive Öje diabases.

Diabase dikes of Jotnian age are numerous in the region between Lake Siljan in the north and Lake Hjälmaren in the south. The dikes with northwest—southeast orientation which are to be seen on the map are all Åsby diabases and thus late Jotnian. Besides them there are numerous smaller dikes, the so-called *Tuna diabases,* which have other orientations. They are especially numerous between Säter and Idkerberget but are found in the whole region from Falun in the north to Kopparberg and Norberg in the south. The Tuna diabases are usually developed as vesicular rocks with chlorite and calcite in the vesicles. Often they also are porphyritic with larger or smaller phenocrysts of plagioclase. These rocks are similar to some Öje diabases and are certainly of the same age, that is, early Jotnian.

Together with the Tuna diabases and having the same orientation occur porhyry dikes with phenocrysts of quartz and often also alkali feldspar in a groundmass with micrograniti c or spherulitic structures. Granophyric structure has also been found. As transitional rocks to diabase-porphyrites there occur darker types with phenocrysts of alkali feldspar and a more basic plagioclase and with a large amount of hornblende, biotite, and chlorite. These porphyries are naturally combined with the Dala porphyries and are thus sub-Jotnian. Around Lake Hjälmaren the diabase dikes are orientated east—west. The largest of these is the *Hällefors dike* composed of two types of dolerites, an older rich in olivine and a younger poor in this mineral. In the *Breven dike* these two types of doleritic diabase appear together with a granophyre with phenocrysts of quartz and sporadic green spots of epidote in a groundmass of potassic feldspar and quartz. These dikes are also considered to be of late Jotnian age.

The Jotnian sandstones in Dalarna are most frequently undeformed. Against some faults the layers have, however, been locally bent upwards.

Jotnian sandstones of the same type as in Dalarna appear in several isolated, usually small areas outside the region now described. The largest are the *Gävle sandstone* between Gävle and Storvik and the *Nordingrå sandstone* between Härnösand and Örnsköldsvik. In the former region there are, in the often conglomeratic sandstones, layers of vesicular diabases. The vesicles of the latter are filled with chlorite and calcite. An intrusion of olivine dolerite should also be mentioned. Below the sandstone series a sub-Jotnian rapakivi granite, the *Strömsbro granite,* occurs.

In the Nordingrå region the sandstone series, about 60 m thick, is overlain by a bed of olivine dolerite related to the Åsby diabase in Dalarna. In this diabase there are horizontal concentrations of titanomagnetite with relatively large amounts of titanium, iron, and vanadium. Beneath the sandstone layers the sub-Jotnian peneplane is well developed. On this surface an interesting series of sub-Jotnian intrusive rocks are exposed. The region contains both granite and gabbro. The granites are of a deep red colour and are often more or less distinctly porphyritic, with the larger feldspar lying in a micrographic ground-mass. Miarolitic cavities with quartz, fluorite, and calcite occur in some varieties, and zircon is always present. The feldspars are orthoclase and acid plagioclase. The femic minerals play an insignificant part in the rock. Some varieties of the granite contain quartz only subordinately and closely approach syenites in composition.

The gabbros consist of labradorite, diopsidic augite, hypersthene, often olivine, and some biotite, orthoclase, and quartz. From these rocks there are all transitions to anorthosites dominated by labradorite together with pyroxene, amphibole, biotite, chlorite and serpentine. In the vicinity of the rapakivi granite intermediate rocks often occur. Their extremely varying composition and heterogeneity, together with their mode of occurrence, indicate that they have arisen by a resorption of the basic rocks into the granitic magma.

The island of *Rödö* east of Sundsvall consist of a coarse brick-red rapakivi granite. The granite is accompanied by a great number of dikes. Between the acid quartz-porphyries and the basic porphyrites occur several intermediate rock types, which are often very heterogeneous and contain more or less resorbed inclusions.

The *Ragunda* massif is a laccolithic igneous mass and is chiefly composed of a rapakivi granite grading into syenite and of a gabbroic quartz-diabase. The minimum thickness of the laccolithic mass must have been, in its central parts, at least 300 to 400 metres. Compared with its areal extension, however, its thickness is quite insignificant. The intrusion is broadly considered rather a disc-shaped sheet than an arched lens.

The acid rocks (granite and syenite) are concentrated towards the roof of the laccolith and the gabbro-diabase beneath them. The structures of the laccolithic rocks indicate that they were consolidated under conditions prevailing in smaller magmatic bodies and intrusive sheets. Thus micrographic structures occur in the granite and ophitic structure in the gabbro. It is therefore suggested that the floor of these laccolithic bodies does not lie far below the present earth surface.

A very striking feature of the relation between the diabase and the granite is the intricate breaking up of the former by the latter. The granite forms everywhere a network of veins and dikes in the diabase. Intermediate rocks, generally characterized by chemical and structural inconstancy, have often been produced by the melting and resorption of the diabase by the granite. Some of the basic rocks are amygdaloid, thus proving that the thickness of the covering cannot have been great at the time of intrusion.

In a nearly 150 km broad belt orientated east-west from the coast between Sundsvall and Örnsköldsvik to the Caledonian Mountain chain there are several smaller occurrences of rapakivi granites and syenites often combined with gabbroic rocks. Diabases appear in large numbers as intrusions with moderate, often nearly horizontal dips. They were probably intruded along local thrust planes.

Small isolated areas of Jotnian sandstone occur northeast of Hagfors, the *Svartälven sandstone,* and on Ekerö and some other islands in Lake Mälaren. The latter series, the *Mälar sandstone series,* consists of sandstones, arkoses, conglomerates, and a bed of amygdaloid diabase.

Sub-Jotnian porphyries and granites of the rapakivi type occupy large areas on the bottom of the Baltic Sea and in the southern part of the Gulf of Bothnia, as indicated by finds of blocks along the coast and on the islands of Gotland and Gotska Sandön. The scattered areas demonstrate the great areal extension once displayed by the Jotnian and sub-Jotnian.

To the Jotnian sediment series the *Almesåkra series* around the town of Nässjö, south-east of Lake Vättern, is also relegated. The series begins with a granitic arkose. Then follow white or reddish quartzites (the lower quartzites), above them light, hard sandstones, upwards followed by red slates with red and white sandstones, quartzitic sandstones and arkoses, then the upper white and reddish quartzite. After a sharp discordance there follows in connection with an early folding a conglomerate and the intrusion of diabases in the form of sheets and dikes.

Even outside the area of the Almesåkra series there are several diabase dikes orientated in north-north-east to south-south-west. The most interesting are the so-called *pebble diabases* characterized by a richness in well rounded pebbles of

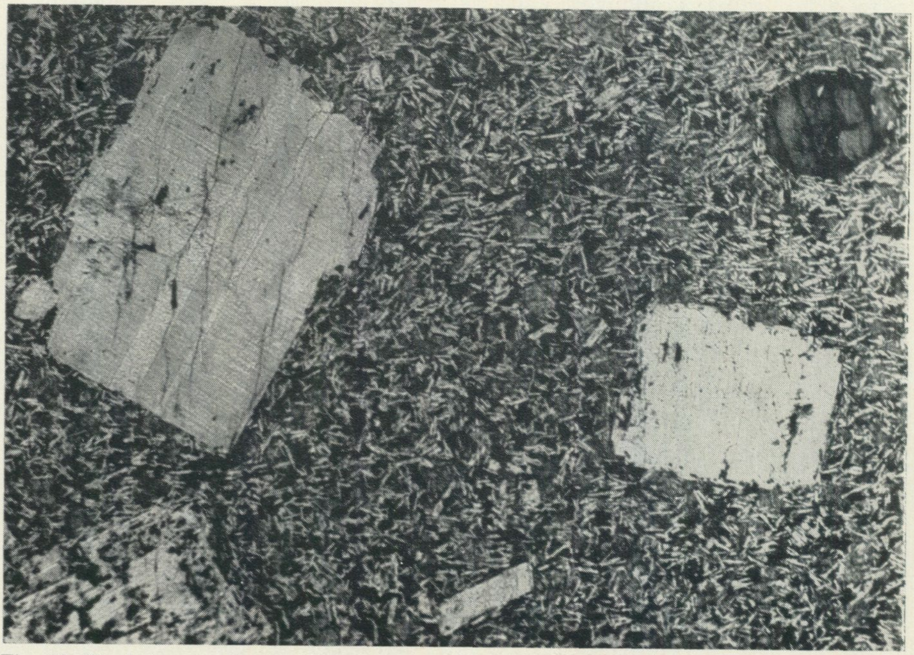


Fig. 33. Plagioclase-porphyrite (dolerite-porphyrite) 3 km west of Ärla church. Thin section, magnification 40 ×. In the upper right corner an olivine fenocryst. (After P. H. Lundegårdh.)

quartzite and more subordinately, of other rocks, especially Gothian porphyries and vein quartz. Often the pebbles are so numerous that the diabase only appears as a cement between them. As the pebbles petrographically are identical with the pebbles of the Almesåkra conglomerate it is probable that they originate from this rock, which at the time of the eruption of the diabase probably had not hardened but existed as gravels. The gravels should then have slid down into the dike fissures and have thereby been included in the diabase.

Pebble diabases of the same kind have been found at a great distance from the Almesåkra area, as for instance east of Karlshamn on the south coast, indicating that the Almesåkra series once had a much larger distribution than at the present time. The diabases of the Blekinge region in south-eastern Sweden are besides quite similar to the diabases of the Almesåkra region and are orientated in the same direction. They are therefore surely of Jotnian age.

With the early Jotnian rocks must also be included the *uralite-diabases* in southeastern Sweden, in which the pyroxene is altered to a uralitic hornblende. These diabases appear as dikes. They are, however, too small to be indicated on the map. Together with them there also occur small *dikes of porphyries* with phenocrysts of alkaline feldspar and/or quartz in a granophyric groundmass. Sometimes the rocks form composite dikes with porphyry in the central part and diabase along both contacts.

In the region along the eastern coast between Valdemarsvik and Lake Mälaren the uralite diabases pass into quartz-diabases with hypersthene-augite or in diabase-porphyrites with phenocrysts of orthorhombic pyroxene and labradorite. These rocks have, in Sweden, long been called *bronzite-diabases.*

To the Swedish rapakivi granites are probably also to be reckoned the granite on the island of Jungfrun east of Oskarshamn and the Götemar massif north of this town.

Eocambrian

The *Visingsö series* is the youngest Precambrian series in Sweden outside the Caledonian Mountain Chain. It is now considered to be of the same age as the Eo-cambrian quartzites in the mountains for which B. Asklund has proposed the term *Varegian.*

The rocks of the Visingsö series have been found on the island of Visingsö in Lake Vättern and at several places along the shores of this lake. Besides there are two outliers northwest and north of the northern part of this lake, one of them at Lake Skagern, the other at Lake Möckeln. These outliers show clearly that the series has had a much wider extent than at the present time.

The Visingsö series has been divided into three groups: At the bottom lies about 145 metres of a yellow sandstone. Then follow arkoses and frequently variegated sandstones with varying grain size and in part rich in feldspar. This group has a thickness of more than 315 metres. In the sandstones of this group there have often been found ripple marks, mud cracks and current bedding.

The uppermost layers of the series consist of shales and can sometimes reach a thickness of more than 580 metres. The shales are dark-coloured. As thin intercalations in the shales there are dark sandy layers. Characteristic for the slates of this series are the occurrences of limestones and lenses of coarse, feldspar-rich material cemented by calcium carbonate. Also in the shales there have been found mud cracks, and in some horizons also small aggregates of phosphorite. From the shales there have recently been described fossils of a unicellular alga, 13 species of spores and pellicles of Laminarites. The spores are indicators of a terrestrial or semiterrestrial vegetation.

Immediately before the formation of the Visingsö series, the climate was probably humid enough to effect strong chemical weathering. During the second stage, it was dryer and cooler, and during the deposition of the shales, it was warm and humid.

After the late Dalslandian sinking southwestern Sweden seems to have risen and undergone denudation in sub-Jotnian, Jotnian and Eocambrian time. As age determinations made on micas from the Visingsö and Almesåkra series by the Potassium/Argon method have given about 1000 million years — the micas must have come from regions influenced by the late Dalslandian regeneration. Probably they came from a highland in the southwestern Sweden. This highland was peneplaned before the earliest Cambrian rocks were deposited. The volcanic activity in sub-Jotnian and Jotnian time took place in the area east of the pre-Gothian gneisses. Together with the volcanics there were formed dikes, sheets and massifs of intrusive rocks. All these rocks were formed in an area characterized by repeated sinking and rising of the whole area and by greater and smaller dislocations along a great many faults intersecting the crust in numerous blocks.

At last the author wish to express his gratitude for the absolute age determinations on 58 Precambrian rocks that Academician A. A. Polkanov and Professor E. K. Gerling in Leningrad have made for him and for the Geological Survey. Academician N. P. Semenenko in Moscow has made complementary determinations on 8 of these rocks. The author also wish to express his gratitude to him.

The Alkaline Rocks of Sweden

By

Nils H. Magnusson

At four places in Sweden there appear alkaline rocks in small rounded areas, namely Särna in northern Dalecarlia, Norra Kärr east of Lake Vättern, Almunge in Uppland, east of the town Uppsala, and Alnö northeast of the town of Sundsvall.

In the *Särna* massif the dominating rock is a nepheline-syenite rich in cancrinate, which has been called *Särnaite*. All transitions occur to nepheline syenites without cancrinite and to aegirine syenites without either cancrinite or nepheline. Connected with these rocks are dikes of tinguaites, the green colour of which depends on the high content of aegirine.

The dominating rock in the *Norra Kärr* area is the *Grennaite* which is composed of katapleite and eudialyte crystals in an aphanitic matrix of alkaline feldspar, nepheline, aegerine, eudialyte, katapleite and occasionally natrolite. Within the grennaite there occur smaller areas of *kaxtorpite* with large grains of soda-microcline in a matrix of albite, pectolite, eckermannite, aegirine, and nepheline. Besides, there occur albite-amphibole-nepheline syenites, the amphibole of which is sodic hornblende (in the *pulaskites*) or arfvedsonite (in the *lakarpites*). Both types contain the rare zirconium mineral rosenbuschite. Along the contacts the surrounding rocks are altered through fenitization into rocks rich in aegirine augite, aegirine and albite.

The main mass of the *Almunge* massif consists of a complex of perthite-hastingsite syenites of very variable texture and mineral proportions, composed mainly of perthitic feldspars, albite or oligoclase-albite, a usually hastingsitic amphibole, biotite and accessory calcite, fluorite, zircon, apatite and titanite. These rocks are grouped together as *umptekites*.

As inclusions in the umptekite mass there are great many occurrences of felsic nepheline syenites to theralites grouped together as *canadites*. They are composed of albite (grading into oligoclase or andesine in the mafic varieties) nepheline, cancrinite, alkali hornblende, aegirine-augite, and biotite.

The surrounding rocks altered to fenites are characterized by porphyroblasts of perthites and antiperthites in an aplitic mass composed of albite, microcline, biotite and alkali hornblende, more rarely diopside or aegirine. Fluorite and calcite are nearly always present.

The central mass of the *Alnö* massif is composed of nepheline-aegirine-augite rocks poor in or free from feldspars, such as *urtites, ijolites* and *melteigites*. The urtites are rich in nepheline, the melteigites in pyroxene. The ijolites are intermediate between them in composition. Among the more basic differentiates the titanomagnetite-bearing *jacupirangites* may be mentioned. Besides the minerals named above there appear in the rocks of the central mass such minerals as melanite, natrolite, wollastonite, pectolite, calcite, titanite, titanomagnetite, apatite. The subordinate feldspar is always soda-orthoclase.

The surrounding rocks are migmatites composed of supracrustal biotite schists, more or less homogeneous gneiss granites and pegmatites. These rocks have, in a broad zone around the central core, been through an intensive fenitization altered into rocks rich in aegirine augites and containing several new minerals such as soda-orthoclase, nepheline, and natrolite. These alterations indicate an abundant supply from the central melt of K_2O, Na_2O, CO_2, H_2O, F, CaO, BaO, P_2O_5 and TiO_2. Quartz, microcline, plagioclase and biotite in the surrounding rocks diminish in amount successively towards the central core and disappear at last totally.

Both the nepheline-pyroxene rocks in the central core and the feritized migmatites around it are intersected by brecciating dikes of *sövites,* that is, intrusive limestone dikes. The sövites of the Alnö region also often contain significant amounts of apatite, biotite and pyroxene. Sövite also appears as a rounded core in the central nepheline-pyroxene mass.

A series of strangely varying dike rocks connected with the Alnö massif has also been found. The most interesting are the *Alnöites* composed of biotite and olivine, often also melilite.

The author has expressed the opinion that the alkaline rocks mentioned above should be of Permian age. H. von Eckermann and F. E. Wickman seem, however, to have got a good absolute age determination of the intrusion of the Alnö rocks, viz. at the most 562 million years. The present surface was at that time according to these authors in the Alnö region covered by sediments, mainly of Jotnian age and of an estimated thickness of about 2 000 metres. A. Holmes has in December 1959 in Transactions of the Edinburgh Geological Society published "A revised geological time-scale". According to him the beginning of the Cambrian is 600 $\pm$ 20 million years. It is therefore possible that the Alkaline rocks are post-Precambrian, at least Cambro-Silurian.

The Cambro-Silurian

By

PER THORSLUND

Introduction

Outside the Scandinavian mountain range the Cambro-Silurian rocks are preserved in different ways within a number of areas. Between these there exist fairly easily demonstrable differences especially in the tectonic structure and the composition of the rock sequence. An exception is formed by the Cambrian sequence the lithological succession of which is similar in different areas, and which exhibits a change from sediments rich in sand and poor in lime in its lower portion to shales rich in kerogen (alum shale) and with a variable amount of limestones in its upper portion. A general survey of the Ordovician and Silurian deposits reveals a pronounced dominance of limestones in the sequence of the Baltic and southern Bothnia, a corresponding dominance of shales in Scania, and an alternation of these types of sediments within the other areas. Exceptions are found in the great foreland area of the Caledonian mountains in Jämtland and adjacent parts of Ångermanland and Västerbotten. In this, the largest area within our country with a continuous Cambro-Silurian rock floor, we meet with special conditions that are obviously connected with the position of the original area of sedimentation at the western margin of the Baltic shield in the north-European Precambrian block and with the development in the Caledonian geosyncline during the Ordovician and Silurian periods.

The nature and the small thickness of the sediments disclose their epicontinental nature and their deposition or formation in shallow seas. They evidently appear to have originated in connection with eustatic changes of level that had led to transgressions over the Baltic shield. At its south-western margin in Scania we must, however, count also with vertical movements of the earth's crust as a cause of the particularly great thickness of the younger Silurian deposits in this region. A similar presumably trough-shaped subsidence has probably taken place also during the Ordovician along the north-western margin of the block east of the Caledonian eugeosyncline.

Provided that the Cambrian deposits are fossiliferous, correlation between the mostly rather distant areas does not present any difficulties. This is the result of the uniform character of the shelly Cambrian faunas in the different series and their biostratigraphic components. Such problems have, however, always existed within the Ordovician and Silurian systems, and have been caused by the great faunistic differences between their limestones and shales, i.e. by the occurrence of two facies characteristic for these systems, viz. the shelly and the graptolitic facies, respectively. A rich and differentiated flora and fauna has likewise contributed to the formation of local masses of limestone, so-called reef limestones. The fossils occurring in these bodies are seldom found outside this particular facies, and on this account it has sometimes been

ORDOVICIAN

	England	Shelly facies		Graptolitic facies		
Upper Ordovician	Ashgill	*Dalmanitina* beds *Staurocephalus* beds	Boda			Unknown
Upper Ordovician	Caradoc	*Tretaspis* limestone and shales *Slandrom* limestone	Boda	Upper	*Dicellograptus* shale	*Dicellogr. complanatus* *Climacogr. styloideus*
Middle Ordovician	Caradoc	*Macrourus* limestone *Ludibundus* —"—	Kullsberg	Middle	*Dicellograptus* shale	*Dicranogr. clingani* | *Nemagr. gracilis*
Middle Ordovician	Llandeilo	*Crassicauda* —"—		Lower	*Dicellograptus* shale	*Glyptogr. teretiusculus*
Middle Ordovician	Llandeilo	*Schroeteri* —"— *Platyurus* —"—		Upper	*Didymograptus* shale	*Didymogr. murchisoni*
Lower Ordovician	Llanvirn	*Gigas* —"— *Obtusicauda* —"— *Raniceps* —"—	*Vaginatum*	Upper	*Didymograptus* shale	*Didymogr. bifidus*
Lower Ordovician	Arenig	*Expansus* —"—	*Vaginatum*	Lower	*Didymograptus* shale	
Lower Ordovician	Arenig	*Lepidurus* —"— "*Limbata*" —"—		Lower	*Didymograptus* shale	*Isograptus gibberulus*
Lower Ordovician	Arenig	*Estonica* —"— *Dalecarlicus* —"—	Billingen	Lower	*Didymograptus* shale	*Phyllogr. angustifolius elongatus* *Phyllograptus densus*
Lower Ordovician	Arenig	*Planilimbata* —"—	Hunneberg	Lower	*Didymograptus* shale	*Tetragr. phyllograptoides*
Lower Ordovician	Arenig	*Armata* —"—	Hunneberg	?		Unknown
Lower Ordovician	Tremadoc	*Ceratopyge* limestone *Ceratopyge* shale		? *Clonograptus* shale		? *Clonogr. heres*
Lower Ordovician	Tremadoc	*Obolus* beds		*Dictyonema* shale		*Dictyonema norvegicum* | *Dictyonema desmograptoides*

CAMBRIAN

Upper Cambrian Olenid Series	*Acerocare*	
Upper Cambrian Olenid Series	*Peltura scarabaeoides*	
Upper Cambrian Olenid Series	*Peltura minor*	
Upper Cambrian Olenid Series	*Protopeltura praecursor*	
Upper Cambrian Olenid Series	*Leptoplastus* and *Eurycare*	
Upper Cambrian Olenid Series	*Parabolina spinulosa* and *Orusia*	
Upper Cambrian Olenid Series	*Olenus* and *Agnostus obesus*	
Upper Cambrian Olenid Series	*Agnostus pisiformis*	
Middle Cambrian *Paradoxides* Series	*Forchhammeri* stage	*Lejopyge laevigata*
Middle Cambrian *Paradoxides* Series	*Forchhammeri* stage	*Solenopleura brachymetopa* (Andrarum Limestone)
Middle Cambrian *Paradoxides* Series	*Forchhammeri* stage	*Ptychagn. lundgreni* and *Goniagn. nathorsti*
Middle Cambrian *Paradoxides* Series	*Paradoxissimus* stage	*Ptychagn. punctuosus*
Middle Cambrian *Paradoxides* Series	*Paradoxissimus* stage	*Hypagn. parvifrons*
Middle Cambrian *Paradoxides* Series	*Paradoxissimus* stage	*Tomagn. fissus* and *Ptychagn. atavus*
Middle Cambrian *Paradoxides* Series	*Paradoxissimus* stage	*Ptychagn. gibbus*
Middle Cambrian *Paradoxides* Series	*Oelandicus* stage	*Paradoxides pinus*
Middle Cambrian *Paradoxides* Series	*Oelandicus* stage	*Paradoxides insularis*
Lower Cambrian Series	*Strenuella linnarssoni*	
Lower Cambrian Series	*Holmia kjerulfi*	
Lower Cambrian Series	*Volborthella* and *Platysolenites*	
Lower Cambrian Series	*Discinella holsti*	

SILURIAN

England		Graptolite zones	Scania	Västergötland (Kinnekulle)	Dalecarlia	Jämtland	Gotland
Ludlow		(Graptolitic facies unknown in Sweden)	Öved-Ramsåsa (100 – 300 m.)		? Orsa sandstone ?		Sundre 10 m, Hamra 40, Burgsvik 50, Eke 15
		Monogr. scanicus / " *nilssoni*	*Colonus* shale (c. 600 m.)				Hemse 100, Klinteberg 100, Mulde 25
Wenlock		*Cyrtogr. lundgreni* and *Monogr. testis*	*Cyrtograptus* shale (c. 350 m.)				Halla 15, Slite 100
		Cyrtogr. rigidus					Tofta 10
		Monogr. riccartonensis				Ekeberg greywacke	Högklint 35
		Cyrtogr. murchisoni			*Bumastus limest.*		
Llandovery	Upper	" *lapworthi*		*Retiolites* shale (26 m.)	Styggfors " *Retiolites* shale	? Bångsåsen shales	Upper Visby 15, Lower Visby
		Monogr. spiralis					
		" *discus*	*Rastrites* shale (c. 120 m.)	*Rastrites* shale (29.4 m.)	*Rastrites* shale (c. 50 m.)		Grey mudstone, Red "
		" *turriculatus*					
		" *sedgwicki*				Berge limestone	Mudstone and limestone
	Middle	*Cephalogr. cometa*					
		Petalolithus folium					
	Lower	*Monogr. gregarius*				Ede quartzite	Hiatus
		" *revolutus*			Poorly fossiliferous grey and red marly shales ?		
		Rhaphidogr. extenuatus				?	
		Akidogr. acuminatus				Upper Kyrkås	
		Glyptogr. persculptus					

difficult to attribute to these limestones their correct places in the stratigraphic scheme.

The correlation on the basis of biostratigraphic data is aided to a certain extent by the layers of metabentonite which occur in the Middle Ordovician *Ludibundus* beds and the contemporaneous graptolitic shales on one hand, and on the other hand in the (Silurian) Upper Llandovery shales and contemporaneous calcareous sediments. On account of the fact that these volcanic sediments have been spread almost instantaneously from the geological point of view they now enable us to pick out synchronous surfaces of sedimentation, and in this way to obtain an exact correlation of certain smaller portions in the sedimentary series of the different areas.

In the above brief review only some general points of view with regard to the sequence in our different Cambro-Silurian areas have been mentioned. In the following short descriptions of the individual areas will be given with the intention of stressing both special features and common characters. In order to facilitate understanding we give below stratigraphic tables with the classification adopted in this paper, and which by its nomenclature and the drawing of the boundaries attaches itself to previous systems. At least as far as the Ordovician is concerned a revision can be expected as the result of new investigations and considerations.

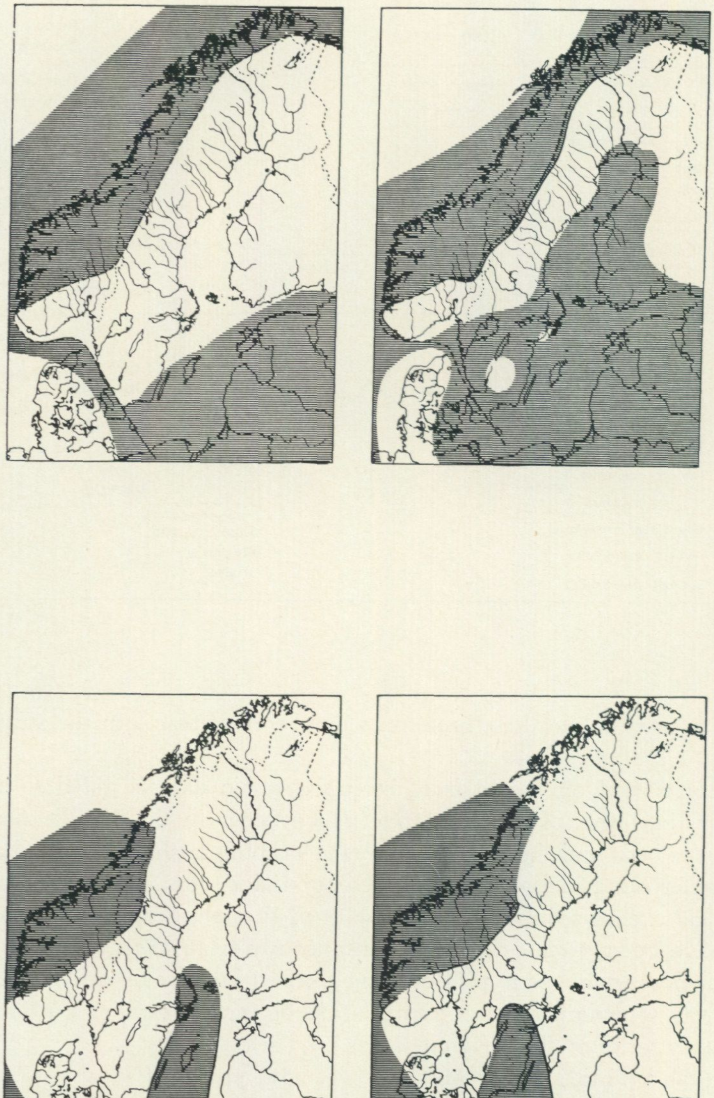


Fig. 1. Maps of Early Cambrian phases (above), and of the successive phases of the early Middle Canbriam epoch (below). Dashed lines denote the western limit of the Baltic shield.

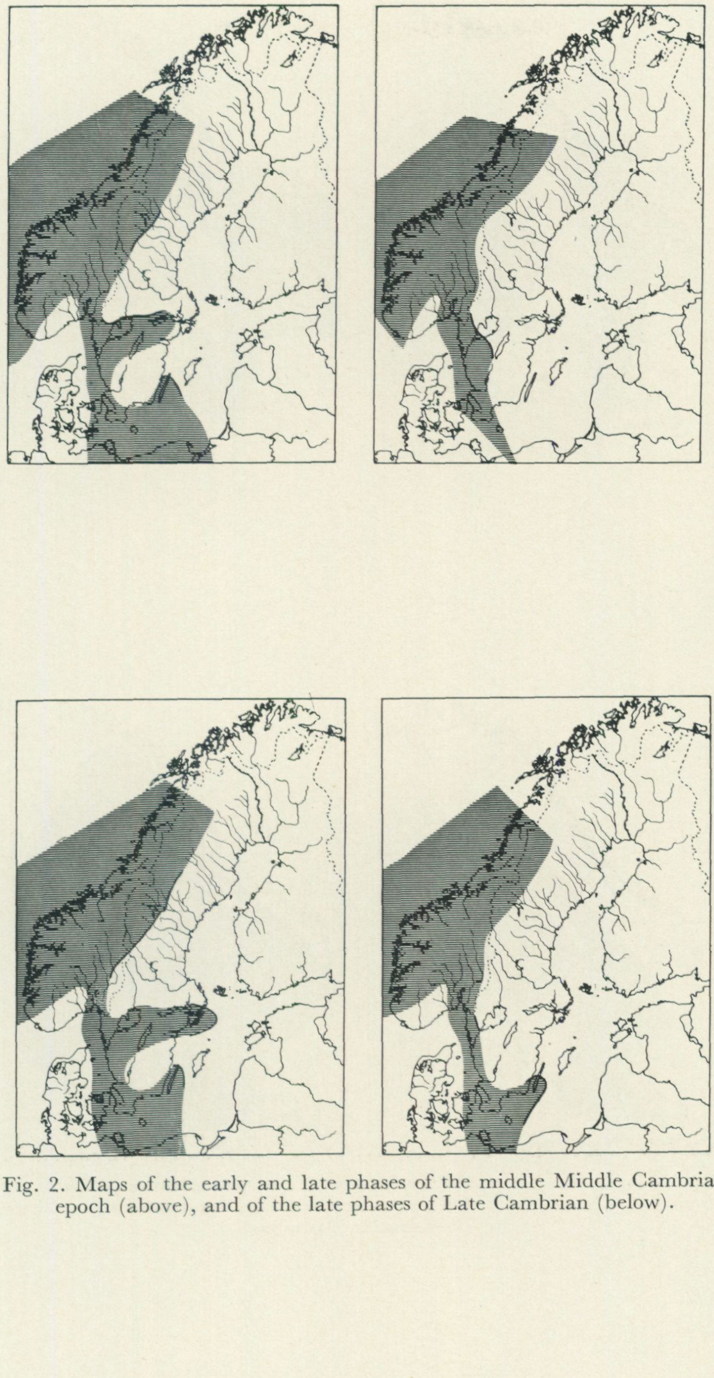


Fig. 2. Maps of the early and late phases of the middle Middle Cambrian epoch (above), and of the late phases of Late Cambrian (below).

Fig. 3. Maps of the Tremadoc age (upper left), of the successive phases of the Hunneberg age, and of the Billingen age (lower right). x denotes the presence of Tremadocian *Obolus* beds.

The Cambro-Silurian areas of our country are relatively small and in most cases situated at considerable distance from each other. For this reason it might appear a difficult task to establish palaeogeographic maps over these areas for the distant times, when the marine sediments in question have been deposited. These difficulties become still more apparent, if we think of the changes of facies and the problems of correlation connected with them. Complications of this kind can become evident on the analysis of the sedimentary sequence even within a limited area. As the result of extensive and detailed investigations we have, however, now such a wealth of data for the Cambrian and early Ordovician deposits that an attempt to establish maps for certain periods of the times during which these sediments were formed can hardly be considered presumptuous.

In spite of all their shortcomings and defects these maps ought nevertheless to represent certain general features of the geographic development apart from their main aim, viz. to indicate and to connect the regions within which deposits belonging to a certain stratigraphic unit (zone, stage, or series) occur. Thus they supply an idea of the vast expansion of the Cambrian transgression over the Baltic shield which culminated in the middle of the Early Cambrian. They also show the change during the Middle Cambrian from a "Baltic" arm of the sea to a pronounced western sea with intermittent transgressions in eastern direction both during this time and during the subsequent epoch of the Late Cambrian and likewise tell about the renewed great transgression in the Early Ordovician, when beginning with and including the early Hunneberg age the sea expands more universally over the area of resistence.

In order to supply the development as drawn up here with the requisite background it is, however, necessary to include in the maps also neighbouring regions outside the boundaries of Sweden. As far as the western and particularly the north-western regions are concerned such considerations could be taken only for certain stretches along the area of resistence. The palaeogeographic development within the Caledonian eugeosyncline has thus been left out.

Skåne (Scania)

In Scania Palaeozoic rocks are found in the south-western part of the province, where they have been preserved thanks to sinking along faults. These faults are mainly orientated S.E. — N.W., but also other directions occur, though more subordinate. They are post-Silurian, and have been formed in close connection with more extensive movements in the earth's crust in north-western and Central Europe. The Cambro-Silurian deposits contribute to the surface of the rock floor with areas near the great horsts. From there they continue under the Mesozoic sediments which become increasingly thicker in south-western direction. This fact was established by deep boring in the extreme S.W. As shown in Fig. 4 most of the surface is occupied by the Silurian deposits which also show the greatest thickness, i.e. considerably more than

1,000 m, while the thickness of the Cambrian is somewhat more than 200 m, and that of the Ordovician between 100 and 130 m. The covering Quaternary deposits and the numerous faults make it difficult to arrive at a more exact determination of the thicknesses of the three systems.

Already in the introduction it has been pointed out that the Palaeozoic of Scania is characterized by a proponderant development of shales in the Ordovician and Silurian systems and by the great thickness of the Silurian. Characteristic is also the fact that the Cambrian and Silurian systems are more completely represented there than in other parts of Sweden, and that the Cambrian series are relatively thick. An exception is, however, formed by the lowermost stage of the Middle Cambrian series, viz. the *Oelandicus* stage, which is probably missing in Scania.

The Lower Cambrian series rests upon Precambrian crystalline rocks, and begins with beds of arkose and occasionally also of conglomerate, i.e. of more or less thouroughly washed, sorted, and redeposited gravel resulting from weathering. These are overlain by the Hardeberga sandstone. This white to lightgrey, unfossiliferous orthoquartzite which is quarried for different purposes makes up the greater part of the thickness of the series, estimated at more than 135 m. In a boring at Hardeberga it was followed for 94 m. On top of it the series consists of a greyish, impure, occasionally somewhat calcareous sandstone. It sometimes contains glauconite and phosphorite, and possesses layers rich in tracks, and in different kinds of filled tubes (*Skolithos, Diplocraterion,* etc.) probably after worms. Uppermost in the series we find shelly layers with *Holmia, Strenuella,* brachiopods, etc. These layers consist mainly of calcareous, occasionally glauconite- and phosphorite-bearing sandstone, but also of laminated sandstone and shale. — The largest area with Lower Cambrian beds is found in south-eastern Scania, and extends for some 40 kilometres in north-western direction from the region of Simrishamn. Sporadically occurring impregnations and fillings of fissures in the sandstone consist of pyrites, galena, and fluorite, and probably date from Permian times. Here they are locally sufficiently frequent and rich to warrant exploitation.

The middle stage of the Middle Cambrian series introduces the alum shale into Scania. This formation then continues through the Cambrian series into the Lower Ordovician. Compared with the corresponding sequence of strata in any other part of Scandinavia the alum shale group of Scania is of greater thickness, and permits the distinction of a greater number of biostratigraphic units or zones. This is in support of the conception, based otherwise upon lithologic and faunistic data, that it has been formed by an uninterrupted process of sedimentation. On comparison with the alum shale of regions outside the boundaries of Scania the Scanian alum shale is found to contain a greater number of calcareous layers, but to be poorer in bituminous limestone (stinkstone). In the Middle Cambrian series we notice two beds of limestone rich in fossils, viz. the *Exsulans* limstone within the lowermost zone of the *Paradoxissimus* stage and the somewhat thicker (0.6—1.2 m thick) Andrarum limestone which represents the middle zone of the *Forchhammeri* stage. The

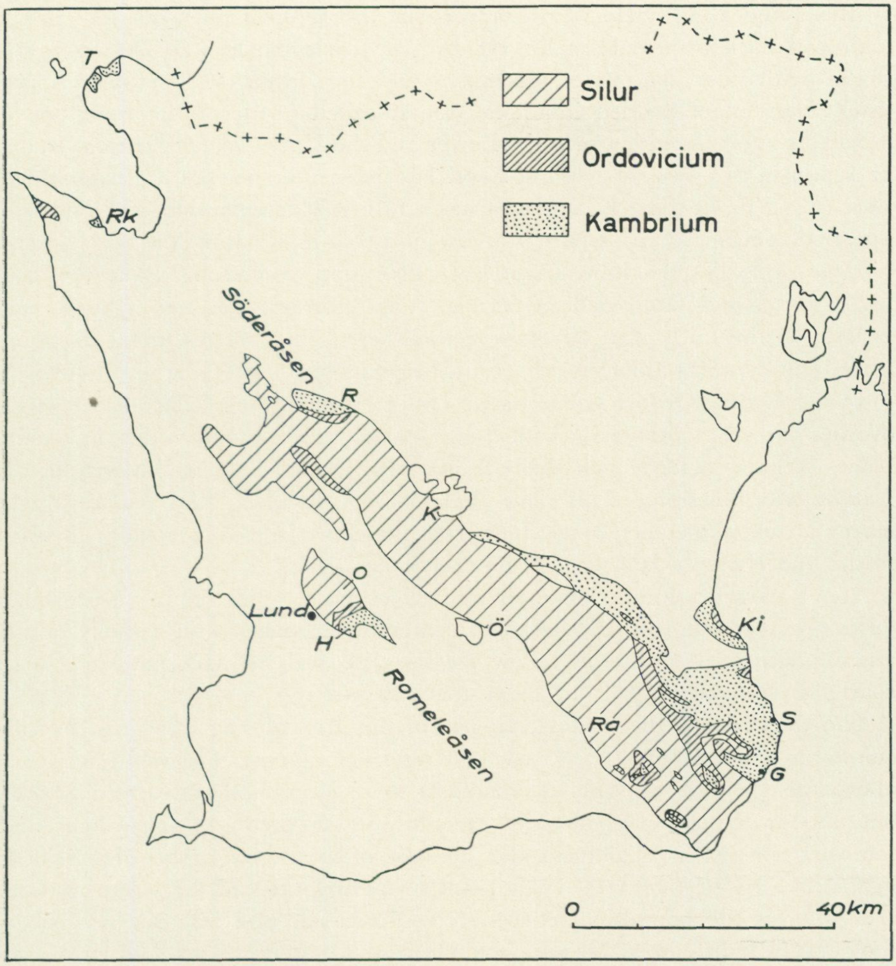


Fig. 4. Map of the Cambro-Silurian rocks of Scania. Legend: G-Gislövshammar, H-Hardeberga, K-Klinta, Ki-Kivik, O-Odarslöv, R-Röstånga Ra-Ramsåsa, Rk-Rekekroken, S-Simrishamn, T-Torekov, Ö-Öved.

Scanian alum shale is distinguished amongst others by the fact that it is not petroliferous, this being at least in part the result of a distillation in connection with the intrusion of the post-Silurian dolerites. — The thickness of the alum shale group decreases towards the S.E. of Scania. At S. Sandby, E. of Lund, it has been estimated at 100 m and at Gislövshammar a boring has given its thickness as 76—77 m. The *Dictyonema* shale, which is the uppermost part of the alum shale group, seems to have its greatest thickness in the S.E. (at Gislövshammar 16.5 m). There it has been shown to be more complete biostratigraphically than within the area of Fågelsång, E. of Lund, where the lowermost of the five zones distinguished in the shale on the basis of dendroid graptolites is missing.

Above the alum shale with *Dictyonema* the Ordovician sequence consists mainly of dark graptolitic shales, viz. *Didymograptus* shales and *Dicellograptus* shales, with intercalations of mudstones and thin layers of limestone. A persistent division of bedded limestone, the so-called Orthoceratite limestone of Scania, is intercalated between the Lower and the Upper *Didymograptus* shales. It is thin in the areas of Röstånga and Fågelsång, but reaches a greater thickness, ca. 10 m, in the S.E., where it has a rather wide extension, and has been quarried at Killeröd and Komstad as an industrial material. Below the *Didymograptus* shale lies the hard *Ceratopyge* limestone, containing glauconite and phosphorite, and often rich in pyrites. It is some few decimetres thick, and rests upon the fairly thin *Ceratopyge* shale which in part resembles the alum shale, and contains amongst others brachiopods, but also scarce graptolites.

In the Middle Ordovician series we notice especially the Sularp shale which overlies the graptolitic shale with *Nemagraptus gracilis,* and which in several places contains a fairly rich shelly fauna with forms occurring likewise in the *Ludibundus* limestone. This dark shale is rich in silica, and contains light clayey layers of metabentonite. It is from these that the high content of silica in the underlying beds of hard shale can be derived.

Above dark graptolitic shales in the lower part of the Upper Ordovician series occur greenish soft shales and calcareous mudstones with a shelly fauna, and uppermost in the series follow *Dalmanitina* beds of dark mudstone with coarse-sandy basal layers, and above them dark shales.

The thickness of the Ordovician within the area of Fågelsång can be calculated to about 100 metres. From the stratigraphic point of view the sequence above the *Dictyonema* shale is completer there than in south-eastern Scania, but also at Fågelsång surfaces of discontinuity in the *Ceratopyge* beds and the occurrence of a conglomerate at the base of the *Nemagraptus gracilis* beds in the middle *Dicellograptus* shale point to interruptions in the sedimentation.

Neither is the boundary between the Ordovician and Silurian systems lithologically indicated in Scania with the result that the black and dark-grey shales of the Lower Silurian series follow immediately on top of the uppermost *Dalmanitina* beds. The *Rastrites* shale of Scania belongs altogether to the Llandovery, and exhibits a complete sequence of zones without demonstrable gaps. The overlying probably much thicker *Cyrtograptus* shale consists mainly of clayey shales of varying colour, usually with concretions, but occasionally with layers of dense hard limestone. The Upper Llandoverian shales of Scania contain thin layers of light-coloured metabentonite. The youngest graptolitiferous beds belong to the thick *Colonus* shales of Ludlow age which on the whole are poor in fossils. Some species of *Monograptus* and the bivalve *Cardiola cornucopiae* are moderately common. Otherwise richer shelly and graptolite faunas have been found only in some few places, and usually in beds of inconsiderable thickness. The sequence is probably more than 600 m thick, and is composed of grey or greenish-grey, sometimes reddish shales which are usually somewhat calcareous, and contain small lenses or thin layers of dense or fine-grained limestone. The shale is distinguished by its content of light mica. In certain places occurs a fine-sandy shale, grading into the Odarslöv sandstone named after the place, where it has been quarried in the past for various purposes. — The Silurian shales and among them mainly the *Colonus* shale form the rock floor within the greater part of the wide diagonal Cambro-Silurian area across the province. They also occupy a fairly large surface N.E. of Lund.

The youngest beds of Palaeozoic age in Scania consist of the group of formations which are comprised under the name Öved-Ramsåsa beds with the widest extension east of Vombsjön. Beds belonging to this group occur furthermore not only at Ramsåsa, but also at Klinta near the shore of Ö. Ringsjön. They consist of light or red sandstones and more richly fossiliferous shelly limestones and shales, and have been divided into four divisions or formations of which the uppermost, the mainly red Öved sandstone, is usually attributed to the top of the Silurian. This occasionally somewhat calcareous sandstone, which amongst others contains small scales and spines of agnathous fishes, has found fairly widespread use for building purposes. — The combined thickness of the Öved-Ramsåsa formations is considerable, but has been estimated at varying figures, 300 and 790 m, respectively.

Västergötland

In the exploration of the Cambro-Silurian sequence of our country the mountains of Västergötland are classical ground, thanks especially to the work of Gustaf Linnarsson in the second half of the nineteenth century. Here the sequence is spread over a fairly large area comprising Billingen and the mountains of Falbygden, whereas the occurrences in Mts. Halleberg, Hunneberg, Kinnekulle and the "mountain" of Lugnås can be regarded as outposts of this area. The easily eroded sediments have been preserved in their present extension thanks to protection by dolerites, once intruded as sills within the Silurian shales, and also to downward movement along faults. In Mts. Halleberg and Hunneberg the dolerites cut obliquely across Cambrian and Lower Ordovician sediments.

Most of the mountains are terraced plateau mountains, and thus terminated above by wide plane surfaces of dolerite. Exceptions are provided by the "mountain" of Lugnås which is a comparatively low hill without dolerite covering, and where no higher part of the sequence is represented than the Upper Cambrian zone of *Parabolina spinulosa,* and by Mt. Kinnekulle resembling in its upper part the frustrum of a cone with a small cap-like remnant of dolerite on the very top. The beds rest practically horizontally upon the sub-Cambrian peneplane that is locally exposed in the plains near the plateau mountains. Between the mountains the peneplane extends in a hardly modified condition, and continues westward around Lake Vänern, where we find in the flat Archaean surface of Dalsland fissures filled with fossiliferous Cambrian sandstone.

This briefly described geomorphology imprints upon the mentioned part

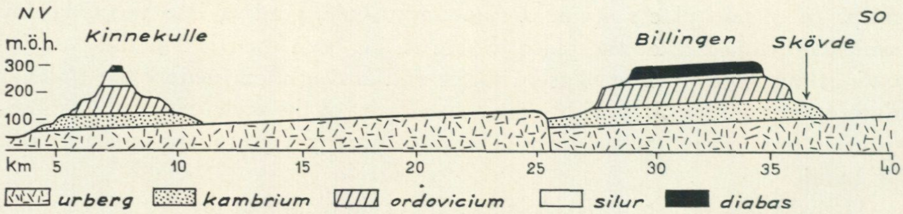


Fig. 5. Diagrammatic section from Västergötland. Legend: m. ö. h. - height above sea-level, urberg — Archaean rocks, diabas — dolerite.

of the province a stamp that is peculiar among the Cambro-Silurian regions of our country. With regard to the sequence of strata it is admittedly possible to point to many details of development and changes in horizontal direction, but there exists on the whole a close agreement with contemporaneous formations of Östergötland and Närke.

In the Lower Cambrian sandstone series two divisions can be distinguished, viz. the *Mickwitzia* sandstone which is rich in clayey matter and in part thin-bedded, and on top of it the light, thick-banked Lingulid sandstone that consists of almost pure quartz sand. The series has an average thickness of about 30 m, in Mt. Kinnekulle 34 (10 + 24) metres. Its heads form in several places steep cliffs, called locally "sandstensklev". The coarse basal beds, that are encountered in depressions of the not very deeply weathered underlying gneiss, consist of coarse sandstone rich in felspar, arkose, or conglomerate with fragments of different rocks and minerals, amongst others rounded pieces of quartz with wind-worn surfaces, occasionally in the form of dreikanters, and of a rock rich in siderite probably derived from a continental sediment. The sandstone divisions and especially the lower of them contain numerous casts of tracks of trilobites and other organisms. They are found upon clayey and shaly bedding planes upon which we also find radially symmetrical natural casts of medusae, while the sandstone layers contain vertical, straight and simple or U-shaped fillings of tubes of worms as is usual in the sandstones of the Lower Cambrian.

Close to or at the very boundary towards the Middle Cambrian series the Lingulid sandstone possesses a conglomeratic bed with well rounded pebbles of dark phosphoritic sandstone. A similar conglomerate, but with a matrix very rich in glauconite occasionally introduces the Middle Cambrian series which otherwise begins with a phosphoritic sandstone rich in glauconite or with a greenish-grey glauconitic shale. These beds belong to the *Paradoxissimus* stage. The stratigraphic gap at the boundary in question thus represents not only the uppermost zone of the Lower Cambrian, the sediments of which are known in our country in Scania and in the marginal Caledonian mountains of Lappland, but also the *Oelandicus* stage of the Middle Cambrian.

With the exception of the not very thick basal beds the Middle Cambrian series and the entire Upper Cambrian of Västergötland are developed as alum shales with bituminous limestone (stinkstone). The combined thickness of these series amounts to 22—23 m, and is thus much smaller than in Scania. The content of limestone is high, but varying; remarkable in this respect is

Mt. Kinnekulle, since there the quantity of limestone in the Upper Cambrian series increases considerably in western direction, and forms up to one half of the beds in the alum shale terrace at the western slopes of the mountain. The series contain two persistent conglomeratic horizons, occurring in the limestone beds. This circumstance is by itself sufficient to suggest the formation of the sediments in shallow marine basins. This conception receives additional support by the relatively high frequency of the limestone. One of the horizons is the thin *Exporrecta* conglomerate which is contemporaneous with the Andrarum limestone of Scania, the other is the partly conglomeratic so-called great stinkstone bed in the lower part of the Upper Cambrian series, a usually more than 1 m thick bed comprising 3—4 of the lowermost zones of the series. In addition to these there occur in several places conglomerates in the upper limestone beds of the *Peltura* zone. — In Mt. Kinnekulle the uppermost bituminous limestone beds contain chert.

The content of natural oil of the alum shale varies in vertical direction, and is greatest in the beds immediately above the great stinkstone bed. It is also subject to a certain variation in horizontal direction, and is greatest in Mt. Kinnekulle, where content of oil and thickness of the layers rich in oil increase towards the north-eastern part of the mountain. On account of distillation which probably has taken place in connection with the intrusion of the dolerite sills the content of oil is considerably smaller in the other mountains, and in Mts. Halleberg and Hunneberg the shale is almost completely coked. A product of the distillation is the so-called vanadium-bearing coal, an easily crumbling asphaltite, occurring in thin layers or as a film upon the bedding planes, but also as fillings of vertical fissures within the sequence at the boundary between the Cambrian and Ordovician systems of Mt. Billingen and in Falbygden.

In Västergötland the alum shale has been extensively used mainly as fuel in lime-kilns, but also as raw material in the manufacture of Ytong, a porous building stone. Its relatively high content of uranium, especially in Mt. Billingen, has opened new possibilities for its exploitation. This content has its maximum in the "kolm", a kind of coal rich in ashy material which occurs as lenses within the *Peltura* beds, and which is most abundant in the northern part of Mt. Billingen.

As in Scania the alum shale group includes the *Dictyonema* shale. In Västergötland the *Dictyonema* shale is, however, fairly thin, attaining only in exceptional cases a thickness of little more than 1 m, and its distribution is restricted to the southern part of Falbygden and Mt. Hunneberg. The sequence of strata in Västergötland exhibits furthermore a stratigraphic gap of varying size at the lower boundary of the Ordovician system. Biostratigraphically this gap can be demonstrated in the alum shale group within the areas, where it contains also the *Dictyonema* shale. Within other areas it is well marked also lithologically, and as a rule larger.

Lithologically the Ordovician sequence, which in Mt. Kinnekulle reaches a thickness of 115 m, can be devided into two divisions. The lower of these comprises the lower and middle series of the system, and is built up mainly of beds of limestone, whereas the upper one represents the Upper Ordovician series, and consists of mudstones and shales with few beds of limestone. The boundary between these two divisions is indicated by the plane of the upper terrace from which the slopes rise steeply to the dolerite plateau, especially on the eastern and western sides.

The *Ceratopyge* beds of the Lower Ordovician series consist in several places of both soft glauconitic shale and hard limestone, and are found in the same areas as the *Dictyonema* shale, but in addition also at Mt. Kinnekulle. The following Hunneberg and Billingen stages have a much greater extension. Their sediments have been deposited during times of intermittent transgressions with a main direction from west towards east within Västergötland. The repeated interruptions of the sedimentation are marked in Mt. Billingen and the Falbygden by numerous surfaces of discontinuity in the limestone beds. The preponderant direction of the transgressions has been determined by a comparison between the stratigraphic completeness of the sequences of the stages in different localities. This comparison has shown that at Mt. Hunneberg the sedimentation has been going on without noticeable interruption from and including the *Ceratopyge* limestone into the upper Billingen stage or as far as the sequence of strata is preserved in this mountain, that on the western slopes of Mt. Mösseberg the Hunneberg stage is incompletely represented, while the Billingen stage is well developed and relatively thick, and that these two stages thin out, become increasingly incomplete, and are occasionally lacking in the slopes of the mountains of eastern Falbygden that face the mountain Hökensås. In Mt. Hunneberg graptolitic shales occur also in the Hunneberg stage which otherwise consists mainly of glauconitic limestone, while the Billingen stage is represented in several places by the lower *Didymograptus* shale or, as e.g. in the northern part of Mt. Billingen, is developed with a mixed facies, graptolitiferous clayey shales with intercalations of limestone.

The shelly facies of the Hunneberg and Billingen stages and the succeeding *Limbata* limestone form the basal part of the so-called Orthoceratite limestone which is a group of bedded limestones with a thickness of the beds between some few centimetres and 10—12 cm. Its examination is still incomplete in several respects. Stratigraphically the group reaches up into the Middle Ordovician series, where it can in part consist of grey calcareous mudstone and knobby limestone. Its thickness amounts to about 50 m in Mt. Kinnekulle, but is 5—10 m smaller in Mt. Billingen and the Falbygden. It occupies the largest surface of the Cambro-Silurian formations in Västergötland. With regard to the colour, which is reddish brown or grey in different shades, the group in Mt. Kinnekulle has since old been divided into four divisions. But since the colour changes in horizontal direction such a division is without value for correlation. In Mt. Kinnekulle two divisions of red limestone have been distinguished of which the lower one has a thickness of nearly 20 m, comprises the entire *Limbata* limestone, and extends upwards into the *Vaginatum* limestone. It is this so-called "lower red rock" that is mainly quarried here for the manufacture of cement. This group, with the exception of its upper clayey portions, is exploited for the same purpose in Mt. Billingen near Skövde, where the bedded limestone corresponding to the "lower red rock" of Mt. Kinnekulle is mainly greyish. From the lower portions of the group limestone is taken in several places for burning, but also other parts of it have been quarried for industrial purposes.

Above the Orthoceratite limestone the Middle Ordovician series is rich in mudstones, and consists apart from them of beds of marly limestone, and on the very top, at least in Mt. Kinnekulle, of dark graptolitic shale with *Dicranograptus clingani.* Within this series the greatest interest attaches to the beds of metabentonite within the *Ludibundus* division. In Mt. Kinnekulle they are more numerous and thicker than elsewhere. The mudstones and beds of limestone which directly underlie these beds are strongly silicified, sometimes resembling chert. From the geomorphological point of view the occurrence of the soft and loamy bentonite beds ought to have contributed in an essential degree to the formation of the upper terrace plane, its notch in steep slopes of the mountains being situated below the head of the thickest among these layers. The upper bentonite bed is a horizon with numerous springs, the bentonite swelling when moistened, and thus preventing the continued descent of the water from the overlying fissured rocks.

The Upper Ordovician series is separated from the Middle Ordovician by a break, and begins with a division of dark, grey, or green occasionally calcareous shales and mudstones which within certain regions are overlain by a bed of "masur limestone". The basal beds consist usually of dark or black shales containing in Kinnekulle a graptolite fauna with *Climacograptus styloideus.* The "masur limestone", which is a knobby dark calcilutite traversed by narrow fissures filled with calcite, is overlain by reddish brown, partly greenish mudstones with a well preserved shelly *Tretaspis* fauna. On top of them there follow within Mt. Billingen and the Falbygden dark and grey-mottled shales with scattered beds of limestone. The *Staurocephalus* beds are represented by such a grey-mottled dark shale which by its fossil contents can be distinguished in the mountains of the Falbygden, but not in Mt. Billingen. In Mt. Kinnekulle it probably has its counterpart in partly fine-sandy mudstone.

The lithological development of the uppermost stage of the Ordovician, the *Dalmanitina* beds, is somewhat varying in horizontal direction, but displays everywhere a characteristic feature in an otherwise pelitic sedimentary sequence, and is obviously formed by shallow water deposits. In Mts. Kinnekulle and Billingen the stage includes a bed of limestone which in part includes fine-sandy portions. In Mt. Kinnekulle it merges into calcareous sandstone, and is delimited by surfaces of discontinuity, while the mountains of the Falbygden exhibit a thick-banked, greyish blue, calcareous siltstone with intercalations of limestone. On weathering it assumes a brownish grey colour. In Mt. Ålleberg the siltstone contains portions with cross-bedding and a bed of limestone in part rich in corals. The latter is locally developed as a conglomerate with pebbles of grey limestone. Also the occurrence of ripple-marks in thin-bedded calcareous siltstone in Mt. Billingen points to deposition in shallow water.

Of the Silurian we find in Västergötland only the lower division or Llandovery series. It is most complete in Mt. Kinnekulle, where the thickness has been measured to 55.4 metres. 26 m of these belong to the *Retiolites* shale. Upon the other mountains the dolerite rests almost everywhere directly upon the *Rastrites* shale, and only in Mt. Billingen the sequence of strata has in one locality N.E. of Öglunda been found to be terminated above by *Retiolites* shale, about 2 m thick. The Silurian sediments are burned or otherwise influenced by the heat of the dolerite magma. The depth of these changes varies. From the lithological point of view the sediments are variable, and consist by no means exclusively of black graptolitic shales, but to the greatest part of grey and dark mudstones with intercalations of black mudstone or shale. The lower and middle portions of the sequence sporadically contain layers or lenses of limestone, while the uppermost portion possesses parts of reddish mudstone, thin layers of metabentonite spread within the sediments of the three lower zones, and thin fine-sandy intercalations in the lower *Retiolites* sediments of Kinnekulle.

Östergötland

The Cambro-Silurian sequence of Östergötland agrees in its essential features with that of Västergötland with regard to stratigraphy and lithology, but presents a different tectonic and geomorphologic picture. Only faults with relatively great but varying throw have contributed here to the preservation of the Cambro-Silurian sediments that are sunk into the more resistent pre-Cambrian rocks. There exist several isolated areas, where the rock floor consists of such beds, all of them being conditioned by the east-western faults which are noticeable in the topography. North and east of the central plain of Östergötland with its triangular Cambro-Silurian area between Lakes Vättern and Roxen Cambrian deposits are found at Tjällmo in Hällestad, in and east of Lake Glan, in and west of the western portion of the bay Bråviken, and in the bay Slätbaken and its continuation towards the east. The two last-mentioned areas probably contain also Lower Ordovician limestones. The southern limit of the areas ought to be determined essentially by denudation in spite of the occurrence of minor faults along rather short distances as e.g. along the line Linköping—Svartåforsen. Also in the west the Cambro-Silurian rocks of the plain are bordered by faults along which the Precambrian rocks and the Visingsö group have been lifted up. Now the Precambrian rocks reach their greatest altitude in Mt. Omberg. A granite occurs around Granby, E. of Vadstena. This seems to be a portion of the Precambrian rock which has been pushed diapirically through the sequence of strata. It is still an open question, whether or not this portion has been mobile also prior to the time of the post-Silurian faults. In the immediate vicinity the Cambrian sediments exhibit, however, certain deviations from the normal development, as no alum shale has been encountered in drillings for water from the Ordovician beds down to the Lower Cambrian. The occurrence of the sediments of the Visingsö group

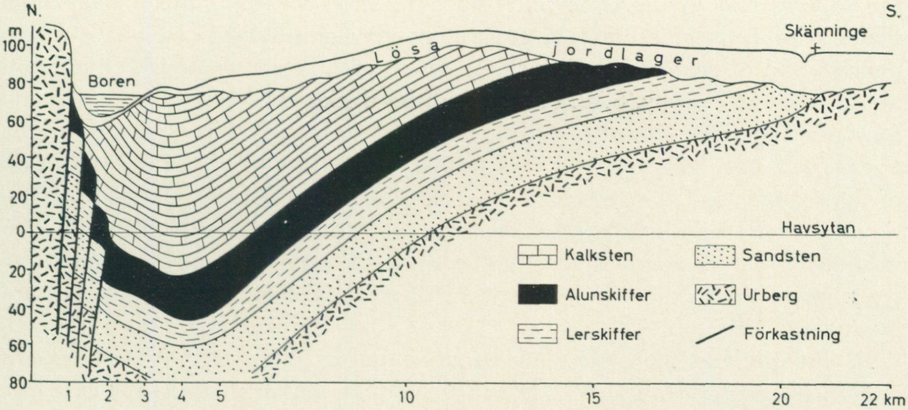


Fig. 6. Diagrammatic section through the central plain of Östergötland. Legend: Lösa jordlager — Quaternary deposits, Kalksten — Ordovician limestone, Alunskiffer — alum shales, Lerskiffer — clayey shales, Sandsten — Lower Cambrian sandstone, Urberg — Archaean rocks, Förkastning — fault, Havsytan — sea-level.

near Lake Vättern in the shape of pebbles in the stinkstone conglomerate of the *Dictyonema* shale can find its explanation also by vertical movements which probably have taken place within previously mobile stretches, and in this case on the verge from the Cambrian to the Ordovician periods. In this connection it is interesting to note the thinning-out in Västergötland in an eastern direction of the Lower Ordovician stages, since this is indicative of the existence of a land area in the region of Lake Vättern during early Ordovician times.

The deepest depression of the sequence is found between Lakes Vättern and Boren N. of Motala within a region in which the sub-Cambrian peneplane now descends to more than 90 m below sea-level (Fig. 6). This region is excentrically situated within the great central Cambro-Silurian area. On top it contains Silurian strata, while progressively older parts of the sequence outcrop in the north, east, and south of it. These northern outcrops appear within a, relatively spoken, very narrow belt, and exhibit occasionally very steep dips. The Cambro-Silurian area thus forms a syncline with westerly dip of the axis and a steep northern limb that has been formed in connection with a complex of faults which find their expression in the zig-zag course of the northern border of the area towards the Precambrian.

A comparison with Västergötland shows the Lower Cambrian sandstone series in Östergötland to have the same stratigraphic extent. From the lithological point of view it possesses, however, in its lower and middle parts certain features with a "Baltic" stamp. This makes itself noticed in the occurrence of beds with plastic clay and of a variegated, green, yellow, and red-coloured sandstone in the lower part, and of so-called "kråksten" in the middle part (cf p. 95). As in Västergötland the Lower Cambrian is terminated by Lingulid sandstone with a sandstone conglomerate at the very top. The development of the Middle Cambrian series is, however, essentially different. Below the upper part of the *Forchhammeri* stage the series consists of green glauconitic shales with beds of sandstone, containing glauconite and occasionally phosphorite, and of grey and darker clayey shales with layers of hardly bituminous alum shale. At Tornby, S.W. of Fornåsa, the thickness of this shaly and sandy formation is about 18 metres. In this place its lower third belongs to the *Oelandicus* stage which is not represented in Västergötland. The distribution of the sediments of the *Paradoxissimus* stage seems to indicate that during the time of their deposition the sea became increasingly shallower from east to west, as only the lowermost zone of the stage, the *Gibbus* zone, is found in the sequence in the east, while in westward direction the two following zones are gradually added to it.

In Östergötland the alum shale group is not as thick as in Västergötland. Within the central area it is ca. 20 m thick, and contains stratigraphically the uppermost zone of the *Forchhammeri* stage, the Upper Cambrian, and the *Dictyonema* shale in the lowest Ordovician. An examination of its different parts clearly reveals a thinning-out of the entire formation in eastern or rather south-eastern direction. This becomes obvious, amongst others, from the fact that the frequency of the limestone in the Upper Cambrian series increases in eastern direction, that almost every limestone bed is conglomeratic and often also contains phosphorite, and that the *Dictyonema* shale exhibits within the central area an decreasing thickness in eastern direction, while it is altogether missing at the bay Slätbaken. The character of the *Dictyonema* shale as a shallow water deposit is evidenced also by the occurrence of sandstone beds in its lower part.

Stratigraphically the *Dictyonema* shale is remarkably complete within the central area, all its zones with the exception of the uppermost being represented here. The stratigraphic gap at the boundary of the system in the area in question thus comprises mainly the upper parts of the Upper Cambrian. It increases, however, in eastern direction, and at Slätbaken comprises in addition to the *Dictyonema* shale also the *Ceratopyge* beds which are otherwise altogether missing in Östergötland. The oldest Ordovician strata above the *Dictyonema* shale belong to the Hunneberg stage the lower zone of which consists of a fairly thin glauconitic limestone with surfaces of discontinuity, while its upper part is built up of beds of limestone with few and thin beds of clayey shale. The *Didymograptus* shales are missing, and the Lower Ordovician above the *Dictyonema* shale and the Middle Ordovician are represented by bedded limestone of somewhat varying composition and colour. Borings have permitted to calculate in the region of Motala the thickness of the Orthoceratite limestone as about 60 metres. Upwards it extends to the *Ludibundus* division which likewise consists of bedded limestone locally rich in cystoids. Of this limestone group only the part that belongs to the Lower Ordovician is accessible for study mainly in quarries opened for the exploitation of the limestone for the stone industry and for the burning of lime. As in Västergötland and Närke the alum shale has been used as fuel in the lime-kilns, but also for the manufacture of Ytong (cfr p. 81).

Our knowledge of the above-mentioned parts of the limestone sequence in Östergötland is on the whole still rather imperfect, but can be substantially augmented by a closer examination of existing drilling cores. This remark applies likewise to the remainder of the sequence which belongs to the Ordovician and Silurian, and which enters into the rock floor around Motala Ström, though mostly on its northern side. Here the Upper Ordovician and Silurian strata are known from isolated outcrops, where the beds show different dips. These outcrops do, however, not form part of the rock floor, but enter as detached masses into the Quaternary sediments which are very thick. They have evidently been torn off and transported by the inland ice during its phase of stagnation and advance at the transition from Gotiglacial to Finiglacial time. This process has probably been considerably facilitated by the layers of soft and soapy metabentonite that have been shown to occur in the upper part of the *Ludibundus* limestone, and that are found also in the lower three of the Upper Llandovery zones of the Silurian graptolitic shales. There they are, however, much thinner than in the *Ludibundus* beds.

The Upper Ordovician series differs from that of Västergöland by the preponderance of limestone. The detached masses mentioned above contain as the oldest formations in this series black *Tretaspis* shale, greenish grey nodular limestone, and dark-greyish "masur" limestone. This knobby calcilutite is followed higher up by red *Tretaspis* mudstone and finely nodular limestone which at Råsnäs, west of Motala, is succeeded by a limestone conglomerate belonging to the *Dalmanitina* beds. These beds otherwise consist of argillaceous limestone with layers of calcareous shales. They are so far best known from Borenshult through the shelly fauna that could be collected there in connection with the digging of a canal.

Best known among the Silurian strata is the so-called Klubbudden shale. It belongs to the *Turriculatus* zone, and enters at the type locality into a loose overthrust mass. At Råsnäs mainly Upper Ordovician beds are seen in a similar mass. They exhibit a grading from the upwardly increasingly pelitic sediments of the *Dalmanitina* stage to darker graptolitiferous Silurian shales. The examinations which have been carried out so far make it probable that the rock floor belonging to the Silurian does not contain any higher stages than Upper Llandovery. The occurrence of the uppermost graptolite zone of the latter could be established only by finds of boulders of shale.

Närke

The main part of the rock floor below the plain of Närke is formed by Cambrian and Lower Ordovician strata. They are sunk and preserved thanks to faults that are well visible topographically along great distances. The Ordovician beds, which stratigraphically extend upwards into the lowermost *Vaginatum* limestone, are preserved within relatively small areas close to the bordering faults. Also within the plain itself some faults with small throw are found. They have resulted only in local deviations from the otherwise practically

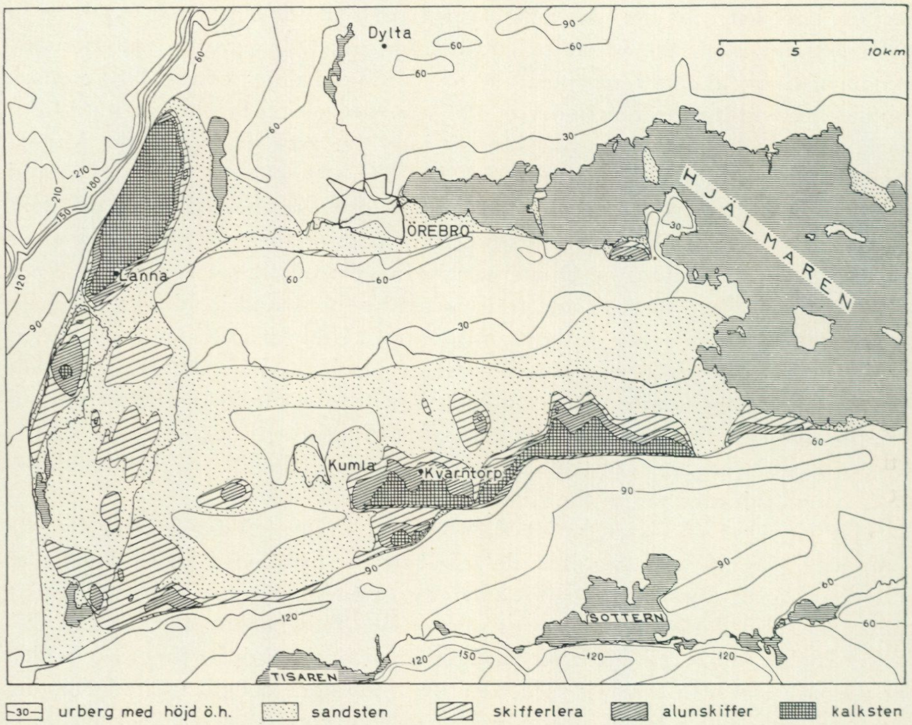


Fig. 7. Map of the Cambro-Ordovician of Närke. (Communicated in 1959 by J. Eklund.) Legend: Urberg med höjd ö. h. — Archaean rocks with height above sea-level, sandsten — Lower Cambrian sandstone, skifferlera — Middle Cambrian shales, alunskiffer — Cambrian alum shales, kalksten — Lower Ordovician limestone.

horizontal position of the strata. More obvious are the disturbances that have been brought about by the Quaternary inland ice, and that appear mainly within the shaly areas, i.e. areas without a cover of Ordovician limestone. Here the pressure of the inland ice has as a rule produced sliding movements along the soft and slippery clayey shales of the Middle Cambrian. The numerous drumlins of the plain often contain a nucleus of detached shaly masses.

The sequence of strata in Närke corresponds in its correlatable parts to that of Östergötland. We thus distinguish in the Cambrian portion three different lithological divisions or groups. Of these the two lower ones have the same stratigraphic compass as their counterparts in Östergötland, while the uppermost, the alum shale group, lacks the *Dictyonema* shale which is found in the plain of this province.

The thickness of the Lower Cambrian sandstone which occupies the greatest area within the plain is somewhat smaller than in Östergötland, and seems to increase from N.W. towards S.E. It is thus 15.7 m at Klara mine (N.W. of Lanna) and 18.5 m at Bresäter (S. of Kvarntorp). The *Mickwitzia* sandstone which has the greatest thickness, viz. 9.5—11 m, contains beds of "kråksten" and layers of clay, but lacks often a basal conglomerate. This fact can be explained by the circumstance that within wide areas the *Mickwitzia* sandstone rests upon an almost perfectly plane surface of denudation. As in Östergötland and Västergötland the Lingulid sandstone is a fairly pure and thick-banked quartz sandstone.

Within the group of the Middle Cambrian clayey shales the greenish *Oelandicus* shale with its basal glauconitic and phosphoritic sandstone shows a thickness which decreases from east towards west, 15 and 7 m, respectively, while the *Paradoxissimus* shale shows the opposite behaviour, being 0.3—5 m thick in the east, but ca. 12 m in the west. Stratigraphically the groups of clayey shales comprises the upper part of the *Oelandicus* stage and the lower part of the *Paradoxissimus* stage.

The alum shale group, of especially great importance in Närke as source of energy and raw material for the manufacture of Ytong (cfr p. 81), is characterized by its relatively small content of limestone. On account of the fact that the Middle Cambrian *Forchhammeri* stage is very incompletely represented the alum shale belongs essentially to the Upper Cambrian. The *Forchhammeri* stage has usually an inconsiderable thickness, not more than 1 m, and is sometimes missing. The group has its greatest thickness in the region around Yxhult, the maximum being 19.3 m at Hynneberg, 1 km S.W. of Yxhult. The shale is characterized by the low content of limestone above the often conglomeratic "great stinkstone bed" and also by a maximum and average content of natural oil that surpasses that of the corresponding group in any other part of our country. The shale is richest in oil in the south-eastern part of the area, where it can rise occasionally to 8 % within a bed. In the section which is quarried for distillation and which in the region around Yxhult contains roughly 13.6 m of shale the average content of oil is higher than 5.4 %.

Like the Middle Cambrian also the Upper Cambrian series is incompletely developed stratigraphically. Particularly noticeable is the gap in the uppermost Cambrian at the boundary of the system, where the Lower Ordovician limestone series rests with basal transgressional deposits upon shales or upon bleached stinkstone belonging to the uppermost but one zone of the *Peltura* beds. At the lithologically very distinct boundary of the system the stratigraphic gap is further accentuated by the absence of Tremadocian sediments and by the incomplete development or occasional absence of the lower part of the Hunneberg stage.

In the localities in the west and south, where the sequence is best preserved, the Lower Ordovician limestone series has a thickness not surpassing 20 metres. This series ist characterized by a rhythmic sedimentation which is especially evident in the Billingen stage and the upper Hunneberg stage, and which reveals the oscillations of sea-level during the deposition. A similar rhythm in the sedimentation is found in the Early Ordovician sediments of other regions (Fig. 8, p. 92 and Fig. 9, p. 97), but ought to be best developed in Närke. The numerous surfaces of discontinuity thus indicate interruptions of the sedimentation, and delimit its different cycles. When it is as complete as possible, each of these cycle consists of two beds of limestone with an intercalated layer of clayey shale or marl.

The series of Ordovician limestones of Närke within which the reddish, as yet little studied *Limbata* limestone has the greatest thickness, has been extensively exploited for the stone industry and for the manufacture of quicklime. At Lanna it is quarried as raw material for cement.

Dalarna (Dalecarlia)

In Dalarna Palaeozoic beds are found in the north-western part and in the so-called Siljan region. Farthest in the north-west they occur within the eastern border of the Caledonian mountain range, and form a continuation of similarly situated Cambrian and Lower Ordovician deposits in Härjedalen and south-western Jämtland, consisting preponderantly of sandstone and alum shales, and bedded limestone, respectively. It has been possible to establish in the parish of Idre the occurrence of both Lower and Middle Cambrian strata, known since long from outcrops, and also of Upper Cambrian alum shales, which have been more recently encountered in borings.

In the ring-shaped Palaeozoic belt of the Siljan region, where the strata are disturbed by numerous faults as well as by some minor overthrusts, the Cambrian system is missing. The oldest Ordovician deposits are the *Obolus* beds in the southern and eastern parts of the region, while as far as is known the late Precambrian rocks (porphyry, Digerberg sandstone, etc.) in the north-west are covered by younger deposits, consisting at Orsa of a thin basal conglomerate without shells or fragments of obolids, sandy glauconitic clay, and on top of it the richly fossiliferous *Planilimbata* limestone. Recent investigations have shown the Djupgrav conglomerate, that occurs in the north near Skattungbyn with a thickness of more than 3 metres, and which had been deposited upon Jotnian sandstone, to contain in its upper part a thin layer of alum shale with *Dictyonema sociale*. On this account the conglomerate must be considered contemporaneous with the *Obolus* beds. It has probably been deposited in a depression of the sub-Ordovician surface, and has been protected there from denudation during subsequent regression in early Ordovician time. The Ordovician sea has obviously invaded from the south-east both the Siljan region and large parts of the isthmus, that during Cambrian times separated the continental shelf of the Caledonian geosyncline from the shallow epicontinental sea over the Baltic area and Central Sweden. An increasingly lessening depth towards north-west has been traced also in certain parts of the rest of the Ordovician sequence, where oscillations of the sea-level could be registered.

The Ordovician of the Siljan region is characterized by its comparative wealth in limestones, among which the reef-like formations attract the greatest interest. These were previously united under the name *Leptaena* limestone, but have been established as formed during two different phases, and are now called Kullsberg limestone and Boda limestone, respectively. The fossiliferous Silurian deposits consist mainly of graptolitic shales, and represent, though not quite completely, the Llandovery and the lower portion of the Wenlock. No fossils have so far been found in the Orsa or Grinding sandstone. Its place in the Palaeozoic scheme is therefore uncertain. It is separated from the fossiliferous Silurian by a stratigraphic gap, probably of considerable size. Presumably the sandstone lies somewhere near the boundary between Silurian and Devonian. — The study of the sequence is made very difficult by the extensive cover of Quarternary deposits and the complicated tectonics.

Ordovician. In the places, where the Ordovician basal deposits consist of beds with *Obolus,* the underlying Precambrian granites and gneisses are weathered to variable depth. Gravel resulting from the weathering of granite is found in this position e.g. near Altsarbyn and in the railroad cutting near Sjurberg in the parish of Rättvik, and in the old phosphorite mine at Mt. Klittberg in the parish of Boda. The *Obolus* beds are usually represented by a conglomerate that consists mainly of redeposited gravel and larger fragments of the pre-Cambrian rocks together with granules of phosphorite and mainly fragmentary shells of *Obolus apollinis.* At Gärdsjö also a soft sandstone has been found with well preserved and therefore probably not redeposited shells of *Obolus,* amongst others of the thin-shelled *O. triangularis.*

The Lower Ordovician consists otherwise preponderantly of Orthoceratite limestone. A mixed facies formed by limestone beds with the fauna of the zone of *Megalaspides dalecarlicus* alternating with shales with *Phyllograptus densus* has been observed only near Skattungbyn. In several places the basal beds contain layers of glauconitic clay. Oolithic limestone, which near Skattungbyn (Leskusänget) is rich in ferriferous ooids of remarkable size, occurs within the *Expansus* limestone, occasionally also within the *Raniceps* limestone.

In the Lower Ordovician distinct gaps can be established. Thus sediments corresponding to the *Ceratopyge* limestone are altogether missing as well as those to the *Lepidurus* limestone. Faunistically less obvious gaps are common especially within the lower stages, and are indicated by surfaces of discontinuity (cfr Fig. 8).

In the Middle Ordovician the lowermost part is developed as Orthoceratite limestone which is overlain by often knobby limestones, richer in clayey matter.

Apart from the exceptions, which will be dealt with in greater detail below, the Upper Ordovician consists of basal *Slandrom* limestone with banks of knobby calcilutite, black *Tretaspis* shale with a mixed shelly and graptolite fauna (zone of *Climacograptus styloideus*), greenish grey *Tretaspis* limestone, red *Tretaspis* beds of marl and finely nodular limestone, *Staurocephalus* beds of greenish grey calcareous mudstone and argillaceous limestone, and, at the very top, of grey calcareous *Dalmanitina* shale with a basal bank of fine-sandy limestone (so-called clink-limestone).

Within the uppermost Middle Ordovician and the upper parts of the Upper Ordovician formations with a local facies, the above-mentioned reef-like limestones, set their imprint upon the sequence and to a certain extent also upon the landscape of today, occurring as they do in ridges and slopes some of them being easily recognizable as well delimited elevations. Their nucleus consists

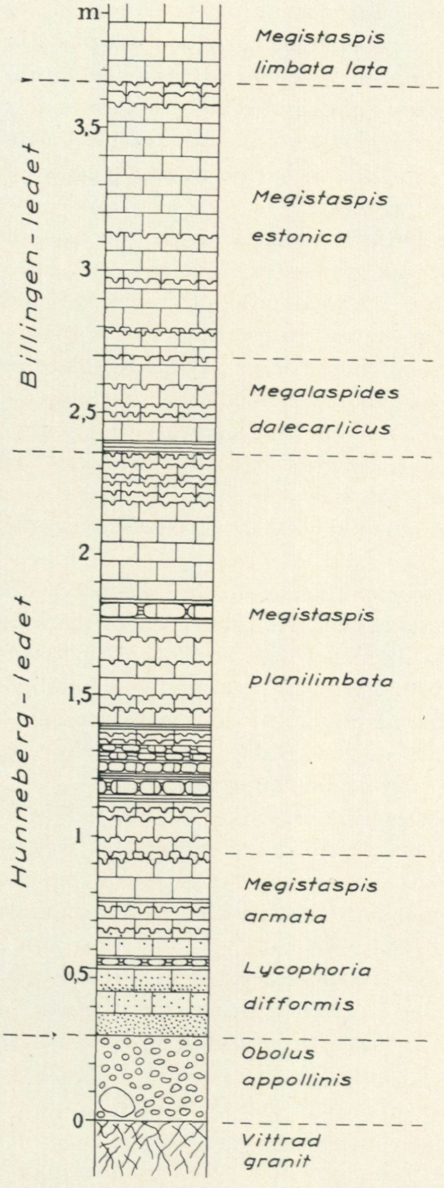


Fig. 8. Diagrammatic section of the sequence of strata at Sjurberg. (After T. Tjernvik 1956). Legend: Vittrad granit — weathered granite, ledet — stage. Pitted lines denote surfaces of discontinuity

of a massy limestone, the reef limestone proper, containing nests or lens-shaped portions full of shells which form a kind of pseudo-conglomerate (*coquina* limestone). The organisms which have been accumulated in this way are especially trilobites and brachiopods, more rarely gastropods and cephalopods. It is a remarkable fact that as a rule each of these nests contains shells of only one species or of species belonging to a single genus. In spite of the wealth of shells the main contributors to the formation of the limestone seem to be algae. This is suggested especially by the ribbon-like, lamellar, and branching structures which resemble *Collenia,* and traverse great portions of the massy limestone. In the upper reef horizon, the Boda limestone, great quantities of the green alga (Codiacean) *Palaeoporella* is noticed.

Each occurrence of the reef limestone is accompanied by a so-called surrounding facies, consisting of reddish or greenish parcels of strata composed of pale beds of limestone, which gradually, with increasing distance from the reef, become thinner, and of coloured, more or less marly beds, that in the same direction increase in thickness and number, and thus interdigitate between the limestone beds. The wealth of fossils is great also in this surrounding facies. Especially common fossils are brachiopods and cystoids and also bryozoans (near Kullsberg) or tabulate corals (near Boda). Occasionally more or less fragmentary stems of pelmatozoans are so abundant that certain beds consist entirely of them. The fauna of the surrounding facies, which thus represents marginal sediments of the reef limestone, differs essentially from that of the latter. As a third facies, the so-called normal facies, we have then to consider the deposits which are contemporaneous with the reef limestones and their surrounding facies, and which extend between the sometimes rather widely spaced localities of the former. At present 34 localities of the reef-like limestone are known. Ten among them consist of Kullsberg limestone, and consequently belong to the older reef horizon. In three places the Boda limestone has been found to be deposited above the Kullsberg limestone. — On account of its high content of $CaCO_3$ the reef limestones have been quarried on a gradually increasing scale in order to satisfy different demands. This has also benefitted the knowledge of their faunae, stratigraphy, and structure. An idea of the size of these lenticular bodies can be obtained from the following figures: length for Kullsberg 300 m, for Boda 1 km; greatest thickness for Kullsberg 40 m, for Boda 100 m.

The beds of the normal facies which occur in the Middle and Upper Ordovician, and which are contemporaneous with the reef limestones and their surrounding deposits differ from them not only lithologically, but also faunistically. They exhibit on the other hand a far-reaching agreement with contemporaneous deposits within other regions (e.g. autochthonous deposits of Jämtland and Palaeozoic of Östergötland), where reef limestones of corresponding age are lacking. On the other hand, species that are characteristic for the fauna of the Boda limestone have been found in far distant occurrences of similar limestones, e.g. in northern England and Ireland.

The thickness of the Ordovician sequence in the regions between the occurrences of the reef limestone has been calculated to an average of 130 metres.

Silurian. The graptolitiferous strata of the Lower Silurian consist preponderantly of dark shales. They differ thereby from the lighter sediments, rich in shells, of the Upper Ordovician and of the little examined grey and reddish, in part marly shales, poor in fossils, that can be observed immediately below the Silurian graptolitic shales. These shales with few fossils occur within the regions between the Boda limestones. No distinct boundary between the systems can be observed in these regions. It is thus unknown, to what extent these shales belong to the Silurian. At the occurrences of the Boda limestone the boundary between the systems is on the other hand distinct, and there we find an obvious stratigraphic gap that widens towards these limestone bodies. During the different phases of the Lower Silurian the latter had obviously protruded to a varying extent from the surrounding sediments. These limestones are in several places traversed by fissures filled with black graptolitiferous shales belonging to the Middle Llandovery. This indicates that no sediments of Early Llandovery age had been deposited upon them. At Mt. Osmundsberg the limestone is locally overlain by a conglomeratic basal bed which together with the following shale, rich in limestone, belongs to a lower zone of the Upper Llandovery.

The graptolitic shales sometimes enclose beds with lenticular or spherical concretions of dark limestone and scattered light layers of bentonitic clay. They are overlain by a grey, in part reddish division consisting of thin-bedded dense limestone and thin beds of shale. This division forms an upper part of the *Retiolites* shales of the region, and has been named Styggfors limestone from its type locality, but also "Cement limestone". The youngest fossiliferous beds belong to the so-called *Bumastus* limestone at Nederberga in the parish of Orsa, where they are also found in original contact with the Orsa sandstone. The basal sandstone beds are coarse-grained, in part conglomeratic and cross-bedded. The main mass of this youngest Palaeozoic sedimentary formation in Dalarna consists otherwise of a fine-grained, soft, sometimes calcareous quartz sandstone. Its colour varies from almost white to red, its clayey, shaly bedding planes show occasionally beautiful mud cracks. It was formerly fairly widely used especially in the manufacture of grinding stones.

The Baltic Area

Öland and Gotland are projecting portions of the Palaeozoic sequence that is lodged in the great Baltic basin, and that constitutes the rock floor for the greater part of the middle and southern Baltic Sea. This rock floor meets the Archaean along a line that extends in an arch from the region of Kalmarsund in eastern Småland to the Gulf of Finland, and in the neighbourhood of the depth of Landsort probably possesses a fairly deep bulge towards the south. The above line is mainly the result of erosion, and now runs some fifty kilometres north of the island of Gotska Sandön. On this island a Cambro-Ordovician sequence of somewhat less than 160 m is covered by Quaternary deposits more than 70 m thick. Outside the boundary Lower Cambrian sediments are found filling fissures in the Archaean rocks, where the sub-Cambrian peneplane emerges from the Baltic Sea in the archipelagos of south-western Finland, Åland, Stockholm, and Östergötland. A comparatively small area with Middle Ordovician strata, preserved in a cauldron-shaped depression caused by dislocations, is found in the bay of Tvären in the coast of Södermanland. Similar to what is the case in Bråviken and Slätbaken in the coast of Östergötland also in

Tvären the sequence of strata is known from boulders found in a sector the apex of which lies immediately north of their source.

On account of the synclinal structure of the Baltic area both Cambrian and Ordovician strata are found at Kalmarsund and upon Öland, while upon Gotland only Silurian is visible. Thanks to deep borings the main features of the Cambro-Silurian sequence are, however, known within the major part of the area. These borings have resulted especially in a better knowledge about the Cambrian series.

The Lower Cambrian series consists of a sandstone group with portions that contain a variable amount of clay. In northern and eastern regions it contains in its lower part a greenish clay. The thickness of this clayey division, the "blue clay" (Lontova formation) of the eastern Baltic areas, increases considerably in eastern direction. The thickness of the entire group increases towards the south and the east as can be seen from the following figures (in metres) for the Lower Cambrian: Gotska Sandön (Hamnudden in the south-west) 72.5, Öland (Borgholm, Böda) 78, Gotland (Visby) 106 and (File Haidar, 8 km W. of Slite) 126, Tallinn ca. 150, and Leningrad ca. 170. Near residual mountains rising from the peneplane, e.g. near Mossberga upon Öland, the thickness is of course considerably smaller.

The group is characterized by the occurrence of so-called "kråksten", i.e. portions of sandstone, as a rule fairly rich in clay, in which the original stratification has been more or less completely destroyed by burrowing organisms. In other portions we find closely spaced fillings of tubes *(Skolithos)* or U-shaped structures *(Diplocraterion)*. Fossils characteristic for the two lowermost zones of the Lower Cambrian have been established to occur in this group. It seems, however, to cover a somewhat greater stratigraphic interval, since in Öland the strata with the oldest zone fossil, viz. *Discinella holsti,* are underlain by 40 m of sandstone. It is this sandstone sequence or its lower part that occurs in the coastal region of Småland as a belt of varying width, and which on this account has been called the Kalmarsund sandstone. It is of somewhat variable composition, and contains a white or red, occasionally quartzitic *Skolithos* sandstone, but also portions of "kråksten" which are fairly rich in clay.

Compared with the Lower Cambrian series the other two series of the Cambrian differ widely in extension and thickness. They are thus absent below Gotska Sandön, and are represented below Gotland by the *Oelandicus* stage only which there exhibits the increase in thickness in western and southern direction that applies to Middle and Upper Cambrian throughout the Baltic area. The thickness is 31.4 m at File Haidar, and 35.1 m at Visby. In Öland, where the *Oelandicus* stage measures 41 m at Böda and probably 43 m at Borgholm, and where it is at the same time more completely developed than elsewhere in Scandinavia, we find in addition sediments belonging both to the other two stages of the Middle Cambrian and to the Upper Cambrian.

Whereas below Gotland the *Oelandicus* stage consists mainly of a sandstone rich in clay, and lithologically forms a continuation of the Lower Cambrian sandstone group, it is built up in Öland of a thin basal conglomerate and of dark-grey, greenish, and grey clayey shales with upwardly diminishing content of sand. The *Paradoxissimus* stage, which is most likely not represented in the sequence of strata of northernmost Öland, constitutes in the middle and southern parts a formation that at Borgholm reaches a thickness of 26 m, and that on top of a thin basal conglomerate with *Acrothele granulata* and of a bed of sandy *Exsulans* limestone consists of a thin-bedded, somewhat calcareous unfossiliferous sandstone with thin beds of shale. In southern Öland the topmost part of this formation contains a thin conglomerate with *Hypagnostus parvifrons*. The *Forchhammeri* stage is on the whole developed in southern Öland only. There it consists in the extreme south of a bed of alum shale and stinkstone with a thickness of 0.5 m which overlies a thin conglomeratic bed with *Oligomys exporrecta*. Elsewhere it consists exclusively of an *Exporrecta* conglomerate which thins out towards the north, and can be traced in the northern part of the island in scattered localities only. There we usually find a compound conglomerate containing an association of fossils from the topmost *Forchhammeri* beds, from the Upper Cambrian series, and from the *Dictyonema* shale. This indicates that during very long times northern Öland has been a flat coastal region.

The *Forchhammeri* stage introduces in Öland the alum shale group which comprises in addition the Upper Cambrian together with the *Dictyonema* shale and *Ceratopyge* shale of the Lower Ordovician. The group reaches its greatest thickness in the most south-eastern part of the island, where in a drilling core from Ottenby 23.8 m have been measured, and its isopachytes run in S.W. — N.E. direction with some deviation in western direction towards the northern part of the island. This is one of the results obtained from a number of deep borings most of which have been carried out within southern Öland. They have shown that there the direction of the isopachytes for the *Dictyonema* shale coincides on the whole with that mentioned above. The parallel isopachytes for the Upper Cambrian series traverse, on the other hand, the island from west to east. The thus demonstrated difference in the distribution of thicknesses suggests a change in the direction of the coastline on the verge from the Cambrian to the Ordovician periods. As hinted above this change does, however, not appear to have applied to the area of the outcropping of the formation in northern Öland, where the formation consists mainly of a *Ceratopyge* shale of small thickness which is locally developed to a variable extent as a glauconitic shale (Fig. 9).

Lithologically the Cambrian part of the alum shale group differs from its Ordovician part amongst others by the fact that the former is rich in stinkstone, whereas the latter is practically devoid of such limestone, and also by the circumstance that in the former the shale contains a higher percentage of kerogen, and thus has a higher calorific value than in the latter in which this value is highest for the *Ceratopyge* shale. The content of oil is considerably lower than in Närke, Östergötland, and in Mt. Kinnekulle. For the entire stack of shales it is on the average 3.2 % at Degerhamn, and decreases in south-

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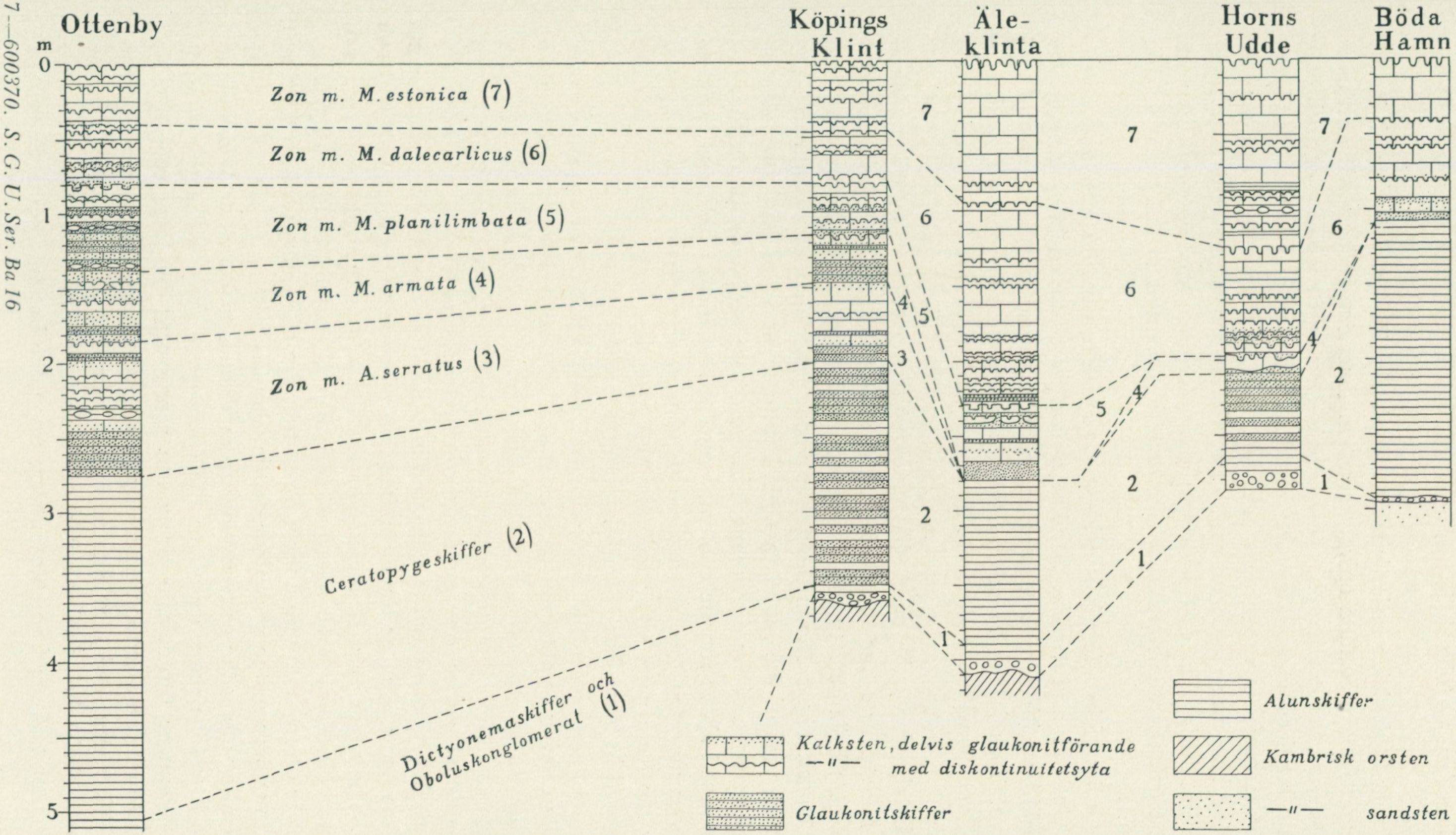


Fig. 9. Diagrammatic sections from Öland comprising Tremadocian (1 + 2 + 3), and the Hunneberg (4 + 5) and Billingen (6 + 7) stages, and their correlation. (After T. Tjernvik 1956.)

Kalksten, delvis glaukonitförande — limestone partly with glauconite, med diskontinuitetsyta — with surface of discontinuity, glaukonitskiffer — glauconitic shales, alunskiffer — alum shales, kambrisk orsten — Cambrian stinkstone, sandsten — sandstone.

eastern direction. — The shale has been utilized in the same way as in Östergötland.

The Lower Ordovician series is most completely developed in Öland. Below Gotland and Gotska Sandön only *Vaginatum* limestone is found. Even this is incomplete from the stratigraphic point of view, and rests without or with only a very thin basal conglomerate upon Middle Cambrian and Lower Cambrian sandstones, respectively. Towards the east the series becomes again more complete, and begins as in Öland with Tremadocian sediments. Thus everything indicates that during Early Ordovician times a continental mass, probably with its greatest extension in north-southern direction, existed in the centre of the Baltic Sea.

From studies of boulders it is evident that within a region west and north-west of Gotland and Gotska Sandön a conglomerate containing, amongst others, pebbles with Upper Cambrian trilobites forms the basal bed of the Ordovician. This is the so-called *Ahtiella jentzschi* conglomerate which is contemporaneous with the *Raniceps* limestone and the Pakri (Rågö) sandstone in Estonia.

Immediately above the alum shale group the sequence of strata in Öland contains both *Ceratopyge* limestone or the zone with *Apatokephalus serratus* and sediments belonging to the different faunal zones of the Hunneberg and Billingen stages. Fig. 9 shows the varying occurrence of these sediments from the southern part of the island to Böda Hamn in its north, and furnishes an additional example of the development in the course of sedimentation that has been mentioned above for the contemporaneous sequences in Central Sweden. The obvious agreement between these sequences which have been deposited relatively far from each other indicates that the changes of level, which are well expressed in them, have been mainly of a eustatic nature.

The alum shale group and the overlying Lower Ordovician sequence enter to a locally varying extent into the coastal cliff of Öland. Its top and the rock floor of the island east of it consist of reddish or greyish bedded limestone belonging to a number of successive divisions or stratigraphic units that can be distinguished either on the basis of biostratigraphic data or by their shifting lithological composition expressed in content of clay, grain size, content of shell fragments, etc., or by a combination of these two principles of classification. The main mass of these units has for a long time been referred to the "Orthoceratite limestone". In a western belt of varying width they belong to the Lower Ordovician series, for the rest they are of Middle Ordovician age. The youngest beds in the rock floor of the island consist of *Ludibundus* limestone extending along the eastern shore from Persnäs to Böda. At Böda Hamn the entire limestone sequence above the *Ceratopyge* shale has a thickness of 39.15 m. Younger Ordovician strata are represented by loose blocks only. Among these we call attention especially to a large mass of calcareous siltstone from the *Macrourus* beds, transported by the inland ice, near Gräsgård in the S.E. It has probably belonged to a part of the rock floor that had been detached along a bentonite layer from the outcrop upon the bottom of the Baltic Sea

N.E. or N.N.E. of Öland. The occurrence within the uppermost *Ludibundus* beds of a number of such layers has been proved by the deep borings upon Gotland and Gotska Sandön.

In Öland an extensive quarrying industry is based upon certain parts of the bedded limestones which have also been utilized for the manufacture of cement.

The coastal cliff of Öland with its top of Ordovician limestone of greater hardness continues upon the bottom of the Baltic Sea in the topography of which it can be followed with relatively few and in general short gaps to the cliff of western Estonia.

The above borings have shown the Upper Ordovician series to consist for the greatest part of limestones of varying composition and bedding, and that mudstones and portions rich in clayey shales can occur in its lower and middle parts. The *Palaeoporella* limestone seems to have wide extension and great thickness. There exist white, fine-grained to dense limestones with chert, and the examination of boulders has shown that the youngest Ordovician strata north and north-west of Gotland are at least locally rich in chert.

The thickness of the Ordovician is 94 m at File Haidar and about 99 m at Visby.

Below Gotland there exists, between the Ordovician and Silurian systems, a marked surface of discontinuity the presence of which has been observed in drilling cores. This surface separates a pale algal limestone with high content of $CaCO_3$ from an overlying division of argillaceous sediments with inclusions of limestone that higher up become increasingly scarce. This surface bears witness of a stratigraphic gap which probably comprises the major part of the Lower Llandovery, since finds of graptolites have shown that sediments belonging to the upper zone of the Middle Llandovery occur already 15.6 m above the boundary between the systems, while at the same time no interruption of the sedimentation could be traced in the portions of the core between this boundary and the graptolitiferous horizon.

The total thickness of the Silurian sequence of Gotland is ca. 650 m of which ca. 140 m are situated below sea-level. The lower fourth of this sequence consists almost exclusively of mudstones, marls, and marlstones, but similar sediments, often with considerable thicknesses, appear also in most of the higher stratigraphic units. Otherwise we observe a dominance of limestones which occur partly as masses of reef limestone of varying size, and partly are spread as layers and beds of different thickness. Also oolitic strata occur among the limestones. Sandstones dominate in the uppermost parts of the sequence in the so-called Burgsvik group, but are rare elsewhere. In addition there occur thin layers of bentonite and of beds of hard mudstone.

On the basis of lithologic or faunistic criteria or of a combination of both the rock sequence of Gotland has been split into 13 divisions representing formations or groups of formations (Fig. 10). The dip is very gentle towards the S.E., but local deviations occur as the result of flexures or dome-shaped

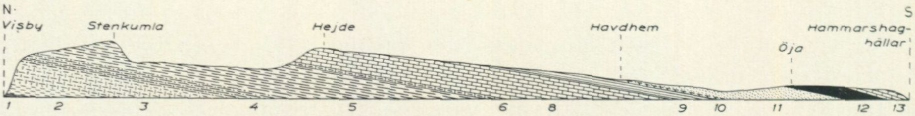


Fig. 10. Diagrammatic section through Gotland. (After J. E. Hede 1921 and 1925.) Vertical to horizontal scale about 90:1. 1 and 2 — Upper and Lower Visby marls, 3 — Högklint group, 4 — Tofta limestone, 5 — Slite group, 6 — Halla limestone, (7 — Mulde marl which has thinned out completely from S. W. to place of section), 8 — Klinteberg group, 9 — Hemse group, 10 — Eke group, 11 — Burgsvik sandstone and oolite, 12 — Hamra limestone, 13 — Sundre limestone.

folding, and of course also in the neighbourhood of the masses of reef limestone.

In the landscape of Gotland the heights are formed by the limestones. Among these especially the reef limestones form pronounced cliffs, while the depressions have been formed in the easily eroded marls and sandstones. A strongly modelled cliff is found along the coast in the N.W., but also the Klinteberg limestone forms in its north-western outcrop a cliff which is well defined in some places. Between this cliff and the north-western limestone belt of the island extends a depression in the marls of the Slite group. The width of this depression increases towards the S.W. This is the result of a change of facies in this direction from a sequence fairly rich in limestone to one with a higher content of marl. This seems to be a lithologic phenomenon that applies to most groups of formations.

Both limestones and marly limestones are often richly fossiliferous. The reef structures consist preponderantly of stromatoporids, but also of corals and other sedentary organisms. Many of the bedded limestones are characterized by their wealth of calcareous algae. Graptolites occur, though sparsely, in some marls, and have permitted a correlation with the Silurian sequence of Gt. Britain (cf. the stratigraphic diagram, p. 75).

The quarrying activity, based upon the limestones, is extensive especially in northern Gotland. The Burgvik sandstone is quarried for the manufacture of grinding stones, and at Slite the marl serves as raw material for cement.

The sequence of strata in Tvären belongs to the lower part of the Middle Ordovician *Ludibundus* zone. The study of erratic boulders has shown it to consist of the following components (from bottom to top): conglomerate, calcareous sandstone, and limestone. It thus constitutes a typical transgressive sequence that attracts especial interest, there being good reason for the belief that it has been deposited along a coast consisting of Archaean rocks within a region surrounded by peneplanes of early Cambrian date. This conclusion is based upon the fact that the conglomerate contains mainly Archaean material together with only occasional fragments of *Vaginatum (Expansus)* limestone. Also the relatively richly fossiliferous limestone contains a varying quantity of fragments of Archaean rocks.

The Gulf of Bothnia

Within considerable parts of the Gulf of Bothnia the rock floor consists of Cambro-Ordovician deposits which have furnished boulders spread in a broad sector comprising great parts of Uppland as well as the archipelagos of Stockholm, Åland, and S.W. Finland. Along the Swedish coast accumulations of boulders are found as far north as Härnön. Upon islands in the bay of Gävle the moraine contains comparatively large coherent portions of Ordovician limestones which during the advance of the inland ice had been torn off along surfaces with clayey films. The depression of the Gulf of Bothnia ought to be conditioned by faults which thus have contributed to the preservation of the sedimentary deposits.

It is probable that in different parts of this area the sequence of strata has a somewhat varying composition both lithologically and with regard to stratigraphic completeness as is the case in the Baltic area. As no deep borings have, however, been carried out which might supply closer information, we shall in the following restrict ourselves to an enumeration of the components of the sequence according to the results of the examination of erratic boulders.

The *Cambrian* is represented by Lower Cambrian sandstone which is in part dark and rich in bituminous matter. At Holmudden, at the northern shore of the bay of Gävle, more than 11 m of clay are found at the base of the Cambrian. The topmost part of the sandstone formation might belong to the Middle Cambrian, although there exists no decisive proof for this opinion.

Ordovician. Its lower and middle series exhibit close agreement with those of the Siljan area with the difference that the Tremadoc of the area of the Gulf of Bothnia is more complete, and contains in addition to the *Obolus* conglomerate both *Ceratopyge* shale and *Ceratopyge* limestone. Reefs of the Kullsberg limestone occur in the Middle Ordovician. The upper series does not reach higher in the stratigraphic sequence than to the middle *Tretaspis* stage, and is formed of calcilutitic limestones of somewhat varying composition and colour. These limestones, among which a reddish *Palaeoporella* limestone is noticed, have been comprised under the designation "Östersjö limestone".

Jämtland

The Cambro-Silurian area of Jämtland along and east of the border of the Scandinavian mountain range, i.e. the region with the so-called eastern Cambro-Silurian, exceeds in extension any other area with Palaeozoic rocks in Sweden. An account of this area has to take into consideration first of all its tectonic structure, this being of essential importance for the understanding of the sequence of the strata and its varying composition within different portions of the area.

T e c t o n i c a l l y the main part of the Cambro-Silurian beds belong to the allochthonous masses in front of the mountain range, and form their most important element. Only a relatively narrow belt along the Precambrian in the east consists of autochthonous beds or of beds which have undergone only a short transport from their original position. This belt is broadest at the south-eastern bay of Lake Storsjön. The allochthonous Cambro-Silurian beds are strongly compressed and folded. In east-western direction a number of successive and superimposed overthrust masses or nappes can be distinguished. The thrust-planes of the eastern masses have a gentle dip towards north-west. The two westernmost overthrust units (Föllinge and Olden) occupy a mainly horizontal position. When compared with the eastern ones they ought to be designated as major nappes.

From the stratigraphic point of view the distinguishable tectonic elements comprise a varying number of stages of the Cambro-Silurian sequence. Silurian strata are missing in the autochthonous, and the Upper Ordovician is represented only by the basal *Tretaspis* beds. In the eastern nappes the Silurian is restricted to the Lower and Middle Llandovery. These stages are encountered only within comparatively narrow belts, mainly in synclines of comparatively great amplitude. Higher Silurian stages, representing the Upper Llandovery and presumably also the lowermost Wenlock, are found within synclines in the Föllinge nappe. In the western major nappes the Cambrian strata seem to thin out in western direction. Within the Olden nappe they have not been observed. Also a great part of the Lower Ordovician is unrepresented in this nappe. Neither could, in the absence of fossils, its upper stratigraphic termination be indicated more closely. — In the autochthonous as well as in the allochthonous sequence stratigraphic gaps have been established. They are most pronounced in the autochthonous. (Cfr the table on the opposite page.)

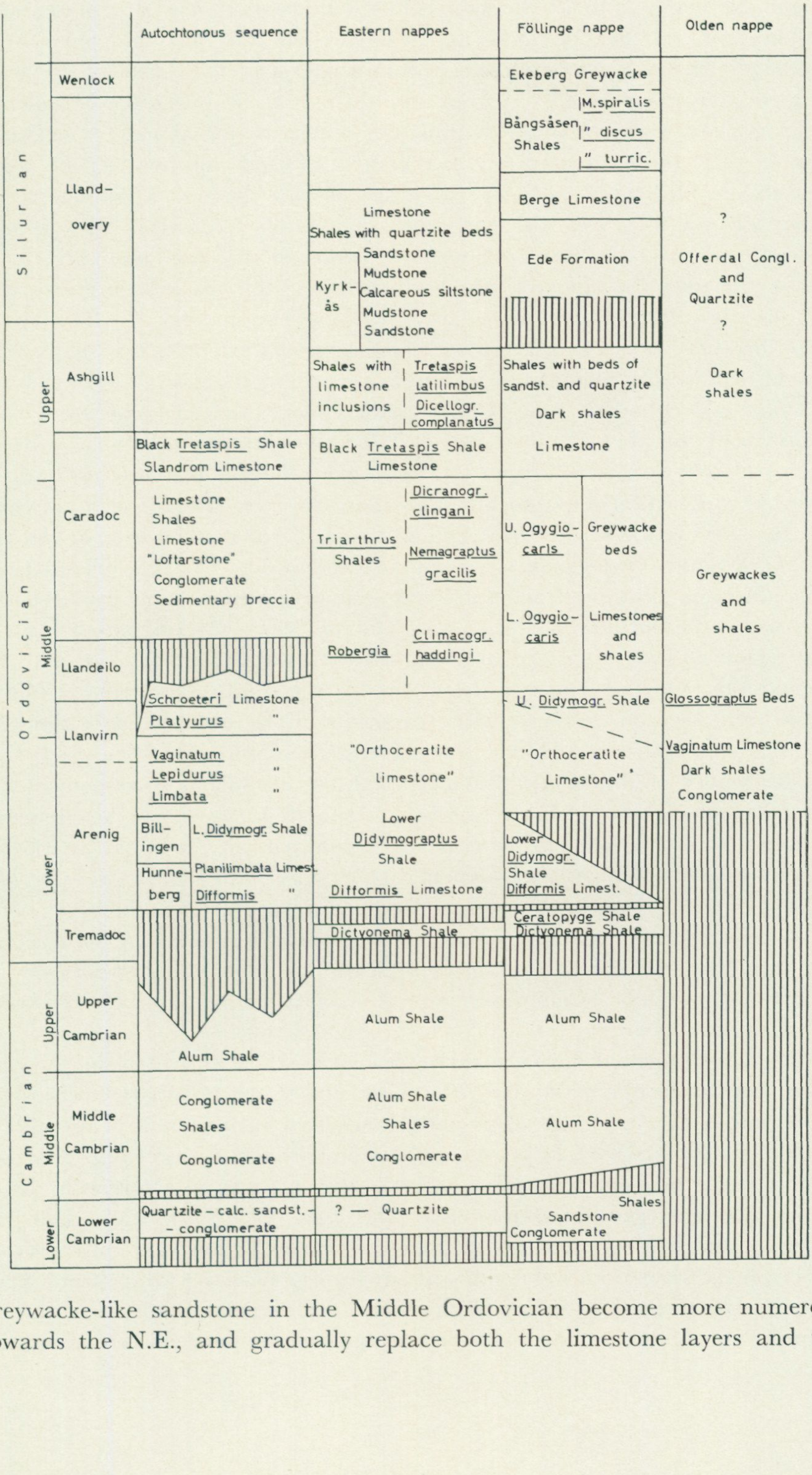
Lithological changes are especially obvious in certain stages of the sequence. The difference in the facies between two neighbouring tectonic units, either between the autochthonous and the easternmost part of the allochthonous or between two adjacent nappes, is striking along lines running in S.E.—N.W. direction. The above circumstance implies the possibility to arrive on the basis of the lithology at an indication to the effect that the correlatable strata belong to different tectonic units. In this way a guidance for the determination of a thrust limit is obtained within areas with few outcrops.

From the eastern to the western parts of the Jämtland area the Ordovician sequence exhibits a general change of facies, expressed by a diminishing content of limestones and an increasing wealth of shales and sandstones. This change is most marked in the Middle Ordovician.

In the autochthonous the Middle Ordovician exhibits local changes of facies about 20 km S.S.W. of Östersund in the so-called Lockne area. There it can be shown that the easily observable horizontal lithological changes within the same stratigraphic unit are conditioned by sedimentation in a relatively strongly undulating coastal region.

Within each of the eastern minor nappes changes of facies can be traced only along the front ends of the nappes, i.e. in S.W. — N.E. direction. Within the more extensive western nappes such changes in this direction seem to be evident. This applies at least to the Föllinge nappe within which the layers of

JÄMTLAND



greywacke-like sandstone in the Middle Ordovician become more numerous towards the N.E., and gradually replace both the limestone layers and the packets of shale with limestone lenses that outcrop, amongst others, upon the island Norderön in Lake Storsjön. Thus, for instance, several representatives of the fauna of the *Ogygiocaris* shale have recently been found 5 km W. of Föllinge (50 km N. of Norderön) within a packet of thick beds of greywacke with thin layers of shale, i.e. within the lithologic facies which has considerable thickness and great extension within the western major nappes. A noticeable change of facies towards an increased content of sand can, however, be proved within the Ordovician sequence also right across the broad Föllinge nappe, from S.E. towards N.W. Generally speaking Middle Ordovician beds of sandstone seem to occur within the overthrust region in close proximity to the eastern boundary of the area in the north, where they have been encountered within the allochthonous immediately west of Hammerdal. — The change described here evidently implies that the overthrusts extend across the boundaries of regions with identical facies within a stratigraphic unit.

Combined lithologic and faunistic observations and facts permit conclusions about the directions of transgressions and of transportation of sediments. The numerous conglomerates and biostratigraphic gaps within the autochthonous indicate sedimentation near the coast. Within the Lockne area even details in the shape of the coastline at the time of the Middle Ordovician *Ludibundus*-transgression can be reconstructed. The direction of transgression in early Cambrian times is indicated by the increase in the thickness of the Lower Cambrian strata towards the west within the region of Lake Storsjön (at Brunflo < 0.5 m, at Marby > 10 m). The composition and the relatively inconsiderable thickness of the basal sediments at Brunflo seem to point to their deposition in a shallow sea without an abundant transport of sediment from the eastern coastal zone. The strata from the last epoch of the Middle Cambrian exhibit an obvious correspondence to the development in the Early Cambrian. The thin *Exporrecta* conglomerate within the autochthonous thus finds its counterpart in the west (at Marby) in alum shale with limestone belonging to the zone with *Solenopleura brachymetopa* of the *Forchhammeri* stage. The *Oelandicus* stage, on the other hand, is of considerable thickness within the autochthonous and the easternmost minor nappes, but could not be established farther towards the west. The autochthonous Upper Cambrian contains conglomerates and great quantities of bituminous limestone.

The development during the early Ordovician does not differ in principle from that during the Cambrian. The large gap at the boundary towards the Cambrian, which in the autochthonous shows local variations, is in the allochthonous partly filled by *Dictyonema* shale and by *Ceratopyge* shale that has recently been discovered. No *Ceratopyge* limestone has been observed in Jämtland. The richly glauconitiferous beds with *Lycophoria difformis,* which are conglomeratic in the autochthonous, are of great extension, and thus indicate the commencement of a more extensive transgression in the Ordovician. Thev form the basal portion of the Hunneberg stage, which in western direction from the authochthonous becomes thicker and contains a successively increasing number of shaly beds. The contrary seems to be the case in the following Billingen stage which in the autochthonous and the minor nappes in the extreme east seems to consist of relatively thick *Phyllograptus* shales, but which is feebly represented already upon the island Andersön in Lake Storsjön, and thins out farther towards the west. Thus the *Oelandicus* stage of the Middle Cambrian and the Billingen stage of the Lower Ordovician seem to exhibit a parallel development with a transport of sedimentary material from an eastern continental area. In the western nappes in the vicinity of Lake Storsjön no fossils have been found that would permit the establishment of the occurrence of the above mentioned stages in the Lower Ordovician. According to recent investigations they are not included in the front portion of the Föllinge nappe upon the islands Utöarna in Lake Storsjön. At Laxsjö and along Vattudalen (at Vedjeön) *Difformis* limestone has, however, been observed in this nappe.

We have still only a limited knowledge about the uppermost Lower Ordovician and the lowermost Middle Ordovician which are mostly developed as "Orthoceratite limestone". This is explained in part by the fact that stratigraphic information based upon fossils can be obtained almost exclusively in the autochthonous, since determinable fossils can be extracted only in extremely rare cases from the strongly compressed limestone beds of the allochthonous. In the autochthonous, where they reach a total thickness of several tens of metres, these limestones bear a "Baltic" stamp. Within the Lockne area the different divisions of this limestone sequence lie upon the Precambrian, with residual breccia at the base. The sequence also contains local intraformational conglomeratic layers, amongst others on top of the *Platyurus* limestone. Also surfaces of discontinuity and mud cracks occur.

Within the easternmost nappes the thickness of the "Orthoceratite limestone" is sometimes still fairly large, e.g. in the parish of Lit north of Östersund. It decreases considerably in western direction, and in the Olden nappe constitutes an unimportant part (< 10 m) of the sequence. It is small also within the Föllinge nappe, especially in its northern and western parts (Laxsjö, Vedjeön). Finds of fossils *(Megistaspis, Pliomera)* have proved the occurrence of the *Vaginatum* limestone at Laxsjö.

Within the allochthonous a change of facies leading to an increase of shaly beds can be established in western direction, and can be shown to affect mainly the lower parts of the Middle Ordovician. It is recognizable in the *Schroeteri* division in the allochthonous of the eastern part of the Storsjö region, but more pronounced in the western nappes. The change cuts, however, across the tectonic main lines, since the lower portion of the Middle Ordovician is developed as shales with limestone lenses containing the graptolites of the Upper *Didymograptus* shale already at the eastern border of the allochthonous along Vattudalen, while obviously no similar development occurs within the region of Storsjön. To the west of Vattudalen the inclusions of limestone in the shale disappear, and within the Föllinge nappe (at Flykälen) sandy beds begin to occur. In the front of the Olden nappe at Laxviken the probably corresponding strata containing graptolites, amongst other *Glossograptus,* consist of sandy shales and quartzites. A transport of sedimentary material from western regions can thus be established in this part of the sequence. The corresponding strata in the autochthonous can still not be pointed out, but they probably comprise the *Schroeteri* limestone together with part of the underlying limestones. The lower boundary of this part cannot be indicated with any precision.

It is uncertain, whether or not the shale below the thin limestone division in the Olden nappe has been deposited contemporaneously with a lower portion of the eastern "Orthoceratite limestone". It is, however, not improbable, since the shale with *Isograptus gibberulus,* correlated with the *"Limbata"* limestone, could be proved to occur in southernmost Västerbotten in the continuation of the area of Jemtland.

With regard to the problems of changes of level and transport of material the rest of the Middle Ordovician of Jemtland supplies elucidating and interesting facts. The gap below the *Ludibundus* beds within the authochthonous is of locally varying magnitude, and shows, from the stratigraphical point of view, a general increase towards the east. The changes of level, indicated by it, were probably not of exclusively eustatic nature, since certain facts favour the assumption of epeirogenetic movements, a tilting of the eastern Archaean with the superimposed Cambrian and Lower Ordovician strata. These facts are gathered from a study of composition and position of the basal *Ludibundus* conglomerate. The latter contains pebbles not only from the eastern Precambrian and the Ordovician beds but also from Cambrian beds in places situated more than 10 km from the regions within the autochthonous that might be considered their source. The Cambrian beds that supplied the fragments have consequently been elevated, prior to the transgression, to an exposed position which allowed their disintegration and the transport in western direction over stratigraphically higher packets of strata. — Thereby also the region of origin of the clastic material in the Middle Ordovician beds of the autochthonous has been indicated.

Within the Lockne area the *Ludibundus* beds lie upon different portions of the Lower Ordovician, upon Cambrian, and directly upon weathered pre-Cambrian, where the latter had formed islands or ridges. In the foregoing we have hinted at the connections of the changes of facies with the sedimentation upon a broken topography of the bottom and the resulting currents. A richly fossiliferous reef-like *Ludibundus* limestone of local distribution occurs mostly immediately on top of the weathered Precambrian, and has probably been formed in connection with a locally vivid circulation of the water. The contemporaneous beds rich in clayey shales ought to have been deposited in more quiet water and less exposed places.

Within the allochthonous no gap has so far been established at the base of the *Ludibundus* beds or their corresponding strata. In spite of the fact that the Middle Ordovician beds of the easternmost minor nappe in the region of Skute are situated only some kilometres west of occurrences of thick *Ludibundus* conglomerate in the Lockne area this conglomerate or correlatable beds with clastic material are missing in this nappe. This fact supplies an indication about the length of the overthrust, since we have from the autochthonous examples of the occurrence of conglomerate with pebbles of Precambrian rocks which had been transported over 10 km, and within Åsarna over a considerably greater distance, from their eastern occurrence *in situ*.

In the western nappes the gap is filled by graptolitiferous beds. All of them belong to, or are contemporaneous with the Lower *Ogygiocaris* shale, a formation which is best exposed upon Andersön and in the front of the Föllinge nappe upon Norderön, and which contains numerous inclusions of dark limestone with both graptolites and a shelly fauna. A similar mixed faunistic facies characterizes also the limestone lenses in the Upper *Ogygiocaris* shale which upon the mentioned islands are separated from the lower division by limestone beds with *Telephina biseriata*. — Within the allochthonous immediately east of Andersön, i.e. upon Frösön and its northern and southern vicinity, the corresponding portions of the Middle Ordovician consist mainly of graptolitic shales with intercalations of limestone containing species of *Triarthrus* that are missing in the *Ogygiocaris* shales. The species of *Ogygiocaris* and *Telephina* which are abundant in the latter are on the other hand not represented or extremely rare in these *Triarthrus* shales. These are without sandy intercalations, while thin (< 15 cm) finely sandy, occasionally quartzitic layers are found in the Upper *Ogygiocaris* shales with *Nemagraptus gracilis* on Andersön. Number and thickness of these sandstone layers increase towards the west, and already upon Norderön up to 1 m thick beds of a relatively coarse greywacke-like sandstone are found in the Upper *Ogygiocaris* shale. In the western parts of the Föllinge nappe and in the Olden nappe the Middle Ordovician consists mainly of such, occasionally thick beds of greywacke with thin, often sandy shaly layers. Fragments of Precambrian rocks of western origin are common in the greywacke. In the Olden nappe the corresponding sequence of strata exhibits structures and thicknesses pointing to deposition in a geosyncline.

The above account thus shows that the material for the Middle Ordovician sequence of the allochthonous has been supplied mainly by western continental masses, and that the transport of sand from these regions reached farthest to the east during the time of *Nemagr. gracilis* or contemporaneously with the sedimentation of the lower *Ludibundus* beds in the autochthonous.

According to our present knowledge the Upper Ordovician exhibits a noteworthy development and change in east-western direction within the *Dalmanitina* stage only. The *Tretaspis* beds consist mainly of shales mostly with limestone lenses. However, a limestone formation, exhibiting a somewhat varying development in western direction, seems always to form the base of the sequence, at least as far as the Föllinge nappe. Within the autochthonous, where the top of the available sequence is formed by the Black *Tretaspis* shale (zone of *Climacograptus styloideus*), the limestone is represented by a "masur" limestone, the Slandrom limestone. A similar dark calcilutite, rich in bituminous matter, is found in the easternmost allochthonous, where the *Tretaspis* beds are best visible in the Skute nappe. Along the railway line west of Skute the *Tretaspis* beds show a development which greatly resembles that in the normal facies of the Siljan region, viz. from bottom to top: Slandrom limestone, black shale, greyish mudstone with layers and lenses of dark limestone, brownish, partly greenish grey *Latilimbus* mudstone with scattered lenses of limestone, and topmost a finely sandy, calcareous shale that might correspond to the so-called *Staurocephalus* shale of more southern regions. Within the allochthonous the changes in western direction seem to be the following: the compact Slandrom limestone becomes thin-bedded with interdigitating shaly beds, the limestone beds within the middle part disappear, and their place is taken by shale, and beds of sandstone and also of quartzite appear in the upper part of the sequence. The latter beds occur within the Föllinge nappe in Offerdal, and thus indicate a transport of sediment from the west. In this nappe the uppermost Ordovician strata consist of dark mudstone, formerly called "Brachiopod shale", which amongst others contains *Tretaspis latilimbus* and *Dalmanitina mucronata,* and probably corresponds to the *Staurocephalus* shale.

Only within the eastern allochthonous, viz. at Rannåsen in Östersund, could the occurrence of the *Dalmanitina* stage be established by finds of fossils. Here a rich fauna of trilobites (*Dalm. mucronata, Brongniartella,* illaenids), cephalopods, lamellibranchs, and brachiopods is found in a black mudstone that is underlain by a thick series of orthoquartzite, sandy shales, and shales interbedded with thin layers of quartzite. Immediately above the mudstone follows a brownish-weathering bed of hard calcareous siltstone. The quartzite beds contain conglomerates with well rounded pebbles of the size of a hazelnut consisting of quartzite and vein quartz. In some places they contain small inclusions of black shales, and exhibit surfaces with ripple-marks and mud cracks.

Above the siltstone follows again black mudstone with graptolites *(Climacogr.* aff. *normalis)* and, on top of it, a fairly thick series of quartzitic sandstone with scattered intercalations of dark shale. According to the delimitation which has to be adopted in our country between Ordovician and Silurian the beds above the siltstone belong to the Silurian. The sequence of strata at Rannåsen forms a group, and this group has been given the name Kyrkås from the parish in which it covers a wide area. Consequently the boundary between the Ordovician and Silurian system lies within this group.

It has been established that at least Lower Kyrkås is found in the eastern minor nappes as far as the Föllinge nappe, that its thickness and extension is considerable in the eastern nappes, and that the clastic material has arrived from an eastern continental mass. The Skute nappe is without the thick sandstone sequence that occurs in Lower Kyrkås within the mentioned region.

Rannåsen is the only place within the allochthonous, where the boundary between Ordovician and Silurian could be established so far. Within the Skute nappe the beds between the *Tretaspis* division in the railway cuttings west of Skute and the Silurian limestone at Gärde could admittedly be studied only in part, but seem to consist of the following beds, in ascending order: calcareous sandstone of moderate thickness, brachiopod-bearing shales, and on top a fairly thin division of dark quartzite with layers of shale. Between the latter, which have been observed close to an outcrop of the brachiopod-bearing shales, and the partly pure limestone at Gärde exist transitional beds with upwardly increasing content of lime. It is possible that here the boundary between Ordovician and Silurian is situated just below the quartzitic division.

In the Föllinge nappe the beds are in several places well visible between the uppermost *Tretaspis* stage, i.e. the shale that has been correlated with the *Staurocephalus* shale, and the Silurian Berge limestone, previously called *Pentamerus* limestone (type locality at Berge in the parish of Offerdal). These beds consist at the base of an unfossiliferous bed of quartzite, about 4 m thick, and above it a succession of beds grading into the limestone. The sequence contains richly fossiliferous calcareous sandstone with *Phacops* cf. *elliptifrons* after which it has since long been called the *Phacops* quartzite, and in addition layers of quartzite and thin layers of shale. The fauna in which tabulate corals and brachiopods are particularly abundant, is Silurian and comparable to a part of the division 6 in Norway. Also the underlying unfossiliferous bed of quartzite is usually referred to the "*Phacops* quartzite". A stratigraphic gap seems to exist between the *Tretaspis* division and this quartzite bed. Also the sharp lithologic boundary between them points in this direction. The name Ede formation (or quartzite) is proposed here for the quartzite bed and its overlying "Phacops quartzite" (type locality at Ede, 1 km S.E. of Offerdal church).

The Silurian strata younger than the Berge limestone occur in the Föllinge nappe only. For this reason a review of these strata becomes mainly stratigraphic.

The Berge limestone has its widest extent in the Föllinge nappe. In the eastern allochthonous it occurs also within the Skute nappe, where its lower part protrudes in front of the overlying Bjerme nappe. In the Föllinge nappe the limestone has a thickness of about 75 m, and consists of both reef limestone and bedded limestone. The limestone formation belongs to the Middle and the lowermost Upper Llandovery, since it is immediately overlain by shales belonging to the zone of *Monograptus turriculatus,* more exactly its lower subzone with *Rastrites linnaei.* Together with the zone of *Monograptus discus* these shales form a lower division of black graptolitic shales containing large lenses of limestone and also beds and thin layers of solidified volcanic ashes, "metabentonite". The thickest of them is situated at the base of the shales, and is ca. 0.5 m thick.

On top of these graptolitic shales follows a division of dark shales of varying composition. It is characterized by its relatively high content of thin layers of limestone and finely sandy intercalations. It contains portions of black shales, but most of the shales are dark or, occasionally, light grey. The finely sandy, sometimes calcareous shales which enter into the upper portion of the division contain thin layers of quartzite and thin lenses of dark dense limestone. In this upper part only *Monogr. priodon* has been encountered so far, but the lower portion, which is in part visible in a road cutting at Bångåsen in Offerdal, contains a rich fauna of graptolites with *Retiolites,* representing the uppermost part of the *Discus* zone or the zone of *Monogr. spiralis.*

On top of these divisions, the Bångåsen shales, we find the youngest Silurian beds that have been observed so far in Jämtland. They can be seen in a road cutting at Ekeberg, and belong to the same syncline as the shales at Bångåsen. They consist of greywacke-like sandstone with layers of shale. The sandstone beds are in part fairly thick, up to 2 m. In an intraformational conglomerate with fragments of dark shale *Favosites gotlandicus* forma *forbesi* has been found. The find of this fossil establishes the Silurian age of this formation, the Ekeberg greywacke, which exhibits great lithological similarity with the Middle Ordovician sequences of strata of the western nappes, and which obviously likewise has obtained its material from western continental masses.

By way of summary we can point out that the eastern Cambro-Silurian of Jämtland consists of shallow-water deposits, laid down in a wide trough, a miogeosyncline, which had probably become deeper in Middle Ordovician times. It extended along the Caledonian eugeosyncline with its wealth of volcanites, but was separated from the latter by land areas that supplied the material for the main part of the clastic sediments. This is evident from the preponderately western extension of these sediments and from their thickness which is great in the west with a decrease in eastern direction. In comparison the quantities of material that have been brought from the east, and deposited in the eastern coastal portions of the basin appear to be small. Here, however, the effects of the changes of level are obvious in the succession of strata.

The Mesozoic

By

F. Brotzen

Introduction

Mesozoic sediments have long been known from southern Sweden. As early as 1719 Swedenborg described coal-bearing beds from Hälsingborg, and Cretaceous fossils were described by Bromell in 1730 (according to Regnéll, 1949). In the nineteenth century knowledge of the Mesozoic increased and during the last 20 years the entire section has been recorded by drilling and detailed studies of new outcrops. The results of the latter show that Triassic, Jurassic and Cretaceous sediments occur in the country. All these systems show large gaps and in general the southern part of Sweden was a typical coast region, where the shoreline crossed Scania and fluctuated in position. This explains the fact that the sections are incomplete, and vary in thickness and facies in both horizontal and vertical directions. Tectonic movements formed tilted fault blocks at different periods and have shaped a geological picture which can seldom be interpreted easily. A few examples will demonstrate such tectonic events. In the northwestern part of the province of Scania on the top of an extremely thick Silurian follow about 300 m of the Triassic, a complete section of Rhaetic-Liassic and a marine Liassic on the top. A post-Cretaceous elevation of this region resulted in an erosion of large parts of the Cretaceous sediments. To the south-west the Rhaetic-Liassic of Hälsingborg is lifted and slightly overthrust on a Cretaceous unit and between both blocks the deeper part of the section is raised and forms a typical flexure. In that region the most complete section seems to be preserved except for the Triassic, but even there the section is not known in all its details. The Triassic is incomplete and its lower and middle parts seem to be lacking. The Rhaetic and Liassic are here more complete than in other places in Sweden. Even the Cretaceous reached a maximum of thickness in one section of at least 1,700 m. The thickness of the lower part of the section below the Upper Cretaceous can be estimated to about 1,300 m. The same part of the section in the region 50 km southwards at Svedala is reduced to only 140 m. In a SW direction from Svedala to Höllviken in the southwestern corner of the province of Scania, the Lower Cretaceous changed its character both as regards facies and thickness. The Lias is here lacking, but the Triassic is most complete and shows the lower, middle and upper divisions. It reaches a thickness of about 800 m.

The mode of occurrence of the Mesozoic sediments is not known. The tectonic movements have resulted in erosion and transportation of previously deposited sediments. So in one place the sediments can reach a maximum thickness, and at another place nearby all evidence of the same period is lacking. The change of facies in sediments and preserved isolated occurrences far from the main preserved sediment bodies of a certain period, indicate often the original extension of a formation. Based on such observations it seems that sediments of

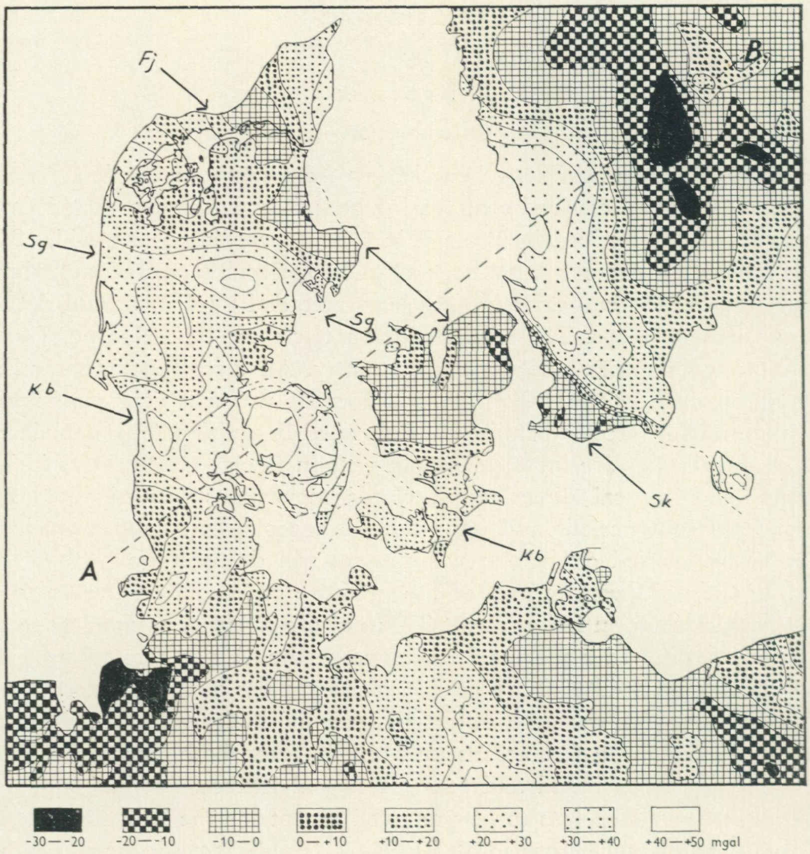


Fig. 1. Gravity anomalies in South-western Scandinavia
Fj — Sk = Jutland — Scania syncline; Sg — Sg = Jutland — Sealand axis; Kb — Kb = Funen axis;

the Triassic extended out of the hitherto known region northeastwards into the province of Halland, and into the southern part of the province of Småland, but have never extended to the east or southeast into the eastern part of Scania or the province of Blekinge.

Isolated Rhaetic and Liassic occurrences give the impression that even these sediments were present over a larger area before the Lower Cretaceous, than is the case to-day. Especially the facies of the marine part of the middle and upper Liassic demonstrates its former existence in such regions in southern and middle Scania, where to-day no remains of these formations are preserved. The Upper Cretaceous is well known from outcrops, quarries and drillings in Scania, southern Halland, and western Blekinge. But its upper part is a facies without terrestrial material. Few isolated fossils and flints from the Upper Cretaceous are known from Gotland and the northern part of Småland.

These rocks and fossils in the Quaternary cannot be transported from south to north. Together with the sinking tendency of the whole country, the several hundred meter thick chalky facies in the south makes it possible that Upper Cretaceous sediments occurred originally over the whole of southern Sweden up to Gothenburg in the west and Gotland in the east. During the uppermost period of the Cretaceous the sea regressed and its sediments were limited to the southern part of Scania, but originally they occurred widely over the sedimentary area preserved to-day. A great destruction of Mesozoic sediments followed movements of the block units and the elevation of the entire Scanian shield during the Tertiary. Finally, large parts of the Mesozoic were transported during the Quaternary from their original locations and their extension at the present time diminished.

The Triassic

In the middle of the nineteenth century Angelin described the coal-bearing formations, sandstones, and red clay layers in northwestern Scania and placed them in the Upper Triassic and lower part of the Jurassic. All reddish and brown sandstones, conglomerates and clays at the bottom of the sections were called the Kågerödformation, and the dark layers on top the Rhaetic-Liassic group. About 20 years ago, Swedish geologists succeeded in finding the boundary between the Triassic and Jurassic, based on changes of composition of the fossil flora as the whole Triassic sequence was available for study in deep holes in S.W. Scania. Thereby it has become clear, that the southern part of Sweden belongs to the large syncline of the Triassic, which extends through northern Poland, northern Germany and into the Netherlands, Belgium and even reached eastern England. This syncline has been filled up by sand and clay from the surrounding highlands, weathered under arid climatic conditions and therefore coloured brownish red, reddish and greenish. In Scania the sedimentation reaches nearly 800 m in thickness. The terrestrial sedimentation i.e. the sedimentation that took place above sea level, has been interrupted for a short time in the middle part of the Triassic by marine invasions represented by marls and limestones containing a middle Triassic fauna and flora. Farther southwards in the direction of Denmark and Germany, the sea transgressed during the middle-Triassic, well known from its fossil-rich limestone, "the Muschelkalk", which gave its name to this part of the Triassic. The red and green sandstones in the lower part of the Triassic below the "Muschelkalk" are known as "Buntsandstein" while the coloured sediments above the "Muschelkalk" represent the "Keuper" or Upper Triassic. The Rhaetic in Sweden is represented by layers of grey clays, sandy shales and coal.

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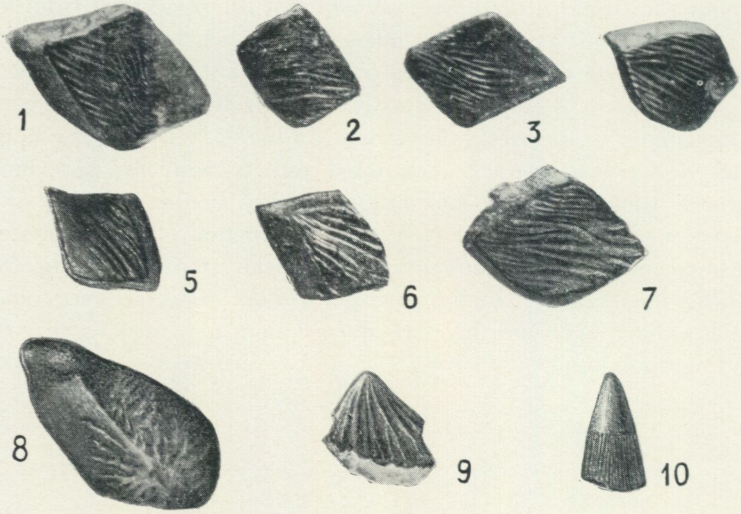


Fig. 2. Fish remains from the Middle Triassic. Test well at Höllviken, 1805—1825 m's depth.

The Triassic profile known to date is given in the following table:

Rhaetic		6) Modiola layers
		5) Coal-bed A with clay (lepidopteris flora)
		4) Sandstones and sandy shales (zones with stegocephalia)
		3) Coal-bed B
		2) Clay with megaspora
		1) »Vallåkra»-clay
Keuper	upper	2) »Kågeröd»-clay
		1) » arkose and sandstones
	lower	3) Sandstones impregnated with $CaCO_3$
		2) Dolomitic breccia
		1) Lower sandstones
Muschelkalk		f) Upper zone with fossils
		e) Red sediment
		d) Lower zone with fossils
		c) Shales
		b) Zones with Characees
		a) Lower zone of sandstones
Buntsandstein		2) Coloured, mostly reddish sandstones and shales
		1) Basal conglomerate with large, well rounded pebbles

The Jurassic

The Jurassic occurs in the northwestern part as well as in the middle part (in the neighbourhood of Eslöv, Hässleholm and Höör) of Scania. In the area north of Ystad the Jurassic is exposed near Sjöbo. It seems that Jurassic sediments are not present in S.W. Scania. The most complete sequences are observed in N.W. Scania, where the Liassic is very thick. But there the Middle or Upper Jurassic seems to be lacking. North of Ystad in the outcrops of the Fyledalen the possibility exists that Upper Jurassic formations are preserved. The main part of our Jurassic sediments belongs to its lower part, the Lias. The rocks here are sandstones and ferruginous sandstones, but even layers of clay and shales are common. Intercalation of layers with plant fossils and molluscs from the sea and brackish water occurs, and here and there ammonites and belemnites have been found. By these fossils it is possible to compare our Liassic sediments with those from abroad.

In the Fyledalen section on the top of ferruginous sandstones without fossils occur sandstones with plant-remains, which seem to indicate a middle or more possibly an upper Jurassic (Dogger or Malm) age. Studies in recent years on Jurassic ammonites (Reyment 1959) resulted in a detailed zonation of the Lias and possibly in the area of Ängelholm (N.W. Scania) Jurassic layers younger than Lias are present. The thickness of the Jurassic varies but it may probably reach at least 300 meters, and often much more.

The stratigraphic division of our Jurassic layers is probably as follows:

<table>
<tr><th colspan="2"></th><th colspan="2">N. W. Scania</th><th>Central Scania</th><th>Southern Scania</th></tr>
<tr><td colspan="2">Malm</td><td colspan="2">lacking</td><td rowspan="4">lacking</td><td rowspan="2">possibly sandstones with plant remains</td></tr>
<tr><td colspan="2">Dogger</td><td colspan="2">possibly uppermost part of Vilhelmsfält section</td></tr>
<tr><td rowspan="7">Liassic</td><td>Toarcian</td><td colspan="2">upper part of Vilhelmsfält section with Dactylioceras tenuicostatum</td><td rowspan="2">possibly iron-shot sandstones without fossils</td></tr>
<tr><td rowspan="2">Pliensbachian</td><td colspan="2">lower part of Vilhelmsfält section</td></tr>
<tr><td colspan="2">upper part of Katslösa section with Bolivina rhumbleri</td><td>possibly boulders at Brandberga</td><td>section with Uptonia jamesoni</td></tr>
<tr><td rowspan="2">Sinemurian</td><td colspan="2">middle part of Katslösa section with Nodosaria issleri</td><td rowspan="2">lacking</td><td>section with Oxynoticeras sp.</td></tr>
<tr><td colspan="2">Döshult formation with ammonites of the »arietes» group</td><td>clay layers possibly belonging to Lias a</td></tr>
<tr><td rowspan="2">Hettangian</td><td>upper</td><td rowspan="2">Hälsingborg-formation</td><td>Höör sandstone</td><td>Cardinia folini zone</td></tr>
<tr><td>lower</td><td>Höör arkose</td><td>Thaumatopteris zone</td></tr>
</table>

The Cretaceous

Besides the occurrence of fire- and coal-bearing clays within the Rhaetic and Liassic sediments, the Cretaceous is economically the most important and most extensive part of the Swedish Mesozoic. Cretaceous layers occupy four synclines in southern Sweden, namely in the regions of Båstad, Kristianstad, Ystad-Vomb and Malmö. In general the Cretaceous is covered with loose Quaternary layers and only a few localities show outcrops, but in some limestone and sandstone quarries the Cretaceous is well exposed. A more complete knowledge of the Cretaceous is obtained from boreholes both deep and shallow for water supply, and especially from deep wells for salt and oil prospecting in SW Scania which reached depths of 2,300 m. The Lower Cretaceous is exposed only at one locality, at Fyledalen near Eriksdal north of Ystad, where glass sand and its underlying fire clay is used. In the quarry a section can be observed through the upper group of so-called green clays, the glass sand, sand with clayish intercalations and plant remains, clayish coal beds with fireclay. The Lower Cretaceous age of the coal layers and clays at the base of this section is not yet established. According to a previous research on the plant remains in the coal- and clay-layers there is a case for placing them in the lowermost part of Lower Cretaceous. In an unpublished report of Seth Stenestrӧm the plant remains are studied and his general result is that the plant bearing-layers can be dated as Upper Jurassic. The age of the glass sand is questionable, but it seems that it should belong to the lowermost Cretaceous. The clay layers above the glass sand contain a rich fauna of molluscs and ostracods, which establish them as Valanginian. North of Landskrona these clay layers occur in a drill-hole (here the fauna is a little more rich than in Fyledalen), characterized by Aucella kayserlingi. It seems that these clays may have had quite a wide extension in Scania, as fossil-bearing boulders found at different places in Scania bear witness of their former existence.

In both Fyledalen and the Landskrona region higher parts of the Lower Cretaceous are lacking and the Upper Cretaceous follows on the clays. In the deep-wells in the region of Höllviken in SW Scania a more complete sequence of Lower Cretaceous has been found. Here occurs a sequence of some hundreds of meters of clays and sandstones above the Rhaetic. These sandstones and clays with tiny coal seams constitute a geological unit, in which plant remains have been determined as Sphenolepidium sternbergianum, a guide-fossil for the Lower Cretaceous. It is difficult to divide terrestrial plant-bearing layers of the Lower Cretaceous into zones. These beds are referred to the Wealden and can be partly correlated with the Valanginian clays and glass sand. Above the Wealden, marine clay shales were deposited with a fauna of ammonites ranged into the Barremian and Aptian. A conglomerate above the shales shows that an interruption in the sedimentation has taken place. Above the conglomerate, glauconitic sand is layered with very characteristic fossils assigning the greensand to the uppermost subdivision of the Lower Cretaceous, the Albian. Such greensand occurs in the region of Svedala, where it is observed in drillholes, and in the vicinity of Trelleborg. Of the same age is a conglomerate rich in fossils occurring in southern Halland, near Tormarp.

While the Lower Cretaceous in Sweden is characterized by many gaps and incomplete sedimentation the Upper Cretaceous is well developed in Scania, southern Halland and Blekinge with the stages: Danian, Maastrichtian, Campanian, Santonian, Emscherian, Turonian and Cenomanian.

In earlier times the lower part of the Upper Cretaceous was unknown and its upper part was divided into:

Chalk	with	Belemnitella	mucronata
»	»	Actinocamax	mammillatus
»	»	»	granulatus
»	»	»	westphalicus

In general these belemnite-zones correspond with the contemporary international divisions from the Emscherian to the Maastrichtian. The sedimentary sequence is marine with light-coloured limestones and chalk, prevailing over marls, sandstones and clays.

In a syncline more or less parallel to the Romeleåsen the Upper Cretaceous reaches its maximum thickness of 1,450 m. During the Cenomanian and Turonian marine transgressions and regressions are documented by conglomerates. From the Båstad region an isolated occurrence of Cenomanian greensand is known, which is only a few meters thick. This occurrence indicates that the lower Upper Cretaceous transgressions have reached farther NE than was previously thought.

During the Santonian the sea proceeded so far NE that nearly 100 m sediments could be deposited in the Kristianstad region. Sediments of the same division attain in SW Scania a thickness of 350—400 m. In the Kristianstad region this stage is represented by sand and sandstones, deposited nearer the shore than the limestone facies of the same age in SW Scania. In the beginning of the Lower Campanian limestones and marls occur in the Båstad—Kristianstad—Ystad and Malmö region. Towards the end of this period the facies changed in all regions to one dominated by sandy and sandy marly sediments. Flints are common in hard limestones. Shell fragment limestones rich in fossils characterize the Lower Campanian in the Kristianstad region. The Upper Campanian can rest on the preceding stage but at some places it is sedimented on older parts of the Lower Cretaceous or Jurassic, or lies directly on the Archean. These phenomena can only be understood if intense tectonic movements existed before the Campanian, partly during the Lower Campanian, and these are well demonstrated by interbedded conglomerates. Together with the tectonic movements the sea must have regressed and transgressed several times in our country. In nearly all observed sections these movements are documented from the Lower Campanian into the lower part of the Maastrichtian where breaks, erosion and corrosion phenomena and conglomerates occur. In the conglomerates the size of the pebbles increased towards the NE, and decreased towards the SW. After this period of tectonic movements the sea transgressed steadily to the NE reaching in Middle and Upper Maastrichtian its maximum of extent. White chalk with and without fossils, i.e. pure limestones, from this time show that the shore must have been far from Southern Sweden. Isolated flints, microfossils and silicified larger fossils are known from Småland and Gotland, and also some morphological facts demonstrate the existence of Maastrichtian sediments far into Middle Sweden.

Some years ago it was possible to study the Upper Cretaceous in many quarries, but now only a few of these are in use. One near Malmö is being worked for white chalk. The chalk belongs to the upper part of the Maastrichtian — the Stevnsian. It is an ice-transported flat and irregular lens, imbedded in boulder clay. The largest quarry for limestones still in use is situated at Limhamn, south of Malmö, where the main part of the section belongs to the uppermost stage of the Cretaceous, the Danian. In this quarry the Danian is exposed with its three substages: the Lower, the Middle and the Upper Danian, and the underlying chalk belonging to the Stevnsian. The Danian occurs below the Quaternary in the southwestern corner of Scania in the region between Landskrona, Malmö and Ystad. On the southern shoreline of Scania, it is exposed in some outcrops. During the last 60 years the stratigraphical range of the Danian has been lively discussed. The problem was whether the Danian, by its facies and fauna, should be placed in the highest Cretaceous or lowest Tertiary. It seems that this is only a question of convention. In Sweden the Danian is ranged as the youngest stage of the Cretaceous according to the original definition of Desor.

Fossils of the Swedish Mesozoic

From the Triassic, except the Rhaetic, only a few fossils are known from drill cores. None of the plant remains indicate for certain a stage of the Triassic. Characees and the remains of higher plants belong to such genera and species which are only known from the Triassic. Some ostracods are not enough studied to be of value for the stratigraphy; but fish remains especially scales and teeth allow the middle part of the Swedish Triassic to be determined and a correlation with the Muschelkalk or Lowermost Keuper established. Rhaetic fossils are common including plants, molluscs and vertebrates. From the Rhaetic of NW Scania are known stegocephalia, large fishes and a few ostracods and foraminifera. Some of the placoid fishes reach a length of more than one metre and are well preserved. From the continental sediments of the Rhaetic and Jurassic the flora is well known and described. It includes, among others, cycads, benetids, gingkophytes and conifers. Guide fossils are, for the Rhaetic, Lepidopteris and for the Liassic, Thaumatopteris species. Molluscs from the lower parts of the Rhaetic-Liassic are badly preserved and a modern description is lacking. From the higher marine part of the Liassic section researches from recent years have produced descriptions of a large mollusc fauna. A paper on the ammonites especially is very valuable. In marine layers of the Rhaetic and Jurassic occur foraminifera, more or less abundantly and these can be used to determine such zones, which cannot be determined by ammonites.

Fossils in the very incomplete sections of the Lower Cretaceous have only been provisionally studied. A few ammonites, molluscs and plant remains demonstrate the presence of a rich flora and fauna, which is well enough characterized to allow stratigraphical correlations. The Upper Cretaceous fauna is known from classical papers to be rich in species and local types. One of the famous localities with numerous fossils, belemnites, molluscs, brachiopods and others is situated on the island of Ivö. There the fauna shows an endemic enlargement of the size of the molluscs. Even a large ammonite Puzosia stobaei occurs there. Belemnites are abundant, but are also common at other places in the region of Kristianstad. Actinocamax verus and Act. westphalicus occur at Ringelslätt. Act. mammillatus of all sizes can even today be collected in hundreds of specimens at Ivö, Ignaberga, Maltesholm and other places; Belemnitella senior is typical for the quarry at Hanaskog and specimens corresponding to the original description of Belemnella lanceolata can be found at Balsvik.

A zonation of the Danian is established on the occurrence of large spines of Cidaris (Tylocidaris). In the different zones the species vary and have been used for more than 40 years as guide fossils in Denmark. Such spines are very common in the quarry at Limhamn and allow a stratification of the sequence. From our Danian no ammonites or belemnites are known. The last occur in Sweden in the highest chalk below the Danian at Limhamn. Vertebrates are rare in all Cretaceous layers in Sweden. A few remains of Mosasaurus and of fishes are known. From the Danian well preserved fishes, bones of birds and crocodiles are described.

Tectonics

Some years ago the opinion prevailed that the Mesozoic was preserved in isolated basins of the Archean. Voigt in 1929 gave a new picture of the tectonics of southern Sweden as one of a mosaic of tilted blocks. This view must even today be accepted in general, but drillings through the Mesozoic have resulted in many new details. It seems that the Scanian shield as a unit sank down and was connected with the Middle European sedimentary basin. The increase of the Paleozoic in southern Sweden shows that this tendency of moving was already marked in the Paleozoic. The old boundary of the Scanian shield is marked on the gravity map of Southwestern Scandinavia (see Fig. 1). A gravity minimum of — 20 mgl is observed in Småland. In a SW direction the block unit is lifted up and its crestline orientated NW—SE can be followed from the northern part of Jutland to the middle part of Scania and into the island of Bornholm to the SE. This large unit is crushed, its eastern boundary being overthrust to the NE, and its western side overthrust to the SW. The next unit is a deep-lying block which extends from the Limfjord region in the NW, over the NW corner of Sealand, and the SW corner of Scania to the SW shore of Bornholm. Towards the continent the main tectonic crestlines change their directions in a fan-like fashion. A block unit occurs in the middle of Jutland and the northwestern corner of Funen with the main direction WNW—ESE, and a depression south of it. Finally a block with a nearly W—E direction exists in the southern part of Jutland. In the depressions the complete Mesozoic may be preserved including even the Permian in the southwest. By tilting movements sedimentation increased on one side of the blocks and diminished on the other side.

The general tectonic tendency seems to be that a gravity maximum on the line northern Jutland—Scania—Bornholm represents a hinge between the Scandic and the Saxonian blocks, with movements already in progress in the Cambro-Silurian. During the Mesozoic the hinge was broken into small units which have suffered their own irregular movements causing transgressions and regressions of the sea in different regions. By these tilting movements the thickness of the Triassic in the SW of Scania increased, likewise the Jurassic in a direction WNW—ESE in northwestern and southern Scania crossing the large flexure of the Romeleåsen at an angle of 30 degrees. The tilting movements during the Jurassic resulted in the lack of Triassic and Jurassic in the centre and south of the Malmö region. The last intensive tectonic movement has formed the high ridges of Archean rocks of Hallandsås, Söderås, Romeleås, Linderås, Nävlingeås and the Cretaceous synclines of Malmö, Vomb, Kristianstad and Båstad. They came into existence in the Lower Tertiary.

The Economic Use of Mesozoic Rocks

Building stones were quarried from the Mesozoic as early as the Middle Ages for ecclesiastical and secular buildings. Some Jurassic sandstones and hard Cretaceous limestones were used for the larger buildings. Even the burning of Cretaceous limestones for lime goes far back into historical times and is still in progress today. Marls and limestones were widely used for agriculture, but during the last ten years many small quarries have closed down. Quarrying of limestones mainly for cement manufacture is today limited to Limhamn, south of Malmö, where nearly 1 million tons of limestone per year are produced.

Coal, together with fire clays from the Rhaetic-Liassic in NW of Scania, are mined by the Höganäs Company. The coal can be used only near the mines and its quality is not very high. North of Ystad, coal and fire clay are taken from layers belonging to the Upper Jurassic or Lower Cretaceous. At this locality named Fyledalen large quantities of Lower Cretaceous glass sand serve industrial purposes. This glass sand contains enough kaolin for practical separation and it is possible that kaolin occurring below some Upper Cretaceous rocks in the Kristianstad region may belong to the Mesozoic. This kaolin is quarried on a large scale.

Iron shot sandstones and ooliths of the Upper Lias occur widely, and also in the flexure north of Ystad and along the western front of the Romeleåsen uplift. The content of iron may be more than 30 % but averages about 27—28 %. They have not yet been exploited. Deep drillings in SW Scania located brines in the lower part of the Mesozoic containing up to 20 % salt, mainly two thirds NaCl and one third $CaCl_2$ besides potash and bromine. The extraction of these salts could be economic, but they are not used at present.

The Tertiary

By

F. Brotzen

Introduction

Tertiary sediments are only known from a few localities in Sweden, but it is necessary to recall that during the Tertiary the morphology of the country received its present-day character. The widely spread remains of the Tertiary which occur here and there in the country allow such an important conclusion to be drawn.

During the last part of the Cretaceous the sea possibly regressed from Sweden for a short time, so that the country at the end of the Mesozoic was elevated above sea-level. The facies of the uppermost Cretaceous does not indicate a sedimentation near a coast, but there exists a characteristic gap between the Cretaceous and the Tertiary. The surface of the Cretaceous below the Tertiary shows erosion phenomena and the Tertiary begins with thick conglomerate beds. The transgression of the sea during the lowermost Tertiary is well documented and even Eocene sediments are known in Sweden. On the other hand vertical movement becomes intensive at the end of the Eocene together with a regression of the sea. The tectonic movements initiated the destruction of such Mesozoic sediments as were most exposed. At the same time widely spread volcanic activity occurred at different places of the whole country.

Oligocene remains are unknown to date and those of the Upper Tertiary are very scanty. In the south and southwest, in northern Germany and Denmark the younger Tertiary is so well known with its thick sediments that we can deduce the geological history during this period in Sweden. Deep weathering of all high land, formation of deep valleys and preparation of existing river beds, are the main features of the Upper Tertiary. The few plant remains bear witness of a tropical humid climate during this period. The Quaternary ice masses destroyed the loose and unconsolidated sediments of the Tertiary, which originally existed as peat and lignite sediments. In general, occurrences of Tertiary sediments are reported at long intervals and even during recent years new localities have been found. Hitherto a systematic search for Tertiary remains in Sweden has not been carried out but it can be rewarding to pursue. The deep fissures of the Archean ground may contain Tertiary remains and during the last years such fissures have been exposed by active building in connection with power stations and other projects. They have not however, been systematically studied. Even a systematic research into boulder clays may lead to the discovery of Tertiary fossils displaced from their original localities. Replaced Tertiary diatomea and silicoflagellata were found by A. Cleve Euler and Å. Berg some years ago in recent sediments both in southern and northern

Sweden. The resistance of such small fossils to erosion is so strong that they are often perfectly preserved at the second place. Cretaceous microfossils were found both in boulder clay and in Quaternary and recent marine sediments.

The Paleocene

In 1908 Paleocene was discovered on the top of the Danian limestone in the quarry at Klagshamn south of Malmö and up to the year 1941 Klagshamn was the only locality where the Paleocene was known in its original position. In the last twenty years Paleocene has been found in numerous bore-holes, near Klagshamn and in the region of Ystad, where its thickness reaches 18 metres. The basal conglomerate and some clayish greensand are exposed at Klagshamn. In the drill-holes south of Malmö and near Ystad the same sequences were found. Therefore the boundary between the Paleocene and the Danian is in all these places very distinct. In the region of Klagshamn dark clay and greensand occur above the conglomerate, but at Ystad the clay layers are small. In the outcrop at Klagshamn fossils are very rare, except microfossils, but the greensand of Ystad contains a rich mollusc fauna. Characteristic for the greensands is a small single coral calyx of Sphenotrochus latus. Higher parts of the Paleocene are represented by a concentration of local boulders near Ystad. These are of hard, brownish, ironshot sandstones with a rich and imperfectly known mollusc fauna. The guide fossil Sphenotrochus latus is very abundant. The boulders are generally large slabs with a diameter up to one metre. Microfossils, Tertiary foraminifera and ostracods are often preserved in fissures in the uppermost layers of the Danian. Such fissures are known from Klagshamn, Ystad, Landskrona and in a small syncline of the Danian directed from Landskrona to the southeast. This demonstrates that Paleocene sediments have originally had a large extension over SW Scania and were later destroyed.

A local occurrence of Paleocene limestone boulders shows a facies very different from all other localities of our region. These contain a rich mollusc and foraminifera fauna which indicates sedimentation conditions far away from a coast-line and possibly also a change of climatic conditions. The fauna dates the blocks as Middle Paleocene, during which period the sea transgressed widely south of the Baltic into Poland and Northern Germany. Fauna and facies of the so-called "Maglehem boulders" demonstrate an original occurrence of Paleocene in southern Sweden and in the southern Baltic below sea level, where hitherto no Paleocene is known.

The Eocene

In northern Germany and in Denmark the Eocene is well represented and it always begins with intercalations of tuff. It is also the volcanic activity which announced the beginning of the Eocene. In the province of Scania, basaltic hills occur which were considered to have been volcanoes which delivered the

Fig. 3. Paleocene boulder from Ystad.

tuff in the sedimentary area. It may also be that the occurrence of rhyolite in Småland and andesite in Hälsingland belongs to the Eocene volcanic activity. Both these occurrences were also explained as explosion craters.

Eocene sediments, except tuffs in Middle Scania, were found in a bore-hole near Åhus (Kristianstad region). They are clays with volcanic ashes containing a rich diatom flora. Even pieces of amber were found and it may be possible to date all the numerous amber pieces on the southern shore of Scania as Eocene. Isolated Eocene diatomea in Quaternary deposits were studied from middle and northern Sweden which resulted in the surprising fact that Eocene sediments could have existed in very different parts of our country and intensive work is necessary to follow up these first indications.

The upper Tertiary (Miocene and Pliocene)

Only a few finds of lignite boulders and fossil wood from the Upper Tertiary in Sweden are reported. The final stratigraphic range of the finds is not yet known but it seems that the remains belong to the Miocene. These few remains must have originated in a tropical humid climate and it seems necessary to postulate a widely spread tropical vegetation covering the country during the younger Tertiary. Large rivers and swamps must have existed during the Pliocene. The intensive tectonic movements at the end of the older Tertiary elevated large parts of the country, which were later exposed to intensive weathering. There exists no other explanation for the origin of the thick sandy sediments in Denmark, Northern Germany and Northern Poland. The old Precambrian peneplanes must have been rejuvenated during the Pliocene so that subsequent Quaternary glaciations met more or less the same landscape we see today except for the Quaternary deposits themselves.

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

By

BROR ASKLUND

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 or 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 Röros 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 distinguishable 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 northwestern 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

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 peneplaine. 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.

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 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 part 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

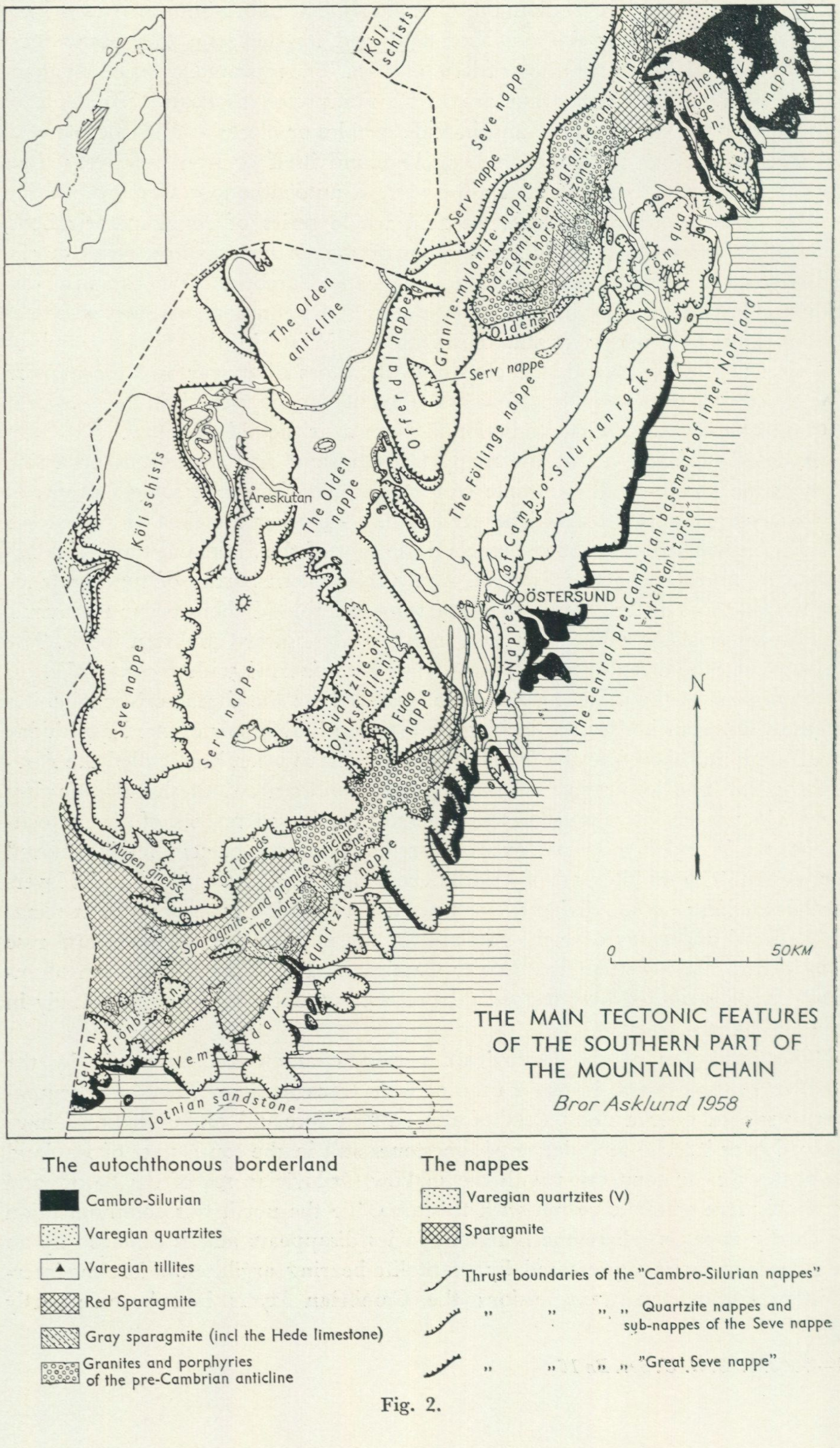

THE MAIN TECTONIC FEATURES
OF THE SOUTHERN PART OF
THE MOUNTAIN CHAIN
Bror Asklund 1958
Köli schists
Seve nappe
Serv nappe
Granite-mylonite nappe
Sparagmite and granite anticline
The horst zone
The Föllinge n.
Olden n.
The Olden anticline
Offerdal nappe
Serv nappe
The Föllinge nappe
Nappes of Cambro-Silurian rocks
The central pre-Cambrian basement of inner Norrland "Archean torso"
Köli schists
Åreskutan
The Olden nappe
ÖSTERSUND
Seve nappe
Serv nappe
Quartzite of Oviksfjällen
Fuda nappe
Augen gneiss
of Tännäs
Sparagmite and granite anticline
The horst zone
quartzite nappe
Vemdal
Serv n.
Jotnian sandstone
N
0
50KM
The autochthonous borderland
Cambro-Silurian
Varegian quartzites
Varegian tillites
Red Sparagmite
Gray sparagmite (incl the Hede limestone)
Granites and porphyries of the pre-Cambrian anticline
The nappes
Varegian quartzites (V)
Sparagmite
Thrust boundaries of the "Cambro-Silurian nappes"
" " " " Quartzite nappes and sub-nappes of the Seve nappe
" " " " "Great Seve nappe"

Fig. 2.

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 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 tribolites, 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 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. Disintegrated older quartzites form masses of hard pebbles. They belonged originally to the late-Precambrian, Varegian quartzites. The coarse conglomerates from the transition period betwen 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 "Hyolithes-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 volcanos 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.

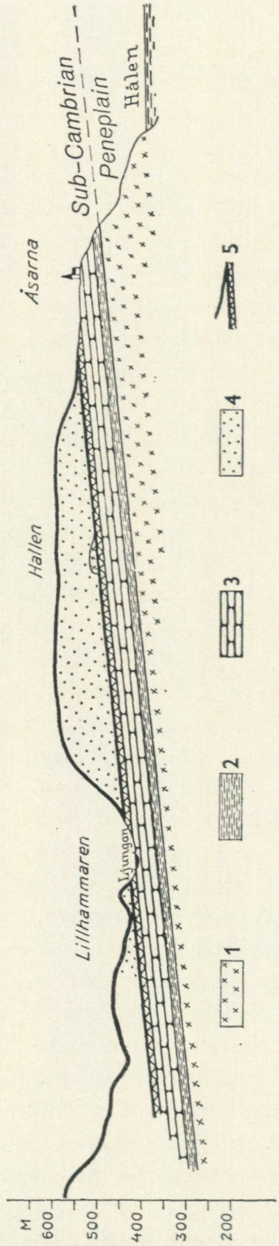
The rocks concerned — "the Köli schists" — occupy a part of middle Jemtland. They belong to the so-called "Tennfors-field" which includes a great deal of schist, partially of the "schiste lustré" type. From the northwestern part of Jemtland to the northern part of Lapland there occurs a series of such 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" 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



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.

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 "Vemdal 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 Vemdal 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-sparagmitic, 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 Varegian 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 Varegian 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 Varegian sediments along the whole geosyncline a profound difference in geological behaviour is evident between the sparagmite-series and the Varegian 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 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 crystalline 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

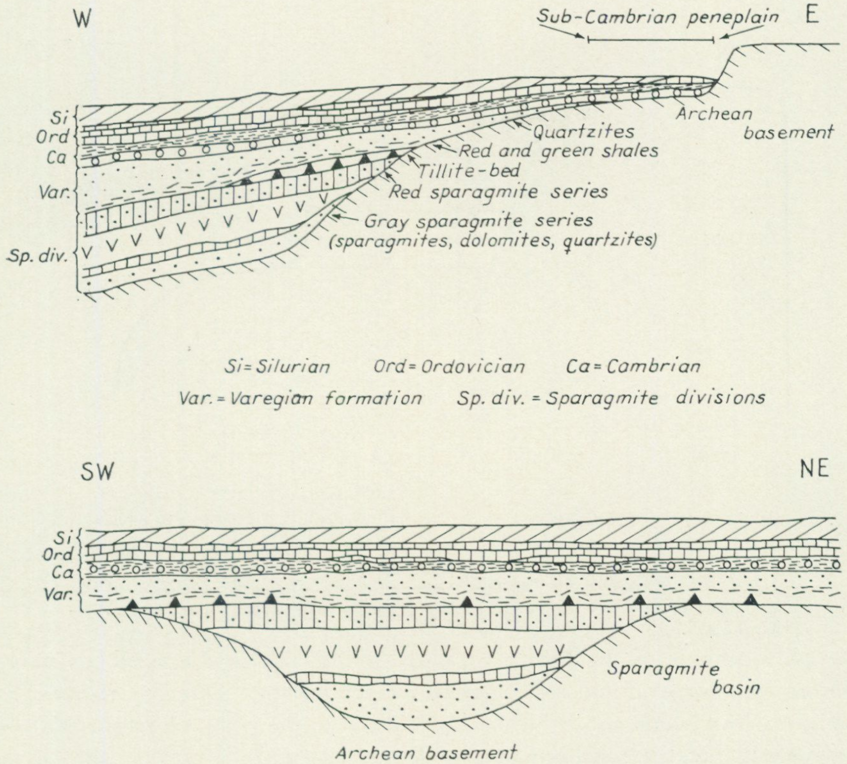
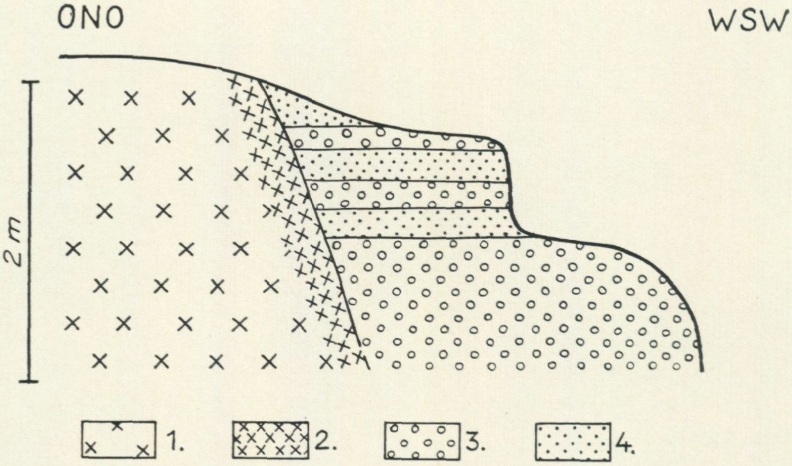


Fig. 4. General scheme for the succession and manner of sedimentation of the late-Pre-cambrian complexes in the Mountain Chain. — The difference between the distribution of the basin-forming sparagmites and the more widely occurring Varegian formation is to be noted. — B. Asklund 1957.

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.



1. Basalt coarser grained
2. Basalt aphanitic
3. Quartzite coarser grained
4. Quartzite fine-grained

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

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 unit 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 "*Fuda nappe*" to the SW of Storsjön in Jemtland, the small "*Alsen nappe*" to the north of Alsensjön in Central Jemtland and the big "*Offerdal nappe*" to the north, passing the Hotagen 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 crystalline basement of the Köli 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 south-eastern 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 crystallisation 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 limestones 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 Törnebohm[1] 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 con-

[1] A. E. Törnebohm (1838—1911), Professor of Geology, Chief Director of the Geological Survey of Sweden.

cepts 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 geeosynclinal 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.

For the author of this review it seems quite clear that the rocks of the "real" Seve 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 mica-schists, 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.

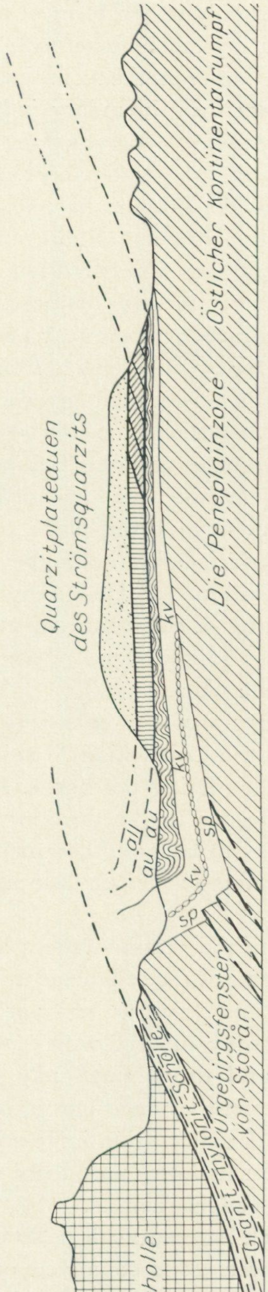
A general review of the detailed tectonic features of the Swedish Mountain Chain is too intricate for this concentrated description. Such a review is inseparably connected with the geological history of the Norwegian part. But some features may be mentioned. The main view of the moment regarding the 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 Jemtlandian 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 Vemdal-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 Varegian 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 crystalline nappes. On the top of these horsts there occur sediment beds of different kinds: grey and red sparagmites, Varegian 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



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.

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 Ångermanland 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 horst 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 Vemdal-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 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 Varegian quartzite with small remnants of overlying Cambrian alum-shales. The nappe is also thought to have overridden outliers of the "quartzite nappe" situated between the lakes

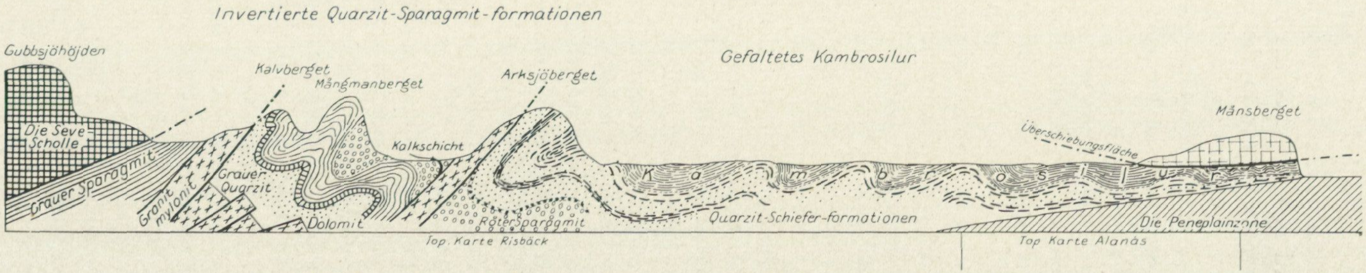


Fig. 7. Schematic profile from southernmost Lapland, Långseleån River and Korpån River. — B. Asklund 1935, 1938.

Malgomaj and Storvindeln in Lapland. It has a continuation into the southern part of the county 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 thrusted 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 it 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 Varegian 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 Seve 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 or acid lavas and tuffs in the Hölonda-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.

On the Caledonides of Swedish Lapland

By

Oskar Kulling

T h e S w e d i s h M o u n t a i n s are broadly speaking the same as the Swedish portion of the Scandinavian Caledonides. T h e L a p l a n d M o u n t a i n s constitute the northern half of the Swedish Mountains. The southern part of the Lapland Mountains is named t h e V ä s t e r b o t t e n M o u n t a i n s, the northern part t h e N o r r b o t t e n M o u n t a i n s.

A monograph on the Caledonides of the Västerbotten Mountains has been published in 1955 by O. Kulling (Geol. survey of Sweden, Ser. Ca, Nr 37). The corresponding monograph on the Norrbotten Mountains geology is wanting. O. Kulling, however, is leader of the Geological Survey mapping of the Norrbotten Mountains.

The representation of the Caledonian bedrock of Lapland on the geological map of Sweden of 1958 is for the most part founded on general field researches of the four last decades. After the above-named monograph of the Västerbotten Mountains was printed some mapping revisions in the southeasternmost border of the mountains were performed by B. Asklund. For some boundaries in that part of the geological map of Sweden are the responsibility of Asklund. Beside the results from the Geological Survey mapping of the Norrbotten Mountains results have been obtained from the southernmost part of the mountains (compiled by N. Marklund) and put at my disposal by the Boliden Mining Company. The map contributions from the Kebnekaise area by H. Johansson as well as the one from the Sulitelma area by G. Kautsky may also be mentioned.

During the Caledonian diastrophism a powerful transport of rock-masses took place from the Scandinavian branch of the Caledonian geosyncline area towards the southeast. The rock-masses advanced over parts of the old Fennoscandian shield adjacent to the geosynclinal area. Relics of these rock-masses now constitute the Swedish Mountains, situated along the national boundary to Norway. According to recent investigations the rock-masses appear as a number of flat-lying, dissected and often rather complicated built up nappes. Of these nappes the lower ones are transported a comparatively short way, the middle ones have a more westerly root-zone than the lower nappes, and the upper nappes have started from the very geosyncline.

The bedrock of the autochthonous portion of the mountain chain and of its lower nappes are only little metamorphosed. The metamorphic alteration grows stronger in every superposing nappe, and in the upper nappes i. e. the ones from the geosyncline, the metamorphism increases towards the lower part of every nappe.

In Scandinavia the Cambro-Silurian deposits of geosynclinal origin, which is the same as t h e m e t a m o r p h i c C a m b r o - S i l u r i a n, are named t h e W e s t e r n C a m b r o - S i l u r i a n. The Cambro-Silurian deposits on the old Archean shield to the east of the geosyncline are named the Eastern Cambro-Silurian, and in the Scandinavian zone of the Caledonides they are situated in the lower nappes, or as autochthonous rocks. With few exceptions the overthrust rock-masses in the eastern part of the Scandinavian Caledonides do not rest on Archean or late pre-Cambrian bedrock but on Eastern Cambro-Silurian. Whether any of these nappes once advanced on to Archean bedrock east of the Eastern Cambro-Silurian to any extent is hardly to be found out.

In his paper of 1955 Kulling divides the Västerbotten Mountains bedrock into a series of tectonic units. The lowest one is, of course, the autochthonous Eastern Cambro-Silurian to the far east of the mountains. In Västerbotten these sediments are of Cambrian and Ordovician age. In the southernmost part of the eastern marginal zone there are thrust Eastern Cambro-Silurian sediments. According to B. Asklund they belong to the Föllinge Nappe, of which they form the northern part. The nappe has a wide distribution in Jemtland. The upper part of the Eastern marginal zone of the Västerbotten Mountains is divided into two nappes: The Blaik Nappe is the lower one, and the Stalon Nappe the upper one. Both of them are to a great extent built up of quartzite and arkose, so-called sparagmite. Slate to shale is furthermore a frequent member of the Blaik Nappe. Minor components in both of the nappes are conglomerate, tillite and dolomite. Igneous rocks of Archean age constitute the lower part of each nappe in some restricted areas. The eastern part of the Blaik Nappe is often called the Ström quartzite Nappe. The sediments of the Blaik Nappe are of sericite-chlorite facies. The sediments of the Stalon Nappe belong to a great extent to the biotite-epidote facies. In its lower parts and towards the west the rocks grade into garnet facies.

The rocks of the eastern marginal zone of the Västerbotten Mountains plunge to the west under the great Seve-köli Nappe, that forms the main part of the Västerbotten Mountains proper and is composed of a great many kinds of low and high metamorphic rocks. Scattered finds of Ordovician and Silurian fossils are made in the low metamorphic sediments, that are, broadly speaking, usually designated as the Western Cambro-Silurian. No fossils of Cambrian age, however, have been discovered.

The northwestern corner of the Västerbotten Mountains is occupied by the Rödingsfjäll Nappe of more highly metamorphosed rocks, and situated above the low metamorphic part of the Seve-köli Nappe.

In the Seve-köli Nappe there are some windows where the underlying bedrock appears. In the Ammarnäs Inlier the principal sedimentary rocks are phyllite, graywacke and arkose. The inlier is situated in the northeastern part of the Västerbotten Mountains proper and is possibly a partly different composed western portion of the Stalon Nappe. In the Bångfjället Inlier, located in the central part of the Seve-köli Nappe, the main constituent is granite and syenite of Archean age and bears relation to the Archean igneous rocks in the lower part of the Stalon Nappe.

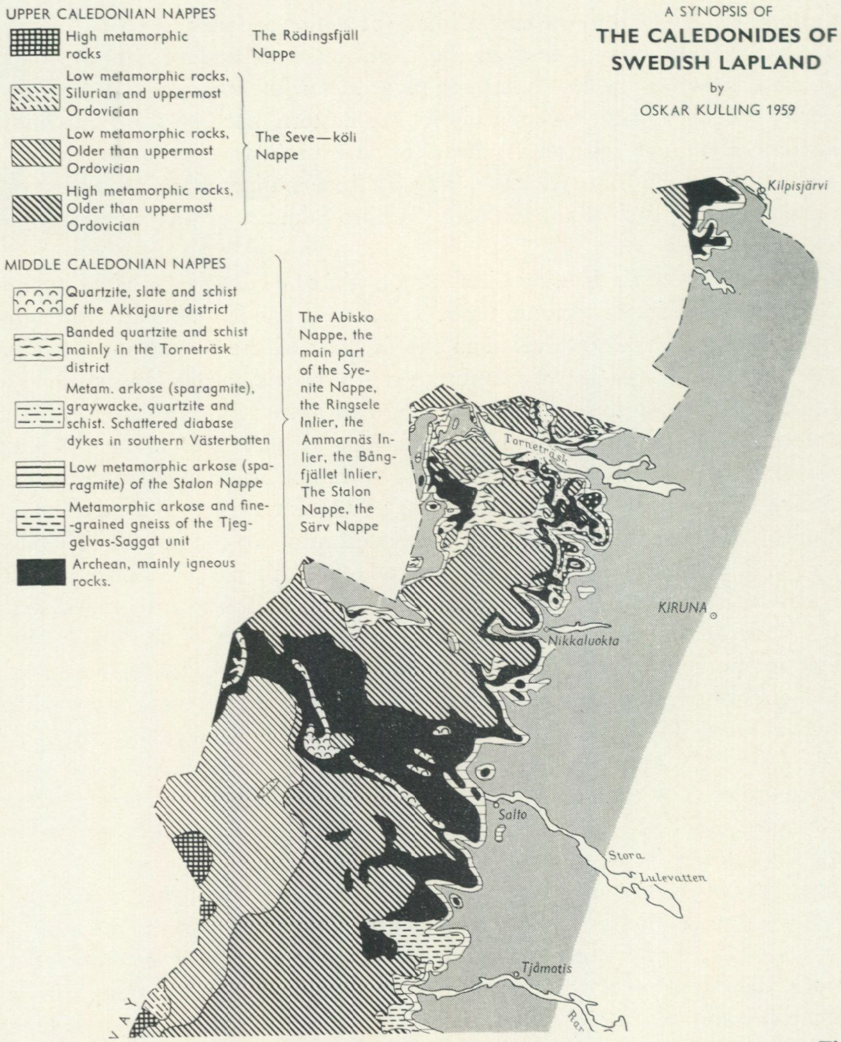
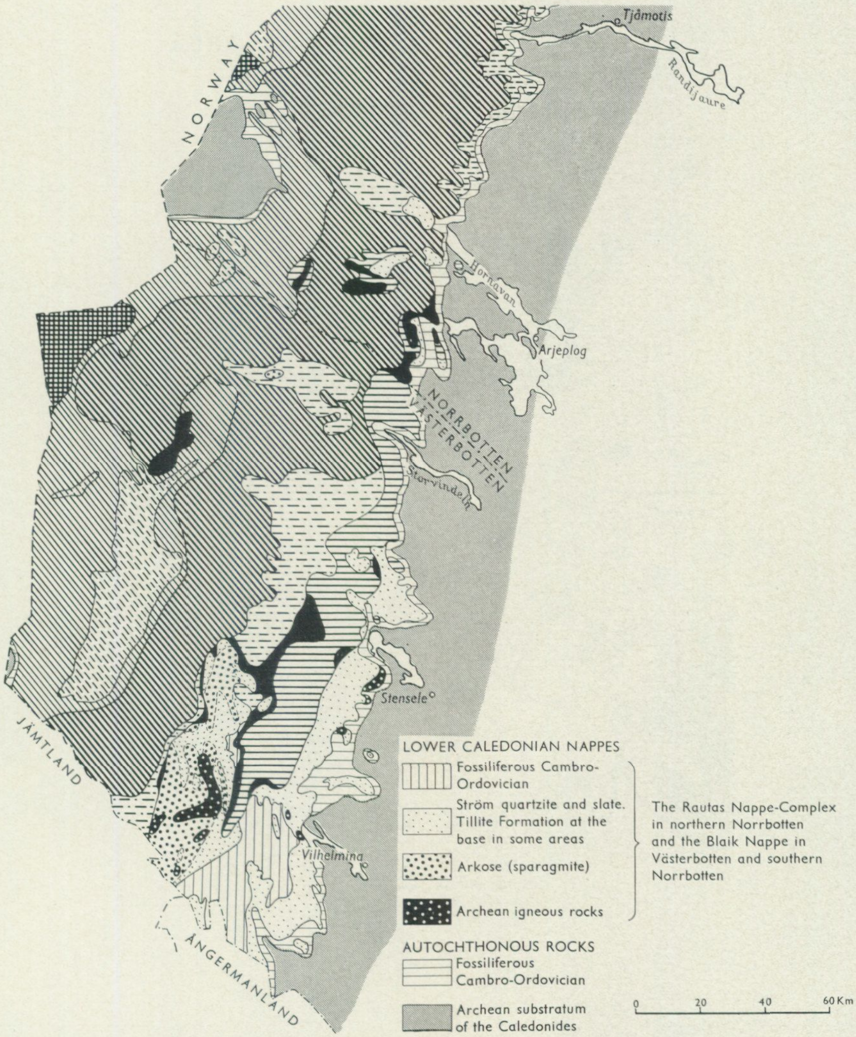


Fig. 1.

After this brief outline of the bedrock of the Västerbotten Mountains we now turn to the bedrock of the Norrbotten Mountains and especially the Torneträsk area in their northern part.

Starting from below we must point out that the Cambro-Silurian of Eastern Facies, in Västerbotten composed of Cambrian and Ordovician formations, in Norrbotten is only built up of Cambrian beds, and for the most part beds of only Lower Cambrian age. This applies to both autochthonous and thrusted units. Tillite and varved shale may be noted in the very basal portion of the sedimentary sequence, mostly built up of sandstones and shales with some minor intercalations of limestone and pebbly beds. The sedimentary series quoted often starts with an arkosic basal conglomerate. The old designation of the sedimentary series along the thrusted masses in the eastern marginal zone of the Norr-



botten Mountains is the Hyolithus Zone or the Hyolithus Series, as specimens of Hyolithes (Hyolithus is an earlier manner of writing) was the first fossil discovered in the sediments themselves. The fossils were collected by Fr. Svenonius in 1882 to the north of Lake Tjeggelvas.

In the Torneträsk area a thrusted unit with quartzite, slate and some minor intercalated limestone with fossils of the uppermost Lower Cambrian is called by the author the Luopakte Nappe. The only locality where fossils have been found in this unit, is the northeast corner of Mt Luopakte to the south of the eastern part of Torneträsk. Thrusted units with quartzites, slates and dolomites with attached basement of Archean crystalline rocks, mainly of granite and syenite composition, are observed in the Torneträsk area and also in some other easterly districts of the Norrbotten Mountains. The Archean

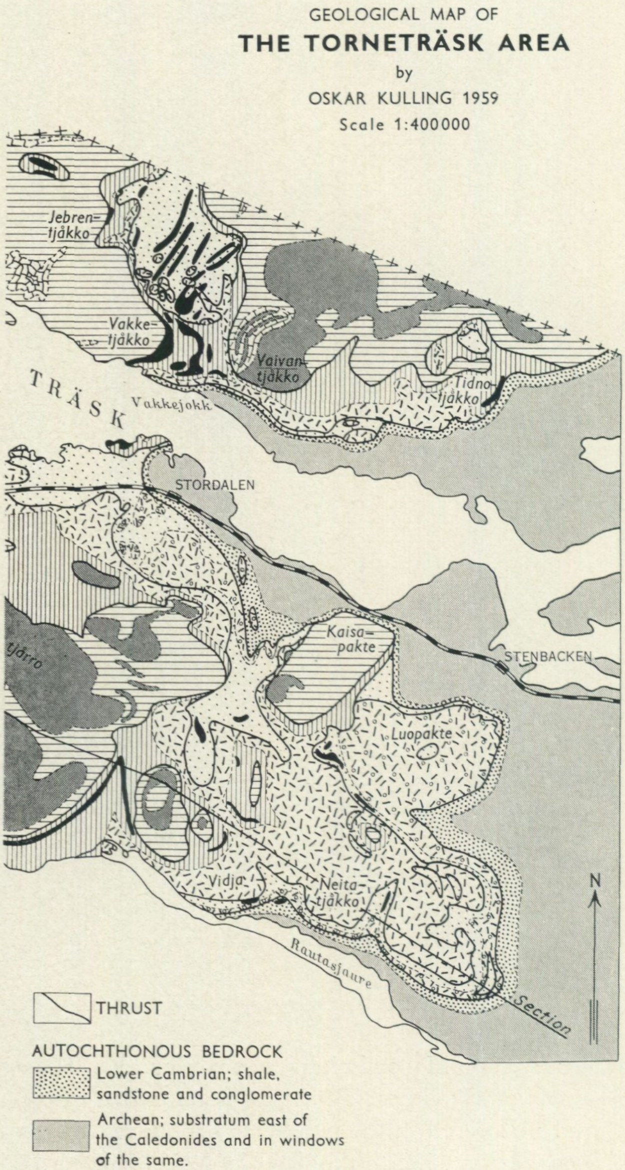

GEOLOGICAL MAP OF
THE TORNETRÄSK AREA
by
OSKAR KULLING 1959
Scale 1:400000
Jebren-tjåkko
Vakke-tjåkko
Vaivan-tjåkko
Tidno-tjåkko
TRÄSK
Vakkejokk
STORDALEN
Kaisa-pakte
STENBACKEN
Luopakte
Vidja
Neita-tjåkko
Rautasjaure
N
Section
THRUST
AUTOCHTHONOUS BEDROCK
Lower Cambrian; shale, sandstone and conglomerate
Archean; substratum east of the Caledonides and in windows of the same.

Fig. 2 a.


NORWAY
NORWAY
TORNE
Pallep. Njuorajaure
Kuokel
Vassijaure
VASSIJAURE
KOPPARÅSEN
BJÖRKLIDEN
Kårkevagge
Vassitjåkko
Låktatjåkko
Kåppastjårro
Nuolja
ABISKO T
Kårsavagge
Håikantjårro
Satnjarastjårro
Nisson
Keron
Pallentjåkko
Adnjetjåkko
Sjangeli
0 5 10 km
THE SEVE-KÖLI NAPPE
Mica-schist and garnet-mica-schist
Amphibolite
Marble, mostly calcite-marble
THE ABISKO NAPPE
Banded sericite-quartzite and schist, the "Hardschist "Series
Dolomite
Archean amphibolite, mainly fine-grained
Archean granite, syenite etc., cataclastic "mylonite" rocks
THE RAUTAS NAPPE-COMPLEX
Quartzite and slate
Dolomite
Archean granite, syenite etc., cataclastic "mylonite" rocks
THE LUOPAKTE NAPPE
Quartzite and slate with some limestone lenses
Parautochthonous? quartz-veined, fine-folded phyllite rocks

Fig. 2 b.

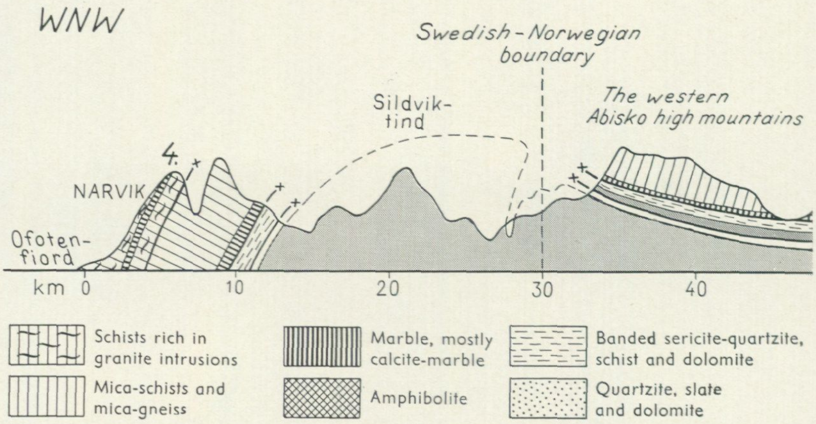


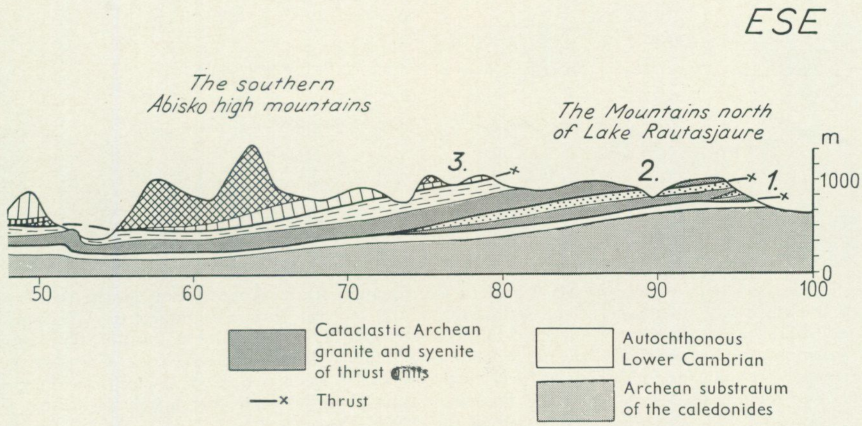
Fig. 3. Section across the Caledonides of the Torneträsk—Ofoten area, running from the eastern border of the Mountains at Lake Rautasjaure towards WNW to Ofot fiord at Narvik. 1. The Rautas Nappe-Complex. 2. The Abisko Nappe. 3. The Seve-köli Nappe. 4. Lowermost part

igneous rocks are to a great portion cataclastic, the sedimentary rocks often schistose. During a short stay in 1930 in the southeastern part of the Torneträsk area, along Lake Rautasjaure, Kulling observed and figured highly imbricated thrust-masses of the above-mentioned bedrock. See the section, Fig. 4. In 1950 he referred to it as the Rautas Complex. Recently he remapped that little known district and demonstrated the wide distribution of the complex around Lake Rautasjaure and in other easterly parts of the northern Norrbotten Mountains. The general name for this complex is the Rautas Nappe-Complex.

The Stalon Nappe of the Västerbotten Mountains crosses the boundary into the Norrbotten Mountains. In southern Norrbotten its portion of Archean igneous rocks increases. In middle and northern districts of the Norrbotten Mountains there are wide areas of thrusted Archean granite-syenite rocks, more or less cataclastic, below the schists of the Seve-köli Nappe. This Archean bedrock complex, however, is often only briefly mapped. In the Torneträsk area such Archean rocks lie above the Rautas Nappe Complex, and constitute together with overlying "hard schists", that is tectonically banded quartzites, sericitic schists, dolomite rocks, etc., the Abisko Nappe of the author. In the middle parts of the Norrbotten Mountains the greater part of the so-called Syenite Nappe is to be placed in the Abisko Nappe.

As in the Västerbotten Mountains the Seve-köli Nappe dominates in the Norrbotten Mountains, and in some restricted areas to the west of the latter badly preserved fossils of possibly Middle and of Upper Ordovician age have been discovered. In the Torneträsk area of the northern mountains of Norrbotten, however, only the lowermost part of the Seve-köli Nappe is present.

In the Västerbotten Mountains the Rödingsfjäll Nappe rests on the Seve-köli rock complex. In the southern half of the Norrbotten Mountains there are



of the Håfjell unit (looked upon as a northern part of the Rödingsfjäll Nappe). The section is indicated on the geological map of the Torneträsk area.

three small areas of more highly metamorphosed rocks extending to the east from the Norwegian side of the national boundary, and are looked upon by the author as representatives of the Rödingsfjäll Nappe.

The preceding brief synopsis on the rock complexes of the Lapland Mountains is shown in the following table. Compare also the map, Fig. 1. The rock complexes are subdivided into the upper, the middle, and the lower Caledonian rock units.

	The Västerbotten Mountains and the southernmost part of the Norrbotten Mountains	The Torneträsk area as a representative part of the northern Norrbotten Mountains (Compare Figs. 2—5.)
The Upper Caledonian Bedrock (Nappes)	The Rödingsfjäll Nappe The Seve-köli Nappe	The Lowermost part of the Seve-köli Nappe
The Middle Caledonian Bedrock (Nappes)	The Ammarnäs Inlier, the Bångfjället Inlier and the Stalon Nappe	The Abisko Nappe
The Lower Caledonian Bedrock (Nappes and autochthonous beds)	The Blaik Nappe (eastern part of it = the Ström quartzite Nappe) "The Föllinge Nappe" = thrusted Eastern Cambro-Ordovician The autochthonous Eastern Cambro-Ordovician	The Rautas Nappe-Complex The Luopakte Nappe The autochthonous Eastern Lower Cambrian
	Archean substratum	Archean substratum

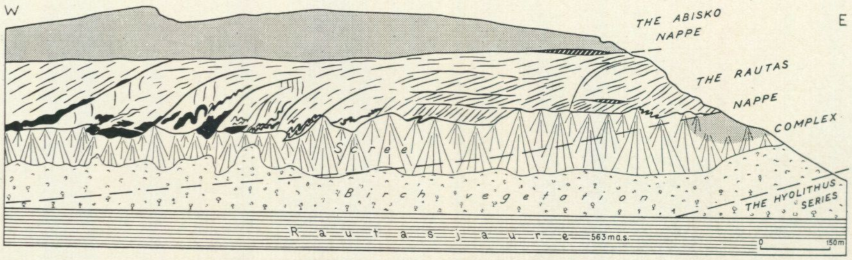


Fig. 4. The southern aspect of Mt Vidja to the north of Lake Rautasjaure. In the mountain scarp the imbricate structure of the sediments of the Rautas Nappe-Complex is well demonstrated. Black areas = white quartzite. Oblique stripped areas = white dolomite. The rest of the sediments is composed of slate, sandy slate and dark-coloured quartzite rock. Grey areas = cataclastic Archean igneous rocks, which crop out in the eastern slope and compose the crest area. The former ones belong to the Rautas Nappe-Complex, and the latter ones form the lower part of the Abisko Nappe.
Sandstone and shale of the autochthonous Hyolithus Series are exposed a short distance to the east of the figured section. From Kulling 1930.

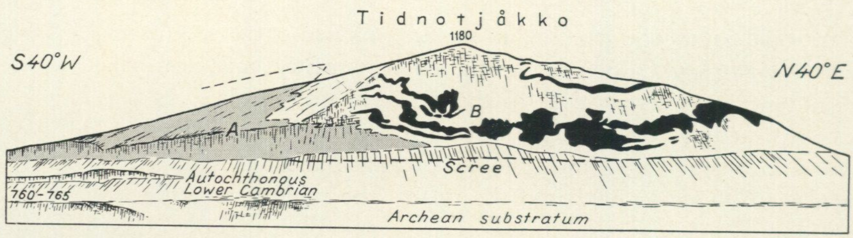


Fig. 5. Mt Tidnotjåkko from the southeast. The mountain constitutes the southeastern corner of the Caledonides north of Torneträsk. On the Archean granite substratum lies autochthonous Lower Cambrian sandstone and shale. Scree covers their upper part. The thrust-rocks of the mountain belong to the Abisko Nappe. A = Cataclastic Archean granite and syenite. B = Metamorphic, partly banded schists and quartzites with intercalated dolomite marble (black on the figure). The dolomite exemplifies the type of transverse deformation of the hard-schists of the Abisko Nappe. The dolomite folds are overturned to the northeast and torn into shreds. From Kulling 1930.

There are several nappes with Eastern Cambro-Silurian facies above the autochthonous sediments of the same facies, recorded to the south of Västerbotten, in Ångermanland and Jemtland. According to P. Thorslund the Föllinge Nappe is the fourth from below. The table above does not intend to show the absolute correlation between the Föllinge Nappe and the Luopakte Nappe, only that in the districts mentioned both of the named thrusted sedimentary units of Eastern facies are superposed on autochthonous fossiliferous beds. That is an example.

The Archean Substratum

Along the eastern margin of the Västerbotten Mountains the Archean substratum of the Caledonian Chain is composed mainly of granite rocks of the Revsund group and of the Sorsele group. Along the Norrbotten Mountains a great many kinds of highly metamorphic sedimentary and volcanic rocks of various Archean formations together with Sorsele granite, Lina granite and its allied perthite-granite and syenite rocks build up the substratum of the Caledonian bedrock.

In the western parts of the Lapland Mountains there are five windows, where the Archean substratum of the Caledonian bedrock is exposed, viz.: 1. the Rombak-Sjangeli window on both sides of the national boundary to the west of Torneträsk, 2. the Kuokel window on the western shore of Torneträsk, 3. the Singis window, a very small one, to the southwest of the Kebnekaise Mountains, 4. the Nasa window, crossing the national boundary in the southwestern corner of the Norrbotten Mountains, and 5. the Västerbotten part (= easternmost part) of the Börgefjell window.

The Archean bedrock of the above-named windows is for the most part of granitic composition. In the windows to the west of Torneträsk, however, there are also some schists, partly with basic volcanic intercalations. These supercrustal rocks are older than the surrounding granite.

Along the margins of all these windows there are remnants of lightly disturbed autochthonous beds of sandstone and shale, western outcrops of the Hyolithus Series. No fossils, however, have been obtained from these western sediments. One may point out that the scattered occurrences of alum shale in the upper parts of these sediments strongly support the opinion of their Cambrian age. The windows with outcropping Archean bedrock represent anticlines. Specially the anticlines in the national boundary zone are very pronounced and large. The bedrock in the upper part of the Nasa window is rather tectonized.

Both in the windows and along the eastern mountain margin the Archean bedrock is for the most part quite fresh up to the boundary of the superposed sediments. In some areas, however, the bedrock quoted is weathered to a depth of some metres below the very boundary.

The Lower Caledonian Bedrock

THE SITO TILLITE FORMATION. The formation rests on Archean bedrock or is separated from it by sandy to arkosic beds. Laminated shale, possibly of real varved shale origin, is observed in connection with the tillite. The thickness of the Sito Formation is often a few to some ten metres. Tillite rocks of this type are observed both in the autochthonous sequence and in thrusted units.

Up to now the Sito tillite has been found only in Norrbotten parts of the Lapland mountains. The tillite rocks have been considered representatives of the Varanger ice age (Kulling 1942 and 1951) or Varangerum. In the legend to the 1958 Sweden bedrock-map another name, the Varegium, has been introduced by B. Asklund. This term covers not only the Varangerum glacials, but also all sedimentary beds superposed on the very glacials, as far as the base of the lowest bed with real Lower Cambrian fossils.

Thus the above-named Ström quartzite is included in the Varegium of Asklund. The author prefers to keep to the name of 1942, distinctly restricted to the old glacials.

THE EASTERN CAMBRO-SILURIAN. In the table of the introductory synopsis "the Föllinge Nappe" of Eastern Cambro-Silurian sediments was mentioned. This nappe-unit, if it is a real tectonic unit, is chiefly a Jämtland-Ångermanland nappe and is consequently dealt with by B. Asklund in the description of the Southern Swedish Mountains.

The sedimentary sequence of the Eastern facies starts with a basal sandstone formation almost devoid of fossil remains. Its name is the Laisberg sandstone or the Laisberg Formation and it lies on the Archean substratum or on the Sito tillite Formation. The Laisberg sandstone can be followed from the national boundary north of Torneträsk along the Lapland Mountains marginal zone to the Lake Malgomaj district in middle Västerbotten. The basal bed of the formation is often an arkose or a real basal conglomerate. In some districts sandy shales of the formation are obviously rich in mica, probably emanating from comparatively adjacent exposures of pre-Cambrian mica-bearing rocks.

Of the four Scandinavian Lower Cambrian faunal zones, viz. 4. Zone with *Strenuella linnarssoni* Kiaer, 3. Zone with *Holmia kjerulfi* (Linrs.), 2. Zone with *Volborthella tenuis* Schmidt and *Platysolenites antiquissimus* Eich., and 1. Zone with *Discinella holsti* Moberg, are the three upper ones clearly established in the east border zone of the Lapland Mountains. Lenses and thin beds of fossiliferous limestone with fossils of Zone 4 are specially noted in autochthonous shales on Mt Luopakte to the south of Torneträsk and in Aistjakk at Lake Storlaisan, both localities in Norrbotten. Also in a thrusted unit in the named Mt Luopakte Zone 4 is found. Fossils of Zone 3 are known from some localities in Västerbotten and fossils of Zone 2 have a wide distribution both in the Norrbotten and the Västerbotten parts of the Mountain border zone. The Hyolithes shale itself belongs to Zone 2. It is possible, that the lowest Zone, no. 1, of which no real fossils are reported from Lapland could be established in the lowest autochthonous beds, called the Laisberg sandstone Formation above.

The fossiliferous Lower Cambrian beds are for the most part composed of shales, marly shales, sandy shales, and sandstones. Pebbly conglomerates, phosphorite conglomerates and limestones are only occasionally met with.

The main facies of the Middle and Upper Cambrian is alum shale. Other kinds of shale and sandy shale to graywacke are also present. The stinkstone-bearing alum shales which are rich in fossils are mainly distributed in the southern part of the Västerbotten Mountains border. As alum shale of more northern districts is poor in fossils, possibly lacking fossils, the age of these alum shales is more or less uncertain. The following Middle and Upper Cambrian faunal zones are established in southern Västerbotten up to north of Lake Storuman in the north.

The Middle Cambrian is represented by the Zone with *Paradoxides* *pinus* of the *Paradoxides ölandicus* beds, and the four zones: *Ptychagnostus gibbus,* Zone with *Tomagnostus fissus* and *Ptychagnostus atavus, Hypagnostus parvifrons,* and *Ptychagnostus punctuosus* of the *Paradoxides paradoxissimus* beds, and at the top the *Paradoxides forchhammeri* beds. The Upper Cambrian is represented by the Zone with *Agnostus pisiformis,* Zone with *Olenus,* the two subzones with *Peltura scarabaeoides* and *Parabolina longicornis* of Zone with *Peltura* and *Sphaeropthalmus.*

From the preceding list it is clear that many zones and subzones of Scandinavian Middle and Upper Cambrian are up to date not identified in the alum shale sequence of Västerbotten. The areas with alum shale are for the most part covered by drift. The fossils collected and examined are mainly from stinkstone erratics in till. Thus future investigations possibly may add new zones to the above-named ones and fill up some of the zonal gaps in the list presented.

The Ordovician of Eastern facies, only met with in the southern part of the Västerbotten Mountains border zone, has a more southerly distribution than the above-named Middle and Upper Cambrian. The most northerly locality of Ordovician sediments is noted from the vicinity of Lake Skikkisjö to the north of Lake Vojmsjön. The lowermost Ordovician strata belong to the Ceratopyge beds, their lower part being the Ceratopyge alum shale and their upper part the Ceratopyge limestone. Of the following Lower Didymograptus beds only Zone with *Isograptus gibberulus* and Zone with *Phyllograptus densus* is up to date recorded at scattered localities. The next faunal zone is the Limbata limestone. On Mt Baktoberget to the south of the southeast corner of Lake Malgomaj the limestone is exposed in an old quarry. Regarding the fossiliferous Eastern Ordovician it may also be mentioned that graptolites, viz. *Climacograptus* and leptograptide remains of possibly Middle Ordovician age are collected from a black shale in a remote district in southernmost Västerbotten. In the very part of Västerbotten where the Eastern Ordovician fossils were discovered, there are large districts with bedrock of gray and black shale, graywacke and dark sandstone. The whole little known and very badly examined sedimentary sequence is looked upon as Ordovician.

The fossil-bearing Eastern Cambro-Ordovician strata of Lapland, if they crop out at all, appear below the thrusted masses in the eastern scarps of the Mountain border or are exposed along rivers and brooks in the otherwise drift-covered more or less plain areas of the same border zone. In these circumstances it is hard to divide the Eastern Cambro-Ordovician into true autochthonous beds and in thrusted ones. The author's brief survey is insufficient for that. The undisturbed Cambrian beds in the very eastern Mountain margin, subjacent to thrusted Lower or Middle Caledonian Bedrock units, are the only verified autochthonous ones. Alum shales are met with in the Blaik Nappe part to the west of Lake Malgomaj. The wide district of Cambro-Ordovician shales with graywacke- and quartzite intercalations to the southwest of Lake Malgomaj may be a downfolded part of the last-named Nappe

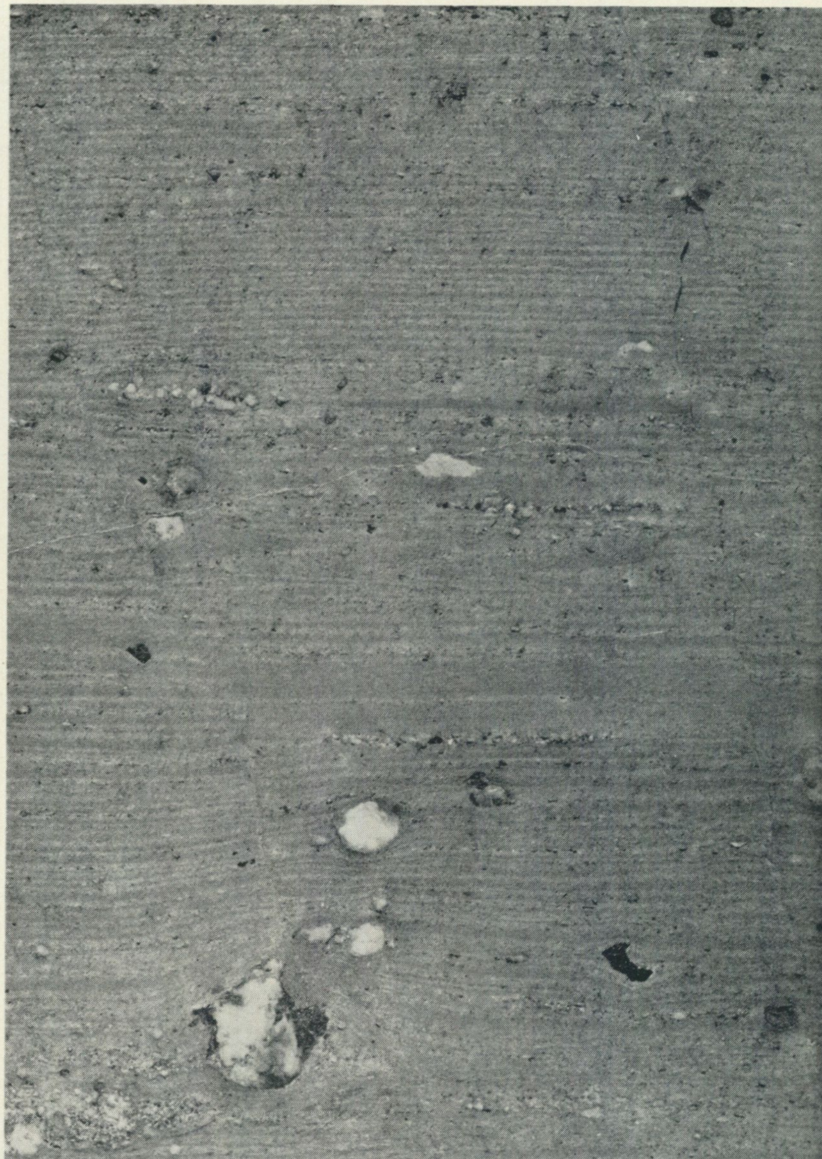


Fig. 6. Varved shale with erratic pebbles. The shale forms the uppermost unit of the Långmarkberg glacial Series. The tillite locality at Mt Långmarkberg in northeasternmost Jämtland close to the boundary towards Västerbotten. Magnified 2×.

complex. The author once (1942) described fossiliferous, probably Cambrian beds, resting on true Ström quartzite in the middle of this district.

THE STRÖM QUARTZITE — LÅNGMARKBERG TILLITE — SPARAGMITE SEQUENCE of the Lower Caledonian bedrock

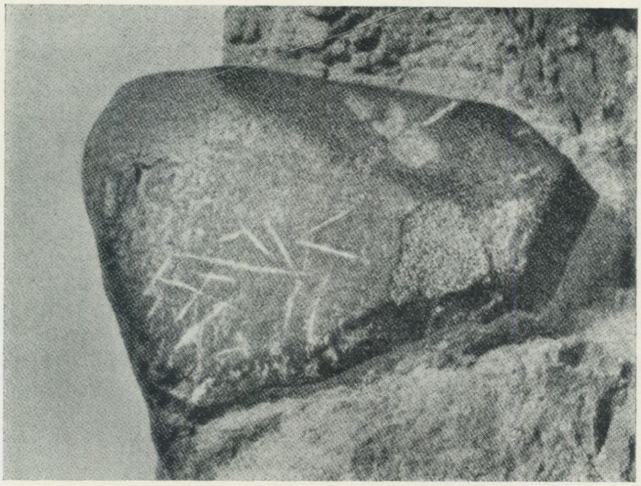


Fig. 7. A glacial erratic pebble with striations, faceting, and subrounded corners, enclosed in the Långmarkberg varved shale. The pebble desposited in glacial clay from floating iceberg. Locality as figure 6. Magnified 2 ×.

is the predominant stratified series of strata in the southwestern part of the Blaik Nappe. The Sparagmite Series is composed of arkoses and more or less feldspar-rich sandstones of red to greenish grey colour, real quartzites, pebbly conglomerates and sandy slates. Above this lowermost series of rocks follows the Långmarkberg tillite Series with real tillites with scratched boulders and with varved slates, compare Figs. 6—7. The author has divided the Series into two formations (Kulling 1942 and 1955), the lower one of dark grey colour with material of possibly eastern origin, and the upper one of reddish to light grey colour with material of a wholly different composition, and pointing to southerly to southwesterly sources. The varved slates of the last-named formation possibly got their clastic material from a floating ice-tongue, advancing in a northerly direction. The Långmarkberg glacial beds are supposed to be equal in age to the above-named Sito tillite Formation of the Norrbotten Mountains. Both of them constitute traces of the world-wide Varanger ice age (cf Kulling 1934 and 1951) in the Swedish Caledonian Mountains. The Ström quartzite Series both in the above-named southwestern district of the Blaik Nappe and in the more eastern occurrences of the same nappe along the eastern boundary of the Mountains is mainly composed of white to light grey quartzites, sandy slates and reddish to greenish grey slates. Arkosic quartzites are of secondary importance, and carbonate rocks are seldom met with.

As pointed out in the preceding synopsis the protruding units of the Rautas Nappe-Complex in northern Norrbotten are looked upon as a northern part of thrusted Lower Caledonian bedrock. The sediments in the complexes are of the same quartzite-slate composition as in the Ström quartzite Series.

The Middle Caledonian Bedrock

The southernmost part of this bedrock is called THE STALON NAPPE, the name proposed by Kulling in 1940 for the Middle Caledonian Bedrock of the Västerbotten Mountains marginal zone. The main constituent of the unit is sparagmite with intercalated or basal coarse conglomerate. The material of these conglomerates is composed of mainly Archean igneous rocks. In the upper part of the nappe unit tillite rocks and light coloured quartzites are noticed, supposed to be equal in age to the tillite of the Långmarkberg glacials and the quartzite of the Ström clastics. The lowermost part of the nappe is in the south and in some restricted parts of its eastern border zone built up of Archean igneous rocks, in the south mainly of highly-schistose greenstones, possibly to a great extent of volcanic origin, and in the east of syenite rocks. In the east the sparagmite often goes down to the very base of the nappe. To the west the metamorphism increases and the sparagmite grades into mica-schistose feldspar-rich schists, arkose rocks in mica-schist facies.

The Archean igneous rock portion of the Stalon Nappe is larger in the southern part of Norrbotten than in Västerbotten. This is so not only in the eastern or Mountain margin part of the nappe, but also in the two windows of the nappe to the west of the margin and situated within the Seve-köli Nappe.

THE AMMARNÄS INLIER in the northeastern part of the Seve-köli Nappe of the Västerbotten Mountains was mentioned in the introduction part of this paper and has also been referred to. In the district between Lake Sädvajaure and Lake Hornavan the so-called RINGSELE INLIER appears in Seve-köli Nappe milieu. The bedrock of the inlier was built up of arkoses (sparagmites), quartzites, graywackes and slates and bears comparison with both the bedrock of the Ammarnäs Inlier and to the Stalon Nappe bedrock in the south.

The next part of the Middle Caledonian bedrock makes up the easternmost part of the thrusted masses from the north of Lake Hornavan to the mountains north of Lake Saggat. This TJEGGELVAS-SAGGAT UNIT is designated on the map of 1958 as sparagmite rocks. In reality the unit is composed not only of arkosic rocks with conglomerate intercalations but also of a lot of fine-grained gneisses and other rocks, up to date insufficiently surveyed and only to a limited extent examined. The age of the different types of rocks is pre-Cambrian but otherwise uncertain.

The northern continuation of the unit just discussed is the thrusted syenite and granite complex including "THE SYENITE NAPPE" of A. Hamberg (1910). In his report on the Caledonian High Mountains of Sarek Hamberg states that the Syenite Nappe is superposed on "Eastern Siluric facies", that is on the Hyolithus Series, and plunges to the west under "the Amphibolite Nappe", Hamberg's name for the easternmost part of the above Seve-köli Nappe, where amphibolite rocks predominate. On the 1958 geological map of Sweden the syenite and granite complex has a wide distribution, and in the broad Akkajaure district runs to the west and crosses the national boundary. Towards the north the thrusted Archean bedrock continues in the eastern part of the Norrbotten Mountains and reaches the Torneträsk area. The main part of "the Syenite Nappe" is looked upon by the author as belonging to THE ABISKO NAPPE. As mentioned above (see for instance the table of the introduction and the Torneträsk map, Fig. 2), the Rautas Nappe-Complex also includes Archean igneous rocks in its lower part. From the Torneträsk area such thrusted igneous rocks can be followed to the south, to the northeast of Kebnekaise High Mountains. Some ten kilometres south of Mt Kebnekaise small remnants of such thrusted units were noticed during current geological mapping. These are not wholly registered on the 1958 geological map of Sweden. In the wide area of thrusted Archean igneous rocks of the Akkajaure district there are several occurrences of quartzitic and argillitic sediments superposed on or involved in the igneous rocks, running for the most part WNW—ESE or parallel with the dominant cross-folding. The metamorphic transformation of the sediments in the southeast is not very prominent but increases to the northwest. Thus the eastern shaly slate type changes to the northwest to sericitic schist, often with more or less pronounced tectonic banding. The bedrock of the above-named thrusted Archean is mainly composed of granite-syenite rock. But anorthosite, gabbro, porphyry, fine-grained gneiss and schistose sediments are also to be found. As to the sediments spoken of, some conglomerates and quartzites of the Archean Sjöfall Series are referred to. The big iron ore deposits of Mt Ruotevare in the mountains northwest of Lake Saggat belong to the thrusted Archean. The ore bodies are irregularly delimited segregations in anorthosite. From anorthosite transitional types of rock appear to the potash felspar syenite and to granite of the Mt Ruotevare area. According to A. Gavelin the whole sequence of rocks constitutes a magmatic stratified body. Some sixty km:s NNW of Mt Ruotevare the author has noticed anorthosite and allied igneous rocks with some small titaniferous iron ore lenses as members of the Archean thrust-masses. Further to the northwest in the far west districts of the Norwegian coast zone, in Lofoten—Vesterålen, there are deposits of titaniferous iron ore, situated in anorthosite-gabbro-syenite of possibly the same age as the named Norrbotten occurrences, representing a connecting link between thrusted igneous rocks on the Swedish as well as the Norwegian side of the national boundary.

At the time of the international geological congress in Sweden in 1910 three different hypotheses of the tectonics and origin of the actual thrusted igneous masses were discussed. A. Gavelin (1910, 1915), based on a survey of the Mt Ruotevare and adjacent areas, claimed that all the named igneous rocks were of Caledonian age. A. Hamberg (1910) looked upon the cataclastic and thrusted syenite-granite of the Sarek High Mountains to the north of the Ruotevare district as a flat-lying nappe unit with bedrock of supposed Archean age. P. J. Holmquist (1910) with experience from the Torneträsk area interpreted the cataclastic igneous rocks as representing a lot of parautochthonous Archean units, each with Archean basement rock with superimposed

"Silur", that is with a sandstone-shale sequence of the Hyolithus Series-type.

The Archean age of the granite-syenite thrust masses or more accurately the age of such rocks in the southernmost part of the Norrbotten Mountains was verified in 1934, when the author came upon localities of the complex where coarse conglomerate, upwards grading into and followed by arkose of the pre-Cambrian Sparagmite Series, overlies the granite-syenite body. Later on, such sediments on thrusted Archean were found in the lower part of the Västerbotten Stalon Nappe and described in the author's monograph of 1942.

The opinion of Holmquist, that every thrusted part of cataclastic Archean is parautochthonous and goes down in the autochthonous substratum of the surveyed part of the Torneträsk area, however, is contradicted on his own geological map. During the last decade G. Kautsky (1946, 1947 and 1953) sticks to Holmquist's opinion with material gathered from some scattered small areas of the Lake Akkajaure district. Kautsky says that the napplets sometimes are so thin that six to seven can occur in one mountain section, everyone with granite in its lower part and overlain by a sequence of arkose, white quartzite, grey-blue quartzite and slate, the last named with intercalated graphite shale and graywacke. Later, he reduced the parautochthonous nappes, called the A k k a C o m p l e x, first to about eight in number, and finally to about three big nappes. Kautsky's map of 1953 does not show the distribution of his three Akka Nappes, as his mapping was restricted mainly to the district along the national boundary. Thus G. Kautsky's opinion on the structure of the bedrock of the Akkajaure district varies, and his knowledge of its problems is restricted to the above-named boundary zone and to some places on the shore of Akkajaure. The present author does not agree to such terms as the Akkajaure Complex or the Akkajaure nappes.

The Caledonian bedrock in the northernmost part of Norrbotten, the bedrock of the so-called Pältsa district, was mapped by the author in 1956. The Middle Caledonian bedrock of the district, superposed on the Hyolithus Series and upwards followed by the Seve-köli schists, is designated as fine-grained gneiss and cataclastic granite of Archean age. On the 1958 geological map of Sweden this Middle Caledonian unit is incorrectly coloured as "Grey sparagmites outside the large western nappes". Regarding sparagmites, the author may call attention to another manifestation of inconsistency of the map-legend. Thus sparagmite and its granitic basement are shown as occurring both outside the large western nappes as well as in them. In the legend to the map, however, sparagmites are confined to "Rocks outside the large western nappes". The terms of the map-legend mainly refer to the bedrock of the southern Swedish Caledonian, and is compiled by B. Asklund. See Asklund's comments to the map.

Before finishing the paragraph on the Middle Caledonian Bedrock the author would like to comment on the western boundary of the Stalon Nappe in Västerbotten and southernmost Norrbotten. The boundary on the Sweden map of 1958 is not in accordance with the author's opinion. The diapthoritic greenstones in the lower part of the Stalon Nappe crossing northwestern parts of Lake Malgomaj—Lake Vojmsjön district were mapped by the author northwards to west of Lake Storuman, and a petrographic description of the greenstones published in a monograph (1942). For instance: the decription names the actual rocks as the Ullisjaure greenstones, referring to some type-rocks on Lake Ullisjaure. On the map of 1958 the Ullisjaure area to the west of Lake Storuman is coloured as grey sparagmite. And in a district to the west of the Ullisjaure area the western continuation of the greenstones is designated on the new map as amphibolite of the western nappes. To the west of the northern part of Lake Vojmsjön a major thrust boundary is shown crossing the Ullisjaure greenstones, and similar mica-schists are on the map placed both below and above the mentioned major thrust boundary. According to the author the west boundary of the Stalon Nappe may be drawn east of the high mountain amphibolites where, on the map, the so-called hardschists i.e. tectonically banded schists occur. Compare Fig. 1.

The Upper Caledonian Bedrock

This bedrock, as stated in the introduction, is divided into a lower part, the Seve-köli Nappe, and an upper part, the Rödingsfjäll Nappe.

THE SEVE-KÖLI NAPPE makes up the major part of the Lapland Mountains. Its name indicates that the nappe is composed of low metamorphic as well as high metamorphic schists. The former name for the lower metamorphic mountain schists is the Köli schists, and for the high metamorphic schists the Seve schists. The mountain schists are built up of a great many kinds of sediment with intercalated volcanics and intrusive igneous bodies. The high metamorphic rocks predominate in the eastern part of the nappe and form the real high mountains of Lapland. The low mountains and the undulating plateaus in the westernmost part of Lapland are mainly composed of low-metamorphic bedrock. Migmatite rocks are on the whole restricted to the lowest part of the nappe in the Västerbotten Mountains. In the Norrbotten Mountains such rocks are sparse and only restricted to some thin zones. The stratigraphy of the higher metamorphic rocks is hard to make out as leading stratigraphical zones are often wanting.

The interpretation of the stratigraphy of the lower metamorphic rocks of of the Seve-köli Nappe is based on the occurrence of some characteristic sedimentary and volcanic rocks, or more accurately termed, on some associations of strata. The best guiding association is a limestone superposed on a light coloured, pure quartzite or quartzite conglomerate, the *Slätdal-Vojtja association*. A characteristic graywacke to graywacke conglomerate, *the Gilliks clastics*, representing a formation in the sequence below the above-named, strengthens the interpretation of the stratigraphy in question. In 1925 the author discovered determinable fossils in two formations situated in the central part of the lower metamorphic rocks of the Västerbotten Mountains. The older of these two formations is the above-named *Slätdal limestone* of the uppermost Ordovician. In the Eastern facies this fossiliferous limestone is parallelised with the Dalmanitina beds and equal in age with the upper part of the Ashgillian. The younger fossiliferous formation is a slate, the Broken slate, with graptolite fossils of Lower Silurian age or more exactly the zone of *Cephalograptus cometa* and the zone of *Petalograptus folium* of Middle Rastrites beds, equal in age with the upper part of the Middle Llandovery. Up to date these two formations are the only ones in the Western Cambro-Silurian of the Swedish Mountains, where the age of the formations is paleontologically well-dated. A stratigraphy of the Western Cambro-Silurian of Central Västerbotten, with the two dated formations included, was worked out by the author and published in 1933. New evidence of stratigraphical value was brought to light during subsequent surveys in other parts of the western Cambro-Silurian of Lapland. Thus, the fossiliferous Slätdal limestone, the Vojtja conglomerate, and the Gilliks clastics were discovered in southern and middle parts of the western Norrbotten Mountains, and the stratigraphy of the Central Västerbotten bedrock extended downwards in many districts. Some names used in the 1933 year's stratigraphy have been substituted by others in order to avoid a mere local meaning. The stratigraphy now valid for the Western Cambro-Silurian of the Lapland Seve-köli nappe is the following: The Viris Series, the Lövfjäll Series and the Broken Series of Silurian age. The Slätdal-Vojtja Series, the Gilliks Series, the Seima Series, the Ro Series, and the Pieske Series all of which have most probably Ordovician age. To these series one may add the Keddåive Series below the Pieske Series in some Norrbotten parts of the bedrock. The Fjällfjäll Series in the southwestern part of the Västerbotten Mountains and exposed in the Fjällfjäll-Ljusfjäll anticline may also be mentioned as belonging to the bedrock below the Ro Series. Because of possibly great stratigraphical gaps above the Fjällfjäll Series its position in relation to other sub-Ro Series rocks is somewhat uncertain. A short description of the rocks and the distribution of the named series is now given.

The Viris Series, the youngest sedimentary unit of the Western Cambro-Silurian of Lapland, is mainly built up of a light grey fine-grained feldspathic sandstone with some detrital fragments of slate. Its name, the Viris quartzite, refers to its distribution around Lake Virisen in the central part of the Västerbotten Mountains. The Viris Series is restricted to the Virisen area and to some occurrences to the north of it, up to Lake Björkvattnet. In a restricted area at the boundary between Västerbotten and Norrbotten Viris quartzite is also reported. In the lower part of the Viris quartzite Series coarse quartzite conglomerate is observed. In another part of the Virisen area conglomerate of the same type occurs in environments of sandy phyllite to calcareous phyllite of the subjacent Lövfjäll phyllite type. Interdigitations of Viris quartzite and Lövfjäll phyllite are also met with. Though not proved, the separate conglomerate occurrences are looked upon by the author as belonging to one and the same stratigraphical bed, the Gimja conglomerate, and registering a gap in the stratigraphical succession.

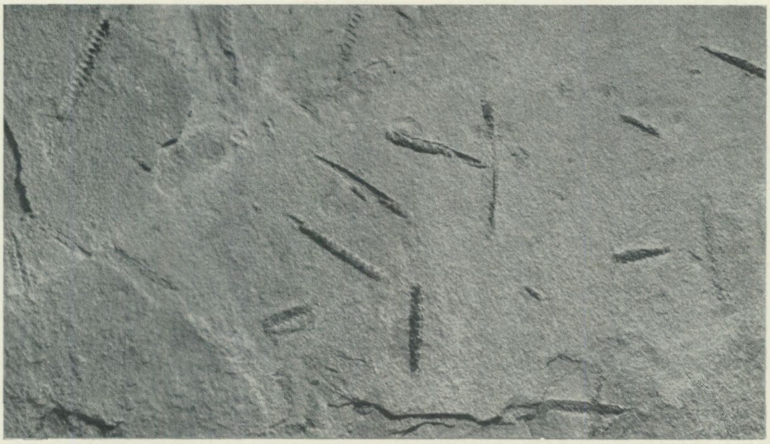


Fig. 8. Broken graptolite slate with *Climacograpti*. The Lake Broken area to the north of Lake Virisen in the middle of the Västerbotten Mountains. Lower Silurian (upper part of Middle Llandovery) age. Nat. size.

The Lövfjäll Series in the central part of the Västerbotten Mountains is predominantly composed of the so-called Lövfjäll phyllite, that is, grey, fine-grained calcareous phyllite with intercalations of slate, sandy calcareous phyllite to calcareous quartzite. Graywacke beds, sometimes with current bedding and graded-bedded slates, occur. Some thin beds of chlorite schist are noticed and may indicate tuffaceous strata. The Lövfjäll Series builds up the south-north running syncline in the central part of the Västerbotten Mountains from north of Lake Kultsjön in the south to north of Lake Björkvattnet in the north. The center of this syncline is the Viris quartzite. In the above-mentioned area on the Västerbotten-Norrbotten boundary Lövfjäll phyllite occurs as substratum of the Viris quartzite of that area. Also the Gimja conglomerate was found by the surveyor N. Marklund. In more northerly parts of the Lapland Mountains, specially in the Lake Ikisjaure district, the probable northern equivalent of the Lövfjäll Series is mainly more or less calcareous slate with greenstone beds. The material collected from the named Norrbotten areas has only been very briefly examined.

The Broken Series. This series of grey to black slate in its upper part and light grey quartzite in its lower part has only been examined in detail in the Lake Broken area situated to the north of Lake Virisen. The only locality with upper Middle Llandovery graptolites up to now is to be found in the vicinity of Lake Broken, compare Fig. 8. The Broken slate succession contains some intercalations of slaty graywacke beds. The Broken quartzite is often calcareous. In districts outside the central part of the Västerbotten Mountains it is hard to verify which slates and quartzites are equal in age to the Broken sediments.

The Slätdal-Vojtja Series. Its constituents are dark slate, fossiliferous limestone, Slätdal limestone, with a fauna rich in corals of uppermost Ordovician age, and at the bottom quartzite conglomerate, the Vojtja conglom-

Fig. 9. Vojtja quartzite conglomerate from west of Lake Vojtjajaure in the middle of the Västerbotten Mountains.

erate, cf. Fig. 9, and quartzite, the Vojtja quartzite. The conglomerate and quartzite register a very big transgression in the Caledonian geosynclinal branch of Scandinavia. The presence of the series was at first only verified in the central syncline of the western Västerbotten Mountains and in an area along the Västerbotten-Norrbotten boundary. Later the author came upon the fossiliferous Slätdal limestone and the Vojtja clastics in the Ikisjaure-Mavasjaure area along the national boundary and in an area to the east of Vastenjaure, both areas situated in western parts of the Norrbotten Mountains.

The Gilliks Series. The graywacke conglomerate, named the Gilliks conglomerate, cf. Fig. 10, and the above-named Vojtja conglomerate are quite different. The latter is a well-washed transgression conglomerate, the former, with its shaly matrix, is sometimes tillite-like, mostly unassorted, with rather heterogeneous detrital material. The graywacke conglomerate from Mt Gilliks-tjåkko in the central part of the Västerbotten Mountains was directly followed by the Vojtja clastics. The wholly different composition of the two clastic formations points to a major stratigraphical break above the graywacke beds. Chloritic schists, looked upon as altered volcanic tuffs, were observed as intercalations in the named graywacke conglomerate beds in central Västerbotten. In all the Norrbotten occurrences of the Gilliks Series there are to be found a great many kinds of rocks, sediments as well as volcanics together with the graywacke sediments, both as intercalated beds and between the graywackes and the Vojtja clastics. The volcanics are mostly basic, the sediments are calcareous phyllite, slate and some minor limestone beds. From the southern part of the Västerbotten Mountains no graywacke conglomerate, occurring below the Vojtja clastics, has been reported, only some graywacke quartzite. The composition of the material of the graywacke conglomerate is remarkable. Na-granite and Na-keratophyre occur both as pebbles, boulders and big scattered blocks. Dark oolitic dolomite, light coloured dolomite and

Fig. 10. Gilliks graywacke conglomerate from Mt Gillikstjåkko in the middle of the Västerbotten Mountains. Magnified 2 ×.

several types of sandstone are other components of the conglomerate material. The detrital material is of the same composition both in Norrbotten and in Västerbotten. In the Ikisjaure-Mavasjaure district of southern Norrbotten a stratified part of the graywacke conglomerate contains limestone lenses with fossils. The presence of *Halysites*-colonies among the badly preserved fossils points to a comparatively late Ordovician age for the graywacke beds. No real index fossils, however, have been met with. The source of material in the Gilliks clastics is probably wholly from the geosynclinal area, as the Na-granite and Na-keratophyre appear in lower parts of the geosynclinal strata, and the sedimentary boulder material, well-preserved as it is, has no pre-Cambrian look. During surveys in the East Greenland and the North-East Land parts of the Caledonian Range the author observed most kinds of sedimentary rocks mentioned above as boulder material, as formations, laid down in the geosynclinal trough. The author's opinion is that the Gilliks clastics were deposited by turbidity currents travelling along the geosynclinal axies. The currents probably transported their material from some northern source.

As to the age of the Gilliks Series the author may add the following statement. In the western part of the Norwegian Trondhjem region (Th. Vogt 1945) the Ordovician Volla conglomerate is in several respects similar to the Gilliks clastics. Together with the late Th. Vogt the author visited some Volla conglomerate localities and made comparisons that strengthened his hypothesis. The Volla conglomerate lies on a black graptolite slate, the so-called *Dicranograptus* shale of the Norwegian Etage 4 b, that is of Upper Caradocian age. In the mentioned part of the Trondhjem region a wide-spread quartzite conglomerate occurs above the Volla conglomerate, separated from the latter by a feldspathic sandstone of varying grain size. This quartzite conglomerate,

Fig. 11. Låtats pillow lava from Mt Låtats to the east of Lake Vastenjaure in the west part o the middle Norrbotten Mountains.

the Lyngestein conglomerate, may be equal in age to the Vojtja conglomerate of Lapland.

The Seima Series. In the central part of the Västerbotten Mountains basaltic volcanics with agglomerate beds lie below the Gilliks graywacke conglomerate. These so-called Seima lava beds form the upper part of the Seima Series. Keratophyre beds also occur. Below the volcanics shaly and sandy beds with some intercalated carbonate rocks predominate. As basal bed of the series pebbly conglomerate of some areas and a graywacke-slate of others is proposed. Possibly these layers are of more interformational than of real basal nature. The distribution of the named series in the Norrbotten Mountains cannot be discussed here, as field-work is still proceeding in the western parts of the mountains, where the series in question occurs. The Låtats pillow lava, cf. Fig. 11, in the author's reports on the field work in these areas is considered to be of Seima age.

The Ro Series. In the lower part of the bedrock of the Central Västerbotten Mountains the author discovered in 1926 a conglomerate composed only of serpentinized periodotite. This conglomerate, cf. Figs. 12—13, the Rotik conglomerate, was deposited on a peridotite substratum. Later, light coloured dolomite and magnetite ore were very occasionally observed as pebbles of this serpentine conglomerate. The conglomerate sometimes grades into a fine-grained facies, sometimes into a sedimentary serpentine breccia. In other parts of southern Lapland quartzite conglomerate with or without sparse

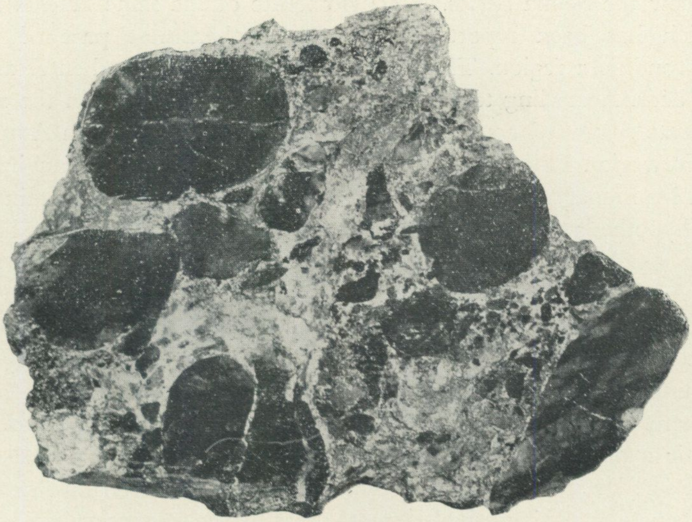


Fig. 12 and 13. Serpentine conglomerate from the Mt Rotikken area in the middle of the Västerbotten Mountains. Fig. 12 nat, size.

serpentine pebbles was met with. These conglomerates are also in the lower part of the geosynclinal sequence of strata. Most probably all the named conglomerate beds belong to one and the same formation and register a transgression in the geosynclinal area. Above the conglomerate beds sandy phyllite, slate and greenstone lava occur. The whole sequence is named the Ro Series and occurs below the Seima Series. A conglomerate of the same kind is the Rotik one, which has been reported from the southernmost part of the Norwegian Trondhjem region. This conglomerate, however, had intercalated fossiliferous beds. According to H. Hedström (1930) the fossils in the serpentine conglomerate suggested comparison with the Lower Ordovician Asaphus beds i.e. the Norwegian Etage 3 c β—γ, or the lower part of the Llanvirnian. The author in his monograph of 1933 on Central Västerbotten Mountains put forward the hypothesis that the Rotik conglomerate is equal in age to the Norwegian serpentine conglomerate. This view was based on the fact that the peridotite rocks of the Norwegian Trondhjem region seem to be restricted to one and the same level in the lower part of the geosynclinal stratification. The author held that the greater part of the ultrabasic magma forced its way upwards into the unconsolidated muds on the floor of the geosynclinal sea and came to rest there. Otherwise it is hard to give an acceptable explanation to the monomictic character of most of the serpentine conglomerates now discussed.

The Pieske Series below the Ro Series is the lowermost stratigraphic series that may be distinguished in most areas of the Western Cambro-Silurian of Lapland. Its most prominent member is the so-called Pieske limestone. Most of the limestones of the Lapland Mountains on the 1958 Sweden map in both high and low metamorphic grades (with the exception of the above-discussed Slätdal limestone) are looked upon as representatives of the Pieske limestone Formation. In districts with peridotite and Pieske limestone the two are mostly associated with each other. Possibly both are of Lower Ordovician age and correspond to the Arenig beds of the British Caledonian branch. The Pieske limestone makes up the upper part of the Pieske Series. In the middle and lower parts of the series there are sediments of varying composition as well as some volcanic rocks. Most of the rocks of the series are mica-schists. Graywacke-schists and conglomerate beds are reported from the lowermost part of the series. As to conglomerate beds the author may discuss such a conglomerate from the Norrbotten Virihaure district. The material in the conglomerate is mainly light-coloured granite. The conglomerate formation appears as feldspathic quartzite with granite conglomerate beds. Th. Vogt (1927) observed the granite conglomerate at the southeastern corner of Lake Virihaure. His opinion is that the granite material of the conglomerate is of Archean age. Above the conglomerate the fine-grained sediments of the Pieske Series are mica-schists of varying composition. In the superposed Pieske limestone small lenses of serpentine-schist occur in its lower boundary zone. G. Kautsky (1953) during his survey of the Sulitelma area came upon such lenses of serpentine-schist. Kautsky speaks of the limestone as of Upper Ordovician age. As Kautsky accepts the author's hypothesis of the Lower Ordovician age of the ultrabasic serpentinized peridotite and has no fossils to support his opinion of Upper Ordovician age of the limestone, the present author holds to his stratigraphy.

The Keddåive Series. In some scattered areas dark dolomite rocks appear below the sediments of the Pieske series. Some twenty kms east of the

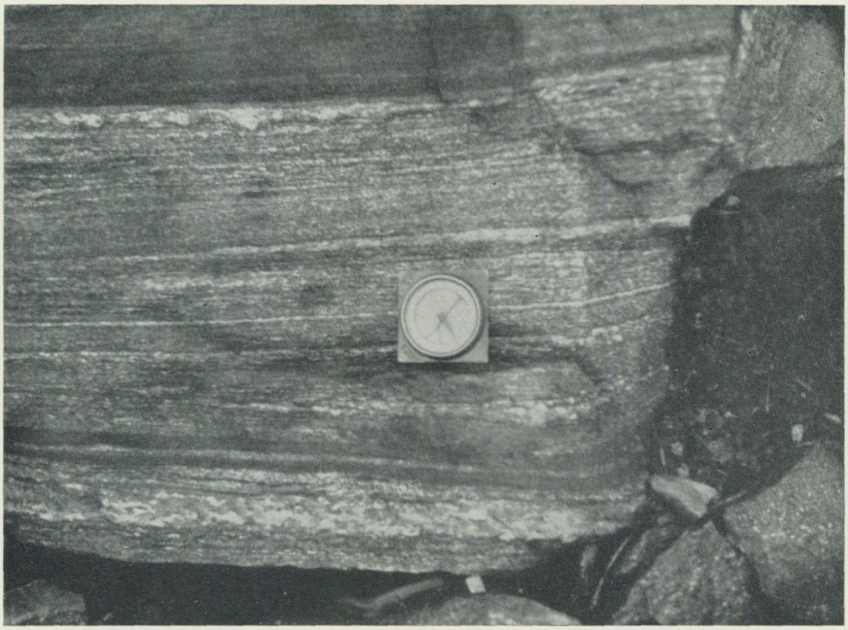


Fig. 14. Migmatite from the lower part of the Seve-köli Nappe. The Lake Gardsjön area in the east high-mountain zone of the Västerbotten Mountains. The specimen, a local erratic boulder, demonstrates the boundary between considerably felsparized part and little felsparized part of the migmatite.

southern part of the above-named Lake Virihaure, in 1948 the author came across such dark dolomite to dolomitic schist. The carbonate formation was followed about thirty kms to the south. Below and to the east of the dolomite rocks a sequence of somewhat quartzose mica-schists predominates. Amphibolite rocks are sometimes intercalated with the carbonate rocks and the subjacent mica-schists. To the east the big amphibolite body, the so-called Eastern amphibolites of the Eastern High Mountains, begins. Included in this amphibolite body scattered carbonate rocks and, of course, also mica-schist rocks are to be found. Both limestone, dolomite and magnesite occur among the carbonate rocks.

The Eastern amphibolite and high metamorphic schists, including migmatitic rocks, see Fig. 14, often make up the lowest part of the Seve-köli Nappe. In some areas, specially in the western parts of the Torneträsk area of the northern Norrbotten Mountains, carbonate rocks of the Pieske limestone type and also of the Keddåive dolomite type make up the lowermost part of the Seve-köli Nappe.

The Rödingsfjäll Nappe. In the introduction to this paper the nappe is called the uppermost tectonic unit of the Lapland Caledonides. The Västerbotten part of the nappe builds up the high mountains along the national boundary around Lake Överuman. The name of the nappe proposed by the author in 1945 (Kulling 1948), refers to the boundary-peak Mt

Fig. 15. Migmatite from the lower part of the Rödingsfjäll Nappe. Mt Brantsfjället in the northwestern part of the Västerbotten Mountains. The zoned trondhjemitization can be clearly seen in the picture.

Rödingsfjället some twenty kilometres south of the lake. All the rocks of the nappe are highly metamorphosed. To the south of Lake Överuman the boundary between rocks of the Rödingsfjäll Nappe and the lower metamorphic Seve-köli rocks below is well exposed. The main part of the Rödingsfjäll Nappe is on the Norwegian side of the national boundary where its high metamorphic schists to migmatite rocks and late-Caledonian granite bodies cover wide areas. Thick limestone and a great many ore deposits, *inter alia* the Dunderland iron ore deposits, may also be mentioned as constituents of this magnificent tectonic unit. On the Norwegian side of the national boundary the eastern margin of these thrust-masses was located in 1951—52 (T. Strand 1953), but not however followed right up to the national boundary. On the bedrock-map of Norway of 1953 this unsurveyed part of the boundary line is shown as a dotted line up to Mt Olfjället on the national boundary, where the point of crossing was put at the disposal of director S. Föyn of the Geological Survey of Norway by the present author. In northwestern Västerbotten the rocks of the Rödingsfjäll Nappe are as follows: Migmatitized schists, cf. Fig. 15, with some amphibolite intercalations, the latter possibly of volcanic origin, make up the lower part of the nappe. Above follows a limestone formation, and as upper part of the nappe, a garnet-mica-schist formation. In southern and middle parts of westernmost Norrbotten some minor thrusted rock-masses in the national boundary zone are looked upon by the author as erosional remains of the Rödingsfjäll Nappe protruding to the east from Norway. The southernmost part of these protrusions, located by the author in the high mountains south of Lake Ikisjaure, is composed of high-metamorphic schists. The northern protrusions, the ones of the Sulitelma high mountains, were surveyed by G. Kautsky (cf. Kautsky 1953) and spoken of by him as the Gasak Nappe. According to Kautsky, the lower part of the nappe is inverted and starts with a gneissic conglomerate, upwards grading first into a breccia and then into rocks, interpreted as weathered and fissured granite. Above this peculiar rock-complex follows an uninverted series of sedimentary and igneous rocks, starting with sandy schists with intercalations of dolomite and graphitic mica-schists, then volcanic rocks, staurolite-mica-schists with conglomerate beds, then mica-schists with lenses of marbles and uppermost, quartzose garnet-mica-schists. In Mt Sulitelma gabbro forms the crest of the peak and is superposed on a volcanic formation. No real basis for dating the several high-metamorphic rock units of the Gasak Complex exists. Kautsky, however, puts forth the idea that the gneissic conglomerate, referred to as the lowermost formation of the whole complex, may be equal in age to the Gilliks graywacke conglomerate of the author, and that the quartzose garnet-mica-schists, the uppermost formation of the Gasak Complex, may be interpreted as metamorphosed Vojtja quartzite. Also the other high-metamorphic sedimentary and volcanic formations of the Gasak Complex are interpreted by Kautsky as of Upper Ordovician age (cf. G. Kautsky 1953).

Do small erosional remains of the Gasak Complex exist in more northerly parts of the Norrbotten Mountains than the ones discussed above? Some forty to fifty kms to the north of Mt Sulitelma the author and G. Kautsky have both surveyed the bedrock and drawn geological maps of the area between Lake Vastenjaure and Lake Akkajaure. The editor of the 1958 Sweden map, professor N. H. Magnusson, preferred to use a geological map of the district composed of most of the author's petrographic contours and most of the thrust zones of G. Kautsky. As to bodies of the Gasak Complex in the district the author's map did not show any. On Kautsky's map and on the Sweden map three such isolated outliers are outlined. The author revised some parts of the actual district some years after the publication of Kautsky's map, and in a report to the director of the Geological survey he gave new arguments as to why he did not accept Kautsky's ideas on the tectonics of the district. In his coming monograph on the bedrock of the Norrbotten Mountains the author will give his evidence for the solution of these and other Caledonian problems.

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