The Porsanger Sandstone Formation and subjacent Rocks in the Lakselv District, Finnmark, Northern Norway

By

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Contents

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Abstract

The Porsanger Sandstone Formation forms an imbricated thrust mass lying between the Precambrian Basement Complex to the south-east and an allochthonous nappe of "Caledonian" metamorphic rocks to the north-west. The Porsanger Sandstone Formation is separated from the basement by a thin sequence of autochthonous "Hyolithes Zone" sediments.

The feldspathic sandstones and shales of the "Hyolithes Zone" rest unconformably upon a weathered surface of Precambrian gneisses. The "Hyolithes Zone" lies in the north-west limb of a north-easterly striking anticline which developed during post-Lower Cambrian time, folding the Basement Complex and the "Hyolithes Zone" as a single unit. The Porsanger Sandstone Formation was thrust over this structure during the Caledonian orogeny. In addition, the Porsanger Sandstone Formation was folded asymmetrically about northerly axes and the sequence is repeated by a number of thrust faults which dip to the west at a low angle.

The Porsanger Sandstone Formation is subdivided into four lithostratigraphical units: 1. Skallenes Sandstone, 2. Bjørnnes Sandstone, 3. Valddak Sandstone, 4. Gorssavatn Shales. Lithologically the formation begins with the feldspathic sandstones of the Skallenes Sandstone, these grade into protoquartzites in the upper part of this member. The Bjørnnes Sandstone is characterised by limonitic sandstones and quartzose shales. The limonite is believed to have been derived from an original siderite cement. Orthoquartzites make up virtually the whole of the Valddak Sandstone and the formation ends with the green and grey quartzose shales of the Gorssavatn Shales.

Transverse ripple marks, cross-stratified units and dessication cracks indicate a shallow-water environment of deposition. Chert micropebbles found in small numbers throughout the sandstones show that part of the provenance was composed of sedimentary rocks. Thus there is indirect evidence of an even earlier cycle of sedimentation, uplift and erosion.

The age of the Porsanger Sandstone Formation is uncertain but is most probably Precambrian. No fossils were found in the formation, although horizontal worm burrows occur at a few restricted horizons. Precise correlation of the Porsanger Sandstone Formation with other formations in Finnmark awaits further work in, as yet, unstudied areas.

1. Introduction

The writer spent the summers of 1962-65 investigating the sedimentary rocks immediately west and south of the Inner Porsangerfjord. The area studied may be conveniently subdivided, on both a geographical and geological basis, by the Stabburselv river (Fig. 1). This paper is concerned with the area south of Stabburselva. It is bounded to the west by Dilljaelva and its main right bank tributary Njuoidosnjoaskeelva, to the east by Porsangerfjord. The southern limit of detailed observations is indicated in Fig. 9, although some work was carried out south of this line, particularly in the area west of Kjøkenes.

High ground is a feature of almost the whole area, with elevations in the Njæidan Mountain area exceeding 600 m. A major topographic feature is the

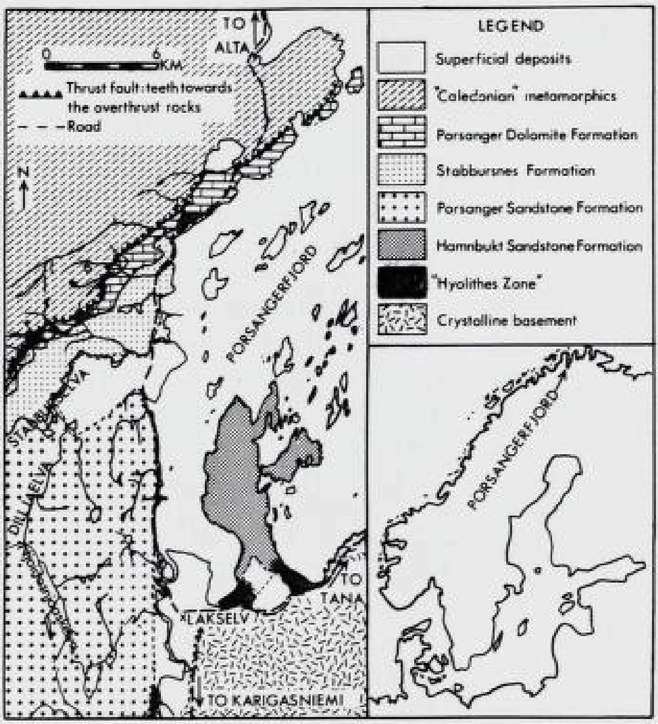

Fig. 1. Simplified geology of the Lakselv District.

steep scarp which extends along the entire eastern edge of the area investigated. The general outlines of the topography are shown in Fig. 8.

Good exposures are found in the scarp and in a number of streams which drain the northern and western flanks of the mountains. In other parts exposure is generally poor, with large areas covered by boulder fields and exotic glacial deposits.

The Porsanger Sandstone Formation forms part of a wedge of sedimentary rocks lying at the eastern margin of the Caledonian Fold Belt. The Porsanger Sandstone Formation is thrust over a thin sequence of autochthonous "Hyolithes Zone" sediments which, in turn, lie unconformably on gneisses of the Fennoscandian Basement Complex. To the north-west the sediments are overlain by an exotic nappe of "Caledonian" metamorphic rocks (Fig. 2).

Mapping was carried out using 1 : 50 000 U.S. Army Map Series maps enlarged to 1 : 20 000. The area described in this paper is covered by AMS Series M711 Sheet 2035 III (Lakselv). Aerial photographs were used in the final field season.

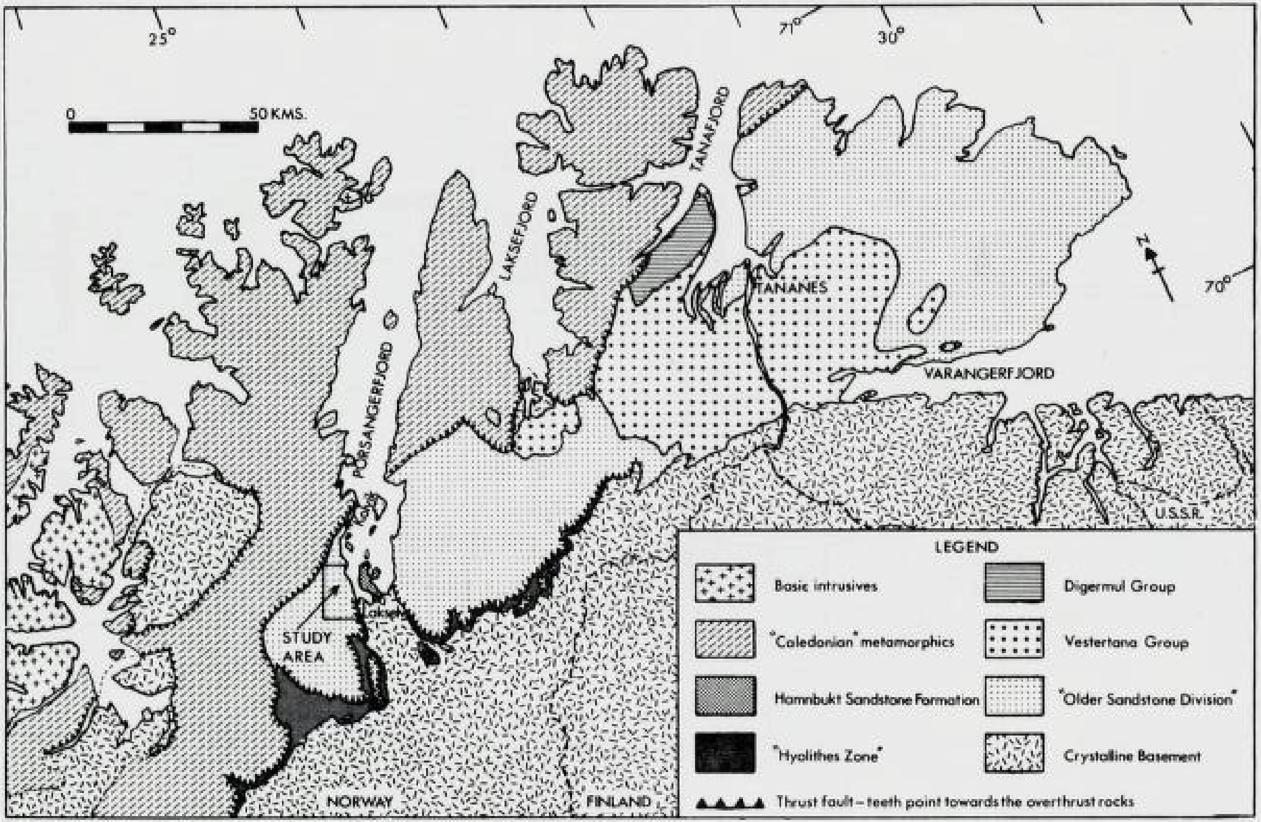

Fig. 2. Geological map of Finnmark. (Largely after Holtedahl and Dons 1960, and Reading 1965).

2. History of Research

Early observations on the geology of Finnmark were made by Dahll (1867, 1891) and Reusch (1891). A more comprehensive account was given by Holtedahl (1918), including a review of earlier work. He subdivided the rocks of Finnmark as follows:

Thrust Caledonian metamorphic rocks
Younger Tillite-bearing Sandstone Division
Older Dolomite-bearing Sandstone Division
Hyolithus Zone[1])
Crystalline Precambrian Basement.

The discovery of *Platysolenites antiquissimus* in the Hyolithus Zone gave its age as Lower Cambrian. The overlying sediments were thought to be conformable upon the Hyolithus Zone and younger than Lower Cambrian. The sedimentary rocks in the Inner Porsangerfjord area were assigned to the Older Dolomite-bearing Sandstone Division and the following succession was established:

Thrust Caledonian metamorphic rocks	
Porsanger Dolomite	100-200 m.
Shales	50-100 m.
Porsanger Sandstone	500 m.
Hyolithus Zone	240 m.
Precambrian metamorphic rocks.	

Later investigations by Holtedahl (1931) showed that there is a thrust separating the Hyolithus Zone and the Porsanger Sandstone. The sedimentary rocks overlying the Hyolithus Zone were thus regarded as being older than Lower Cambrian and, therefore, of Precambrian age.

The results of investigations on the metamorphic rocks of the Lakselv valley were given by Crowder (1959). He describes, very briefly, the relationships between the Precambrian Basement Complex and the overlying sediments in the western part of the Lakselv valley.

3. Stratigraphy and Field Descriptions

(a) General Statement

Almost the whole of the area is made up of rocks belonging to the Porsanger Sandstone Formation. In the extreme south there are small outcrops of

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[1]) Hyolithus Zone was used by earlier workers for what is now generally known as the "Hyolithes Zone".

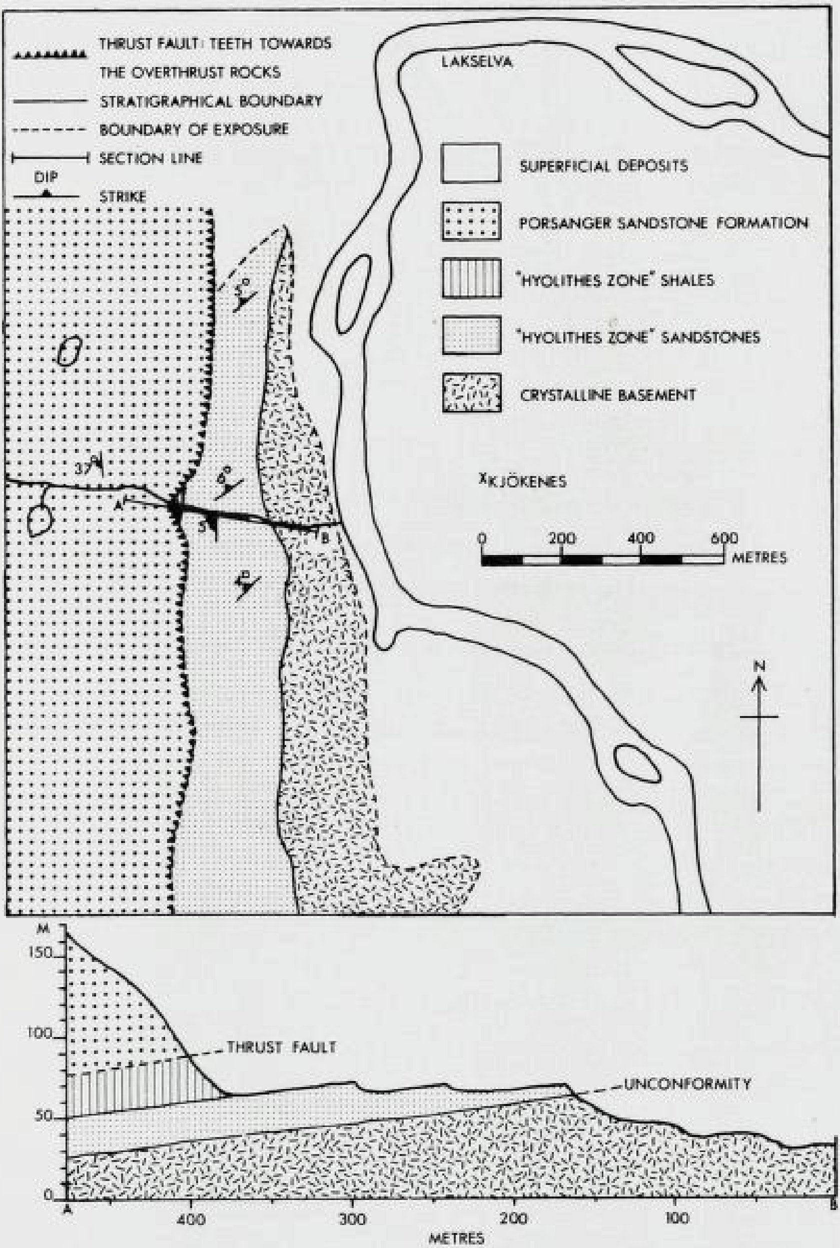

Fig. 3. Geology in the vicinity of the stream section west of Kjøkenes.

"Hyolithes Zone" sandstones and shales lying unconformably upon gneisses of the Precambrian Basement Complex. These sediments are separated from the overlying Porsanger Sandstone Formation by a low angle thrust fault.

(b) Relationships Between the Basement Complex, the "Hyolithes Zone" and the Porsanger Sandstone Formation

Southwards from Valddak for a distance of 15 km. the base of the Porsanger Sandstone Formation is obscured by screes and fluvio-glacial deposits. The relationship between the Porsanger Sandstone Formation and the underlying rocks is revealed in a stream section less than 1 km. west of Kjøkenes. This locality is 2 km. north of the exposure described by Crowder (1959) and represents a further northward extension of the known outcrop of the "Hyolithes Zone". The geology in the vicinity of the stream section is illustrated by Figs. 3 and 4.

The "Hyolithes Zone" sediments lie unconformably on a weathered surface of gneisses belonging to the Precambrian Basement Complex (Plate 1 Fig. 1). The plane of unconformity dips towards the north-west at a low angle. At the base of the "Hyolithes Zone" there is a thin conglomerate with well-rounded pebbles up to 10 cm. in diameter. Although the conglomerate is made up mainly of quartz pebbles, it does contain some fragments of gneiss similar to that found in the underlying basement.

Above the basal conglomerate there are 5 m. of coarse-grained, feldspathic sandstones with pebbly horizons up to 5 cm. thick. There follows 15 m. of medium to fine-grained feldspathic sandstones, with an overall upward decrease in grain size. The upper 4 m. are made up of very hard, fine-grained feldspathic sandstones with a characteristic blue-grey colour.

Occasional cross-stratified units occur, particularly in the medium-grained rocks and these indicate current movement from east to west. The sandstones dip uniformly towards the north-west at around 5°, with no sign of minor folding or faulting.

The sandstones are overlain by 21 m. of grey and green shales. This horizon is usually covered by scree and the only exposures found were where the stream cuts through the scarp. The shales are homogeneous with no indication of bedding planes. An exhaustive search failed to yield any fossils.

The shales are overlain by sandstones belonging to the Porsanger Sandstone Formation. The two are separated by a low angle thrust. The sandstones are cut by numerous small faults and they are strongly folded about northerly axes (Plate 1 Fig. 2). Immediately above the shales the sandstones are considerably shattered and the bedding is obliterated. Higher in the scarp the distinctive Bjørnnes Sandstone outcrops. This horizon may be traced in the upper part of the scarp, northward into the area where detailed mapping was carried out.

The strong folding and minor faulting in the Porsanger Sandstone Formation rocks is in sharp contrast with the uniformly dipping sandstones of the "Hyolithes Zone".

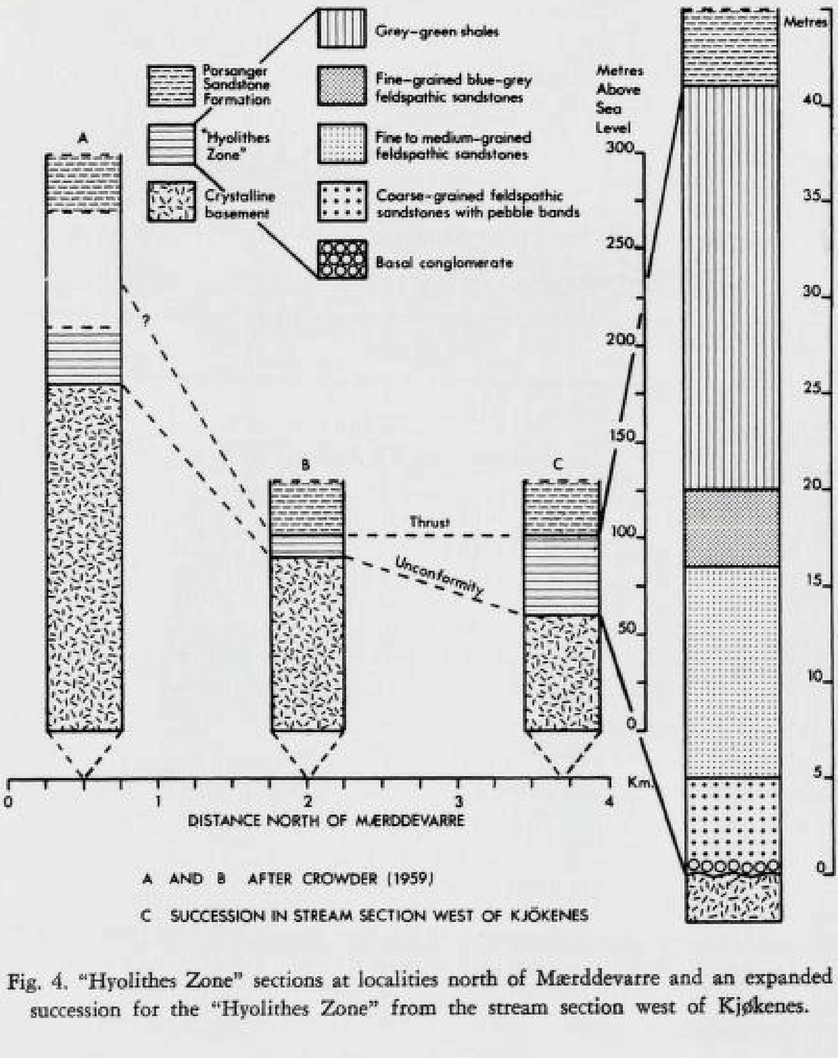

Fig. 4. "Hyolithes Zone" sections at localities north of Mærddevarre and an expanded succession for the "Hyolithes Zone" from the stream section west of Kjøkenes.

(c) The Porsanger Sandstone Formation

The succession for the Porsanger Sandstone Formation is shown in Fig. 5. The entire succession is not fully exposed in any one section and the succession shown in Fig. 5 was built up from the cross sections shown in Fig. 6. The formation name is derived from the usage of Holtedahl (1918, p. 134). Members are named after localities where they are well-displayed. Lithostratigraphical units are used throughout, in accordance with the recommendations of Anon. (1961).

(i) *Skallenes Sandstone.* This lowest member of the Porsanger Sandstone Formation is well-displayed in a stream section north-west of Skallenes and the name has been derived from this locality. The lower 38 m. are feldspathic sandstones, with variable amounts of interbedded green and black shales. The sandstones are light coloured and evenly bedded, with beds reaching a maximum thickness of 40 cm. Shales are generally subordinate to sandstones and occcur as intercalations up to 3 cm. thick. There are one or two horizons where shales predominate, but these are less than 4 m. thick.

The upper 70 m. of the Skallenes Sandstone consists of light coloured, well-bedded sandstones. These show a progressive upward change from feldspathic sandstones to protoquartzites. The rocks also become more massively bedded in the upper part of the member.

Transverse ripple marks are common at some horizons (Plate 2 Fig. 1) and cross-stratified units are found occasionally. In the more shaly horizons mud cracks are common, frequently occurring as casts on the soles of sandstone beds where these overlie thin shales. In the lower part of the Skallenes Sandstone horizontal worm burrows are found at a few horizons (Plate 2 Fig. 2).

The Skallenes Sandstone has a measured thickness of 108 m. As the base is formed by a thrust the original sedimentary thickness probably exceeded this figure.

(ii) *Bjørnnes Sandstone.* This member is well-exposed along the highway near Bjørnnes and it has been named after that locality. There is an abrupt boundary between the massive protoquartzites of the upper part of the Skallenes Sandstone and the rocks in the lower part of the Bjørnnes Sandstone. There is a marked difference in the relative resistance to erosion and streams frequently follow this junction.

Brown-weathering, grey sandstones alternating with black shales form the lowest 3 m. of this member. The sandstone beds are usually less than 3 cm. thick, laterally persistent and of uniform thickness. This horizon is overlain by 3 m of massive-bedded, brown-weathering sandstones, with individual beds

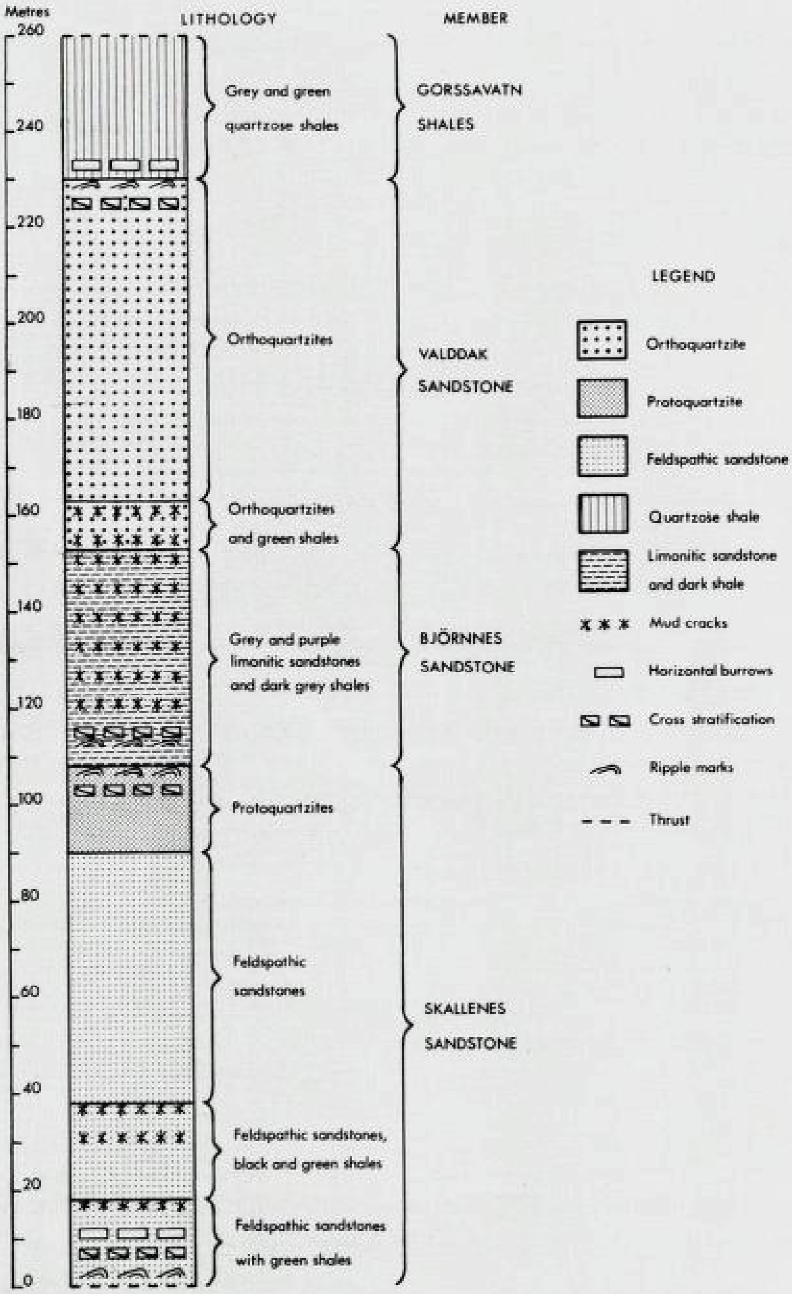

Fig. 5. The Porsanger Sandstone Formation succession.

reaching a thickness of 50 cm. The sandstones extend continuously along the strike but their thickness is rather variable. This horizon contains some transverse ripple marks and cross-stratified units.

The remainder of the Bjørnnes Sandstone is made up of limonitic sandstones with shale intercalations. Sandstone beds vary in thickness from 5 to 25 cm. in the lower part, up to a maximum of 40 cm. in the upper part of the member. Although the thickness of individual beds varies, they can be followed continuously along the strike. The sandstones vary in colour from pale to dark grey, with occasional purple horizons.

Lenses of purple sandstone occur within some of the grey sandstone beds, these have their long axes parallel to the bedding of the grey sandstones. Two sets of joints have developed within the purple sandstone lenses, and these intersect the bedding planes to produce triangular shaped blocks (Plate 2 Fig. 3). Concretions also occur and where these lie within a triangular block a quite spectacular feature is produced. The concretions are made up of alternating concentric shells of light coloured, friable sandstone and iron oxide. The combination of concretions, jointing and bedding produces a characteristic feature which is confined to the Bjørnnes Sandstone. It is particularly evident on weathered surfaces.

The interbedded shales vary in colour from pale grey to black and range in thickness from less than 1 cm. to 8 cm. At the shale-sandstone interface mud crack casts and mud flake impressions are common.

The Bjørnnes Sandstone has a total thickness of 45 m. and is notable for its dark, yellow-brown weathering colour. This coloration readily distinguishes the Bjørnnes Sandstone from any other member of the Porsanger Sandstone Formation.

(iii) *Valddak Sandstone*. The most readily accessible and complete exposure of this member is found near a small lake in the upper part of the scarp 1 km. south of Valddak. Here the junctions with both the underlying and overlying members are exposed, as well as the complete succession for this member. The small lake mentioned above is unnamed on the available topographic maps, so it has been named "Valddakvatn" for convenience of location.

There is a transition from the upper part of the Bjørnnes Sandstone to this member. The brown-weathering, grey sandstones and dark shales of the lower member give way to light coloured orthoquartzites and intercalated green shales. This change is taken as the boundary between the Bjørnnes Sandstone and the Valddak Sandstone.

In the lower 10 m. of this member, well-bedded, very pale grey orthoquartzites up to 30 cm. thick, alternate with green shaly bands usually less than

3 cm. thick. Occasional transverse ripple marks and cross-stratified units occur in the orthoquartzites. Mud cracks are a common feature of the shaly bands.

Above this horizon the shale bands die out and there follows a sequence of massive, very light coloured orthoquartzites. The bedding is uniform and extends along the strike with little change in thickness of individual beds, which reach a maximum of 150 cm. thick. In the upper part of the member prominent transverse ripple marks occur. The total thickness of the Valddak Sandstone is 67 m.

(iv) *Gorssavatn Shales*. This member is best displayed in the vicinity of the stream which drains into Gorssavatn from the northern end of the scarp. The lake is the nearest named locality and provides the name for this member.

There is an abrupt change from the massive orthoquartzites of the Valddak Sandstone to the pale grey and green shales which make up the Gorssavatn Shales. This member is susceptible to erosion and exposures are uncommon. In a few instances streams cut their way along the junction between the soft shales and the much more resistant underlying sandstones. The presence of the Gorssavatn Shales is often only indicated by small, drift-filled valleys extending along the strike.

The shales lack distinctive features other than their colour, uniformity and general lack of discernible bedding planes. The maximum observed thickness of the Gorssavatn Shales is 30 m. In all cases where it is exposed, the upper part of this member is overlain by thrust masses of sandstone and the original sedimentary thickness is unknown.

4. Structures of the Porsanger Sandstone Formation

The broad outlines of the structures in the area were determined to enable the stratigraphical succession of the Porsanger Sandstone Formation to be established.

The Porsanger Sandstone Formation is a thrust mass lying above the sole thrust which separates it from the underlying autochthonous "Hyolithes Zone" sediments. Within the main thrust mass smaller thrust faults occur. These dip towards the west closely parallel to the dip of the strata involved, so producing an imbricate structure. These small thrusts are most readily recognized in sequences where beds dip generally to the west, but with repetition of characteristic horizons. The distinctive Bjørnnes Sandstone is particularly useful in this respect.

Where sandstones of either the Skallenes Sandstone or Valddak Sandstone members lie immediately above a thrust plane their lithology is modified. All

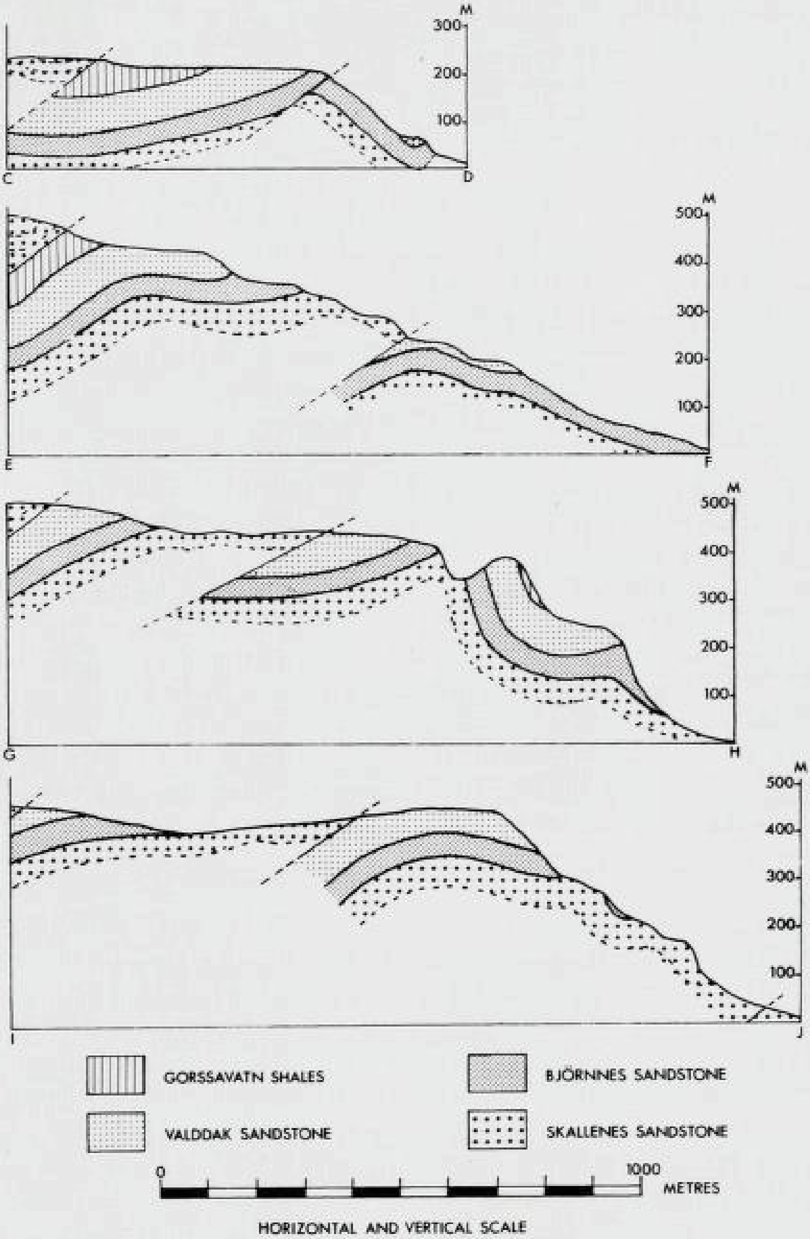

Fig. 6. Cross sections through the scarp west of Porsangerfjord.

traces of individual clastic grains are lost, bedding is to a large extent destroyed and the rock becomes hard and splintery. Where other evidence is lacking these features sometimes allow the presence of a thrust to be detected.

The Porsanger Sandstone Formation is folded into a series of asymmetrical folds, with axial planes striking north to north-north-east and dipping towards the west. The eastern limbs have dips up to 80°, but the dips in western limbs rarely exceed 40° and are frequently much less. The Bjørnnes Sandstone forms a relatively incompetent horizon compared to the massive sandstones both beneath and above it. Thus drag folds are frequently developed where this member lies in the limbs of folds. Structures in the scarp are illustrated in Fig. 6.

5. Petrology

(a) Metamorphic Rocks of the Basement Complex

The metamorphic rocks of this area were described by Crowder (1959) and the present author only examined the gneisses immediately below the unconformity near Kjøkenes. The variation in mineralogical composition of the gneisses related to depth below the unconformity is shown by Fig. 7. Plagioclase generally shows a fairly high degree of alteration, whereas microcline remains unaltered. There is an upward increase in the microcline to plagioclase ratio. Green pleochroic mica occurs at lower levels but decreases in importance towards the unconformity, while at the same time there is an upward increase in colourless mica. In order to illustrate the change in mica content, a distinction has been made between "coloured mica" and "colourless mica". The percentage of quartz increases towards the unconformity.

(b) "Hyolithes Zone"

The sandstones of the "Hyolithes Zone" contain 85 to 93 % quartz, 7 to 14 % feldspar, including microcline and albite-oligoclase. They are, therefore, classified as feldspathic sandstones. Accessory minerals include muscovite and green tourmaline.

The quartz forms a sutured mosaic, produced by secondary quartz overgrowths and later pressure solution. The intensity of pressure solution is greatest where the sandstones have a relatively high clay mineral content. Where distinguishable the original quartz and feldspar grains have well-rounded outlines (Plate 3 Fig. 1). In parts of the sandstones the mosaic is incomplete and the remaining pore space has been infilled by carbonate cement. The carbonate pore-filling is usually a single crystal. Staining, using the method described by Dickson (1965), shows that the carbonate is calcite, with ferroan calcite sometimes occurring at the margin of the crystal. Where euhedral quartz overgrowths project into the carbonate-filled pores they frequently show corrosion (Plate 3 Fig. 2).

Rounded feldspar grains sometimes penetrate adjacent quartz grains without losing their rounded outline (Plate 3 Fig. 3). This suggests that the feldspars are less susceptible to pressure solution than quartz. An example of physical compaction is illustrated by Plate 3 Fig. 4. Here mica is caught between two rounded feldspar grains without any pressure solution effects, but with some disruption of the mica.

(c) Porsanger Sandstone Formation

(i) *Skallenes Sandstone.* The feldspathic sandstones in the lower part of this member contain 75 to 85 % quartz, 10 to 16 % feldspar, up to 5 % lithic fragments and up to 5 % matrix. Both microcline and plagioclase feldspar

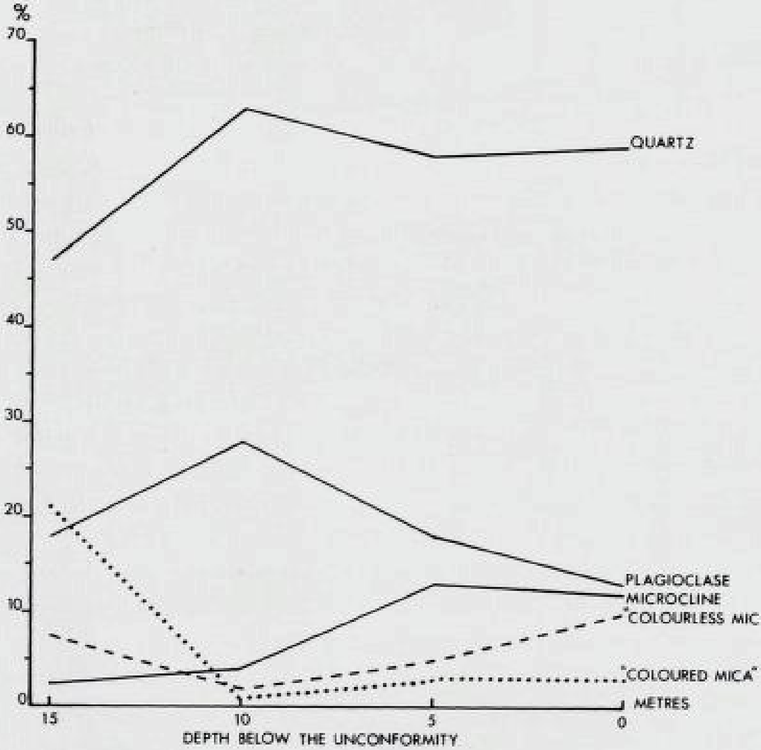

Fig. 7. Variation in the composition of gneisses below the Basement Complex-"Hyolithes Zone" unconformity.

occurs, with an approximately equal number of chert and quartzite grains forming the lithic fragments. The matrix is mainly composed of sericite, probably derived from feldspars. The quartz occurs as a mosaic produced by secondary quartz overgrowths and pressure solution. The feldspar grains are well-rounded, as are the quartz grains where their original outlines can still be seen. Zircon occurs as an accessory mineral.

The quartzose shales from the lower part of the Skallenes Sandstone are made up of angular quartz grains, with minor microcline and plagioclase. The grains are of coarse silt size and they are set in a matrix of clay minerals, biotite and muscovite. Silt size particles make up 20 to 45 % of the total composition of the shales.

The upper part of the Skallenes Sandstone is free of shales and the sandstones show a progressive decrease in both feldspar and matrix. They consist essentially of quartz with up to 5 % lithic fragments, with both chert and quartzite micropebbles being present. Thus there is an overall change from feldspathic sandstones in the lower part of the Skallenes Sandstone, to protoquartzites in the upper. This change is associated with an absence of shales in the upper part of the member.

(ii) *Bjørnnes Sandstone.* The detrital grains in the sandstones of this member are mainly quartz, with feldspar always less than 4 % and usually absent. Well-rounded grains of microcline form the most common feldspar, although plagioclase grains also occur. Up to 6 % of the detrital grains are lithic fragments, with both chert and quartzite present. Green tourmaline occurs as an accessory mineral.

The sandstones differ from others found in the Porsanger Sandstone Formation in their content of iron minerals, mainly limonite but with some associated hæmatite. These minerals occur as pore filling and form 5 to 30 % of the total composition of the sandstones. The contact between the quartz grains and the limonite is frequently jagged and irregular, suggesting corrosion of one by the other. The limonite occasionally appears to corrode secondary quartz which has grown around an original rounded quartz grain (Plate 3 Fig. 5).

In exceptional cases a carbonate mineral occurs in the central part of a limonite-filled pore space (Plate 3 Fig. 6). This carbonate failed to respond to staining using the method of Dickson (1965). However, a deep blue coloration was produced using an acid solution of potassium ferricyanide. This shows that the carbonate is siderite.

In parts of this member the sandstones pass into quartzose shales, with an increase in the matrix and a decrease in the detrital quartz grains. The matrix is composed of clay minerals, chlorite, sericite and limonite. The detrital grains are mostly quartz, with microcline and plagioclase together accounting for less than 1 % of the total composition of the shales. Up to 5 % of the detrital grains are lithic fragments, including both chert and quartzite. The detrital grains are angular to subrounded in outline and lie within the size range coarse silt to fine sand.

(iii) *Valddak Sandstone.* Apart from minor quartzose shales in the lower part, the Valddak Sandstone is made up of orthoquarzites. The rocks contain 95 % or more of quartz, the remainder being chert and quartzite micropebbles. The quartz forms a sutured mosaic with the original grain shapes destroyed by pressure solution.

(iv) *Gorssavatn Shales.* The quartzose shales of this member contain 10 to 40 % quartz grains, with minor amounts of microcline and plagioclase. The detrital grains are angular and range in size from medium to coarse silt. The matrix consists largely of clay minerals and chlorite, with minor amounts of muscovite.

Occasionally concentrations of silt size grains occur which are almost circular in outline. These truncate adjacent seams of clay minerals, indicating that they post-date the deposition of the sediment. It is possible that these structures are cross sections of the horizontal burrows of sediment-eating organisms.

6. Discussion

(a) Metamorphic Rocks of the Basement Complex

The changes in the mineralogical composition of the gneisses below the unconformity are probably due to weathering. Goldich (1938) has studied the weathering of gneiss, including the relative stability of minerals. Quartz is among the most stable of minerals and ought to become relatively more abundant as less stable minerals are removed. He also concluded that among the feldspars, microcline is more stable than plagioclase. On weathering, biotite passes through an intermediate green stage and finally becomes colourless. The mineralogical changes shown in Fig. 7 are consistent with the changes which Goldich indicated should take place on weathering.

The Kjøkenes section occurs in the side of a glaciated valley and the rocks are only likely to have been exposed to weathering since the retreat of the last Pleistocene glacier. Glacial erosion would expose the rocks to weathering virtually simultaneously once the ice withdrew. This suggests that the differential weathering is not a post-glacial feature. The only other period of time available for the weathering of the basement is prior to the deposition of the "Hyolithes Zone" sediments.

Gustavson (1962) in describing the very similar geological circumstances in Dividalen, mentions that the basement rocks show a weathered surface beneath the overlying "Hyolithes Zone" sediments.

(b) The Unconformity Between the Basement Complex and the "Hyolithes Zone"

In Fig. 4 the section west of Kjøkenes is compared with those of Crowder (1959 p. 22, Fig. 2). This diagram shows that the height above sea-level of the unconformity falls from 180 m. just north of Mærddevarre, to 60 m. west of Kjøkenes. These two localities are separated by a distance of 3.2 km. The plane of unconformity dips towards the north-west and the overall dip can be calculated, giving a value of 5° 30'. Thus the dip of the unconformity is the same as the observed dip of the "Hyolithes Zone" sandstones. Holtedahl (1931) put forward the view that the Basement Complex and the "Hyolithes Zone" rocks have been folded as a single unit, to produce a north-east striking anticline. The parallelism of the dip of the plane of unconformity and the "Hyolithes Zone" strata supports this view.

(c) The "Hyolithes Zone"

The sandstones and basal conglomerates represent an advancing shore-line associated with a marine transgression. After deposition of sub-rounded to rounded clastic grains, increasing depth of burial eventually caused pressure solution along grain boundaries. The intensity of pressure solution was greatest where the clay mineral content was highest, a relationship also described by Heald (1956). Silica released during pressure solution migrated to parts of the sediment unaffected by pressure solution, where it was deposited as secondary overgrowths around original quartz grains. This dual process of cementation in sandstones has been described by Heald (1955) and Thomson (1959).

Pressure solution and associated secondary overgrowths did not produce complete loss of porosity and the remaining pore spaces were subsequently filled by calcite cement. In some carbonate-filled pores euhedral quartz overgrowths project into the calcite, showing that the calcite cementation took place later than the formation of the secondary quartz overgrowths. Most of the quartz grains marginal to the carbonate-filled pores show some corrosion by calcite. Siever (1959) noted that carbonate precipitation is the latest stage in the cementation of sandstones and that it is often accompanied by replacement of quartz by calcite. The carbonate filling any one pore is usually a single crystal of calcite. This feature is described by Siever (1959), who also notes that dolomite usually forms a number of small rhombohedra under similar circumstances.

The occurrence of rounded feldspar grains penetrating adjacent quartz grains and the physical squeezing of mica by two feldspar grains suggests variable response of these three minerals to pressure solution. Heald (1955) has discussed the relative stability of minerals under stress and gives the following order of decreasing stability: mica, feldspar, quartz. This sequence is in agreement with the relationships found in the "Hyolithes Zone" sandstones.

The sharp change from fine-grained sandstones to homogeneous shales indicates that a rapid deepening of the sea took place soon after sedimentation began in the area. The uniform grey-green colour of the shales suggests a quiet, non-oxidizing environment of sedimentation.

(d) The Thrust Between the "Hyolithes Zone" and the Porsanger Sandstone Formation

The tectonic break between the "Hyolithes Zone" shales and the overlying sandstones of the Porsanger Sandstone Formation corresponds to the thrust described by Holtedahl (1931). He suggested that the Basement Complex-"Hyolithes Zone" anticline had protected the sediments to the south-east from cutting out by the thrust. He describes an increase in the thickness of the "Hyolithes Zone" below the thrust plane in a south-easterly direction away from the anticlinal axis. Fig. 4 shows that there is a similar, although less marked, increase in a north-westerly direction.

The folding of the Basement Complex-"Hyolithes Zone" unit must have taken place after the deposition of the "Hyolithes Zone" sediments, but prior to the overthrusting of the Porsanger Sandstone Formation. This is in agreement with the conclusions of Holtedahl (1931), which were based on his observations some distance south of the localities discussed here. Gustavson (1962) describes a similar up-doming of the Basement Complex and "Hyolithes Zone" in Dividalen, some 250 km. to the south-west along the margin of the Caledonian Fold Belt. He assigns the age of the folding to post-"Hyolithes Zone" deposition but pre-overthrusting.

(e) The Porsanger Sandstone Formation

(i) *Skallenes Sandstone*. The progressive change from feldspathic sandstones and thin shales to protoquartzites shows that conditions became steadily more stable during the deposition of this member. The presence of transverse ripple marks, cross-stratified units and dessication cracks points to a shallow-water environment of deposition. Of particular interest are the horizontal worm burrows found in parts of the Skallenes Sandstone. These represent the only signs of organic activity found in this member.

(ii) *Bjørnnes Sandstone.* The presence of appreciable limonite in this member distinguishes it from the remainder of the Porsanger Sandstone Formation. The clue to the origin of the limonite probably lies in the presence of siderite in the centre of some limonite-filled pores. Pettijohn (1957) suggests that siderite cementation of sandstones may be more common than has been generally recognised. The ready change of siderite to limonite or hæmatite in outcrop, may destroy all evidence of a pre-existing siderite cement.

If siderite once occupied the whole of the pore space it could explain the present anomalous relationship between the quartz grains and the limonite pore filling. These appear to have corroded contacts, but corrosion of either of these two chemically stable minerals by the other is unlikely. Hallimond (1925) says that siderite may corrode or even totally replace quartz. It seems likely, then, that the pore filling in these sandstones was originally siderite.

This raises the question of the origin and time of formation of the siderite. Secondary quartz overgrowths project into some of the pores, indicating that the pore filling took place later than the development of the quartz overgrowths. Hallimond (1925) suggests that siderite may completely replace an earlier calcite cement. Pettijohn (1957) discusses this replacement and attributes it to an early stage in the diagenesis of sediments. No trace of calcite was found in the Bjørnnes Sandstone rocks, but this does not rule out the possibility of complete replacement of an earlier calcite cement by siderite.

The lack of iron-rich minerals in the members below and above the Björnnes Sandstone, particularly in the otherwise very similar rocks in the lower part of the Valddak Sandstone, gives some indication of the time of origin of the siderite. If the formation of siderite had taken place later than the deposition of the Valddak Sandstone, it would surely have affected the lower part of that member. Thus it seems likely that the siderite was formed either at the time of deposition of the Bjørnnes Sandstone, or very soon afterwards.

The stability fields of hæmatite, siderite and pyrite were investigated by Krumbein and Garrels (1952). Conditions favouring the formation of siderite are a negative redox potential and relatively low pH. These conditions do not apply in normal marine conditions, where the redox potential is positive. James (1954) suggests that conditions of negative redox potential may exist at moderate depths in a restricted marine basin, so allowing the formation of siderite. The ripple marks, cross-stratified units and dessication cracks found in the Bjørnnes Sandstone indicate deposition in shallow, agitated waters, which must have had a positive redox potential. Emery and Rittenberg (1952) show that there will be a change to lower pH and from positive to negative redox potential, on passing from sea-water to unconsolidated sediments on the sea-floor.

James (1954) suggests that iron in the form of a ferric hydrosol, may be carried into a marine basin by rivers. Under normal marine conditions it would be deposited as colloidal ferric oxide. If reducing conditions later develop below the sediment-water interface, this colloid could be converted to siderite.

Thus the siderite in the Bjørnnes Sandstone seems most likely to have formed in an early diagenetic stage, from material carried into the depositional basin at the same time as the detrital grains. As the siderite is restricted to this member there must have been some difference in either the source, the transporting medium or the site of deposition. One possible explanation is that a large river was entering the basin and depositing its load of iron close to the area where the Bjørnnes Sandstone was being deposited.

(iii) *Valddak Sandstone.* This member represents deposition under very stable shelf conditions, with an adequate supply of detrital material. Prolonged wave and current activity winnowed away all the finer detritus and unstable components, so producing a mature orthoquartzite. The chert grains found in this member, as well as in the two underlying members, show that part of the provenance was made up of sedimentary rocks, probably including cherty carbonates. Thus there must have been at least one earlier cycle of sedimentation, uplift and erosion prior to the deposition of the Porsanger Sandstone Formation.

(iv) *Gorssavatn Shales.* The quartzose shales which make up this member indicate a relatively sudden decrease in the energy of the environment of deposition. This was probably due to a deepening of the sea at this time. There are some indications of the activity of sediment-eating organisms in the shales.

7. Age of the Sediments

(a) "Hyolithes Zone"

The limited exposures of "Hyolithes Zone" sediments discussed in this paper are a northward extension of those described by Holtedahl (1918). He reported the discovery of *Platysolenites antiquissimus* from these sediments, so confirming that they belonged to the "Hyolithes Zone". No direct evidence of the age of the rocks was found in the area described, but they are assumed to be the same age as the contiguous rocks to the south.

(b) Porsanger Sandstone Formation

Since the recognition by Holtedahl (1931) of the thrust plane separating the "Hyolithes Zone" and the Porsanger Sandstone Formation, the latter has been considered of Precambrian age. The thrusting took place during the

Caledonian orogeny and the tectonic relationships do not prove a Precambrian age for the Porsanger Sandstone Formation. On purely tectonic grounds the formation could belong to the Lower Palaeozoic just as easily as it could be Precambrian.

Considering the sediments themselves, one of the most striking features is the almost total lack of signs of organisms or organic activity. The nature of the sediments suggests that some signs, at least, of any original fauna should have been preserved. While not being absolutely conclusive, this very absence of fossils is, in itself, a strong indication that the sediments are of Precambrian age.

The Porsanger Sandstone was included in the Older Dolomite-bearing Sandstone Division by Holtedahl (1918). Partially equivalent to this is the Older Sandstone Series of Føyn (1937), the succession for which was established in the Tananes area. Both Føyn (1937) and Rosendahl (1945) commented on the similarity between the Porsanger Sandstone and the Older Sandstone Series of East Finnmark. Lithological similarities, however, are no guarantee of age equivalence. The Older Sandstone Series in East Finnmark is unconformably overlain by the Tillite-bearing Series, which in turn passes conformably upwards into fossiliferous Cambrian rocks (Føyn (1937); Reading (1965)).

If the Porsanger Sandstone Formation could be shown to be equivalent to part of the Older Sandstone Series of East Finnmark, then its age would be confirmed as Precambrian. The present author (White unpublished Ph. D. thesis 1966) attempted to correlate the entire sequence of rocks found west of Porsangerfjord with the Older Sandstone Series of East Finnmark. The weaknesses in this correlation are the dangers of equating lithological similarity with time equivalence: the 140 km. separating the two areas and the lack of geological information about the intervening area. It remains true that there are lithological similarities between the two areas and, perhaps more significantly, there are fairly close similarities between the sequence of lithologies.

The evidence currently available thus points to a Precambrian age for the Porsanger Sandstone Formation. This evidence is, however, negative in the case of the absence of a fauna and suspect in the case of lithological similarity.

8. **Appendix 1. Notes on Fig. 8.**

Geological Localities West and South of Porsangerfjord

This map is designed for the use of any geologist who is able to spend only a few hours in this area, but who would like to see something of the geology. The main road, Riksveg 50, passes through the area, between the

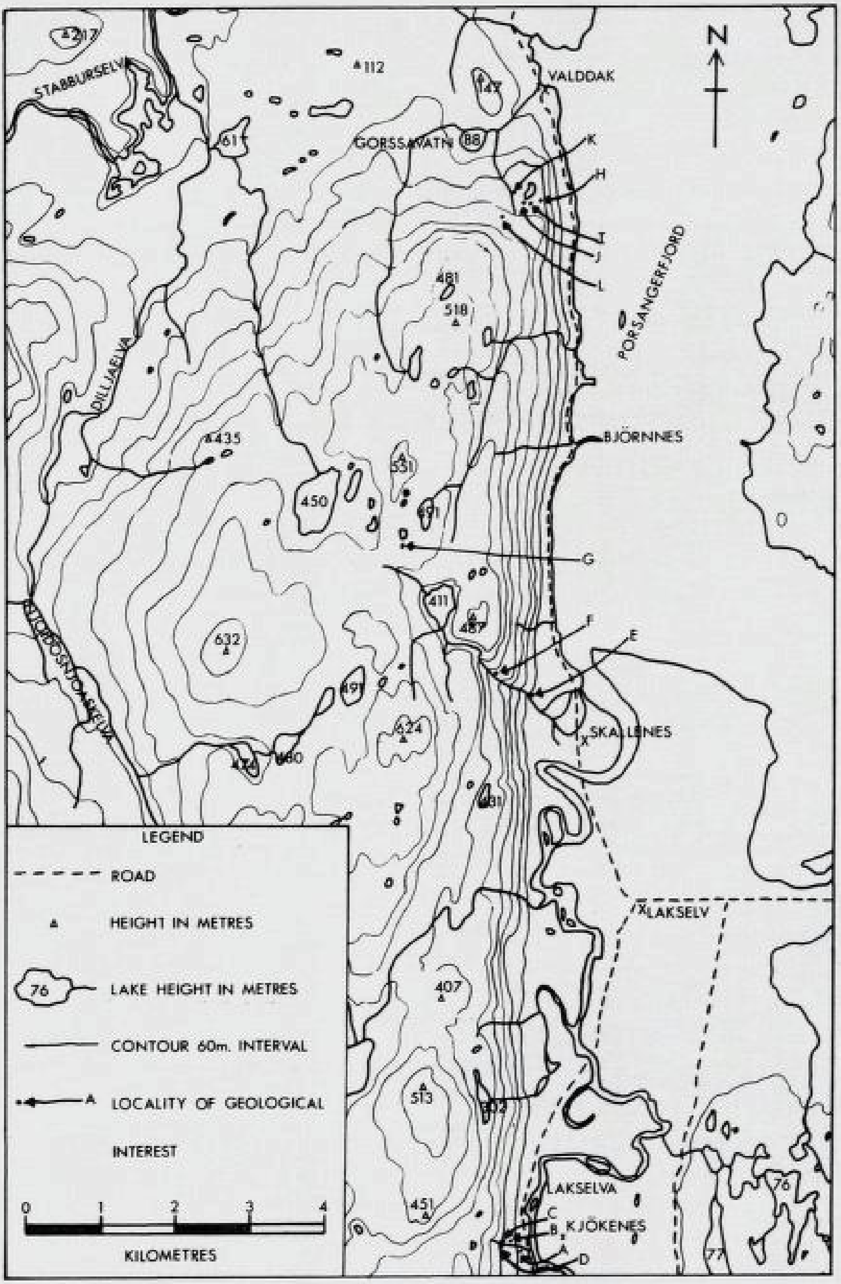

Fig. 8. Geological Localities West and South of Porsangerfjord.

scarp and Porsangerfjord. In addition a minor road leaves Lakselv in a south-westerly direction, crosses Lakselva and passes by the important section west of Kjøkenes. This road is not shown on the AMS Lakselv map, but its approximate path has been drawn on Fig. 8.

Places where particular geological features are well-exposed are indicated as localities of geological interest on the map. Some account has also been taken of proximity to roads in selecting these localities. The localities fall into three main clusters and each of these will be described in turn.

(a) The Stream Section West of Kjøkenes

This area is readily accessible by taking the road south-west from Lakselv. The stream section lies very close to this road.

Locality A. Here the gneisses of the Precambrian Basement Complex are unconformably overlain by almost flat-lying sandstones and thin conglomerates of the "Hyolithes Zone" (see Plate 1 Fig. 1).

Locality B. "Hyolithes Zone" sandstones are well-exposed along the stream.

Locality C. Small exposures of "Hyolithes Zone" shales are exposed where the stream cuts through the lower part of the scarp.

Locality D. A little higher up in the stream section the strongly folded sandstones of the Porsanger Sandstone Formation are thrust over the "Hyolithes Zone" shales. Plate 1 Fig. 2 shows the strong minor folding in the Porsanger Sandstone Formation of this locality.

(b) The Stream Section North-west of Skallenes.

The stream which drains Lake 411 passes through an area which is notable for its interesting geological features and spectacular scenery.

Locality E. Here the stream reaches the foot of the scarp and spreads out to lose itself over the drift deposits which fill the valley. This part of the scarp consists of rocks belonging to the Skallenes Sandstone. Here may be seen ripple marks, dessication cracks in the thin shaly bands, horizontal worm burrows and cross-stratified units.

Upstream there are several waterfalls, some of which must be by-passed either to the north or south.

Locality F lies at the top of the highest and most spectacular of these waterfalls (see Plate 1 Fig. 3). Here the stream follows the junction between the Skallenes Sandstone and the Bjørnnes Sandstone. Hill 487 is an anticline with the topography closely following the structure. The side of the hill consists of rocks belonging to the Bjørnnes Sandstone and these show numerous drag-folds due to their relative incompetency. The transition to the Valddak

Sandstone is well-displayed and the massive orthoquartzites of this member form a protective cap at the summit of hill 487. Plate 1 Fig. 3 is a view of hill 487 showing the structural and topographic conformity.

Locality G. Here purple sandstone lenses of the Bjørnnes Sandstone are well-exposed. The triangular blocks formed by intersection of joints and bedding planes and iron-rich concretions occur near a tributary of the small stream which flows into the north-west corner of Lake 411.

(c) The Northern End of the Scarp

The northern end of the scarp is readily accessible from the main highway.

Locality H. The Bjørnnes Sandstone - Valddak Sandstone junction is well-displayed in the upper part of the cliff.

Locality I. A complete succession of the massive orthoquartzites of the Valddak Sandstone is exposed here. Prominent ripple marks occur in the upper part of the member.

Locality J. The junction of the Valddak Sandstone with the overlying Gorssavatn Shales is exposed in this vicinity.

Locality K. A small stream drains the northern end of the scarp. In and near this stream the Gorssavatn Shales are well-exposed.

Locality L. Here sandstones of the Skallenes Sandstone are thrust over the Gorssavatn Shales.

9. Appendix 2. Notes on Fig. 9
The Geology of the Njæidan Mountain Area

It will be noted that there is an east to west decline in the geological information presented by this map. This is a reflection of the decrease in the degree of exposure. In the scarp face which extends along the eastern edge of the area, exposure is very good. It is in this area that the Porsanger Sandstone Formation succession was established and where the structures are best displayed.

To the west of the top of the scarp, exposures become fewer and less continuous. Nevertheless, by utilizing topographic features such as lines of lakes and valleys which parallel the strike of softer members, as well as exposures of the more resistant members, a reasonably reliable map can be drawn.

West of a line drawn south from Nasteelva exposures become scattered and limited in extent. It was not found possible to draw any sort of reliable map in this part of the area. Exposures are frequently limited to hard, massive sandstones which could belong to either the Skallenes Sandstone or the Valddak Sandstone, as far as their field appearance is concerned. Such exposures have been mapped as undifferentiated sandstone.

Some exposures of the more characteristic Bjørnnes Sandstone and Gorssavatn Shales occur, but their relationships to the other members, in such a structurally complex area, are not clear.

10. Acknowledgements

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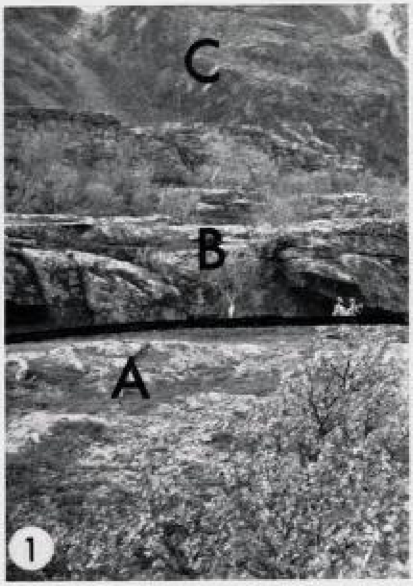


Plate 1 Fig. 1. Sandstones of the "Hyolithes Zone" (B) lying unconformably upon gneisses of the Precambrian Basement Complex (A). The scarp in the background is made up of a thrust mass of sandstones belonging to the Porsanger Sandstone Formation (C). West of Kjøkenes.

Plate 1 Fig. 2. Strongly folded sandstones of the Porsanger Sandstone Formation. Upper part of the section west of Kjøkenes.

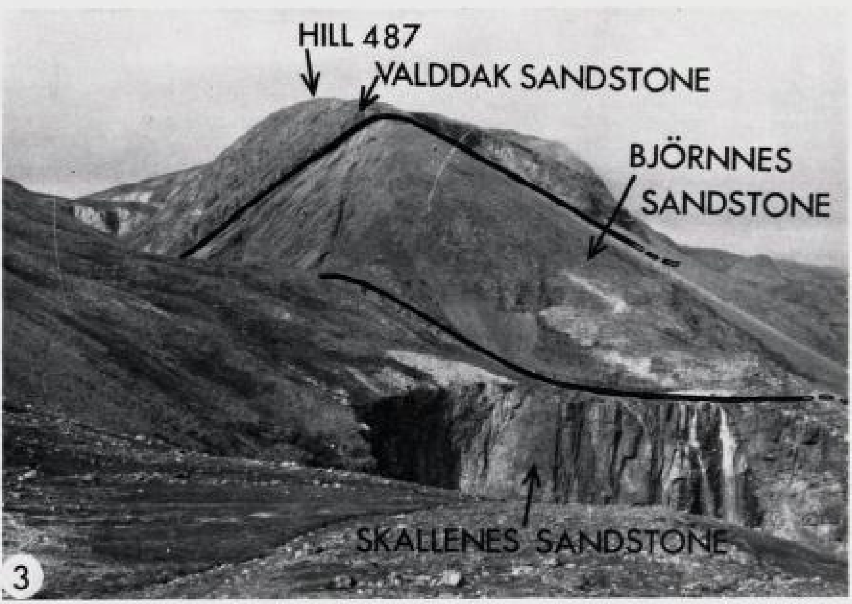
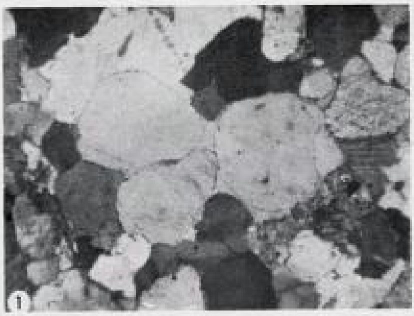


Plate 1 Fig. 3. View of the upper part of the stream section north-west of Skallenes and of Hill 487. The stream falls over a 60 m. high cliff of sandstones belonging to the Skallenes Sandstone. The side of Hill 487 is formed by the less resistant Bjørnnes Sandstone. The harder rocks of the Valddak Sandstone form a protective cap over the top of the hill. The whole of Hill 487 is an anticline and there is a strong relationship between the structure and the topography.

Plate 2 Fig. 1. Ripple marks in the Skallenes Sandstone. Upper part of Nasteelva.

Plate 2 Fig. 2. Rippled sandstones with horizontal worm burrows, in the Skallenes Sandstone. Stream north-west of Skallenes.

Plate 2 Fig. 3. Purple sandstone lens in the Bjørnnes Sandstone, with triangular shaped blocks produced by the intersection of joints and bedding planes. North-west of Lake 411.



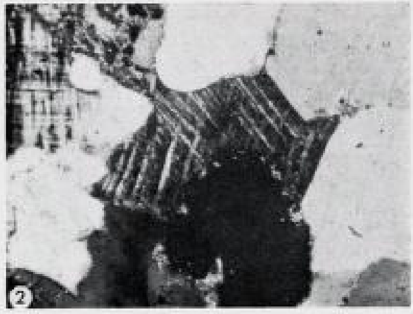
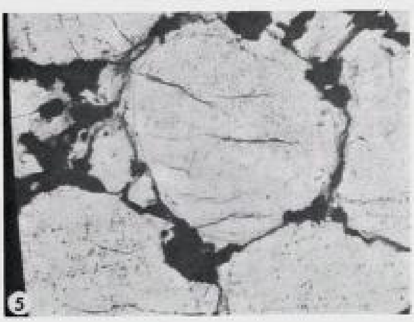


Plate 3 Fig. 1. Rounded quartz grains with secondary overgrowths. "Hyolithes Zone" feldspathic sandstone. Crossed polarisers. X33.

Plate 3 Fig. 2. Calcite pore filling in feldspathic sandstone of the "Hyolithes Zone". Euhedral quartz projects into the carbonate but most of the marginal quartz shows some corrosion. Crossed polarisers. X94.

Plate 3 Fig. 3. Rounded feldspar grain projecting into adjacent quartz grains. Feldspathic sandstone of the "Hyolithes Zone". Crossed polarisers. X94.

Plate 3 Fig. 4. A mica flake squeezed between two rounded feldspar grains. "Hyolithes Zone" feldspathic sandstone. Crossed polarisers. X94.



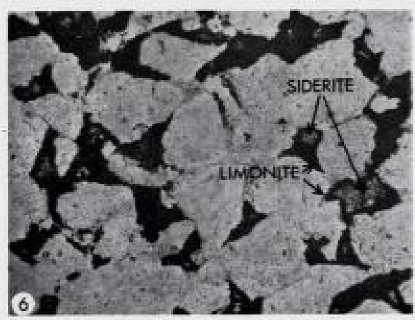


Plate 3 Fig. 5. Rounded quartz grain with secondary overgrowth, apparently corroded by limonite. Limonitic sandstone of the Bjørnnes Sandstone. Plane polarised light. X94.

Plate 3 Fig. 6. Limonitic sandstone of the Bjørnnes Sandstone, with siderite at the centre of a limonite-filled pore. Plane polarised light. X33.

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NGU = Norges Geologiske Undersøkelse

NGT = Norsk Geologisk Tidsskrift

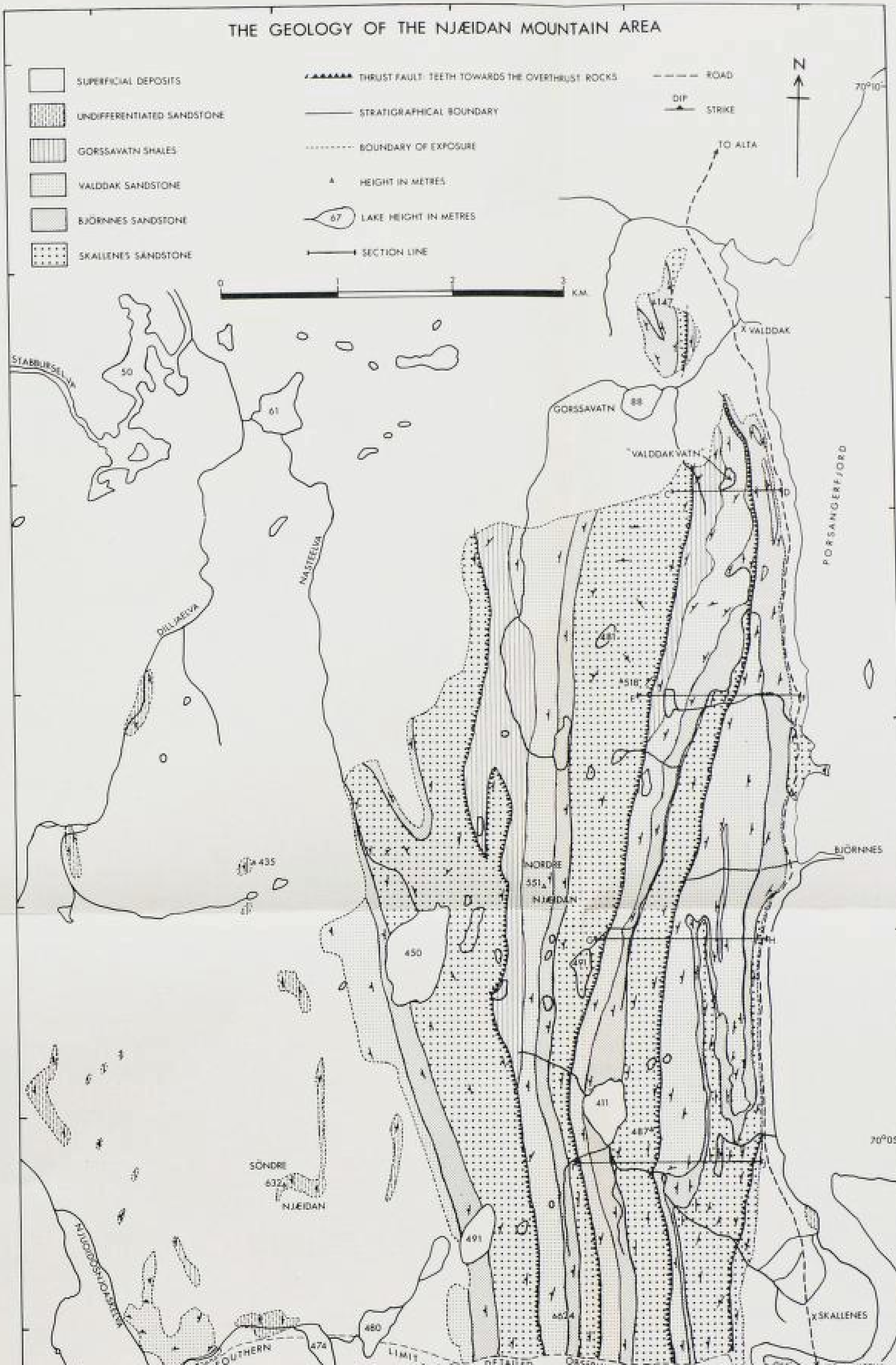

Fig. 9. The Geology of the Njæidan Mountain Area.