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THE GEOLOGY OF AN AREA SOUTH OF GASBAKKEN.

A.E.BESWICK 1962

CONTENTS

An area south of Gåsbakken

Introduction.

Gåsbakken is a small agricultural community located approximately 12 km east of Lökken . Lökken being situated some 55 km to the south of Trondheim in Norway.

Geological mapping was carried out using aerial photographs with tracing paper over-lays, the scale being 1 to 15,000. It should be made clear that some inaccuracies occur in the map and the overlays . This is due to the aerial photographs having rather bad distortion around their margins due to tilt. Such inaccuracies as do occur are , however, considered to be acceptable and do not affect the geological interpretation.

Three areas were divided rather arbitrarily between Chadwick , Rowling and myself. The area which I mapped lies to the south of the Skolda river which flows through Gåsbakken in a rather meandrine fashion and into Svorksjöen lake a few kilometers to the north-west . The area was bounded by a small tributary of the Skolda in the east and by the road from Stornaeve toGåsbakken in the west. The southern boundary was a line approximately parallel to the northern boundary , running eastward from Stor Damtjern lake across a series of ridges to intersect the eastern boundary. Chadwick and Rowling mapped two adjacent areas, Chadwick to the N &NW , and Rowling to the S.E.

The object of the mapping was to attempt to elucidate the structure and the stragigraphy and to correlate the results with either or both of two adjacent ,previuosly mapped ares. One of these areas , to our west , was mapped by Blake and Chadwick during the summer of 1960 . The other, a larger area to our north-east, was mapped by the late Thorolf Vogt who published his results in a paper in the Norsk Geolsk Tidsskrift in 1945.

The late Dr. Carstens of Trondheim University had also done some mapping in a nearby area. His map was printed posthumously but unfortunately no translation of his written work is available. Other than the work mentioned above, very few investigations have been made.

Mapping was carried out over a period of 7 weeks between July and September 1961. Due to bad weather conditions (the summer was the worst for 40 years according to local reports) mapping had to be extended for a week longer than origionally planned ,in an attempt to cover the area. Finally some 6 to7 sq.ml. (18 sq.km.) were covered.

The object of the mapping was fulfilled for the most part but,as will be seen in the following pages,correlation of some rock types remains a problem due to lack of fossils.

Physical Geology

The area forms part of a dissected peneplain grooved during the Pleistocene glaciation. As a consequence the majority of the main valleys and ridges run in a N.W. to S.E. direction - the same direction in which the glaciers must have moved (see pages 29).

The area is drained by the river Skolda , many tributaries of which rise on the ridges in the southern part of the area. The valleys occupied by many of these small streams have obviously been enlarged by glacial action. A good example of this is the wide valley containing Rödtjern, Skogstad, and Ellingsvatnet (see plate 1). These lakes are joined by a small stream which runs in and out of each in turn, eventually running into the Skolda after leaving Ellingsvatnet.

Although most of the large la kes occur in the low lying valleys, many others occur in hollows or depressions at higher elevations, the best examples in this area being Stor Damtjern and Lille Damtjern. Evidence suggesting the existence of former lakes is also present in numerous other depressions. This evidence being swampy peat bogs and small areas of shallow water occuring in flat bottomed depressions which are generally elongated in a NW-SE direction. Some of the existing lakes show signs of being infilled in perhaps the same way as the ones described above. This is indicated by deltas and areas of shallow-water reeds which show up very well on the aerial photos. As this infilling progresses the lakes will gradually be reduced in extent and ultimately replaced by flat lying areas of peat bog.

The area has quite a strong relief of 300 m. The lowest valleys have an elevation of 200 m. or a little more,and most of the ridges rise to an elevation of approx. 500 m. Many of these ridges have very steep sides and flattened tops (see photos 2 & 3). Since their summits are closely similar in elevation this supports the idea of a pre-existing peneplain. The dissection of this peneplain in many cases cuts across the structural trend of the rock s, being more generally related to the trend of the glaciation. As a result of this marked trend,any pre-glacial drainage pattern is virtually impossible to determine.

Only one abandoned river course was observed (see sketch 1) and this seems to have been formed quite recently. This abandoned course must, at one time,have linked the stream which now runs from Middagsaasen ridge into Skogstad lake with the stream now running from Skogstad into Ellingsvatnet lake. At the time of observation the river course was in fact carrying small amounts of water, however under normal,drier conditions this water would be represented by no more than a few stagnant pools.

Much of the area is covered by thick pine forests, especially the higher ground. Small cultivated areas are generally resticted to the lower valleys , elsewhere the forest cover is broken only by small lakes or flat lying peat bogs. Due to this thick cover exposures are poor ; less than 1% is exposed. Ironically some of the best exposures are to be found under the roots of fallen trees where the thin soil mantle has been stripped away. The insect life which the forest supports was virtually intolerable in the early weeks but as the summer passed and their numbers diminished they caused less discomfort. More pleasent were the numerous red squirrels and the more evasive deer and elk. Adders were rather a menace but fortunately only a few were encountered.

Introduction to the stratigraphy

The rocks of the area exhibit a low grade regional metamorphism and, as Vogt points out, this is rather remarkable when one realises that they are completely surrounded by rocks of a much higher metamorphic grade.

Some of the first investigations in and around this area were made by Kjerulf and Hauan who gave the rocks their stratigraphic names in the latter half of the last century e.g. the Storen Group, which occurs in the areas mapped by Chadwick and Rowling, and the HovinGroup which occurs throughout our combined areas. Although no identifiable organic remains were observed in any localities in my area some fossiliferous horizons have been observed in the Hovins. Blake in 1960 discovered a graptolitic shale horizon which has proved to be Arenig in age. Vogt collected fossils from the Hölonda Limestone including trilobites which are regarded as Llanvirnian in age. Until such times as fossils are discovered within my area correlation with Blake or Vogt can only be attempted on a lithological basis. Such a correlation cannot be absolute due to the facies changes soon to be outlined.

On the map only four main groupings (other than superficial deposits) are indicated. It should therefore be explained why these broad groupings have been made since many more than four distinct rock types occur. The succession from oldest to youngest is as follows:-

(a) The oldest rocks exposed are the Purple Breccias, a thick series of breccias, grits, and sandstones with occasional bands of shale, usually well bedded and having a deep red or purple colour. These can be traced into Vogt's area and, in the main, correlated with his Gaustadbak Breccia.

(b) Above the Purple Breccias occur the Banded Shales and Sandstones. These are mainly comprised of alternating bands of shale and sandstone usually with a dark grey colour but occasionally being somewhat greenish.

(c) The third group is the Blue Grey Limestone which occurs interbedded with the above shales and sandstones apparently at more than one horizon. The limestone generally has a peculiar brecciated appearance and seems to have a limited distribution occuring, as far as can be determined, in the form of lenses.

(d) The final group is the Porphyrites which occur in numerous small sheet-like masses. The relationship of these igneous rocks to the sedimentary succession is rather a questionable one.

It seemed, early during the mapping, that it might be possible to establish a more finely divided succession than the one outlined above. However as mapping progressed and larger areas were covered the idea had to be abandoned. This was due the repeated observation of facies changes in some of the sediments when followed along their strike from one exposure to the next. For example when greenish grey shales were encountered in the Banded Shales and Sandstones it was impossible to trace them laterally for more than a few tens of meters. The same situation occurs in the Purple Breccias ; green grits and sandstones were observed inter-bedded with these but they could not be traced for any distance which might make them worthy of being distinguished as a seperate group.

It is therefore proposed to describe these intercalated types together with the groups with which they are interbedded, rather than under seperate headings which may tend to make the succession misleading.

The Purple Breccias

This group forms the base of the succession in my area, being the oldest rocks exposed. The group consists in general of a rapidly alternating series of breccias, grits, sandstones, and less frequently, shales; all with a characteristic deep purple or reddish- purple colour. Exeptions to this general colour do occur but in such cases the colour is always green. The coarser rock types are seen to be comprised of fragments of various kinds of material, much of which is quartzite and limestone together with fragments of blue-grey shale, red shale, sandstones and gritstones of various colours, volcanic rock (similar to the Storen Greenstone), and occasional fragments of jasper which vary in abundance from one exposure to the next.

A thin section was made of the red sandstone from locality 5(See fig. 4). Under the microscope the rock is seen to be made up of abundant, angular, grains of quartz in nearly all cases showing strained extinction under crossed nicols. Grains of untwinned felspar and of lamellar twinned albite are also present in small numbers, other grains are more notably ; fine grained calcite, epidote, opaque and dark red-brown ore minerals (hematite and ilmenite ?), and more infrequently grains of volcanic rock and grains of quartzite are seen. The quartzite grains show highly sutured,individual quartz margins, a point which may be helpful in determining the source of these rocks. It is not certain whether or not the epidotes and the rarer clinozoisites represent original detrital grains , or whether they have grown in the rock as a result of the regional metamorphism. The calcite occurs in irregular patches and in moderatly well defined grains, the former are probably in this broken down form due to the metamorphism. The groundmass is made up,as far as can be determined, of fine grained quartz, calcite, epidote and iron ores. The grains show a slight tendency to be oriented in the groundmass, this is best displayed by the opaque minerals and the rusty streaks of iron oxide(?) which are drawn out in a parallel fashion. Epidotes in the groundmass are seen to occur in the form of minute needle-like crystals with random orientation which seems to suggest, from their idiomorphic habit, that they grew in the rock during metamorphism.

The rocks are generally well bedded and there seems to be no regular rhythm in the occurence of the different lithologies: a bed of breccia may be followed by a bed of shale, sandstone, or grit(see plates 4&5). Although most of the group is made up of well-bedded strata exceptions are observed. At locality 22, for example, lenses of breccia of a variety of dimensions from 0.1m to 1.5m are seen intercalated in beds of purple sandstone and grit (see fig. 7). In other instances more massive horizons occur (see plates 7,8,&10) in some of which bedding is difficult or impossible to determine. At localities 199 & 275 individual fragments are frequently 0.5m or more in greatest dimension so that the rock may best be termed a boulder conglomerate. In these localities most of the boulders are rounded or at least sub-angular, the matrix is of purple grit and sandstone sometimes mixed with green tuffaceous material. The fragments are of a variety of rock types including odd pieces of red jasper.

'Agglomerates'also were observed although only in a few exposures. They appear to be best developed just to the west of the road which runs through Nordlien to Skogstad (see plates 11 &12) especially at locality 122. Here they appear,at first sight,to be distorted pillow lavas but on closer examination it can be seen that this is not the case: not all the material is igneous, occasional large boulder-like fragments of white quartzite are present and also some smaller pieces of purple sandstone. The bulk of the rock is made up of large,rounded and sub-angular fragments of dark,grey-green, weakly porphyritic, igneous material . In the locality mentioned it seems that this particular bed is about 6m. thick, however it can only be picked out in three exposures no more than 100 m. apart, and apparently it thins out along the strike in either direction.

Other intercalations are mainly of green sandstones and grits. These are well developed in the centre of the area at localities 190 - 200, midway between Rod and Stornaeve. In some of these exposures green grits and sandstones are observed alternating with similar beds having a purple colour. Individual beds are usually 20cm. to 30cm. thick(see plate 13a).

At localities 198 & 199 light green coloured grits and sandstones are observed which show beautiful cross bedding emphasised by the bottom surface of each foreset bed being purple in colour (see plate 14 & fig. 2). The purple colour seems to be due to finely disseminated iron ores, probably hematite. The reason for the purple colour occuring at the base of each bed can be explained in two ways. Either the grains which had thin coatings of iron compounds were generally heavier than the bulk of the uncoated grains and this caused them to settle out of the depositing current at a faster rate, and hence to be concentrated at the base of each bed. Or the alternative explanation would be that the colour is a post depositional feature resulting from the seepage of solutions rich in iron compounds which would tend to accumulate along the bedding planes at the base of the beds and hence such areas would be more liable to staining. The former alternative requires some explanation as to why some of the original grains should be stained and others not. The obvious explanation would be that the material was derived from two distinct sources, perhaps from two tributaries of a large river.

Other instances of current bedded were also observed the most noteworthy of these being at locality 147 (see plate 6). Here the rocks are all purple sandstones and the form of the bedding is different to that described above, being rather reminiscent of the grain in a knotty piece of wood.

Light green coloured alternating shales and sandstones were observed interbedded with purple grits and breccias about 1 km. S.S.E. of Svartvatnet at localities 150 & 166. In both instances their total thickness was no more than 5 m. and they could only be followed for short distances along their strike.

A rather characteristic but apparently impersistent green, somewhat tuffaceous breccia has also been included with the Purple Breccias. This is only exposed in the valley which runs from Stor Damtjern lake to Lillenaeve (see plate 2). The breccia is well bedded and in places slightly sheared. It is composed of numerous angular fragments of white crystalline limestone between 1 cm. and 10 cms. across, green and grey sandstones and occasional fragments of jasper. These are all embedded in a matrix of green tuffaceous sandstone(see plates 15 & 16).

Thin beds of pure white limestone are to be observed inter-bedded with the breccias. This limestone is identical to that found as fragments in the breccias, suggesting contemporaneous erosion and deposition of the limestone. The margins of the limestone beds are, however, usually quite regular and show no signs of having been eroded. It must therefore be assumed that the fragments in the breccia have been derived from a similar limestone within the same approximate horizon and which has either all been eroded or is not now exposed. The beds of limestone were, with one exeption, usually about 0.5 m. thick a similar spacing to the bedding planes in the breccias and grits (see plate 16). The exeption is a bed of limestone of a minimum thickness of approx. 50 m., not all of which is exposed.

Rather similar grits and less coarse breccias are to be seen in the vicinity of locality 260 to the S.W. of Hameraasen, in the S.E. corner of my area. Here the rocks have the same green colour but are far less rich in limestone fragments , fragments of purple sandstone and shale being rather common, no limestone beds are seen.

In the same valley as the white limestones mentioned above, another limestone is exposed at the base of the steep sloping west side, at localities 108 & 107. This limestone is not the same as those described above : it is pale grey in colour and contains thin bands of fine grained, green tuffaceous material,and is commonly brecciated and somewhat nodular in appearance. As far as can be determined this limestone appears to be interbedded with purple and green grits and breccias.

The occurence of current bedding has already been mentioned; although most of the individual beds are very poorly sorted, if at all, the occurence of graded beds is not uncommon. At locality 226 one can see relatively thick beds which are graded from breccia at their bases to sandstone at their tops (see plate 9). One should note the underlying, relatively much thinner beds which exhibit little or no signs of sorting, although a few are rather weakly graded. Although thicker beds generally indicate accumulation over longer periods than do thin beds, the reverse is probably true in this particular instance. The thin sandstone beds probably accumulated over a period of years whilst the much thicker, and somewhat coarser, graded beds probably each were deposited in a matter of a few hours, representing perhaps the load of a large river during a period of spate.

Graded beds were also seen near Stornaeve at locality 13 but in this case it was far less obvious. The grading occurs in thin beds of purple sandstone, being only weakly developed.

On the whole sedimentary structures are not abundant, current bedding being more common than graded bedding. Generally the rocks of this series are fairly well bedded and the coarser horizons unsorted.

The Banded Shales and Sandstones.

This group of rocks directly overlies the Purple Breccias; the boundary between the two was not actually seen but in many cases its position could be determined to within a few meters. Although the boundary was never exposed the relationship betweenthe two groups appears, in all cases ,to be a conformable one.

The group is comprised of dark grey, and less frequently, green-grey shales which are usually interbedded with thin persistent bands of similarly coloured sandstones and fine gritstones. In many instances both the shales and the sandstones are characterised by the presence of rust coloured speckles often elongated in a parallel fashion due to tectonic forces. These have been described by Vogt as representing the alteration products after original pyrrhotite grains. Rarely the original pyrrhotites were found preserved in the form of minute crystals no more than 1 mm. across having a yellow, silver-grey colour.

The shales are generally well foliated and very fissile, disintegrating very easily when struck with the hammer, and in many cases exposures are covered by a thin layer of fragmented shale laminae produced by weathering (see plate 17a).

The green- grey shales and sandstones mentioned above are generally found at low horizons near the base of the series e.g. near Hameraasen where they are found just above the lower boundary. In the same area at a similarly low level are seen beds of green grits and breccias upto 0.5 m. thick interbedded with the usual grey shales and sandstones some of which are slightly greenish in colour.

Assuming that these above described intercalations are continuous, which does not seem to be the case, they could only constitute 1 or 2% of the total thickness of the group, the other ninety-odd percent being of dark grey shales and sandstones. The most striking feature of these shales and sandstones is perhaps the persistence of the individual bands which are usually only a few cms. in thickness (see plate 18).

In many cases graded bedding is weakly developed in the sandstone bands especially when they are slightly coarser than usual. Generally one has to look closely before the grading is apparent.

Although the shales are generally very fissile and easily broken, in the south of the area they are frequently much harder and more difficult to break with the hammer. Otherwise they are identical in lithology to the more fissile type.

Two thin sections have been made of the dark grey shales, in both cases the specimens were taken from localities where they are strongly folded. The two sections are more or less identical so that only the one from locality 50 will be described.

In this section it can be seen that the shale is made up of fine grained bands of pelitic materials usually alternating with thin, often incontinuous bands of fine grained calcite (see fig. 10). A noteworthy feature is the presence of small angular fragments of quartz and albite of a size one would be more likely to encounter in a fine sandstone. These grains are present not only in the pelitic areas but also in the fine grained calcite to a lesser extent. Occasionally minute epidotes are seen and areas of coarsely recrystallized calcite. One can also see small reddish streaks in the pelitic bands, elongated parallel to the bands and to the fissility of the rock. Very rarely small, highly birefringent, elongated grains were observed which may be muscovite.

Very rarely thin bands of tuff are seen interbedded with fissile shales. These are best developed at locality 209 where continuous bands of light grey-brown tuff were seen only 1 or 2 cms. in thickeness. The tuff is easily mistaken for a band of sandstone but it is seen to be quite soft and friable, and porous and light in weight; unlike the bands of sandstone which are much harder and more compact. A thin section has been made of a specimen of tuff from this locality, which is in a small quarry on the east side of the road between Gåsbakken and Hameraasen.

The thin section shows the rock to be made up of numerous fresh, angular quartzes together with less numerous lamellar twinned plagioclases. Untwinned felspars are seen rarely, as are grains of pale green, weakly pleochroic amphibole which seems to be hornblende. Another mineral is also present, it is colourless with moderate relief and occurs in minute, elongated, needle-like aggregates showing low first order interference colours and having a very small oblique extinction under crossed nicols. This mineral may be Tremolite; interference figures are difficult to obtain so that this cannot be proven. No pyroxenes were observed. The only other minerals are rusty brown stains, of iron compounds probably, and rare minute epidotes. As was seen in hand specimen, the rock is very porous. A few fine grained, composite fragments are also present.

Very few traces of organic material were observed in the series, and nothing could possibly be identified. However Chadwick did collect some poorly preserved brachiopods from similar shales in his area. These have, I believe, been identified approximately as a species of Rafesquina which, according to the British Museum (Natural History), cannot be older than Llanvirnian.

The Blue Grey Limestone.

These limestones are best developed near Lille Fuglaas and near Svartaasen. In both these areas they are light to dark blue-grey in colour and seem to be slightly impure. It appears that they are not continuous and that they in fact wedge out in either direction along their strike, thus occuring in the form of lenses. They are completely interbedded in the Banded Shales and Sandstones generally near thetop of that group. In the two areas mentioned the limestones may in fact be one and the same, lying on opposite limbs of a fold. Unfortunately this cannot be proved as the structure of this area is the most difficult of all to elucidate.

In almost all cases the limestone is brecciated in a rather unusual fashion and frequently rusty spots are obseved, very reminiscent of those in the shales and sandstones already described. The brecciation is not thought to be a result of tectonic deformation as such, but due to some kind of slumping and compaction before or after burial. These features, together with the colour, afford easy distinction from the pure white limestones grouped with thePurple Breccias.

In the Svartaasen area thin beds of shale and sandstone are intercalated in the limestone being identical to the shales and sandstones in which the limestone is enclosed. In this same area at locality 117 fragments of porphyrite are seen embedded in the limestone (see plate 22). These fragments are usually elongate and oval in shape with their long axes between 5 cms. and 15cms. and many are vesicular. In other cases fine grained tuffaceous material can be observed in vein-like streaks around nodular shaped pieces of the brecciated limestone. This is more common in the thinner limestone in the S.E. of the area particularly at locality 254. It is suspected that the tuffaceous material was originally in thin even bands as a pyroclastic deposit and that it took on its present appearance as a result of the brecciation of the limestone caused by the slumping mentioned above.

At locality 36 the limestone is partly pale blue and partly pale pinkish grey in colour. It was at this same roadside exposure, near the road junction close to Lille Fuglaas, that a specimen was taken from which athin section has been made. In this section the rock is seen to be made up of an extremely fine grained aggregate of calcite with very minor quantities of opaque minerals and quartz grains. Extremely thin veinlets of quartz and some associated brown ore mineral cut the rock. Other than these one sees only a rare grain of epidote or clinozoisite and nothing else. Occasionally the calcite is recrystallized in small localised areas.

Conditions of deposition

It is now proposed to discuss the environments of deposition of the sediments so far described, dealing, as far as possible, with each of the three groups in turn.

The red and purple colour of the Purple Breccia sediments strongly suggests their derivation from a land area with an arid climate and, due to the coarseness of the majority of these sediments, probably one of fairly high relief. However it need not follow that they represent terrestrial accumulations and it is here suggested that deposition was possibly in a shallow marine environment. This is suggested because of well defined bedding which is so characteristic of the group in general and also becauseof the sedimentary structures observed. As Prof. O.T.Jones 1938 points out, such deposits of shallow marine environment "vary greatly from point to point in a horizontal sense and often from bed to bed in a vertical sequence, and bedding planes are usually sharply defined." The pure white limestones interbedded with breccias as described on page 10 may well be chemical precipitates in small shallow coastal lagoons of a very temporary existence. The eroded fragments found in the adjacent breccias, of this same limestone, representing contemporaneous erosion by turbulent waters which swept into the lagoons from time to time. If the limestone are in fact precipitates, as their purity suggests, thenthe waters must have been quite warm, so that the adjoining land mass may have been rather like a hot desert. The thin bands of purple shale and also the bands of grey-green shale which occur interbedded with the arenaceous sediments suggest frequent oscillations in the sea level. Volcanic activity is indicated by the agglomerate bands and pyroclastic material. Whether this is associated with the porphyrites or whether it is a persistence from the older Storen greenstones cannot be determined. Current directions in the current bedded sandstones suggests, allowing for the folding as far as possible, derivation from the N.E. but this is not reliable as it depends only on a handful of observations.

The sediments of the Banded Shales and Sandstones represent a distinctly different environment from that outlined above and are suggested as being deposited within a geosyncline. Such deposits are described by O.T.Jones (1938)in the following way: "The arenaceous and argillaceous constituents are intimately mingled, so that sandstones are either muddy sandstones or have a considerable proportion of finely divided chlorite and muscovite disseminated through them, giving rise to grey or green rocks. Many of the mudstones are ....sandy mudstones; abundant grains of quartz are associated with fine muds or silts, and some are of considerable size". He then goes on to say that the bedding is uniform and usually well marked, sometimes with an appearance of rhythmic deposition. It is further stated that graded bedded sandstones occur in assocation with grey or greenish mudstones; coarser particles in the sediments being frequently very angular and organic remains being sparse throughout great thicknesses of the deposits.

All the features outlined in the above extract can equally well be applied to the group under discussion. Other features are also mentioned in the same paper some of which do not apply to the sediments in my area e.g. no slump structures were observed; this does not, however, invalidate the other evidence supporting their geosynclinal environment. The rapid, rather rhythmical, alternation of thin bands of sandstone with the shales still remains unexplained and perhaps two alterntive explanations are possible. Either the shale and sandstone bands each represent one of two rhythmically alternating sets of conditions or they represnt two distinct rates of settling from suspension. In the latter case large volumes of suspended material would need to be transported into the geosyncline where the coarser material would settle out at a faster rate leaving the finer material in suspension for a longer period. Since grading, although present, is not particularly obvious it may be suggested that there was an incomplete range in the sizes of the suspended particles and that two discreet size ranges were present. This would then explain the poorly developed grading in the sandstone bands only, instead of the 2 units (shale and sandstone) being represented by one completely graded unit with all intermediate grain sizes present e.g. if the original composition were:-

Original sediment completely mixed = 30% of total in range 20-30units diam.
70% " " " " 1-5 units diam.

ON settling such a mixture would give first of all a bed composed of grains ranging from 20 to 30 units mean diameter with some gradation from coarse at the base to finer at the top. Assuming a uniform rate of settling there would then be a pause in deposition before the finer material settled out giving abed in which grading cannot be detected .

This hypothesis is regarded as the most probable explanation of the grading in the sandstones and they are regarded as being greywackes, despite the lack of slump structures, since they so closely correspond to the descriptions of these rocks in the literature.

Carbonate is abundant in these rocks (apart from the limestone beds) and it seems from the fine grained habit of this material that it represents a fine calcareous mud possibly of precipitated origin. The occurence of pyrrhotite grains seen on the bedding planes of the shales and sandstones, and also the limestones would seemto indicate reducing conditions and stagnant bottom waters saturated with H_2S. This gas may possibly be the product of bacterial action. M.Black(1933) has described the precipitation of calcium carbonate by sulphate-reducing bacteria,in swamp waters of the Bahamas, with the production of large volumes of hydrogen sulphide.

$$CaSO_4 + 8H = CaS + 4H_2O.$$

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S.$$

Such a series of reactions cannot be proved to have occured in the depositiom of the sediments in my area but they illustrate how carbonate and possibly pyrrhotite (iron+hydrogen sulphide) could be produced under similar conditions to each other. This does of course assume an abundant supply of calcium sulphate the source of which is unknown.

The Porphyrites

These porphyritic igneous rocks occur, so far as can be determined, in sheet-like masses at various levels throughout the succession so far described. Their relationship to the sedimentary succession is a difficult problem to solve. Their occurence at such a variety of horizons could be taken as supporting an intrusive mode of origin , it seems, however, that some masses are probably extrusive in their origin whilst others are almost certainly intrusive in character. The evidence for this statement will be given in the following pages.

The margins of the porphyrites are in nearly all cases perfectly concordant with the bedding in the sediments (see plates 23 &24). One remarkable exeption to this was observed at the margin of a small mass near Björkjenaasen at locality 145 (see plates 25 & 25a). At this particular exposure an intrusive character seems undeniable, however this does not mean that all the porphyrites must be intrusive.

An interesting point is that the porphyrites are much more commonly observed in contact with the Banded Shales and Sandstones than with the Purple Breccias. If one were to suppose that they were extrusive lavas then of necessity they must have some intrusive representitives which fed the lava flows and which would be found at lower stratigraphical levels. It seems quite feasible that these feeders could also have concordant intrusions associated with them whilst they themselves would be either dykes or plug- like intrusions. This explanation does, for the most part, fit the facts as observed in the field.

In all cases the sediments above and below the porphyrites show little, if any, signs of contact metamorphism. Similarly the porphyrites show no sign of chilled margins. Such evidence could be used to support an extrusive mode of origin but it would be far from conclusive.

It was frequently observed that the basal contacts were cut by small, reverse faults (see plate 23) usually spaced at rather regular intervals of afew meters. This seems to suggest some sort of stress in the country rocks, there is no veining along the fault planes by the porphyrite suggesting that they were formed after solidification and possibly as a result of contraction of the porphyrite due to cooling. In a number of instances xenoliths of the country rock were seen completely enclosed in the porphyrite, some of these xenoliths were 3 m. or more in length still having a similar orientation to the bedding in the country rocks. More usually these xenoliths were of a smaller size showing slight signs of having been baked. Such evidence is perhaps suggestive of the porphyrites being intrusive in character. The large xenoliths could hardly be interpreted in any other way since they are not confined to the basal portions of the sheets.

The occurence of fragments of porphyrite in the Blue Grey Limestone has already been mentioned; together with the tuff bands in the shales, at locality 209 and elsewhere, this strongly suggests an extrusive mode of origin associated with pyroclastic material.

In only two cases was any sign of banding or layering observed (see plate 27 & fig. 8). Near Ellingsvatnet at locality 68 alternating light and dark, greenish grey bands were seen. These may either be a product of some sort of differentiation within the sheet, or they may represent flow structures of some description. Unfortunately, due to the smoothness of the exposed surface, no specimens could be obtained which were not too strongly weathered to be of use for making thin sections. The second case was also near Ellingsvatnet at locality 72, here banding, or perhaps a better word would be layering, was seen to be distorted by movement along a small joint plane (see plate 27). In this case the porphyrite appeared to be homogenous throughout, both in colour and in texture. In this particular case it may well be that the layers are solely the result of stresses, either tectonic or as a result of cooling.

Although the porphyrites generally show no signs of any layering (see plate 28) one quite commonly sees small scale, localised variations either in the form of veins or in patchy areas (see plates 29 & 30). These occurences suggest that one later stage liquid was injected into an older one which had already solidified.

I would therefore suggest that the porphyrites are both intrusive and extrusive in origin, and that no one mode of origin will explain all the field relationships.

Such evidence as there is is insufficient to allow all the extruded types to be distinguished from all those which are intrusive in their origin and therefore on the map they must all be represented as of one type.

According to Vogt two distinct types of porphyrite occur in his area which he has termed theBerg and Ålmas types. From his descriptions it appears that the mineralogy is almost identical in each, but the Berg type is a normal andesite whilst the Ålmas type is more basic in composition being "transitional between basalt and andesite". The main distiction between the two types,apart from their chemical compositions, seems to be "the much more crowed phenocrysts of albite and altered pyroxene" in the Ålmas type.

Within the area south of Gåsbakken it seems that all the porphyrite is of one type with the exeption of one small body which stands up as a prominent hill near Gåsbakken to the south of the road bridge over the river Skolda. This particular mass will be described in due course. Other than the exeption mentioned the remainder of the porphyrites are all very similar in appearance although minor variations are present as regards coarseness andto a certain extent colour also. All are seen to have white or pale green grey phenocrysts usually between 0.5cms and 1,0cms. in length, with a tabular shape. These phenocrysts are seen to be randomly oriented in a medium to dark grey, fine grained, groundmass which is commonly weathered to a pale grey or buff colour so that the phenocrysts are less obvious than they otherwise would be.

Thin sections have been made of specimens taken from four localities 81, 34, 127 & 104. The last of these is of a clearly distinct type and will be described after the others.

Specimen 81 was collected from the porphyrite ridge which runs in a N.W.-S.E. direction between Skogstad lake and Björkjenaasen farm. The specimen is taken from an exposure approx 15m. from the margin of the sheet near locality 81(see plates 29 & 30). In thin section the phenocrysts are seen to be of felspar which is now almost totally broken down into a fine grained mass of sericite, epidote and clino-zoisite together with minute prisms of apatite which are probably original. Occasionally moderate sized remnants of the felspar are preserved, these have been determined as albite plagioclase from the symmetrical extinction angles of their twin lammellae and from their axial angle as observed on the universal stage. It is thought that the albite is secondary and that the plagioclase was originally of a more calcic type.

All these 'ghost' phenocrysts are quite large and closely spaced in the groundmass (see figs. 5 & 9). Phenocrysts of pyroxene are also present and these are unusually well preserved in comparison to the plagioclase which one usually imagines as having greater metastability than pyroxene. In this section one pyroxene of quite large dimensions is seen being polysynthetically twinned and having the characteristic large extinction angle. It is not entirely free from breakdown products, around its margins and along fractures and cleavages, it is seen to be in the process of being replaced by a thin inner coating of pale green almost colourless amphibole and successively by an equally thin outer rim of green chlorite. The pyroxene has been identified as augite, the amphibole as hornblende and the chlorite as penninite (?) on the universal stage. Other smaller phenocrysts of sphene are also quite common which due to their high dispersion do not extinguish under crossed nicols. Small phenocrysts of epidote and more rarely clinozoisite are also to be observed in small numbers, which are here interpreted as products of the regional metamorphism. All these phenocrysts are embedded in a fine grained groundmass composed, as far as it is possible to determine, of albite, sericite, epidote, ore minerals (magnetite and ilmenite ?), chlorite and quartz. Thin veinlets of quartz cut the rock in aparallel fashion and some minute needle-like aggregates of colourless amphibole are also seen in the groundmass.

A section was also made of a specimen from locality 127 near the margin of the porphyrite N.W. of Björkjenaasen farm. In hand specimen the rock was very similar to specimen 81 but having vesicles and not being so abundant in phenocrysts. Under the microscope the rock is seen to be remarkably rich small idiomorphic epidotes. The plagioclase phenocrysts are even more strongly replaced than in the section previously described and very few remnants are present. Around the replaced plagioclases thin mantles of a brown, weakly pleochroic mineral occur. This mineral appears to be fine grained stilpnomelane, very similar in its optical properties to biotite but with brighter, more golden birefringence colours. Irregular patches of calcite are present and also sphenes, ore minerals and some chlorite, but unlike the previous section pyroxenes and amphiboles are not observed.

The third thin section was made of a specimen taken from locality 34, approx. 1m. from the margin of the porphyrite. In the field the weathered rock appears almost like a conglomerate. This is due to the presence of amygdales which appear at first sight to be small rounded pebbles. On closer examination , however, phenocrysts of felspar are also observed indicating that the rock is in fact porphyrite. One particularly large amygdale was 5cms. across surrounded by a zone of bleached rock approx. 2cms. wide. Usually the amygdales were no more than 1 or 2cms. in diameter. At the margin dark grey shales and sandstones dip steeply under the porphyrite.

In thin section the rock is very similar to section 81 but the plagioclases are not quite so large. These plagioclases, as before, are strongly replaced by fine grained epidotes, sericite and rare clinozoisites and remnants have been identified as albite (An10 approx.). In most cases the plagioclase phenocrysts have a thin mantle of fine grained radiating aggregates of light brown coloured stilpnomelane. This mineral and the epidotes are regarded as metamorphic products. Small phencrysts of sphene are also present as well as a few augites and rare small hornblendes. The groundmass is very fine grained and made up of albite, chlorite, epidote, quartz and small quantities of pyroxene. The chlorite is penninite, showing anomalous, ultra-blue, birefringence colours under crossed nicols. The augites were identified with the help of the universal stage which revealed the axial angle as approx. 60 degrees therefore they could not be pigeonite as Vogt has suggested they might be. It is interesting to compare the chemical formulae of augite and penninite, to which the augite is being broken down. This comparison gives one an idea of the chemical change involved in the replacement of the former by the latter. (see fig. 5)

Augite:- $Ca(Mg,Fe)(SiO_3)_2.(Al,Fe_2O_3)x$

Penninite:- $Mg_5(Al,Fe)(OH)_8\ (Al,Si)_4\ O_{10}$

Thus the change from augite to penninite requires the expulsion of Ca and a little Fe and SiO_2, and the addition of a little OH. The elements expelled could well be accounted for by the presence of epidote ($Ca_2(Al,Fe)_3.(SiO_4)_3.(OH)$) and clinozoisite($Ca_2,Al_3(SiO_4)_3,(OH)$). This need not necessarily be the process by which the epidotes were formed.

The amygdales, seen in the hand specimen, when they are observed under the microscope, can be seen to be of two distinct types. The first type are filled with granular quartz which is commonly coarser grained in the centre of the amygdales than around their margins. The second type are perhaps more interesting as they are filled with cloudy hypidiomorphic crystals of axinite many of which were arranged parallel to the margins of the amygdales. The mineral posed some difficulty in accurate identification by optical methods. In order to make a definite identification an X-ray photograph had to be taken. This photo was then compared with another photo of some axinite from Queensland, Australia. The two photos compared favourably with each other and this confirmed the suspicion beyond doubt. Two grains of axinite were also identified in the groundmass away from the amygdales. Some small quartz veinlets cut the rock in parallel arrangement and probably represent the infillings of minute tension gashes. These were too small to be noticed in the field and thus their orientation is unknown and cannot be compared with larger structures in the area.

In the three thin sections so far described both the mineralogy and the textures are very similar in each. All three are regarded as corresponding to Vogt's Berg type porphyrite.

The last thin section is of a specimen of porphyrite from locality 104. In hand specimen the rock is seen to be strongly porphyritic with the phenocrysts very closely packed. The overall colour of the rock is greyish brown. In thin section (see fig. 13) the bulk of the rock is seen to be made up of large, interpenetrating, phenocrysts of plagioclase felspar (An10 approx.). In contrast to the felspar in thin sections so far described the plagioclase in this case is only weakly altered. Some show weak zoning but most are of apparently homogeneous composition. The section also shows beautiful radiating aggregates of tabular stilpnomelane cryatals showing bright golden brown birefringence colours but otherwise very similar to biotite in appearance. Penninite is present filling in the interstices between the plagioclases. Augite is also present in small phenocrysts usually surrounded by a thin rim of penninite, and more rarely small aggregates of acicular hornblende are observed. Other minerals are pale green, weakly pleochroic epidotes in small idiomorphic and hypidiomorphic crystals, and also sphenes, and small amounts of quartz, apatite, axinite and ore minerals.

As can be seen, from the description and a comparison of figs. 9 and 12 with fig. 13, this last porphyrite is of a distinctly different type. It is thought that this type corresponds to the Almas type porphyrite as described by Vogt in 1945. Chemical analyses are at present being carried out on each of the two types by D.H. Blake. One analysis is being made of a specimen from locality 104 (the Almas type) and the other of a specimen taken locality 75 (the Berg type). It is hoped that the results will be included before this report is completed.

Chemical analyses of two porphyrites

The chemical analyses as given here are recalculated to give the norm also . It is interesting to compare the results with those published by T. Vogt and which have been reproduced from his publication so as to afford an easy comparison. Perhaps the most striking difference between the two specimens from my area is the albite/anorthite ratios of the two rocks. The other big difference is the diopside/hypersthene ratio in the one as compared to the other.

If one totals the amounts of diopside to that of hedenbergite and lets this total equal the same amount of diopside only, and if one similarly lets the total of enstatite and ferrosilite equal hypersthene: in Vogt's Norms, then one gets a similar difference in the diopside/hypersthene ratio of his Ålmas type as compared to his Berg type. In both cases, however, the value for hypersthene is greater than that for diopside. In specimens 75 & 104 this is not the case; in one the hypersthene is more abundant than the diopside (no.104) and in the other (no. 75) the reverse is true.

In Vogt's Berg type, albite is more abundant than anorthite;this is also the case in specimen 104 suggesting that this too might be of the Berg type. Such a suggestion is, however, completely against the petrographic description given previously, when it was suggested that specimen 104 was of the Ålmas type since it differed from all other porphyrites in the much more closely crowded plagioclase phenocrysts which Vogt described as being characteristic of the Ålmas type.

It would seem that more analyses are required before the classification of the porphyrites into two types can be made. It may be that the porphyrite from locality 104 has undergone albitization in which case the analysis would not be a true representation of the origional composition of the rock. Albitization would cause an increase in the soda content and hence more albite to be present in the norm than would be the case in the non albitized rock.

Chemical Analyses of two Porphyrite specimens.

Specimen 75. (Berg type ?)

SiO_2	49.9 WT.%	0.832 Mol.%
Al_2O_3	19.14	0.118
Fe_2O_3	4.70	0.029
FeO	3.44	0.048
MgO	4.63	0.116
CaO	9.57	0.171
Na_2O	3.54	0.057
K_2O	1.71	0.018
H_2O+	2.73	
H_2O-	0.04	
TiO_2	0.64	0.008
P_2O_5	0.44	0.003
MnO	0.11	0.002
Total	100.59	

Norm.

Orthoclase	10.07%
Albite	29.91
Anorthite	31.50
Diopside	10.59
Hypersthene	3. 68
Olivine	2.95
Magnetite	6.76
Ilmenite	1.25
Apatite	1.04
Water	2.77
Total	100.52

Specimen 104. (Almas type ?)

SiO_2	54.10 Wt. %	0.902 Mol%
Al_2O_3	16.82	0.165
Fe_2O_3	5.39	0.034
FeO	3.62	0.050
MgO	3.09	0.077
CaO	3.91	0.070
Na_2O	6.16	0.100
K_2O	1.14	0.012
H_2O+	3.52	
H_2O-	0.37	
TiO_2	1.41	0.018
P_2O_5	0.70	0.005
MnO	0.18	0.003

Norm .

Quartz	2.64%
Orthoclase	6.67
Albite	51.68
Anorthite	14.32
Diopside	0.41
Hypersthene	9.79
Magnetite	7.35
Ilmenite	2.67
Apatite	1.58
Water	3.89
Total	101.00

Chemical Analyses, as given by Vogt, of the two types of porphyrite in his area, the first is the Almas type and the second the Berg type.

	Wt %
SiO_2	53.46
TiO_2	0.90
ZrO_2	0.03
Al_2O_3	17.00
Fe_2O_3	2.04
FeO	6.11
MnO	0.13
MgO	4.87
CaO	8.71
BaO	0.04
Na_2O	3.16
K_2O	1.73
P_2O_5	0.31
S	0.01
CO_2	nil
H_2O+	1.42
H_2O-	0.08
	100.00

Norm

Quartz........	2.66 %
Orthoclase....	10.24
Celsian.......	0.11
Albite........	26.74
Anorthite.....	27.01
Diopside......	7.25
Hedenbergite..	4.31
Enstatite.....	8.76
Ferrosilite...	5.97
Magnetite.....	2.96
Ilmenite......	1.71
Zircon........	0.04
Apatite.......	0.72
Pyrite........	0.02
H_2O..........	1.50
	100.00 %

ALMAS TYPE HOLONDA PORPHYRITE
C.I.P.W. classification- Hessose.

	Wt. %
SiO_2	53.90
TiO_2	1.10
ZrO_2	0.03
Al_2O_3	19.14
Fe_2O_3	2.02
FeO	4.74
MnO	0.14
MgO	3.58
CaO	6.71
BaO	0.04
Na_2O	4.68
K_2O	1.26
P_2O_5	0.49
S	0.04
CO_2	0.17
H_2O+	2.31
H_2O-	0.07
	100.24

Norm

Quartz........	2.06 %
Orthoclase....	7.46
Celsian.......	0.10
Albite........	39.59
Anorthite.. ..	27.42
Diopside......	0.85
Hedenbergite..	0.40
Enstatite.....	8.52
Ferrosilite...	4.72
Magnetite.....	2.93
Ilmenite......	2.33
Zircon........	0.04
Apatite.......	1.14
Pyrite........	0.08
Calcite.......	0.39
H_2O..........	2.20
	100.23 %

BERG TYPE HOLONDA PORPHYRITE
C.I.P.W. classification- Andose

Superficial Deposits

The superficial deposits can be grouped into three main types:-

(1) Glacial deposits

(2) Peat deposits

(3) Alluvial deposits

(1) The glacial deposits were best seen near Skogstad lake where the land had been stripped of vegetation prior to drainage and cultivation (see plate 31). Here one sees a wide area of large and small boulders sitting in a grey brown sandy soil. The boulders are of a variety of rock types including granite(trondhjemite), gneiss, and many of the rocks which have been described as occuring in situ in the area. Many of the boulders bear glacial striations on them, usually these are made of sedimentary material and the igneous rock types are generally, not always without such striations. Most of the boulders are angular or sub-angular in shape.

Something has already been said about the direction of glacial movements but the evidence of glaciation is given here. Only on six occasions were well pronounced glacial striations observed on rocks which were definitely in situ and in all cases the rock were grits or sandstones of the Purple Breccia group(see plates 32 & 33). Readings on the orientation of these grooves and striae are remarkably constant in direction being between 310° and 325° mag.N. This is closely similar to the orientation of many of the valleys and elongate hollows. Since many of the ridges have their steepest faces at their S.E. ends one can suggest that this is a reflection of the sense of movement of the glaciers i.e. from S.E to N.W. It is also suggested that the ice sheets completely covered the whole area, with no rocks piercing its cover. This is due to the large erratic blocks which can be observed sitting on the tops of most of the ridges at high elevations. (see plate 34).

(2) Peat bogs are numerous over the area and are usually seen filling in flat bottomed valleys and depressions. They have probably been built up on the sites of pre-existing lakes which it is thought must have existed in the hollows produced during the glaciation and some of which were probably partially filled with glacial deposits.

(3) The alluvial deposits of the area were best exposed in a small pit near the mouth of the small river which runs into Ellingsvatnet. In these deposits bands of current bedded sands and grits were seen interbedded with coarser band of pebbly grits, all having a grey brown colour. One may here draw an analogy with some of the beds in the Purple Breccias although the alluvial deposits have no purple colour. The material in the coarser beds is seen to be of great variety and some has obviously been derived from nearby glacial deposits. Other similar deposits are seen along the banks of the river Skolda and other smaller streams in the area. They are always built up on wider areas of glacial material or peat bog.

Structural Geology

A full elucidation of the structure is very hard to make. This is due to the difficulty in obtaining sufficient data regarding the plunges of minor folds and lineations, and dips of schistosity planes, owing to the poor exposure.

Bedding dips throughout the area are generally high and very variable in orientation. In a few cases in the E. & S.E. the dips of beds fall as low as 37 degrees. Sedimentary structures and cleavage/bedding relationships have proved invaluable as way-up criteria.

The area has been subjected to two phases of folding at least. The first phase has folded the beds into a series of tight almost isoclinal anticlines and synclines with steeply inclined axial planes. A younger phase has since folded the axial planes of the first phase into more open, asymetric structures whose axial planes are almost at right angles to the probable, original orientation of those of phase 1. It should be pointed out that the minor structures used to make this interpretation have been regarded as being approx. conformable to the major structures; always bearing in mind that two phases of folding have occured causing many of the linear structures (and also the planar structures) to be inconsistent in their orientation.

Faulting, either associated with or younger than the second phase, confuses the picture somewhat and probably many more faults exist than have been indicated on the map. Indeed very few faults were exposed to view and had to be placed on the map to explain shifts in the stratigraphical boundaries.

Minor folds and lineations are best preserved in the dark grey shales (see plates 38 to 42 inclusive) less frequently similar structures are to be seen in purple sandstones and grits (plates 4 & 13 and fig. 11). About 20 readings were obtained of linear structures (see figs. 15 & 16) and these have been plotted as apoint diagram on a stereo-net(see fig 19). Whilst there is some scatter between these points one will note that they nearly all lie in the N.W. quadrant indicating structures plunging in this direction. Owing to the scatter it remains impossible to locate the true position of the axis of the folding but one can suggest that it probably plunges fairly steeply in a N.W. direction. This direction is regarded as that of the second phase fold axes.

A π-pole diagram has also been produced of bedding dips throughout the whole area (see fig. 20). On this diagram a broad crescentic zone of concentration is observed around the E. & S.E. margins This zone is regarded as being approx. perpendicular to the axis of the second phase of folding which must therefore plunge fairly steeply in a W.N.W. direction. Such a direction approx. corresponds to that indicated by previous plot of the linear structures. Two other less conspicuous and smaller concentrations are also indicated on the same diagram, one in the N.W. quadrant and the other in the S.W. quadrant. These are thought to represent the dominant directions into which the non- overturned portions of the inverted limbs of the first phase folds have been oriented by the second phase of folding (see fig. 17)

A third stereogram has been produced of the poles of cleavages over the area. Readings from 30 localities have been plotted, in most cases the cleavage being oblique to the bedding (see plates 19 &39). The diagram illustrates a wide scatter of cleavage poles with no concentrations apparent. To support the case for two phases of folding these poles should lie on three great circles,in theory at least. In practice these great circles can be drawn in, only very approx. and on the diagram are not meant to represent the actual directions but are merely drawn to indicate the required form. Even so, the poles of these great circles do bear some resemblance to the results obtained with the previous two diagrams.

Other plots were made within localised areas in an attempt to fix the fold axes with more certainty but the results obtained were once again inconsistent and merely supported the approx. orientations already outlined.

Although joints are well developed in the area and are more commonly observed than any other structures, they are practically without value for elucidation purposes as they are so inconsistent in their orientation even in small localised areas.

Shear zones were observed in the porphyrite on a few occasions but one cannot be certain whether these are related to the folding or perhaps to stresses associated with intrusion of the porphyrite.

Shearing of purple and green grits and breccias was also seen, the shear planes and elongated grains usually being parallel to the bedding (see plate 15).

The orientation of major faults as indicated on the map could be related to the second phase of folding. Most of the faults appear to have both a tear movement and a vertical displacement. The direction of sideways displacement indicates that they are dextral in type. It is from such evidence that one may suggest that the directions of the principle pressures producing the second phase folds and the tear faults are closely related (see fig. 18).

My general interpretation of the structure as a whole is given by figure 14.

The folds are thought to have been produced in the Caledonian orogeny following the infilling of the lower Palaeozoic geosyncline. The first phase folds are Caledonian in trend (generally N.E.to S.W.) and they are overturned to the S.E., their axial planes in general dipping to the N.W. This indicates that the main movement due to the orogenic pressures was from the N.W. tothe S.E. that is towards the Scandinavian platform and away from the axis of the geosyncline. The second phase of folds may be a slightly younger product of the same orogeny or be completely unrelated to it. The second alternative is regarded as unlikely as it is well established that more than one disturbance affected this part of Norway within the Caledonian orogeny.

The Metamorphism.

As mentioned in the introduction to the stratigraphy (page 5) the area has suffered some regional metamorphism. All the rocks throughout the succession have been affected by this metamorphism which must therefore be post-Llanvirnian(?) in age. The grade of the metamorphism is, so far as can be seen, low and uniform over the whole of the area and belonging to the greenschist facies as originally defined by Eskola. In this area the facies is characterised by the following minerals: quartz, epidote, chlorite, calcite, albite and stilpnomelane (the last only occuring in the porphyrites). This is a rather similar assemblage to that of the greenschists of Otago, New Zealand as described by C.O. Hutton and D.S.Coombs where stilpnomelane is also characteristic.

The rare occurence of axinite in some of the porphyrites is not regarded as a regional metamorphic product but rather as contact metasomatism due to contamination near the margins by calcareous shales.

There is no indication of any increase or decrease in grade in any direction across the area.

Whether the metamorphism can be related to the folding can hardly be determined without a more detailed inspection of the area. However it seems that it is younger than the first phase of folding at least. This is stated as a result of observations of epidotes in some of the thin sections which appear to have grown after folding of the sediments.

Acknowledgements.

First of all I like would to express my grateful thanks to the Orkla Grube Aktiebolag of Lokken and in particular to Herr Sandvik for the invaluable help which made this mapping possible and for the kind hospitality received during the visit.

Two days were spent in the field in the company of Professor T. Strand of Oslo University and I would like to express my thanks to Professor Strand and to Herr Sagvold of the Orkla Grube for this introduction to the area. I am also indebted to Herr Nœve of the Orkla Grube for the hire of his wonderful cabin in which we were accomodated, and to his brother Herr O.Nœve and his family for their every kindness.

During our visit we were also priveleged to meet Herr and Fru Ingvaldsen, Herr Smith and Herr Thams, and I would like to take this opportunity to thank them all for their kindness and hospitality.

I am also indebted to Mr. R. Curtis for his X-ray identification of the Axinite in specimen 34, and to Mr. D.H. Blake for chemical analyses of two porphyrite specimens.

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Plate 2. A view of the glaciated valley which runs S.E. from Lillenæve, showing a steep sided porphyrite ridge on the right and two small hillocks of white limestone on the left.

Plate 3. A view from the ridge above Lillenæve showing the peneplained landscape in the background.

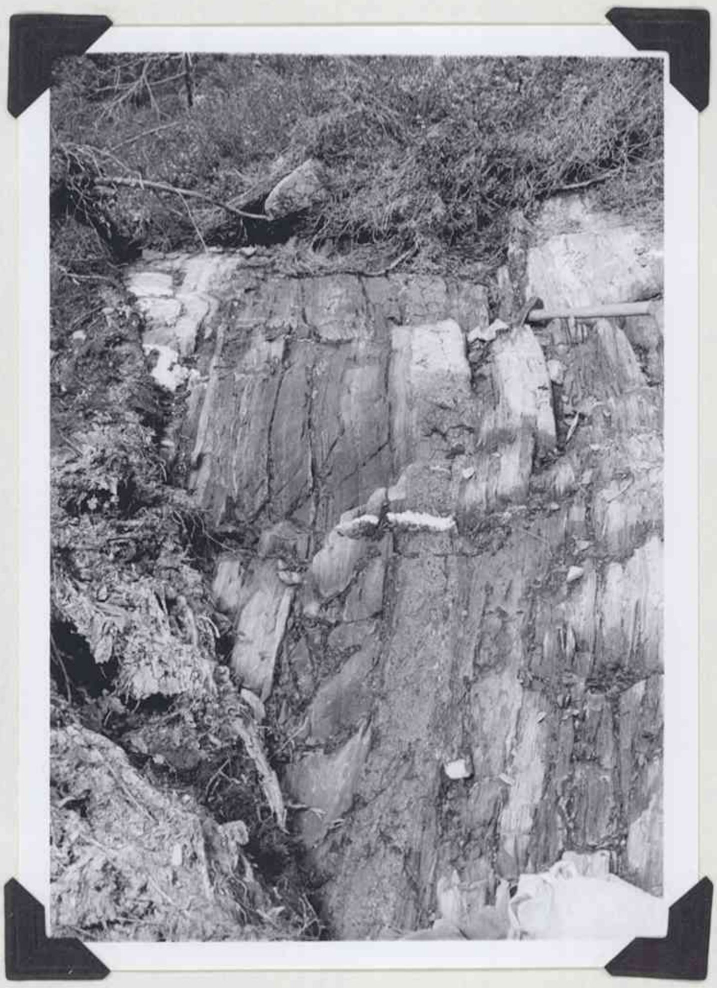


Plate 4. Well bedded purple sandstones, grits and breccias at locality 175. The beds show a minor plication in the top left portion of the exposure.

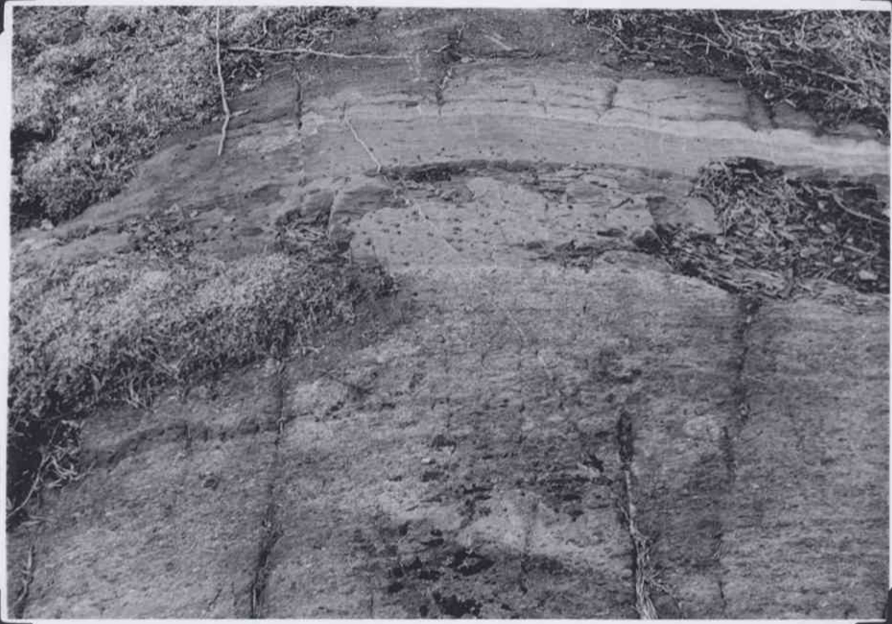


Plate 5. Quartz veined joints in sandstones, grits and breccias of the Purple Breccia Series, seen at locality 148.

Plate 6. Current bedding in purple sandstones, best seen at the point of the hammer and to the right of the shaft of the hammer (locality 141).

Plate 7. Coarse purple breccia rich in fragments of whitish grey limestone,and jasper (locality 151).

Plate 8. Coarse purple breccia made up of fragments of-grits, sandstones and shales of a variety of colours; of volcanic rocks, jasper and limestone. The photo was taken 100m E. of locality 152.

Plate 9. Graded bedding, from breccia at the base to sandstone at the top, in green and purple sediments at locality 226. The dip is away from the camera hence the beds are the right way up.

Plate 10. Coarse purple breccia rich in fragments of jasper and limestone. The rocks are exposed at locality 153 and are seen to be somewhat sheared.

Plate 11. A roadside exposure of agglomerate to the south of Nordlien near locality 80.

Plate 12. Agglomerates exposed at locality 122, the dip is approx. parallel to the shaft of the hammer.

Plate 13. Quatrz veined tension gashes in green and purple grits and sandstones at locality 101. A matchbox gives the scale.

Plate 13a. Beds of green and purple sandstone standing up in the bed of a small stream at locality 191.

Plate 14. Well displayed current bedding in coarse green sandstones and grits, the base of each foreset bed is outlined in purple obviating the nature of the bedding. Note the truncated bottoms and the asymtotic tops which indicate that the beds are inverted. See also fig. 3.

Plate 15. Sheared breccias with fragments of various kinds of rock, of which limestone is the most common, embedded in a green gritty matrix. Photo takem at locality 110 a matchbox gives the scale.

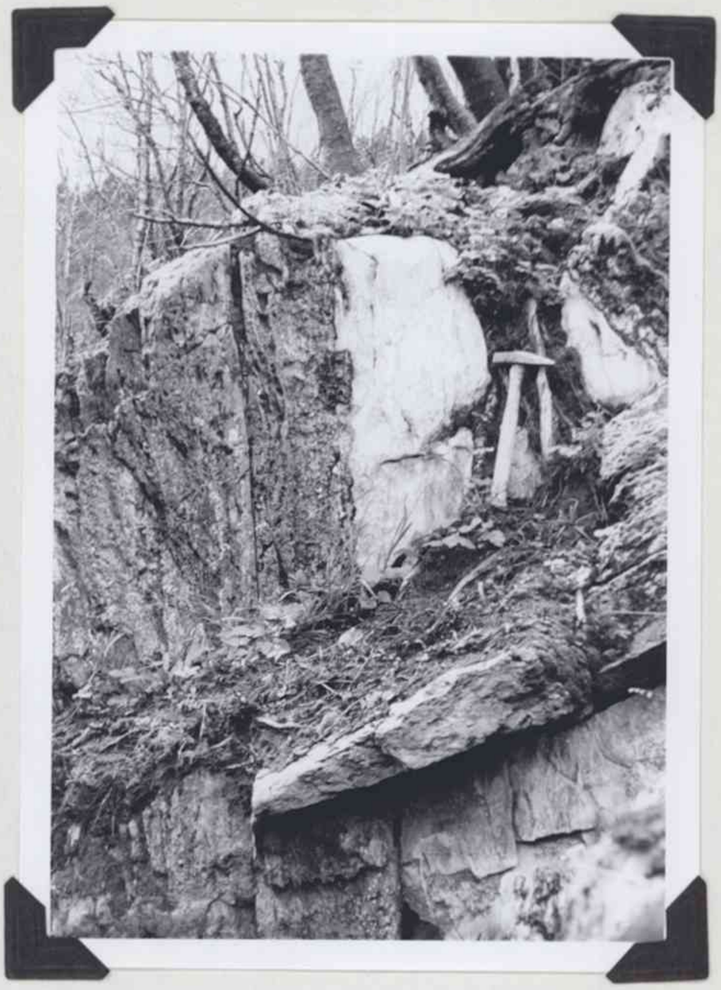


Plate 16. A thin bed of pure white limestone interbedded with coarse green grits and breccias containing fragments of this same limestone (locality 110 -10m.west).

Plate 17. Loose undulating folds in grey green shales at locality 82 near the farm of Bjorkenaasen.

Plate 17a. Grey shales overturned by surface creep at locality 131 near Bjorkenaasen.

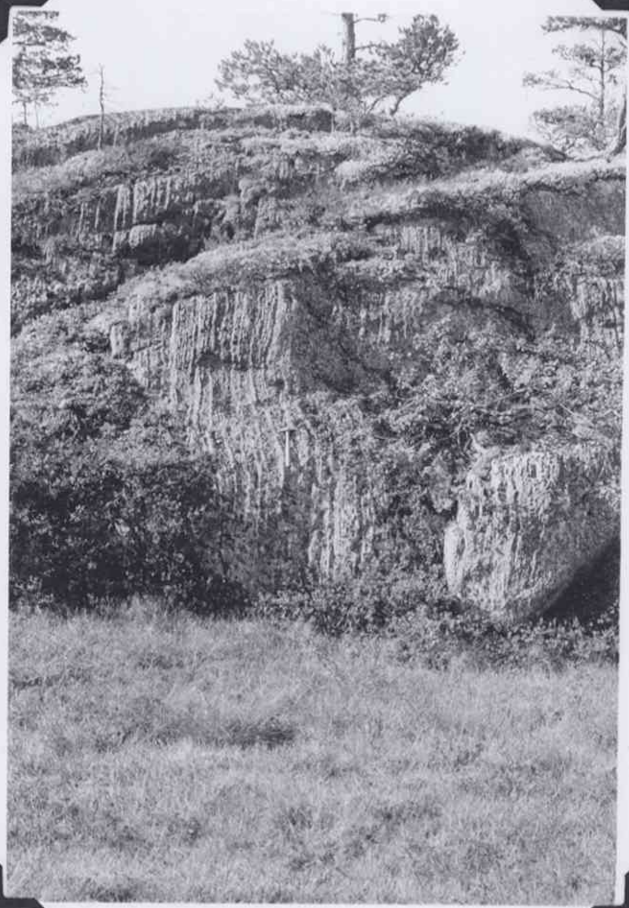


Plate 18. Nearly vertical beds of the Banded Shales and Sandstones as seen to the south of locality 162.

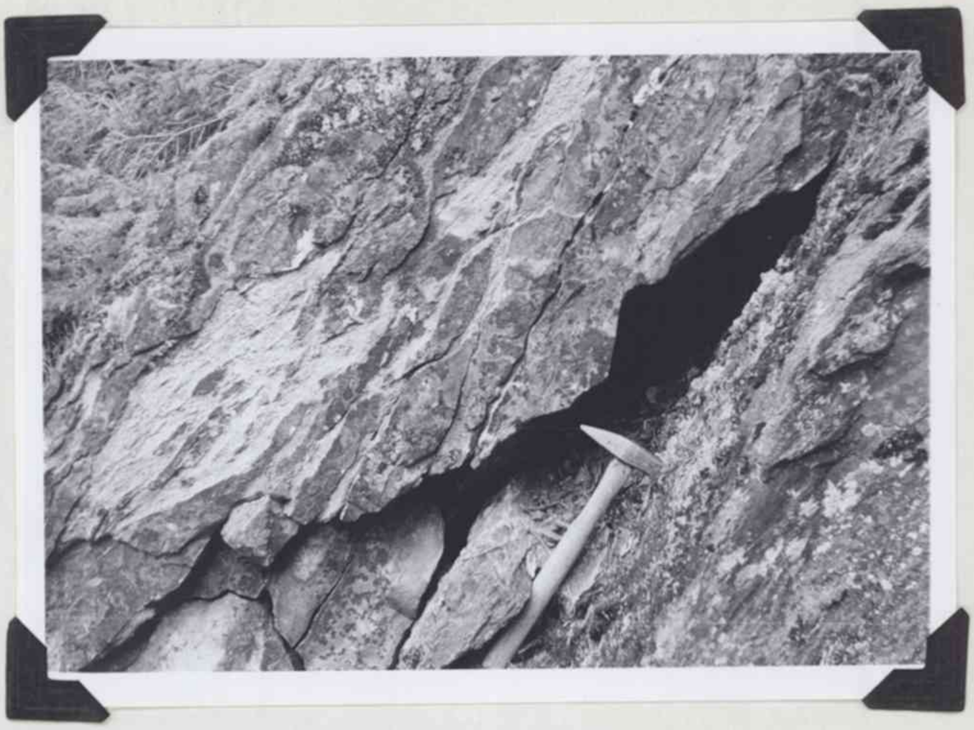


Plate 19. Cleavage/bedding relationship in grey shales and sandstones, as one can see the beds are dipping le steeply than the cleavage which suggests that they are inv erted.

Plate 20. Green grey shales and sandstones with slightly undulated bedding exposed 30m. N.E. of locality 228.

Plate 21. Banded Shales and Sandstones cut by a small fault and showing signs of brecciation. Note the almost boudinaged form of some of the sandstone bands best seen to the left of the hammer.

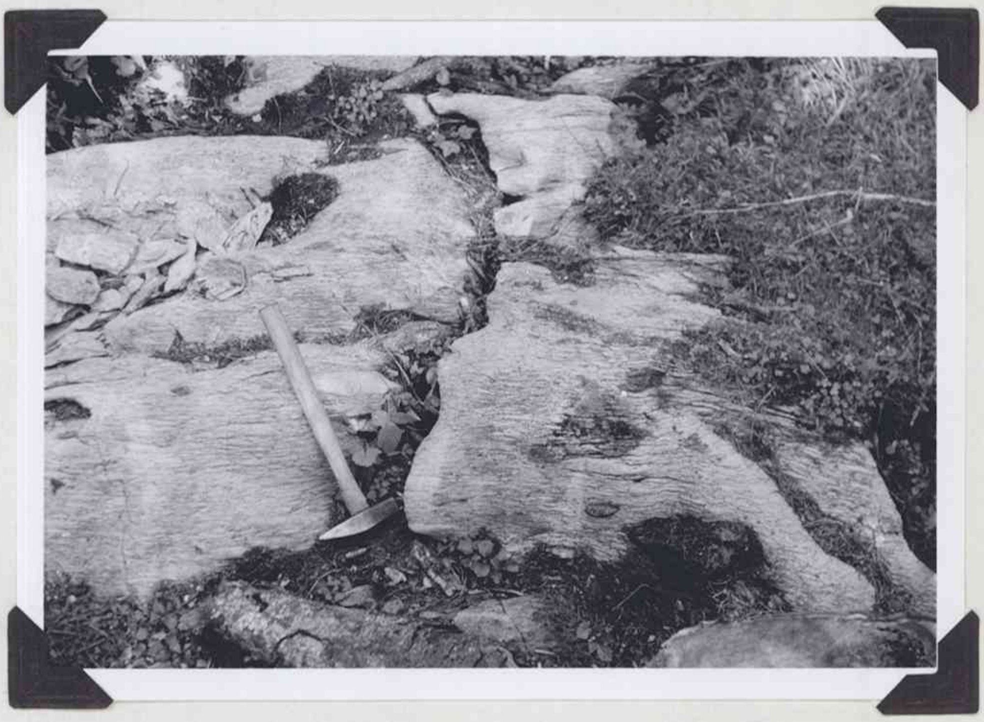


Plate 22. Fragments of porphyrite in the Blue Grey Limestone at locality 117. Note also the brecciated appearance of the limestone.

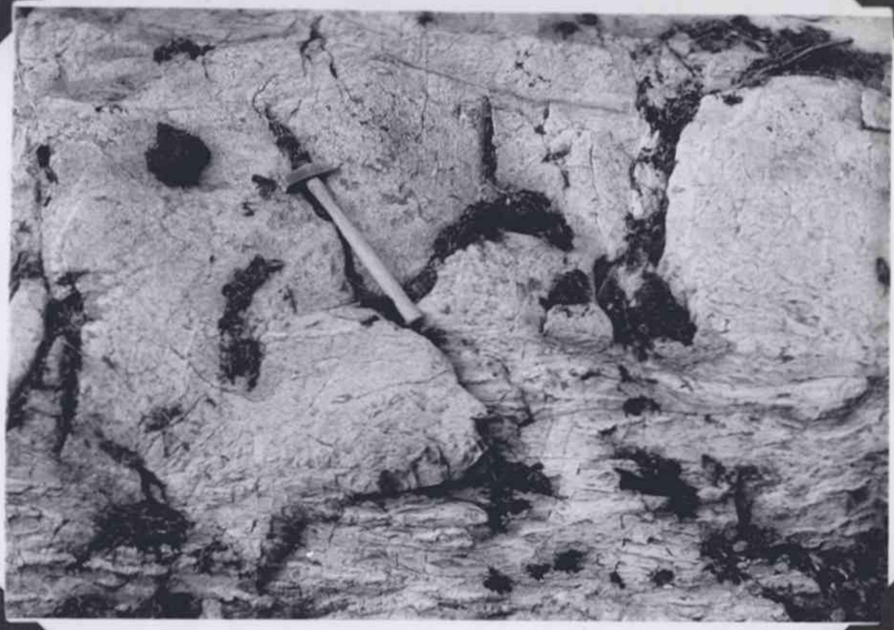


Plate 23. Contact of the porphyrite with the Banded Shales and Sandstones at locality 211. The contact is cut by a small reverse fault and the sediments show signs of being brecciated and slightly baked.

Plate 24. A less well exposed contact of the same porphyrite with the same sediments as in plate 23.

Plate 25. A close-up of porphyrite in contact with strongly contorted shales. These contortions are thought to be a result of the intrusion of the porphyrite into the shales since they are only contorted around the margin of the porphyrite.

Plate 25a. The same contact as in plate 25 but showing a greater field of view. The contact is seen to be bounded by a thick vein of quartz.

Plate 26.

Plate 27. Layers in porphyrite folded, it seems, as a result of movement along the joint plane.

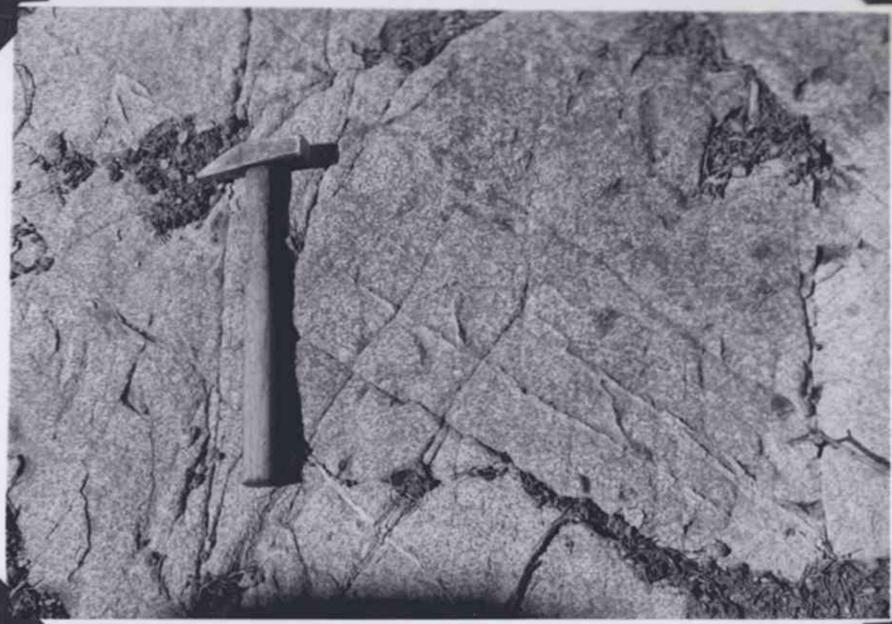


Plate 28. Well jointed porphyrite at locality 289.

Plate 29. Porphyrite veined by porphyrite at locality 81.

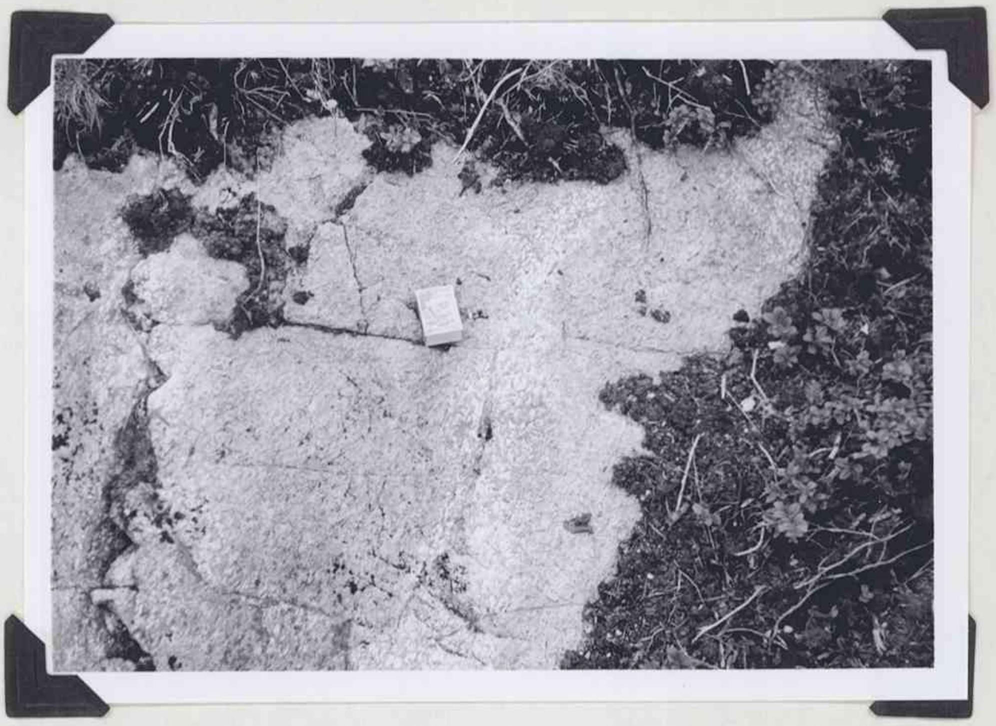


Plate 30. Porphyrite near locality 81 showing once again that it is veining itself.

Plate 31. An area of glacial deposits near Skogstad. The boulders in many cases bear glaciations and they are exposed as a result of the land being stripped of vegetation and having been ploughed prior to cultivation.

Plate 32. Glacial grooved and striated green and purple grits and sandstones.

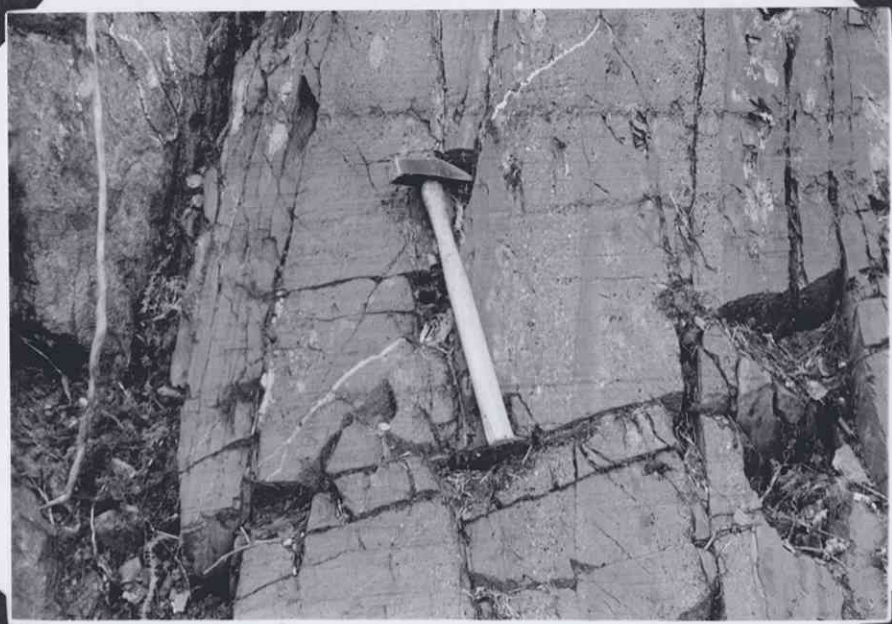


Plate 33. Fine glacial striae on jointed purple grits and sandstones at locality 139.

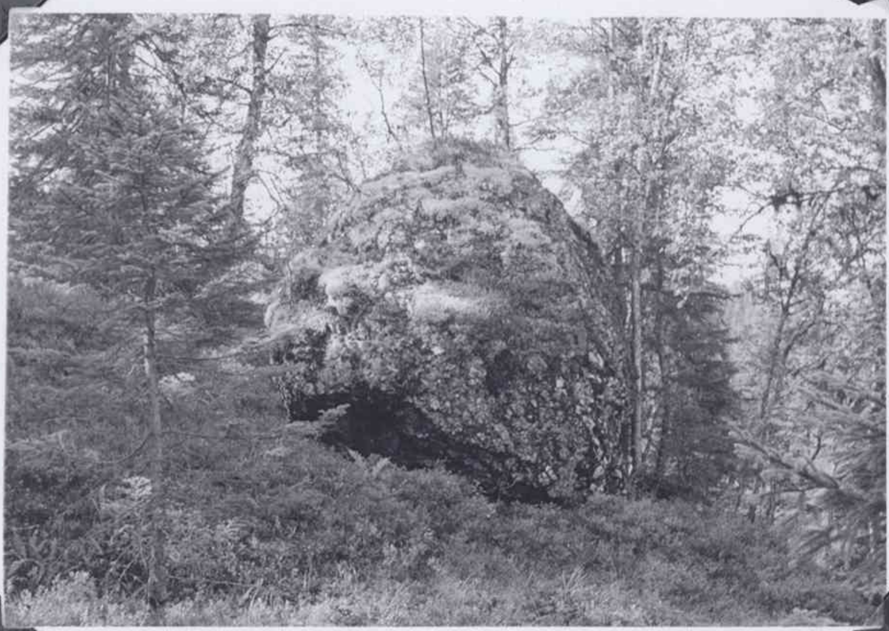


Plate 34. A large erratic block of conglomerate dumped during the glaciation of the area at an elevation of approx. 400m. near locality 289.

Plate 35. A small fault cutting green and purple interbedded grits and sandstones at locality 193.

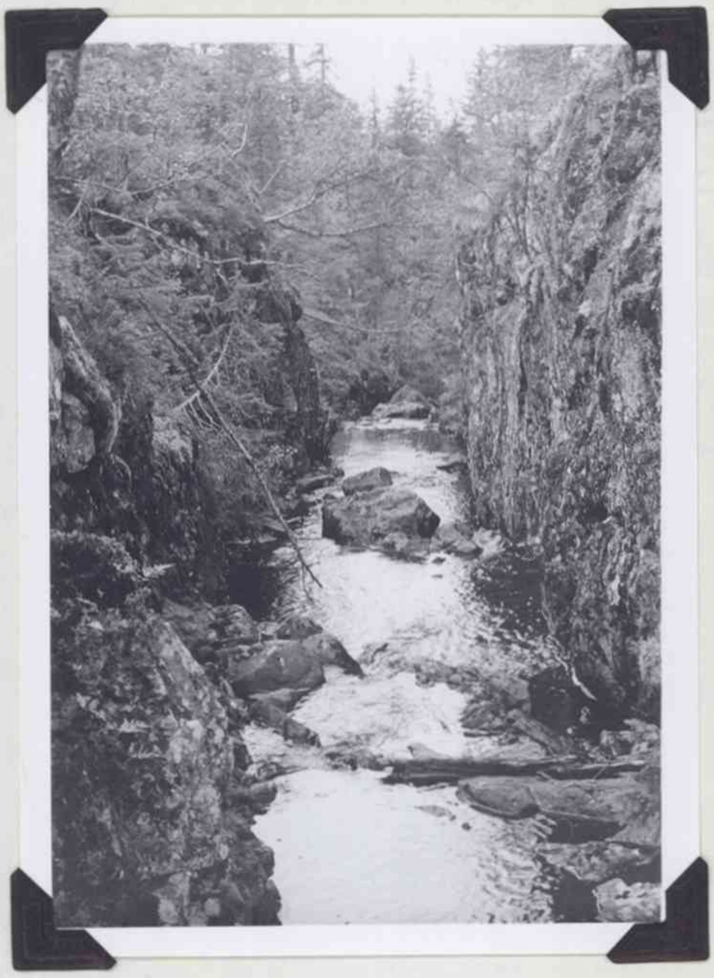


Plate 36. A small stream running along a fault line at locality 292.

Plate 37. A small tear fault cutting beds of green and purple sandstone. The fault is bounded by two closely spaced planes between which the beds have been caused to be distorted into sigmoidal flexures.

Plate 37a. A close-up of the above feature in which one can see jointing associated with the fault showing that it was probably produced as a result of oblique compession.

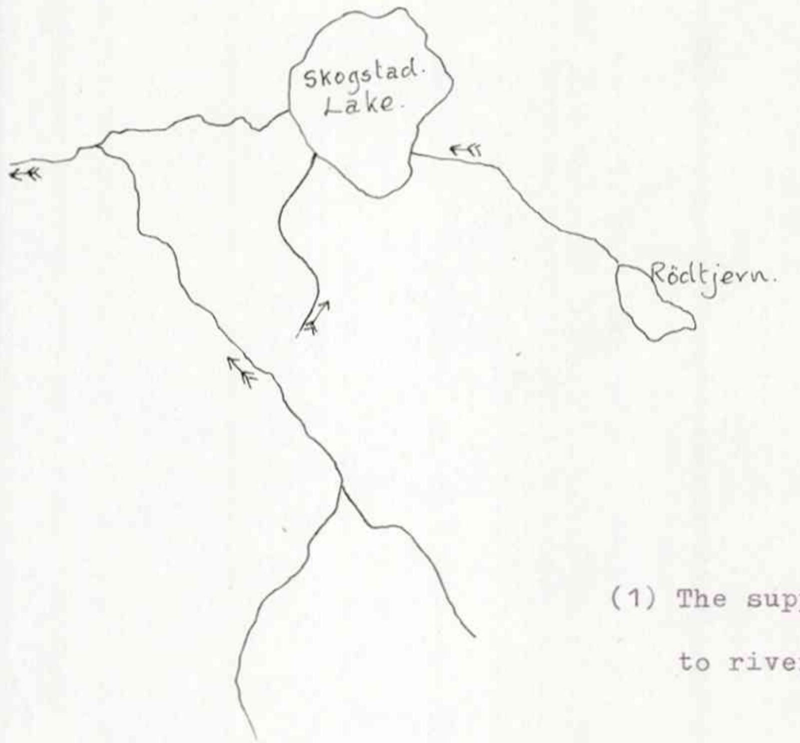
Plate 38. Sharp angular minor folds in the shales at locality 132.

Plate 39. Cleavage oblique to the bedding in purple shales and sandstones at locality 285.

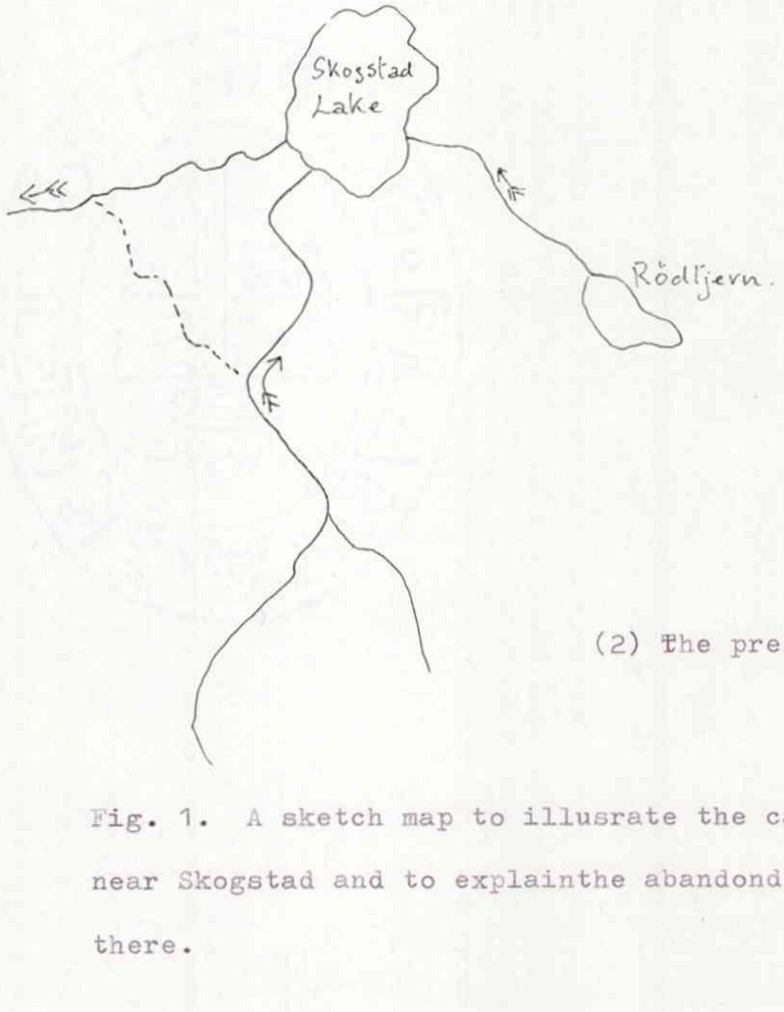
Plate 40. Minor folds in sheared sandstones at locality 101.

Plate 41. Drag-folds in calcareous shales at locality 71 which suggest that the beds have been overturned.

Plate 42. Sharp angular folds in grey shales at locality 86. Note the well pronouced axial plane cleavage.



(1) The supposed situation prior to river- capture.



(2) The present situation.

Fig. 1. A sketch map to illusrate the capture of the river near Skogstad and to explainthe abandonded river course found there.

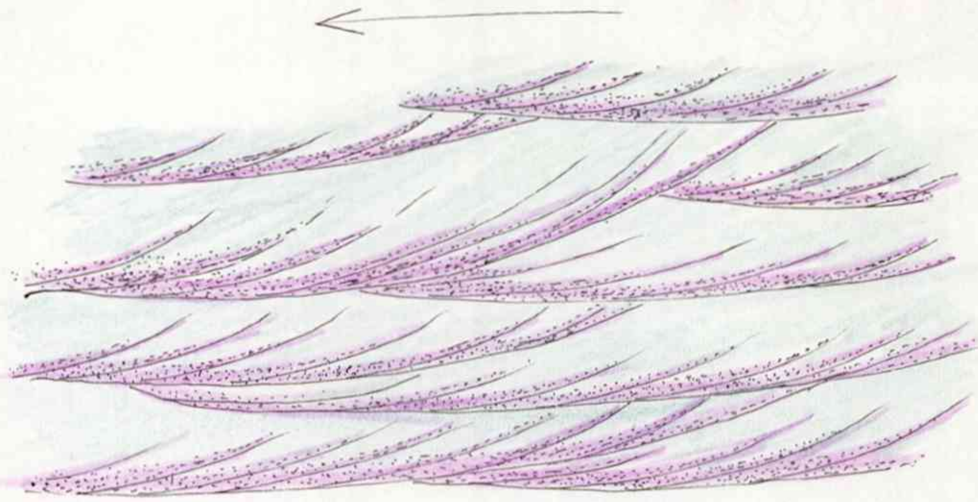


Fig. 2. Current bedding in green, epidote-rich, purple-banded grits and sandstones as seen at locality 198. The beds are here shown the right way up so as to indicate the direction of the depositing current (right to left). In the field each foreset bed is also seen to be weakly graded at it's base.

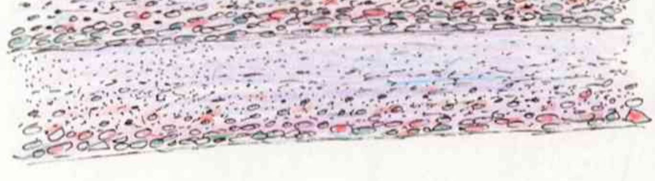


Fig. 3.
Graded bedding as seen in the purple sandstones near locality 226. The beds are thereby indicated as being the right way up.

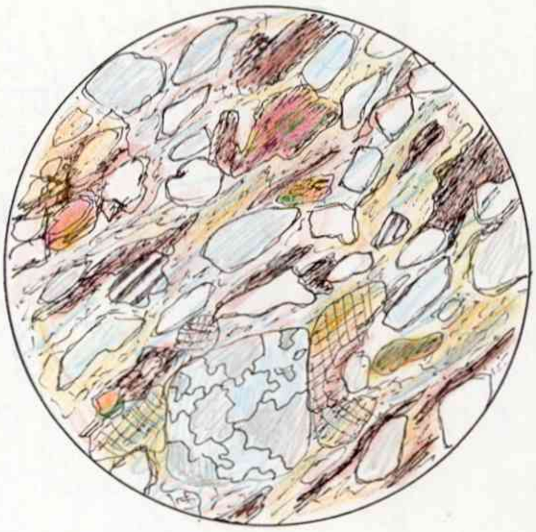


Fig. 4. A thin section of the purple sandstones of locality 5 . Note the abundance of quartz grains and the rare grains of plagioclase, also note the areas of calcite and the presence of epidote, composite grains and dark brown streaks of iron compounds,

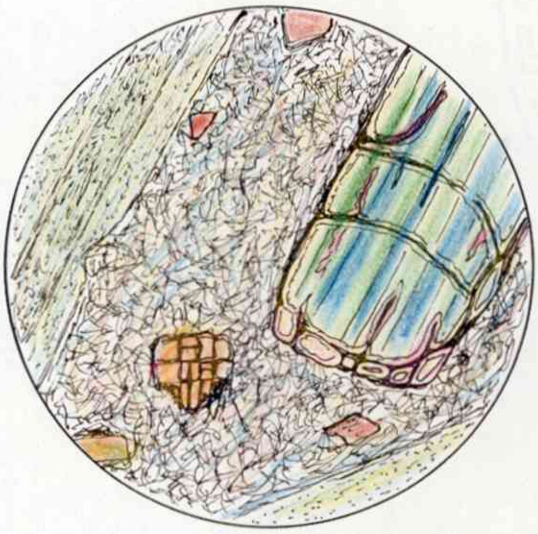


Fig. 5. A thin section of the porphyrite of locality 81 (Berg type?). Note the large phenocryst of augite which is polysynthetically twinned and is being replaced along cracks and cleavages by a thin inner rim of amphibole and successively by a thin outer rim of chlorite.

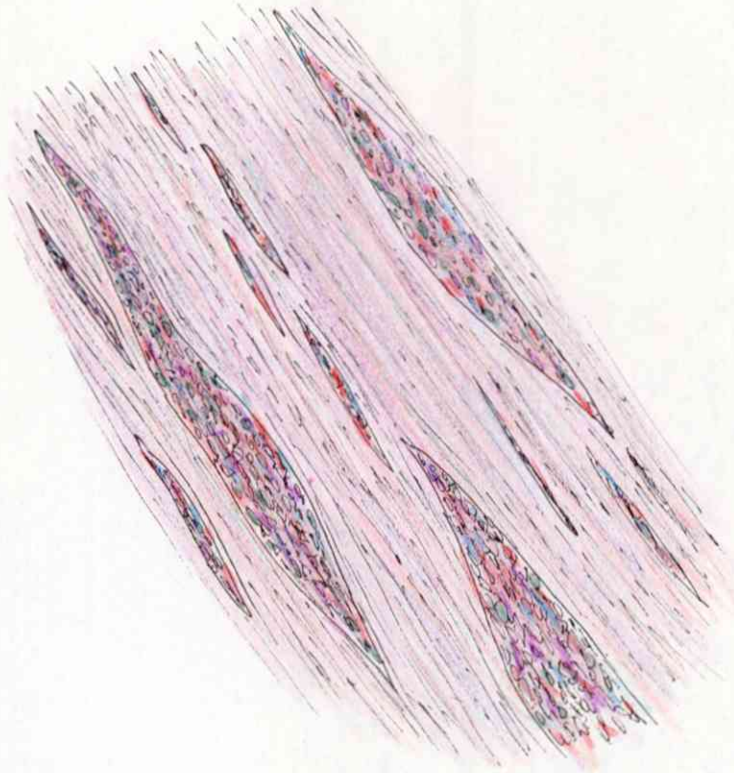


Fig. 7. Lenses of breccia in purple grits and sandstones at locality 22.

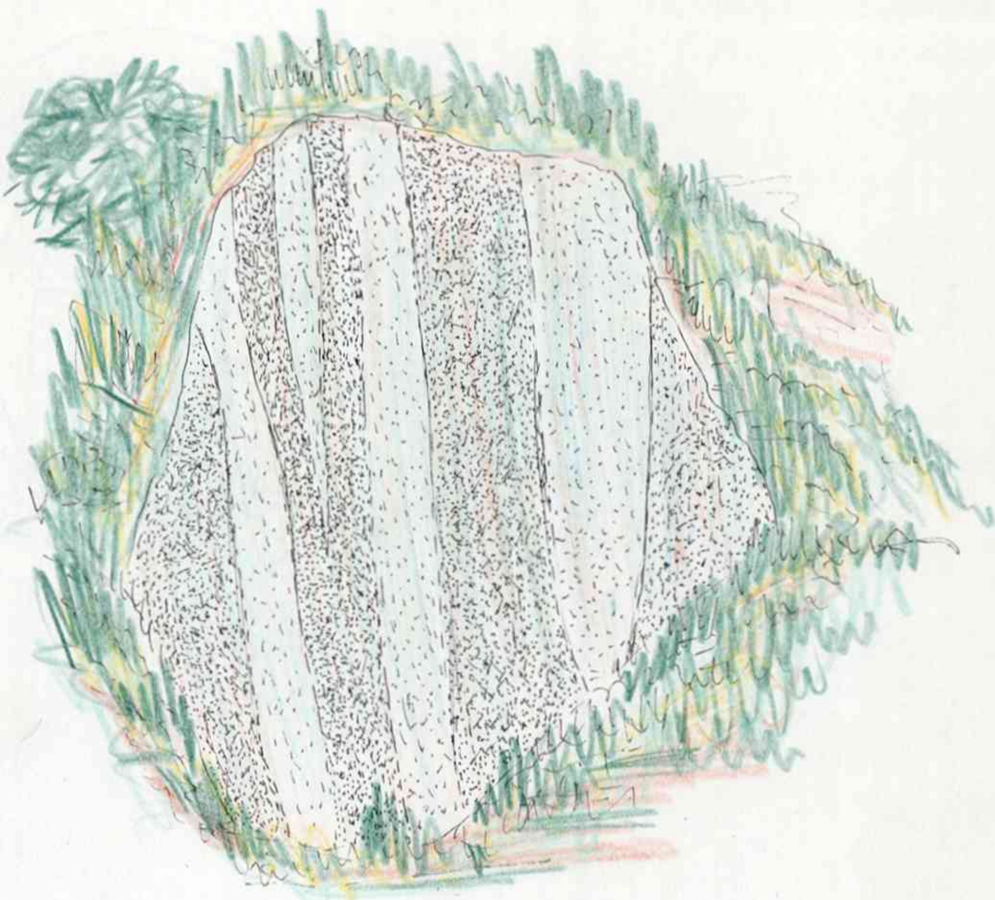


Fig. 8. A sketch of the porphyrite at locality 68 showing the alternation of light and dark grey-green bands.

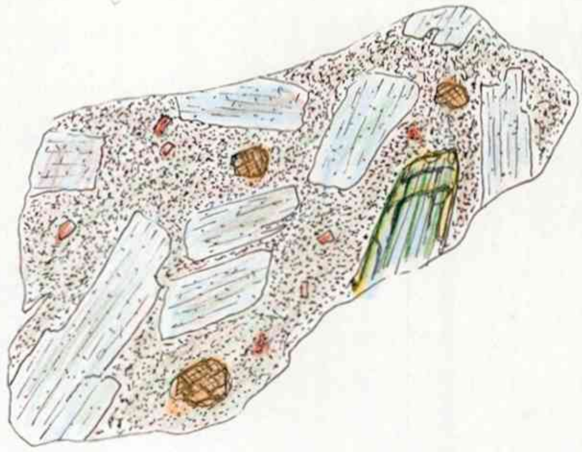


Fig. 9. A drawing of thin section 81 to show the distribution of the phenocrysts in the groundmass.

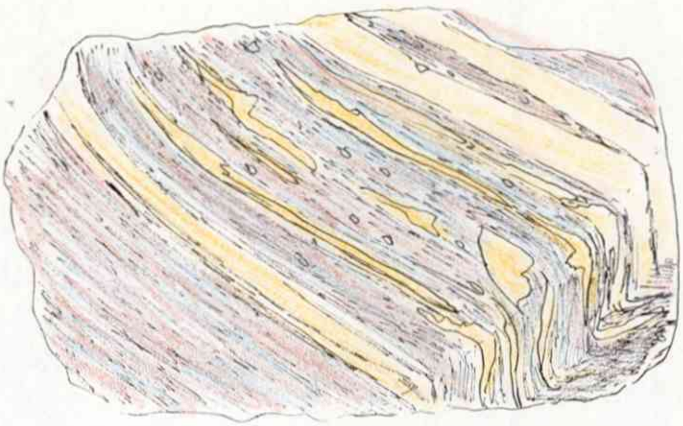


Fig. 10. A drawing of thin section 50 to show the type of folding in the grey shales and to illustrate the abundance of calcium carbonate in the form of thin usually impersistent bands.

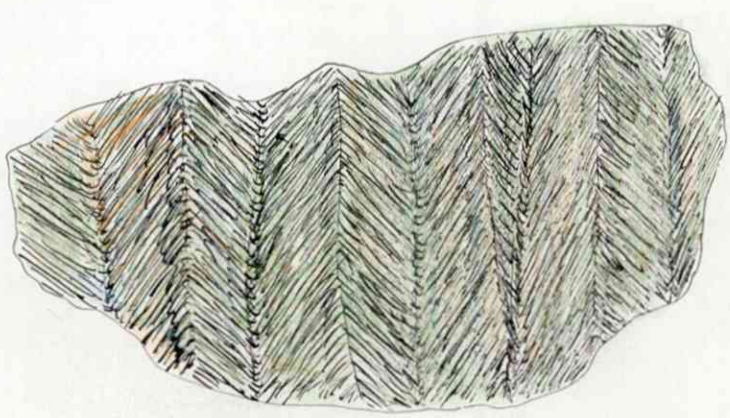


Fig. 11. A drawing of thin section 122 to show the type of minor folds displayed in the green sandstones of that locality.

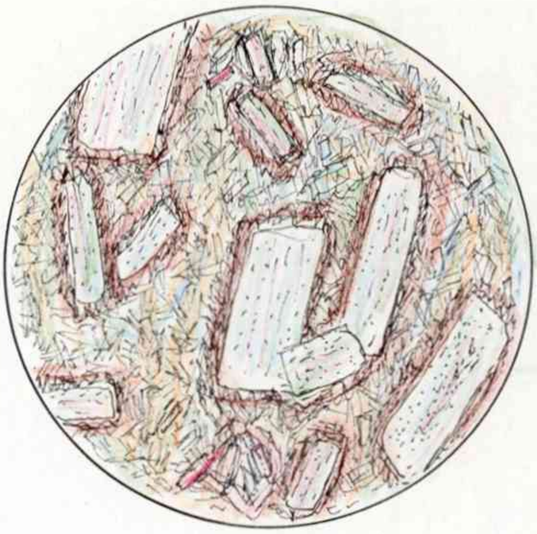


Fig. 12. A thin section of the porphyrite from locality 34. Note thin thin mantle of stilpnomelane around the plagioclase pheno-crysts. This porphyrite is also thought to be of the Berg type.

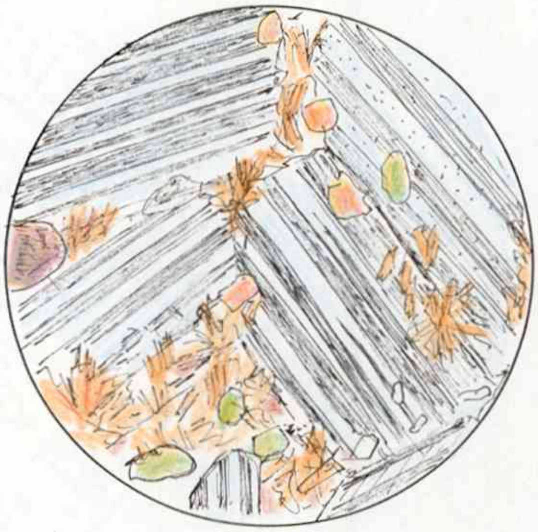
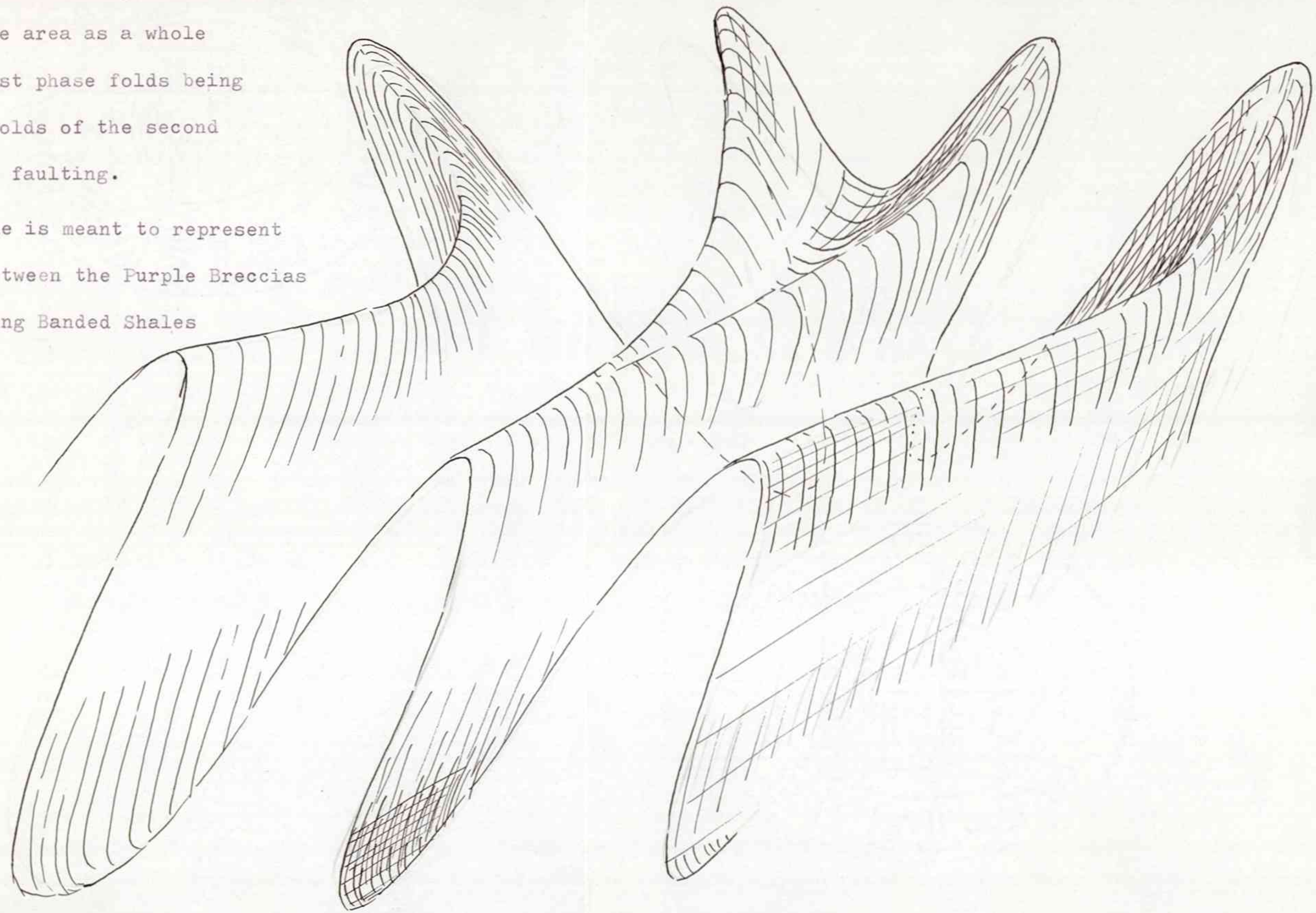


Fig. 13. A thin section of the porphyrite from locality 104 showing the well developed stilpnomelane in the in terstices between the plagioclases and also growing across the phenocrysts themselves. Note the generally well pfeserved nature of the plagioclasesand the presence of epidotes. This porphyrite is thought to be of the Almas type since the phenocrusts are much more crowded than in the other porhyrites desfribed.

Fig. 14. A general interpretation of the structure of the area as a whole showing the first phase folds being folded by the folds of the second phase, prior to faulting.

The folded plane is meant to represent the boundary between the Purple Breccias and the overlying Banded Shales and Sandstones.



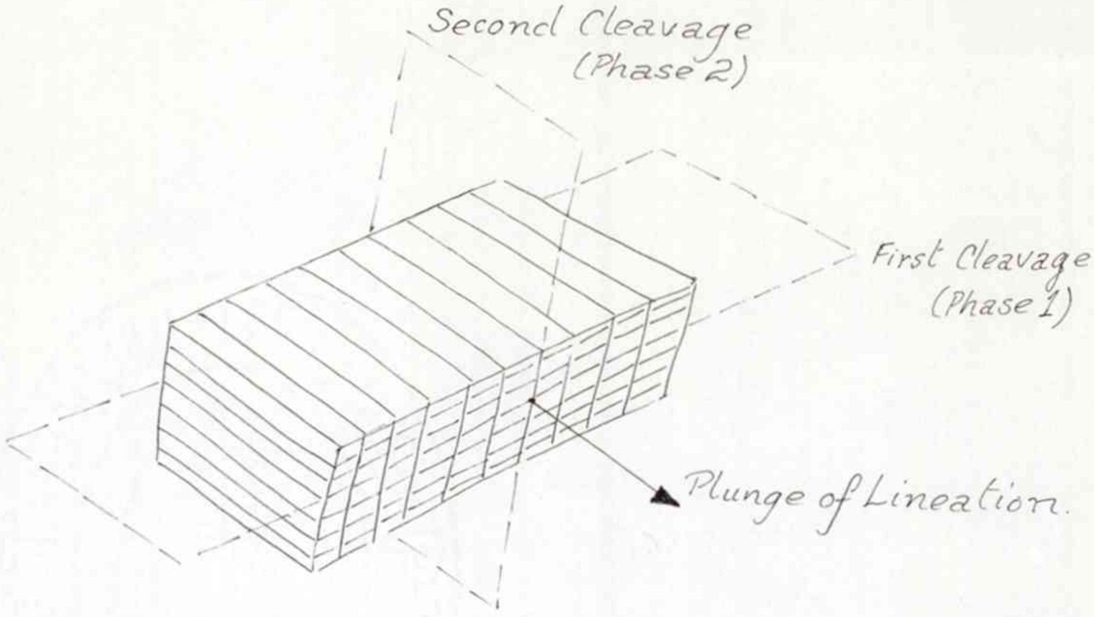


Fig. 15. A diagrammatic illustration of the production of lineations by the intersection of two cleavages.

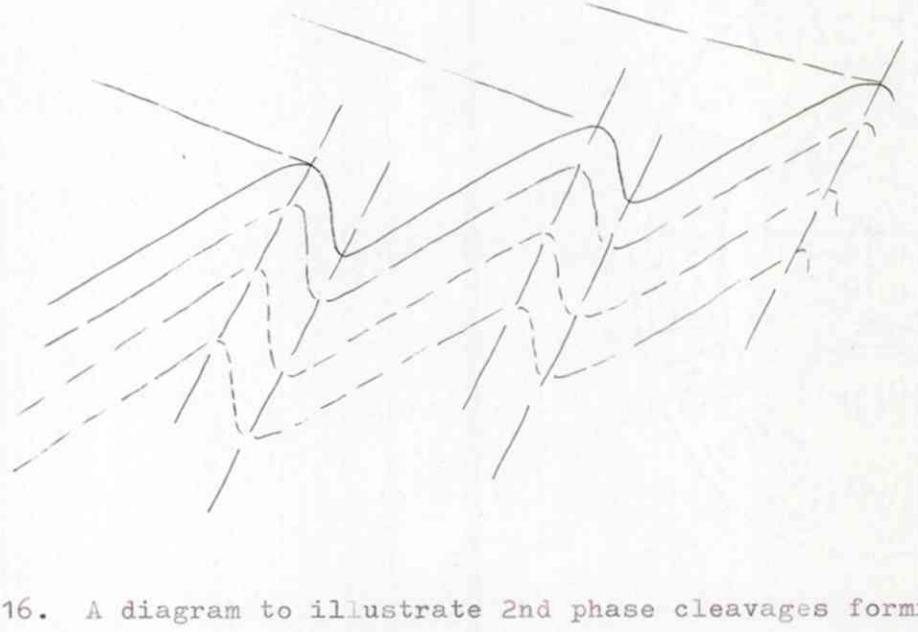
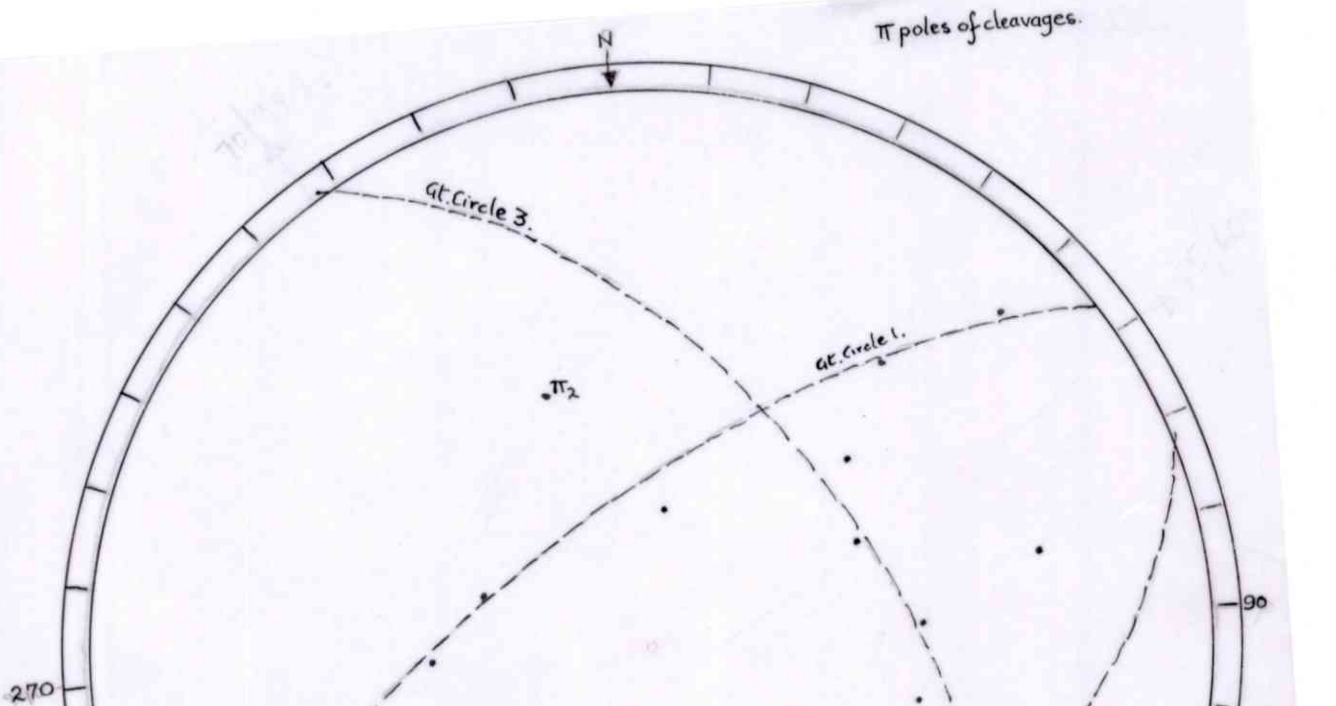
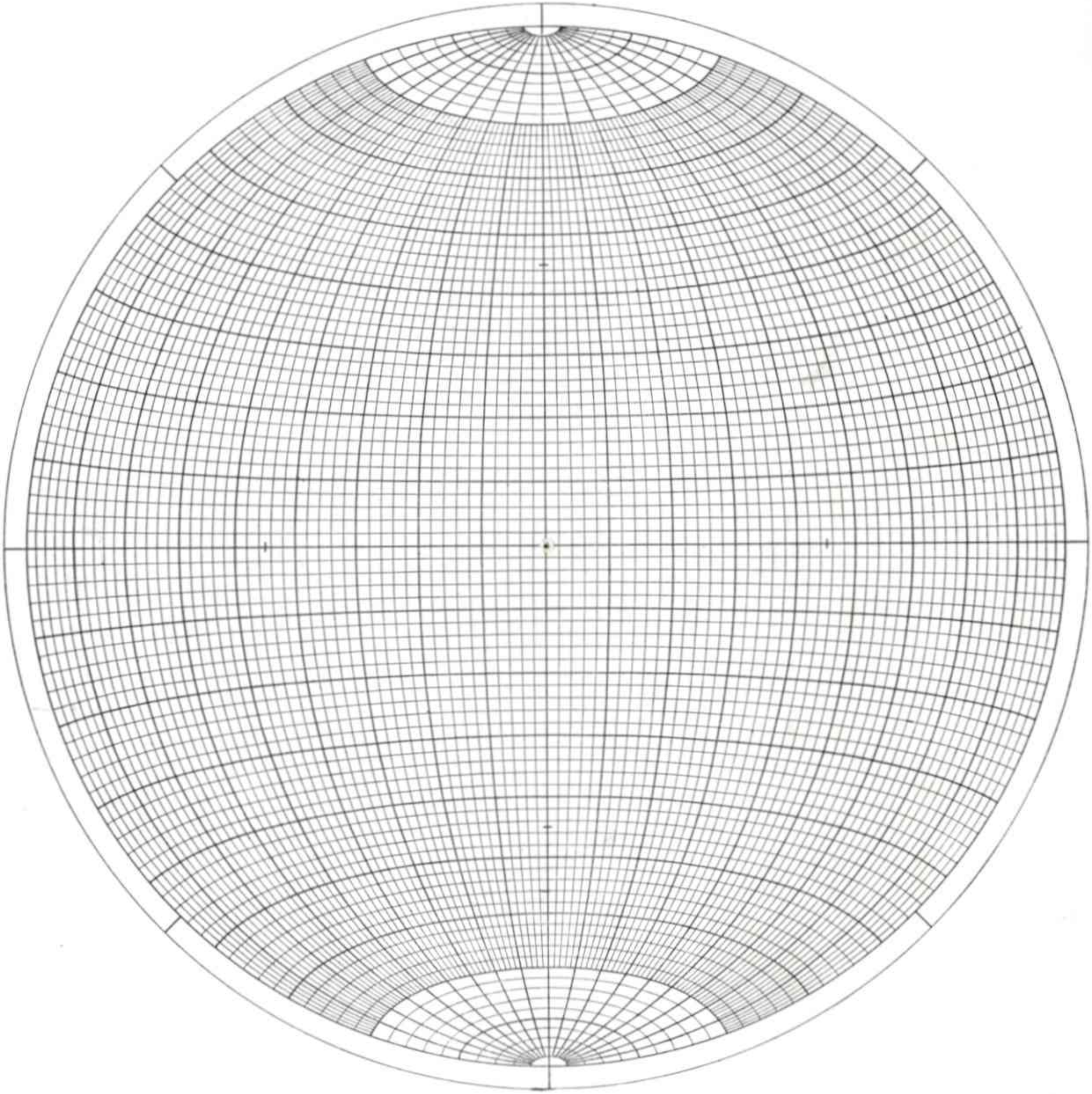


Fig. 16. A diagram to illustrate 2nd phase cleavages forming the axial planes of minor folds (c.f. plate 42.)


π poles of cleavages.
N
90
270
180
Gt. Circle 1.
Gt. Circle 2.
Gt. Circle 3.
π1
π2
π3



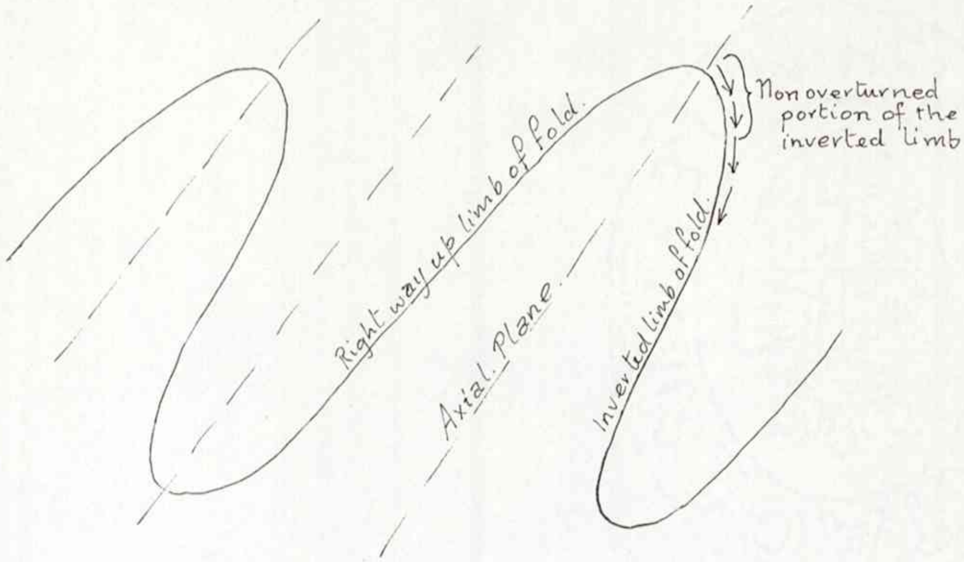


Fig. 17 A diagram to illustrate the phrase "non- overturned portion of the inverted limb" as used in the text.

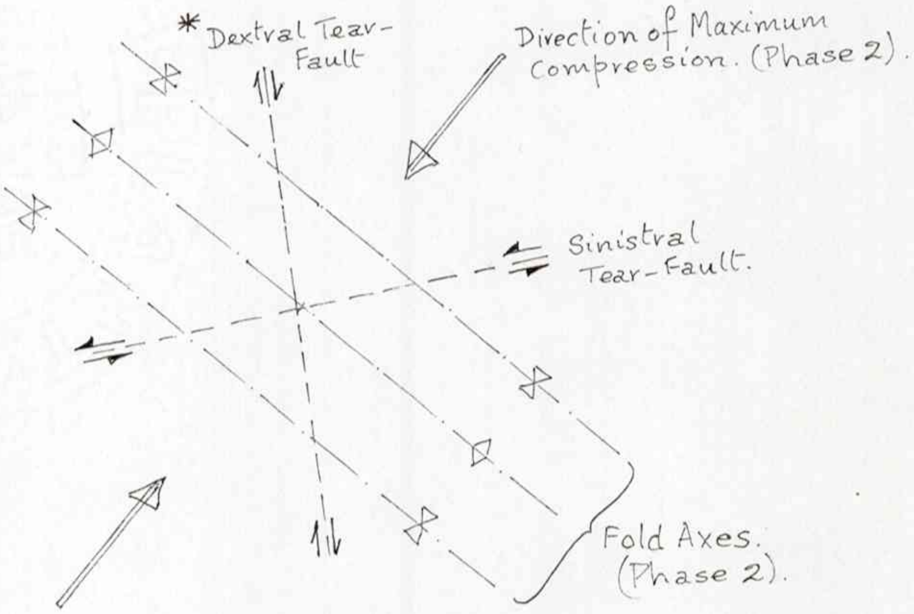
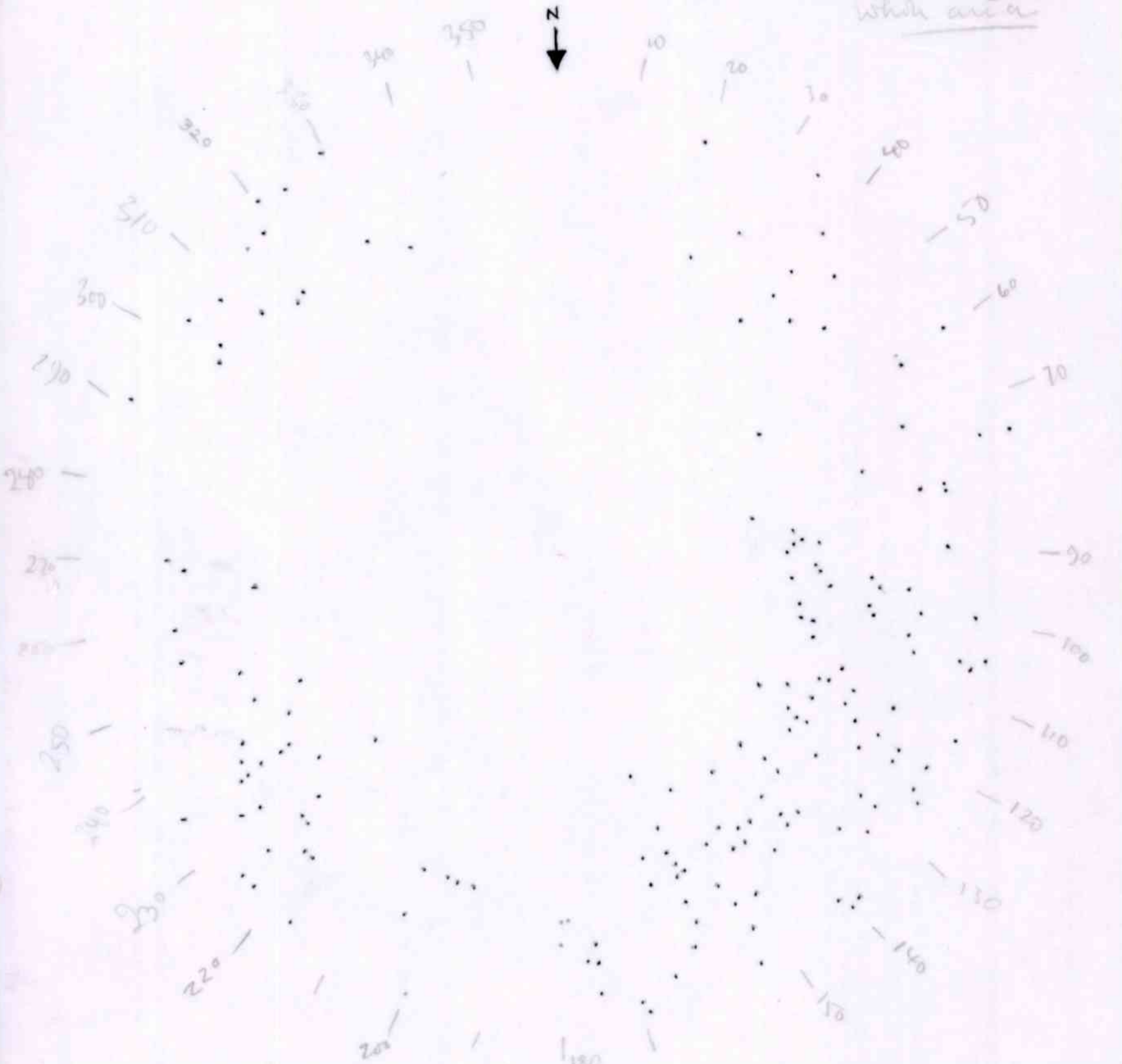


Fig. 18 A diagram to illustrate the possible relationship between the principle forces causing the production of the 2nd phase folds and the faults in the area.

π pole diagram of bedding dips



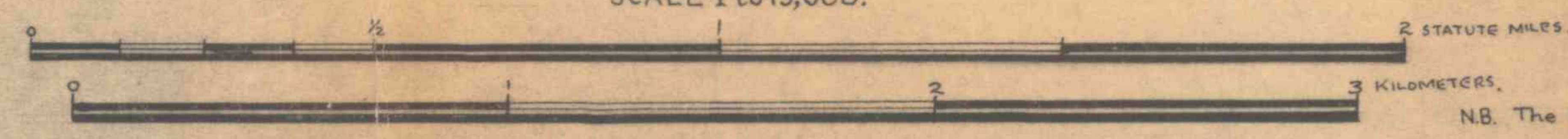
Point Diagram of Linear Structures.

OVERLAY NO.3.

A modified reproduction of part of the Melhus sheet.

Contours at 30m. intervals.

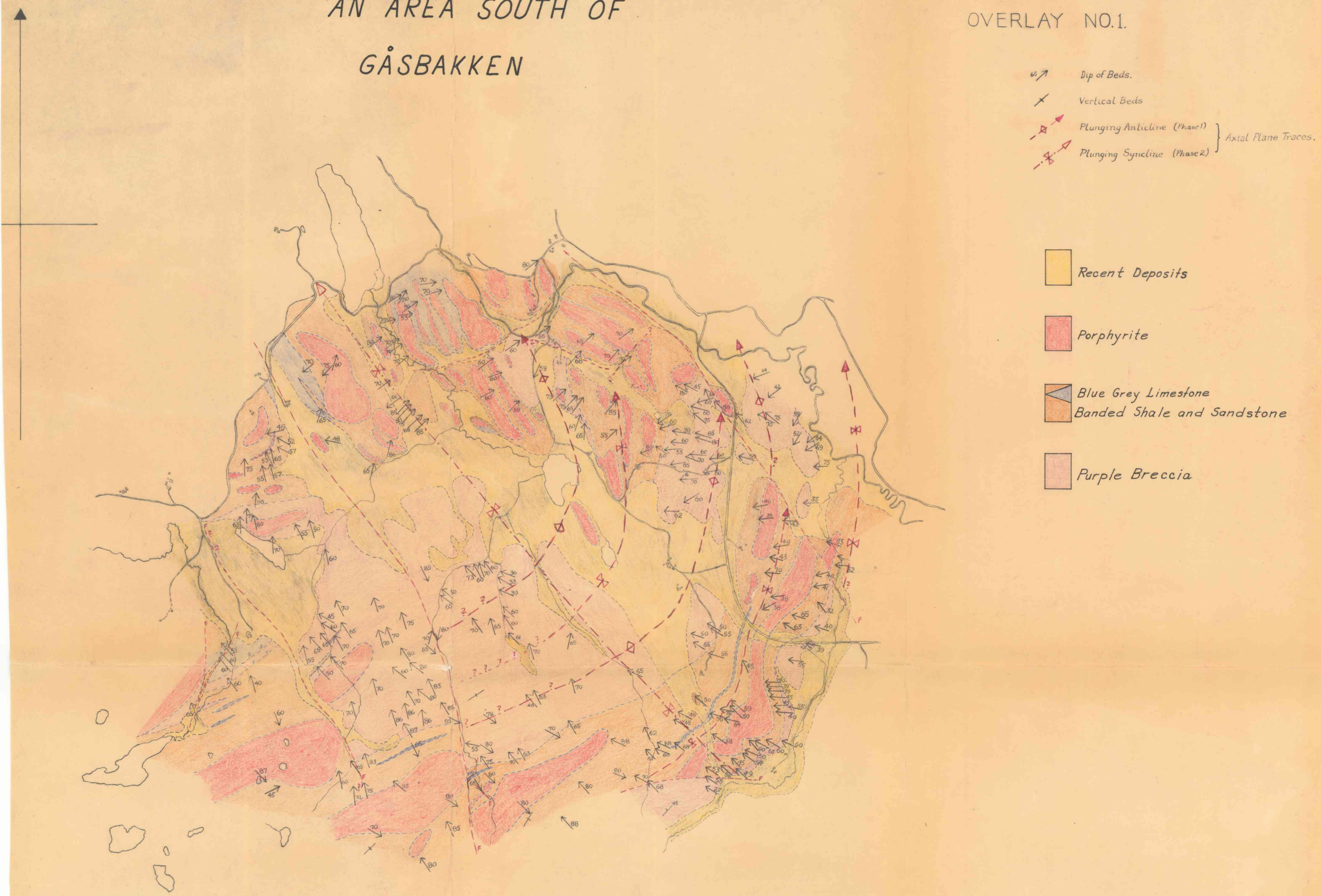
SCALE-1 to 15,000.



N.B. The lower scale is a correction of the kilometer scale shown on the map and on overlay No.2.

AN AREA SOUTH OF GÅSBAKKEN

OVERLAY NO.1.



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OVERLAY NO. 2.

·104 Locality Number.

55 Plunge of Minor Fold Axes.

85 Dip of Cleavage.

Orientation of Glacial Striations.

A E BESWICK 1961