A preliminary account of the geology of the Signaldalen-Upper Skibotndalen area, Inner Troms, N. Norway

By

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Contents

Abstract

A preliminary account of the petrography, stratigraphy and structure of an area at the Caledonian front in inner Troms, N. Norway, is given. Precambrian autochthonous gneisses are overlain by autochthonous and par-autochthonous Cambrian sediments - the Hyolithus Zone. These are themselves overlain by Caledonian thrust metamorphics, divided into the Lower and Upper Allochthonous units. The lower unit consists mostly of quartzo-feldspathic phyllonites, which may be mainly sedimentary in origin. It is bordered below and above by low angle thrusts. The Upper Allochthonous unit has a very varied lithology of calcareous, quartzitic, pelitic and basic rocks all in a fairly advanced metamorphic state. Some of the rock boundaries (especially quartzites) are tectonic. A provisional stratigraphy is suggested but this is uncertain due to the structural complexities in the area. At least one early period of isoclinal folding is recognised, and the main thrusting is associated with this. These structures were refolded by a system of open NW-SE folds and a possibly later system of gentle NE-SW flexures. The regional significance of this structural history is discussed.

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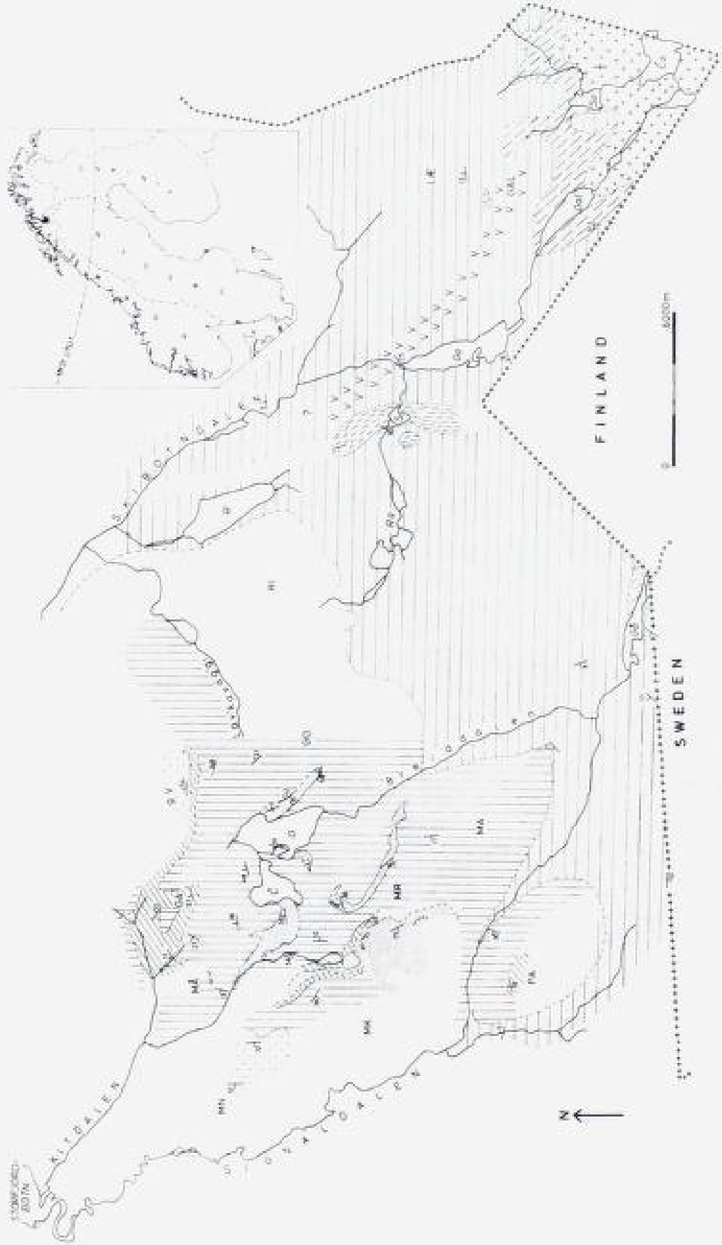
FINLAND
SWEDEN
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Introduction

The area being mapped lies in the innermost part of Troms county, N Norway, some 400 km N of the Arctic Circle, at about 69° 10′ N, 20° 30′ E. The precise location is shown on the maps (Fig. 1).

This is an area of elevated lake plateaux and high, steep mountains. The area is geologically fairly well exposed, though lakes, and lake and river deposits, together with morainic material, cover extensive stretches of the flatter land, whilst block-fields are extensive on the mountains in the eastern

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Fig. 1. Simplified Geological Map of the Signaldalen - upper Skibotndalen area (p. 232).

Undifferentiated rock		UPPER ALLOCHTHONOUS UNIT
Norddalen Schist		
Limestone, schists, basic and acid rocks	Plateau Limestone Group	
Quartzite		
Phyllonite (granitised - V V)	LOWER ALLOCHTHONOUS UNIT	
Phyllite and Limestone		
Cambrian		
Precambrian basement		
Glacier		

25 Dip of Bedding and Schistosity
Vertical Foliation

MOUNTAINS		*LAKES*	
gV	*gaskamus Viessugas*	*C*	*Čaccajav'ri*
GA	*Gas'kasuorgigaï'si*	*CO*	*Čoap'peluobbal*
GAL	*Gal'laoaï'vi*	*G*	*Gâv'dajav'ri*
GO	*Goatte raš'ša*	*Ga*	*Galgujav'ri*
LÆ	*Læt'tačâk'ka*	*Gal'*	*Gal'lajav'ri*
MA	*Mar'kus Mal'la*	*Gå*	*Gåldajav'ri*
MK	*Markusfjellet*	*R*	*Riep'pejav'ri*
MN	*Mannfjellet*	*Ra*	*Raš'šajavrit*
MR	*Mar'kusriep'pi*	*S*	*Sallujav'ri*
MÅ	*Måskogaï'si*	*SO*	*Sað'gejav'ri*
PA	*Paras*		
RI	*Riep'pe gaï'si*		

half of the area. Snow cover in the past three summers has been unusually heavy and has, together with the generally poor weather, proved a serious drawback to the mapping programme.

Very little work has been done in the area previously. Pettersen (1868, pp. 91-2, 1870, pp. 4-15) has mentioned some observations he made, mostly on the edges of the area. Padget (1955) has described a profile along Skibotndalen. An account of the Hyolithus Zone and associated rocks in the Finnish-Norwegian border area has been given by Hausen (1942) and the geology of the neighbouring part of N Sweden has recently been outlined by Kulling (1964).

The present mapping was begun in 1961 whilst I was a member of an undergraduate scientific expedition from University College of Wales, Aberystwyth. Some observations were made in 1963, but the bulk of the work has been done in parts of the summers of 1964-66 and it is hoped to complete most of the work in the summer of 1967. The present paper is a preliminary account of the stratigraphy, petrography, and structure of the area. As the mapping so far accomplished has revealed several features which do not fit in well with some of the previously published ideas on the geology of the region as a whole, it seems desirable to present some of these matters, now, so that other workers in the region, now and in the near future, can be aware of the other possibilities in interpretation and correlation that may be applicable.

Mapping is being done mainly on a scale of 1 : 25,000 using base maps photographically enlarged from the new Series M 711 1 : 50,000 topographical maps.

Autochthonous Precambrian

The autochthonous Precambrian is exposed only in the SE corner of the area where it continues across the Finnish-Norwegian border from the extensive granodioritic-quartz dioritic complex of Svecofennian age in N Finland (Eskola 1963). Glacial drift and lakes cover most of the solid rock, but scattered exposures of granodiorite, with some quartz diorite, granite and granite-aplite occur. Intersecting and partly cross-cutting, semi-amphibolitised dark-green basic bodies occur here and there, sometimes sub-parallel to the steep, near N-S, foliation which is generally developed in the acid rocks.

The acid rocks are normally poor in dark minerals, which even in the granodioritic types, are mostly represented by a dirty green biotite. The granodiorite contains considerably more plagioclase than potash feldspar, and the plagioclase seems to be older as it is filled with minute sericitic and other inclusions, whilst microcline is noticeably fresh.

The Precambrian surface is uneven and has been subject to sub-Cambrian weathering, as also observed by Hausen (1942, p. 16) at the same locality, NE of Saðgejav'ri.

The basement rocks show clear evidence of shearing and the constituent minerals are sometimes very tectonised. This has affected rocks both at the Precambrian surface and some way below it.

Autochthonous and par-autochthonous Cambrian

Some details of the Cambrian Hyolithus Zone stratigraphy in the SE corner of this area have been given by Hausen (1942). According to Hausen, and Kulling (1964), the Cambrian also extends across the border from Sweden beside Treriksrøysa. A fairly intensive search in most of the bog and woodland here, has failed to reveal any exposures of anything E of the approximate boundary (shown on the map in Kulling 1964) between the Cambrian and the overlying thrust rocks. The junction on Fig. 1 is therefore based on the maps published by Kulling and Hausen.

The Cambrian sediments have only been studied in a very cursory manner. They consist chiefly of grey, reddish and greenish-brown shales and fine grained sandstones, with a basal conglomerate rich in pegmatitic quartz and other pebbles derived from the underlying weathered basement. The rocks are generally more or less untectonised and should offer good opportunities for finding fossils. However, the uppermost greenish-brown shales are considerably deformed in the exposures S of Gal'lajav'ri, and must be considered par-autochthonous.

Lower Allochthonous Unit

As indicated on the map, this group of rocks is very extensive in the S of the area. It chiefly consists of more or less phyllonitic, banded, quartz-feldspar-mica tectonites which have been thrust over the Cambrian sediments. Small scale shears and thrusts are often seen, and small tight, isoclinal and recumbent folds are frequent in many parts. Joint drags are common. Most of the unit is metamorphosed in the quartz-albite-epidote-biotite subfacies of the Green Schist grade (Turner and Verhoogen 1960, pp. 537-8).

The major part of this unit can quite likely be equated with the so-called sparagmite which outcrops in large areas of outer Finnmark and in Troms, and continues S in Sweden and Norway.

Light- and subordinate dark-grey, fine grained banded phyllonite and grey-green, fine grained phyllonite are the most extensively exposed varieties, and reach a total thickness of several hundred metres. The latter variety, especially, has a distinctly green and glassy appearance when wet.

The term "phyllonite" is used to describe these rocks, because this, as defined and used by Knopf (1931) and Christie (1961) seems to best describe their macroscopic and microscopic appearance.

Feldspar porphyroclasts are frequently present and microscopic examination shows that these are mostly of micro-perthitic microcline, with some albitic or oligoclasic-albitic plagioclase. A few plagioclases are zoned but generally they are more or less clouded with inclusions. These feldspars seem to be partly regenerated relicts incompletely crushed by the tectonisation.

The granulated, mostly recrystallized, groundmass consists chiefly of quartz and mostly untwinned feldspar, with varying amounts of mica mainly segregated in layers. Most of the mica is white - partly large muscovite felts containing biotite inclusions, and partly fine sericitic flakes. Biotite occurs also as tiny flakes of late date. Garnets are present in some horizons, but are inconspicuous. They occur as near euhedral, fresh grains, but often as more or less altered relicts filled or replaced with epidote, zoisite, chlorite, etc. The feldspar content varies somewhat but often approaches 30 % of the total mineral content. Though the frequent independent occurrence of epidote, in coarser quartz-feldspar-mica schist layers, might suggest that these rocks were originally semi-calcareous (Harker 1939, pp. 247-8), some of the epidotes contain a core of allanite, normally an accessory mineral of acid igneous rocks. The near uniformity in composition of the plagioclases may also suggest an acid eruptive origin for these phyllonites. This problem will be mentioned again later (pp. 248-9).

This phyllonite is clearly the same rock as that described by the name "Sparagmite Schist", by Skjerlie and Tan (1961, pp. 185-6) from Reisadalen, E of here.

In the Gåldajav'ri area the lowest part of this Lower Allochthonous unit is a highly tectonised, light coloured or pinkish-brown rock of apparent granitic origin, with minor amounts of darker, partly more basic, rock.

This relatively insignificant portion of the unit is probably derived by imbrication from the Precambrian basement. Another similar body is seen high up in the thrust sheet W of Står'magied'di in Breiddalen.

In thin section it is seen to consist of large and medium-sized porphyroclasts of potash and alkali feldspars, with epidote, ore, and especially quartz and mica. The potash porphyroclasts are micro-perthitic and both microcline and orthoclase are represented, though the former is dominant and outweighs the albite-oligoclase alkaline feldspar. Some of the feldspars are zoned, but generally the plagioclases are cloudy and filled with small inclusions and all the feldspars are extensively cracked and disrupted, the cracks being generally filled with quartz and a lesser amount of untwinned feldspar, whicn cohtinue unbroken from the groundmass.

The groundmass is mostly of very small, sutured quartz, with some feldspar and a little calcite, and muscovite has crystallized along some shears and around porphyroclasts. Green biotite occurs as very small flakes with a semi-parallel alignment.

In Skibotndalen are two other horizons worthy of special mention here. The first is the zone of granitization described by Padget (1955), of which the southerly outcrop is within the area now being studied, and the second is the belt of dark, somewhat phyllitic rocks with pale-coloured limestone bodies that immediately overlies this southerly granitisation belt.

Padget believed that the granitisation zone overlay his so-called sparagmitic schists (banded phyllonite, here), but reconnaissance mapping in the fairly well-exposed ground N of Gal'lajav'ri indicates otherwise. Here the banded phyllonites overlying the Cambrian sediments on the lower S slope of Gal'laoai'vi become gradually more granitized and mixed with basic material in the upper part of the hill. In the summit region pink and white quartzo-feldspathic layers alternate with fairly coarse pale- and grey-green bands similar to the normal phyllonitic schist. Green amphibolitic horizons are important. In the floor of the high E-W trending valley N of Gal'laoai'vi is a small anticlinal core containing a pure, white, crystalline limestone and a highly puckered phyllite. The relatively complex folding of the granitic/basic zone and the speed of the mapping here make it a little uncertain, but this seems to immediately overlie the granitisation zone and is overlain by a little more granitic/basic material and then feldspar-porphyroclastic grey phyllonite of a type very characteristic for this Lower Allochthonous unit and described by Padget from Helligskogen (Padget 1955, pp. 10 and 52-53). This rock appears to outcrop continuously between Skibotndalen and the Finnish border for several kilometres northwards.

Scattered observations in the ground between Galgujav'ri and Gal'laoai'vi indicate that the granitisation belt on the latter is continuous with that by the road at the N end of the lake. W of the road it continues to outcrop in a NNW direction and is overlain in the area around Mul'kejav'ri-Sallujav'ri-Råg'gejav'ri by a broad belt of dark phyllitic schists with irregular pale-coloured limestone horizons. This is the other limb of the open NNW-SSE antiform that occurs in the upper part of Skibotndalen, and this horizon is doubtless equivalent to the similar rock N of Gal'laoai'vi.

The approximately 600 m thick, dark, fine grained phyllitic belt is mostly highly tectonized quartz-biotite-feldspar-clinozoisite rock, but appears to be derived from amphibole-rich material as this still occurs in rare relict porphyroclasts and in more or less untectonized and unrecrystallized bands. Skarn is developed locally in association with one amphibolite layer. The quartz often occurs in lenses and is then coarse grained and has strongly undulating extinction. These lenses sometimes contain relict feldspar fragments. Larger pods of quartz occur at two horizons and they then simulate sheared and folded remnants of once more continuous bands. The feldspar is partly microcline, but mostly plagioclase. The plagioclase is extensively altered and occurs mostly as small porphyroclasts of relict albite. Amphibole, sphene, zircon, chlorite, white mica, allanite and ore occur in varying amounts.

The limestone is white, pale-grey or pale-green and partly severely tectonized. It consists essentially of medium to very fine grained calcite and dolomite, with varying amounts of colourless amphibole and white mica, both of which sometimes occur as very large, bent, porphyroblastic sheets.

The limestone is not confined to one horizon and has often reacted extremely plastically to the deformation forces. A large outcrop in the cliff immediately WSW of Sallujav'ri is enclosed within the fine grained, light grey, banded phyllonite which otherwise overlies this belt, here. The limestone varies from a few to over 60 m in thickness.

Except for the basic nature of the non-calcareous rock and its structural position it would be natural to correlate this belt with the Rautas rocks of N Scandinavia (the par-autochthonous Blue Quartz - Shale - Dolomite of Hausen (1942) and the Lower Thrust Rocks of Kulling (1964)). The rock may also be correlateable with the greenschists described from a similar horizon in Reisadalen (to the E) by Skjerlie and Tan (1961, pp. 186-7). But the question must be left open for the present.

Allanite occurs especially often in the granitic layers of the granitized belt but is sometimes present in the dark phyllitic rock and the normal phyllonite. The allanite nearly always has an outer shell of epidote (?clinozoisite - with blue interference colours - in the phyllites) but is occasionally seen in tiny pleochroic haloes in biotite. Its significance will be subject to a closer study, later, but it is provisionally considered to be a pneumatolytic mineral formed during the granitisation phase and to have migrated from the highly granitized parts by hydrothermal action along the shear planes in the surrounding phyllonites, thus dating the granitisation to a fairly late stage in the recrystallization and deformation of the Lower Allochthonous rocks.

Cataclasis is widespread throughout the Lower Allochthonous rocks, being represented among other ways by tectonically segregated quartzo-feldspathic material, by fracturing and bending of feldspars, granulation, undulating extinction and Böhm lamellae in quartz, bent micas and the stretching of epidotic minerals, garnet, sphene and zircon - though not allanite.

But the most extreme forms of dynamic metamorphism are restricted to certain levels representing shear zones varying from a few millimetres to many metres in thickness. The larger zones have been mostly observed and studied in the upper part of the unit in Parasdalen and Stordalen, the upper branches of Signaldalen.

They take the form partly of very dark rocks consisting of an extremely fine grained mylonitic groundmass containing stringers of medium grained cataclastic quartzo-feldspathic material. Elsewhere they are medium to fine grained, brown weathering, puckered phyllites, or sheared lenses of amphibolitic material. Kyanite and sillimanite are widely developed and garnet occurs. Trains of graphite and the development of Cu/Fe sulphides are common features. In the amphibolitic rocks the coloured amphiboles appear both as squat, often euhedral, prisms, and long blades. The plagioclase is more calcic (oligoclase-andesine) than in the bulk of the phyllonites, though some albite still occurs sometimes, and labradorite is found. Most of the mica is brown biotite.

These mylonitic rocks are associated with the major thrust separating the Lower Allochthonous and Upper Allochthonous units, which is mentioned in more detail later (p. 247).

Upper Allochthonous Unit

This is exposed in the northerly, mainly higher, parts of the area being mapped. The structure, as outlined in a later chapter, is rather complex and the following divisions are only in a provisional stratigraphical order. The rocks are mostly metamorphosed in the lower half of the almandine-amphibolite facies (Turner and Verhoogen 1960, pp. 544-8).

Plateau Limestone Group

This name is used, for the moment, for the most extensive association of rocks within this unit. All the lithological variations outcrop typically on and around the 700-750 m lake plateau, in the centre of the region, around Čaccajav'ri and Gåvdajav'ri.

The group has a very varied lithology. Calcareous rocks, both nearly pure limestone and calc-silicate schist, quartzites, semi-pelitic and pelitic schists, and basic rocks are all important, and the lithological changes are sometimes lateral. Metasomatic processes, particularly, have led to gradations between various rock types and to a frequent development of semi-gneissic and granitic rocks. A detailed description of these rocks will be reserved for a later paper, but some of the most characteristic features may be mentioned here.

The light coloured crystalline limestones are mostly fairly coarse grained, light-grey or pale-brown weathering, and vary greatly in thickness laterally. They are sometimes nearly or wholly replaced by pelitic and semi-pelitic schists. Sometimes only one thick (ca. 60 m) bed occurs in a profile (e.g. at Mar'kusriep'pi, S of Čaccajav'ri), but more often several thinner ones are found. They swell and thin out rather rapidly along the strike, and this and the complex minor folding, seen very clearly in some water-washed exposures, demonstrate the plasticity of the limestone during the metamorphism. The limestone, strictly defined, makes up a relatively small proportion of the group.

Mineralogically the limestone consists predominantly of calcite, with some diopside, clinozoisite, pyroxene, quartz, feldspar and varying amounts of ore, mica, graphite, yellow vesuvianite and fluorite. The last two have not been observed in thin sections containing mica. The vesuvianite occurs either as individual euhedral to anhedral crystals or in clots up to 1½ cm across, and where developed most coarsely fluorite is sometimes associated with it. Until identified by X-ray diffractometer powder patterns the yellow minerals were thought to belong more probably to the humite group, and this may still be true for some of them.

Where silicate minerals are more strongly developed the limestone becomes a brown, calc-silicate schist, or a characteristic green calc-amphibolite in which thin pale-green epidotic bands alternate rapidly with equally thin dark-green amphibolite ones. The calc-silicate schists, especially, reveal small-scale complex folding and shearing, and are particularly strongly developed just NW of upper Breiddalen, but are also seen in upper Norddalen, lower Stordalen and on the SE end of Mar'kus Mal'la around 950 m. The calc-amphibolite is widespread around Čaccajav'ri, and usually grades into a dark green amphibolite.

Quartzitic rocks occur in varying thicknesses (up to ca. 400 m on Goatteraš'ša) at several horizons within the Plateau Limestone Group. The larger bodies, at least, usually have tectonic boundaries with the encompassing rock. They are dominantly pale-brown weathering, more or less white, medium grained rocks containing interbedded, sometimes slightly transgressive, very thin garnetiferous amphibolites, and speckled semi-pelitic schists occur. They are frequently quite feldspathic, containing abundant sodic-plagioclase and some potash feldspar. Muscovite, and especially biotite, are scattered throughout and segregated into layers or laminae which, together with the basic layers and flattening of quartz, help to define the schistosity. The present outcrop pattern of the quartzites is partly due to structural repetition.

Those semi-pelitic rocks that are not associated with the quartzites are also highly feldspathic, but some of this oligoclase-andesine is very fresh and clearly metasomatically introduced. The rocks are otherwise characterized by garnets and by the abundance of biotite and muscovite, the latter occurring both as unorientated poikiloblastic grains and in parallel intergrowth with the better orientated biotite. These semi-pelitic rocks are extremely varied in appearance, at least partly because of differing degrees of metasomatism.

More pelitic schists, varying in thickness from one traverse to another, are often tectonized and display abundant evidence of stress, with strained quartzes and feldspars, bent micas, stretched and partly recrystallized garnets, and the development of kyanite. The most pronounced of these are believed to represent relatively minor thrust zones, partly contributing to the regional imbrication.

Thin, irregular, grey or dark-green garnetiferous amphibolites occur throughout the group, and are often boudined. Some are oblique to the foliation. Garnet-epidote skarn is frequently developed in the contact zone of neighbouring limestones, but vesuvianite is never observed in close proximity to them.

Granitisation is irregularly developed throughout the Plateau Limestone Group, and several zones of granite, granodiorite, and granite-gneiss occur. Much of the granitisation however shows itself by small scale metasomatic introduction and recrystallization of quartzo-feldspathic material, and as porphyroblasts, clots, veins and lenses in the semi-pelitic, quartzitic aid basic parts.

Except for the development of the vesuvianite and fluorite, and some other porphyroblasts, the limestone members are little affected, even where they are in close proximity to migmatised rocks, as on the 1100 m plateau area W of Mar'kusriep'pi and on the upper N slope of Markusfjellet. In some cases the granitisation seems to be more marked in the vicinity of late NW-SE fold cores. Pegmatitic dykes, lenses and pockets are common in some parts, and the dykes often trend around NNE-SSW.

Norddalen Schist

The Norddalen Schist, named after one of its typical occurrences in Norddalen, is apparently tectonically interlayered with the Plateau Limestone Group, in this area.

It is mostly a platy to well-bedded, dark-green to black, hornblende schist containing, in addition to hornblende, variable, but small, amounts of quartz, intermediate to sodic plagioclase, clinozoisite-epidote, biotite, sphene and ore. Garnets are not always present and tend to be concentrated in certain layers.

Interbedded with this are rare, thin, highly pelitic schists and very subordinate, but often characteristic, dolomitic limestones and calc-silicate schists. The limestones, and especially the calc-silicate schists are notable for their often high amphibole content. In thin section this mineral is colourless, lacks pleochroism and is often poikiloblastic. It tends to form large porphyroblasts which are black and sometimes conspicuously ribbed in hand specimen. In addition to the dominant carbonates and amphibole, a little quartz, rare sodic-plagioclase, muscovite and rare biotite, a little clinozoisite, much graphite, and in one section, abundant diopside, occur. Calcareous rock makes up no more than some 5-10 m out of perhaps 80-200 m in any of the profiles examined. Its appearance varies markedly from layer to layer and sometimes between separate occurrences. In one profile, in the N slope W of Mar'kusriep'pi, a nearly pure limestone occurs, a thin section of which reveals no amphibole, and only a little muscovite, quartz, clinozoisite and ore, whilst immediately below is the more typical, amphibole-rich, calc-silicate schist.

In the upper 500 m of the E shoulder of Mannfjellet, outcrop other, structurally higher, stratigraphical elements. These have been only superficially studied so far, due to their elevated occurrence and consequent heavy snow cover in recent years. They probably have quite an extensive distribution on the Markusfjellet-Mannfjellet range, making up much of the rock on the upper W side of these mountains, where mapping still remains to be done.

On Mannfjellet a 200 m thickness of thinly platy, green hornblende schist containing notable amounts of quartz and intermediate plagioclase, overlies a granitic horizon which is interpreted as belonging to the Plateau Limestone Group. Above that is a grey quartz-garnet-hornblende schist with poorly orientated porphyroblastic hornblende, and then a grey, apparently non-feldspathic, quartzite. Above that come several hundred metres of mixed pelitic and semi-pelitic schists, partly granitized near the top, and always with conspicuous garnets where the rock could actually be observed at close hand.

On the upper part of gaskamus Viessugas are brown schists which cannot at present be correlated definitely with any other unit in the area.

Structure

As stated previously the tectonic history and structure of this area is rather complex. It seems possible to draw a certain parallel between the Skibotndalen-Signaldalen district and that around Glomfjord in Nordland, some 400 km SW in the Caledonian chain, that has been described in a series of detailed papers in recent years (e.g. Rutland and Nicholson 1965, Holmes 1966).

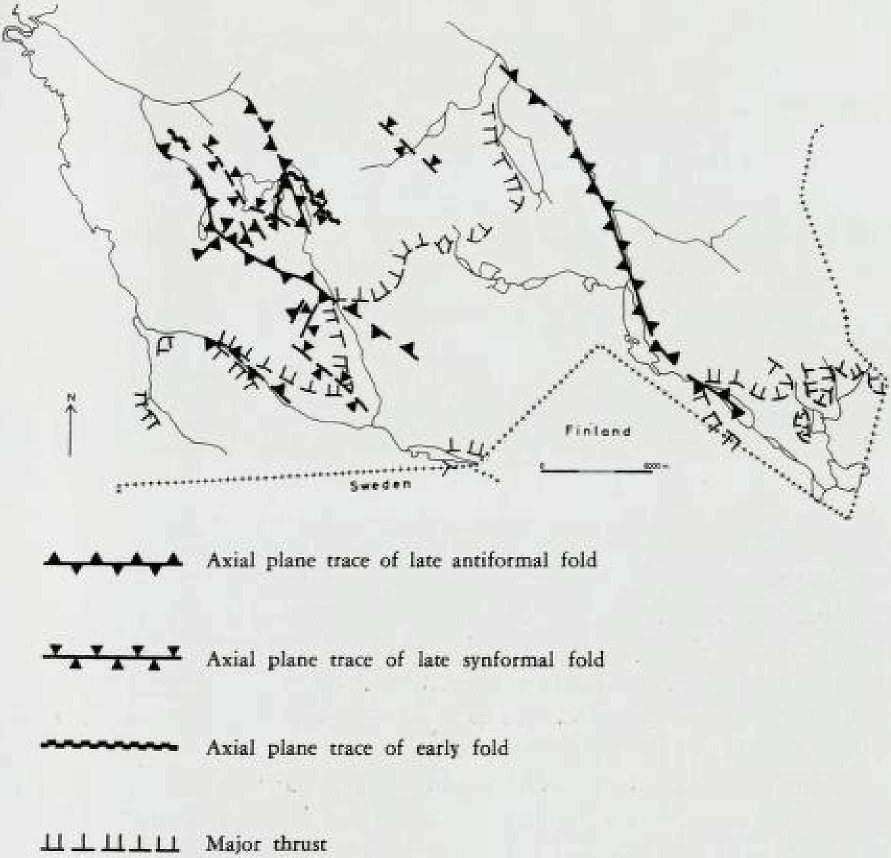

Fig. 2. Simplified Structural Map of the Signaldalen - upper Skibotndalen area.

However, due at least in part to the much less favourable exposure here, especially during the heavy snow cover of recent years, the tectonic history and structure have still not been fully worked out with certainty. Fig. 2 shows the main structural features. An outline of the main features and problems will be given below.

The most obvious structural trait in the area is a system of fairly open, more or less symmetrical folds, trending about NW-SE. Two major antiforms with a complementary synform cross the area. The westernmost one, which may be called the Kitdalen-Breiddalen antiform, is a complex anticlinorial fold, whilst the easternmost one (and apparently the synform too) is more simple. This easterly antiform, which trends more or less along Skibotndalen, has only

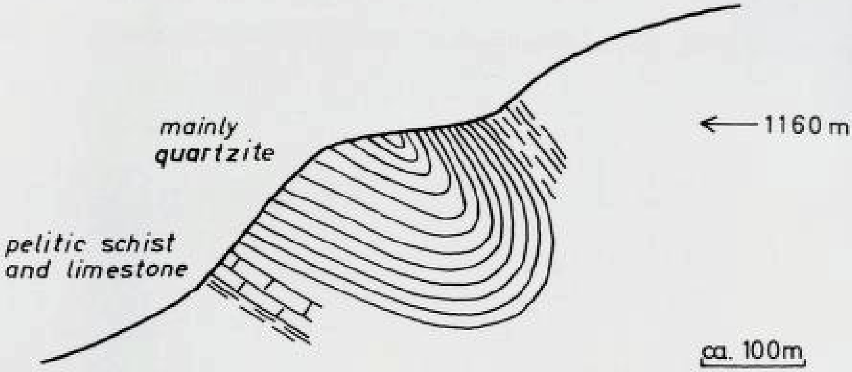

Fig. 3. Sketch-profile of part of the S face of the N part of Goatte raš'ša to show the shape of the early isoclinal fold here.

been observed where it affects rocks below the Upper Allochthonous unit and this may be the reason for its apparent simplicity as the westerly antiform appears to have a much simpler form in the outcrop of the Lower Allochthonous unit.

These folds are crossed at about right angles by more gentle, open folds. They may have developed simultaneously with the NW-SE folds, but several features point to a somewhat later development.

It is undoubtedly these fold systems that were recognized by Padget in the adjacent Birtavarre area (Padget 1955).

As the mapping has proceeded several features that will not fit in with this relatively simple structural pattern alone have become apparent, and it is clear that in this area, and consequently doubtless in the adjacent region too, the rocks have had a more complex structural history. Intensive deformation has resulted in inclined and recumbent isoclinal folds which pre-date the fold systems mentioned above (as these refold the earlier structures), and early thrusting has also occurred.

A couple of examples will suffice to demonstrate this at present.

In the W side of the N part of Goatte raš'ša is a large early fold, the closure being seen in the quartzite outcrop at the S end of the W face. As indicated on the map (Fig. 1) and in Fig. 3, the rocks dip for the most part to the E at a moderate angle, but about ¾ of the way across the outcrop (moving from W to E) a belt of vertical and near vertical dips is encountered. Fig. 3 shows the shape of this structure. Pelitic schists with thin limestones and basic bodies dip beneath the quartzite on the lower slopes and are seen on the other side of the quartzite along the N face of the mountain. The top part of the mountain consists of highly tectonized, heavily (reddish-brown) weathered rock

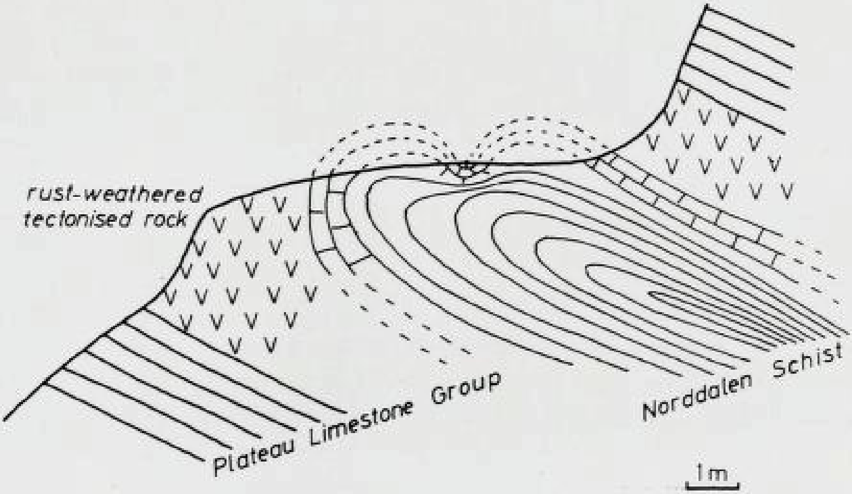

Fig. 4. Field sketch of relationships at the early fold closure on the W slope of Måskogai'si.

which seems to be granodioritic. This weathering colour is extremely characteristic for the whole of this mountain block between here and Riep'pejav'ri, as has been noted already by Pettersen (1870, p. 9).

As Figs. 1 and 2 show, this early fold is refolded by anticlinorial folds of the E limb of the Kitdalen-Breiddalen antiform, which also trend in a general NW-SE direction plunging to the NW at a moderate angle. The early fold is also refolded by a very gentle flexure trending about NE-SW. This occurs about half way along the W face of Goatte raš'ša (see Fig. 2). The fold closure is characterized by intensive shearing and very contorted minor folding, and there is a tendency for the basic material in the quartzite to be gathered in the lower horizons whilst the upper part of the trough consists of more pure quartzite than is normal.

The second example concerns a recumbent fold which outcrops across the mountains of Måskogai'si and Gas'kasuorgigai'si and no doubt continues further E and N, too. A closure consisting of a core of fissile hornblende schist, with pelitic schists and limestones folded round it, is seen in an exposed position high on the W side of Måskogai'si (Fig. 4). The E side of this mountain has suffered a large landslide at the position of the continuation of this hornblende schist, and consists mostly of large unstable boulders and displaced blocks of solid rock and the actual shape of the outcrop has not been determined yet. But on Gas'kasuorgigai'si a thick succession of hornblende schists with very subordinate pelitic and calcareous horizons (Norddalen Schist) overlies schists and limestones of the Plateau Limestone Group and underlies more schists and limestone, in no way distinguishable from the Plateau Limestone succession and very like that high on Måskogai'si. This recumbent fold is refolded by the anticlinorial waves of the Kitdalen-Breiddalen antiform.

The presence of this recumbent fold, here, seems difficult to reconcile with the succession seen in the E side of Markusfjellet. As the map (Fig. 1) shows this consists of two thick horizons of typical Norddalen Schist with an intervening thick quartzite, and underlain by Plateau Limestone rocks. The upper horizon of hornblende schist is overlain by a granitic gneissic zone, which is at present extensively snow covered except in the hollow between Markusfjellet and Mannfjellet. However, sticking out of the snowfield on the upper slope is a large exposure (the structure symbol on the map) of crystalline limestone of a type very characteristic for the Plateau Limestone lithology. The quartzite, moreover, is to all appearances equivalent to the quartzitic horizons in the Plateau Limestone Group. No satisfactory explanation for the nature of this succession has yet been evolved, but it is likely that very low angle thrusting has played some part in its development. There are several slide-like zones in the lower horizon of the Norddalen Schist, and the lower junction of the quartzite is a tectonic boundary - a characteristic of nearly all of the major quartzite junctions seen in the Plateau Limestone Group. The close proximity of this succession to the recumbent fold closure on Måskogai'si may be accounted for by postulating a slide between them, but this will not be discussed further at the present stage.

Unless the main quartzitic horizons of the Upper Allochthonous unit, included now within the Plateau Limestone Group, are really correlateable with part of the lithology of the Lower Allochthonous unit, no part of that unit occurs at a higher structural level in the present area. It nevertheless shows abundant evidence of having taken part in the early severe isoclinal folding, as recumbent and inclined, stacked zig-zag folds are frequently seen on a minor scale. Middle limbs are often sheared out. On the other hand the later deformation is not so marked in the Lower Allochthonous unit, probably because of the dying out of its effects at depth.

Minor structures related to all the major folds are frequently observed. The majority of the minor fold axes and the mineral and other lineations trend around NW-SE. But trends of anything between N-S and about E-W are common too. Further discussion of the minor structures will be postponed until a later occasion.

The thrust between the Lower Allochthonous unit and the underlying Cambrian sediments is well documented in the literature of the Caledonian chain. On the other hand evidence for a similar tectonic discordance above what is termed the Lower Allochthonous unit in this paper, is contradictory. Padget (1955) found no indication of a discordance in the profile he studied E of Helligskogen, but Skjerlie and Tan (1961, p. 189) found evidence for it further E in Reisadalen. Kulling (1964, pp. 86 and 148) says that a tectonic break is not discernable locally in N Sweden.

The present mapping has revealed a marked tectonic discordance at the top of the Lower Allochthonous unit at the head of Signaldalen. It continues in the area to the E too, and was noted by Pettersen (1870, pp. 8-9) at the S foot of Goatte raš'ša, though his interpretation of the relationship of the units is open to question.

This thrust is clearly folded by the late NW-SE deformation phase, which, as it to some extent affects both the thrust units along the same axial lnies, must post-date the main thrusting. It is therefore likely that the thrusting can be correlated with a culminating stage of an earlier isoclinal folding phase.

A summary of the structural history of the area, as far as it has been discerned at this stage, may now be given.

The sub-vertical foliation of the Precambrian basement may be attributed to a Precambrian orogenic phase, but the local shearing and tectonization in the basement is perhaps mostly derived from the Caledonian orogeny. At least one phase of isoclinal and recumbent folding has affected the allochthonous units. This plastic deformation was accompanied by disruption of certain horizons, notably at junctions between more and less competent rocks (e.g. the tectonic boundaries of the quartzitic horizons).

Sliding and low angle thrusting took place during and after the early fold phase. These structures are seen both intraformationally and bounding the lower thrust unit.

These structures were refolded by more or less open folds trending mostly NW-SE and about NE-SW, which may or may not have been formed during one and the same folding phase.

Regional Implications

Considering the paucity of recent published data on the Caledonides of Troms and neighbouring regions, and the considerable differences between the provisional results of the present mapping and those of other workers in much of the region, it may be rather premature to try and draw far-reaching correlations. However, it seems appropriate to make a few suggestions which can be tested and confirmed or disproved by degrees as the mapping of the region becomes more complete, and isolated areas are linked up. Kulling (1964) has also attempted some broad correlations, between N Sweden and N Norway.

There seems little room for doubt that at least one early period of isoclinal folding with accompanying thrusting has taken place on a fairly large scale in the present area. This folding period (if only one) can scarcely be confined to an area of 700 sq. km or so, and must therefore be identifiable in the surrounding region when the right localities are hit upon and when more continuous mapping of individual horizons is accomplished. Ball, Gunn, Hooper and Lewis (1963) have recognized a similar fold episode (F_1) in the Loppa-Øksfjord district, further NE. The Bedford College (London) group working in the Sørøy region, still further NE, have also identified an early recumbent folding phase (see e.g. Dr. B. A. Sturt's comments (pp. 107-8) in the discussion after Rutland and Nicholson 1965).

Thus an implication from the present discoveries and those in Øksfjord and Sørøy is that there has probably been an early isoclinal folding phase in the Birtavarre area also. This implies that stratigraphical repetition, unrecognized during the Birtavarre mapping, may be present there. My own observations, from a short excursion in the Abmelašvag'gi profile, E of Manndalen in the Birtavarre district, reveal that the Big Limestone succession there is indistinguishable from the Plateau Limestone succession described in this paper. Furthermore, the very characteristic calc-silicate schist of the Norddalen Schist is the dominant rock type in the Guolas Limestone in that profile. The hazard a guess at which units may in fact be repetitions of each other in the Birtavarre area, I would suggest that the Schists-with-thin-Limestones may be equivalent to the Big Limestone.

If we look further afield, to the SW, we may cite a calc-silicate schist (etc.) succession of exactly the same appearance in the field to that in the Norddalen Schist, found in considerable thickness in the E side of Kirkesdalen (near Bjørkås).

We may now look at the "sparagmite" problem. Padget (1955) named rocks in Skibotndalen, that I have called banded phyllonite, Sparagmite Schists, and correlated them with the Eocambrian feldspathic quartzites which are supposedly extremely extensive in their metamorphic state, from the N coast of Finnmark through Sweden and Norway for hundreds of kilometres southwards. The lower quartzite zone of the Målselv area (Landmark 1959) is believed to represent the Eocambrian Sparagmite (Landmark, personal communication). As stated earlier (p. 236) Skjerlie and Tan (1961) have also proposed the same correlation for similar rocks in inner Reisadalen. Kulling (1964, pp. 127-8, 161-2) has cast doubt on Padget's and Skjerlie and Tan's correlations, and even on the identification of the original, pre-metamorphic, material, stating that apparently identical rocks in the Pältsa area (among elsewhere) of N Sweden consist of fine grained gneisses, granites and syenites. He states furthermore, that elsewhere in N Sweden there are fine grained overthrust feldspathic rocks which are leptitic gneisses, granites, and sediments of the Precambrian Sjöfall Series. Kulling then suggests that the above sparagmitic schists of inner Troms are older than Eocambrian and probably mostly or wholly non-sedimentary in origin. He partly uses the evidence of the greenschists described within the sparagmitic schist by Skjerlie and Tan to deny a Caledonian age for the unit, and it may be remarked that these greenschists could perhaps be represented in Skibotndalen by the basic phyllitic belt. I have not yet, as stated previously, found any basis for definitely determining the original character of the major varieties of the phyllonitic rock. Though various features suggest that it may be a meta-sedimentary rock, the only slight variation in plagioclase composition and the presence of allanite may point to an acid eruptive parent rock. If this large area of problematic rock is really of pre-Eocambrian age the implication is that the same applies to the rest of the adjoining belt to the NE (e.g. Strand 1960, pp. 270-1) which is generally correlated with sedimentary Eocambrian rocks of eastern N Norway and S Norway.

On the basis of this generally accepted Norwegian theory, Ramsay and Sturt (1963) have accepted an Eocambrian age for the meta-sedimentary succession of Sørøy.

The lowest part of this, termed the Klubben Quartzite, is white and grey, partly feldspathic, quartzites and quartz schists, with micaceous layers, and bears some similarity to rock seen on the E side of Lyngenfjord, NE of Kvesmenes (Landmark, personal communication) and at the head of Ullsfjord. This latter possibility has also been thought likely by Dr. D. Roberts (personal communication) who has made a close study of the Klubben Quartzite. Part of the Ullsfjord succession has been described by Randall (1959) under the name of Quartzite Series and this as he admits is scarcely distinguishable from his Blue Schist Group in this part of his area.

Green, fine grained, tectonized quartzo-feldspathic rock similar to horizons in the Lower Allochthonous unit, is also present at the head of Ullsfjord. At the S end of Nord Fugløy (Binns, in preparation) is a quartzitic succession that bears strong resemblance to these rocks in Lyngenfjord, Ullsfjord and on Sørøy.

Well over 2000 m of the Upper Allochthonous rocks separate the Lower Allochthonous phyllonites from these quartzo-feldspathic schists and quartzites of Lyngenfjord and Ullsfjord. If the Lower Allochthonous unit does not prove to be wholly of Precambrian age the thrusting and overfolding recognized in the area described in this paper, may enable this to be correlated with these quartzitic rocks. Only a more extensive field and laboratory study can confirm this.

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