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T H E   G E O L O G Y

O F A N A R E A A R O U N D

G A S B A K K E N,   N O R W A Y.

B R I A N   C H A D W I C K.

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T H E

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OF AN AREA AROUND

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INTRODUCTION

This report describes the stratigraphy, structure and physical geology of an area around the west and north of the village of Gasbakken, Norway. Gasbakken is situated about 40 kms. south of Trondheim and about 15 kms. east of the important mining centre of Løkken.

It was the intention of three students, A.E.Beswick, J.W.Rowling and the author, to map in detail the country between the Hølonda district, east of Gasbakken, which was surveyed geologically by Th. Vogt (1945), and the areas west of Gasbakken which were mapped by D.H.Blake and the author in the summer of 1960. These latter areas are situated around the estate of Fjeldheim and the lake Svartvatnet, which lies a short distance south of Fjeldheim. They occur in the north-east of a large area mapped on a reconnaissance scale by the late C.W.Carstens, whose findings were published posthumously as the map "Geologisk kart over Løkkenfeltet" in 1952.

The aim was achieved, but the fieldwork was severely curtailed by very wet weather. Of a total of 49 days spent in the area by the author during July and August 1961, only 36 days were spent in the field.

Aerial photographs on a scale of 1:15,000 were used in the field and the final map is based on a mosaic drawn from the aerial photographs. The photographs were very kindly supplied by the Orkla Grube Aktiebolag, Løkken. Fairly large errors occur when drawing a mosaic from aerial photographs, but it is felt that the map obtained in the present instance is adequate for presenting the geological data. The north point was obtained from compass measurements in the field.

Th. Vogt, who made an important contribution to the geological knowledge of the district, gives an admirable survey of the literature, relevant to the area described in this report, in his paper "The Geology of part of the Hølonda-Horg district, a type area in the Trondheim region" in the Norsk Geologisk Tidsskrift 25, 1945.

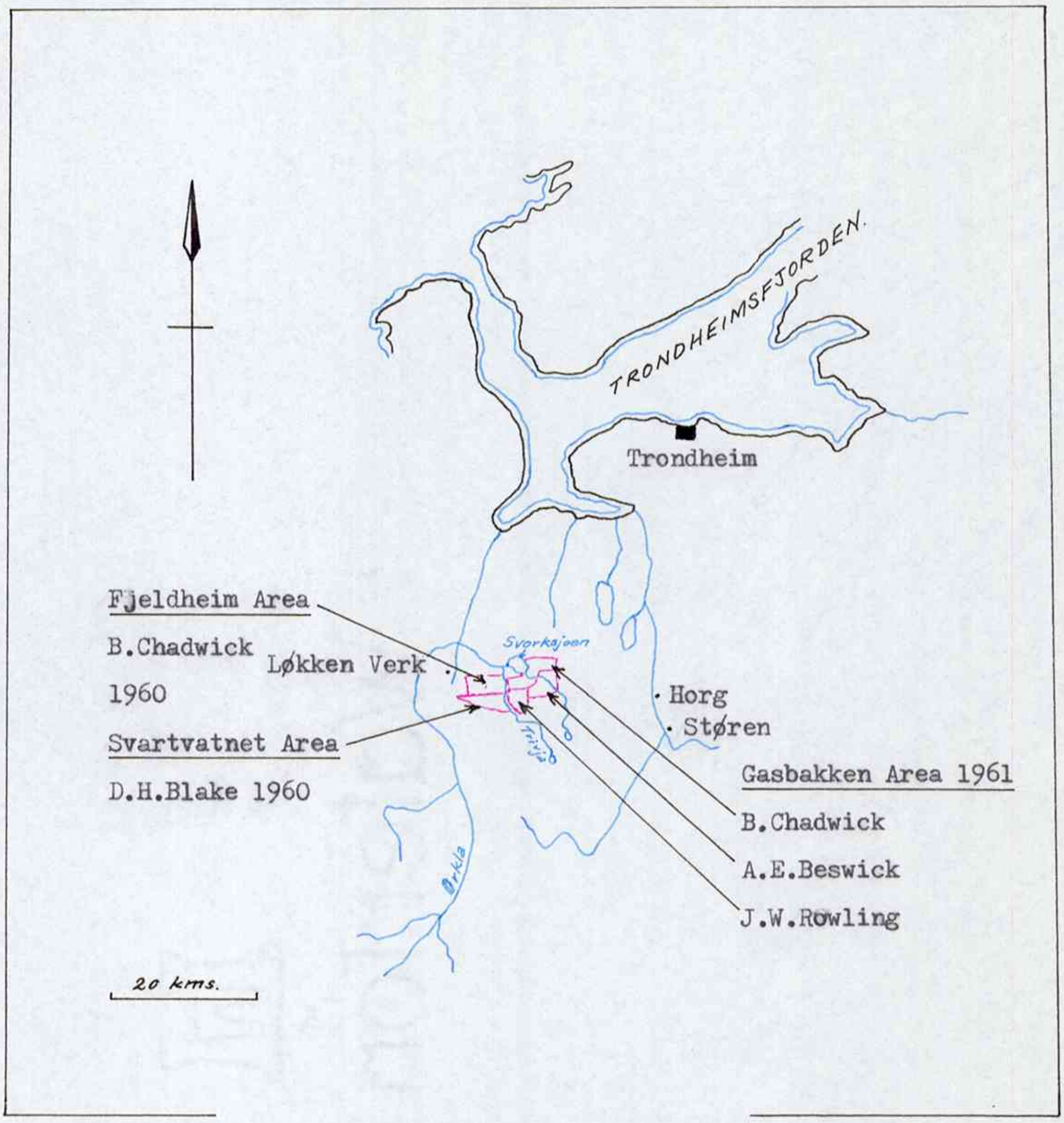


Fig.1 Sketch map to show the Geographical Location of the Gasbakken, Fjeldheim and Svartvatnet Areas.

SYNOPSIS OF THE GEOLOGY

The rocks of the Gasbakken area, are typical of the Trondheim region facies (Holtedahl, 1960). They consist of spilitic pillow lavas and associated pyroclastic deposits which are followed, unconformably, by a boulder conglomerate. This conglomerate grades up into a series of graded feldspathic sandstones and dark green and grey shales containing intercalations of impure grey limestones. Numerous sill-like intrusions of porphyrite occur in the later sedimentary rocks and a large gabbro pluton exists in the volcanic series.

The rocks have been folded, faulted and regionally metamorphosed up to chlorite grade during the Caledonian orogenesis. Two distinct acts of folding have been recognised.

No absolute dating by radioactive methods are known from within the immediate neighbourhood of Gasbakken and, therefore, the dating is based purely on palaeontological evidence. This evidence, which will be discussed later, indicates that the rocks considered in this report were deposited during Lower Ordovician times.

The oldest rocks examined were the Støren Greenstones, which, from their stratigraphical position, appear to be Upper Cambrian to Tremadocian in age. The Greenstones are a mainly volcanic formation of spilitic pillow lavas and pyroclastic deposits. Thin beds of red hemmatitic mudstone, red jasper and sedimentary pyrite sometimes occur within this volcanic series.

The Støren Greenstones are followed by the Stokvola Conglomerate, a polygenous boulder conglomerate, which has been taken by earlier workers to represent the base of the Hovin Group. The Hovin Group is the name given to a thick sucession of dominantly sedimentary rocks occurring stratigraphically above the Støren Greenstones. The rocks lying stratigraphically above the Støren Greenstones in the Gasbakken area all belong to the Lower Hovin Series.

The Stokvola conglomerate grades up into a series of feldspathic sandstones and shales which appear to be equivalent to the Hølonda Shales and Sandstones of Vogt (1945). Frequent thin beds of an impure grey limestone occur within the sandstones and shales and it is probable that these limestone horizons are equivalent to Th. Vogt's Hølonda Limestone.

Intruded into these rocks, in particular into the Lower Hovin Series, are the Hølonda Porphyrites. These are sill-like masses, which are usually only a few metres in thickness. The porphyitic feldspar, which was probably originally calcic, has been either saussuritised or albitised. Analyses given by Vogt (1945) indicate that the Hølonda Porphyrites were probably originally andesites. The large gabbroic mass, which occurs within the Støren Greenstones, is probably related to the Hølonda Porphyrites in that they had a common magmatic origin. Possibly,in conjunction with the lavas of the Greenstones, the porphyrites and the gabbro represent the initial magmatic stage of a particular geosynclinal phase of the Caledonian Orogeny. Evidence of the geosynclinal phase is preserved in the rocks of the Gasbakken area and this evidence will be discussed fully in the Stratigraphical section of the report.

Subsequent to the final effects of the Caledonian Orogenesis, the area experienced a prolonged period of erosion and general geological quietude. The most recent major geological event was the Pleistocene glaciation, which was the dominant agent responsible for the present topography.

PHYSICAL GEOLOGY

1. Topography and Drainage

The topography and drainage of the Gasbakken area is essentially consequent on the major rock types and structure of the area. The topography, as a whole, is fairly smoothly undulating and there are no horns or prominent peaks. Johan Kiaer (1932) observed that " Here are typical highland regions, strongly broken, wooded ground with small ridges and lakes, now and then with wide outlook on distant mountains ". The higher relief around Gasbakken is formed of the more resistant Støren Greenstones and the Hølonda Porphyrites and the valleys have been cut in the softer sedimentary series of the Hølonda Shales, Sandstones and Limestones.

Malberget, 533 m., which has been smoothed overall by glacial action, is the highest feature in the area; it is formed from the resistant Støren Greenstones. This prominent landmark is bounded to the east by a high, vertical fault scarp. To the west lies the deep gorge of the Trivja river which isolates the mass of Malberget from the Greenstones forming the high ground which passes westwards into the Fjeldheim area. North of Malberget and south of the farm Fuglaashogstret, there is a topographical depression which is occupied by the large gabbro intrusion. This depression contrasts with the high ground, which is also formed of gabbro, to the west of the Trivja river, in the Fjeldheim area. It is possible that the river course follows a fault zone in this particular region.

Throughout the area the Hølonda Porphyrites invariably form the backbone to high ridges and other positive features. The softer sediments usually occur beneath or on the flanks of the Porphyrite masses and therefore they have received a slight degree of protection from erosion.

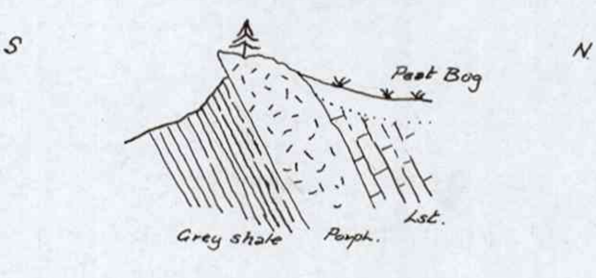


Fig.2 Sketch section of Hølonda Porphyrite intrusion, near Stornaeve. Locality 054.

Low-lying areas are frequently occupied by poorly drained peat bogs, which are underlain by alluvial and/or morainic material. Reksaasmyren is an extremely large area of marsh to the east of the lake Svorksjoen. At present, this marsh is undergoing drainage and clearance presumably for agricultural development. A similar marsh, Lillebumyren, occurs in the extreme south-west.

Rock exposure is generally poor over the whole area due to the extensive peat bogs and the moderate forest cover of fir and silver birch. Frequently, in the forested areas, 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. The better exposures were usually to be found on the higher ground.

The drainage is mainly consequent in that it is controlled by the underlying geology. The lakes appear to lie either in strike valleys cut in the softer rocks, e.g. Stensvd., Bjornlivd, and Langaasvd., or in large fault depressions, e.g. Svorksjoen and possibly Ellingsvd..

As a result of the recent isostatic adjustments subsequent to the glaciation, the rivers and streams generally show a youthful character and the majority are actively cutting their courses deep into the country rocks. The youthfulness is especially well exemplified by the Trivja gorge. In cutting back southwards through the resistant Støren Greenstones, the Trivja river has entrenched itself in a deep, steep-sided gorge which extends upstream to the marsh area of Lillebumyren. 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 waterfall is about 25 m.. Lillebumyren is a depression which is almost entirely infilled with alluvial material deposited from the Trivja as its current is checked on entering the marsh area. In the summer months the river meanders placidly across the marsh until it reaches the weir and regains its vigorous erosive power on plunging into the gorge. During the spring thaw and after periods of very heavy rain, such as occurred during the summer of 1961, the river floods over its confining levees and deposits a fresh cover of alluvium on the marsh. Successive migrations of the river course, due to lateral corrasion and deposition on the meander bends, are clearly visible on the aerial photographs. Due to the reduction of the current velocity, the river bed is braided for some distance upstream from the point where it enters the marsh area.

Similar phenomena are visible on the Skolda, a major river flowing across the area from east to west into the lake Svorksjoen. This river clearly occupies a major fault valley and it is particularly interesting because, just west of Gasbakken village, it appears to have changed its course. Instead of running directly into the extensive marsh area of Reksaasmyren, the river turns sharply south and then after a few hundred metres it turns west again and eventually runs into the marsh a further few hundred metres downstream. This short discordant stretch of the course also appears to occupy a fault zone. Meanders and ox-bow lakes have been developed as the river crosses the marsh. The river appears to be building a bird-foot delta as it enters Svorksjoen.

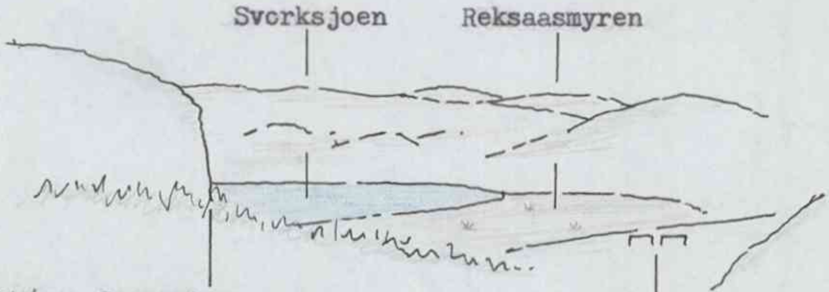


Fig. 3 Sketch and photograph $P_1$24 to show the Greenstone fault scarp, east of Malberget, the lake Svorksjoen, the marsh area of Reksaasmyren, the farm st. Fuglaas, and the generally undulating topography.

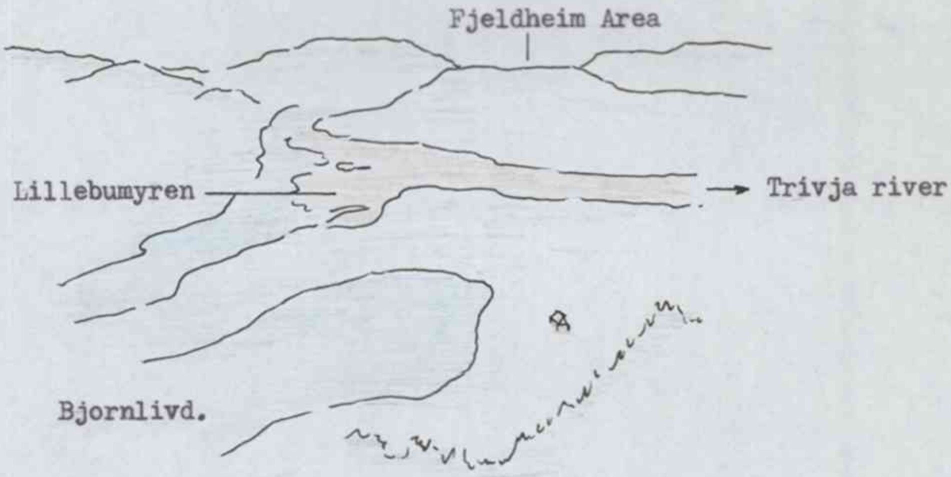


Fig.4 Sketch and photograph $P_1$19 to show the lake Bjornlivd., Lillebumyren and the Fjeldheim area. Photograph taken from the Porphyrite ridge, near Stornaeve.

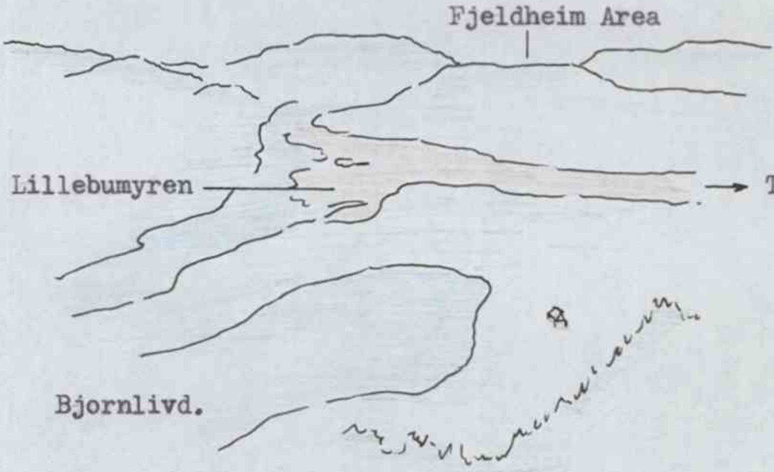


Fig.4 Sketch and photograph $P_1$19 to show the lake Bjornlivd., Lillebumyren and the Fjeldheim area. Photograph taken from the Porphyrite ridge, near Stornaeve.

Photograph $P_1 5$. The gorge and a major knick point on the Trivja river. Malberget lies to the east, on the left of the photograph, which was taken from a short distance downstream from the Trivja dam.

Photograph $P_{3}37$. Typical peat bog and forest covered ridge of Hølonda Porphyrite, near Hølonda.

2. The Recent Glaciation

Evidence that a recent ice-cover existed over the whole area is very abundant. Apart from the undulating topography and the lack of prominent horns and peaks, the fact that an ice-cover existed over the highest ground is indicated by the presence of numerous massive erratics, weighing many tonnes, obviously requiring a considerable thickness of ice for their transportation. The erratics are of white granite (trondhjemite), gneiss, conglomerates and local country rock. Numerous occurrences of trondhjemite are present around the Gasbakken region so that no definite indication of the direction of ice movement can be determined using the erratics. However, glacial striae, which were found in six localities, have an average strike of 325°. Thus it seems probable that at one stage during the glaciation of the Gasbakken area the direction of ice flow was from the mountainous region in the south-east.

Table of Glacial Striae

Outcrop and locality	Strike
0 01 Hølonda Ssts., Lillebumyren.	327°
0 08 Greenstone, near Trivja dam.	342°
0 59 Porphyrite, road near Stornaeve.	325°
0 128 Greenstone pillow lava, Malberget.	325°
0 214 Hølonda Ssts. & Shale, Trotland.	312°
0 323 Porphyrite, near Hølonda kirke.	320°

These diections correspond closely with glacial striae which are recorded, from adjacent areas, on the glacial map of Norway compiled by Holtedahl and Andersen, (Holtedahl, 1960).

Crag-and-tail features are common and their strikes are generally parallel to the overall striae directions. A particularly large example occurs around the farm st. Fuglaas; here the more resistant Hølonda Porphyrite forms the 'crag' while the softer shales and limestones of the Hølonda group form the 'tail', which extends for about 1000 metres north-west of the porphyrite 'crag' before vanishing beneath Reksaasmyren marsh. The strike and disposition of this particular feature confirms that the ice was moving towards the north-west from a source in the south-east.

The source of the ice probably existed on the mountainous region around Forelhogna, 1359 m., about 50 kms. to the south-east.

At some time in the late glacial history, a relaxation of the severe climatic conditions resulted in a degeneration of the overall 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 Gasbakken area, in particular, sources lay in the Langaasen and Trotland valleys and in the valley east of Malbergat.

Further retreat occurred with extended periods of still-stand such that pronounced terminal moraines had time to form in some localities. A good example is the Hølonda terminal moraine, which acts as a dam to the lake Langaasvd.. The glacier giving rise to this moraine was channelled to a certain extent by the porphyrite ridges rising up each side of the lake. The moraine south of Trotland may be the terminal moraine of a glacier in the Trotland valley or it may be a lateral moraine of a glacier in the Reksaasmyren area.

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 valley glaciers seem to have contributed only to local deepening and the formation of the terminal moraines. That this is the case can be judged from the fact that the valleys around Gasbakken 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 mush 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.

Photograph $P_1 3$ Glacial striae on Hølonda Sandstone, Lillebumyren. Strike 327°. Locality 0 01.

Photograph $P_3$22   The moraine at the south of the Trotland strike valley. This is possibly a terminal moraine of a small, late-stage valley glacier.

STRATIGRAPHY

1. THE STØREN GREENSTONES

The Støren Greenstones, occurring in the area considered in this report, most probably belong to the Upper Støren Greenstones, which is the youngest formation of a major Lower Palaeozoic group in the Trondheim region. This major group is known as the Støren Series. It is a principally volcanic series and it is named after a locality at Støren in Gauldalen. The name was introduced into the literature by Kjerulf in 1875 and explicitly defined and applied by Tornebohm in 1896. The series has also been called the Bymark Group by C.W.Carstens (1920), but the present author has followed Vogt (1945) in retaining the older and probably more widely known term. From palaeontological evidence, the Støren Greenstones in the Gasbakken area are probably Upper Cambrian to Tremadocian in age.

At Støren, which is situated about 20 kms. south-east of Gasbakken, the thickness of the entire series may be about 2500 m., (Vogt, 1945). The base of the Støren Greenstones, which were mapped by the author in the Gasbakken, was not seen. On his map, "Geologisk kart over Løkkenfeltet" (1952), C.W.Carstens records that the Greenstones are in contact with the Røros Group, about 5 kms. north-west of Svorksjoen. The Røros Group consists of mica-schists, which appear to be of uncertain age. This group in turn rests upon sparagmitic schists, which Strand (Holtedahl, 1960) suggests may be an original basement. From varioas parts of the Trondheim region and adjacent districts, Strand (Holtedahl, 1960), records evidence of thrust contacts between original basement and overlying younger rocks and it is conceivable, at least to the present author, that the rocks in the Gasbakken area, together with the Røros Group and perhaps even the sparagmitic schists, possibly belong to an allochtonous series.

The Støren Greenstones examined by the author in the Gasbakken area are dominantly volcanic rocks, containing infrequent, relatively thin, discontinuous horizons of red hematitic mudstones, red jasper and sedimentary pyrite. In the Hølonda-Horg district, Vogt (1945) found that the Upper Støren Greenstones contain a green tuffaceous slate called the Høve Slate. No evidence of these slates was found the Greenstones of the Gasbakken area.

The volcanic rocks, which may be generally described as 'spilitic', take the form of pillow and massive lava flows, tuffs and pillow agglomerates. The pillow structures indicate that the volcanic eruptions were most probably submarine in origin.

Pillow lavas are well exposed in numerous localities on and immediately surrounding Malberget. It was unfortunate that in many places the exposure was usually an ice-smoothed, roche-moutonnee surface and hence it was often impossible to determine the third dimensions of the pillows. Near the Trivja dam, Loc. 156., large exposures of pillow lavas indicate that generally the pillows are roughly elliptical and are fairly large, reaching up to 0.6 m. x 1.0 m. x about 2 m. in size. At this particular locality it was possible to establish, from the interlocking attitude of the pillows, that the flow is inverted, i.e. 'V'-upwards. At the Trivja dam, Loc. 157., the pillows are also very large and it was noticed that they sometimes took the form of long sausage-like rolls, which were about 2.5 - 3 m. in length and about 0.1 - 0.3 m. in width. Their third dimension was not visible. In an assemblage of pillows, exposed on a large ice-smoothed surface at the trig. point on Malberget, Loc. 37., the pillows range in size from dimensions of about 6 cms. up to those of about 1 metre. Also, in an assemblage on the south-east side of Malbergat, Loc. 128., the sizes varied from about 1 cm. x 0.5 cm. x ? up to about 0.3 m. x 1.3 m. x ? . In this locality the flow appears to be inverted. In the area as a whole, the pillows appear to have been squashed tectonically along a strike of about 270^{o}, such that the maximum compression was acting north-south. Unfortunately, no measurements for possible structural analysis could be made because of the ice-smoothed exposures.

The pillows generally have chilled, fine-grained rims and on weathered surfaces the rims are indicated by pale brownish areas about 2 - 3 cms. wide, depending on the size of the pillow, which extend all the way around the circumference of the exposed pillow . In fresher exposures the rims are usually paler green than the interior of the pillow and it is possible that there was some reaction between the material in the rim and the large volumes of steam produced by the eruption. The vast quantities of steam and hot sea-water must have played an important part in assisting the pillow movement by buoyancy and lubrication effects. The skin of the pillows must have remained fairly plastic for some time to permit movement of the pillows as they were pushed forward by subsequent brethren and to allow the pillows to infill depressions between underlying pillows in order to produce the protuberances which give the typical 'V'-shaped section which is so useful in determining the attitude of the flows.

Towards the top and the bottom of a pillow lava flow one would expect to find more sediment mixed in with the pillows compared with the centre of a flow. This appears to be the case in the Støren Greenstone pillow lavas because in some localities there was an abundance of matrix material and in others there was little, if any, matrix.

On the south-west side of Malberget, Loc. 136., what appears to be the top of a pillow assemblage is exposed. The pillows are fairly small and they are surrounded by a fine-grained homogeneous red deposit, Fig.5. This red deposit appears to be similar to the red hematitic mudstones. The small pillows may represent the final stage of an eruption and the matrix may represent some of the great volume of sediment stirred up by the eruption and which was deposited fairly rapidly after the major violence of the eruption had subsided. That this is the top of a flow is indicated by the graded bedding of the dark green feldspathic tuff which occurs in this exposure.

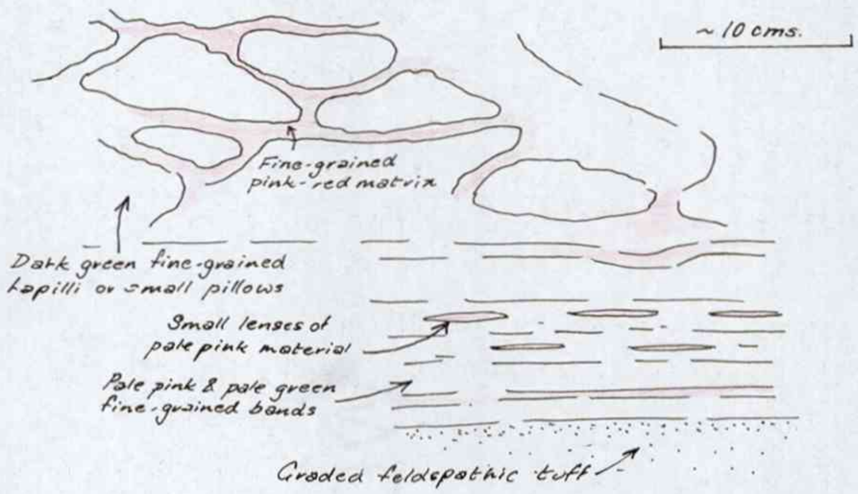


Fig.5. Loc. 136. Sketch of exposure showing the red matrix within the presumed top of a pillow lava flow, and the graded bedding of the tuff, which indicates that the succession is inverted.

In comparison, at the localities 37, 156 & 157, the pillows are usually touching and there appears to be almost an entire lack of any matrix, apart from very small amounts of coarse-grained, feldspathic material which is greenish in colour.

In all the localities examined the pillows consisted of dark green, relatively homogeneous, fine to medium grained rock formed almost entirely of fine grains of dark and pale green minerals; small grains of pyrite also occur, distributed apparently at random, throughout the rock. The pillows are frequently vesicular, especially towards their centres; the vesicles are invariably infilled by chlorite and calcite.

Vesicular pillow lava from Loc. 156., near the Trivja dam, is dark green, holocrystalline, fine to medium grained and lacking in phenocrysts. Vesicles are fairly common and they appear as small, irregular white areas up to about 8 mm. in length. It is possible that they have been deformed tectonically. Microscopically the vesicles are filled with chlorite and calcite and they lie in a groundmass of albite, chlorite, leucoxene, epidote and an opaque mineral, which is probably pyrite. In thin section, the albite occurs in very small laths which have a sub-trachytic texture. It is most probable that the albite is an alteration product of an originally calcic plagioclase feldspar. The laths are very small, sub-hedral, colourless and equi-dimensional. Under high power, some of the laths show lamellar twinning and extinction angle measurements, combined with the fact that the refractive index of the laths is less than Canada balsam, indicates the following composition - $Ab_{92}An_{08}$. The chlorite, which is pleochroic green, occurs abundantly as small blebs in the groundmass. Here it shows the 'Berlin blue' interference colours and it is probably normal pennine. However, the chlorite rimming the vesicles, which is also pleochroic green in colour, shows a plum red interference colour. This may be a variety of pennine. It is probable that the chlorite is the alteration product of some original ferro-magnesian mineral, which may have been pyroxene. The leucoxene, which is semi-opaque, brownish in colour, is randomly distributed throughout the groundmass in small irregular blebs. It is probably an alteration product of ilmenite, indicating that the original lava was probably titanium-rich and probably the original pyroxene was titaniferous-augite. The completely opaque mineral, which is of minor occurrence appears, from field observations, to be pyrite. Epidote also ocurs in the matrix as very small grains and as larger sub-hedral crystals. It is pleochroic yellow-green and has a large optic axial angle. The calcite, which also occurs in small amounts in the groundmass, is most prominent as a mosaic of anhedral twinned crystals in the central areas of the vesicles.

The exposures along the vertical fault scarp east of Malberget appear to be essentially of massive lava. Generally, Loc. 162., it is massive, dark green, medium grained, with no obvious structures or notable features. Thin sections of massive greenstone lava from the Fjeldheim area indicate that the composition is basically similar to the pillow lavas, except that feldspar is usually absent apparently. Chlorite and pleochroic pale green amphibole are common.

The term spilite is generally applied to these chloritic, soda-rich lavas but unfortunately much confusion has arisen concerning both the application of the term and the origin of the spilite lavas. There has been a tendency to regard the two terms, spilite and pillow lava, as synonymous. That this is not the case is demonstrated conclusively by the occurrence in the Gasbakken and Fjeldheim areas of pillow lavas and massive lavas of similar spilitic composition. Pillow structure seems to 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. The origin of spilites by a process of magmatic differentiation appears to be rather unlikely, to the present author at least, and the most acceptable origin is that of albitisation of normal basalt lava by soda 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. The calcium displaced from the calcic plagioclase would combine with the chlorine ions in the sea-water and so escape as the soluble calcium chloride. Some of the calcium would be retained as calcite; the carbonate ion probably coming from the sea-water and surrounding sediments.

The pyroclastic deposits occurring within the Støren Greenstones in the Gasbakken area are essentially of two types. The first may be described as 'pillow agglomerate'. On the south-east side of Malberget, Loc. 56., an exposure of typical pillow agglomerate is visible. It consists of small pillows and lapilli, of various sizes up to about 1 metre in length, contained in a dark green coarse to fine grained, feldspathic matrix. The pillow agglomerate appears to overlie a pillow lava and it is possible that the deposit represents the top of a flow, but the presence of the abundant matrix indicates that it is probably an agglomerate. From the attitude of the pillows in the flow, the succession at this locality is inverted.

Further examples of pillow agglomerate occur near the entry of the Skolda river into the lake Svorksjoen. The small pillows or bombs consist of vesicular, dark green, fine to medium grained rock similar to that found in the lavas. The bombs are about 20 cm. x 5 cm. x 10 cm., Fig.6. The matrix is also dark green.

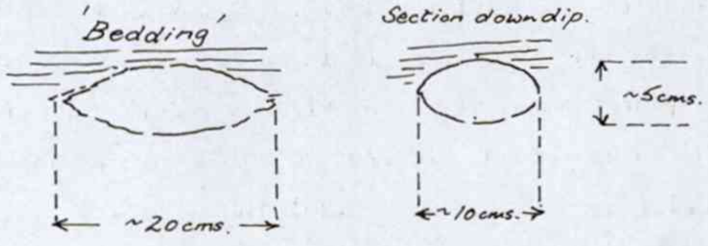


Fig.6. Sketch to show the size of 'bombs' in the pillow agglomerate, near Svorksjoen. Loc. 178.

Further south, Loc. 173., the matrix is fine grained and apparently hematitic. Elsewhere, Loc. 182., the pillow agglomerates contain some large angular fragments of crystalline red jasper, about 30 cms. across. It is possible that these pillow or bomb agglomerates represent periods of more explosive eruption.

The second type of pyroclastic deposit is the more normal feldspathic tuff, which appears to be moderately common in the Greenstone succession. On the south-east side of Malberget, Loc. 127., there is an exposure of a dark green, medium to fine grained rock which appears to contain much fibrous green amphibole, grains of dark green mineral and some very small grains of pale greenish feldspar (probably altered). On the weathered surface the amphibole appears to have been removed leaving the feldspar and dark green mineral grains standing out slightly to give a rough 'sand-paper' surface. A slightly coarser band is present and this is graded, indicating that the succession is inverted. It is possible that this is a submarine tuff deposit.

Apart from the pyroclastic deposits, there is the interesting red sediment, which, as well as occurring as the matrix in some of the pillow lavas, also occurs as distinct lens-like bodies. At locality 175, on the northern edge of Lillebumyren, a large lens of this red sedimant measures about 2.4 m. in length and about 0.4 m in thickness; its areal extent was not visible. The sediment appears to be homogeneous, fine grained, hematitic mudstone. In places it is thinly banded; this may be a sedimentary feature because it appears to roughly parallel the bedding of the surrounding tuffs. It is very similar to what has been called 'Red jasper' which occurs in the Palaeozoic Highland Border Series of the South-east Highlands of Scotland. The origin of the material is uncertain because it may represent a wind-blown terrigenous deposit, a biogentic deposit, or it may be a syngenetic sedimentary iron ore.

In a disused working, Loc. 155., near the Trivja dam, there is a large exposure of a much purer from of jasper. It is a massive, pink-red fine grained crystalline rock and it is extremely hard. This large exposure is surrounded by pillow lava but the exact limits of the jasper were not recorded. The jasper contains thin bands of a fine grained grey chert and also pyrite, which in a hand specimen found on a nearby tip-heap appeared to be graded as if it were a sedimentary formation. It is possible that this pyrite is related to the sedimentary pyrite which is of moderately common occurrence in the Greenstones. It is known as 'vasskis' after C.W.Carstens, (1924). Bodies of jasper are common in the Greenstones, both as knolls such as that seen in the Fjeldheim area, and as layers recorded by Vogt (1945). He notes that these layers 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 landslides. In the less metamorphosed jasper elsewhere in the Trondheim region, Goldschmidt and C.W.Carstens (Holtedahl, 1960) claim to have observed radiolarian structures.

In conclusion, it may be noted that it was virtually impossible to trace separate flows and tuff horizons for any distance across the country because of the lack of exposure. Therefore, on the final map, the Støren Greenstones have been considered simply as one formation.

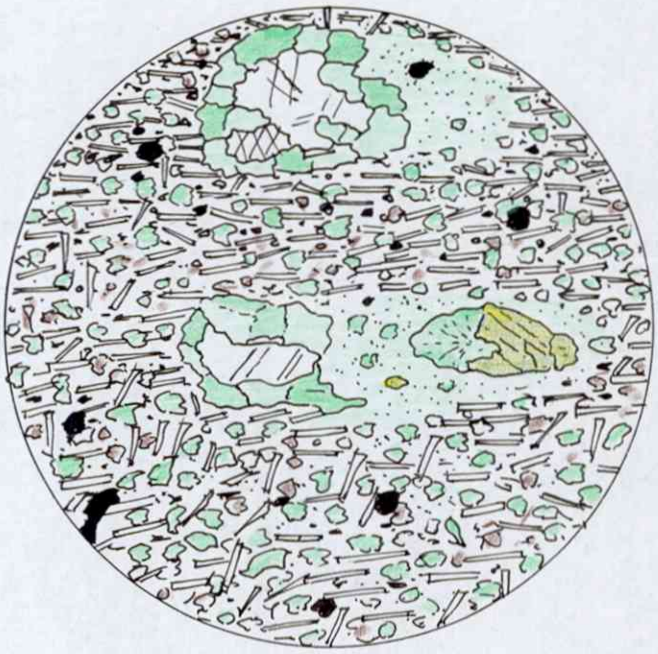
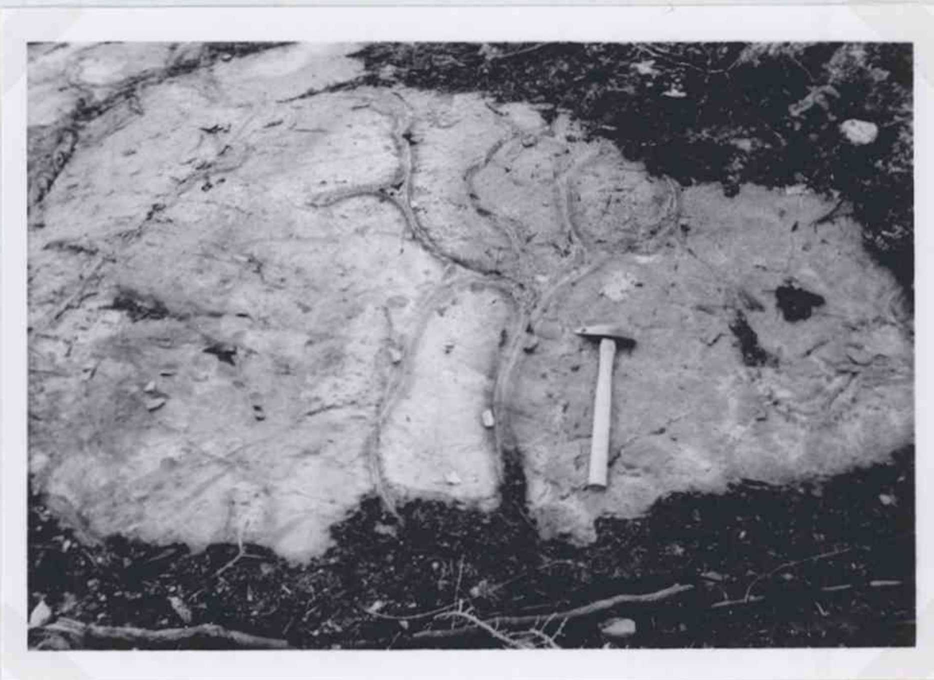


Fig. 7. Vesicular spilite pillow lava, Støren Greenstones.
Locality 156., near the Trivja dam.
Low power; plane polarised light.

The vesicles are rimmed with green chlorite and infilled centrally with a mosaic of calcite. The significance of the areas lacking in the normal groundmass, to the right of the vesicles, is uncertain. It is possible that they represent some sort of flow phenomenon, indicating that the direction of movement of the vesicles was from right to left and therefore parallel to the movement of the feldspar laths.

A large grain of yellow-green epidote is visible.
The groundmass consists of albitic feldspar, chlorite, leucoxene, epidote, calcite and opaque mineral.

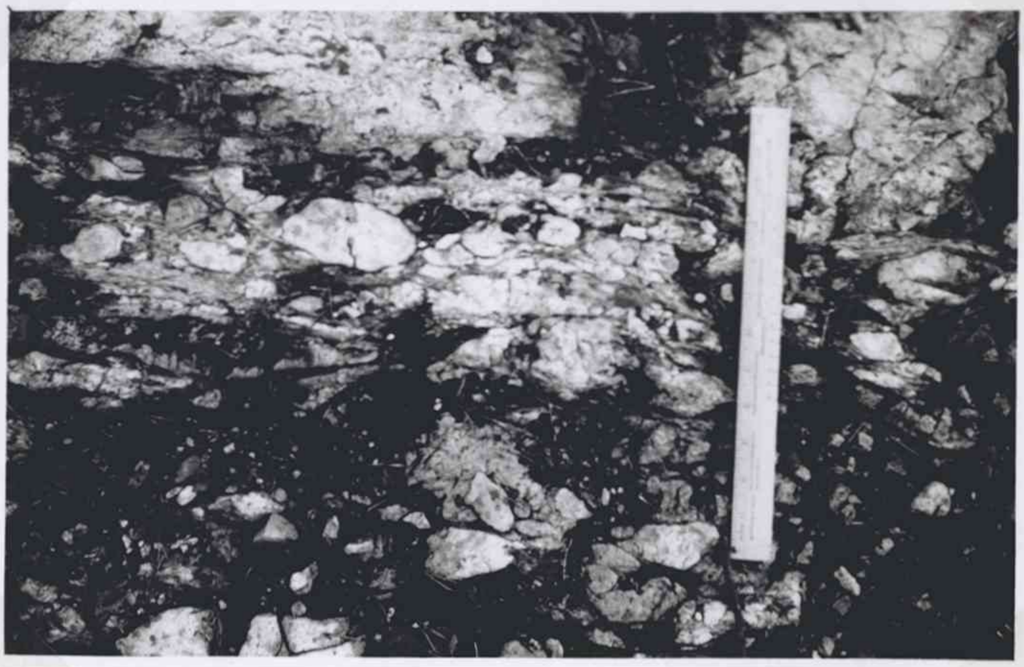


Photograph $P_2$19. Pillow lavas from the Fjeldheim area, which are exposed on an ice-smoothed surface about 500 m. north of the Trivja dam. A small amount of matrix is visible to the upper left of the hammer head; it consists of angular fragments of dark green feldspathic material, up to about 3 cms. in size.

Photograph $P_2$23. Over-turned pillows, Støren Greenstones.

The haft of the hammer is approximately parallel to the strike - east-west and the pillows are dipping steeply to the north, which is right of the photograph.

Locality 128., south-east side of Malberget.



Photograph $P_1$26. Pillow agglomerate, Støren Greenstones.

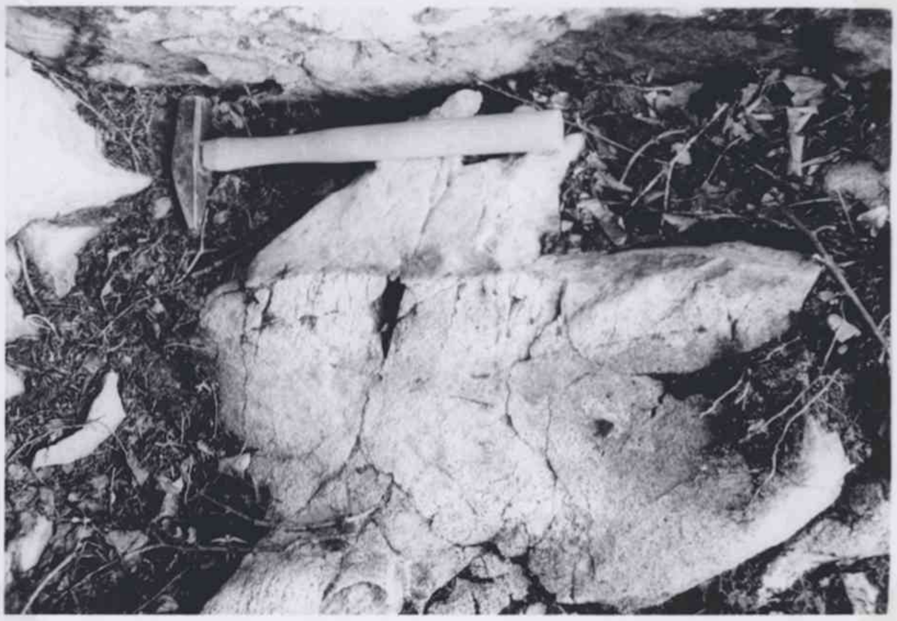
Small vesicular pillows or bombs and lapilli are contained in a coarse to fine grained, dark green matrix. Stratigraphically, the agglomerate lies above a pillow lava, which indicates that the succession is inverted,

Locality 56., south-east side of Malberget.

Photograph P_34. Pillow agglomerate, Støren Greenstones.

In this locality, which is close to a major, sub-horizontal shear zone, the vesicular pillows and lapilli have been deformed tectonically.

Locality 178., Svorksjoen.



Photograph $P_2$21. Tuff deposits, Støren Greenstones.

The tuff bands appear to be graded and indicate that the succession is over-turned.

Locality 127., south-east side of Malberget.

2. THE STOKVOLA CONGLOMERATE

Stratigraphically above the volcanic Støren Greenstones, to the west of Gasbakken, there is a very coarse, unsorted boulder conglomerate which apparently forms the base of the Hovin Group. It is probably equivalent to the Stokvola conglomerate which occurs in a similar stratigraphical position in the Trondheim region. From palaeontological evidence, it appears that the boulder conglomerate in the Gasbakken area is about Tremadocian to Lower Arenig in age.

The conglomerate is exposed in a belt of varying width on the south of Malberget, and also it occurs along the shore of Svorksjoen, east of Fuglaashogstret. A conglomerate having similar texture and composition is well exposed in a road cutting on the north side of Svorksjoen and it is most probable that it is also equivalent to the Stokvola conglomerate, although its relation to the Støren Greenstones was not seen. Conglomeratic horizons also occur on Bjorkliodden, but it is thought that these should be included in the Hølonda Shales and Sandstones.

The exposures on the south side of Malberget will be considered first. The true thickness of the conglomerate, calculated from the width of the exposure and the angle of dip, appears to vary between about 100 m. and 180 m. at its thickest. Any angular unconformity, which may have existed between the conglomerate and the Støren Greenstones, has probably been obliterated by tectonic action, i.e. similar folding. Further west, on the north of Lillebumyren, there is no basal conglomerate and the Hølonda Shales and Sandstones occur directly against the Greenstones. Perhaps this particular area was one of non-deposition or else the conglomerate was eroded soon after its deposition.

The composition of the conglomerate at Locality 14 is typical. The fragments are unsorted, rounded to angular with the angularity apparently increasing with increasing hardness of the fragmental material. The fragments vary from about fine sand grade up to boulders about 1.5 metres in size. They consist of crystalline red jasper, dark green Greenstone, fine grained pink and olive green rocks which may be felsitic, soft whitish feldspathic (?) material and sedimentary material which is very similar to the overlying Hølonda Shales and Sandstones. The matrix is fine to coarse grained and feldspathic. Elsewhere, Locality 43, the conglomerate contains fragments of similar size and composition but including white quartzite and coarse whitish-green quartzitic grit, both of which are fairly abundant. There is also a green rock which weathers pink and it is probably similar to the 'felsitic' material in Locality 14.

At Locality 14 the conglomerate grades rapidly into dark green, fine grained argillaceous bands. The grading indicates that the succession is inverted, with the younger beds to the south. In all the exposures along the south of Malberget the fragments appear to have a preferred orientation such that their longer axes occupy a plane dipping about 60° to 70° north and striking about east-west. Thin veinlets of quartz, which are parallel to this planar direction, are of frequent occurrence. The plane is approximately parallel to the axial plane cleavage found in finer grained horizons in this particular area and it is most probable that the conglomerate fragments have experienced some degree of tectonic deformation.

In the localities to the north of Svorksjoen, the conglomerate consists of rounded to sub-angular fragments which vary from about 1 mm. up to boulders about 1.5 metres in size. The fragments are of crystalline red jasper, dark grey quartzite and dark green, medium grained rock which is probably Greenstone. The matrix is dark green and medium grained. From Locality 71 eastwards the conglomerate grades rapidly into grit beds of variable thickness, some up to 10 metres thick. Then comes another grit bed, about 2 m. thick, containing scattered large boulders of Greenstone and jasper. This bed also contains small areas of fine grained green material. It is possible that these are mudlumps which may have been deformed tectonically. Sometimes the fine material occurs in thin bands which form convolute bedding. This boulder bed passes into similar dark green grits containing coarse pebbly layers. An abundance of authigenic chloritoid grains was found at this particular locality, 73; the presence of the chloritoid will be discussed in the Structure and Metamorphism section. Further horizons of grit and conglomerate occur westwards. Graded bedding is visible occasionally and its inconsistency indicates that there may be a series of tight folds here having axial planes dipping at a moderate angle to the north-west; their occurrence will be discussed in the structural section.

Along the shore of Svorksjoen, near Fuglaashogstret, the basal conglomerate is very substantially deformed because there is a series of strong shear zones in this area. In the less affected exposures the fragments are of jasper, grey and white quartzitic rock and Greenstone. Mostly, however, the fragments have been deformed into flat pancake like objects, which lie parallel to the shear planes. Usually only the crystalline jasper has resisted the deformation.

Generally, the basal conglomerate appears to have been produced under conditions of rapid and confused deposition. These conditions could have been glacial, but from the occurrence of mud-lumps, convolute and graded bedding and the sedimentary evidence of the overlying 'turbidite' horizons of the Hølonda Shales and Sandstones it is most probable that the conglomerates were deposited in a geosynclinal environment. They were probably produced by rapid erosion due to abrupt orogenic uplift. The conglomerates are probably submarine deposits because they lack any red coloration which is typical of a conglomerate occupying a similar stratigraphical position in the Hølonda-Horg district, Vogt (1945), and which is thought to be a sub-aerial deposit. Holtedahl (1920) introduced the term Trondheim disturbance for the orogenic phase which gave rise to the production of these conglomerates. Breaks corresponding to the Trondheim disturbance are known from most of Southern Norway and possibly from some areas in Northern Norway, Vogt (1945). Until the new dating from the graptolites, found by D.H.Blake in 1960, the Trondheim disturbance was regarded as Upper Skiddavian in age. Now, however, it must be regarded as slightly older, probably Tremadocian to Lower Arenig, 3a-3b.

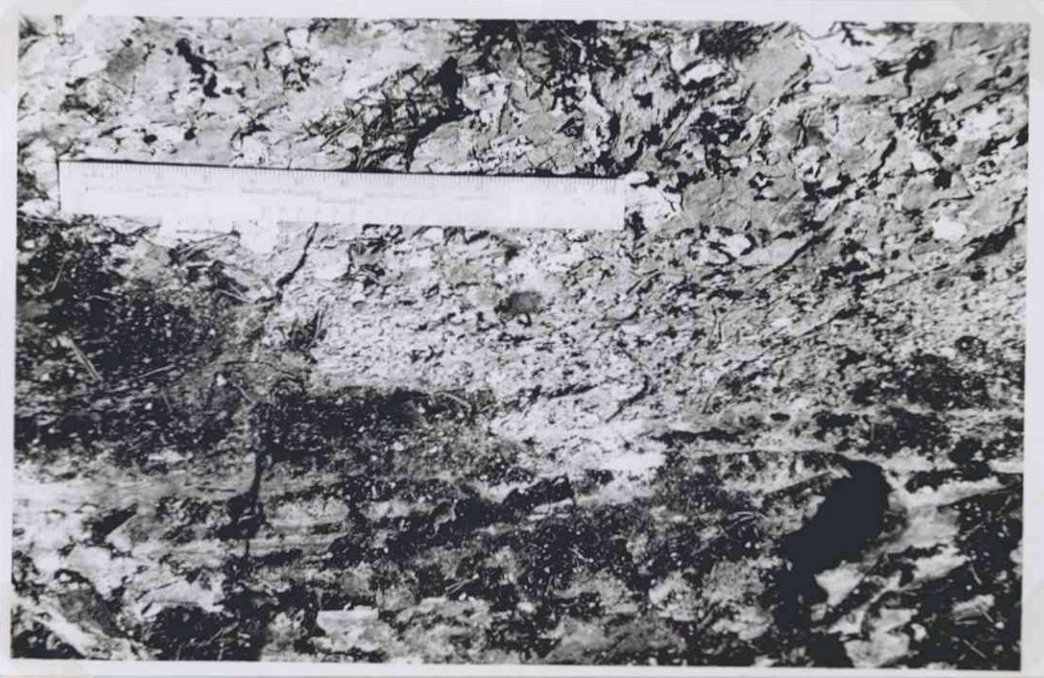
The conglomerate described in the previous pages is petrologically and stratigraphically eqivalent to the Stokvola conglomerate. In the Hølonda-Horg district, Vogt (1945), describes the Venna conglomerate lying directly on the Støren Greenstones and obvously occupying a similar position to the Stokvola conglomerate. It differs from the Stokvola conglomerate in that the fragments consist of a characteristic sandstone rich in calcite; the colour of the rock is light grey to light purplish 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 large boulders and smaller pebbles of red jasper also occur.

Furthermore, in the Hølonda-Horg district, the Venna conglomerate is overlain by the Gaustadbakk Breccia. According to Vogt the breccia cosists of thick beds with fragments of Greenstones, red jasper and several sediments, which are embedded in a reddish to reddish purple sandstone. Intercalated within the breccia are thin beds of the same reddish sandstone, green sandstone and chocolate coloured shale. In 1960, D.H.Blake found a purple agglomerate, which may be similar to the Gaustadbakk Breccia, in the east of the Svartvatnet area. A.E.Beswick and J.W.Rowling, in 1961, found extensive beds of purple material, which is probably equivalent to the Gaustadbakk Breccia, in the areas to the east and south of the area mapped by the present author in 1961.

However, no evidence of (the evidence of) the presence of the Venna Conglomerate or the Gaustadbakk Breccia was found either in the Fjeldheim area or in the area mapped by the present author in 1961. It is most probable therefore that there is a facies change from west to east. The more marine conditions are represented by the Stokvola conglomerate to the west of Gasbakken and the more continental conditions are represented by the Venna conglomerate and the Gaustadbakk Breccia to the south and east of Gasbakken. Unfortunately the precise positions of the facies changes are obscured by folding and faulting.

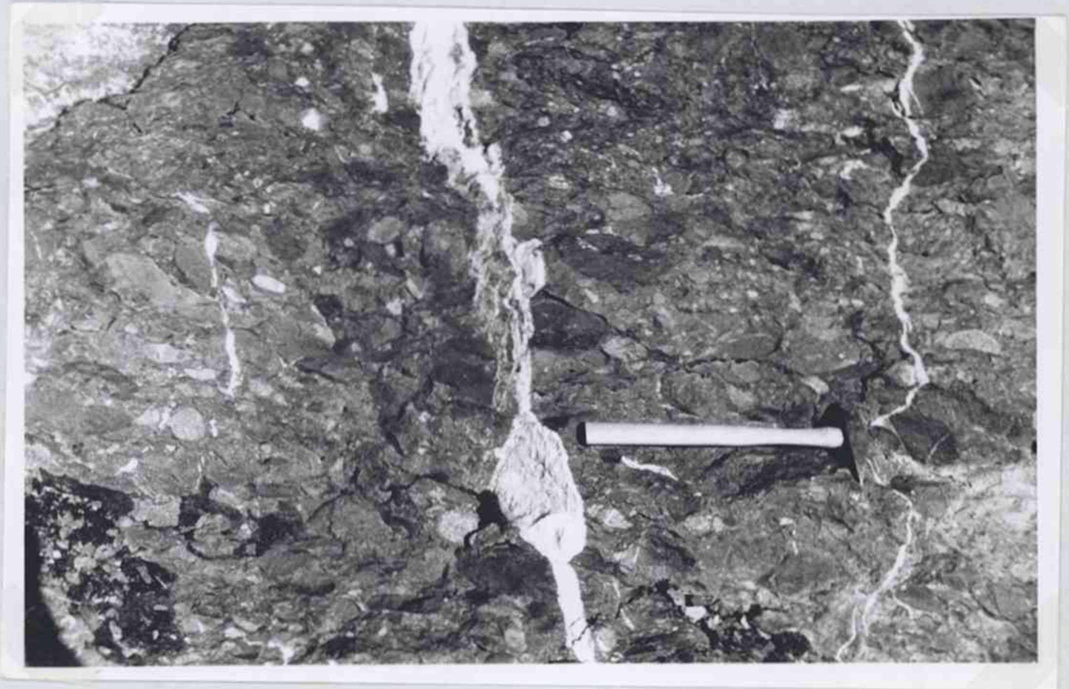
Photograph $P_1$8. Fragment of bedded sedimentary material in the Stokvola conglomerate.
Locality 14., north of Bjornlivd.

It is possible that the fragment represents a large consolidated mudlump which was torn off the sea-floor by the passage of the conglomeratic material. As already mentioned the conglomerate was probably deposited rapidly and it may have been the fore-runner of a turbidite flow produced by a sub-marine slump which was triggered off by orogenic activity.



Photograph $P_1 7$. Stokvola conglomerate grading into the Hølonda Shales and Sandstones. The grading indicates that the succession is overturned.

Locality 14., north of Bjornlivd.



Photograph $P_2$2. Stokvola conglomerate traversed by irregular veins of quartz and calcite.

Locality 71., road cutting on north shore of Svorksjoen.

Photograph $P_2 5$. Rounded to sub-angular boulders and cobbles with graded grit band in the Stokvola conglomerate. The grading indicates that the beds are overturned.

Locality 75., road cutting on the north shore of Svorksjoen.

3. THE HØLONDA SHALES AND SANDSTONES

The Stokvola conglomerate in the Gasbakken area grades up into a series of graded, green sandstones and shales, which were probably originally feldspathic. Conglomeratic horizons also occur in the lower levels of these beds. Higher in this series there are beds of dark grey, fissile shales. These sandstones and shales of the Lower Hovin Group are equivalent to the Hølonda Shales and Sandstones, Vogt (1945), on the grounds of petrological and stratigraphical similarities. The grey fissile shales are similar to the Skjegstad Shales, Vogt (1945), which have a wide distribution at Hølonda. The thicknesses of the shales and sandstones are very variable and there appear to be many facies along the strike, which together with the poor exposure makes structural interpretations rather difficult. The age of the group as a whole is probably about Arenigian to Llanvirnian. Two new fossil localities containing brachiopod faunas were found but despite intensive searches nothing was found in the dark grey shales which may be equivalent to the Bogo Shales of D.H.Blake (1960), which contain profuse graptolitic faunas.

In the lower parts of the succession, which are exposed between Lillebumyren and north of Bjornlivatnet, the series consists of banded grey-green grits, sandstones and shales. The coarser beds weather white and generally stand out slightly above the surface of the exposure. The grading of the coarser material into the fine shale indicates that the succession south of Malberget is overturned. The graded beds are generally only a few cms. thick and from their number it is obvious that there must have been many turbidity currents flowing in the area. The problem of the frequency of the turbidite flows provides an interesting ground for speculation but there is not time to enter into it here. The turbidite origin of the beds will be discussed in more detail later. From thin sections of similar rocks, from Hoidal in the Fjeldheim area, the coarse whitish grains, which look feldspathic in hand specimen, consist of a fine grained mass of sericite. The sericite is most probably the alteration product of original feldspar grains. Apart from rare red jasper grains, very few original clastic grains of quartz occur in these rocks.

On the north of Lillebumyren the dark green graded sandstones rest directly against Greenstone pillows,

pillow agglomerate and phyllites (tuffs). Any angular unconformity is not visible. The absence of the basal Stokvola conglomerate in this area may be due to the fact that the Greenstones formed a submarine rise which was covered some time later by the banded finer grained sediments.
At locality 2., the dark green shales contain thin layers of slightly coarser material. There are minor bedding disturbances in this exposure and they are probably due to slumping. The bedding dips steeply to the north and they are cut by an equally steeply dipping cleavage which has a similar east-west strike. In many localities it was difficult to distinguish between bedding and cleavage.
At locality 4., the thickness of the coarser bands is only a few cms.. The cleavage is especially well developed in the finer shaly bands but in the coarser bands the cleavage is less distinct. The cleavage is puckered by later movements which are probably related to the second act of folding.

Further south-east along the shore of Voldmovd. at locality 22., there is a large exposure of grey-green shales and sandstones which contain thin horizons of conglomerate. The conglomerates grade into the finer shale within about 30 cms. - Photograph $P_1$11. The fragments, which are rounded to angular, have a maximum size of about 3 cms. They consist of red jasper, fine grained white and fine grained green material. The matrix increases upwards in the bed. The grading shows conclusively that the strata are inverted. A few metres north-west along the shore of Voldmovd. there is an exposure of grey-green shales and sandstones containing some fragments of bedded green shales and sandstones, which are apparently identical to the Hølonda Shales and Sandstones. These fragments are probably consolidated mud-lumps - Fig.9. They probably originated from the sea-floor by the lacerating effect of a submarine quake and were then assimilated into and eventually deposited from a turbidite flow.

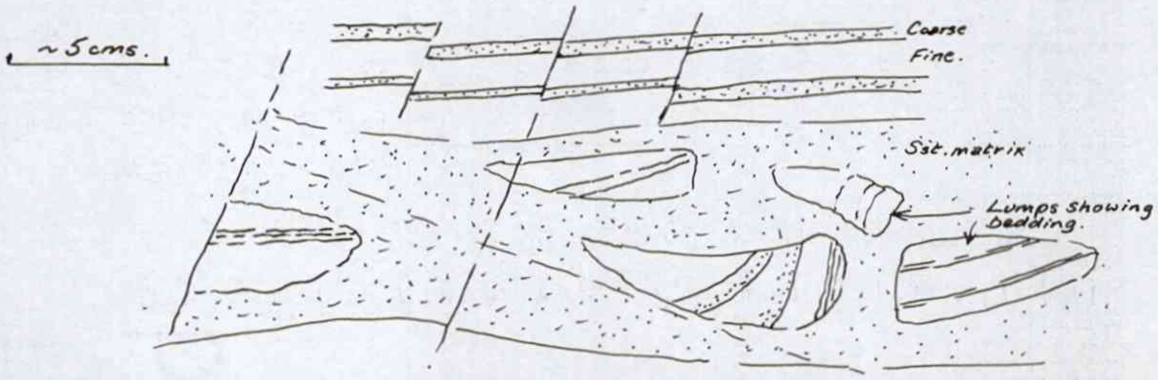


Fig.9. Sketch of mudlumps in Hølonda Shales and Sandstones. Locality 22., Voldmovatnet.

On the south side of Malberget these lower grey-green beds pass stratigraphically upwards into a bed of fossiliferous impure grey limestone, which is very similar to what Vogt describes as the Hølonda Limestone. The bed is about 50 metres thick and it passes southwards into fissile grey shales which are very similar to the Skjegstad Shales. The shales, which have been widely used for road-surfacing, are exposed in two small disused quarries near Bjornlivatnet, locality 19. Here the shales are very fissile due to the first fold cleavage and later closely spaced joints. It is dark grey to black in colour. The bedding is indicated by slightly harder bands about 1 cm. thick and in the larger quarry there is a 2 metre thick bed of dark green shales within the grey shales. The bedding and cleavage are almost parallel and dip about 70° north and strike east-west. They are rucked by slight movements on planes about 10 cms. apart, which dip 64°W and strike 155°; they are probably related to the second folding. Similar grey shales occur to the south of these quarries on the shore of Voldmovatnet. The shales at locality 21 contain small calcareous nodules, about 0.5 cms. in size, on the bedding planes. Graded bedding indicates that the succession is still inverted. There is a complex contortion of the first fold cleavage in this particular exposure.

Unless there is a strike fault through the Bjornlivatnet - Stornaeve area then this particular shale bed is about 300 to 450 metres thick (true). At localities 49 and 50 the grey shales are in contact with an intrusion of the Hølonda Porphyrite. The intrusive nature of the Porphyrite is demonstrated by its discordant contact with the bedding and the slight baking of the shales. Frequently the shales here contain brown specks of brown limonite, probably after pyrrhotite; brown iron-staining is common. Very small scale convolute bedding occurs within slightly coarser beds, (locality 52).

Further south beyond a further Porphyrite intrusion, the grey-green graded sandstones and shales re-appear. From conclusive graded bedding they are overturned and unless there is a strike fault through Bjornlivatnet and Stornaeve these beds must be younger than the grey shales described above. At locality 62 a whole series of graded sandstone beds are visible. The complete graded bed from sandstone to shale is about 15 cms. thick . It would appear that the Porphyrite intrusions mentioned above have been intruded along the boundaries of the major facies types.

Around st. Fuglaas there are further exposures of green and grey shales containing a thin bed of limestone, which are arranged in a synformal structure. It was in this area that the second fossil locality was found - locality 117. This area will be discussed under the section on the Hølonda Limestones.

The exposures on the peninsula of Bjorkliodden are mainly of dark green sandstones, grits and conglomerates. They probably represent a protracted grading of the Stokvola conglomerate into the Hølonda Shales and Sandstones. The conglomerate fragments are similar to those in the Stokvola conglomerate, but generally they are smaller and are not touching because there is a greater amount of gritty matrix than there is in the Stokvola conglomerate. Furthermore, occasional thin argillaceous bands occur. It is for these reasons that the rocks forming the Bjorkliodden peninsula have been included in the Hølonda Shales and Sandstones by the present author.

South of Bjorkliodden and west of st. Fuglaas there is a very large mass of rock projecting from the marsh surface, locality 165. The mass is much too large to be an erratic. It consists of a conglomeratic rock containing almost exclusively small, angular to sub-angular fragments of a densely "porphyritic" dark green rock. The "phenocrysts" are anhedral grains of white saussuritised feldspar. The matrix is similar in composition to the fragments themselves. Rarely, a little red jasper and some white quartzite fragments are present. This deposit may perhaps be a volcanic agglomerate or possibly it is a reworked tuff. The stratigraphical position is unknown because of the isolated position in the middle of the marsh.

The Hølonda Shales and Sandstones are also exposed in the area north of Gasbakken and around Hølonda itself. In these areas there appear to be no conglomeratic horizons. The grey fissile shales and the graded green sandstones and shales are similar to those already described south of Malberget. Generally the dark grey fissile shales are very similar to the Skjegstad shales except for slight differences in the concentrations of limonitic grains. Around the farm Reksaasen, west of Trotland, the grey shales are exposed in a number of small quarries and beneath the intrusive porphyrite scarps. The shales contain thin graded beds which are inverted; the slightly coarser bands illustrate the phenomenon of cleavage diffraction rather well. The shales in the porphyrite of Svartaasen, west of Gasbakken, are also inverted and they may belong to the same horizon as those occurring at Reksaasen. However, there appears to be a major fault through Reksaasmyren in this particular region so that any connection is uncertain.

Around Trotland the grey shales are slightly calcareous and they pass into impure shaley limestones. Vogt (1945) suggested that this grey shale was intercalated in the Hølonda Limestone. However, from observations of the present author, it would seem more reasonable to include these shales within the Hølonda Shales and Sandstones because they are very similar to the normally occurring grey shales. Furthermore, the Hølonda Limestone does not appear to be a discrete formation in itself, rather it is a series of limetones horizons within the Hølonda Shales and Sandstones.

North of Stensvatnet there is a complex structural area. The rocks consist of green shales, sandstoness and grits, grey shales, nodular rubbly limestones, purer limestones and porphyrite. Forest cover and facies changes add to the difficulty of interpretation. The complexity is probably due to the superimposed folding. In places the green sandstones contain large pyrite cubes, up to 2 cms. in size. A detailed re-investigation of this area and that to the north would be very useful.

Grey-green shales and sandstones, grey shales and impure limestones are exposed in numerous localities to the east. Around Hølonda Kirke and Langaasvatnet, the grey fissile Skjegstad Shales are exposed in a number of small quarries. In a large quarry -locality 310 - some distance south-east of Hølonda Kirke, the shales are dark grey and contain brown spaecks of limonite after pyrrhotite. They are weathered and broken for a metre or so beneath a soil and boulder clay cover about one metre thick. Thin bands about 1 cm. thick of dark and light grey shales occur at intervals of 1-2 cms. indicating a bedding dip of about 20^{o} NW, strike 045^{o}.

Examples of slumped bedding and possibly a sole sast were found in green sandstones to the south of the porphyrite intrusion near Hølonda - locality 331. These particular structures indicate that here the beds are right way up. Numerous thin limestone beds occur with the grey shales and green shales and sandstones in this area.

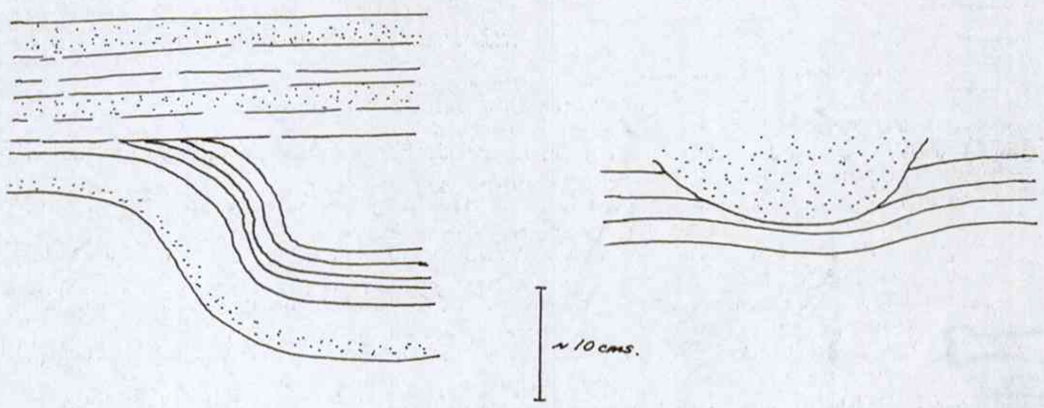


Fig. 10 Sketches of slumped bedding and sole cast in green sandstones, south of Hølonda Kirke. Locality 331.

In the Skolda valley north of Ellingsvatnet - locality 335, a grey shale was found which contained numerous large lath-like "porphyritic" bodies about 1 cm. X 2 mm. in size. In hand specimen and in thin section the matrix appears to be normal grey shale and the "phenocrysts" are dark grey but apparently of the same material as the matrix. It is thought that they may represent the beginning of some metamorphic effect, i.e. a crudely spotted rock. The major axes have a sub-parallel orientation pitching about 45°W down a parting plane dipping 68°W, strike 138°.

From the evidence of their own lithology and that of the surrounding stratigraphy it seems obvious that the Hølonda Shales and Sandstones are a geosynclinal deposit and they were most probably deposited from turbidity currents. The darker green coarser beds probably represent deposits which were formed nearer the source of the turbidite flow and the grey shales were probably formed at greater depth and represent the final fine-grained components of the turbidite flows. The source of the turbidite flows probably lay in the coastal fringe of unconsolidated conglomerates, sand and mud which had been eroded very rapidly from abruptly uplifted land areas surrounding the geosynclinal seas. These unconsolidated masses were probably triggered off into slumps and turbidite flows by intense marine erosion and earth movements due to fluctuations in the orogenic activity.

From the succession of coarse green sandstones and shales and grey shales followed by green sandstones and shales it would appear that the area of depsoition varied either in depth or in its distance from the source of the turbidite flows. These variations could have been due to infilling and hence shallowing of the area or it could have been due to an orogenic effect such that the down-warping of the geosyncline was interrupted by minor uplifts in particular areas. This orogenic shallowing of the geosyncline sea would also account for the occurrence of the impure grey Hølonda Limestones, which were probably shallow lagoonal depsoits.

On the final map only the green sandstones and shales and the grey shales have been distinguished because the individual conglomeratic horizons are too small to be represented separately.

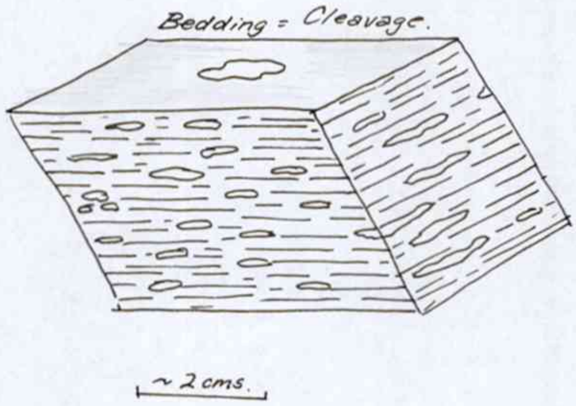


Fig.11 Calcareous nodules in grey shales. Locality 021., north shore of Voldmovatnet.

Fig.12 Small-scale slumped bedding in coarser bands in grey shales. Locality 052., Stornaeve.

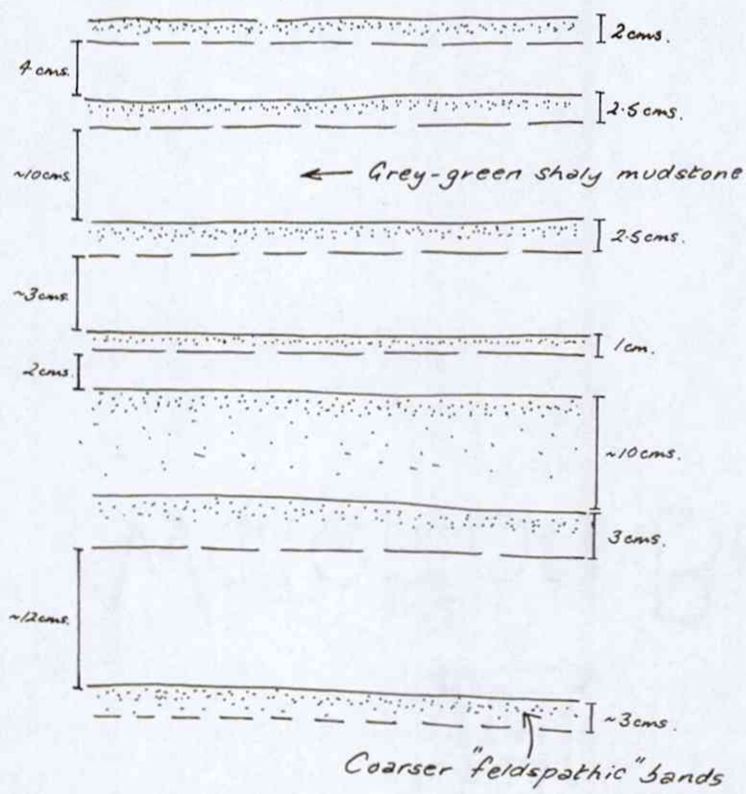


Fig.13 Series of graded beds in green sandstones and shales. Graded beds indicate inversion of the succession. Locality 062., south of Stornaeve.

Photograph $P_1$11 Conglomerate grading into fine argillaceous material. The direction of the grading indicates that the beds are inverted.

Hølonda Shales and Sandstones.

Locality 022., north shore of Voldmovatnet.

Photograph $P_1$12 Series of thin graded beds in overturned Hølonda Shales and Sandstones.

Locality 022., north shore of Voldmovatnet.

Photograph $P_2$10 Gritty conglomerate on the Bjorkliodden peninsula.

Locality 095.

Photograph $P_3$3 Volcanic agglomerate or reworked tuff forming large isolated mass in the marsh west of st. Fuglaas.

Locality 165.

4. THE HØLONDA LIMESTONES.

Vogt (1945) describes the Hølonda Limestone as consisting of one horizon of variable thickness which contains in its upper part an intercalated dark grey shale. From observations of the present author, it would seem more reasonable to regard to Hølonda Limestone as a series of horizons occurring within the Hølonda Shales and Sandstones. The intercalated grey shale within Vogt's limestone would therefore become part of the Hølonda Shales and Sandstones as has already been noted. Simply by extending Vogt's term stratigraphically, all the limestones occurring within in the Hølonda Shales and Sandstones in the Gasbakken Area may be called the Hølonda Limestones.

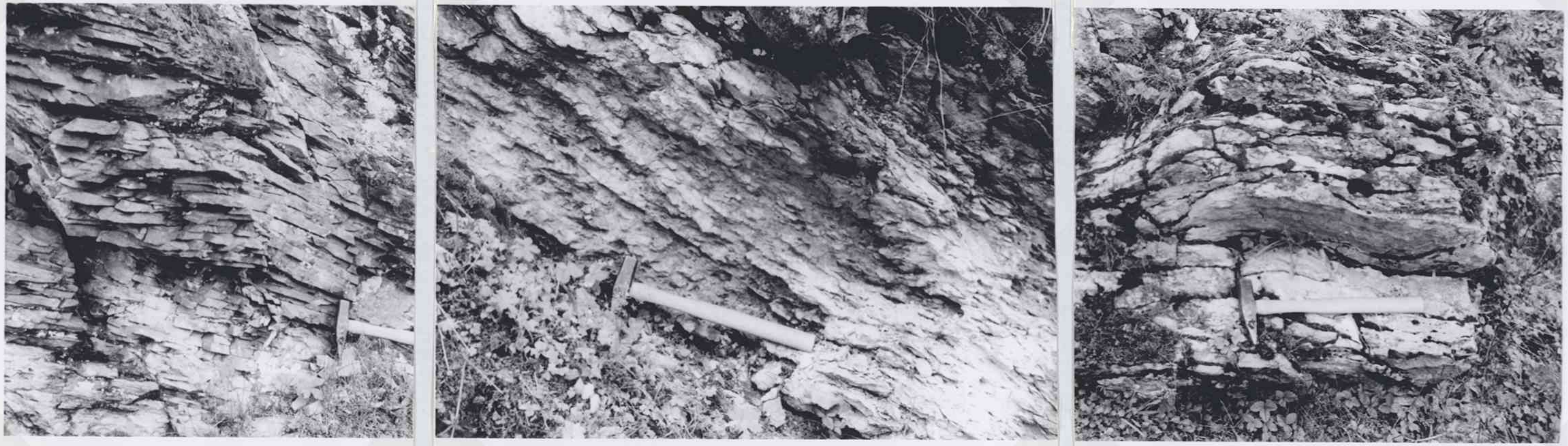
The limestones are generally fine-grained, impure and dark or pale grey in colour. They are also fossiliferous in many places, but in the Gasbakken area the fossils are mostly fragmentary and only one definitely recognisable fossil was found. It is a turretted Gasteropod, possibly Hormotoma sp.. Fossil evidence from other parts of the Hølonda Limestone will be discussed in the palaeontology section.

The 50 metre thick bed of limestone in the Bjornlivatnet - Stornaeve area is exposed from near Voldmovatnet up to some distance north-east of Bjornlivatnet where it vanishes into a marshy area between the Støren Greenstones and the Hølonda Porphyrite. Around the log cabin north of Bjornlivatnet - locality 27 - the limestone is dark grey with an imperfect shaley parting which dips steeply to the north. There are a number of thin irregular veinlets of calcite. Fossil fragments are visible and they are possibly of small brachiopods and corals. A thin section of this limestone proved to be particularly interesting because it contains a number of almost perfect euhedral crystals of albite. They are fairly small, the largest being only about 2 mm. in its greatest dimension. The most obvious origin for these crystals is that they are volcanic; whether they were originally albitic is very uncertain. Thin sections were cut from other limestones over the area mapped, but no albite crystals were found in any of these. The matrix of the limestones consists of very fine grained calcite and impurities and sometimes there are small areas of calcite mosaics which may be recrystallised organic material.

The exposure of limestone in the synformal structure at st. Fuglaas - locality 122 - is interesting in that it shows the passage of grey shales into the limestone, or vice versa because the order of the succession is uncertain. Towards the limestone the shales becomes increasingly calcareous and contain more and more calcareous nodules until eventually the limestone dominates. This transition from shales to limestone takes place over a bedding thickness of about a few metres. - Photographs $P_2$13 - 15.

The limestone occurs very frequently north of Gasbakken and the beds are of variable thickness, from 1 to 2 m. up to about 50 m.. In many places there appear to be facies changes along the strike and this is brought out on the section CDE on the final map. Frequently near a porphyrite body the limestone is brecciated and riddled with small porphyrite masses only a few cms. in size. This brecciation can be seen on both sides of a porphyrite body in a road cutting east of Gasbakken - locality 275 - and it appears that the porphyrite is definitely intrusive.

The Hølonda Limestones probably originated in relatively short-lived lagoonal shelf areas, where less turbid conditions and a supply of calcium carbonate favoured the existence of Coelenterates and shelly organisms. It is possible that normal sea-water sources of calcium carbonate were augmented by calcium salts which had been liberated by the albitisation of the basaltic lavas in the geosyncline.



Photographs $P_2$13 - 15 Transition of grey shales into impure limestone. Locality 123., st. Fuglaas.

5. THE HØLONDA PORPHYRITES AND THE MALBERGET GABBRO.

I. The Hølonda Porphyrites.

The Hølonda Porphyrites are altered porphyritic basic igneous rocks, which form concordant horizons in the Lower Hovin rocks of the Gasbakken and Hølonda-Horg areas. According to analyses published by Vogt (1945), they are soda-andesites; the soda content being due apparently to the albitisation of originally calcic plagioclase feldspar. In the Hølonda-Horg district Vogt (1945) found two different types of Porphyrite ;-

(i) Berg type, which is composed of thickly tabular phenocrysts of a formerly more basic plagioclase and more sporadic phenocrysts of altered pyroxene contained in a very fine-grained groundmass consisting of laths of albite, epidote, hornblende, chlorite, etc..

(ii) Almas type, which differs from the Berg type inter alia in the much more crowded phenocrysts of albite and altered pyroxene. Furthermore, Vogt maintains that he could distinguish between entirely separate horizons of Berg and Almas Porphyrite, but in the Gasbakken area it was found that both types frequently occurred in the same horizon. It is rather uncertain whether Vogt's distinction is entirely valid and no distinction has been made between the two types on the final map of the Gasbakken area.

The Hølonda Porphyrites are of very widespread occurrence over the area as a whole, but none were found in the Støren Greenstones or the Stokvola Conglomerate, in the Gasbakken area. Generally they are about 10 to 50 m. thick. Near Stornaeve - locality 34 - where the porphyrite is in contact with dark grey shales it is fairly densely porphyritic. The phenocrysts are pale and dark green in colour and measure about 1 cm. X 2 mm.. The paler feldspathic phenocrysts are more abundant, but in some places they appear to be segregated from the dark ferromagnesian phenocrysts. There did not appear to be any ropey or blocky structures or any preferred orientation of the phenocrysts in this locality. Towards the top (true, since inverted) of the porphyrite mass some large ellipsoidal cavities about 5 cms. in max. dimension, were found; they are probably vesicles. They are infilled with a soft, white mineral which may be calcite.

Elsewhere near Stornaeve - locality 57 - the porphyrite is coarsely porphyritic and similar to Vogt's Berg type. The feldspathic phenocrysts are tabular, measuring about 1 cm. X 0.2 mm. There are also smaller dark green ferromagnesian phenocrysts, which are much less abundant - by a factor of about 1 : 8 as seen on the surface of the exposure.

On the road from Stornaeve to Gasbakken - locality 59 & 60 - the occurrence of both the Berg and Almas types in the same horizon is very obvious. In the Berg type to the south the large phenocrysts of pale green altered feldspar are surrounded by smaller phenocrysts of altered feldspar and ferromagnesian minerals. The groundmass is fine grained, dark green to blue. Just to the north there are abundant large feldspathic phenocrysts and ferromagnesian phenocysts. The matrix is blue -green in colour. The feldspar phenocrysts stand out on the weathered surface and the ferromagnesian phenocrysts generally lie below it. This latter type is approaching the Almas type.

In thin section, the Berg type - locality 60 - consists of tabular phenocrysts of partially saussuritised albite, which shows lammellar twinning. The prismatic laths are extensively fractured and sometimes have irregular ragged margins due to slight displacements on the fractures. The fractures are often infilled with either pleochroic green chlorite or fresh secondary albite growing in crystallographic continuity with the albite phenocrysts. The albite in the rock is most probably a product of the albitisation of a formerly more calcic plagioclase feldspar. The dark ferromagnesian phenocrysts visible in hand specimen consist of ragged mats of fibrous, pleochroic pale green tremolite-actinolite. These mats are about the same size as the albite phenocrysts, but they are much less abundant. The amphibole is most probably the alteration product of original pyroxene. The phenocrysts are contained in a fine-grained groundmass of abundant anhedral prisms of albite, granules of pleochroic yellow-green epidote, clino-zoisite and chlorite. Semi-opaque, brownish blebs of leucoxene after ilmenite are fairly abundant.

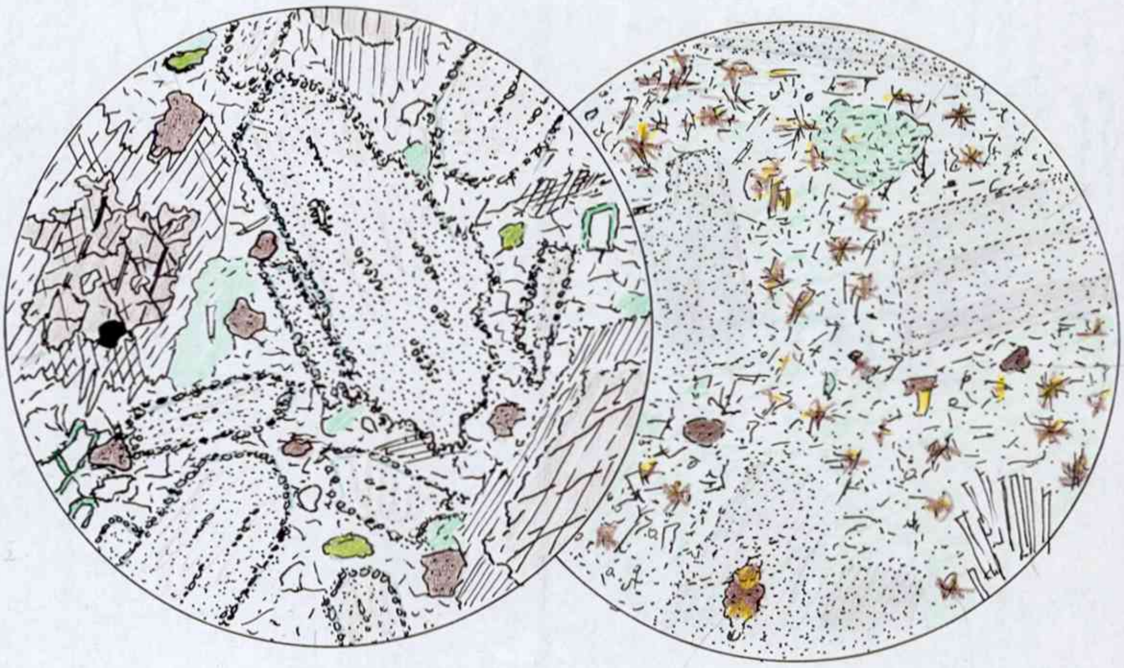
Berg porphyrite from a road cuting east of Gasbakken - locality 249 - contains an abundance of pleochroic yellow-brown stilpnomelane arranged in rosettes of small needle-like crystals. This fine-grained stilpnomelane is also visible in the hand specimen. Stilpnomelane was not found elsewhere in the Gasbakken area, but it was found in a dyke rock of similar composition to the Hølonda Porphyrite in the Fjeldheim area in 1960. The origin of the stilpnomelane is probably due to iron meta-somatism of the chlorite. It may be due to the entry of iron-rich solutions via fractures associated with the major fault which passes a short distance to the south of this locality.

The Almas type - locality 321, a quarry near Hølonda Kirke - contains feldspar phenocrysts which have been entirely saussuritised. Ferromagnesian phenocrysts are more abundant compared with the Berg type. The original pyroxene is preserved in parts of the slide. It is substantially altered around the margins to tremolite-actinolite. The pyroxene is pale brown in colour, with a high optic axial angle; it is optically positive and has a moderate birefringence. The pyroxene is probably augite. Semi-opaque, brownish leucoxene after ilmenite is fairly abundant as small granules. The groundmass is fine-grained and consists of granular albite, pleochroic green chlorite, epidote and a little quartz.

The origin of the Hølonda Porphyrites has been a matter of debate since the earliest geological investigations in the region. Vogt (1945) thought that probably they were extrusive lavas but C.W.Carstens (1951) believed they were intrusive. From observations of the present author of the Hølonda Porphyrites in the Gasbakken area, it appears that the majority are intrusive sills. The intrusive origin is clearly demonstrated in many localities - Stornaeve 34, 50, 63; st.Fuglaas 115; Svartaasen 195, 201; Reksaasen 209, 211; Gasbakken 249, 262, 275; Hølonda 280, 328. In these localities the following characters indicate the intrusive origin of the porphyrite :-

(i) Shales near contact are baked for about 0.5 - 2 m. - 34, 249.
(ii) Porphyrite cuts the bedding - 280, 328.
(iii) Large xenolithic fragments up to about 0.5 m. caught in the top (true) of the porphyrite - 57, 63.
(iv) In shales and limestones large fragments of porphyrite occur both near the top and bottom of the intrusion - 115, 262, 275, 328.

The porphyrites rarely showed any cooled margins and they were always coarsely porphyritic up to the contact with the country rock. This could mean that the intrusions were relatively cool when they were being intruded. No conclusive evidence was found to confirm an extrusive origin of any of the porphyrites in the Gasbakken area.

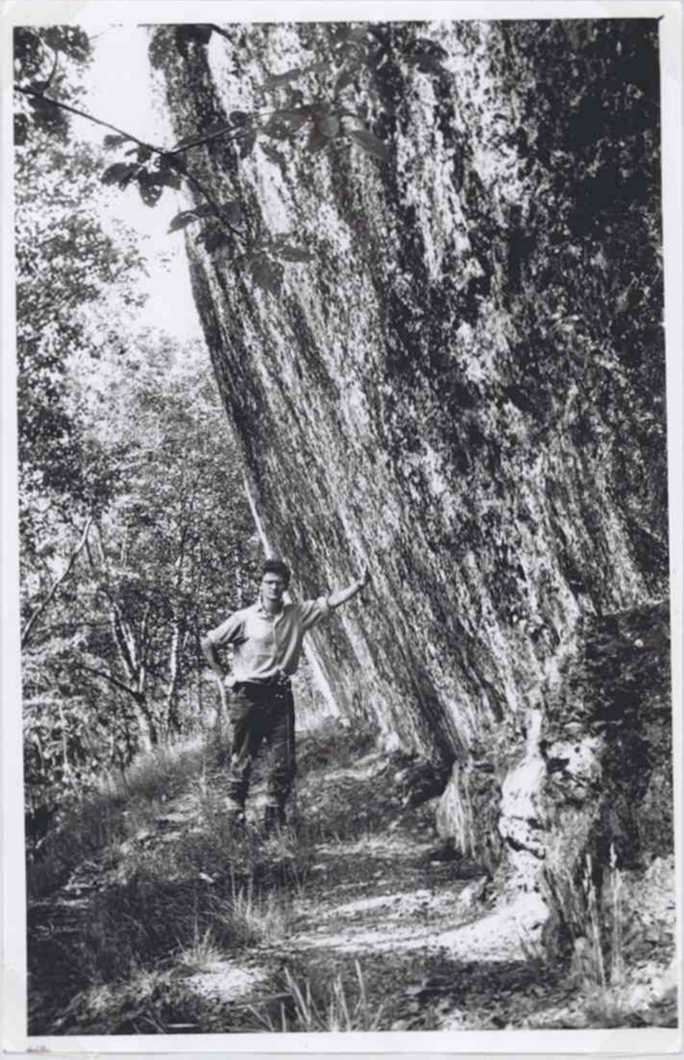


A. B.

Fig.14 The Hølonda Porphyrites.

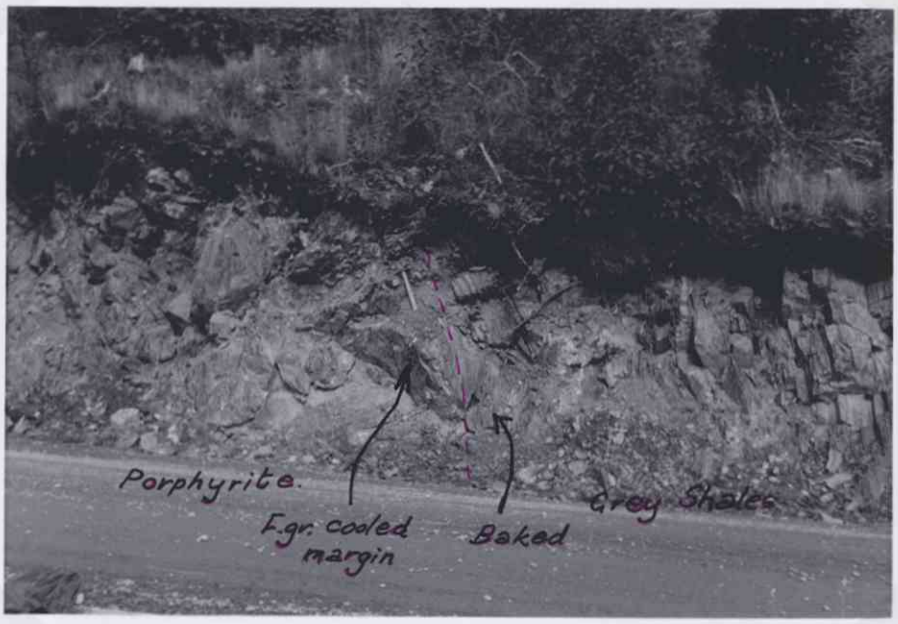
A. Almas type containing phenocrysts of saussuritised felspar and augite altered at the margin to tremolite-actinolite. Groundmass of brownish leucoxene, yellow-green epidote, green chlorite, albite and a little quartz and opaque pyrite. Low power, p.p.l. Locality 321, near Hølonda Kirke.

B. Berg type containing phenocrysts partially saussuritised albite and mats of fibrous tremolite-actinolite in a groundmass containing an abundance of yellow-brown stilpnomelane, green chlorite, epidote, leucoxene and albite. Low power, p.p.l. Locality 249, road cutting east of Gasbakken.



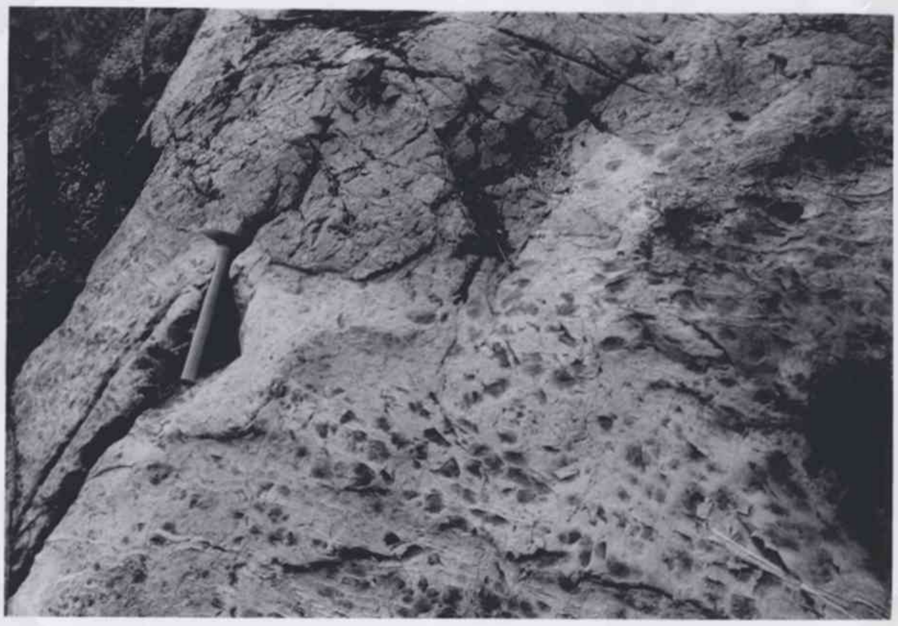
Photograph $P_1$21 Smooth upper surface - true, since overturned - of intrusive sill of Hølonda Porphyrite.

Locality 48., near Stornaeve.



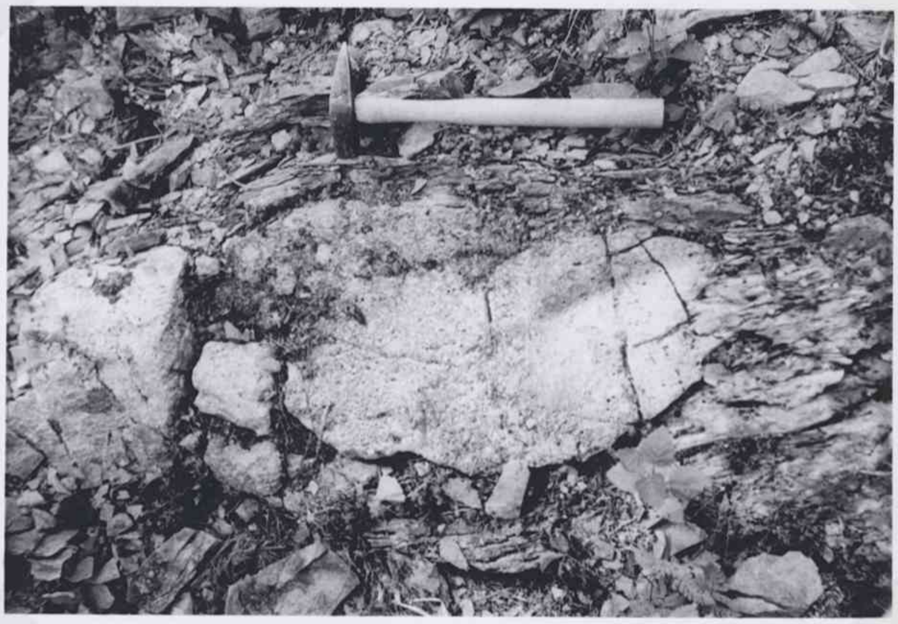
Photograph $P_3 29$ Hølonda Porphyrite intruded into grey shales. The porphyrite appears to have a non-porphyritic, medium-grained cooled margin about 2 to 3 metres in width. The grey shales are baked for a metre or so from the contact. Stilpnomelane is abundant in this exposure.

Locality 249., east of Gasbakken.



Photograph $P_3$34 Hølonda Porphyrite intrusion cutting the bedding of grey-green shales. The shales are baked for about 30 cms. from the contact and the porphyrite is coarsely porphyritic up to the contact.

Locality 280., west of Hølonda.



Photograph $P_2$12 Dark grey-green shales containing a large fragment of Hølonda Porphyrite.
The fragment is probably part of a small intrusive stringer associated with the major intrusion a few metres to the north.

Locality 115., Ellingsvatnet.

Photograph $P_3 9$ Hølonda Porphyrite containing xenoliths of very hard, grey-green baked shales and sandstones. The xenolithic fragments probably originated by the brecciation of the adjacent shales and sandstones by the intrusion of the porphyrite.

Locality 195., Svartaasen.

II. The Malberget Gabbro.

The mass of uralitised and saussuritised gabbro, which occurs within the Støren Greenstones on the north of Malberget and west of Fuglaashogstret, appears to be one of a number of Caledonian gabbro intrusions in the Trondheim region. The Malberget gabbro is a continuation of the gabbro which was partly mapped in the east of the Fjeldheim area in 1960. The exposures of gabbro were very rare in the Malberget area and the boundaries have been deduced mainly from the topography. The contact with the Støren Greenstones was obscured by vegetation but it is probable that the gabbro forms a lens-shaped intrusive mass which is probably concordant with the structure. Generally it is coarse-grained but near the contact inthe Trivja gorge area it was medium-grained. The extent of a contact aureole, if one exists, was not seen.

In thin section the typical gabbro consists of completely saussuritised euhedral feldspar, partially altered ophitic augite, chlorite, epidote, hornblende and a little tremolite. The elongate laths and plates of the original plagioclase feldspar are entirely saussuritised to a mass of micro-granular secondary minerals. Relics of original lamellar twinning are sometimes visible. The ophitic augite is is very pale brown and it is sometimes twinned on 100. Possibly it is titanium rich because there is an abundance of leucoxene in the rock. The augite is altered at its margin to pleochroic green hornblende and sometimes tremolite, after the process of uralitisation. Leucoxene, after ilmenite, occurs in the form of relic skeletal structures of the original ilmenite. Pleochroic pale green chlorite occurs as small irregular patches and it is occasionally developed around the hornblende uralite margin of the pyroxene, probably as an alteration product of the amphibole. Epidote is also present in the groundmass.

At Løkken similar gabbro masses appear to be linked with valuable cupriferous pyrite ore bodies.

Since the Støren Greenstone spilitic lavas, the Hølonda Porphyrites and the Malberget Gabbro originally had a similar original basic composition, it seems probable that they had a similar magmatic origin. Furthermore, it is known that the Støren Greenstone lavas are Lower Palaeozoic in age and it is likely that the Hølonda Porphyrites and the Malberget Gabbro are probably not very much younger. Therefore it seems reasonable to suppose that these basic igneous rocks belong to an initial magmatic phase of the Caledonian orogenesis.

6. THE METAMORPHISM AND STRUCTURAL GEOLOGY

The rocks in the Gasbakken area have been regionally metamorphosed up to chlorite grade. The Lower Hovin rocks appear to have been affected slightly less than the Støren Greenstones. Chlorite is abundant in the Greenstones and the Hølonda Porphyrites but it is much less abundant in the sedimentary rocks of the Lower Hovin Group. Although the relative abundance of chlorite is partly a reflection of the chemical composition it does appear that the Lower Hovin rocks did not suffer the same degree of metamorphism as the Støren Greenstones.

One of the most interesting features of the metamorphism was the occurrence of chloritoid in the dark green grits exposed in the road cutting north of Svorksjoen - loc. 73. The chloritoid appears as crowded, angular black porphyroblasts, about 2 X 2 mm. in size, which are distributed regularly throughout the rock irrespective of the grain size. The distribution appeared to be about two crystals per sq. cm.. They occur in a well-defined zone about 40 metres wide, which appears to be parallel to the strike of the bedding of the grits. The northern extent of the zone was not seen because it lies on the extreme north of the map area. In thin section, the chloritoid occurs as sub-hedral prismatic crystals; the (001) form appears to be best developed. There appears to be an imperfect 110 cleavage. The mineral is pleochroic pale green to dark blue and it commonly shows an "hour-glass" inclusion texture. Polysynthetic twinning is common. Chlorite, calcite and clastic fragments of quartz and altered feldspar are also present. Many of the clastic fragments are broken and show signs of cataclasis - quartz, for example, shows strained extinction. It appears that the growth of the chloritoid was subsequent to the deformation. According to Harker (1960), chloritoid is produced only in rocks which, with an abundance of alumina and a sufficiency of iron-oxide, are relatively poor in magnesia, lime and potash and its formation is probably dependent upon the presence of kaolin. The reactions which would give rise to andalusite or cordierite being inhibited, kaolin reacts with magnetite to give the stress-mineral chloritoid. Further work in the area north of Svorksjoen to study the extent of the chloritoid zone would prove very useful.

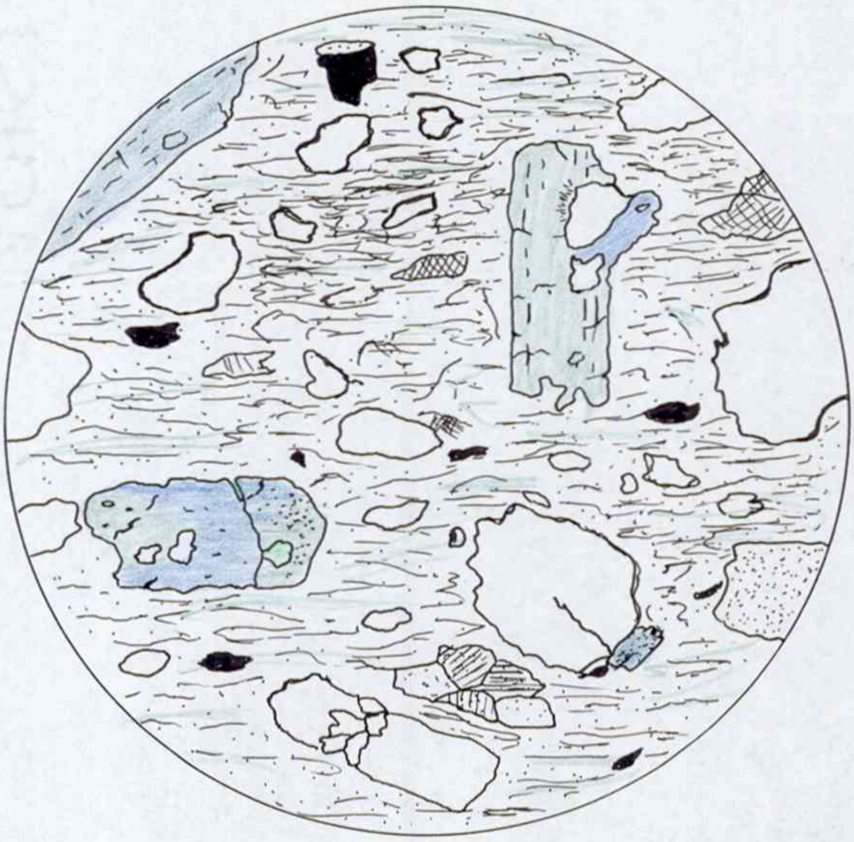


Fig.16 Chloritoid in Stokvola grit.
Locality 73., road cutting north of Svorksjoen.
Low power; plane polarised light.

Sub-hedral porphyroblasts of pleochroic blue-green chloritoid in grit containing clastic quartz and altered feldspar. Chlorite, calcite and pyrite are common in the groundmass.

Concerning the structure of the area, it can be shown that there were two distinct acts of folding. The first folds are fairly tight structures. They have been folded rather more gently apparently about folds which strike approximately north-west - south-east. The original disposition of the first folds is uncertain because in the west of the Gasbakken area and in the Fjeldheim area the dominant strike of the axes is east-west, while east of Gasbakken and in the Hølonda-Horg district the axes strike about north-east - south-west. The first folds therefore have an arcuate form which has a centre towards the north-west. The approximately north-west - south-east radius is parallel to the axial direction of the second folds. The Gasbakken area itself occupies a zone of "puckering" of the first folds by the second set.

The tight major fold in the Fjeldheim area plunges to the east but south of Malberget the direction and amount of the plunge is uncertain. The entire Fjeldheim fold was not traced into the region mapped south of Malberget where the rocks belong to the steeply dipping, overturned limb of the Fjeldheim fold. The axial plane cleavage here dips steeply to the north - usually about 70°N, strike 270°. Occasionally this first fold axial plane cleavage is "rucked" by slight movements on planes which are related to the second folding. This "rucking" is usually known as shear-cleavage.

This overturned limb may be traced as far as the major fault on the east of Malberget. This fault has a pronounced down-throw to the east - the amounts of the vertical component and the horizontal component, if any, are unknown. The fault appears to be younger than the later folding.

To the north of Gasbakken and around Hølonda Kirke the first folds appear to remain fairly tight structures with axial planes dipping about 40°NW. The plunges of the folds are uncertain but they depend on their position relative to the second fold axial planes. The section CDE on the final map is purely a possible explanation of the structure in this area and it also illustrates the possible aspect of the first folds. Shear cleavage is frequently developed in the shales. The Hølonda Limestone tends to develop small minor folds with axial planes parallel to the planes which give rise to the shear cleavage in the shales. These shear cleavage planes appear to be the axial plane cleavage of the second folds.

The presence of the second folds is based essentially on the following evidence :-

1. Outcrop patterns from :-
   (i) Areas mapped by the author and fellow students.
   (ii) The Hølonda-Horg area, Vogt (1945).
   (iii) Geologisk kart over Løkkenfeltet, Carstens (1952).

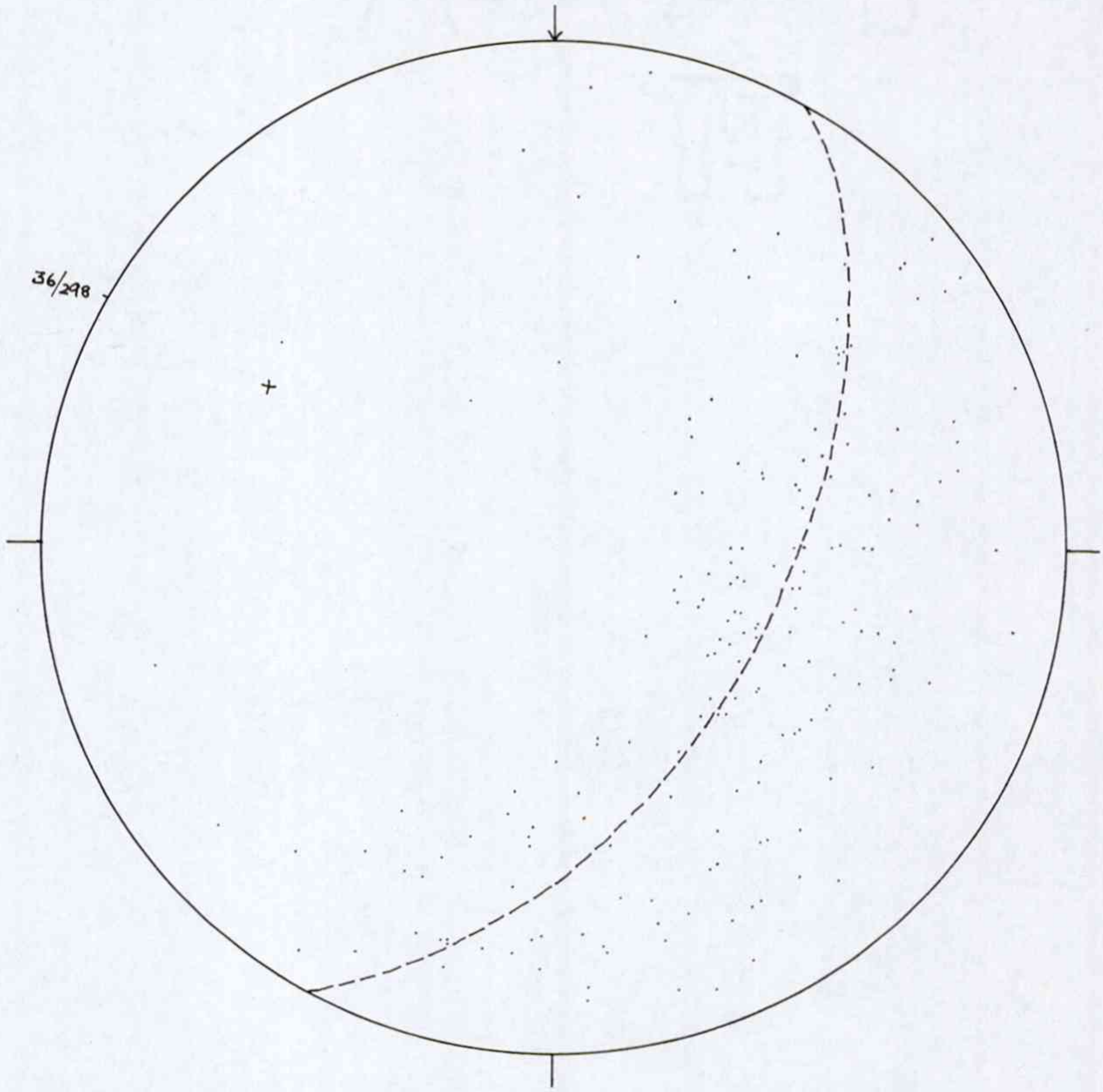
2. Stereogram I. π-poles of bedding planes from the whole area are distributed about a great circle which has a pole plunging 36° to 298°, i.e. the second fold axial direction.

3. Stereogram II. π-poles of first fold axial plane cleavage from the entire area are distributed about a great circle which has a pole plunging 45° to 292°, i.e. the second fold axial direction.

4. Stereogram III. π-poles of planes giving rise to puckers in first fold cleavage have a sub-parallel orientation, i.e. these planes appear to be an axial plane cleavage of a second fold system. Minor folds developed in limestones have an approximately similar plunge to the north-west and are comparable to the poles of the great circles obtained in I and II.

5. Stereogram IV. Plunges of intersections of supposed second fold axial plane cleavage with the first fold cleavage and the bedding planes. These plunges were calculated using a β-diagram. They all plunge to the north-west indicating a second fold axial direction,,which also plunges in this direction.

All these separate pieces of evidence point to the existence a second set of folds which have axes plunging to the north-west at about 40°. The axial planes dip about 65° to the north-east.



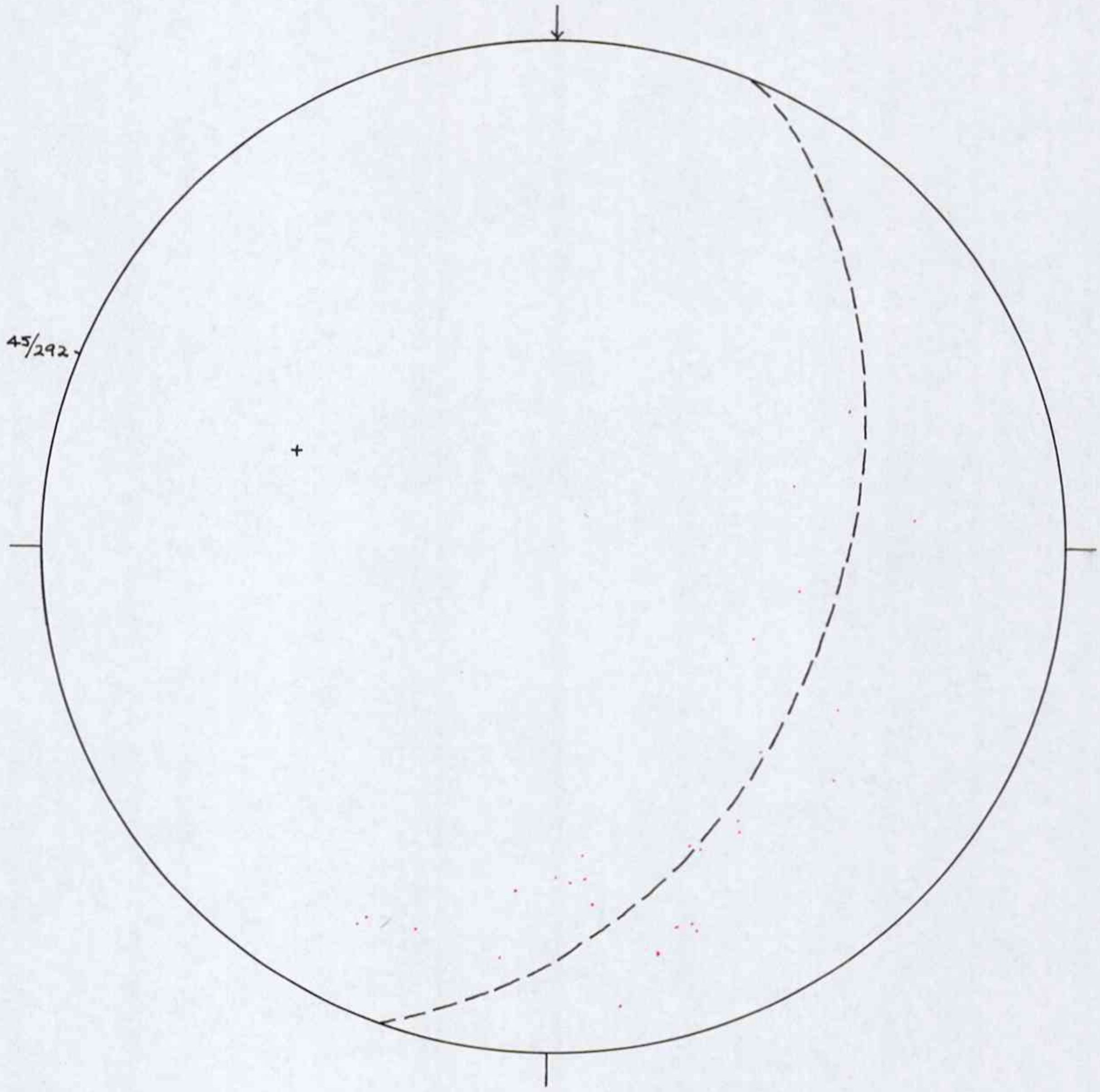
STEREOGRAM I

π -poles of the bedding planes from the entire area.
An indication of the plunge of the second fold axial direction is given by the pole to the plane containing the poles to the bedding. This pole plunges 36° to 298°.

· bedding plane poles.

--- plane containing the bedding plane poles.

+ pole of the above plane.



STEREOGRAM II

π-poles of the first fold axial plane cleavage.

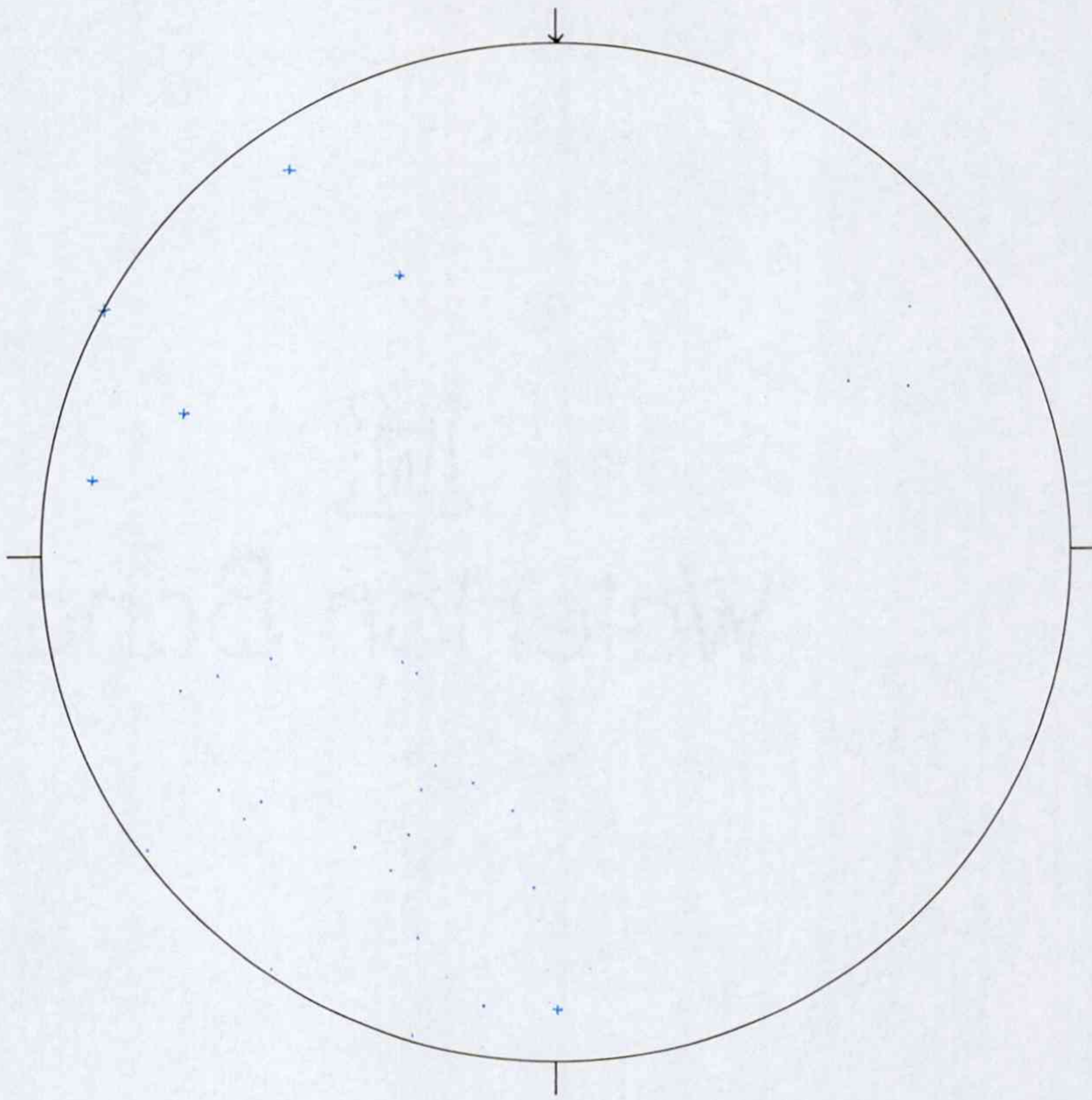
(observations from the entire area)

An indication of the plunge of the second fold axial direction is given by the pole to the plane containing the poles to the first fold axial plane cleavage. This pole plunges 45° to 292°.

· poles to first fold axial plane cleavage.

--- plane containing the cleavage poles.

+ pole of the above plane.

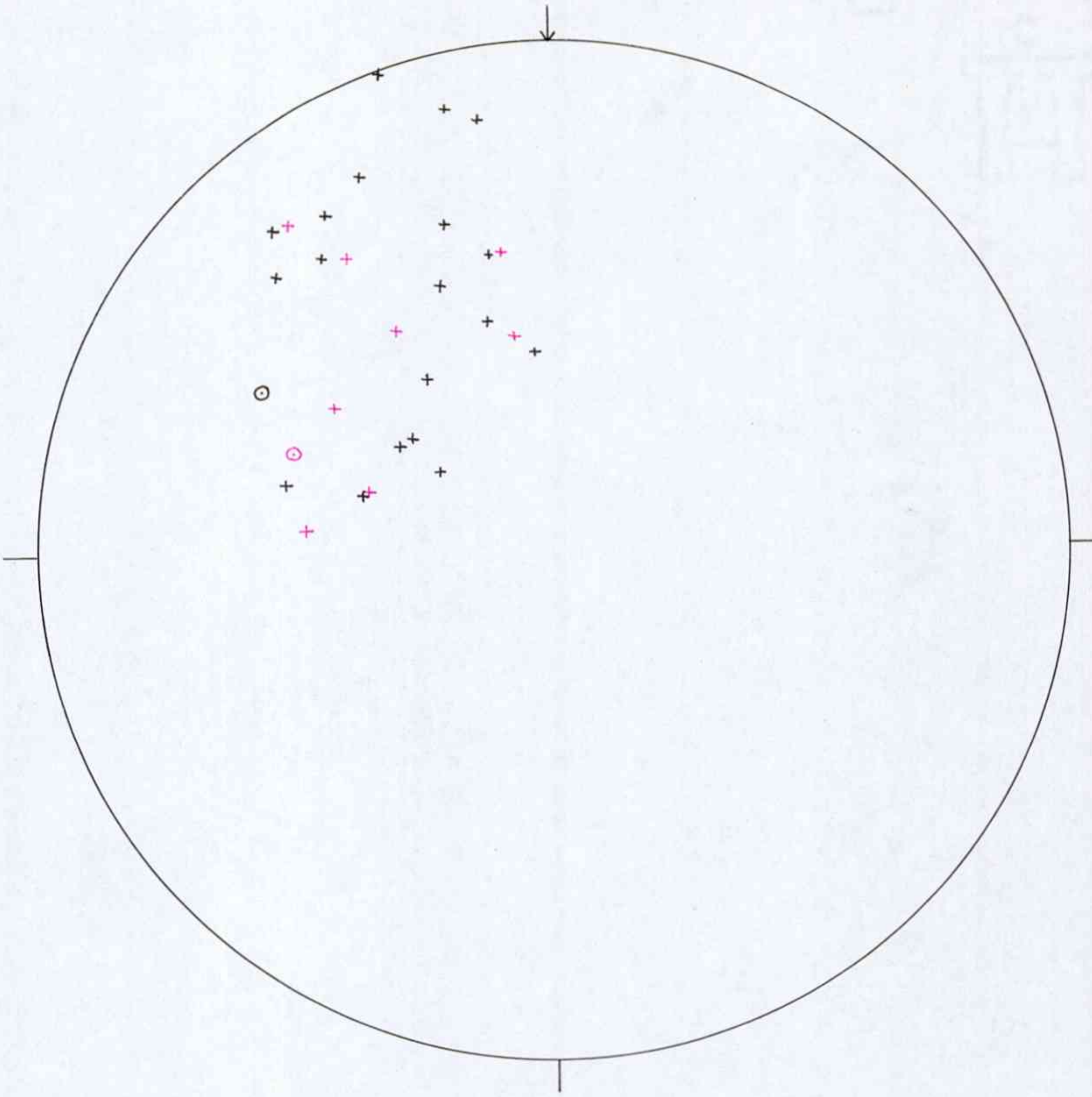


STEREOGRAM III

π-poles of the second fold axial plane cleavage and the plunges of minor folds which appear to be related to the second fold system.

· poles to second fold axial plane cleavage.

+ plunge of minor folds.



STEREOGRAM IV

Plunges of intersections of the second fold axial plane cleavage with bedding planes and first fold axial plane cleavage. The poles of the planes containing the poles of the bedding planes and the first fold axial plane cleavage are also given.

The plunges of the intersections indicate an overall plunge of the second fold axial direction to the north-west.

+ intersection of second fold cleavage with bedding planes.

+ intersection of second fold cleavage with first fold cleavage.

⊙ pole to plane containing bedding plane poles.

⊙ pole to plane containing first fold cleavage poles.

It appears that the synformal structure at st. Fuglaas is a product of the second folding. Also the major fault through Gasbakken is perhaps related to the second folding and from its position it is possible that it may represent a major movement on axial plane surface of the second folds, i.e. it may be an major example of shear-cleavage.

The thrusting east of Fuglaashogstret - locs. 170, 185, 189, and on Bjorkliodden - loc. 107 - is very intense. At locality 185, only the crystalline red jasper resisted the shearing and the remaining material has been thoroughly deformed. The age of the shearing is uncertain, but it appears to have taken place before the Malberget faulting.

Shear zones also occur in the Hølonda Porphyrite east and west of st. Fuglaas - locs. 68 and 159. Thin section from loc. 68 reveals that the porphyrite has suffered severe cataclasis. None of the original phenocrysts remain. The rock is simply a mass of fine-grained saussurite minerals, chlorite, epidote, leucoxene, a little quartz and a great deal of interstitial calcite. This shearing in loc. 68 appears to have occurred prior to the second folding because the typical second fold shear cleavage is developed in the sheared rock.

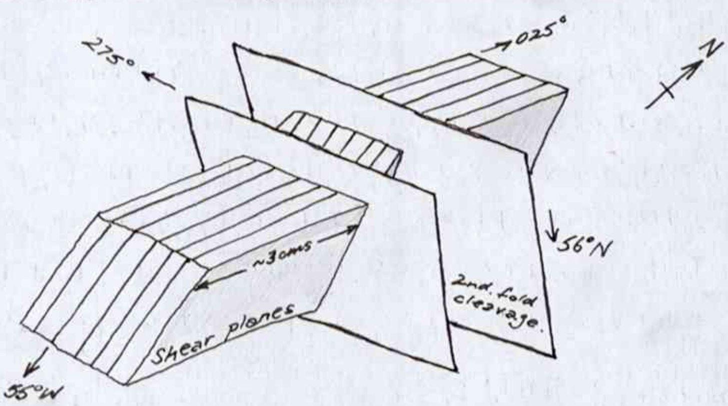


Fig.17 Shear cleavage of second folds developed in deformed Hølonda Porphyrite. Locality 68., st. Fuglaas.

Shear zones are also developed north of Svorksjoen in the Stokvola conglomerates and grits., locality 77. Here the shistosity is best developed in the finer material; the conglomeratic bands have an irregular blocky appearance. Again the red jasper has withstood the deformation. The shear planes dip 60° SW, strike 095°. The relative age of this deformation is uncertain but it may be related to the major fault passing through Gasbakken. The growth of the stress mineral chloritoid is probably related to this shearing.

The probable relation of the eugeosynclinal and initial magmatic phases, the tectonic activity and the regional metamorphism of the Caledonian Orogenesis are shown on the para-genesis diagram overleaf. Apart from indicating that the eugeosynclinal and initial phases probably occurred during the Lower Palaeozoic, no attempt has been made to assign an absolute date to any of the events.

PARAGENETIC HISTORY OF THE AREA.

— — Støren Greenstones →
(Spilitic lavas & pyroclastics)

— Stokvola Conglomerate — Hølonda Shales, Sandstones →
& Limestones

— Uplift →
(The Trondheim Disturbance)
& Målberget Gabbro ?

Hølonda Porphyrites
& ? Målberget Gabbro
— Faulting & Thrusting ? →

— 1st. folds & shearing - 2nd. folds →
— Faulting — ? →

— Eugeosynclinal & initial magmatic phase. →

— Regional Metamorphism →

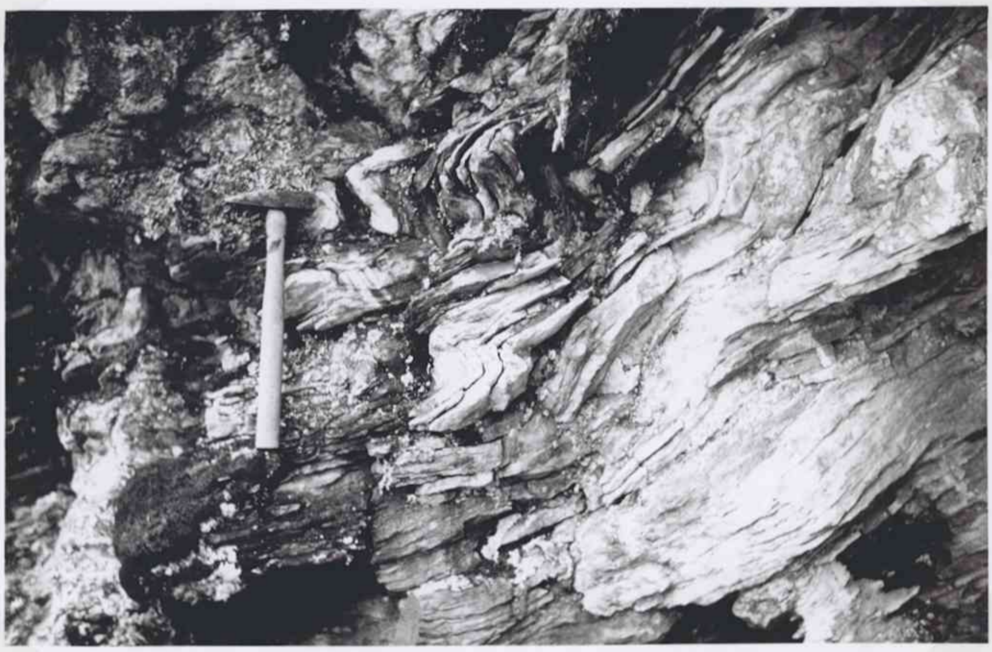
— CALEDONIAN OROGENESIS →

— TIME →

— — LOWER PALAEOZOIC — — — → ?

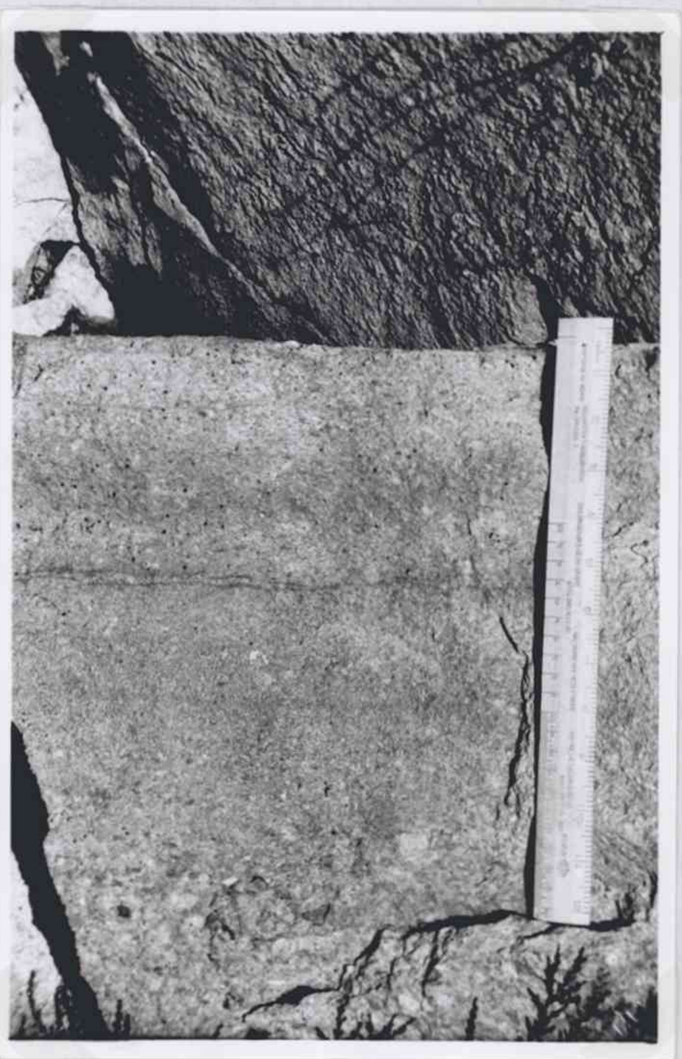
Photograph $P_3$31 Typical shear cleavage produced by displacements of the first fold cleavage by movement on the second fold cleavage planes.
Calcareous grey Hølonda Shales.

Locality 270., south-east of Stennsvatnet.



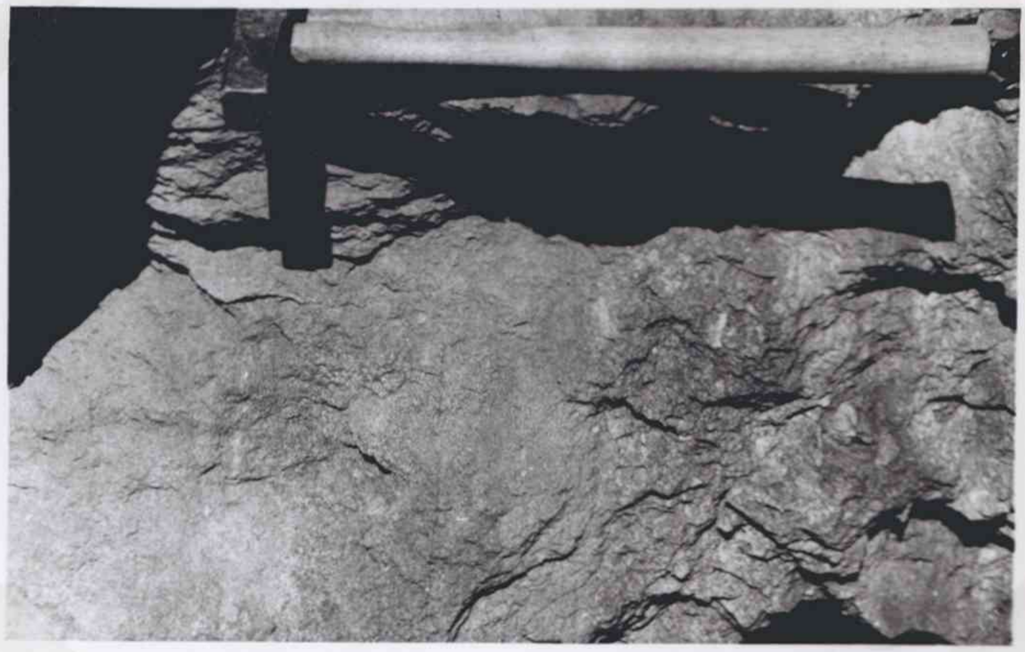
Photograph $P_2 8$ Minor folds developed instead of shear cleavage in Hølonda Limestone, due to the difference in competence between shales and limestone.

Locality 80., peninsula in NW parp of Svorksjoen.



Photograph $P_2 4$ Chloritoid, visible as black specks, developed in Stokvola grits.

Locality 77., road cutting on north side of Svorksjoen.



Photograph $P_2 7$ Sheared Stokvola grits and conglomerate.

Locality 77., road cutting on north side of Svorksjoen.

Photograph $P_3 5$ Sheared grits/conglomerate or perhaps agglomerate.

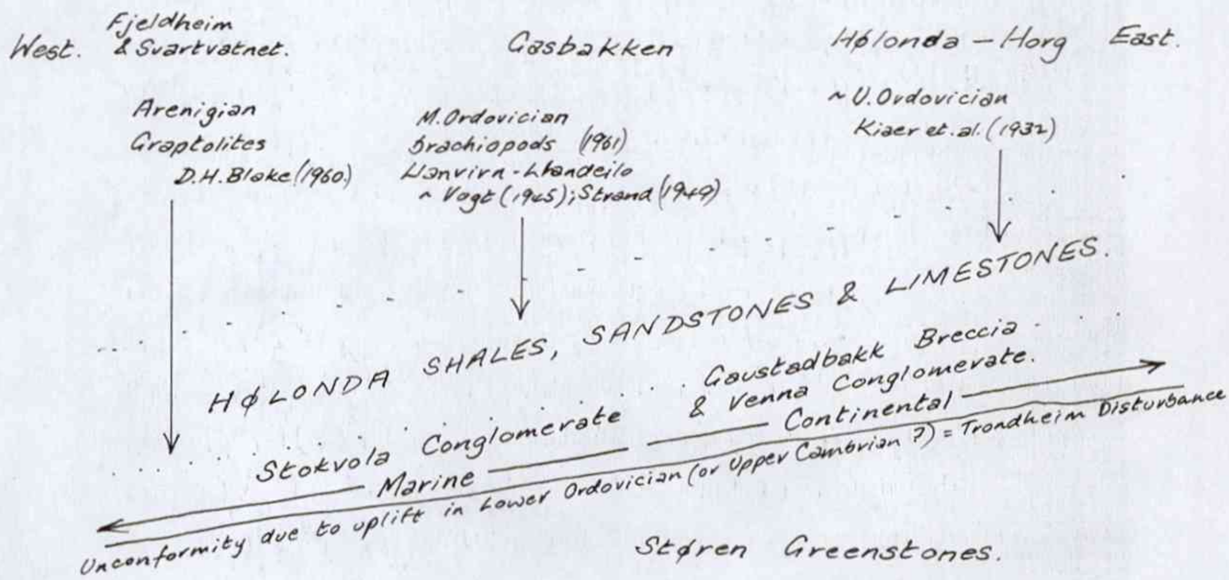
Locality 185., shore of Svorksjoen, east of Fuglaashogstret.

7.PALAEONTOLOGY

Two new fossil localities containing brachiopods were found at locality 30, north of Bjornlivatnet, and at locality 117, st. Fuglaas. At locality 30, in an exposure at the side of the track to the log-cabin north of Bjornlivatnet, an abundance of brachiopods was found in the Hølonda shales which lie above (true) a limestone bed. At locality 117, a few metres north of the farm houses of st. Fuglaas, the brachiopods occur in green Hølonda Shales. Faint impressions of possible brachiopods were found at locality 50, Stornaeve, and at locality 115, st. Fuglaas. A specimen of possibly the gasteropod Hormotoma sp. was found in the Hølonda Limestone at locality 118, near st. Fuglaas. Elsewhere the Hølonda Limestone frequently contained unidentifiable fossil fragments.

After comparing the brachiopods, rather unsuccessfully, with the descriptions by Reed (1932) of brachiopods found in the Hovin sandstone at Grimsaasen, which lies about 4 kms. east of the Gasbakken area, and in the Hølonda Limestone and Shales at Katuglaasen which is about 4 kms. north-east of Hølonda Kirke, it was decided that professional advice should be sought. The fossils were taken to the British Museum (Natural History), London, where they were examined by Dr. W.T.Dean.
Dr. Dean describes the brachiopods as follows :-
"Generally speaking the specimens are too poorly preserved for even generic determination. The best specimen is from locality117, which is a single valve bearing a general resemblance to Rafinesquina, though it has not been possible to confirm such an identification in the absence of any internal structures.
One specimen from locality 30 shows markings suggestive of those on the interior of a clitambonitid brachiopod, while others might well be clitambonitid pedicle valves, but in all cases the specimens are too distorted or badly weathered for anything more than a tentative suggestion.
If the above groups of brachiopods are, in fact, present, it seems unlikely that the age of the fauna is earlier than about Middle Ordovician. The large number of species described by Reed from the region does not seem to correspond with this new material, as far as comparison is possible with such poor specimens. "

This suggested Middle Ordovician age is not in accordance with the Arenigian age indicated by the graptolites found by D.H.Blake in the Svartvatnet area in 1960. The stratigraphical position of the graptolitic shales is uncertain, but it certainly appears to be younger than the Støren Greenstones and it was thought that they occurred somewhere within the Hølonda Shales and Sandstones. Therefore, either the brachiopods are actually older than Dr. Dean suggests or the graptolitic shales occur in a faulted mass from much lower in the succession, i.e possibly in the Støren Greenstones. A more acceptable alternative to the above propositions is that the Lower Hovin rocks are fairly strongly diachronous such that the marine deposition began much earlier in the west of the combined Fjeldheim-Svartvatnet-Gasbakken-and Hølonda-Horg areas. In support of this argument is the fact that the basal conglomerate of the Lower Hovin rocks is distinctly marine in the west and becomes more continental in the east. The possible diachronism and fossil ages found by other authors is shown in the following diagram :- (No allowance has been made for crustal shortening).



Lists and descriptions of a large variety of fossil organisms from the region may be found in papers by Kiaer, Hoeg, Hadding, Reed, Foerste, Strand and Størmer (1932), Vogt (1945) and Strand (1949). It is hoped that a paper by D.H.Blake describing the graptolite fauna in detail will be published very shortly in the Norsk Geologisk Tidsskrift.

8. STRATIGRAPHICAL CORRELATIONS

The value of any geological survey is enhanced if it is possible to make stratigraphical correlations with other areas. Some correlations with the Fjeldheim, Hølonda-Horg and other adjacent areas have already been mentioned in earlier sections. However, because of the possible diachronism of the Lower Hovin Group and the fact that synonymous terms have probably been given by various workers to deposits of different ages in the Lower Hovin Group in the region, it is felt that, at present, it may be unwise to say more concerning stratigraphical correlations of the Gasbakken area with others in the region. More fossil evidence is required and further detailed work is needed, particularly in the Hølonda-Horg district, to help clarify the situation.

9. ACKNOWLEDGEMENTS

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We are also indebted to Professor T. Strand of Oslo University for spending a day with us in the Fjeldheim area and for showing us some of the geology in the vicinity of the Mine. We are also grateful for his co-operation in the preparation of a paper on the combined areas which, it is hoped, will be published early in 1963.

We are also very grateful to Herr Naeve of the Orkla Grube Aktiebolag for allowing us to stay in his magnificent log-cabin near Bjornlivatnet. Our thanks are due too to the farmer Herr Olav Naeve and his family, both for their warm hospitality and for supplying us with fresh farm produce. We were also very pleased to enjoy the company and hospitality of Herr Ingvaldsen, of the Norwegian Geological Survey, and his wife and family.

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~Structure and Locality Numbers.