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Sammendrag

THE GEOLOGY OF THE FJELDHEIM AREA, LÖKKEN, NEAR TRONDHEIM, NORWAY.

BRIAN CHADWICK.

THE GEOLOGY OF THE FJELDHEIM AREA, LOKKEN, NEAR TRONDHEIM, NORWAY.

Brian Chadwick,
Imperial College, London.
December 1960.

There are some phenomena to which it is not enough to assign one cause : we must enumerate several, though in fact there is only one. LUCRETIUS.

INTRODUCTION.

This report covers the work done during six weeks geological fieldwork in July-August 1960 in the Fjeldheim area, which lies just east of Lokken, an important mining centre, about 70 kms. south-west of Trondheim.

Accommodation at Fjeldheim Farm, on the estate of Herr Cappelen Smith, was kindly arranged by Herr Per Sandvik of the Orkla Grube-Aktiebolag. Herr Sandvik's enthusiasm and interest and helpful suggestions concerning the fieldwork were most welcome and encouraging. Grateful thanks are due also to Herr Smith and his family and Herr Chr. Thams for their very kind hospitality and their permission to work over their land. Finally, thanks are due to Herr Skjevdal and his family for our most enjoyable stay at the farm, and to Herr E. Sagvold, the geologist at the Mine, who spent some time in the field with us.

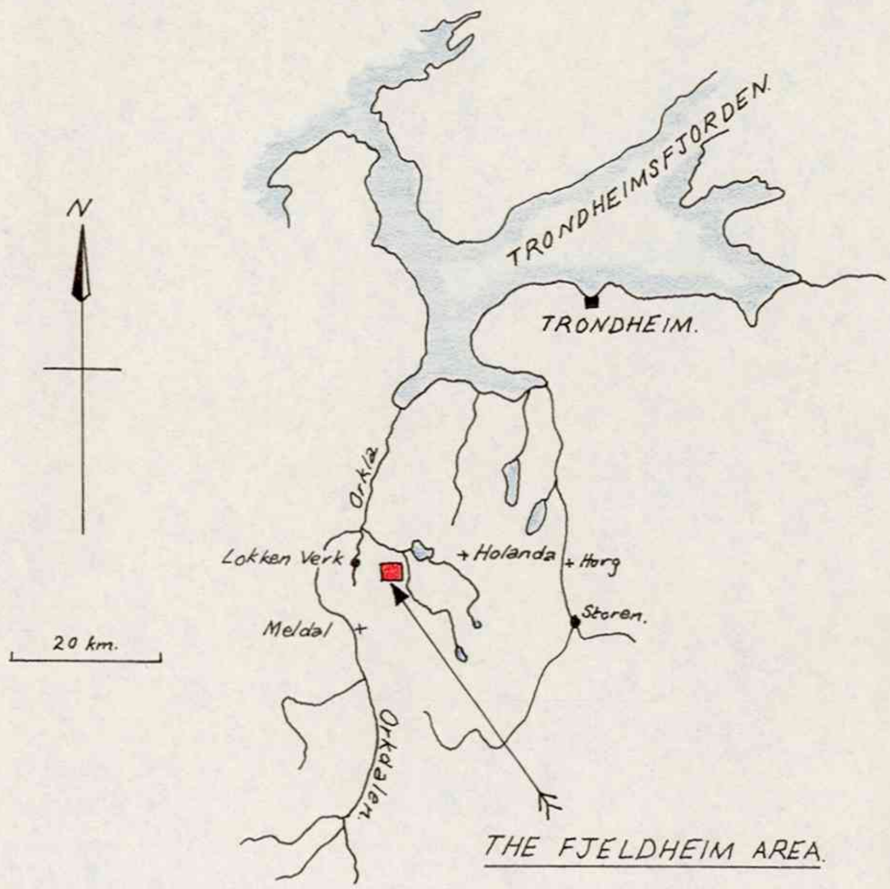
At the kind invitation of the Orkla Grube-Aktiebolag, the opportunity was taken to look over the mine at Lokken. It is, at the present day, the largest Norwegian producer of cupriferous pyrite, with a run-of-mine capacity approaching half a million tons a year. Vokes (1960) has written an admirable history of the mine, with a description of the geology and a review of the theories concerning the origin of the ore. The disused partially open-cast mines at Dragset, 15 kms. west of Lokken, and at Hoidal, just to the east of Lokken, were also visited.

The base map used in the field and to record the final results was prepared in the Geology Department at Imperial College, under the direction of Dr. J.G.Ramsay. The aerial photographs were kindly supplied by Messrs. Wideroe's Flyveselskap A/S, Oslo. Unfortunately, it was discovered, after work had progressed some way, that the tilt on the photographs was too much to allow the construction of an accurate map. So a mosaic had to be traced off the photographs instead, with a scale approximating fairly closely to 1:10,000. With such a mosaic the centre was tolerably accurate, but large errors accumulated in areas away from the centre such that similar points on the edge of the map were sometimes up to 10 cms. apart. These errors could only be corrected by tracing the more extreme areas separately. The Orkla Grube-Aktiebolag kindly provided us with 1:10,000 maps of the north Fjeldheim area and it was found that the mosaic compared quite well with the map prepared from a ground survey. The north point on the mosaic is taken from the Stats-Skoger til Svorka-Trivja map.

The weather was generally good and fieldwork was not hindered too much by bad weather conditions occurring in August. At the beginning very hot sunshine with occasional thundery outbrea ks prevailed, but towards the end of the six weeks rain was very frequent in the form of heavy prolonged showers and temperatures were noticeably cooler - one could sense, in fact, that autumn had arrived.

For the final report a number of thin sections were made in the Geology Department at Imperial College, under the enthusiastic direction of Mr.E.Hill. It was most interesting to learn the techniques involved in making rock and coral sections, but it proved very time-consuming.

As well as a map of the solid geology of the Fjeldheim area, this report contains a description of the rock types and their statigraphical relations and an attempt has been made to account for their mode of origin. Furthermore, a description is included of the recent glaciation, the topography and drainage, and some of the flora and fauna.



Sketch Map to show the Geographical Location of the Fjeldheim Area.

SYNOPSIS OF THE GEOLOGY.

In the Fjeldheim area rocks of Cambro-Silurian age occur, with the younger rocks preserved in synclines of the major synclinorium of the Trondheim region. The particular syncline of Cambro-Ordovician rocks examined at Fjeldheim has an axial plane cleavage which strikes about 270° and dips north at 70°; the northern limb is overturned. Within the syncline minor isoclinal folding appears to be present.

The oldest rocks occurring here are the Upper Cambrian Storen Greenstone Series, a mainly volcanic formation of extrusive submarine spilite lavas and associated pyroclastic deposits. They appear to belong to the initial magmatic stage of a Caledonian phase, which both deformed the rocks and gave rise to the regional metamorphism to a chlorite grade throughout the area. Intrusions of gabbro plutons appear to have accompanied this initial magmatic stage.

Following the extrusion of the lavas and deposition of the pyroclastics a more severe disturbance seems to have occurred, resulting in the formation of the boulder conglomerate, which lies unconformably on the Greenstones, forming the base of the Fjeldheim Series. It is most probable that the Boulder conglomerate is statigraphically equivalent to the Stokkvola (Venna) Conglomerate, which occurs in a similar position on the Greenstones inother parts of the Trondheim region. Also the Stokkvola (Venna) Conglomerate forms the base of the Hovin Group, a major series of shales, sandstones, conglomerates and volcanic rocks and the Fjeldheim Series appears to represent an early member of this major group. The boulder conglomerate occurring at Fjeldheim will, for convenience, be called the Stokkvola (Venna) Conglomerate in this report.

This conglomerate grades up into the Fjeldheim Series, which consists of a series of feldspathic grits, sandstones and banded shales with occasional intercalations of coarse conglomerates.

After the major deformation, dyke intrusions, of varying composition, took place.

Evidence of recent glaciation is widespread and recent uplift, apparently after isostatic re-adjustment subsequent to the dissipation of the ice cover, is reflected in the juvenile features of many of the rivers and streams.

THE TOPOGRAPHY AND DRAINAGE.

The topography of the Fjeldheim area consists, generally, of a series of smooth whale-back ridges and complementary valleys running parallel to the average east-west strike of the country rocks, reflecting the resistance to erosion of the major rock types in that the ridges are formed of the more resistant Storen Greenstone volcanic series and the valleys have been cut in the softer sedimentary series of the Hovin Group of shales, sandstones and grits.

The resistance to weathering and erosion of the Greenstones is well exemplified by Grefstadfjeldet, a whale-back tongue-like mass some distance south of Fjeldheim, running out from the main mass of Greenstones west of Orkladalen, and tapering eastwards into the Hovin sediments. Rising to a height of 790 m., the ridge is bounded on the north by a steep fault scarp, but in the south its relation with the Hovin Group is uncertain. Fine exposures of pillow lavas are visible on some of the ice-smoothed surfaces high on the ridge.

The Greenstones also form the high ground, rising to about 400 m., which runs through Fjeldheim to Storbuan where it tapers out, possibly through faulting, into the Hovin sediments again. This ridge is a continuation of the high ground south of Hoidal valley; the continuity is broken by the large depression occupied by the western limit of the lake Prestbuvatnet.

North of Fjeldheim farm is the lake Mjovatnet which lies in a valley excavated along the length of the Fjeldheim syncline. The valley continues west through the lake Loktj and the low-lying marshy area between this lake and Prestbuvatnet into Hoidalen, the valley occupied by Hoidal farm. Hoidalen has clearly been cut out of the Fjeldheim series by glacial activity, which has left the steep valley sides partially obscured at their bases by moraine. Directly north of Mjovatnet the valley sides of Fjeldheim sediments and Greenstones rise quite steeply and pass northward into Greenstones, which maintain an altitude of about 400 m. until Urvatnet is reached, where a Greenstone cliff, possibly a fault scarp, plunges nearly vertically down to the water level 100 m. below.

The east-west continuity of the ridges is frequently broken by steep-sided depressions cutting at right-angles across them; it would appear that some of the depressions are due to faults and others are due to joints. Weathering has been accelerated by the fault shatter zones or joint planes providing access for weathering solutions and freezing water to break up the rock.

/The depressions

The depressions vary in width from a metre to about 150 m. and in depth from a few metres to about 50 m.. Generally, the joint depressions are smaller, extending longitudinally only a few metres, whereas the fault features often extend across country for hundreds of metres. Slickensides are frequently well preserved on the walls of the faultdépressions.

The drainage is mainly consequent in that it is controlled by the underlying geology. The lakes are mostly consequent in that the majority occupy strike valleys in the less resistant Hovin sediments. None are of very great depth since they occupy the relatively flat, moraine strewn floors of the glacial valleys.

Major rivers cut across the country apparently ignoring structure and rock type. They do not apear to be super-imposed because no younger discordant rocks seem to have been present for the development of a super-imposed drainage. The rivers appear to be mainly consequent however because they seem almost invariably confined to weaker zones in the structure, such as joints or fault zones.

The rivers and streams show,generally, a youthful character and are actively down-cutting their courses as a result of the recent uplift following the glaciation.
The youthfulness is especially well exemplified by the Trivja gorge. The Trivja river has cut back southwards throughthe resistant Greenstones forming a deep, steep-sided gorge as far as the infilled lake area of Lillebumyran. At this point an artificial weir has been built on the site of what appears to be a major knick point on the Trivja river profile ; the height of the water-fall here is about 20 m.. Lillebumyran is almost entirely infilled with alluvial material deposited from the Trivja river as its current is checked on entering the lake area. In the summer Lillebumyran is an extensive marshy region with the river meandering placidly across the marsh until it reaches the weir and regains its vigorous erosive power. During the spring thaw the river floods over its confining levees and deposits a fresh cover of alluvium on the marsh. Due to the reduction in current velocity the river bed is braided for some distance upstream from the point where it enters Lillebumyran.
A similar marshy area is being built up where the Bogo river enters the lake Prestbuvatnet.

Finally, peat bogs are develpoed extensively in badly drained areas.

RECENT GLACIATION.

Evidence that a recent ice-cover existed over the whole area is very abundant. The topography is smoothly undulating and no horns or prominent peaks occur. Massive erratics weighing many tonnes, requiring a considerable thickness of ice for their transportation, are common on the highest ground. The erratics are of white granite (trondhjemite), gneiss, conglomerates and local country rock. Numerous occurrences of trondhjemite are present around the Fjeldheim area so that no definite indication of the direction of ice movement can be determined using the erratics. However, glacial striae, which were found in four localities, have a fairly consistent strike of about 333°. Thus, it seems probable that at one stage during the glaciation at Fjeldheim the direction of ice flow was from the mountainous region in the south-east.

Table of Glacial Striae.

Outcrop & Locality	Strike
O 190 Congl. West end of Mjovatnet	337°
O 182 Pillow lava, New road ½ km. south of weir, Trivja gorge.	333°
O 180 Vesic. lava, Lillebuan	330°
O 138 Banded shale, east side of lake Loktj.	332°

At some time in the late glacial history, a relaxation of the severe climatic conditions resulted in a degeneration of the over-all ice sheet, confining it to small valley glaciers. With the degeneration of the ice sheet the ice source was "decentralised" so that, instead of a major source in the south-east, local nuclei were developed. In the Fjeldheim area, in particular, a prominent source was developed in the Hoidal valley, which appears to have fed the Prestbuvatnet glacier in the east and contributed a tributary glacier to the major glacier in Lokken valley in the west.

Further retreat occurred with periods of still-stand such that pronounced terminal moraines had time to form in some localities. Remnants of these moraines, now about 10 m. in height, are found at the east and west ends of Prestbuvatnet; those at the west end appear to belong to a series of terminal moraines continuing up into the Hoidal valley where the ice seems to have had a final hold.

It appears from the westward slope of the Mjovatnet valley that the valley ice here flowed west from the Lertj area towards

Loktj, where it joined the Hoidal ice and then flowed either back to the east with the Prestbuvatnet glacier or along the depression running north from Loktj.

Generally, over the whole area, it seems that the valleys were excavated by the sheet ice where it occupied and accentuated pre-glacial shallow depressions in the less resistant Hovin Group. The later valleys glaciers seem to have contributed only to local deepening, the enlargement of lateral moraines and the formation of the terminal moraines. That this is the case can be judged from the fact that the valleys around Fjeldheim are relatively shallow and if true valley glaciers had occupied them for any length of time they should surely be much deeper than they are at present. Thus it could be inferred that, compared with the life-span of the sheet ice, the valley glaciers were relatively short-lived. The reason why the sheet ice did not excavate deep valleys was most probably because much of its energy was used up on moving over intervening ridges of resistant material so that the lower ground was not eroded a great deal. In the same way the energy of present day glaciers tends to be dissipated on more resistant topographical irregularities in the path of the ice. It seems, therefore, that sheet-ice , rather than distinct valley glaciers, was the dominant form adopted by the ice during the glaciation.

The major occurrence of moraine lies between Prestbuvatnet and Hoidal farm ; the thickness of the deposit varies and on the north side of the valley streams have cut down through the terminal moraines and moraine field cover to expose the bed-rock. Although the streams are actively down-cutting on the south side no solid rock was seen. An extensive lateral moraine cover exists along the southern slopes of the Fjeldheim ridge, north of Prestbuvatnet, providing, apparently, a good foundation for Fjeldheim farm. Lateral moraines also occur along the sides of Mjovatnet valley, though here they are relatively thin.

Gravitational slumping (landsliding), subsequent to the melting of the ice support, has occurred south of Mjovatnet and at Storbuan where massive blocks of Greenstone, loosened by frost action, have broken away and slumped down to the valley floor.

HISTORICAL GEOLOGY.

A probable succession of events and corresponding ages is represented in the following table ;-

1. Upper Cambrian - Tremadocian.	Extrusion of basic submarine lavas with associated pyroclastic material; apparently belonging to the initial magmatic phase ofan exo-geosyncline formation in the Trondheim region. ? Intrusion of gabbro plutons.	Storen Greenstone Series.
2.	Uplift and erósion.	The Trondheim Disturbance.
3. Tremadocian-Arenig.	Deposition of basal boulder conglomerate, which grades up into -	Stokkvola (Venna) Conglomerate. (taken as the base of the Hovin Group)
4. Arenig - Llanvirn.	a series of feldspathic grits, sandstones and banded shales, with conglomerate intercalations. Continued downwarping to accommodate the sediments.	Fjeldheim Series. (and others subsequently removed by erosion)
5. Upper Ordovician - Silurian.	Severe orogenic activity, with compression acting north-south, resulting in Fjeldheim syncline. Faulting and intrusion of the dykes.	
6. ?	Prolonged uplift and erosion.	
7. Pleistocene.	Glaciation, deposition of erratics and moraine.	
8. Recent.	Uplift and entrenchment of present drainage. Formation of peat bogs.	

The essential reasons for the conclusions expressed in the prevdous table are as follows :-

1. A rich graptolitic fauna found in black shales of the Hovin Group, on the Bogo river just south of Prestbuvatnet, contains species of Arenig - Llanvirn age. Some habe been identified by David Blake and are listed below :-

Tetragraptus quadribrachiatus.

Tetragraptus serra.

Tetragraptus amii.

Isograptus sp.

Didymograptus extensiforme.

Dichograptus sp.

Phyllograptus sp.

Glossograptus sp.

Glyptograptus sp.

Unfortunately no fossils were found in the Fjeldheim Series of the Hovin sediments north of the Fjeldheim ridge, so this is the only palaeontological evidence available in the immediate vicinity. Occurring stratigraphically below these shales it seems that the Fjeldheim Series can be no younger than Lower Arenig - Tremadocian in age.

2. Stratigraphically, the Storen Greenstone volcanic series underlies the basal Stokkvola (Venna) Conglomerate of the Hovin Group so that the Greenstones appear to be Cambrian, or at most Tremadocian.

3. A greater problem arises when one attempts to assign an age to the intrusive gabbro pluton in the north-east of the area. De Sitter (1959) defines the initial magmatic stage of an orogenesis as "basic rock intrusions and extrusions of spilitic lavas in the geosynclinal stage ", so the gabbro could be placed in this period of the Fjeldheim orogeny. However, no precise age can be given to the gabbro because the duration of this initial phase, considering the Trondheim region as a whole, was probably from Middle Cambrian to about the Upper Ordovician. A lower time limit can be put on the gabbro because it appears from its discordant relation with the Greenstones to be younger than this series. How much younger is unknown. With the recent advances in absolute dating by radio-active decay determinationsit may be hoped that, in the not too distant future, the gabbro could be dated using one of the modern isotope techniques.

4. From their discordant relations with the country rocks the dykes appear to be post-folding in age, though they may be related to

/ late-tectonic

late-tectonic faulting. Again no positive absolute date can be assigned to these intrusive rocks.

5. Regional metamorphism to a chlorite grade is found in all the Fjeldheim rocks, showing the youngest to be at least late tectonic in age. This assumes the regional metamorphism is assoαiated with the Caledonian orogenesis ; the assumption seems reasonable since it is difficult to imagine such severe folding unaccompanied by some degree of metamorphism.

6. That the orogeny is Caledonian is indiacated by its parallelism to other manifestations of the Caledonian phase in N.W.Europe, N.E.Greenland and Spitzbergen.

STRATIGRAPHY.

1. The Storen Greenstones.

Named after a locality at Storen, about 30 kms. south-east of Fjeldheim, and introduced into the literature by Kjerulf in 1875, the term Storen Series was explicitly defined and applied by Tornebohm in 1896. The series is also known as the Bymark Group after C.W.Carstens (1920).

The thickness of the Greenstones at Storen is estimated by Th. Vogt to be about 2500 m.. The base of the series is not visible in the Fjeldheim area. From C.W.Carsten's map, Geologisk Kart over Lokken-feltet, (1952), the Greenstones appear to rest unconformably on the Roros Group of mica-schists and phyllites, which in turn overlie Sparagmitic schists, thought by T. Strand to represent an original basement.

At Fjeldheim, the Storen Greenstones consist essentially of a series of extrusive submarine spilite lavas and associated pyroclastic material, with some intercalated conglomerate beds. All the various members of the series here appear to be metamorphosed to a chlorite grade. As mentioned earlier, the Storen Greenstones appear to belong to the initial magmatic stage of a Caledonian exo-geosyncline in the Trondheim region.

That the lavas are submarine in origin is shown by the many classic examples of pillow structures visible in the Fjeldheim area. They are particularly well developed and exposed along the new road cutting above the west side of the Trivja gorge, around the north of lake Brathustj, where the flows are many metres thick, and along parts of the Fjeldheim ridge.

The pillows have, nearly everywhere, been squeezed out tectonically along a strike of approximately 280°, resulting in ellipsoidal bodies with an average squashing ratio of major to minor axes of 4 : 1. Assemblages of pillows of various sizes occur ; the largest pillow measured was about one metre long and 0.25 m. wide and it was accompanied by pillows rangeing down to dimensions of only a few centimetres. Occasionally, a " way-up " determination is possible based on the knowledge that pillows normally " V " downwards. Pillows along the Trivja gorge are obviously inverted when this criterion is applied.

Caught up between the pillows there is usually some angular to rounded pyroclastic material and a red hematitic shaley deposit, which probably represents fine mud from the sea floor. The mud was stirred up and trapped between the pillows

pillows and then probably slightly baked. Since none of this shaley material was observed within any of the pillows it appears that quite a fárm skin had formed around them as soon as the lava came in contact with the sea-water. The skin must have remained fairly plastic for some time to permit movement of the pillow as it was pushed forward by subsequent brethren and conformably infilled depressions between underlying pillows to produce the typical " V " protuberance. Vast quantities of steam must have played an important part in assisting the pillow movement by buoyancy and lubrication effects.

The pillows generally have chilled rims, about 3-4 cms. wide, which are paler green in colour than the main mass of the pillow, due perhaps to a leaching effect removing iron. At one exposure along the Trivja gorge, small pyrite crystals form an inner rim a few cms. within the chilled margin ; whether these are of primary or secondary origin is uncertain. Elsewhere, small flecks of pyrite are distributed throughout the entire pillow. Sometimes the pillows are highly vesicular with the vesicles rimmed by chlorite and infilled by a calcite mosaic; yet in other exposures very few vesicles occur. Very few vesicles are found in the more massive flows where pillow structures have not developed. The massive type of flow can be seen near Storbuan where the massive lava forms the eastern wall of the major fault which runs N.E.-S.W. through Storbuan.

Vesicular lava from an exposure on the north side of Mjovatnet is dark green in hand specimen, with the vesicles appearing as irregular white areas about 0.75 cms. in length. In thin section the rock is holocrystalline, fine-grained and vesicular. Small euhedral feldspar are mostly saussuritised or replaced by clear anhedral albite. Secondary calcite and pale green chlorite are very abundant as small irregular patches. Leucoxene, an alteration product of ilmenite, is also common as small black-brown semi-opaque specks. Minute specks of an entirely opaque mineral, probably pyrite, also occur. Trachytic texture is suggested in places by sub-parallel orientation of some remnants of the feldspar laths. The large irregular vesicles, which have most probably been deformed tectonically, are rimmed by pale green pleochroic chlorite and infilled by a mosaic of anhedral twinned calcite.

Massive Greenstone lava from an exposure north of Lertj has the following composition. The rock is holocrystalline, fine-grained with apparently globular clusters, about 2 mm. in diameter, of euhedral to sub-hedral prisms of pale green epidote held together in a micro-granular groundmass of epidote and tremolite. In hand specimen, these clusters show up as pale green discs against the darker green groundmass throughout which they are irregularly distributed. Some of the prisms show twinning on the 100 twin plane. The remainder of the rock is a micro-granular mass of pleochroic pale blue-green tremolite-actinolite arranged in bundles of parallel thin elongate laths, which are slightly bent so that, on rotation of the microscope stage under crossed nicols, the oblique extinction of the laths appears to flow across the aggregate. It has been suggested that the tremolite-actinolite has replaced original variolitic plagioclase feldspar. Except for one small irregular patch of secondary micro-granular anhedral albite, feldspar seems to be absent entirely from the thin section. Small irregular aggregates of pale green chlorite, distinguished by the anomalous ' Berlin blue ' birefringence colours, also occur. Very small grains of epidote are also randomly distributed throughout the section. One instance of a palimpsest of what was probably originally ophitic augite was observed. A pillow lava containing similar globular clusters of epidote prisms occurs at Fjeldheim farm.

The term spilite is generally applied to such chloritic, soda-rich lavas, but unfortunately a great deal of confusion has arisen as a result of its application in the literature concerning the spilites. The literature on the spilites is well reviewed by Sundius (1930).

As Wells (1923) points out, there is a tendency to regard the two terms, spilite and pillow lava, as synonymous. Although pillow structure is extremely characteristic of spilites it is neither restricted to nor invariably developed by them. That pillow structure is not necessarily developed in spilite lava is well exemplified in the Fjeldheim area. The massive lavas which do occur are, from their composition, spilite lavas, but no pillow structures seem to have developed in them. The reason why no pillow structures seem to have developed is probably because the rate of extrusion of the lava was adequate enough to permit the formation of a very thick flow, such that sea-water did not come into contact with the central portions of the flow so that, consequently, no pillows were developed in the interior. Pillow structure seems to

/ be simply

be simply a flow phenomenon developed in submarine lavas irrespective of their composition, and depending for its formation on suitable conditions of temperature, viscosity and rate of extrusion. Originally the sense of the term spilite was cheifly textural and referred to the dense, vesicular and non-porphyritic consistency of the respective greenstone rocks. Later authors gave the term a chemical-petrographical sense, designating femic rocks with a high soda content and containing an acid plagioclase feldspar as the dominating feldspar.

The problem of the origin of spilites provides much food for thought. Wells puts forward a theory for the origin of spilites, which basically is that fractions of magma of spilitic composition are split off from a basic magma and these are extruded as spilite lava flows. He suggests that the magma, before extrusion, was different ffom normal basaltic magma in that it possessed a marked richness in soda and a deficiency in magnesia. However, Dr. G.P.L.Walker maintains that he has never seen any zoned plagioclase, characteristic of a rapidly cooled lava, in any spilite and furthermore he suggests that if a spilite magma were so rich in soda why should normal pyroxene be developed and not soda-rich pyroxenes, such as aegerine ? The sodic feldspar, which appears to be replacing euhedral feldspar laths, does not appear to be zoned. Furthermore, no soda-rich pyroxenes were observed in any of the tin sections. As is generally the case in all spilites, the lavas in the Greenstones appear to have been albitised some time after their extrusion.

It is necessary now to account for the supply of soda to produce the albitisation. Turner and Verhoogen (1960) have produced the most acceptable theory for the otigin of the required soda. They suggest that the soda comes from sea-water, which is trapped within sediments surrounding the lavas as they are down-warped into the depths of the geosyncline. As the water-logged sediments and lavas sink, geotherms of increasing temperature are encountered so that, eventually, soda-rich hydro-thermal solutions pass throughout the descending material to produce the albitisation. Temperatures, deep in the geosyncline, would be adequate to enable the chlorine, associated with the sodium in the sea-water, to escape as ag gas. The hydro-thermal sodium replaces the calcium in the plagioclase feldspar (albitisation), and the calcium is re-deposited in vesicles and elsewhere as calcite.

Since, usually, it is the simple process which operates in preference to a complex process, it seems that the spilites

/ were originally

were originally basalts, which have been altered simply by " stewing in a soda-rich juice ", derived from surrounding deposits. Such a theory satisfactorily discounts any fanciful, complex methods of magmatic differentiation required by earlier theories.

Apart from the pyroclastic agglomerates and tuffs, which are richly feldspathic, and occasional intercalations of conglomerates, consisting mainly of apparently re-worked pyroclastic material and fragments of jasper, the Storen Greenstones around Fjeldheim contain scattered deposits of massive red jasper. The jasper occurs as massive knolls or thin layered formations which wedge out rapidly along the strike. Generally, it is a fine-grained, hard, siliceous rock coloured red by finely disseminated hematite. The knoll formation at Fjeldheim farm is about 2 metres high and 2-3 metres wide at its lowest exposure. Lying a few centimetres above it there is a small layer a metre in length and about 20 cms. thick. Vogt (1945) records such layers of jasper in the Storen Greenstones occurring in the Holanda-Horg area, a few kilometres east of Fjeldheim. He notes that they are often fractured due, he suggests, to laceration of somewhat consolidated jasper beds through disturbances of the deposits on the sea-floor, either through volcanic eruption or by submarine slides on steep slopes. In the less metamorphosed jasper elsewhere in the Trondheim region Goldschmidt and C.W.Carstens (Holtedahl 1960) claim to have observed radiolarian structures. Vogt suggests that the conditions for their appearance in the Greenstones may be the absence or very scant supply of terrigenous sediments and a certain supply of siliceous water from volcanic action to the sea-water. It is noteworthy that in the Fjeldheim Series only re-deposited jasper is found; presumably because the turbid conditions and scant supply of silica discouraged the establishment of radiolarian life.

Two other deposits found in the Storen Greenstones around Fjeldheim are worthy of mention. The first is a thin bed, only a few metres thick, of a fine-grained yellow-black shale, which is very rich in sulphur. It is exposed some metres up the first stream which flows from the west into the river flowing north out of Loktj. When first seen it looked as if it might be fossiliferous, but nothing was found after two hours' intensive examination. This deposit is probably associated with one of the syngenetic sedimentary pyrite ores (vasskis), which are commonly found in the Greenstones. Unfortunately they are too often

/ inadequate

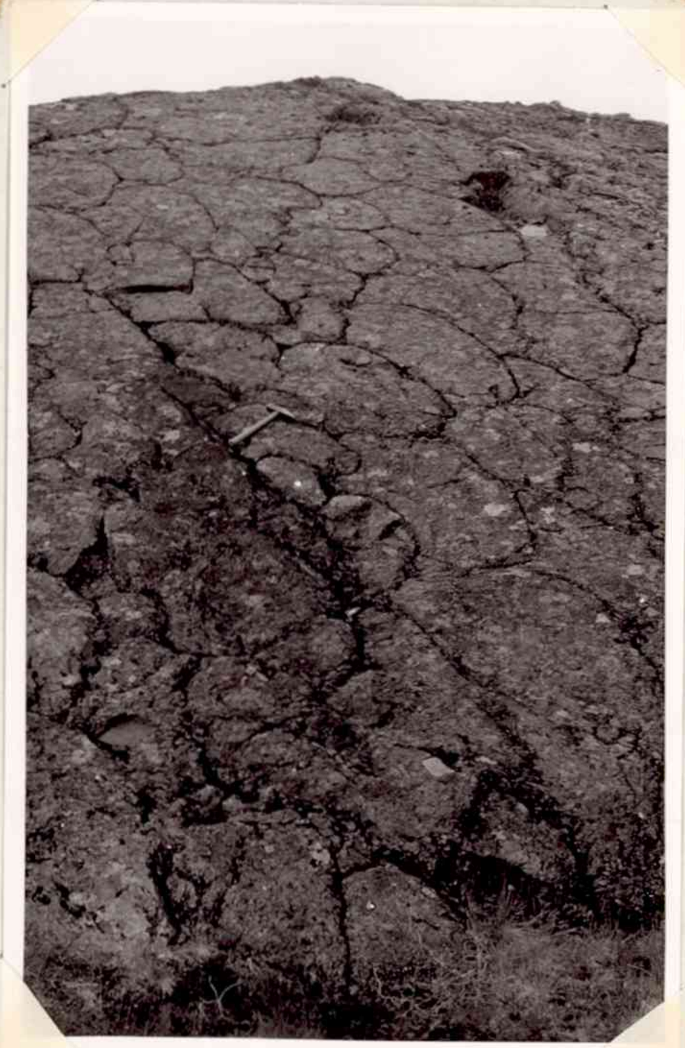
inadequate to be of economic value. It is generally recognised that such sulphide ores were deposited in a reducing environment with the sea-water rich in hydrogen sulphide ; C.W.Carstens suggests that the sulphur most probably came from submarine volcanic exhalations.

The second deposit occurs in a large exposure about 30 m. wide, some metres north of Mjovatnet. It consists of a homogeneous, fine-grained, hematitic red shale containing minute flecks of a colourless mineral. Three possible origins of the deposit are as follows :-

1. Terrigenous material from an arid landmass.
2. Biogenetic i.e. an association with radiolaria .
3. Oxidation of a syngenetic iron sulphide deposit.

The first possibility is probably the most likely origin, but it cannot be proved conclusively. The deposit forms an area of low ground, which is occupied mostly by peat bogs. The shale appears to pass along the strike into massive boulder conglomerate. Unfortunately, exposure was inadequate to determine its relation with the Greenstones and the Støkkvola (Venna) Conglomerate.

In conclusion, it may be noted that, except for areas of conglomerate, no attempt has been made to distinguish, on the final map, different petrological divisions within the Greenstones because of the difficulty of tracing individual beds and boundaries owing to lack of exposure.



D.H.B.

Pillow lavas in the Storen Greenstones,
Grefstadfjeldet.

2. The Stokkvola (Venna) Conglomerate.

In the Fjeldheim area a polygenous boulder conglomerate appears to lie unconformably on the Storen Greenstones. The conglomerate is polygenous, consisting of sub-angular ffagments rangeing in size from small pebbles to sub-angular bóulders about a metre in length - in one locality a boulder 3 m. in length was found. The fragments are of Greenstone, a pale grey quartzite and jasper. The matrix is, generally, fine-grained, feldspathic and green in colour. Except for the jasper, the fragments have in most cases been squashed tectonically with a similar deformation ratio of 4 : 1 as the pillows ; the major axes have a similar strike of about 280^{0} like the major axes of the pillows. The tough jasper seems to have resisted the tectonic deformation to a great extent; it is also more resistant to weathering because the jasper fragments invariably stand out above the exposed surface.

In the Holanda area, a few kilometres east of the Fjeldheim area, Vogt (1945) describes the Venna conglomerate lying directly on the Storen Greenstones. He notes that the bulk of the fragments consist of a characteristic sandstone rich in calcite: the colour of the rock is light grey to light purplish red and consisting of fine-grained quartz with much fine-grained calcite, frequently so much that the rock is on the border of a quartz rich limestone. Many larger boulders and smaller pebbles of red jasper also occur. Vogt is uncertain whether any Storen Greenstone pebbles occur in this conglomerate. He notes also that a basement conglomerate of another type , with pebbles of Greenstone and red jasper, was found in the west of the Holanda area, i.e. towards the Fjeldheim area. This could be the eastern continuation of the basal conglomerate found in the Fjeldheim area. From the map it can be seen that the Fjeldheim Series rests directly on the Greenstones in the east of the area, with no intervening basal conglomerate. Possibly, unless there is a fault here, this region was either a landmass during the formation of the boulder conglomerate or the conglomerate was deposited here and eroded away soon after its deposition. Holtedahl (1960) points out that above the Greenstones of the Storen Group is a polygenous conglomerate with jasper as a characteristic material in the boulders - the Stokkvola conglomerate, which can conveniently be taken as to mark the boundary between the Storen and overlying Hovin Group. The typical jasper bearing Stokkvola conglomerate is not present in the Holanda-Horg district, but here the Venna conglomerate is in a corresponding

/ stratigraphic

stratigraphic position. It has been decided therefore to call the basal boulder conglomerate occurring in the Fjeldheim area the Stokkvola (Venna) Conglomerate since it is very close, spatially, to the Venna conglomerate and similar, petrologically, to the Stokkvola conglomerate and finally because it is in a similar stratigraphical position to both of them.

The Stokkvola (Venna) Conglomerate appears to mark a period of major disturbance. The fragments, being sub-angular and reaching the size of boulders, have probably been transported only a short distance. The conglomerate therefore probably represents a period of rapid erosion due to a period of abrupt uplift. Earlier authors had theorised on rapid elevation and denudation of the Storen Greenstones after their formation and finally Holtedahl (1920a) introduced the term " Trondheim Disturbance " for the orogeny implied. It is of interest that a break corresponding to the Trondheim disturbance may be traced over widespread areas of Norway.

3. The Fjeldheim Series.

On the west of the lake Loktj, to the north and south of Mjovatnet and in the north of Hoidal valley, the Stokkvola (Venna) Conglomerate grades up into the Fjeldheim Series.

The Fjeldheim Series is possibly equivalent to Vogt's Holanda Shales and Sandstones. However, in the Holanda area, Vogt records an intervening breccia, the Gaustadbakk breccia, followed by a chocolate coloured mudstone between the Venna conglomerate and the Holanda group. The Holanda Group are topped by the Holanda limestone, which is followed, in the Horg area, by the Krokstad group of shales and sandstones, which from their description seem very similar to the Fjeldheim Series. Thus the series could be corelated either with the Holanda Group or the Krokstad Group, but from their position immediately following the Stokkvola (Venna) Conglomerate it would seem most logical to co-relate the Fjeldheim Series with the Holanda Group of Shales and Sandstones,

The Fjeldheim Series could be termed an arkosic greywacke formation since it possesses the characters required to define a greywacke. The series has a minimum thickness of about 400 m. ; the top of the formation was not seen. It consists of alternating thin bands , about 2-3 cms. thick, of feldspathic grits, sandstones and fine-grained banded shales. The banded shales are frequently developed to a considerable thickness in preference to the grits or sandstones. The beds are green to greyish-green in colour and the coarser bands weather white, standing above the weathered surface as thin ridges. Intercalations of coarse conglomerates occur, notably south of Lertj and east of Mjovatnet. The regional cleavage is not so well developed in the coarser beds as it is in the banded shales, where it was sometimes difficult to unravel the cleavage - bedding relationship. Brown specks of limonite, after pyrrhotite or pyrite, are of frequent occurrence and brown iron-staining is common. North-west of Mjovatnet some unusual ellipsoidal cavities occur on a weathered joint surface of banded shale. The cavities have a major axis about 4 cms. long which lies in the plane of the bedding. They have brown iron-stained rims and small pyrite cubes were found within a freshly exposedd cavity. It is possible that these cavities may represent some type of nodular concretion or even ill-preserved fossil remains.

Near Lillebuan the sandstone contains very thin bedded, fine grained fragments of red jasper. The occurrence of jasper, other than in the intercalated conglomerates, seems to be very uncommon.

In many localities the Fjeldheim Series exhibits classic graded bedding, which was invaluable for determining the orientation of the bedding. Using the graded bedding it is possible to establish that the northern limb of the Fjeldheim syncline is overturned. Furthermore, at the east limit of Lertj and north-west of Mjovatnet slump structures and smallscale current bedding are developed. The graded bedding and the above phenomena give an indication of the mechanism of formation of the series.

It seems most probable that the mechanism responsible for the deposition of the Fjeldheim Series was turbidity current action. Kuenen (1951) defines a turbidity current as a current containing suspended sediment which flows along the floor of a standing body of (clear) water due to its higher density. Gradual loss in velocity of the flow as it travels over the bottom will cause the head of the current to deposit first coarse material and then finer material, which is subsequently deposited on this as the current moves on over it, thus building up a graded bed.

Having established the effect it is now necessary to account for the cause of the series of turbidity currents needed to form the Fjeldheim succession. In an early paper on the problem of graded bedding following the dramatic realisation of the power of applying graded bedding to problems of orientation, after Th. Vogt, the Holanda-Horg authority, recognised its occurrence in

/ the Appin quarzite,

the Appin quartzite, in the N.W. Highlands, E.B.Bailey (1930) suggested floods, hurricanes and sea-quakes as possible causes. Floods and hurricanes he dismisses as being inadequate in force and frequency, but he believes that the triggering off of a coastal fringe of unconsolidated sand and mud by earth movements (sea-quakes) could provide the required effect. He notes finally that the sea-quake hypothesis retains floods and hurricanes as " useful auxiliaries".

Other causes (S.E.P.M. Symposium 1951) likely to give rise to marine turbidity currents may be considered, in relation to the Fjeldheim Series, as follows:

(i) Rapid introduction of sediment into an ocean by rivers, windstorms volcanic eruptions, mudflows and landslides. Other climatic effects may be included here because when first seen the Fjeldheim Series is suggestive of a varved glacial deposit and the idea of a Palaeozoic glacial origin for both the Stokkvola (Venna) conglomerate and the Fjeldheim sediments was considered. The boulder conglomerate could represent morainic material discharged from an ice sheet and then perhaps re-deposited, with the later beds being seasonal varved deposits. However, when the thickness and extent of the conglomerate and the Fjeldheim beds are considered it seems obvious that pronounced subsidence must have occurred to accommodate the beds. Such a marked subsidence could hardly be obtained by invoking isostatic adjustments or eustatic changes following a glaciation because neither would be adequate. Finally, the association with other rock types indicates a geosynclinal environment and points to the origin of the turbidity currents by crustal movements rather than seasonal floods. Nevertheless, a glacial theory need not be discounted entirely because it is possible to visualise glaciation associated with the orogenesis, i.e. ice-caps formed on areas uplifted to adequate altitudes, assisting in the provision of sediment during the geosyncline formation and infilling.
It seems that the causes postulated above, as well as tidal currents, storm waves, tsunamis and oceanic currents, cannot be considered as major reasons for the formation of marine tubidity currents. To borrow Bailey's apt phrase , they should be assigned as " useful auxiliaries ".

(ii) Slides, slumps or mudflows. These effects, triggered off by earth movements, seem to be the most likely causes of the required

/ turbidity currents.

turbidity currents. A laterally extensive graded bed can be formed in a few minutes by a large-scale turbidity current, so that relatively few would be necessary during the long period of the geosyncline formation and infilling. This in turn means that only a relatively small number of sea-quakes would be necessary during this period to trigger off the slides or slumps. As subsidence progressed the unconsolidated coastal fringes of recently eroded material from the complementry uplifted landmasses became increasingly unstable until slumping eventually took place. The slumping was due either to a maximum stable weight of unconsolidated material being exceeded or it was triggered off by shock waves due to earth movement within the geosyncline.

The interbedded conglomerates within the Fjeldheim Series probably represent, like the Stokkvola (Venna) conglomerate, periods of major disturbance. West of Mjovatnet and south of Lertj the conglomerates are polygenous, consisting of fairly well-rounded fragments of Greenstone lava, agglomerate, schist, quartzite and sub-angular jasper. The matrix is feldspathic, coarse to fine-grained and green in colour. The size of the fragments varies from pebbles to boulders up to 18 cms. in length. They are generally squashed along a 270° strike with a ratio of major to minor axes of 4 : 1 .

Individual beds of different grades of sediment within the Fjeldheim Series are not indicated on the final map owing to lack of exposure making it impossible to trace individual beds for any distance along their strike. Areas of interbedded conglomerate have been indicated separately. The limits of the Stokkvola (Venna) Conglomerate, where they are exposed conclusively, have been marked with solid lines. Howevmr, these limits are slightly arbitrary because although the boulder conglomerate grades up into the Fjeldheim Series it does so fairly rapidly, within a few metres at most.

THE GABBRO.

The probable association of the gabbro intrusion in the north east of the area with an initial magmatic stage has already been described. Unfortunatelytime was inadequate for a detailed study of the gabbro and its contact with the Greenstones. Tt was noted that the gabbro became finer grained as the chilled margin with the Greenstones was approached; the extent of any contact aureole, if it exists, was not seen.

Fresh exposures of gabbro along the new road cutting by the Trivja river show that patches of fine-grained gabbro exist within the main mass of coarse gabbro, indicating that convection currents were active during the molten stage.

The gabbro from the Trivja gorge is holocrystalline, medium grained, containing ophitic augite, altered euhedral feldspar, chlorite, epidote, hornblende and a colourless amphibole, probably tremolite. The augite is generally uralitised at its boundary where a thin rim of hornblende or tremolite has replaced it. Leucoxene, an alteration product of ilmenite, occurs as an accessory mineral in the form of relic skeletal structures of the original ilmenite. The elongated laths and plates of the original plagioclase feldspar are entirely saussuritised to a micro-granular mass of secondary minerals. Relics of original twinning are sometimes visible. The ophitic augite occurring between or enclosing the plagioclase laths is very pale brown (possible it is titanaugite since titanium is abundant in the rock) and it sometimes twinned on 100 . It is altered at its rim mostly to pleochroic green hornblende and sometimes tremolite, after the process of uralitisation, which is thought to develop during the slow cooling of the gabbro body.
The following accessory minerals are present:

(i) Leucoxene, which is brown-black, almost opaque and occurs as skeletal remnants of ilmenite.

(ii) Chlorite occurs as small irregular patches; it is pale green and pleochroic with diagnostic "Berlin blue" birefringence colours. It is sometimes developed around the hornblende uralite rim of the augite, possibly as an alteration product of the amphibole.

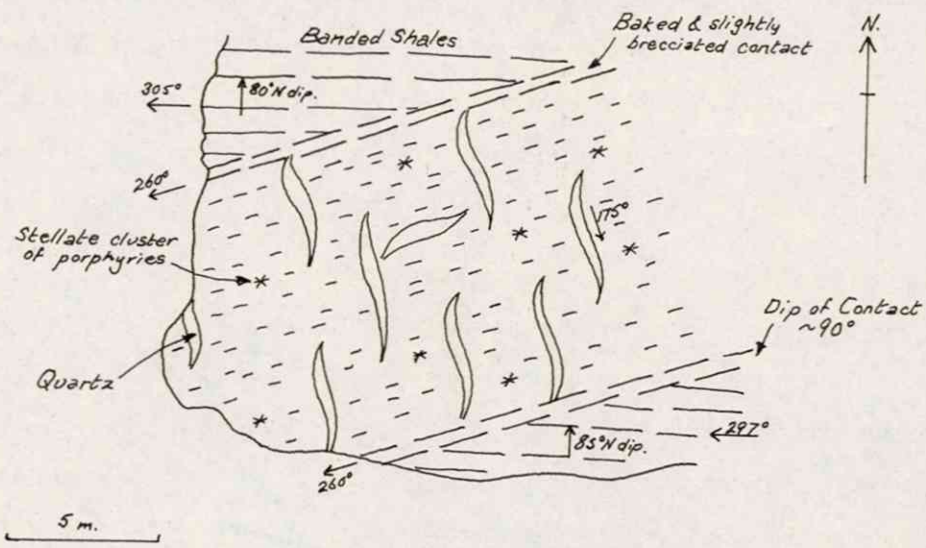
(iii) Epidote occurs in small anhedral crystals; it is pale brown-green, slightly pleochroic, with a bright moderate birefringence and high relief.

At Lokken similar gabbro bodies appear to be linked with valuable cupriferous pyrite ore bodies. After intensive geophysical prospecting around the Fjeldheim gabbro, no economic ore deposits were found.

THE DYKE INTRUSIONS.

(i) A dyke striking N.E.-S.W. can be traced for about 0.5 kms. on each side of the lake Loktj. It varies in width from 20 m. at south-west extremity, to 10 m. south of Loktj, and to 16 m. at its north-east limit. The dyke walls dip about 80° to the south-east. At the contact with the shales south of Loktj it is fine- grained, though porphyritic crystals occur to within 2 cms. of the contact. The shales are only very slightly baked; the baked zone being about 5 cms. wide on each side of the dyke. The influx of the dyke material seems to have contorted the shales to a certain extent. At its north-east limit where it has intruded the Stokkvola (Venna) Conglomerate its weaker resistance to erosion contrasts with the tougher conglomerate, which stands out some metres above the weathered surface of the dyke. The conglomerate margin is also only slightly baked. Porphyritic laths of altered feldspar, about 1.5 cms. long, are nearly always orientated parallel to the dyke walls, which strike about 230°. Frequently a small number of laths are arranged in radiate clusters, like the spokes of a wheel.

The dyke appears as if it might be associated with faulting since it has a strike similar to the major faults; in particular, it dips south at 80° - an angle similar to that of the Storbuan fault plane. Quartz veining is commonly associated with the dykes. A common relation is shown in the accompanying sketch:

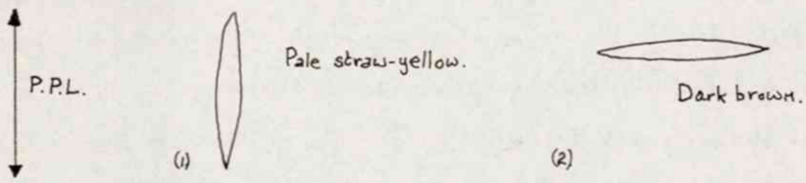


Sketch of Dyke Intrusion 0248.
North Edge of Mjovatnet.

It is notable that the quartz veining does not pass out into the surrounding country rock.

In thin section (0114) the rock is holocrystalline, medium to fine-grained with many porphyritic laths of pale green alterdd feldspar. Pleochroic green chlorite in anhedral platey patches occurs throughout the rock in fair abundance. A little quartz, secondary albite and leucoxene are also present. Small needles of a pleochroic straw-yellow to brown mineral occurs very abundantly. The altered feldspar occurs as euhedral porphyritic crystals and medium grained laths, which have been saussuritised forming a micro-granular groundmass of secondary minerals, including pale green grains of epidote. The rims of the laths are characteristically darkened by what appears to be a concentration of much finer granules. Traces of original zoning are sometimes visible.

The pale yellow-brown mineral has the following pleochroic scheme:



The refractive index is greater than Canada balsam and it has a parallel extinction. It occurs in micro-graphic intergrowths with secondary feldspar or chlorite. It has been suggested that this mineral is stilpnomelane, an iron rich variety of chlorite, but it has not been possible to prove this conclusively.

Brown semi-opaque leucoxene, after ilmenite, occurs in ragged shreds rather than as skeletal crystals found in the gabbro. Pyrite is commonly present.

(ii) The intrusion on the south side of Hoidal valley is the only one of its kind found in the area. Only the northern boundary is visible and the contact surface dips 55° south and strikes 250°. A little quartz veining, about 2.5 cms. thick, occurs across the intrusion-grit contact at right-angles to the contact strike. In thin section the rock is holocrystalline, medium grained and very abundant in euhedral to anhedral pleochroic green-brown hornblende. Sub-hedral, mostly saussuritised feldspar occurs in poikilitic intergrowths with the hornblende, i.e. the feldsper crystallised later than the hornblende. Neither the feldspar or hornblende crystals show any preferred orientation. Anhedral quartz is fairly abundant and accessory chlorite, leucoxene and an opaque mineral occur in small anhedral grains. The hornblende, which is the dominant mineral, is dark brown to green, pleochroic and is sometimes rimmed by a zone less rich in iron than the centre. Some of the euhedral prismatic laths have a thin overgrowth of a colourless amphibole. Occasional twinning on 010 occurs.

(iii) The third type of intrusion occurs north-east of Mjovatnet as two masses, whisch ate apparently lozenge-shaped in plan. The boundaries were mostly obscured by vegetation.

In thin section the rock is holocrstalline, coarse grained, consisting mainly of euhedral prismatic laths of altered feldspar, about 5 mm. in length, in a micro-granular groundmass of secondary minerals, which is dominated by anhedral albite. A little sub-ophitic augite occurs, which is almost entirely altered to chlorite, hornblende and a pale green amphibole. Irregular patches of leucoxene, sometimes as skeletal remnants, occurs quite abundantly. The feldspar is saussuratised to a micro-granular replacement containing small pale green grains of epidote, which are concentrated especially around the rims of the altered laths. Secondary albite occurs as a micro-granular mosaic of anhedral crystals. The ophitic augite is pale brown in colour (titanaugite ?). It is uralitised at its rim with green hornblende and pale green actinolite. The augite is also extensively veined by chlorite, which is distinguished by its anomalous "Berlin blue" birefringence colour. The variety of chlorite possessing these colours is pennine. Very rarely a red-brown isotropic mineral occurs in the amphibole.

This type of intrusion was found only at this one locality. From its mineralogy it could be termed a dolerite and it is probably closely related to the gabbro.

(iv) A thin dyke, about 1 metre thick, is intruded into the gabbro of the Trivja gorge. It is remarkable in that it contains fresh albite in unaltered laths. In thin section the rock is holocrystalline and medium grained containing sub-hedral laths of twinned feldspar and irregular patches of fine acicular aggregates of pale green pleochroic chlorite with anomalous "Berlin blue" birefringence colours (pennine). Small patches of ophitic pale brown augite (titanaugite ?) occur. Opaque, unaltered skeletal crystals of ilmenite are quite abundant. It is noteworthy that all the above constituents occur in almost equal abundance, with the feldspar slightly in excess.

Maximum symmetrical extinction measurements of the twinned feldspar laths revealed the following composition: $Ab_{90}An_{10}$. The refractive index is less than Canada balsam. The albite does not appear to be secondary because it occurs in well-shaped laths, which are often simply twinned and frequently in ophitic arrangement with the augite. If the albite is primary then

/ the intrusion

the intrusion possibly represents a very late stage differentiation product of the gabbro body. However, a major problem would exist to explain why the feldspar used up the soda in the magma leaving none to form any soda-pyroxene. With regard to this it seems more probable that the albite is secondary,thogh why the original feldspar was replaced entirely by euhedral albite and not saussuritised,as in all the other ihtrusions, is unknown.

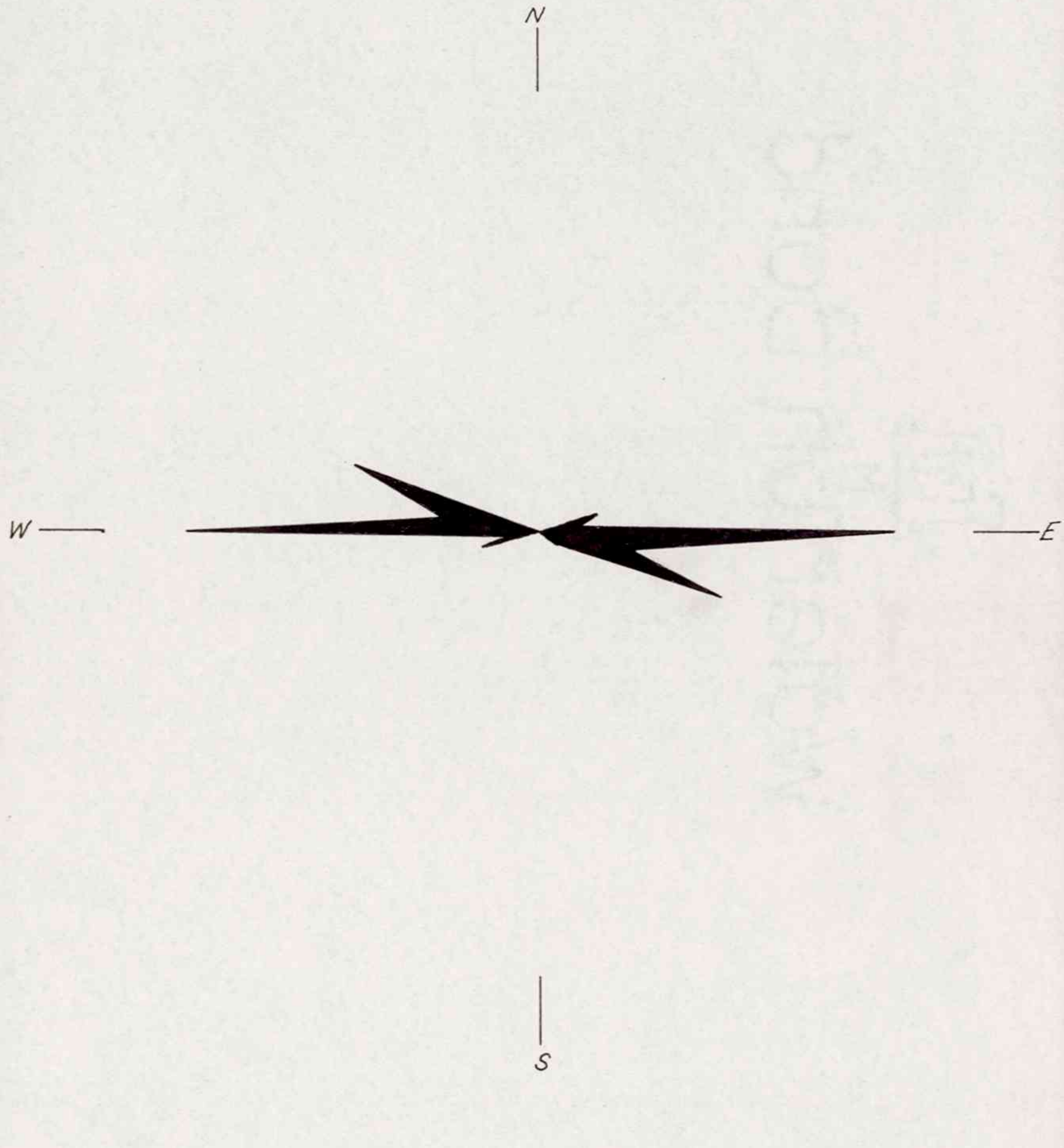
From their spatial relation and mainly basic composition it appears that the dykes in the Fjeldheim area had a common origin in a major basic magma body. Owing to present lack of knowledge, little can be said about the physico-chemical modes of magma differentiation, which resulted in their final composition.

STRUCTURAL GEOLOGY.

Basically the rocks in the Fjeldheim area occupy a syncline, which has an axial plane cleavage striking about 270° and dipping north at about 70° . It can be demonstrated using graded bedding that the northern limb of the fold is overturned. The fold appears to be plungeing towards the east, but the angle of plunge is uncertain. At some exposures fairly tight folds occurred having axial planes orientated similar to the axial plane of the major fold. It seems likely that isoclinal folding is fairly common within the major syncline. Exposures are inadequate to comment at length on the type of folding present, but it seems most likely that similar folding has taken place, aided by shear along the cleavage. From strike of the cleavage it can be deduced that the maximum compression acted north-south.

Faulting is very common in the area; those indicated on the map are probably only a few of the faults occurring, the majority being unexposed. Faults of both the tear and normal variety occur. Slickensides, where they are visible, have been recorded on the map. Quartz veining and large pyrite cubes, up to 0.75 cms. square, are commonly associated with the faults, due to the heating effect derived from frictional resistance of sliding rock faces bringing about a migration and condensation of material in the rock. Shaley, fine-grained mylonitic material was found associated with the plane of the major fault at Storbuan. It is probable that many of the dyke intrusions, which have a sub-parallel orientation to the faults, are genetically linked with the faulting.

The major faulting took place after the folding. The dykes are metamorphosed to a similar degree to the other rocks, and if the dykes are intimately connected with the faulting then the major faults occurred soon after the folding.



Rose Diagram to show the Distribution of Cleavage Strike in the Fjeldheim Area.

CORALS FROM THE KALSTAD LIMESTONE, NEAR MELDAL.

At Kålstad, near Meldal, a few kms. south of Lokken, the Kalstad limestone appears to be faulted into the Storen Greenstone Series. The limestone is a light grey to grey-black impure limestone, often somewhat crystalline, which in part is very rich in fossils such as corals, crinoids and calcareous algae.

From material collected by Messrs. David Blake and Ehrling Sagvold from localities shown on the accompanying sketch map, two corals were identified, from thin sections and cellulose peels, as Streptalasma sp. and Nyctopora aff. parvotabulata. The basis for the identification was the description and photographs in a paper on the corals of Mjosa limestone, near Oslo, by Hill (1953).

1. Streptalasma sp.

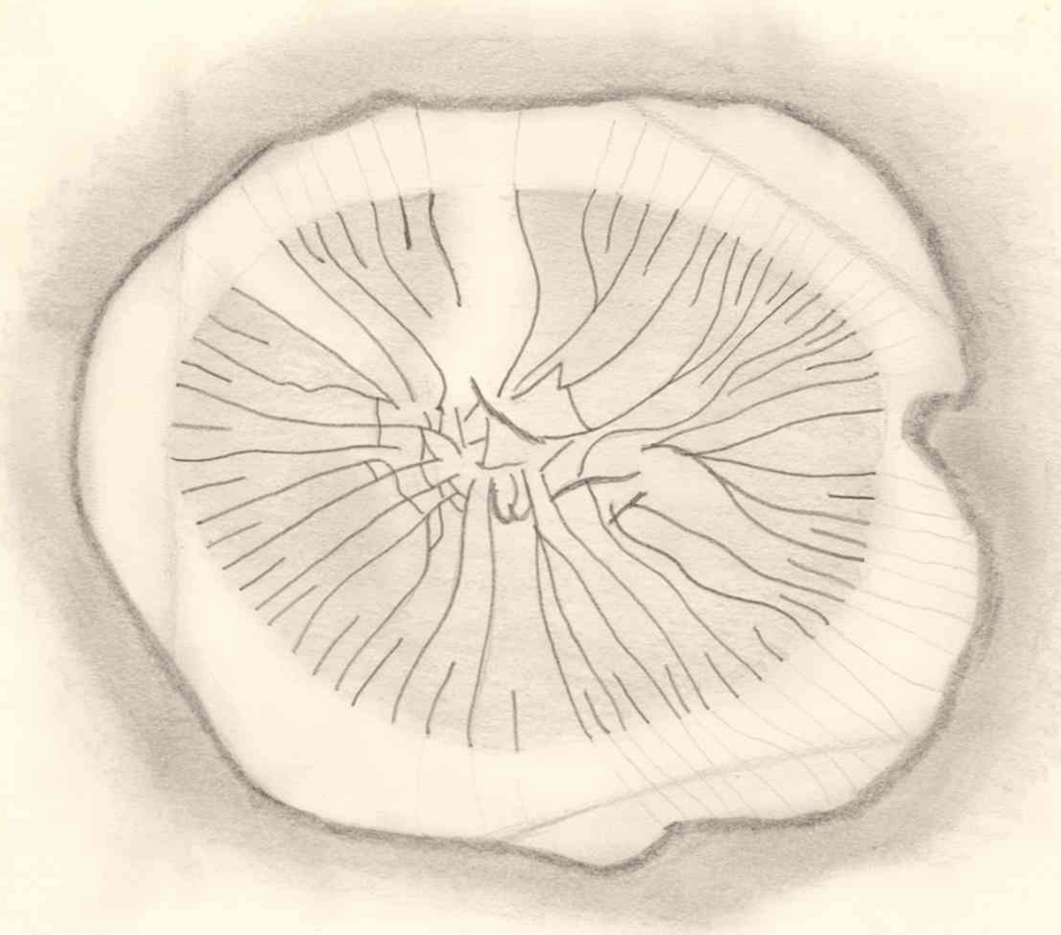
The solitary, simple corallum is conical and attains a diameter of about 2 cms.. The septa are numerous (about 40), alternately long and short and dilated at the peripheral stereozone, which is about 2 mm. wide at a corallum diameter of 2 cms.. Some of the major septa twist together at the axis, others unite about ¾ of the distance from the stereozone to the axis continuing to the axial zone as one septum.

2. Nyctopora aff. parvotabulata.

The coral is compound with slender corallites. The central and tabular structures are replaced by a mosaic of calcite. No epithecal line of division occurs between neighbouring corallites. The corallites are about 2 mm. in diameter and they are mostly irregular six-sided polygons, in cross-section. Small irregular pores occur permitting communication between the corallites.

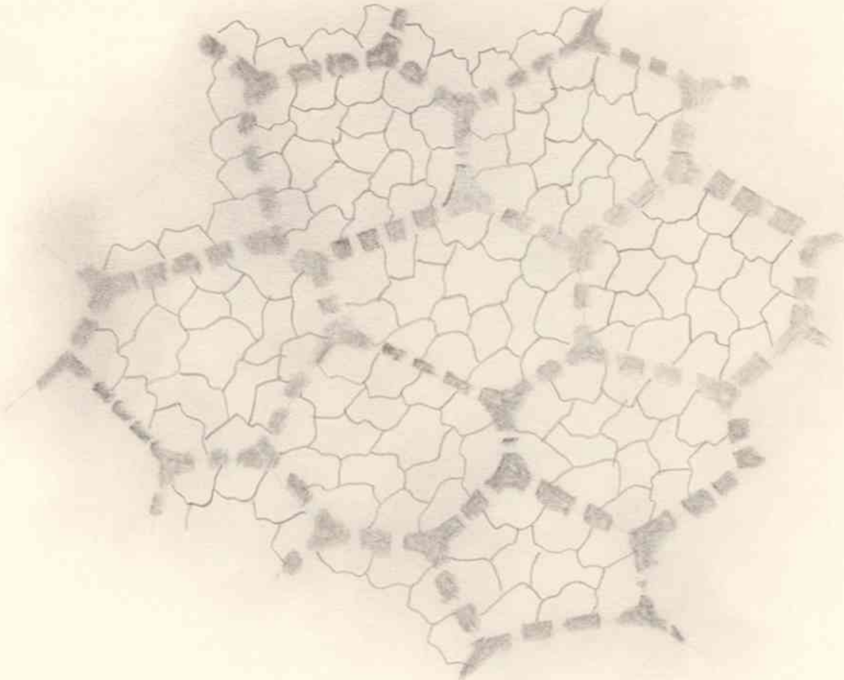
Hoeg (1932) discovered that algae from the Kalstad limestone indicate an age contemporaneous with the Mjosa limestone, near Oslo, of Upper Caradocian to Ashgillian. Cowper Reed (1932) maintains that brachiopods from the Kalstad limestone also point to an Upper Ordovician age (Ashgillian). In addition, both the above corals are closely similar to corals in the Mjosa limestone, indicating an Upper Caradocian to Ashgillian age. Thus it may be concluded that the Kalstad limestone is of Upper Caradocian to Ashgillian age.

It is most unfortunate that, although the age of this formation is known so precisely, it has not yet been possible to correlate the Kalstad limestone with any other stratigraphical division in the Trondheim region.



0.5 cm.

Transverse section
Streptalasma sp..
Kalstad limestone, Meldal.



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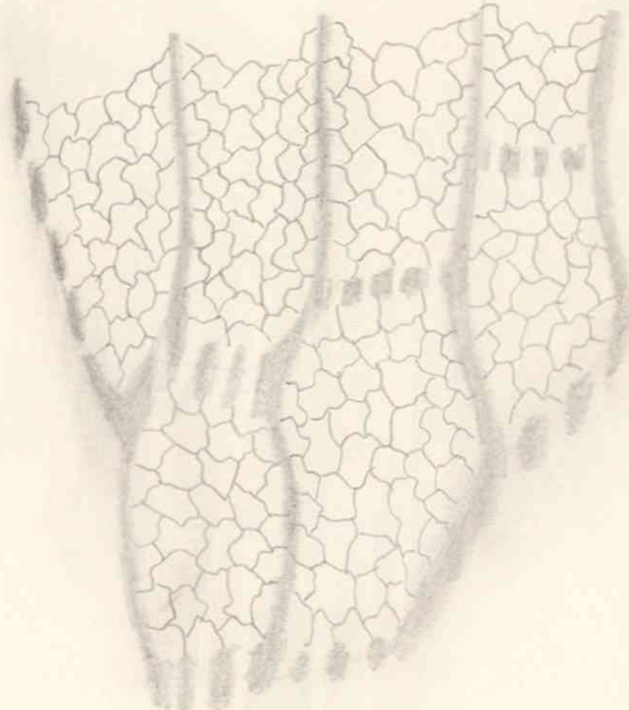
Transverse section.
Nyctopora aff. *parvotabulata*.
Kalstad limestone, Meldal.



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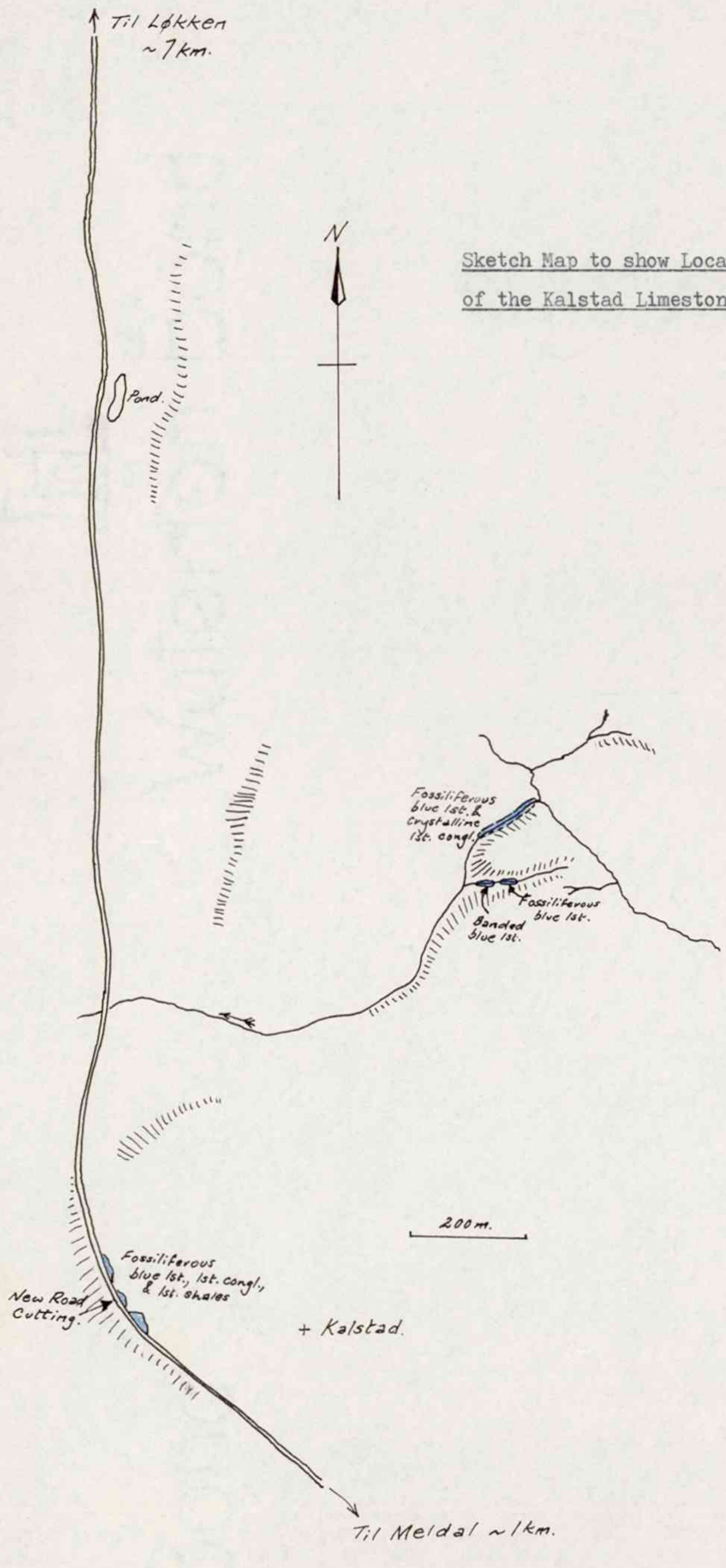
Longitudinal section.
Nyctopora aff. parvotabulata.
Kalstad limestone, Meldal.

Sketch Map to show Localities of the Kalstad Limestone.



FLORA AND FAUNA.

A moderate cover of forest, mainly of fir and silver birch, exists, with a tree-line at about 600 m.. The percentage of rock exposure is generally not very high. The best exposures are on the high ground and high on valley sides where gradients are too steep for vegetation to establish itself. Over the valley floors a moraine cover commonly provides a foundation for plant life and acts as an effective blanket over the underlying solid rock. Often a clean well-exposed surface would be found where the thin soil cover had been stripped off in the root mesh-work of a fallen tree.

In badly drained areas extensive peat bogs are developed providing a basis for the growth of heather, cloudberries, blueberries, sedges and grasses. Water-lilies commonly thrive well in some of the lakes. Numerous types of fungi also occur, living especially in the damp sheltered areas in the forests.

Of the fauna, fish, mainly trout, are very abundant in all the lakes and the lake edges are also a great attraction for many varieties of large and colourful dragonflies. Evidence of elk is very common though most unfortunately none were seen. Adders, which are unpleasantly abundant, frequently prefer to sun themselves on an important exposure. Further attractions of forest life are the redd squirrels, pine martens and a great variety of birds, which include woodpeckers, fly-catchers and magpies. Last, but by no means least, the flies. It cannot be over-emphasised that an effective fly-repellant is an essential accessory for field-work in the area - without one work is impossible.

Finally it may be noted that the agriculture of the area is generally devoted to sheep-rearing and beef and dairy production.

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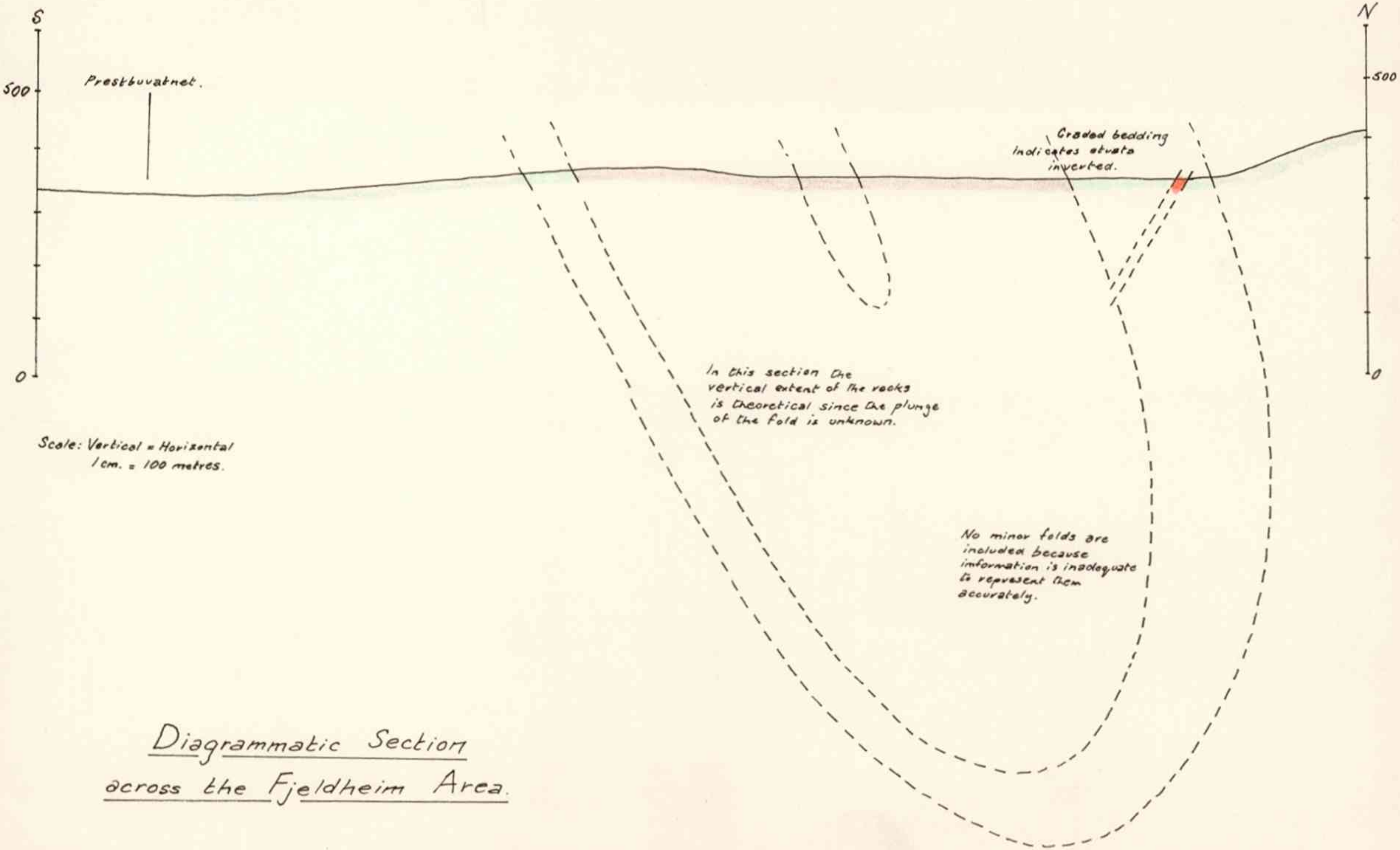

Diagrammatic Section
across the Fjeldheim Area.

B.C.