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THE EXTENSION OF THE SERV
NAPPE IN THE SCANDINAVIAN
MOUNTAIN CHAIN

BY

BROR ASKLUND

WITH TWO PLATES

STOCKHOLM 1961

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Introduction

The last international geological congress (Norden 1960) called attention to studies of the Scandinavian Mountain Chain which were presented in several Swedish and Norwegian congress guides. The present author described and demonstrated the southern part of the Caledonides in Sweden (Asklund 1960) and the following paper is a further contribution on this subject. It deals with one of the most prominent tectonic problems of the Scandinavian Caledonides, namely the extension and nature of one of the greatest nappes occurring in both Sweden and Norway, the *Serv-Kvitvola Nappe*. From both sides of the political border a series of new suggestions has been given on this interesting subject.

Though Törnebohm distinguished the nappe character of Schiötz's *Kvitvola-etage* in Norway and gave the name *Kvitvola Nappe* to it he does not seem to have appreciated its continuation in the lower part of the great Seve Nappe from adjacent areas of Sweden. This distinction was made by A. Strömberg (1955) for a part of the county of Härjedalen and he introduced the name *Serv Nappe* for this tectonic unit. Contemporaneously and previously the present author distinguished in the northernmost Jemtland county and the southern part of Lapland, in Västerbotten county, a corresponding tectonic unit belonging to the great Seve Nappe but separated from it by thrust planes. During a short investigation together with professor Sven Hjelmqvist in the county of Dalecarlia (Dalarna), the southernmost part of the Swedish Caledonides, the present author had the opportunity of seeing the continuation of the *Kvitvola Nappe* in Sweden and its close similarity with the *Serv Nappe* of Härjedalen county.

Regarding the northern part of the area concerned observations made by the present author at Valsjöbyn showed that between the upper 'real' Seve Nappe and the deeper-lying 'Granite-mylonite Nappe' there occurs a series of sediments forming a distinct part of the 'great' Seve Nappe. These sediments exactly correspond to the rocks of the *Serv Nappe* and have the same characteristic and rather simple stratigraphy. In this way it has been possible to follow remnants of the *Serv Nappe* far into Lapland.

The following paper will demonstrate the existence of the *Kvitvola-Serv Nappe* as a major tectonic unit as far as can be done at present. In this connection some problems of the stratigraphy and tectonics of the Caledonian nappes and thrust tectonics arise. The most interesting is perhaps the continu-

ation of the large subjacent nappe, composed of the widely distributed late Precambrian quartzites and slates: These belong to the upper part of the Eo-cambrian in Norway and are known as the Vargian series in Sweden. They form the 'Quartz-sandstone Nappe' in Norway and the 'Vemdäl' or 'Ström' quartzite Nappes in Sweden. As has been found more recently these quartzitic nappes of Sweden coincide with the westernmost of the 'Cambro-Silurian' nappes of the county of Jemtland, the Olden Nappe. This is made up of thick sequences of Ordovician graywacke and slate resting upon Vargian quartzite. The latter rests upon anticlines of Precambrian granite and porphyry within the Olden Nappe. The largest of them is the Olden anticline at the Norwegian boundary. Others are the anticlines of Mullfjället and the 'frontier' anticline to the southwest, continuing far to the south, and the Vigeln anticline to the north of Lake Femund in Norway. It is now obvious that all these anticlines are allochthonous and belong to the Quartzite-Olden Nappe of Sweden. Entering the 'sparagmite-field' of southern Norway, however, we have the opportunity of observing a continuous series of anticlines fringed by Vargian sediments resting upon granites and porphyries of the same types as found within the Swedish anticlines just mentioned. It seems obvious that these Norwegian anticlines are *ex analogia* also allochthonous complexes forming the basal elements of the 'Quartz-sandstone Nappe' of southern Norway. And, if we seek the continuation of the 'Quartz-sandstone Nappe' in the neighbourhood of the main south Norwegian sparagmite area, we find it forming an outer frame round the sparagmites north of Mjösen Lake. Resting upon it we recognize Ordovician "phyllites", for the most part shales and dark shaly sandstones, to the west of the sparagmite field and to the south of it forming the numerous small remnants of allochthonous Cambro-Silurian above the quartz-sandstone. They are in stratigraphic and lithologic respects different from the autochthonous Cambro-Silurian of the Mjösen area and they are more similar to the Cambro-Silurian beds of the Olden Nappe of Jemtland with its shales and greywackes.

Thus it seems probable that there exists a continuous and consistent nappe-structure across the political boundary as discussed in the following pages.

In order to facilitate the geographical orientation the names of the different parts of the country are given in Plate I. From the guide book of 1960 (Ask-lund 1960) the table of the different nappes of the southern part of the Mountain Chain in Sweden is summarized here.

Schematic table of the nappes of the southern part of the Swedish Mountain Chain

III. THE GREAT SEVE NAPPE (ASKLUND 1938)

3. *The »real» Seve nappe*, including the Köli schists and Seve rocks
2. *The Seve nappe* (STRÖMBERG 1955)
1. *The Granite-mylonite nappe*. Outliers: Offerdal nappe, Alsen nappe, Fuda nappe, Frön-berg nappe (in Dalecarlia)

 II. QUARTZITE NAPPES

Vemdal quartzite nappe to the South

Ström quartzite nappe to the North

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

I. JEMTLANDIAN NAPPES (ASKLUND 1938)

5. *Olden nappe*, ASKLUND 1938

4. *Föllinge nappe*, ASKLUND and THORSLUND 1935

3. *Sunne nappe*, ASKLUND and THORSLUND, ASKLUND 1938

2. *Bjärne nappe*, THORSLUND 1940, ASKLUND 1938

1. *Skute nappe*, ASKLUND and THORSLUND, ASKLUND 1938

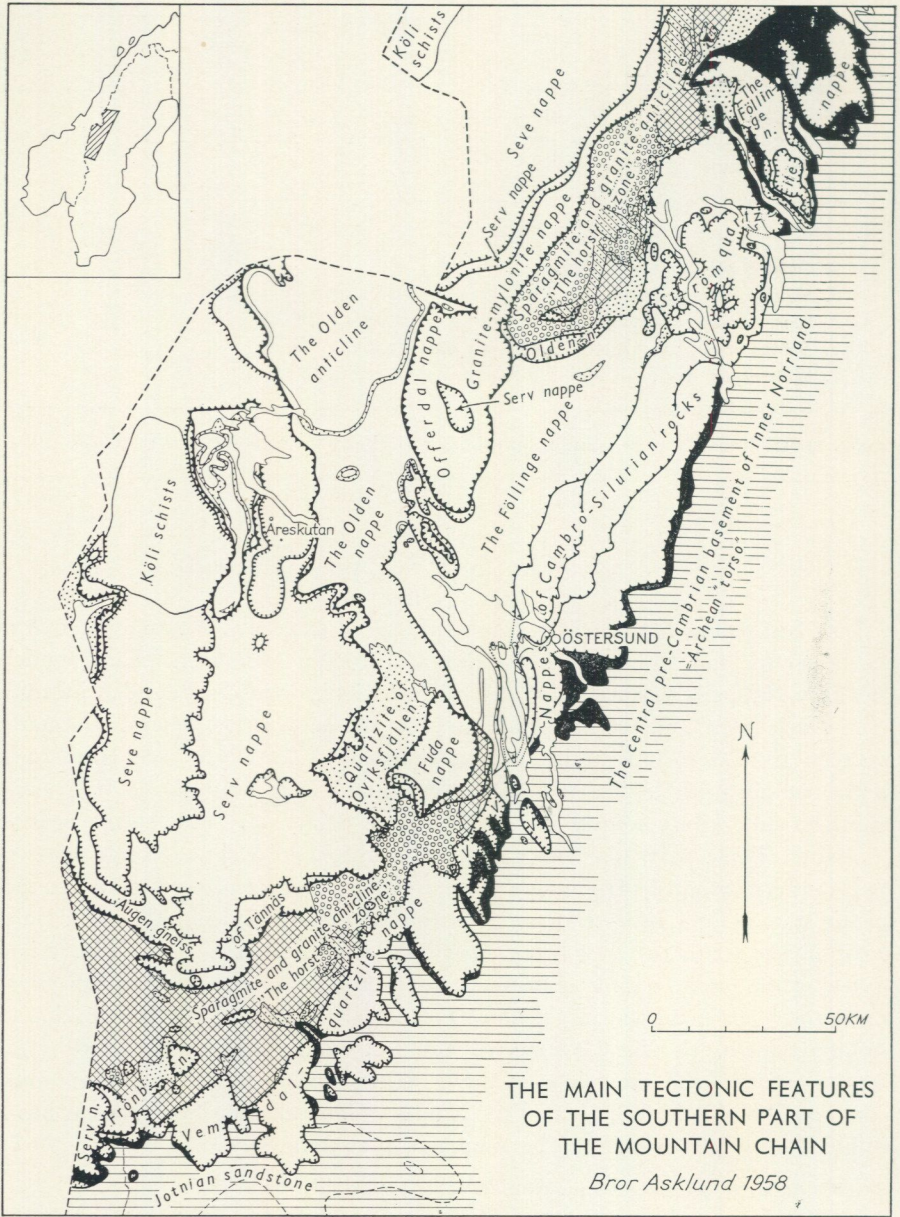
(BASAL BEDS: Autochthonous Cambro-Silurian or Archean floor to the east.)

The Serv Nappe

Arne Strömberg has recently suggested a very appropriate name for one of the larger tectonic units of the Swedish Caledonian Mountain Chain, namely the 'Serv Nappe' (A. Strömberg 1955, "Zum Gebirgsbau der Skanden im mittleren Härjedalen", cf. the list of literature at the end of this paper). The name is taken from Servfjället (the 'Serv' Mountain) in the province Härjedalen in the southern part of the Swedish Caledonides. This mountain is built up of characteristic light-coloured or nearly white quartzites and feldsparbearing quartzites. These particular rocks can be distinguished over very large areas of the southern Swedish Highlands as a tectonic unit composed of a characteristic stratigraphic series which can be followed in the Caledonides from Dalecarlia in the south to the southern part of Lapland in the north. Fig. 1 is a review of the main tectonic features of the southern parts of the Swedish Highlands and their neighbouring regions. From this we can see the distribution of the above-mentioned Serv Nappe the name of which has been adopted by me for the guide to the excursions in these regions during the 21:st International Congress 1960 (Asklund, 1960, Fig. 2, p. 8). Generally the Serv Nappe has a simple stratigraphy which can be summed up as follows:

3. Quartzite-schists or quartz-mica schists, variably deformed.
2. Massive or distinctly stratified layers of greyish or yellowish white quartzites, often with a microscopically recognizable content of feldspars.
1. A lower division of magnesia-bearing crystalline limestones, sometimes resting on dark-coloured, partly greywacke-like argillaceous schists.







Over large areas of Härjedalen, where the Serv Nappe has its widest extension, it has been invaded by numerous diabase dikes, the characteristic 'Ottfjäll' diabases. They occur not in hundreds but thousands, and have various directions. Sometimes they are in the form of sheets or small stocks.



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

Bror Asklund 1958

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. 1.

Neither the particular rocks of the Serv Nappe nor their wide distribution escaped the observation of the first geologists who visited the relevant areas in Sweden or the adjacent parts of Norway. A. G. Högbom has, on his general bed-rock map of Jemtland—Härjedalen-district (1894), marked with the designation "highland sandstones" (fjällsandstenar): "sparagmite schists" the rocks of Servfjället and adjacent areas to the west towards Ljusnedal and Tännäs, and a slice to the west of the Oviksfjällen (Oviken Mountains) extending northwards to the south of the railway station at Mörsil in central Jemtland. This concept is repeated on the bed-rock map by A. E. Törnebohm (1896). An outer slice of the eastern part of the Seve Nappe he has designated as 'the clastic facies of the Seve Group' generally comprising 'light-coloured and reddish sparagmite and sparagmite sandstone'. Inside this outer margin, which includes the main part of the area referred to by Strömberg as the Serv Nappe, Högbom has separated 'quartzite and light-coloured mica-schists of the Åreschists', and Törnebohm an area of 'crystalline facies of the Seve group (Åreschists)'. Concerning the distribution of the Ottfjäll diabase-dykes both Högbom and Törnebohm have shown them to occur in the clastic as well as in the crystalline facies of the Seve Group. Törnebohm has demonstrated in a more precise way the occurrence of the Ottfjäll diabases as groups of dikes with varying directions.

The essentially new aspect which Strömberg in 1955 has contributed to the problem of the extension of the 'clastic Seve Group' and its tectonics is that the sediment series invaded by the basalt (diabase) dikes seems to form a distinct nappe. This seems to be well separated from higher and lower masses of the "Great Seve Nappe". The upper limit is marked by a mylonite zone (e.g. in the mountain Gunnarstöten) which is characterized by a strong cataclastic deformation, and shows that the rock-masses designated by Strömberg as 'the Åreschist Nappe' are separated tectonically from the 'Serv Nappe'. The tectonic differences of milieu are reflected also by the differences of metamorphism in the Serv Nappe compared with the 'Åreschist Decke' of Strömberg. He has also shown that at several places the Serv Nappe rests upon the deepest parts of the Great Seve Nappe: augen-gneisses form a lowermost nappe of the whole. Among the augen-gneisses is the 'Tännäs augen-gneiss' of Härjedalen, a characteristic coarse, mostly strongly deformed augen-granite.

The significant observations of Strömberg tally very well with a lot of partly unpublished observations by the present author concerning the deeper parts of the Seve Nappe at different places in Jemtland. To the west of the mountain Sällsjöfjället with its thick masses of Vargian quartzite and overlying layers of Cambro-Silurian shale and greywacke, these are overlain by greyish quartzites forming the bottomlayers of the Seve Nappe. On top of them occur the mica-schists of the Åre gneiss type. On the western side of the well-known mountain Åreskutan itself with its gneisses and garnet-mica-schists occurs a series of quartzite-schists or light-coloured mica-schists containing layers of dolomitic limestone. This unambiguous series of sediments is separated by a thrust plane from the overlying Åre-gneisses. Analogous rocks including dolomitic limestone

to the south and north of Lake Kallsjön also occur on the eastern side of Mount Åreskutan. To the north, this still thinner nappe seems to vanish. It reappears, however, in the north-western part of Jemtland at Valsjöbyn, where it rests upon the northern continuation of the 'Offerdal Nappe', made up by partly mylonitized granite and syenite rocks which I have connected with the 'Granite-mylonite Nappe', the lowermost part of the 'Great Seve Nappe' of these regions. Such a quartzite series has been found also at Åkersjön in the centre of the outlier the 'Offerdal Nappe'. All these areas are to be seen in Fig. 1, and the scheme for the nappe division below is taken from the author's guide-book of 1960.

As regards all these remnants of quartzitic or leptitic crystalline schists, the author has stated several times (1938, 1959) that only detailed mapping would permit their separation from the rocks of the Seve masses.

For the preparation of the new bed-rock map of Sweden (Pre-Quaternary Rocks of Sweden, Sveriges Geologiska Undersökning, Ser. Ba, nr 16, 1958) it was essential to get a more realistic picture of the Serv Nappe which obviously formed an essential part of the 'Great Seve Nappe'. It was obvious that the revision of the province of Härjedalen, the southern part of the county of Jemtland, should be assigned to Mr. Strömberg. The other parts have been revised by the author, partly with the assistance of Mr. Göran Stålhös. This revision was made from Dalecarlia in the south to southern Lapland in the north. In the description attached to the bed-rock map quoted above, I have used the name 'Serv Nappe' as the most convenient one for the tectonic unit considered here. The main division of the nappes is the following (Asklund 1960):

- (III.) The 'Great Seve Nappe' (Asklund 1938)
 - 3. The 'Real Seve Nappe', including the Seve schists and Seve rocks (Asklund 1938)
 - 2. The Serv Nappe (Strömberg 1955)
 - 1. The 'Granite-mylonite Nappe' (Asklund 1938)
 - Outliers: Offerdal Nappe, Alsen Nappe, Fuda Nappe, Frönberg Nappe (in Dalecarlia).
- (II. and I. Deeper lying nappes, see Guide-book *f.* 1960, p. 60).

With regard to the petrography of the Serv Nappe, Strömberg (1955, p. 236) points out that the majority of the sediments are sandstones. This tallies very well with my own conception from the southern part of the Swedish mountain chain. In spite of this fact Strömberg follows A. G. Högbom and designates the rocks as 'light-coloured sparagmites'. This seems, however, to be the reason for Strömberg's supposition that the rocks of the Serv Nappe belong to the Sparagmite Formation. In his publications mentioned above, the present author has raised objections against such a schematical interpretation based on lithological reasons only, which cannot be sustained by more reliable proof. Thus it must be emphasized that real sparagmites, with their usually high content of feldspar, scarcely occur in the Serv Nappe, or very rarely only. There exist no equivalents to the red sparagmites rich in feldspar and to the frequent polymict conglomerates of the sparagmites.

In reality the sediments of the Serv Nappe show greater resemblances to the older Precambrian formations with their more feldspar-poor psammites, local arkoses, and intercalated shales. For correlations the author has referred to the sediments of the Norwegian Telemark-formation or the 'Dal'-formation of Sweden, belonging to an older part of the Precambrian sequences, and also to the 'Jatulian' sediments of the eastern and northern parts of Finland and northernmost Sweden.

There is the fact, too, that the autochthonous sparagmites lack the diabases which occur so abundantly in some parts of the Serv Nappe, *e.g.* in Härjedalen as thousands of parallel orientated dikes. The abundance of these dikes recalls the basalt dikes which occur on some old shelf-areas of the earth. After the intrusion period they have been elevated. Now their areas are often deformed and appear as characteristic former marginal areas of the continents. As examples we may call to mind the dike-complexes of the Hebrides, the late-Paleozoic basalt dikes in the boundary areas between northern England and Scotland, and the parallel basalt (diabase) dikes of Scania in southern Sweden (cf. Hjelmqvist 1939). Another typical example is the swarm of Precambrian hyperite-dikes on the Koster-islands off the Swedish west-coast (Asklund 1950). The Serv Nappe gives the impression of having originally formed such a shelf-zone intruded by basalts.

The following pages are devoted to an outline of the geographical extension of the Serv Nappe in the Scandinavian Mountain Chain. This shows a very wide lateral distribution along the highland range from south to north. In this study some previously misinterpreted rock will be included in the Serv Nappe. These are not shown on the 1958 map.

Very early investigations by Schiötz, Törnebohm and others made it quite clear that in Norway the rocks now recognized to belong to the Serv Nappe continue as the so-called '*Kvitvola quartzite-etage*' of Schiötz and the '*Kvitvola Nappe*' of Törnebohm. This is a direct continuation of Törnebohm's 'Clastic Seve Group'. The connection is demonstrated by an outlying nappe fragment situated on the boundary between the parish of Idre in Dalecarlia and the adjacent area of Norway, and from the north of Lakes Drevsjön and Flötningen to Lake Grövelsjön (cf the middle part of the 1958 map).

In the following pages the extension of the Serv Nappe is demonstrated for the Swedish Highland provinces from the south to the north. Afterwards, a new comparison will be made with the relevant Norwegian areas, cf. Plates I and II.

Dalecarlia

The boundary nappe discussed above in the parish of Idre, province of Dalecarlia, is readily accessible in its northern part along the road between Storsätern in Sweden and Valdalen in Norway. Here occur flat-lying, banded and probably primarily bedded quartzite-mica-schists, evidently identical with

the 'light-coloured quartzites' ('lyse kvartsitter') which have been distinguished and described by Gunnar Holmsen (1935). They belong to the allochthonous *Kvitvola-etage*. On the Swedish side the *Kvitvola Nappe* (according to Törnebohm) rests upon granite-mylonites of augen-gneiss type, the so-called 'augen-gneiss of the Frönberget Mountain' which is very similar to the 'Tännäs augen-gneiss' of Härjedalen. The 'augen-gneiss' rests upon a western continuation of the 'Vemdal Quartzite Nappe' which forms a very thick mass in the mountains Städjan and Nipfjället. Towards the south the 'Frönberget Nappe' thins out, and the 'Serv Nappe' comes to rest directly upon the 'Vemdal-quartzite Nappe'.

The latter nappe also thins out very much towards the lakes Flötningen and Drevsjön, and may disappear altogether so that the Serv Nappe reaches the autochthonous Cambro-Silurian. To the south of the lakes mentioned a new part of the Vemdal-quartzite Nappe is again visible.

Härjedalen and the Western Part of Jemtland

What has already been related in the above quoted papers by Strömberg and the present author is sufficient for the present description, especially since Strömberg intends to publish a monograph about this part of the Serv Nappe. However, it is a new and significant item that the Serv Nappe containing quartzite schists and diabase-dikes also occurs on the western side of the central masses of the 'real' Seve Nappe. A thin zone of the Serv Nappe occurs also to the west of the big gabbro and amphibolite masses of the Sylfjällen, and can be recognized also in the eastern vicinity of the railway station Storlien. To the north of Storlien it disappears as it does between Åreskutan and Lake Kallsjön.

A revision of the bed-rocks in the middle part of the 'Offerdal Nappe' has proved that there is a central part of the Serv Nappe also here round Lake Åkersjön and along the road Åkersjön—Häggsjön. After the discovery of the Serv quartzite in this area (Askund) Mr. G. Stålhös has carried out further mapping. The stratigraphy tallies with that mentioned before from Härjedalen and the middle part of Jemtland. The lowest part of the nappe contains the main dolomitic limestone-layer. Upon it follow darker coloured quartzite-schists and white, more pure quartzites. They are overlain by more dark-coloured quartzite-schists and argillaceous shales with numerous diabase intrusions, for the most part forming sheets. The extension of the rocks of the Serv Nappe is probably wider than shown in the bed-rock map of 1958. However, the distribution of the Serv Nappe cannot be so extensive as implied by the designation for the 'Röros-schists' on Törnebohm's bed-rock map of 1896. It is obvious that Törnebohm comprehended this outlier of the Serv Nappe rocks as belonging to the deepest part of the western Cambro-Silurian facies, placed on an outlier of his 'Clastic Seve Group'.

A new area of the Serv Nappe occurs near the Norwegian boundary at Val-sjöbyn. There road-widening operations resulted in a large road-cutting exposing the quartzite of the Serv Nappe. It is a white lamellar rock, strongly

deformed being near the thrust plane of the 'Real' Seve Nappe above. To the south-west on the isthmus between the two lakes Valsjön and Stora Rengen, a white quartzite, only slightly deformed, is exposed in large outcrops and overlain by quartzite-schists which pass into rather dark-coloured argillaceous shales. At the base of the quartzite mass a crystalline dolomitic limestone occurs, of the type known from the bottom-layers of the Serv Nappe of Härjedalen. All the rocks mentioned are traversed by numerous basalt dikes, sometimes porphyritic, and sometimes thicker and coarse-crystalline with a typical ophitic texture.

The rocks of the Serv Nappe continue from the western and south-western vicinity of Valsjön into Norway (the province of North Trøndelag). There they become much broader, reaching also the southern shore of Lake Stora Rengen and the northern side of the Lake Lenglingen. Here a comparably thick series of light-coloured quartzites and quartzite-schists is to be seen and at their base layers of dolomitic limestone. At Jule-strømmen in the parish of Sörli and between the Lakes Lenglingen and Ulen the bottom of the Serv Nappe is exposed, showing a very distinct thrust contact against the granite-mylonite rocks below.

The Serv Nappe rocks of Valsjön also continue in a north-easterly direction showing outcrops of the bottom dolomite. It is probable that they continue as a very thin slice to Bågede at the so-called Water Valley of Ström (Ströms Vattudal).

Västerbotten County of Lapland

At the boundary between Jemtland and Västerbotten the author has marked an area of the Serv Nappe (cf. the 1958 map). It forms a narrow slice of quartzite etc. on either side of Lake Stora Dabbsjön. It has been studied by the author on the north side of the lake, where well-banded quartzite-schists, sometimes more fine-grained and similar to 'leptites', occur. In this respect they also resemble more feldspar-rich quartzitic schists of the Serv Nappe in Härjedalen. Of great interest is the large number of basalt (diabase) dikes here some of which cut pronounced banding and bedding structures of the quartzites. As in Härjedalen the sedimentary structure of the latter is manifestly older than the diabases, and as these are pre-tectonic in comparison with the Caledonian thrusting and deformation, we get new and unmistakable proof of the occurrence of very old primary structures in the rocks of the Seve-complex. The diabases are quite similar to the Ottfjälls-diabases described above, and often show an analogous porphyritic structure with sharply defined phenocrysts of plagioclase.

The area has been mentioned also by O. Kulling in 'Description to the bed-rock map of the Västerbotten County' (Kulling 1955), where it is stated that the rocks show relic-clastic structures, and are in contact with diabase-like intrusions. The main part of the rocks, however, Kulling seems to attribute to

'quartzitic hartschiefer' — rocks of metamorphic origin. These 'cannot be regarded as layered sediment but as metamorphically differentiated rocks' (Kulling *op. cit.*, p. 242). This interpretation seems to emanate from the original statements of P. Quensel who considered a comparable, banding structure to be 'of completely secondary nature' (review of a paper, Quensel 1924).

From an area not far from that here considered, the Dutch geologist Dr. J. A. Staargaard has given a description of similar rocks representing a metamorphic product of arkoses, and now forming a complex of 'hartschiefer-bearing gneiss formation' (Staargaard 1955). The same designations reappear in the description of the Dutch geologist, Dr. T. H. van der Harst dealing with the adjacent Borga region (v. d. Harst 1956). It is very interesting that also here parts with a relic structure of sedimentary bedding occur, and are cut by diabase dikes, even if other parts of the complex have been affected by intense Caledonian deformation.

It is not yet possible to separate the rocks discussed from the main part of the 'Great' Seve Nappe. We can, however, presume that they represent a northern continuation of the Serv Nappe. On the bed-rock map of 1958 the present author used his observations from 1934 (Asklund 1935 b), where he named the rocks of the Serv Nappe 'mylonitic quartz-sericite-schists'.

Later Kulling (1960) has marked a somewhat broader area in an analogous position on a very schematic outline map of the northern part of the Swedish Caledonides (*op. cit.*, Fig. 4), where the rocks are indicated as 'metamorphic arkose (sparagmite), including greywacke, quartzite, and schist; scattered diabase dykes in southern Västerbotten'. The same designations are used also for a wide area from the vicinity of Lake Vojmsjön and Dikanäs to the neighbourhood of Lake Storvindeln to the north. This area of metamorphic arkose now partly replaces rocks previously designated as 'higher metamorphic sediments' belonging to the 'real' Seve rocks (cf. Kulling 1955, the map). Kulling's newly presented interpretation of the bed-rock distribution in the middle part of Västerbotten thus represents a considerable change from his previous conception.

The same designation, viz. 'metamorphic arkose (sparagmite)' is given by Kulling also for two other anticlines or 'windows' of typical sedimentary rocks to the north. These are exposed in the so-called 'Ammarnäs-window' of northern Västerbotten, and the 'Bångnäs-window' in southern Norrbotten (the northern county of Lapland), north-west of Lake Hornavan. This interpretation has been adopted also in the bedrock map of 1958 (Sveriges Geol. Undersökning Ser. Ba 16).

During recent years the present author has had the opportunity of studying the Caledonides of Västerbotten and of seeing the above mentioned areas in the field. The view is gained that the Serv Nappe of the southern regions continues still further northwards into Västerbotten county. It has also become fully evident that the Serv Nappe includes the so-called 'hartschiefer' at Järvsjö near the Lake Umnässjön along the main-road Slussfors—Tärna. These very significant rocks, which had previously been observed as loose blocks to the north and south of the road, have recently been exposed in road-cuttings in

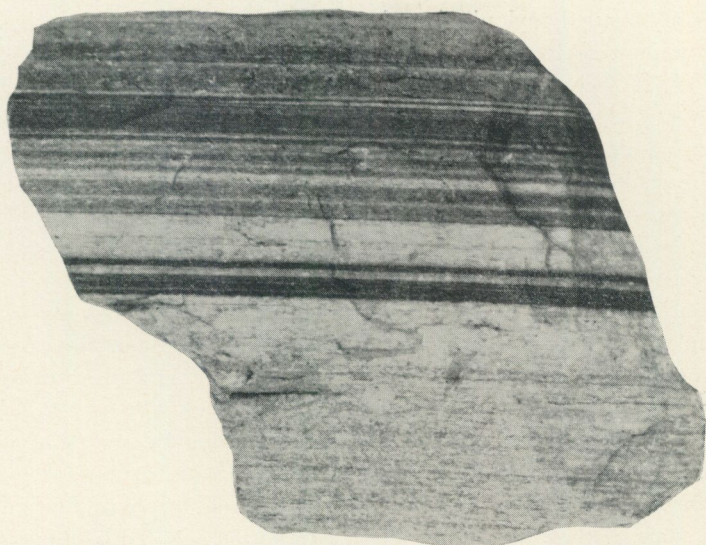


Fig. 2. Banded quartzite from the brook of Järvsjö, at the highway bridge north of the western part of Lake Umnäs. (After Kulling 1955).

the vicinity of Järvsjö and Nordanås. In an outcrop to the west of Nordanås on the northern side of the road a layered quartzite occurs, of alternating beds of light-coloured and more dark-coloured layers. The rocks are very similar to the 'quartzitic hartschiefer' from the rivulet Järvsjöbäcken at the road bridge reproduced by Kulling (1955, Fig. 164, p. 241). Fig. 2 is a reproduction of Kulling's fig. 164.

An examination under the microscope gives the following data about the quartzitic rocks. The light-coloured rocks, with only slight megascopic bedding, are for the most part made up of quartz. The feldspars are represented by plagioclase as well as by microcline-perthite. The latter occasionally forms somewhat bigger individuals. Muscovite is rare, so is a light-coloured epidote or clinozoisite. The microscope reveals an obvious bedding caused by the alternation of fine-grained layers and somewhat coarser layers. The rock has also a typical crystallisation-schistosity without primary mineral boundaries. However, the banding with finer or coarser layers represents a relic sedimentary bedding-structure. Neither mylonitization nor cataclastic deformation occur.

The darker quartzites, which exhibit alternating lighter and darker coloured layers, are mostly more fine-grained and show a more pronounced change of the mineral components. The darker layers are somewhat richer in feldspars and micas, and contain grains of epidote, sometimes in such abundance as to suggest that originally the rock contained calcium carbonate which later contributed to the formation of epidote. In the light-coloured layers especially the quartz grains are of larger size. There are no signs of a mylonitic cataclastic structure.

In the discussion about the origin of these 'hartschiefer' they were presumed

to represent 'banded mylonites' and to correspond to real 'hartschiefer' from more prominent tectonic boundaries. A quotation (in translation) from P. Quensel (1924) who first called attention to them is significant: 'The reader called attention to the occurrence of quite identical types of light-coloured, quartzitic, banded mylonites along the tectonic cliff in the Kebnekaise-section and in the geologically equivalent thrust-plane at Järvsjö, to the west of Slussfors. The specimens taken from these two localities, 300 km from one another, could not be distinguished from each other. Every effort to explain the extraordinarily regular banding as relic bedding in an otherwise unknown sedimentary formation seems to be untenable, since the rocks are strongly localized to an area in which, on account of the intensity of the tectonic movements, other components of the rock-complexes in both the overlying and underlying layers have become deformed beyond recognition'. Later on Quensel (1925) developed his views that the 'hartschiefer' and the 'mylonites' in question seem to mark a significant 'tectonic plane of movement' which should represent the first major thrust plane in the west. — In Quensel's newly published description of a map of the bed-rock in the Västerbotten highlands (Quensel 1960) the banded 'hartschiefer' are again discussed (pp. 20—21 and 41—43). The interpretation offered seems to imply that they originate from different primary elements of rocks, and might be characterized as 'tectonized horizons'.

Kulling has made some volumetric determinations on the minerals of the different layers in the bedded quartzitic rocks. There some differences occur, but no relic structures are to be seen, if the uneven distribution of the ore minerals is disregarded. Kulling (1955, p. 242) also says 'that the hartschiefer generally cannot be regarded as bedded sediment but as metamorphically differentiated rocks'. He also points out that their separation on the map is not satisfactory, and supposes them to have a considerably wider extension than indicated in his map of 1955. This is of very considerable interest, since similar rocks have a wide extension in the county of Norrbotten, the northern part of Lapland (Kulling 1955, p. 240).

With regard to the origin of the quartzitic rocks in question it can be pointed out that the changes of rock-texture seen in Härjedalen and Jemtland clearly occur in Västerbotten also. For comparison my observations from the Valsjö fragment of the Serv Nappe may be mentioned. In this we have on the one hand a great abundance of obviously relic-clastic structures in the quartzites very poor in feldspar and dolomitic limestone, and on the other hand a very high deformation in the quartzite-schists which have a certain similarity with real 'hartschiefer'. The latter occur quite close to the thrust plane between the Serv Nappe and the 'real' Seve Nappe. It is obvious that either structural type occurs also in the fragments of the Serv Nappe in Västerbotten. However, it seems quite evident to me that from the beginning of the geological mapping in the 1920's the deformation-type of the relevant rocks has been overemphasized, and that this was the reason why they were considered as 'tectonites', generally unconnected with a sedimentary rock-complex. Concerning the Dabbsjö—Borgasjö-area such a connection occurs without any doubt as found by

Staargaard, van der Harst, and, but not so evidently, by Kulling. The same explanation the present author considers feasible also for the supposed 'tectonites' of the Slussfors—Tärna-section to the north. We can probably trace a continuous zone of the rocks from the area of Dabbsjön—Borgasjön to Saxnäs and towards Silverberg—Järvsjö and even farther to the north towards Kopparberg and the vicinity of Lake Överst-Juktan (compare Kulling 1955, the map). In other words: This zone is the continuation of the sediments of the Serv Nappe towards the north and obviously not purely a tectonic zone as supposed by Quensel.

Now the question about the lateral boundaries of the nappe arises. In southernmost Västerbotten, along the Korpå-profile, the nappe seems to reach the autochthonous or parautochthonous quartzites and sparagmites in the east. Here we have no continuation of the 'Granite-mylonite Nappe' from Jemtland.

It is, however, in the section of the river Uman—Slussfors that it first becomes evident that the Serv Nappe has a foot-wall which is not tectonically connected with it, but represents an independent nappe belonging to the Seve Thrust Nappe-complex. Now this tectonically lowest sub-nappe is not composed of granites or syenites as in the south, but of gneisses, garnetiferous mica-gneisses, or mica-schists very similar to such rocks of the 'real' Seve Nappe. These gneisses occur east of Nordanås, and continue to the east of Slussfors, where the thrust-boundary between the Seve-complex and the underlying quartzite-sparagmite complex is situated. The garnetiferous gneisses are the same as the Åre-gneiss type to the south. It is, indeed, very interesting to find that these gneisses rich in feldspar here take the place of the deformed granitic slices or nappes in the more southern highlands. Naturally, it is not to be expected that granitic rocks can continue *ad infinitum!* The wide Precambrian block — of which the 'Granite-mylonite Nappe' is a slice detached by the thrusts — has certainly had a very varied composition!

The author has no personal experience of any continuation of the Serv Nappe north of Överstjuktan in Västerbotten. On the bed-rock map of 1958 the so-called 'Ammarnäs-window' has also got the same designation as the Serv Nappe. According to the opinion of the present author this is wrong, since the rocks within the window are mainly the greywackes and shales of the Cambro-Silurian, and exhibit very great similarity to the Ordovician greywackes and shales which build up the Olden Nappe in Jemtland. He therefore believes that the rocks of the Ammarnäs-window belong to the Olden Nappe, except a little area of sparagmite and Vargian quartzite beneath a lower thrust-plane.

The upper limit of the Serv Nappe in Västerbotten is obviously represented by a thrust plane against the 'Real' Seve Nappe. It will without doubt be an interesting task to trace the thrust boundaries of the Serv Nappe of Västerbotten, and by analogy also their possible continuations in the northern part of Lapland.

The Serv Nappe in Norway

The northern part of Trøndelag (Nordtrøndelag.)

After establishing that the Serv Nappe forms an integral part of the 'Great Seve Nappe' in Sweden it seems logical to follow it into Norway (Sörli and Nordli parishes). To the south of the lakes Valsjö and Stora Rengen the Serv Nappe rocks turn westwards into Norway, forming there an upper nappe upon the continuation of the 'Granite-mylonite Nappe'. The latter reaches the valley of the little river Grubbdalsån resting upon the Cambro-Silurian of the Olden Nappe. Upon the revised edition of the bed-rock map of Norway (Holtedahl and Dons 1960) the continuation of the granite-mylonites is marked as 'porphyry in the eastern border areas'. The thrust plane beneath the Granite-mylonite Nappe on the Norwegian map follows the Olden granite anticline from Sweden, in Norway called 'the Grong culmination' (Chr. Oftedahl 1956). On the Norwegian side the rocks of the Serv Nappe are included in the designation 'Cambro-Silurian sedimentary rocks, etc'. Obviously, however, the quartzites, schists, and insignificant dolomitic limestones of the Serv Nappe have a wide distribution, and the task of distinguishing them is of great interest (cf. above p. 11).

The boundary-region between Norway and Dalecarlia—Härjedalen of Sweden. — The 'Kvitvola Nappe'.

On page 9 above some remarks were made about the continuation of the Serv Nappe into Norway, where it corresponds to the 'Kvitvola Nappe' of Törnebohm.

In the 'symposium' held in 1952 at Uppsala University concerning the Inter-Scandinavian 'Caledonian' problems the three Norwegian geologists Per Holmsen, Christoffer Oftedahl and Steinar Skjeseth presented an important contribution in the shape of a comprehensive tectonic map of the south-Norwegian 'sparagmite-field' (cf. B. Asklund and Nils Marklund, 1954, p. 106, here Fig. 3). A very significant novelty was their attempt to identify those areas of the sparagmite-field which ought to belong to the 'Kvitvola Nappe', i.e. the thrust, partly deformed so-called sparagmite-quartzite masses lying upon the 'quartz-sandstone Decke' or nappe. These supposed sparagmite-quartzite masses seem to belong to the overlying rocks of the *Kvitvola quartz etage*. This 'etage' was distinguished by Schiötz (1891), and interpreted by him originally as an uppermost autochthonous layer of the sparagmite-quartzite complex. Törnebohm, however, recognized it as a thrust nappe which he named the *Kvitvola Nappe* (cf. above p. 9 and Fig. 3 here).

The concept given by the three Norwegian geologists in 1952 is certainly schematic. Its details may be subject to discussion and change, but the main features give valuable clues for a deeper understanding of the tectonic structure

of the 'sparagmite-field'. Their work is thus an advance beyond the outlines drawn up by Törnebohm in 1896.

For a comparison with the present author's interpretation of the neighbouring region on the Swedish side, incorporated in the bed-rock map of 1958, some points may be discussed here.

South-east of Engerdalen in Norway the Kvitvola Nappe does not continue towards Sweden, but the Norwegian 'Quartz-sandstone-Nappe' = the Swedish 'Vemdals-quartzite Nappe' does (in the mountain Härjehogna at the boundary).¹ The same quartzite nappe forms an isolated outlier to the south of the lake Flötningen. To the north of the lakes Flötningen and Vurusjön the quartzite nappe seems to have become squeezed out, and for this reason the overlying Kvitvola — Serv Nappe reaches the autochthonous Cambro-Silurian beds beneath it. To the east of the big Lake Femund (Norway) the *autochthonous* sparagmite area in Sweden has been supposed to reach nearly as far northwards as the road Fjällnäs—Brekken (to Röros) and to pass the boundary-lake Rogen (Högbom 1894, Törnebohm 1896, Asklund 1958, bed-rock map). On the Norwegian map however (here Fig. 3) the area to the north of Lake Rogen has been represented as the Kvitvola Nappe.

The contrast encouraged the present author to undertake a revision of the area in question by means of a critical examination of the original maps and specimens of Törnebohm and others on the Swedish side, and also to study the rock samples collected by Dr. Gunnar Holmsen in the area covered by the map sheets Nordre Femund and Söndre Femund (lodged in the collections of the Geological Survey of Norway, Oslo) on the Norwegian side. By this revision he has got a new picture of the area Rogen—Vigeln—Tännäs on the Swedish side and the Rogen—Vigeln—Röa on the Norwegian side (the last place at the northern part of Lake Femund).

This revision and his own field-studies along the road Fjällnäs—Brekken—Aursunden and further towards the north, to Nedalen, have convinced the author that the northern part of the autochthonous sparagmite-area on the Swedish side as designated by Törnebohm and Högbom must be thoroughly restudied. Although designated by them as 'lower sparagmites' most of the area belongs, however, to the Vemdals-quartzite, and thus must be comprehended as allochthonous, forming a part of the Vemdals-quartzite Nappe (see Plate I). This has evidently a northern part which on the Swedish side plunges beneath the Tännäs' augen-gneiss on the stretch between Tännäs and Malmagen. On the Swedish side the quartzite continues to the granite-anticline of Vigeln on which it rests with a basal conglomerate on the Vigeln-granite (observation made by Törnebohm). Upon the quartzite probably already on the Swedish side follows a series of dark-coloured shales and greywackes quite similar to the Ordovician greywackes and shales in the Swedish Olden Nappe and belonging mostly to the Chasmops Beds (Caradoc, cf. Asklund 1960, pp. 10—12 and 16). On the Norwegian side these greywackes and shales have a greater extension,

¹) According to oral information given by S. Skjeseth, however, also this southern part of a quartzite nappe belongs to the Kvitvola Nappe.

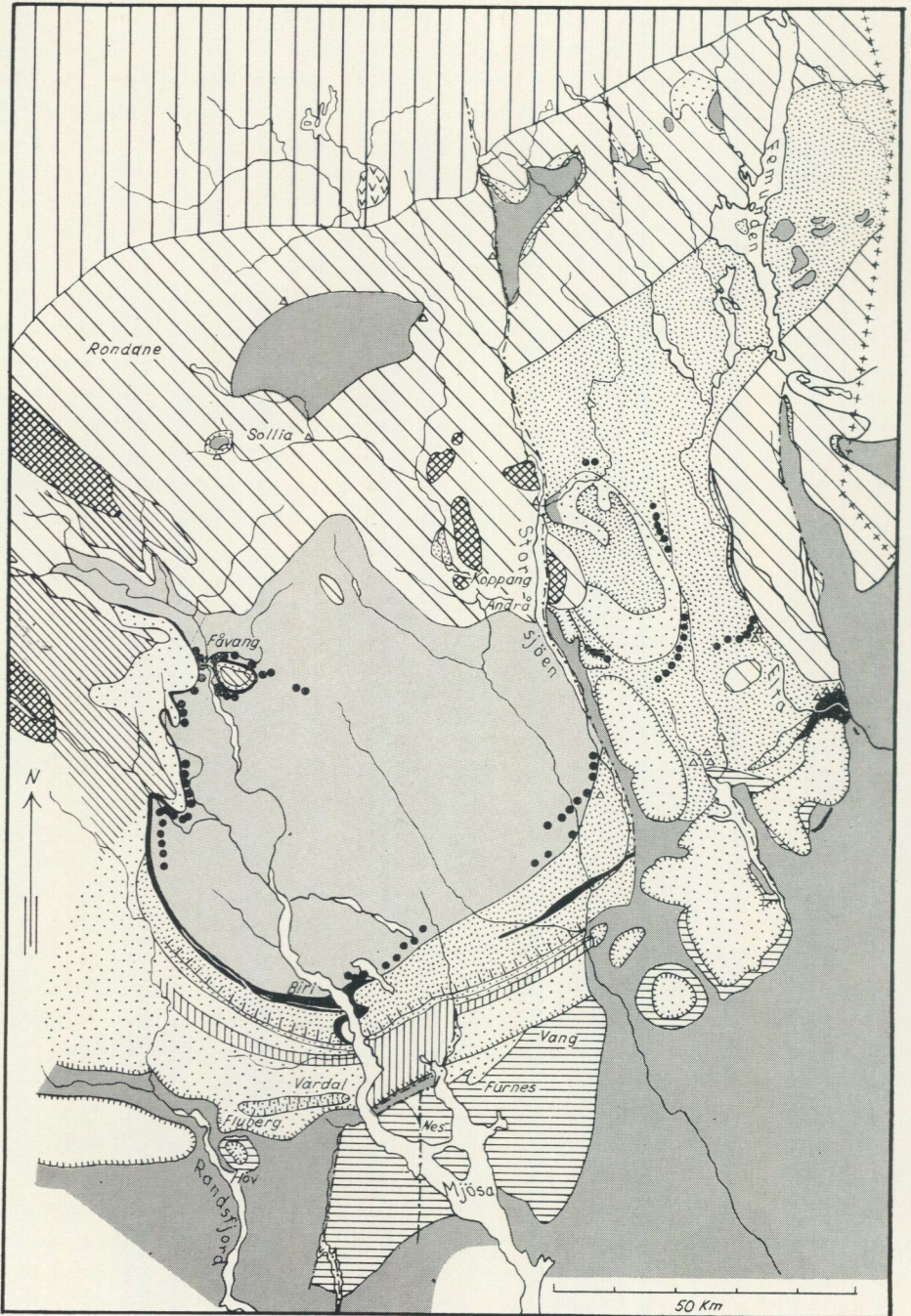
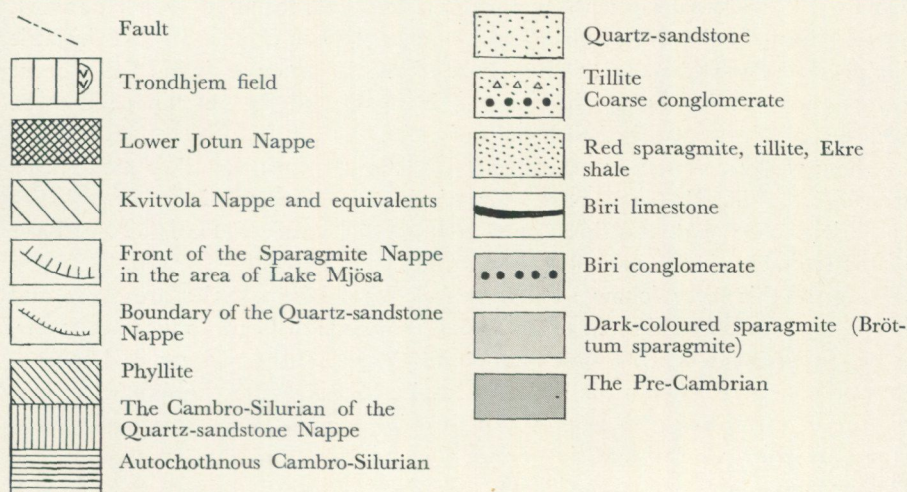


Fig. 3. General map of the 'Sparagmite field' of Southern Norway, drawn by P. Holmsen, Chr. Oftedahl, and S. Skjeseth 1952. (After Asklund and Marklund 1954.)

and seem to pass round the southern part of the Vigeln-massive and to join the 'phyllite-formation' which occurs combined with 'blue quartz'. The latter forms layers lying upon the eastern part of the 'Femund-quartzite' (cf. G. Holmsen 1935). On top of this complex follows the *Kvitvola Nappe* at Røa to the eastern part of Lake Femund, forming an outlying part of the nappe. Its distribution is not shown to be so extensive as on the Norwegian bed-rock map of 1952 (Holmsen, Oftedahl and Skjeseth, cf. Asklund and Marklund 1954, here Fig. 3). The outlying part of the nappe on the eastern side of Lake Femund was supposed by Törnebohm to be an independent nappe which he called the Røa-Nappe. It seems, however, to have its direct continuation in the mountains Flenskampene on the western side of Lake Femund, as has also been supposed by the Norwegian geologists. On the other hand it becomes quite obvious that *beneath* the Røa-Kvitvola Nappe there occurs a phyllite-blue-quartz formation resting upon a *lower* quartzite-formation *not belonging* to the *Kvitvola Nappe*. The scarce specimens collected from this boundary region have also more resemblance to the Vemdal-quartzite on the Swedish side than to the strongly deformed feldspar-bearing quartzites of the Røa-Kvitvola Nappe.

Beneath the *Kvitvola Nappe* in the mountains Flenskampene occurs a 'phyllite-bluequartz-formation' in the same position as on the slopes of the Vigeln-anticline. Very interesting is then the statement of Gunnar Holmsen (1935) that the granite occurring beneath the phyllite-bluequartz-formation of Tufsingdalen is quite similar to the granite of the Vigeln-anticline, and represents a 'granite tricolor', a three-coloured granite in the sense of Th. Kjerulf. For this reason it may be asked, whether or not the Cambro-Silurian (phyllite-bluequartz-formation) of Tufsingdalen is allochthonous, like the phyllite-bluequartz-formation of the Vigeln-area which, according to the author's interpretation given above, rests upon the long transported Vemdal-quartzite. This question opens a wide perspective which may now be examined.



The Vigeln-anticline with its very large extension to the north passing on the western side of the Syl-Mountains towards Storlien on the western side of the middle part of Jemtland is very similar to the anticline-areas of Jemtland, *e.g.* the anticline of Mullfjället to the west of Åreskutan and Olden (cf. Plate I). In the northern part of the Vigeln-anticline, *e.g.* at Enaälven in Jemtland, the porphyry of the anticline is overlain by a quartzite similar to the Vargian quartzite which rests upon the porphyry and granite of the Mullfjäll and Olden anticlines. Upon this Vargian quartzite rests a series of shale and bluequartz layers which correspond to the Cambro-Silurian brims of the anticlines of Mullfjället and Olden. These brims belong to the Cambro-Silurian greywackes and dark-coloured shales in the Olden Nappe. To the south this nappe is equivalent to the Vemdal-quartzite Nappe, here lacking Cambro-Silurian remnants. Upon the bedrock maps published and quoted above this marginal zone of Cambro-Silurian beds has not been indicated for the Vigeln-anticline, Törnebohm has, however, shown a little area of bluequartz on the quartzite of Glucken Mountain south of Storlien. However, the old observations of Hörbye and Törnebohm along the boundary between Sweden and Norway to the west and southwest of the source of River Ljusnan have shown that there occur such shales, to some extent similar to alum shale (Törnebohm 1896, p. 150).

In consequence of the facts considered here the Vigeln-anticline seen as a whole from Storlien to Femund must be understood as an allochthonous anticline of the same nature as the mentioned Mullfjäll and Olden-anticlines; and the Vigeln-anticline forms a more south-westerly situated anticlinal part of the bottom of the Swedish Olden—Vemdal-quartzite Nappes. It rises from a very big sheet of Vemdal-quartzite. By analogy the same seems to be true as regards the geological and tectonic position of the anticlines of Precambrian rocks occurring beneath the Kvitvola Nappe on its continuation stretch towards the south-west to the areas of Rondane and the valley of Lågen—Ottadalen. Among these anticlines are to be mentioned: Brydalen—Undsetdalen's anticline (the window of Spekedalen) with 'granite tricolor' (according to Per Holmsen), Atnasjö-anticline between Lake Atnasjö and the River Glommen, and the little Snödöla-anticline. Also to the northeast of the Brydalen-anticline there occur several small anticlines, not investigated in detail. All the anticlines are to be seen on the Norwegian bed-rock map of 1960.

These western anticlines are characterized by the fact that they seem to be overlain by the Vargian part only of the late Precambrian ('upper' Eo-cambrian) complexes and thus not by sparagmites *sensu stricto*. The basal layer of the sediments is the so-called *basal tillite* (Chr. Oftedahl, 1945, p. 285). On the top of this layer follow sometimes redcoloured Ekre-shales, quartzite and bluequartz, and, to a limited extent, small remnants of Cambro-Silurian layers, mica- or graphite-bearing slates. Opposite to the southern areas real sparagmites are lacking beneath the Kvitvola Nappe of this region. This characteristic feature of the Norwegian zone of anticlines is common to the Jemtlandic anticlines, to which we can add six smaller ones, *viz.* the porphyry-anticlines of the Oviken mountains (in Stenfjället), Nordbyn, Djupsjön and Kaxås, Hover-

berget and Bingsta-berget. As can be seen from the bed-rock map of 1958 these anticlines are spread over a large area of Jemtland, and the area with the Vargian formation alone, *i.e.* without the sparagmite formation beneath, is very large.

This whole area seems to have been covered also by the Kvitvola-Serv Nappe. The widening of the *Kvitvola Nappe* postulated by the Norwegian geologists (Holmsen, Oftedahl and Skjeseth, cf. Asklund and Marklund 1954) for the Norwegian part of the Mountain Chain means a widening of the Seve Nappe of Törnebohm. When we elongate this southern boundary of the Great Seve Nappe from the Swedish boundary it means that the Seve Nappe will advance a great distance over the South-Norwegian Sparagmite field. In the front of the Kvitvola-Serv-Nappe we now and then find zones of the bottom nappe of the Great Seve Nappe, namely the Granite-mylonite Nappe manifested by the occurrence of 'augen-gneisses'. The boundary of the Great Seve Nappe passes from the broadest part of Lake Femund to the upper part of the Rendalen valley. There it seems to turn to the east or south-east over the sparagmite fields in a somewhat different way from what has been indicated by the three mentioned geologists, and then continues beneath the outliers of the Jotun Nappe at Koppang, Björånes, and Ytre Rendal.

The boundary of the Kvitvola Nappe towards the northwest, on the northern side of the Norwegian anticlines mentioned above, certainly needs re-mapping. It seems evident that the Hummelfjeld-area with its numerous dikes of diabase south of Rörås, represents a repetition of the diabase rich Serv Nappe of Härjedalen as was supposed by Törnebohm. The contact between the Kvitvola Nappe and the 'Real Seve Nappe' situated more to the north-west is here perhaps difficult to determine as is the contact between such a zone and the Röröschist above it. It is without doubt an important task to map again the rock-boundaries given by Törnebohm in the area between Rörås-Feragen and Lilla Elvdal-valley and the Folladal-valley to the west in order to see what significance his boundaries have.

However, Per Holmsen has also claimed that the Trondhjem field should represent an upper thrust complex, advanced over a lower thrust nappe of deformed, light-coloured sparagmites. This statement is a valuable contribution to the discussion which has been arisen around this question (Asklund 1955, P. Holmsen 1955 and O. Holtedahl 1956). However, the southernmost boundary of the Trondhjem field cannot traverse the map sheet Tynset (cf. Per Holmsen 1950) as shown, because deformed 'light-coloured sparagmites' also occur to the north of the supposed boundary. Furthermore, on the northern side of the boundary the diabase-traversed Hummelfjeld area is situated, and this is supposed to belong to the Kvitvola-Serv Nappe. Consequently we must assume the occurrence of a thrust-plane (or two thrust-planes) situated further north, between the Kvitvola rocks and the Trondhjem field.

Concerning the limitation of the Kvitvola Nappe to the south against the autochthonous sparagmite-area it seems possible here to recognize the augen-

gneiss granite-mylonite nappe. Towards the north-east a sheet of augen-gneiss obviously occurs beneath the Kvitvola Nappe to the east of Lake Feragen, on the western side of the Vigeln anticline. Also the large augen-gneiss mass of Sålekinna seems to lie beneath the Kvitvola Nappe. It is, however, not clear, whether or not this augen-gneiss is directly connected with the augen-gneisses in the western parts of the Tynset-quadrangle, continuing to Brydal or to the east of Brydal. On the Swedish side the augen-gneisses of the Frönberg type are unevenly distributed, and are similarly lacking in Norway over long distances. The sub-nappe of this type seems often to have thinned out or to have disappeared altogether.

The limit of the Kvitvola Nappe towards the south as shown in 1952 by the three Norwegian authors seems to imply that this Kvitvola Nappe should include also the occurrences of dolomitic limestone at Koppang and likewise the carbonatic rocks more to the west, as *e.g.* at Sollia and Atna. These had previously been interpreted by Törnebohm as Cambro-Silurian rocks or as belonging to the Biri-limestone of the sparagmite-formation.

When the augen-gneiss nappe beneath the Kvitvola Nappe is lacking, we find the Kvitvola Nappe lying on the 'Quartz-sandstone Decke', *i.e.* the nappe corresponding to the Swedish 'Vemdalen-quartzite Nappe' or its continuation to the north, the Olden Nappe. Thus we find in Norway a couple of localities, where the Kvitvola Nappe lies directly upon the quartz-sandstone. The most interesting of these is on the eastern side of the Rendalen Valley and Lake Storsjön. Here the Kvitvola Nappe at Andrå has a base of the underlying Quartz-sandstone Decke which forms a 30—40 km long outlier. A new outlier appears again to the east of Deset and another to the south-west of Ossjö. If we refer all these outliers to one gigantic sheet of quartzite thrust over a basement of different rocks belonging to the sparagmite-formation and Cambro-Silurian, we get a minimum length for the thrust of 70 or 80 km. This length very closely approaches the thrust length assumed by Chr. Oftedahl for the 'Quartz-sandstone Decke', *viz.* 100—150 km (cf. the discussion in Asklund and Marklund, 1954, p. 161).

Over several stretches, however, the 'Quartz-sandstone Decke' is lacking beneath the Kvitvola Nappe. This may be due to the fact that the Decke is completely squeezed out or that it may have been primarily lacking over some stretches. Yet, we have also to reckon with the eventuality that it has not been separated from the sparagmites during the mapping. Such an example may be represented by the Snödöla-anticline where, according to Christopher Oftedahl's original opinion (1949, p. 164 ff.), the 'lower light-coloured sparagmite' stratigraphically corresponds to the 'quartz-sandstone'. Following the concept developed here the present author is inclined to develop this supposition still further, and to suggest that this quartz-sandstone on the Snödöla-granite in reality is the main rock of the allochthonous Quartz-sandstone Decke (= the Swedish Vemdalen-Olden Nappe).

Concerning the question of the Cambro-Silurian layers resting upon the 'Quartz-sandstone Decke' Steinar Skjeseth has supplied very interesting data.

He has emphasized the evident change of facies and the significant increase in thickness which becomes manifest on comparison of the relatively thin Cambro-Silurian of the autochthonous beds with the rather thick beds of the same age belonging to the allochthonous series upon the Decke in the neighbourhood of the great Lake Mjösa. If we assume the so-called 'phyllite-formation' situated to the west of the big central sparagmite-field (cf. Fig. 3 here) to be the continuation of the allochthonous Cambro-Silurian to the south, at the northern part of Lake Mjösa, we also have a parallel with the differences of facies seen in the Cambro-Silurian beds resting upon the Vemdalen-Olden Nappe in Sweden: Towards the north-west the amount of shale increases at the expense of the limestone-facies. In Sweden the middle part of the Ordovician is dominated by greywackes and alternating argillaceous shales. In Norway, so-called 'sandstone-shales' with alternating layers of dark-coloured argillaceous shales predominate, as described by K. O. Björlykke from Gausdal, north-west of the town of Lillehammer. The descriptions from the last area indicate a distinct coincidence with the Cambro-Silurian of the Jemtlandian Olden Nappe (K. O. Björlykke 1905, p. 57, Ths. Münster 1900).

Review of the Norwegian Sparagmite field

The conditions on the Norwegian side of the boundary which come under consideration due to the appearance of the Serv Nappe and other nappes on the Swedish side may be summed up as follows:

1. The *Serv Nappe* continues as the *Kvitvola Nappe* on the other side of the border. It has a probable extension as schematized by P. Holmsen, Chr. Oftedahl and S. Skjeseth, after correcting the extension of the nappe round the Vigeln-anticline, where the Vemdal quartzite Nappe = the 'Quartz-sandstone Decke' has a wider extension than previously supposed.
2. The boundary of the *Kvitvola Nappe* towards the northwest, with the Trondhjem-field, is still vague, as is the existence here of the 'Real Seve Nappe'.
3. The *substratum* of the *Kvitvola Nappe* made up of anticlines of Precambrian or Archean rocks — the windows of Spekedal, Atnasjö, Snödöla and others — corresponds to the Jemtlandic allochthonous Precambrian anticlines which form the base of the Vemdal quartzite-Olden Nappe. The late Eocambrian layers on the Norwegian anticlines correspond to the Swedish Varegian Vemdal-quartzite and the other stratigraphical elements which form the Varegian formation of the Eocambrian *sensu stricto* (Brögger 1900). The Cambro-Silurian layers upon the Varegian quartzites — in Norway the so-called phyllite-formation — correspond in general to the lower Cambro-Silurian of the Olden Nappe in Sweden.
4. With regard to its uniform composition, the 'Quartz-sandstone Decke' in Norway seems to be a true parallel to the 'Vemdal-quartzite Nappe' of Sweden. Also the allochthonous Cambro-Silurian beds resting upon it show very great

similarities in facies with the (allochthonous) greywackes and argillaceous shales of the Olden Nappe, belonging mostly to the Middle Ordovician.

5. *The younger tectonic phase* of the Norwegian Sparagmite field is characterized by minor thrusts, younger than the big thrusts and giving rise to the 'roof-tile structure' (Norw. 'takstein-struktur'). This kind of imbricate structure is similarly characteristic for the sparagmite-formation of Härjedalen and southern Jemtland. It is a phenomenon parallel to the 'inversion tectonics' of the north-Jemtlandic-Laplandic sparagmite-area which is also younger than the big thrusts of the Caledonian range (cf. Asklund 1935 p. 84, in Asklund and Thorslund 1935 a and Asklund 1938).

The extension of the Serv-Kvitvola Nappe

As the result of his studies of the extension of the Vemdal-quartzite Nappe and Ström-quartzite Nappe in Sweden and the 'Quartz-sandstone Decke' as a continuation of the Swedish quartzite Nappe(s), the present author has pointed out (Asklund 1951, 1954, p. 144) that the quartzite nappe, taken as a unit along the mountain chain, is about 700 km long extending from Hallingdal and Hemsedal in the middle part of southern Norway to Lake Hornavan in Swedish Lapland. The Serv-Kvitvola Nappe has a known length of about 550 km from Rondane south of the Trondhjem-field to Överst-juktan in southern Lapland (Plates I and II). It raises the same problem as all these nappes, namely their great length compared with their very small thickness. How could they resist tearing, when movements over such long stretches are postulated from the thrusts themselves? For the present we can only state it as a fact. But if we do so, the still unknown thrust-lengths are explicable: In other words if these nappes have such great lateral dimensions, there is no difficulty in postulating a corresponding length in the direction of overthrusting — or underthrusting. Concerning the Vemdal-Olden Nappe we can establish for Jemtland and the adjoining part of Trøndelag that its visible breadth is about 250 km from the easternmost outliers in Jemtland, the Bingstaberget and Vemdalen mountains, to its westernmost parts in the vicinity of Formofoss and Grong in Norway, where the Olden-anticline (= Norw. Grong-culmination) plunges beneath the West-Norwegian slice of Archean in the Granite-mylonite Nappe. The Serv-Kvitvola Nappe has a breadth from Rondane in the west to Idre parish in the county of Dalecarlia in the east, of about 150 km. However, it is not unlikely that the Kvitvola Nappe plunges beneath the whole Trondhjem-field and reappears on its western side, for example along the valley of the Driva-River and also occurs as free-lying sheets of the 'Seve Nappe' shown by Törnebohm on his bed-rock map of 1896 far to the west of the Trondhjem-field. From own field-experience the author remembers the slices of Seve-rocks which Törnebohm has indicated between the Örkedalen-valley and Vinjefjord SW and W of Trondhjem. At the above mentioned fjord the schistose 'Seve'-quartzites are very similar to corresponding rocks of the Serv Nappe.

Age of the Rocks in the Serv-Kvitvola Nappe

The Norwegian geologist Schiötz interpreted the rocks of the Kvitvola Nappe as forming a younger sparagmite group, the 'Kvitvola-etage' which was considered to be even younger than the Cambro-Silurian. Törnebohm interpreted the quartzite-sparagmite rocks of the Kvitvola mountain as forming a nappe of older rocks, and meant that they represented a higher layer of 'light-coloured sparagmites', the sparagmites proper. They then correspond to the clastic Seve group of Törnebohm.

The concept of the more or less deformed sparagmite rocks has been adopted by the Norwegian geologists and by A. Strömberg (1955) in Sweden.

In contrast to this more prevalent interpretation the author (1960, p. 18 ff.) has offered another proposal. He has called attention to the fact that the main mass of the rocks is no sparagmite in the proper sense. In reality the rocks are very unlike sparagmites *sensu stricto*. The original definition of Esmark of 'sparagmite' was a fragmentary rock in which angular or more rounded fragments of rocks and minerals formed the rock mass. It was in fact the conglomeratic types of sparagmite which had caught his attention. In the Serv Nappe conglomerates are rare and quartzites dominate, for the most part with only little feldspar. Quartzite and argillitic shales have a wide extension, and to some extent real shales too. Very characteristic are also the dolomitic layers which in Norway as well as in Sweden are always situated at the base of the nappe. There are *no* occurrences of red upper sparagmites from the autochthonous beds of the Sparagmite formation. Nor are there any occurrences of the widely distributed greyish green quartzites rich in feldspar or of sparagmites which build up the lower parts of the autochthonous sparagmite-formation. It is only the light-coloured, mostly pink sparagmites rich in quartz which to a certain degree may be comparable with the light-coloured quartzites of the nappes. However, the real sparagmites are coarser and richer in feldspar.

If we consider the geological conditions very great differences are to be observed. The numerous diabase(basalt-)dikes over wide areas of the Serv Nappe are completely lacking in the real sparagmites: the author, who has seen a good deal of the Swedish sparagmite areas, has never seen a single diabase-dike traversing the sparagmite, and has never heard a report about such a locality, excepting Permian diabases. One extremely interesting fact is that pre-Caledonian diabases in the Serv Nappe, which were intruded *before* the thrust of the nappe, cut an older fold structure and also recrystallisation structure of the rocks of the Serv Nappe. These then have had, at least in part, a pre-Caledonian regional metamorphic structure which is totally lacking in the real sparagmites. Apart from diagenesis these had never been affected by any regional metamorphism before they became involved in the Caledonian folding and deformation.

The facts advanced in this paper, which previously perhaps in part have been too little regarded and thought over, suggest the possibility that the rocks

of the Serv-Kvitvola Nappe might be considered as having originated long before the Sparagmite Formation. We are then referred to a period of the Precambrian lying in the middle or earlier Proterozoicum or perhaps still earlier. The present author has proposed a comparison with the sediments of the Norwegian Telemark group or the Swedish Dal Formation with their widespread quartzite rocks. It may be remembered that for some quartzite layers in the Driva-valley on the western side of the Trondhjem-field Th. Kjerulf has considered a comparison with the "quartz-stones" (= kvartsfjeldet) of the Telemark formation (1879, p. 94). When the age of the rocks of the Serv Nappe and Kvitvola Nappe is studied, this suggestion seems worthy of further discussion.

Concluding remarks

Since the manuscript was written and finished, in January 1961, I had the opportunity of discussing some mutual problems of the boundary-region between the sparagmite bearing areas in the southern part of the area presented in Plate I with Mr. Steinar Skjeseth, Oslo. He told me of some, new features from the borings in the Kvitvola-region to the south of Lakes Femund and Feragen. At Lövbekken in the vicinity of the wellknown geological locality Knappen to the east of Engerdalen, a vertical diamond drill boring was carried out in the year 1960. After passing the uppermost flat-lying series of the deepest layers of the Kvitvola-Nappe containing quartzite, dolomite and sandstone-schist, a slice of augengneiss was reached. It rests upon a Cambro-Silurian series of *Ogygia*-shales, *Orthoceras*-limestone and Cambrian which is resting upon a 100 m thick plate of quartz-sandstone or quartzite. Beneath this plate follow the autochthonous Cambrian with Middle Cambrian and Lower Cambrian strata, the latter belonging to the *Holmia*-shales. They rest upon Eo-cambrian or Varegian quartz-sandstone and this sandstone rests in turn upon the Precambrian granite basement.

The boring has given an excellent demonstration of the tectonic stratigraphy which agrees with tectonic and stratigraphic results given in this paper. Thus we recognize the different nappes piled up on one another; an autochthonous basement of the Precambrian crystalline rocks overlain by a thin series of the Varegian and Cambro-Silurian. These are succeeded then by the Quartz-sandstone Nappe (= Vemdals-quartzite-Olden Nappe) with an allochthonous series of Cambro-Silurian, and in addition the Granite-mylonite Nappe represented by augengneiss. Uppermost comes the Kvitvola Nappe — Serv Nappe. Mr. Skjeseth has also given the present author the hint that the small areas of the Cambro-Silurian phyllite formation resting upon the Ringsaker-quartzite to the east of Lake Storsjön on the map sheet Ytre Rendal belongs to the allochthonous Cambro-Silurian series. This supposition tallies very well with the opinion expressed on Plate I of the present paper, namely, that the Cambro-Silurian of Tufsingdalen and the area Håloydal — Langsjön (map

sheets Nordre Femund and Tynset) also belong to the allochthonous series resting upon the Quartz-sandstone Nappe.

Concerning the reproduction of the geology given on the Plates I and II the author has used the Swedish bed rock map of 1958. (*vide* Sveriges Geologiska Undersökning, Ser. Ba nr. 16). For the Norwegian part, the geological map sheets have been photographically reduced to the reproduction-scale of the plate and combined with the Norwegian bed rock map of 1960 (Holtedahl and Dons). For certain new interpretations of different problems of the geology the present author is of course responsible. They represent contributions to further discussions!

















When the printing of this paper was nearly finished Mr. Strömberg published his monograph about the Serv Nappe in the county of Jemtland (Bull. Geol. Instit. Upsala XXXIX, 1961).

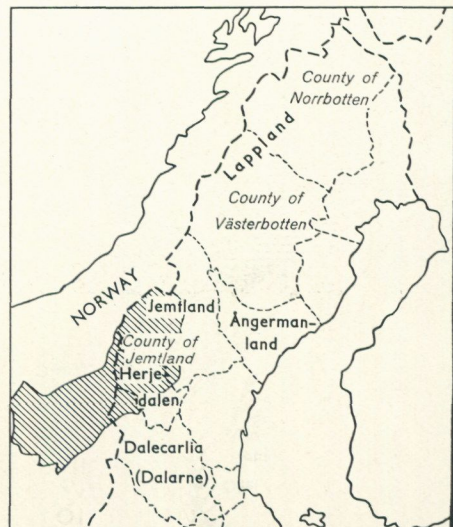
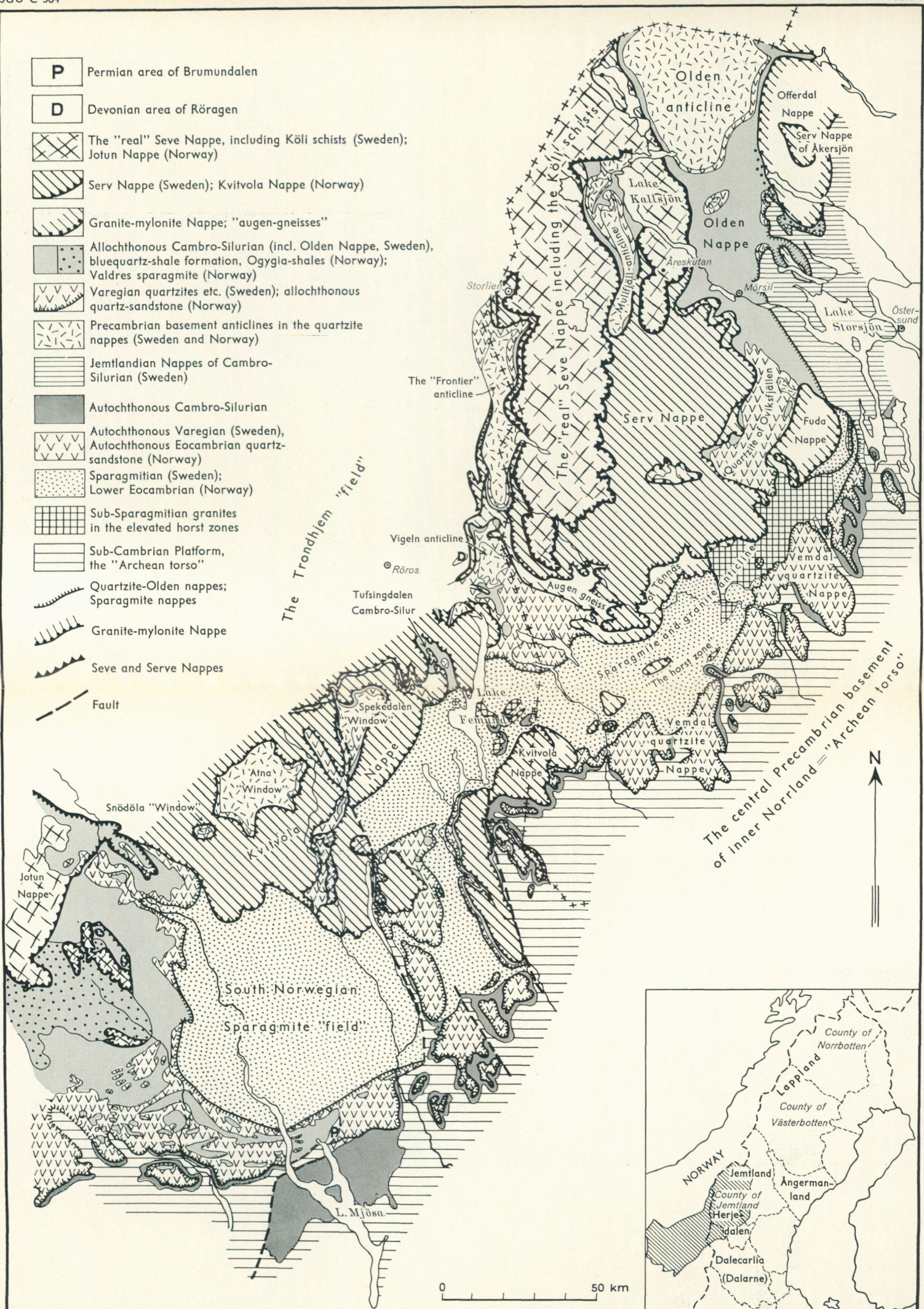
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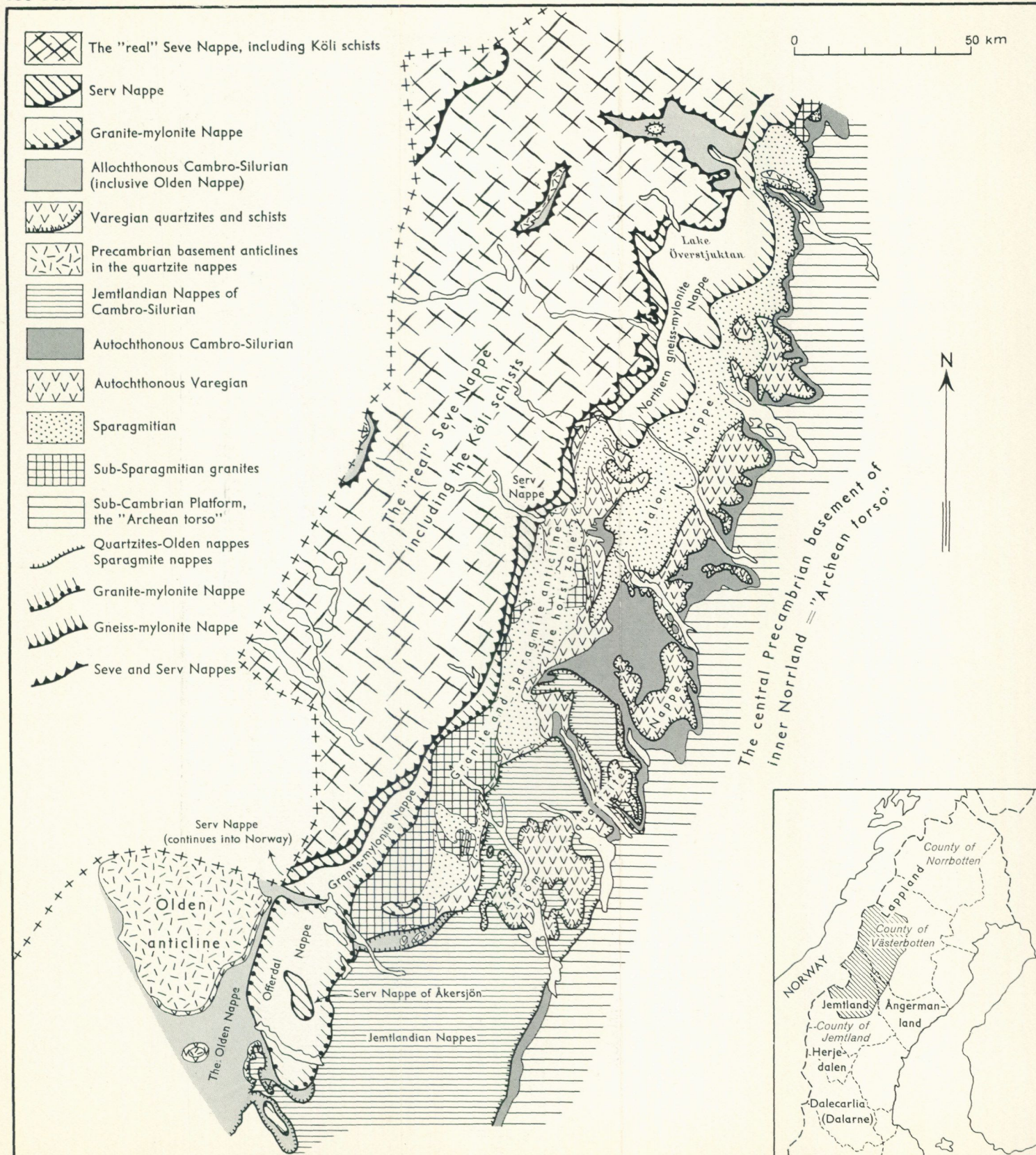
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- P** Permian area of Brumundalen
- D** Devonian area of Rörägen
-  The "real" Seve Nappe, including Köli schists (Sweden); Jotun Nappe (Norway)
-  Serv Nappe (Sweden); Kvitvola Nappe (Norway)
-  Granite-mylonite Nappe; "augen-gneisses"
-  Allochthonous Cambro-Silurian (incl. Olden Nappe, Sweden), bluequartz-shale formation, Ogygia-shales (Norway); Valdres sparagmite (Norway)
-  Varegian quartzites etc. (Sweden); allochthonous quartz-sandstone (Norway)
-  Precambrian basement anticlines in the quartzite nappes (Sweden and Norway)
-  Jemtlandian Nappes of Cambro-Silurian (Sweden)
-  Autochthonous Cambro-Silurian
-  Autochthonous Varegian (Sweden), Autochthonous Eocambrian quartz-sandstone (Norway)
-  Sparagmitian (Sweden); Lower Eocambrian (Norway)
-  Sub-Sparagmitian granites in the elevated horst zones
-  Sub-Cambrian Platform, the "Archean torso"
-  Quartzite-Olden nappes; Sparagmite nappes
-  Granite-mylonite Nappe
-  Seve and Serve Nappes
-  Fault





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Ser. Ba **Översiktskartor (Survey maps)**

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	Description to this map in English by N. H. MAGNUSSON, P. THORSLUND, F. BROTZEN, B. ASKLUND, and O. KULLING. 1960	15,00
» 17	Karta över Sveriges jordarter. (Quaternary deposits of Sweden.) Skala 1 : 1 milj. Sammanställd av G. LUNDQVIST 1958. Karta i tre blad. (Map in three sheets; each 15 Sw. cr.) Pris per blad.	15,00
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