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GEOLOGICAL REPORT ON THE KOMAGFJORD TECTONIC WINDOW, FINNMARK, NORWAY.

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Geology of the Komagfjord Tectonic Window, Finnmark, Norway.

Field Report based on mapping in 1975 and 1976.

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Contents

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I. Introduction

This field report is based on mapping carried out during the summers of 1975 and 1976.

In the Komagfjord Tectonic Window a thick sequence of greenstone metavolcanics and interbedded metasediments (Raipas Suite) of supposed Karelian age (Reitan 1963) is exposed, within the Caledonian mountain chain. Unconformably lying upon the Raipas rocks, and overthrust by the Kalak Nappe Complex during the Caledonian orogeny, is a thin sedimentary sequence of Eocambrian age.

The most detailed investigation of the window as a whole was that of Reitan (1963). Some of his stratigraphical nomenclature has been retained, but more detailed mapping of the greenstones has required the addition of a number of new formational and group names (Fig. 1).

Stratigraphic Column

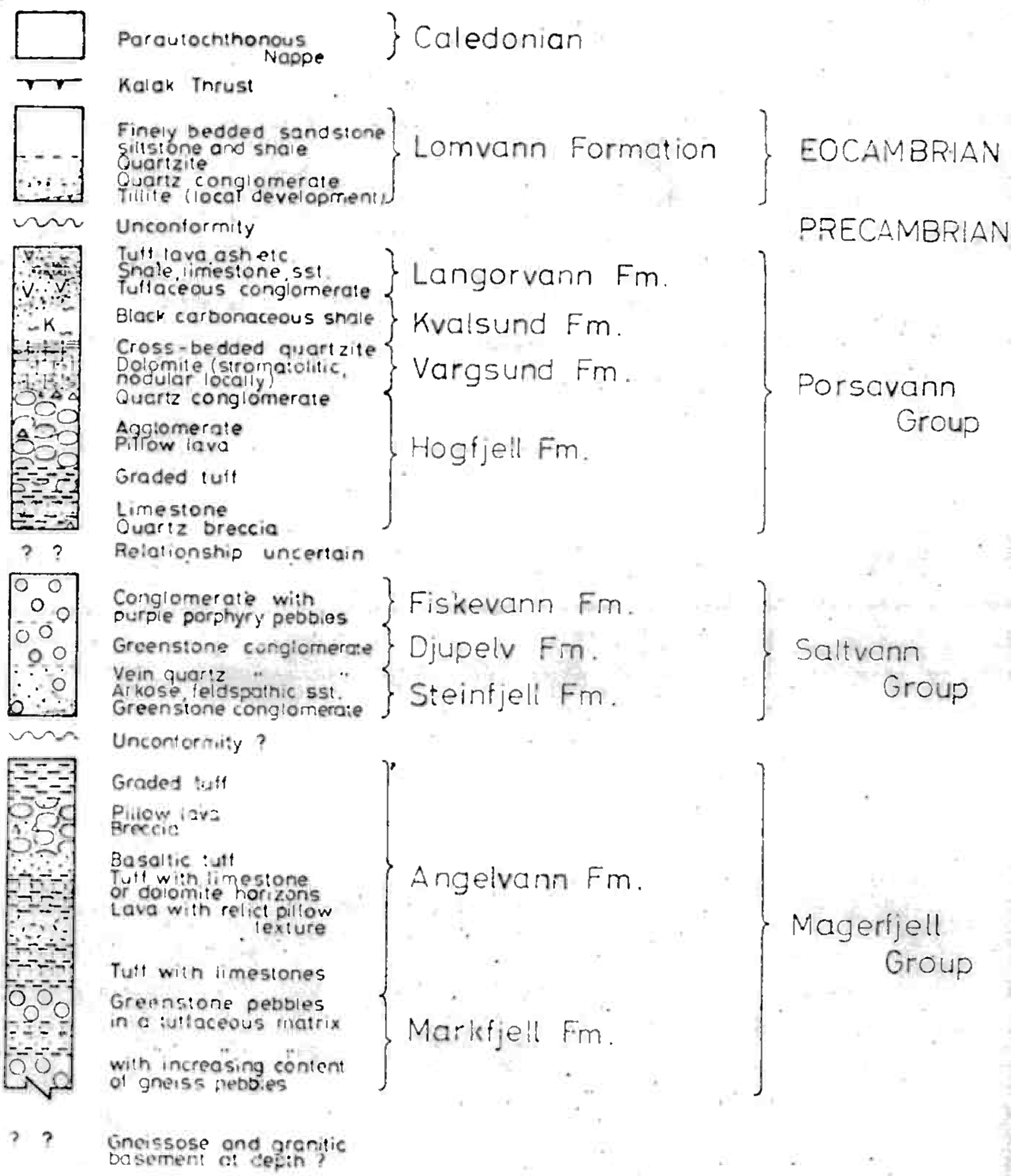


Fig. 1. Stratigraphic Column

II. Precambrian Stratigraphy

The Precambrian Raipas Suite is divided into three groups (Fig. 1). The Magerfjell Group, a sequence of volcanics and interbedded sediments at variable metamorphic grade, underlies the arkoses and quartzites of the Saltvann Group. The relationship of the Porsavaan Group to the other groups is not known with certainty, but it possibly overlies the Saltvann Group.

a. Magerfjell Group

The oldest rocks exposed in the area are those of the Magerfjell Group, exposed over a very wide area of the Komagfjord Window south-east of the outcrop of the Saltvann. This group is composed of a thick sequence (possibly greater than 3 kilometres) of basaltic lavas, tuffs and interbedded sedimentary units. Near the outcrop of the Saltvann Group, the metamorphic grade is low and primary features such as pillows, amygdales, hyaloclastite breccias in lavas, and grading in tuffs, can be recognised. Towards the south however, metamorphic grade rises from the biotite to hornblende sub-facies. Accompanying this is a complete recrystallisation and metamorphic differentiation, and recognition of primary textures becomes difficult, then impossible. Lavas recrystallise to hornblende schists, tuffs to hornblende-quartz schists.

Within the Magerfjell Group a number of medium-grained mafic intrusives occur, quite distinct from the lavas and from a later synorogenic intrusive suite. These mafic intrusives are strongly deformed and folded by the Precambrian deformation, and may represent sub-volcanic complexes which fed the lavas.

Thin sedimentary units are interbedded with the dominantly volcanogenic sequence. Thin quartzo-feldspathic units interbedded with mafic tuffs were probably originally acid pyroclastics or arkosic sandstones. Carbonate horizons of exceptional purity are very common towards the top of the Angelvann Formation, frequently associated with mafic tuffs. With increasing metamorphic grade towards the south-east, dolomitic units develop tremolite porphyroblasts.

In the centre of the window, in the area of highest metamorphic grade, conglomerates form much of the outcrop. These consist of pebbles and boulders of greenstone lithologies and granitic gneiss set in a tuffaceous matrix. Striking differences in the proportion of each rock type present occur. The lowest stratigraphic levels are dominated by boulders of granitic/dioritic gneiss and little deformed granite, some up to a metre across. These are presumably derived from a gneissose basement upon which the greenstone sequence was deposited, although this does not outcrop anywhere within the window. At higher stratigraphic levels greenstone pebbles become more common and eventually dominate. This conglomeratic unit is so distinctive that it has been given formational status and named the Markfjell Formation.

The remainder of the Magerfjell Group has been termed the Angelvann Formation but in all probability more detailed mapping will enable finer subdivision.

b. Saltvann Group

The stratigraphical nomenclature erected by Reitan (1963) is retained for this group, which stratigraphically overlies the Magerfjell group. At several localities, quartzites of the Steinfjell Formation contain well preserved current-bedding which clearly demonstrates younging into the Saltvann Group, and away from the sedimentary contact with the greenstones, which must therefore be older. In a number of places, the Steinfjell Formation is underlain by graded tuffs which also indicate younging into the Saltvann Group. Furthermore, the bedding in these tuffs appears to be concordant to that of the quartzite, so if an unconformity exists at all, it is only a very shallow discordance. In other places, for example at Ulveryggen, the nature of this contact has been obscured by high strain and faulting and appears to be tectonic.

The lowest Steinfjell Formation is a sequence of medium to coarse-grained meta-arkoses, metaquartzites of variable purity and conglomerates. The arkosic units are frequently cross-bedded, enabling determination of way-up, while the conglomerate beds are useful indicators of true bedding. Over much of the outcrop, bedding can only be recognised with difficulty, especially in the impure quartzites. Current bedding indicates that the formation was laid down in a sedimentary basin with the provenance of materials to the west or north-west. Most of the pebbles in the conglomerate are of vein quartz, though locally pebbles of greenstone and jasper are found.

The Steinfjell Formation appears to pass up conformably into the Djupelv Formation, which is a conglomerate with numerous boulders and pebbles of greenstone lithologies set in a sparse sandy matrix. This is in turn overlain by the Fiskevann Formation, which is a sandy arkosic conglomerate frequently current bedded, dominated by pebbles of purple volcanic porphyry.

The Saltvann Group is a minimum of 2 kilometres thick.

c. Porsavann Group

The stratigraphical nomenclature erected by Ramsay and Jansen during the course of detailed mapping in the Kvalsund/Vargsund districts is retained here.

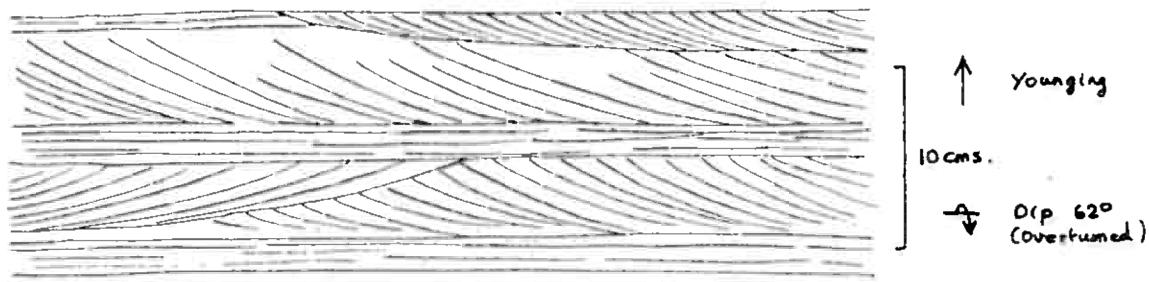
The nature of the contact between the arkoses of the Saltvann Group and the greenstone/sedimentary sequence of the Porsavann Group remains a difficult problem. From Porsavann in the south-west to Nusserenvann in the north-east, the contact appears to be tectonic one, with considerable discordance in places. For example, east of Skinnfjell, the bedding in the Djupelv Formation has a 90^{o} discordance of strike with that of the greenstones on the other side of the contact. On Nusseren itself however, there appears to be a conformable passage up from the Saltvann Group into the Porsavaan Group. Current bedding in the Fiskevann Formation youngs to the north-east, as does grading in tuffs immediately north of the contact.

It is provisionally suggested therefore, that the Porsavann Group is stratigraphically younger than the Saltvann Group, the complexity of the contact in the west being due either to tectonic processes, initial primary unconformity or both. Further evidence for these age relationships is summarised below.

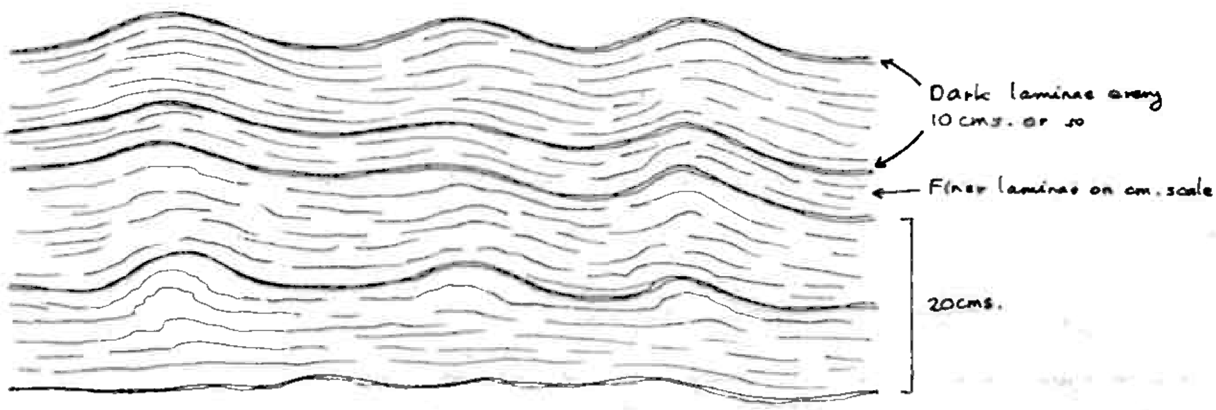
1. As Jansen (1976) has shown, it is impossible to correlate the greenstone units north (Porsavann Group) and south (Magerfjell Group) of the arkosic Saltvann Group. These two groups exhibit striking differences in lithology. For example, the Porsavann Group is dominated by pillow basalts with an overlying sequence of dolomite, carbonaceous slates and other sediments, while the Magerfjell Group consists mainly of basalts and interbedded tuffs with very little sediment. In a volcanic environment, rapid facies change is to be expected (and is demonstrable within this area) but this is not thought to be the reason for the dissimilarity of the two groups. A major aim of the geochemical sampling programme is to compare the lava types of both these groups. At present however, it is not thought they are contemporaneous.

2. Stratigraphic evidence from the Nusseren district, with progressively younger units of the Saltvann Group appearing to the north and apparently passing up into tuffs at the base of the Porsavann Group, appears very convincing to the author.

3. Lavas and tuffs on the southern flank of Skinnfjell and Nusseren contain xenoliths of quartzite, probably derived from the Saltvann Group during upward passage of the magma



a. Current-bedding in a quartzite interbedded with massive Vargsund Formation dolomites. Current directions were from North and North-East at time of deposition.



b. Low amplitude mounds produced by stromatolitic algae.

Fig. 2. Sedimentary structures in the Vargsund Formation.

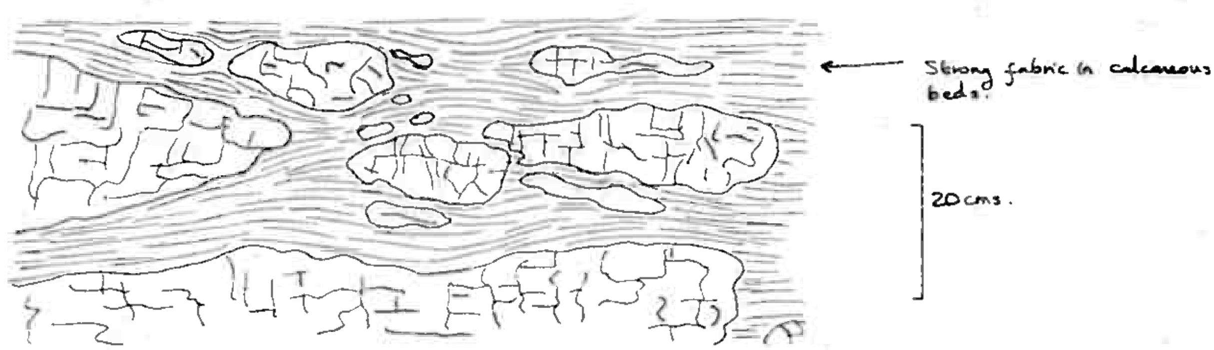
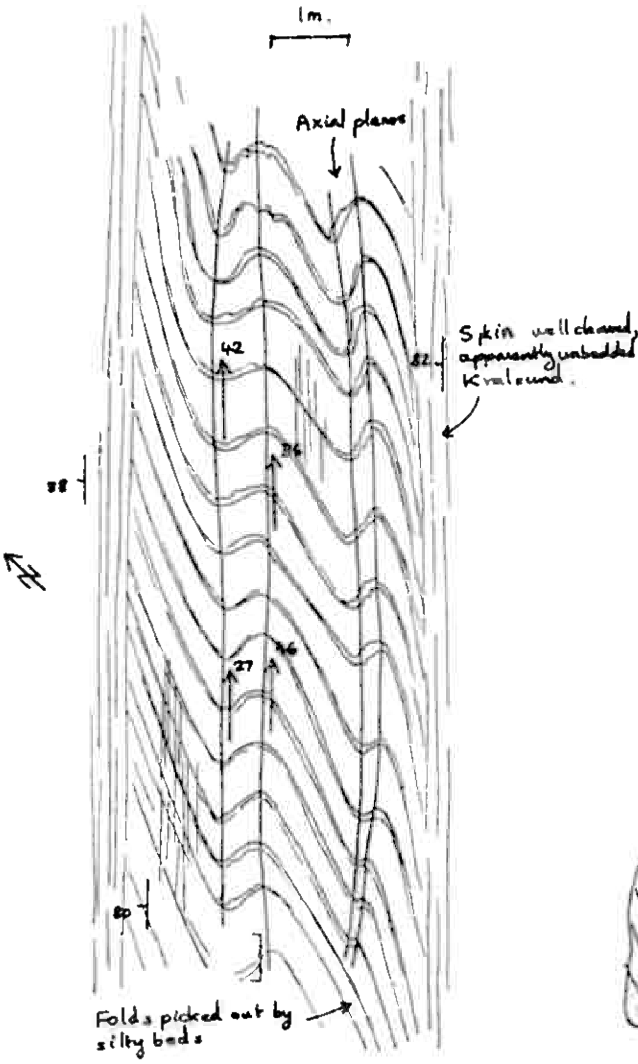


Fig. 3. Boudinage of competent dolomite beds within more ductile calcareous horizons.

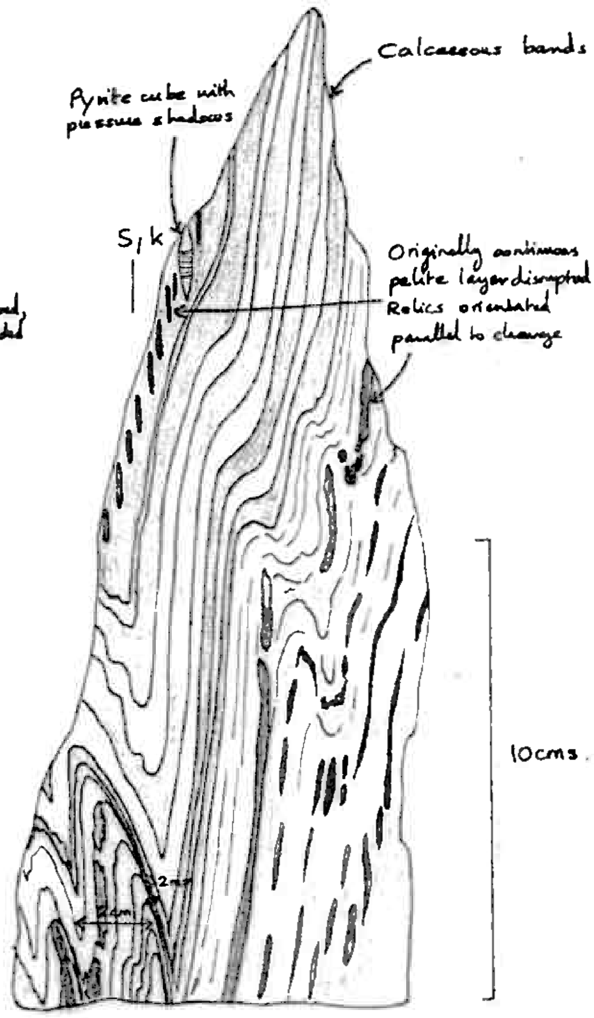
The lowest Hogfjell Formation is the thickest of the Porsavann Group and is at least 2 kilometres thick. It is a sequence of partially spilitised basaltic lavas, with subsidiary amounts of graded tuff, agglomerate, hyaloclastite breccia and conglomerate, metamorphosed under very low greenschist facies metamorphic conditions.

This is overlain by the Vargsund Formation, a sequence of carbonate-rich sediments, dominantly dolomitic, but with some limestones and interbedded pure quartzites (frequently current-bedded eg. Fig. 2). At the base, grey shales intercalated with thin beds of dolomite form a transition series with the Hogfjell Formation. At higher levels the dolomite is more massive and contains in places very simple, laterally-linked hemispheroidal domes produced by stromatolitic algae. Frequently all sign of primary textures is oblitered by strong flattening in the long limbs of folds of Precambrian age, or by cataclasis during the Caledonian orogeny. Certain horizons are rich in cherty nodules. At least 100 metres of dolomite is present locally, but this can be thinned, or even cut out altogether, by folding and faulting.

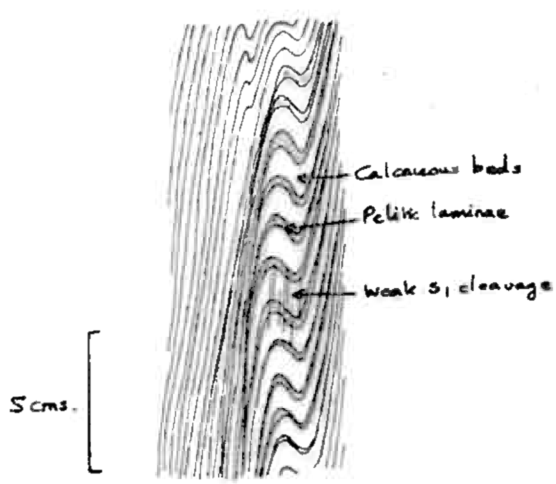
The Vargsund Formation is conformably overlain by black, highly graphitic slates of the Kvalsund Formation, as is readily seen from the map. (Plate 1). As it forms an integral part of the Precambrian Porsavann Group sequence, Reitan's attempt to correlate it with the Eocambrian Lomvann Formation is clearly mistaken. The Kvalsund Formation is a well cleaved, monotonous lithology, though occasional palebeds of silty sediment reveal that these slates exhibit a style of



a. Fold in silty laminae in Kralsund Formation carbonaceous slates — outcrop plan.



b. Folds in carbonate rich horizon of Langorvann Fm, with marked thinning of limbs — section of hand specimen.



c. Similar to b.

Fig. 4. Fold styles typical of pelitic lithologies in the Holmvann Group and Kralsund Formation.

deformation similar to that found in the overlying Langorvann Formation (Fig. 4). The Kvalsund Formation exhibits marked changes in thickness, Some of this may be due to original sedimentary facies variation, but most of it can be attributed to folding.

The Langorvann Formation forms the uppermost unit of the Porsavann Group. At the base a thin conglomerate horizon is sporadically developed, especially in Vesterdalen. Sub-rounded pebbles of greenstone lithologies with subsidiary clasts of shale and vein quartz pebbles are set in a greyish-green pelitic matrix. This is followed by a much thicker sequence of dark, slightly graphitic shales, which become increasingly calcareous until eventually micritic limestone beds appear in the sequence (some up to 25cms thick). In Kvalsund-dal these beds contain stromatolitic algal structures. In addition beds of coarser-grained clastic sediment appear, giving the sequence a turbiditic aspect. The highest unit of the Langorvann Formation exposed consists of greenish-grey ashes and tuffs with thin interbedded lavas.

III. Interpretation of the Precambrian Stratigraphy

a. Magerfjell Group

The primary textures of this group of lavas, tuffs and sediments suggest that they were deposited subaequeously. Pillow textures have long been taken to indicate a submarine origin. In a few places, lensoid zones of hyaloclastite breccia are interbedded with the pillows. There appears to be a complete transition from unbrecciated pillows to hyaloclastites

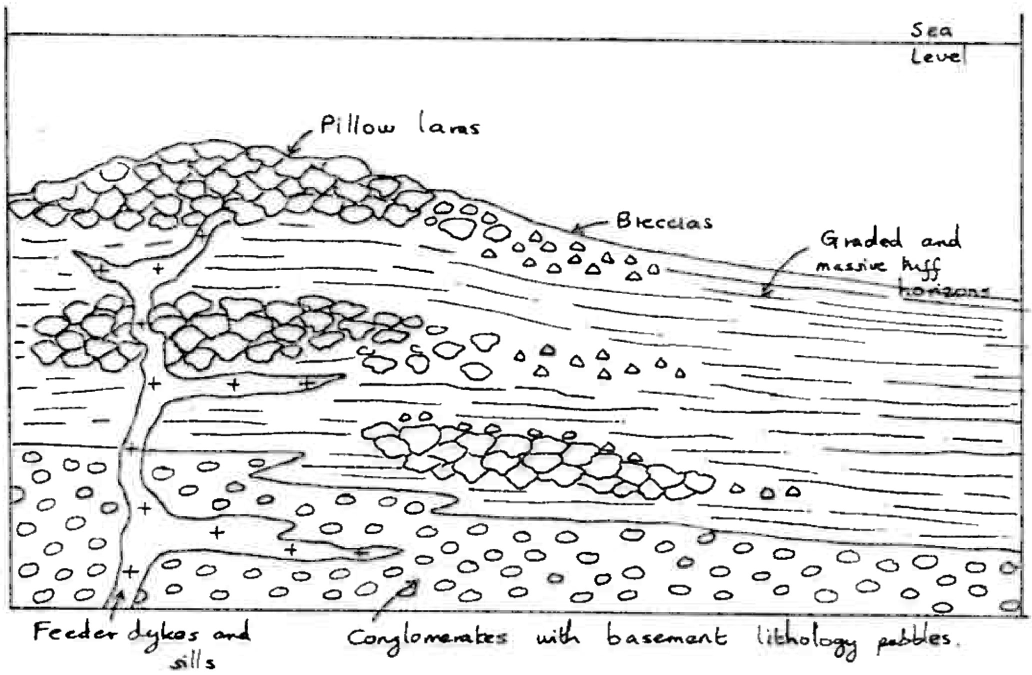


Fig. 5. Diagrammatic representation of facies relationships within the submarine volcanic environment as envisaged during the formation of the Magerfjell Group.

showing the typical 'micro-crackle breccia' texture described by Furnes (1972). Amygdales have been identified at a number of localities and locally form 15-20% by volume of the rock. This suggests that they were chilled in a fairly shallow depth of water, perhaps less than ½ kilometre. In other places, the pillow lava is free of amygdales and may have been poured out at greater depths. In some cases, it is probable that deformation has obliterated the evidence for vesiculation. It has certainly made identification of individual flows very difficult.

In general therefore, the environment of deposition of the Magerfjell Group seems to have been one of submarine eruption and construction of lava piles in gradually shallowing marine basins. On the flanks of these submarine volcanoes talus derived from brecciated lava and aquagene tuffs would have been deposited, and possibly reworked to produce graded tuffs and tuffites (Fig.5).

b. Saltvann Group

The primary features of the Saltvann Group indicate that these sediments were deposited in shallow water, possibly in estuaries or more likely, in a shallow marine environment under deltaic conditions. At individual localities, cross-bedding displays a distinct tendency towards a bimodel distribution, suggesting reworking by channels or by tides. Taking the Steinfjell Formation as a whole, currents at the time of deposition were from the north-west quadrant. Much of the sediment is highly feldspathic in aspect (true arkoses are quite common) and the presence of conglomerates with pebbles derived from the Magerfjell Group greenstones suggests that at least some of the sediment was locally derived. At the extreme south-western end of its outcrop, where it disappears below the Kalak Thrust, the Steinfjell Formation contains a considerable amount of conglomerate. This lenses out in a north-easterly direction until at Saltvann very little conglomerate is present. At Ulveryggen conglomerates are of localised occurrence, and mostly restricted to thin beds and channel infills. This indicates very rapid facies change within the Steinfjell Formation, probably also true of the Saltvann Group as a whole.

Reitan (1963) was not able to identify a source for the porphyry pebbles of the Fiskevann Formation with Norway, although andesites and porphyries are known from many other places in the Karelian e.g. the porphyries of the Kiruna district.

c. <u>Porsavann Group</u>

The extrusion of lavas and tuffs comprising the Hogfjell Formation marked the return of a deepening marine environment. This volcanic sequence is dominated by pillow lavas with subsidiary hyaloclastite breccias and tuff horizons. It is overlain by dolomites of the Vargsund Formation which were deposited in a shallow marine or intertidal environment, the depth of water being critically important for algal photosynthesis. Current-bedded quartzites interbedded with the dolomite indicate a north-easterly provenance for these mature clastic sediments. Quiet shallow water marine conditions seem to have persisted during the deposition of the Kvalsund Formation and the lowermost part of the Langorvann Formation, but the youngest Precambrian rocks preserved in the Komagfjord Window are ashes, tuffs and lavas marking a return to volcanogenic sedimentation.

IV. Precambrian Synorogenic Intrustions

It is possible to recognise three broad divisionsof intrusive rocks. These include metagabbros and ultramafic rocks which are found throughout the window (even in the Vargsund district) and quartz-diorite, which is restricted to the area around Tverelv-vann in the south-west of the window, east of Skillefjord.

a. Metagabbros

Metagabbros are widely distributed throughout the window, with retrograde metamorphic assemblages reflecting the grade of the surrounding country rocks. In the north-west, e.g. at the Lappish ritual shore on the coastal road between Neverfjord and Kvalsund, and on the summit of Skinnfjell, the metagabbros are at chloritegrade. The rocks frequently retain a poor ophitic texture but in thin section are seen to be highly retrogressed to alteration minerals such as serpentine, chlorite, sericite and actinolite. Calcic plagioclase has altered to albite, which is frequently intergrown with quartz. Occasionally relics of the original mineralogy are preserved e.g. recognisable pyroxene phenocrysts, but these are generally rare. As metamorphic grade rises towards the interior of the window, recrystallisation of the gabbros is more complete and the ophitic texture is completely destroyed. It is replaced by a strong L - fabric of metamorphic origin produced by the parallel alignment of of nematoblastic green hornblende porphyroblasts set in a matrix of plagioclase.

Due to the metamorphic recrystallisation of the gabbros it is very difficult to investigate mineralogical variation within and between each of the intrusive bodies. In places, some of the gabbro has a distinctly leucocratic aspect, and this may well indicate some differentiation of the gabbroic magma.

b. Ultramafic intrusions

Intrusives of ultramafic composition are also common and can occur closely associated with gabbros, or completely independent of them. In a number of places, e.g. south of Grubevann and Saltvann, intrusions are of mixed composition with serpentinite grading into gabbro, particularly at the margins of the intrusion. This is thought to be due to compositional differences upon intrusion, rather than due to differentiation in a layered intrusion subsequent to emplacement but prior to complete crystallisation. Either the ultramafic rocks have been emplaced with thin skirts of gabbroic composition, or they represent separate intrusions into the gabbro with which they are associated.

In the north-west of the window the ultramafic intrusives are completely retrogressed to alteration minerals, mainly serpentine, chlorite and talc. Towards the interior of the window it is possible to recognise relics of the original mineralogy, including olivine, ortho-pyroxene and clinopyroxene, which show that the intrusions were dunite or lherzolite peridotites before metamorphism.

c. Mode of emplacement of the gabbroic and ultramafic intrusions

The contacts between these bodies and the country rocks into which they are intruded are exposed at a number of places. The contact is always sharp and regular, and the intrusions are for the most part, free of xenoliths. The marginal zone of the intrusives is nearly always fine grained indicating some degree of chilling of the magma, and occasionally contains xenoliths of the country rocks, e.g. south of Indrevann a gabbro contains rounded disaggregated grains of quartz, derived from the Steinfjell Formation host rocks. Evidence for dilation of the country rocks during intrusion is also found in the form of rotation of bedding out of the regional trend.

The intrusions are frequently irregular in shape and discordant to bedding, although they tend to be concordant with the first schistosity and frequently are associated with the weak core zones of folds. The evidence suggests that the gabbros were emplaced by a combination of forceful intrusion, with comparatively little stoping of xenoliths.

d. Contact metamorphic effects associated with the intrusions.

Reitan (1963) states that there are no contact metamorphic effects attributable to the intrusions. In fact, aureoles are well developed around the intrusions, particularly the ultramafic bodies, but their study is hindered by the refractory nature of the country rocks, which tend to be either quartzites, arkoses or greenstones, not chemically suitable for the production of aluminosilicate porphyroblasts such as cordierite. Nevertheless, in thin section many of the country rocks adjacent to the intrusions can be seen to have recrystallised and developed anew, more granoblastic, annealed fabric. In one locality, tuffs close to an ultramafic intrusion have been contact metamorphosed to pyroxene hornfelses.

e. Tverelv-vann Quartz-diorite

A large intrusion of quartz-diorite (trondhjemite) is exposed around Tverelv-vann in the south-west of the window, with a surface outcrop of approximately 25 square kilometres. It is quite poor in ferromagnesian constituents, and is composed of quartz,sodic plagioclase and a little biotite, with accessories such as quartz and magnetite. Much of the biotite has altered to muscovite during metamorphism, and the rock is brecciated in places. This suggests that the quartz-diorite has suffered metamorphism and deformation subsequent to emplacement. As shales of the Lomvann Formation

(Eo-Cambrian age) which outcrop just south of the quartz-diorite are unhornfelsed, this metamorphism must be of pre-Caledonian age.

Xenoliths of country rock occur within the intrusion but are not common. The margin of the quartz-diorite is poorly exposed but where it can be seen it dips gently outwards. At the margin of the quartz diorite the S_1 foliation and F_1 folds are completely out of the regional trend, suggesting updoming by the magma upon intrusion.

f. Relationship of the intrusions to deformation

It is believed that the gabbroic, ultramafic and dioritic intrusives were injected into the greenstone sequence towards the end of the Karelian deformation episode. All exhibit evidence of retrogressive metamorphism which has largely obliterated the original igneous textures. Many of the gabbros have very strong tectonic fabrics, but these are not found in the north-west where metamorphic grade is lowest, and original ophitic textures are preserved. The quartz-diorite, although intruded into a region of comparatively high metamorphic grade appears itself to be metamorphosed at low grade and this may suggest that the quartz-diorite was a comparatively late intrusion, as the Precambrian metamorphism was waning.

Quartz/potash-feldspar pegmatites are known from a number of localities in the valley of the Repparfjordelv. In some cases thin pegmatite veins discordant to S_1 are deformed by chevron style D_2 folds.

V. Structural and metamorphic history of the Precambrian rocks.

The structural history of the Precambrian rocks is best studied in the central and south-eastern districts of the window. The north-western part of the window acted as a 'buffer' against which most of the force of the Caledonian orogeny was spent. Considerable reworking of the pre-existing structure occurred at this time in the Vargsund district. It was from this area that Pringle obtained a Rb/Sr isochron age of 950 million years (as yet unpublished), on shales of the Langorvann Formation, at the top of the Precambrian sequence. In all probability this represents an older Precambrian (Karelian ?) age partially modified by the Caledonian orogeny to produce an apparent 'Grenvillian' age.

Away from Vargsund Caledonian effects are limitied or absent and it is here that the Precambrian structure is least ambiguous. In the 1977 field season it is hoped to obtain material from the pegmatites and synorogenic intrusives in this zone which can be dated radiometrically. This should then establish the unmodified age of the Precambrian event.

A. Structure of the central and south-eastern districts.

1. First phase of deformation (D_1k)

The dominant structural feature of this area is the regional schistosity (S_1k) which maintains a north-east south-west trend and generally steep south-easterly dip throughout the window. The majority of the rocks are greenstone lavas, tuffs and conglomerates at amphibolite grade. Primary layering in the tuffs is transposed parallel to the S_1k tectonic fabric, pillows are flattened beyond recognition and the only evidence for bedding comes from thin beds of acidic tuff and sandstone sporadically developed throughout the sequence.

F_1k folds are rare, but where observed are steeply plunging, and tight to isoclinal in style. Where cleavage and bedding can be seen in the same outcrop, as in tuffs with sedimentary beds, the angle between bedding and cleavage is small again suggesting that the regional structure is dominated by tight or isoclinal folding.

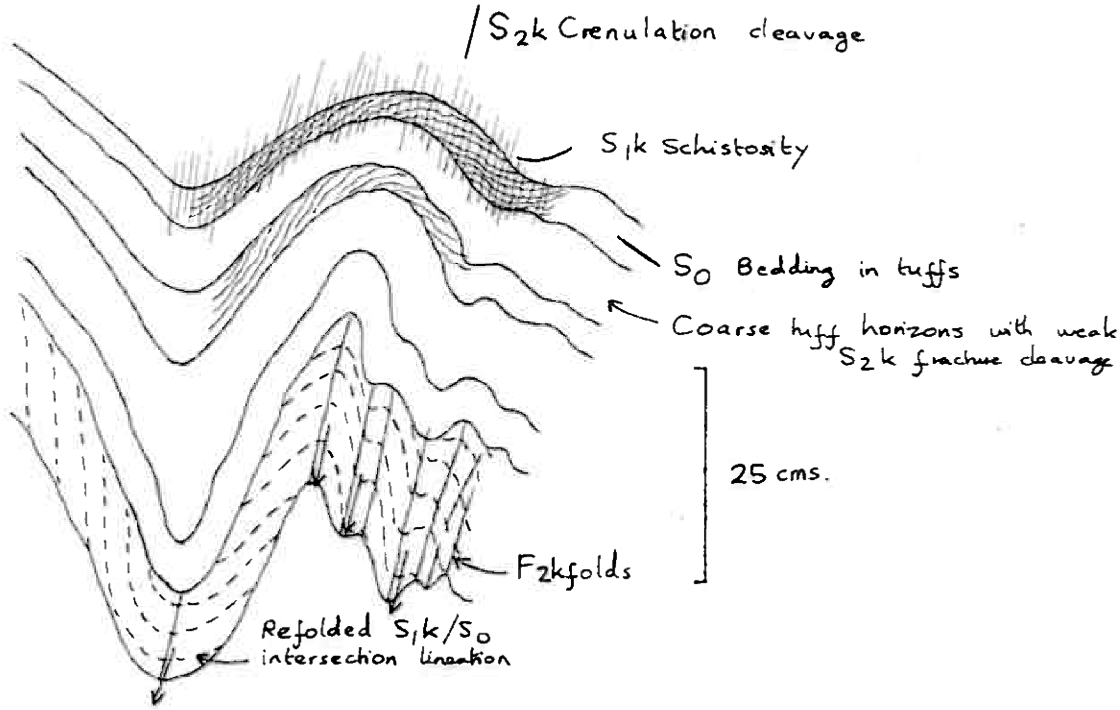
Green hornblende is found in all the stratigraphic units and exhibits a strong preferred orientation (L_1k) within the first schistosity. This lineation is steeply plunging and parallel to the principal (X) axis of the finite strain ellipsoid as deduced from stretched pebbles. There seems to be a very close relationship between the orientation of all 3 linear elements - F_1k axes, L_1k and the X axis of the strain ellipsoid. This is a situation which is also very common in true Archaean greenstone belts, where all of these structural elements are steeply or vertically plunging. It is believed that this relationship is a consequence of high strain during the formation of the first schistosity, with rotation of linear structural elements into the principal finite extension direction.

This effect is most marked in rocks where layering is is orientated at a low angle to the flattening field and/or marked non-cylindrism of fold axes prior to high flattening strain during deformation. As Ramsay and Sturt (1973) have shown, the superimposition of high strain in this situation can lead to rotation of the parasitic fold axes so that they no longer maintain a pumpellyan relationship with the major fold axes, a situation they call incongruous folding. If the strain is high enough, nearly all fold axes will eventually be rotated towards the longest (X) axis of the finite strain ellipsoid, representing the direction of maximum finite extension.

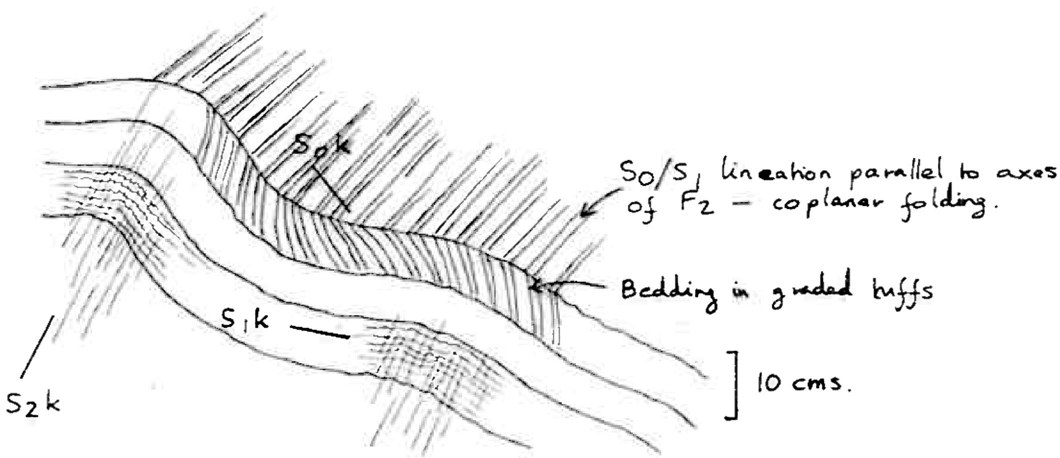
The conglomerates of the Markfjell Formation display variable grade of deformation as a consequence of the ductility contrast between the pebbles and their matrix. In some places, little deformed gneiss pebbles occur together with very highly deformed greenstone pebbles. The former frequently retain their original clastic shape, while the latter may be so deformed (in the same outcrop) that it is difficult to distinguish them from the highly deformed matrix.

2. Injection of pegmatites

Quartz-potash-feldspar pegmatites are known from a number of localities in the valley of the Repparfjordelv. At one locality, 5 kilometres south-west of Skaidi, thin pegmatite veins discordant to S_1k are deformed by chevron style D_2k folds. This phase of pegmatite emplacement presumably represents the thermal maximum of metamorphism, with anatexis occurring in the lower levels of the greenstone



a. Non-cylindrical D2k folds of S1k and bedding in graded tuffs west of Arisvann.



b. Concentric D2k folds of S1k and bedding in graded mafic tuffs on Skinnfjell.

Fig. 6.

sequence or perhaps, remobilisation of the underlying granitic basement.

3. Second phase of deformation (D_2k)

Conjugate folds of the first schistosity occur, on north-east - south-west axes and axial planes generally dipping steeply south-east or north-west. They are quite variable in style, mainly kink and chevron folds, though some more ductile buckle folds are found. Non-cylindrism is a very frequent feature, as is the variability of axial planes, which is a consequence of the S_1k anisotropy resulting in markedly inhomogeneous strain. The S_1k schistosity is crenulated into an S_2k strain slip cleavage, but little recrystallisation appears to accompany this second fold phase. Where the structures of the first fold phase were suitably orientated with regard to the second fold phase, they were refolded into gentle hook-type interference fold patterns. This is best seen where metamorphic grade and finite strains were low during D_1, so that bedding is preserved (Fig. 6a).

In conclusion, it can be said that the structure and stratigraphy of the central district of the Komagfjord Window is as yet poorly understood. This is due in part to the obliteration of primary textures by metamorphic recrystallisation which accompanies the development of green hornblende at the amphibolite isograd. This makes determination of bedding and way-up virtually impossible, and without such structural information, and useful marker horizons, detailed structural interpretation is very difficult. A further complication is that the stratigraphy in such a volcanic environment may be subject to rapid facies changes, and therefore difficult to use as a mapping tool.

B. Structure of the North-western district

1. Introduction

It is less easy to unravel the Precambrian structural sequence here as most structures in the Vargsund district are composite, a consequence of Caledonian reworking of Precambrian structures. The metamorphic grade attained during the Precambrian orogeny declines towards the north-west, falling to biotite grade in the area south of the Steinfjell Formation outcrop, and chlorite grade north of Skinnfjell. This area has not been subjected to intense recrystallisation and metamorphic differentiation as in the south-east and primary textures such as amygdales, hyaloclastite breccias and pillows in lavas, and current-bedding and algal structures in dolomites, are well preserved. None of the sedimentary units (including numerous shale horizons) suggest that the metamorphic grade has ever exceeded the muscovite-chlorite sub-facies in the Vargsund district.

The structure of this district is dominated by steep break thrusts on the overturned limbs of folds, so that greenstones forming the cores of anticlines are thrust over the sediments in the synclinal cores. This relationship is clearly seen along the coast of the Vargsund in the Porsa district (Fig. 9 and Plate 2 - Geological sections). These thrusts are closely associated with intense imbricate thrusting in the sediments (Fig. 10) and in places very strong cataclasis. For example, in Vesterdalen, south of Neverfjord, the stratigraphy is so cataclased that only in a few places can relics of relatively undeformed sediment be identified. In addition, the S_1k cleavage in the Vargsund and district dips steeply to the north-west, whereas elsewhere in the window it dips to the south-east

It is believed that these essentially 'brittle' phenomena of thrusting and cataclasis are a consequence of compression from the north-west during the Caledonian orogeny. At the same time the existing Precambrian cleavage (S_1k) was rotated a few degrees to dip to the north-west. It is also possible that continued sub-vertical extension occurred in the reactivated cleavage plane, so the first cleavage in this district may be a compound one. The fibre lineation (L_1c) seen on many cleavage planes in the greenstone lavas on the coast may well be an indication of Caledonian reactivation of the Karelian cleavage.

Moving away from the Vargsund, Caledonian effects become less noticeable and eventually die out altogether. The S_1k cleavage is vertical in the greenstone on Skinnfjell, and is either vertical or steeply south-east dipping in finer grained sandstones of the Steinfjell Formation.

Despite the strong reworking during the Caledonian orogeny, it is still possible to identify the Precambrian structural sequence.

2. First phase of deformation (D_1k)

The first folds are of variable style, depending for the most part on the lithology involved. The best folds are seen in striped lithologies containing beds of differing viscosity and thickness, such as the Langorvann Formation (Fig. 4). More massive formations such as quartzite and lava do not have well developed minor folds. The first fold axes plunge at variable angles to noth-east and south-west, and in some outcrops a very wide range of plunge is present. This suggests the development of non-phasal, non-cylindrical folds during this deformation. These folds are associated with the first penetrative cleavage (S_1k) which is best seen in the graphite slates of the Kvalsund Formation.

Minor folds are rarely seen in the Saltvann Group, but D_1k folds on a large scale are clearly recognisable in the area of good exposure around Ulveryggen Mine. Here the folding can be tight on a major-scale, with strong shearing along axial planes, and almost certainly the copper mineralisation is related to these Precambrian structures. The southern margin of the Saltvann Group is a folded primary contact with the underlying greenstones. East of Indervann the interfolding is by fairly gentle folds, but it is tight or isoclinal just north of Magerfjell. With increasing tightness of folding, flexural slip becomes very important. In the Ulveryggen district this contact is clearly tectonic with partial truncation of a major syncline in the Steinfjell Formation by a fault.

The post-D_1 pegmatites seen in the south of the window are not seen in this region of lower metamorphic grade.

3. Second phase of deformation (D_2k)

The second generation of folds isseen on Skinnfjell, but has not been identified elsewhere in the Vargsund district. These are folds of S_1k, bedding in tuffs and intersections of these were present (Fig. 6b). They are frequently of chevron style and many are markedly non-cylindrical. As in the south, the F_2k folds are more or less coaxial with the F_1k folds, with axial planes dipping steeply to the north-west.

The Saltvann Group arkoses and quartzites appear to have been too massive to be affected by the D_2k deformation, and folds of this generation have not been identified in the sediments of the Porsavann Group.

VI. Eocambrian sedimentation

Around the margin of the Komagfjord Tectonic Window a sequence of sediments is preserved lying unconformably on the Precambrian rocks described above. This thin unit of shales and sandstones is truncated by the basal thrust of the Caledonian Nappe sequence, the Kalak Thrust.

a. Lomvann Formation in the northern part of the Komagfjord Window

In addition to the outcrops of the Lomvann Formation described by Reitan at Faegfjord in the north-east, the formation also outcrops along the western margin of the window near Porsavann and Hermanvann, and on into the south-west of the district, at Store Lerresfjord and Korsfjord. Jansen (1976) has described the unconformity at Hermanvann, where the

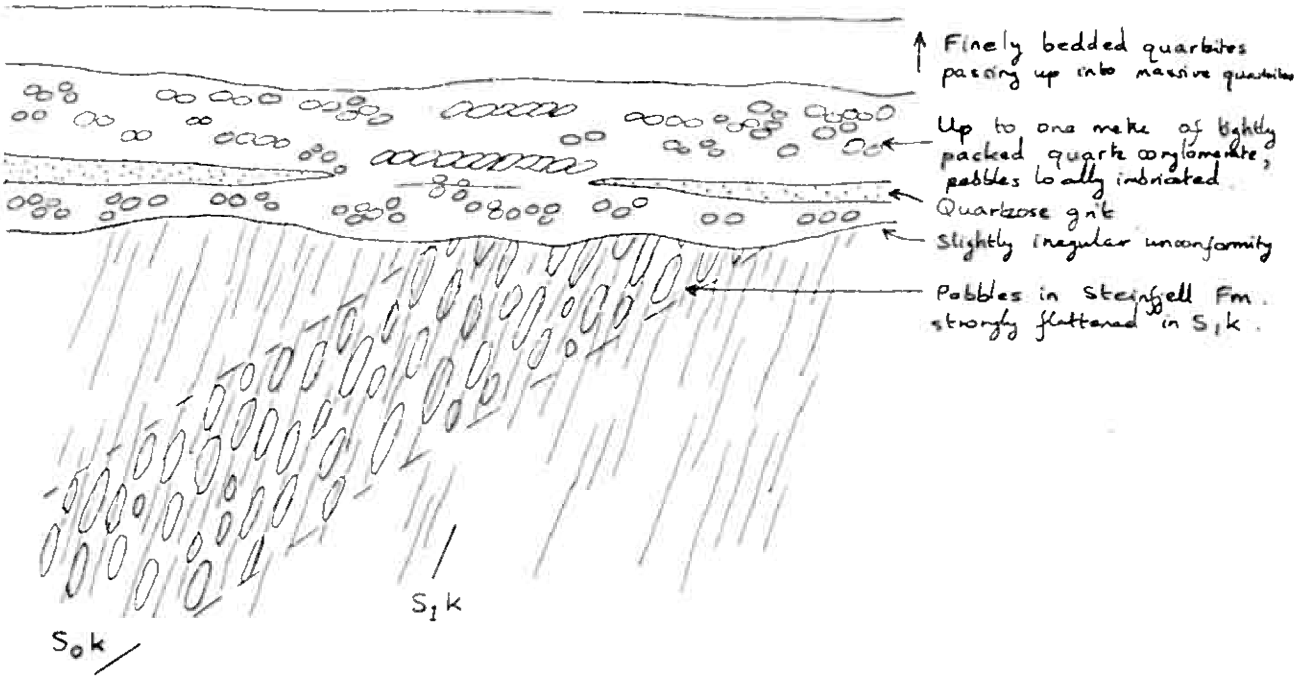


Fig. 7. The sub-Lomvann unconformity at Hemanvann.

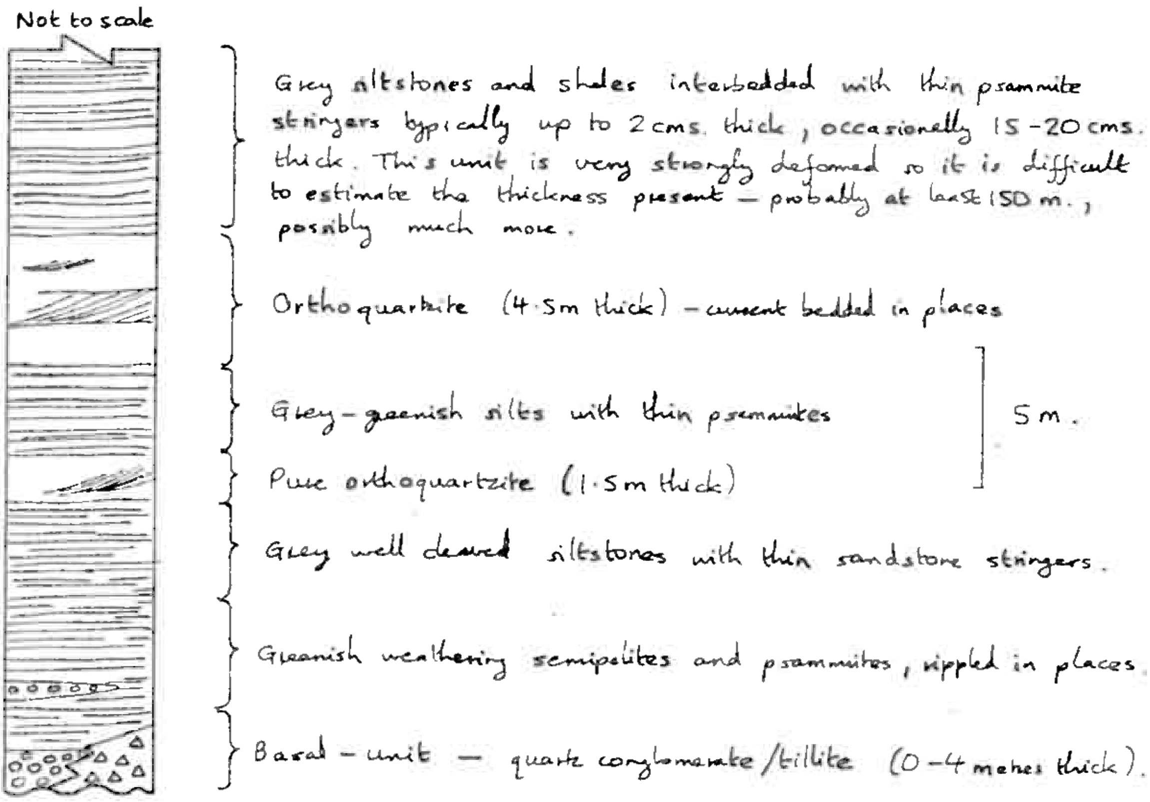


Fig. 8. Stratigraphic Column for Lomvann Formation near Porsavann.

relationship of the Lomvann Formation to the Precambrian basement is clearly revealed (Fig. 7).

Here the Lomvann Formation consists of a sequence of dark grey shales with thin sandstone stringers, although more massive pure white quartzites are present at the base of the formation (Fig. 8). This autochthonous sequence rest unconformably on arkoses and conglomerates of the Steinfjell Formation, the base of the Lomvann Formation being discordant to both bedding and cleavage in the underlying unit. Vein quartz pebbles in the Steinfjell Formation are flattened in the cleavage and truncated by the unconformity, while quartzite and vein quartz pebbles in the thin basal conglomerate of the Lomvann Formation are undeformed.

In places, a thin conglomerate with a poorly sorted tilloid-like texture is found at the base of the sequence. The Lomvann Formation was itself deformed during the Caledonian orogeny, and in view of its age relationships is almost certainly an equivalent of the Eocambrian Dividal Group found on the autochthon along the Caledonian front. As it is traced south-westward along the southern margin of the window, the shale in the Lomvann Formation changes colour to greenish-grey, and the amount of sandy material present declines. By Vuggenes-stein it has begun to take on a reddish colour.

VII. Caledonian deformation

During the Caledonian orogeny the autochthonous Lomvann Formation described above was interfolded with the

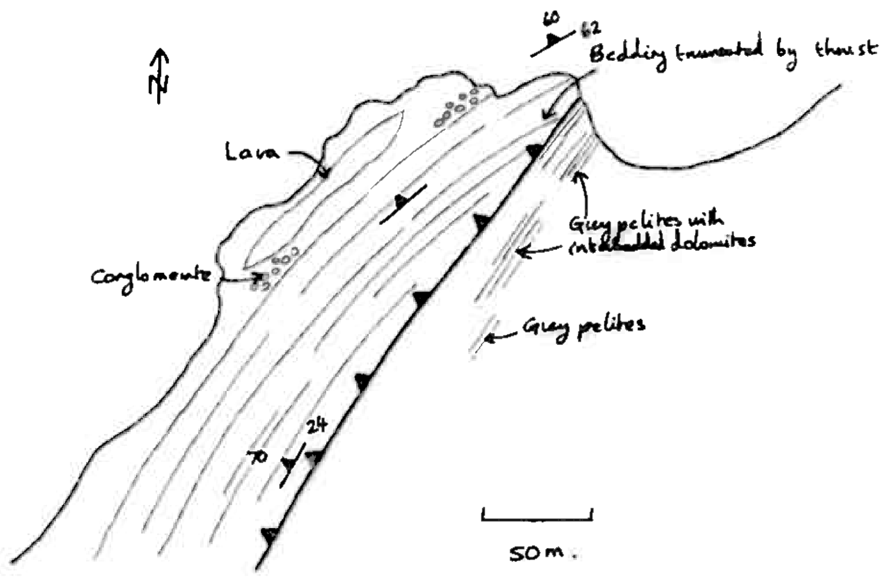


Fig 9. Marked truncation of bedding in Vargsund Formation dolomite on the coast just west of Neverfjord.

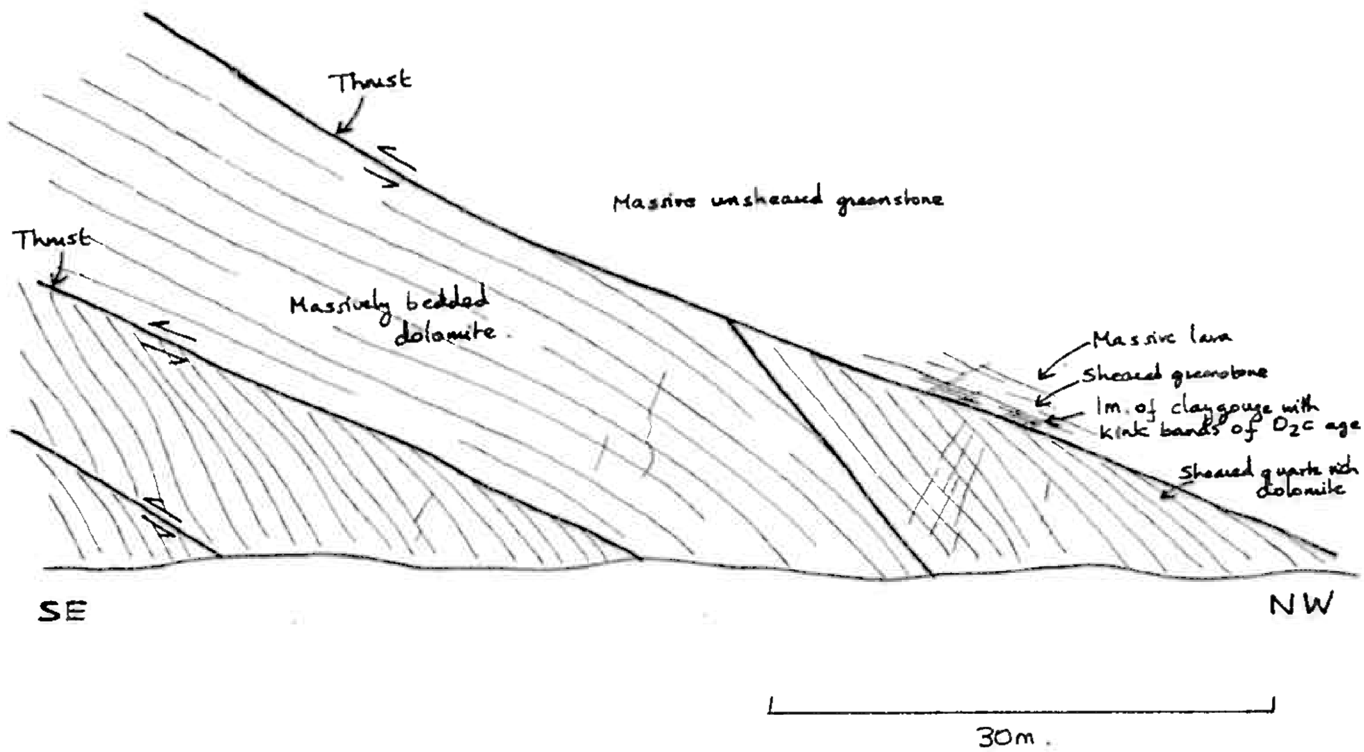


Fig 10. Section in the cliff behind the fish factory and quay at Kremkluben showing the complexity of the thrusting in dolomite which has been overthrust by greenstone during the Caledonian D_1c event.

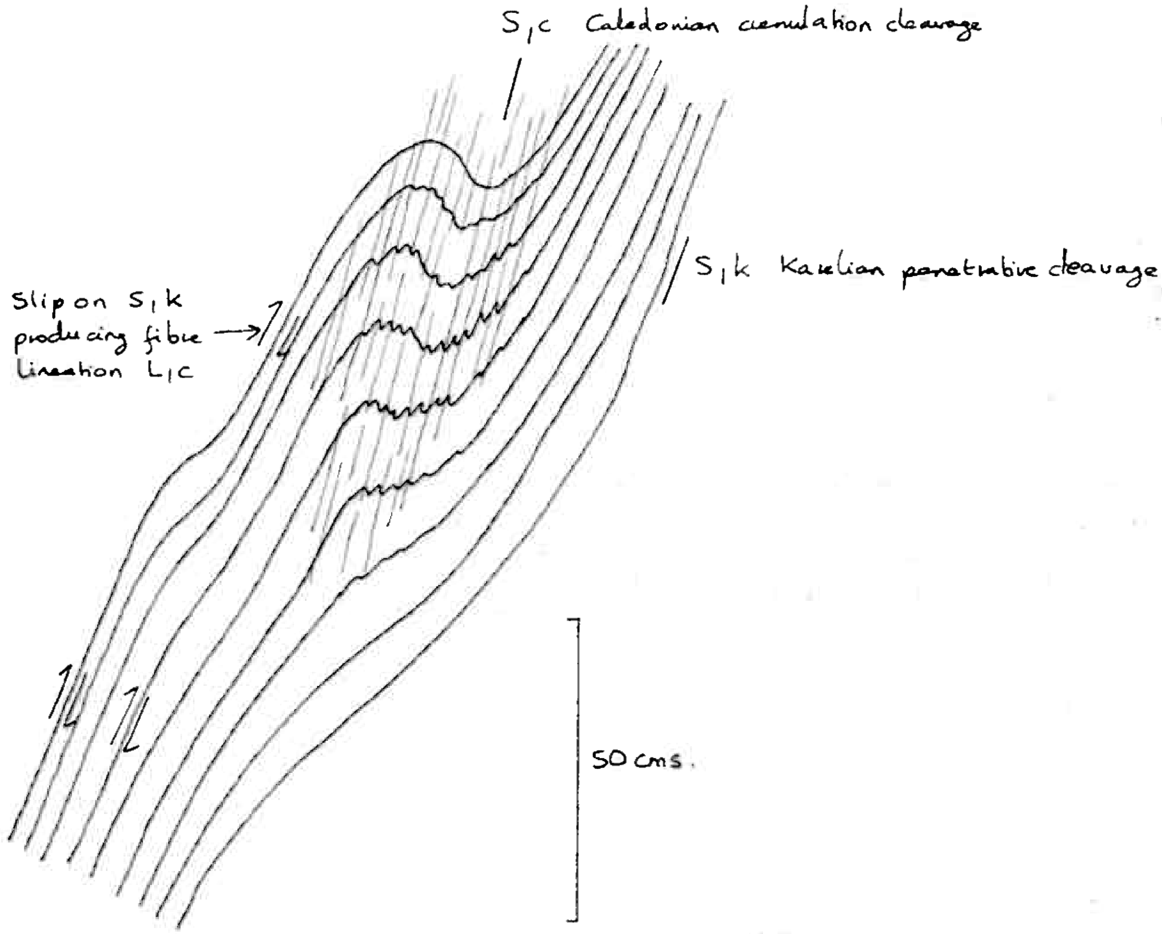


Fig. 11 Caledonian D1c fold of cleavage (S1k) in Kvalsund Fm. slates unconformably below the EoCambrian at Porsavann.

Precambrian basement rocks and then overthrust by the Kalak Nappe Complex. At no time during the Caledonian orogeny does metamorphic grade appear to have risen above muscovite grade in the Lomvann Formation. Reworking of the basement rocks was mainly brittle in nature, producing the north-west dipping break-thrusts of the coastal district and cataclasis in certain areas.

1. First phase of deformation (D_1c)

The first folds of bedding in the Lomvann Formation are associated with a weak slaty cleavage (S_1c) dipping at between 55 and 80^o to the north-west. This is very nearly coplanar with the cleavage (S_1k) in the Precambrian rocks below the unconformity, and the latter may well have been rejuvenated at this time. Evidence for continued extension in the Precambrian cleavage (S_1k) comes from a well marked sub-vertical, fibre lineation (L_1c) developed on that cleavage in the Precambrian rocks of the Vargsund district.

At one or two localities it is possible to see the Precambrian cleavage in the rocks below the unconformity being refolded by open folds with a steeply inclined axial planar crenulation cleavage which has the same orientation as the first slaty cleavage (S_1c) in the Eocambrian rocks (Fig. 11). This is however, comparatively rare, and is likely to have happened only where the Precambrian cleavage was favourably orientated with regard to the Caledonian plane of flattening, so that it could be folded. In most places the Precambrian cleavage was rotated only a few degrees from a steep south-easterly dip to a steep north-westerly one, effectively coplanar with the cleavage in the Eocambrian. Further deformation in the basement rocks was then achieved by extension in the plane of the pre-existing S_1k anisotropy, producing the fibre lineation (L_1c), and cataclasis in suitable lithologies e.g. interbedded dolomite and shales.

Fold style in the Lomvann Formation is controlled by the ductility of the underlying basement and of the sediments being deformed. Where the basement lithologies are more ductile, e.g. dolomite or shale, the deformation of the Eocambrian unconformity was greater than over the more competent lavas and sandstones. The lower part of the Lomvann Formation consists of fairly competent sandstones and quartzites in which open folds are developed. These pass upwards into shales with thin sandstone and siltstone stringers which are much more tightly folded.

The north-westerly dipping thrusts at Porsa and elsewhere along the coast of the Vargsund(Fig.10) were a consequence of this first phase of deformation because the thrust fabric at Porsa is refolded by kinkfolds of an orientation and style typical of D_2c.

2. Second phase of deformation (D_2c)

The second Caledonian event in this district was the emplacement of the Kalak Nappe Complex across the basement and its autochthonous cover of Eocambrian sediments. The minimum distance for the translation of the allochthonous elements of the Kalak Nappe Complex towards the south-east

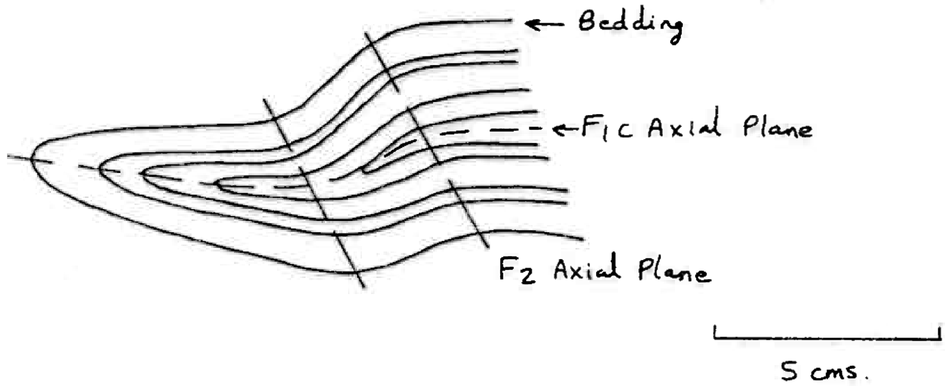


Fig. 12. D_{2c} kink folds refolding F_{1c} in Lomvann Formation west of Porsavann.

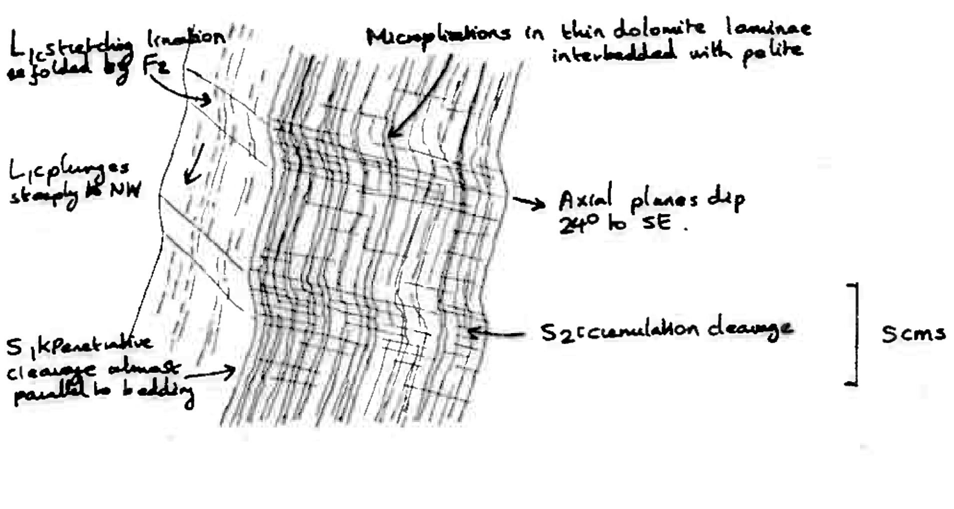


Fig. 13. Small scale F_{2c} folds with associated crenulation cleavage refolding S_{1k} cleavage and bedding in a striped unit of dolomite and pelite.

is of the order of 85 kilometres. This is the distance from the western edge of the Komagfjord Window to the edge of the Caledonides to the south-east.

In the Hermanvann area, the parautochthonous nappe is underlain by a mylonitic zone of variable thickness, passing up into sheared greenstones with a gently dipping foliation. The emplacement of the nappes was recorded in the underlying Eocambrian rocks by the development of kink folds (F_2c) which refold the F_1c axial planes (Fig. 12), and also by sigmoidal tension gashes. Both have a geometry determined by a shear couple with overthrusting from the north-west. The tension gashes may represent dilatant fractures opening in the rock below the nappe and recording incremental movements during its emplacement.

The strain-slip cleavages and folds affecting the S_1k in greenstones along the coast of the Vargsund may have developed during this D_2c event.

3. Caledonian intrusives

Reitan's map shows gabbros intruding the Lomvann Formation at Vuggenes stein, about 5 kms south of Aisaroaivve on Sennaland. These gabbros were sampled and were found to be much fresher looking than any of the other gabbros in the window, with well preserved gabbroic textures. It seems probable that they are of Caledonian age for they appear to pass under the Kalak Thrust Plane. Exposure is very poor in this area and it has not yet proved possible to find hornfelsed Lomvann Formation lithologies, to confirm the map evidence. This raises the possibility that some of the intrusions elsewhere in the window may be of Caledonian age.

VIII Mineralisation

It is apparent that ore-bearing hydrothermal fluids have been generated several times during the geological history of the Komagfjord Window. It is known that basalts contain up to 150ppm of copper, with a more normal range of 25-75ppm. Hydrothermal solutions permeating through a thick pile of such volcanic rocks could take into solution a considerable amount of copper, which would then be reprecipitated nearer the surface of the Earth in cooler rocks. Such hydrothermal solutions could have been generated on a number of occasions -

1. Associated with the Precambrian metamorphism, generated either by anatexis in the Lower levels of the greenstone pile, reactivation of the basement, or both.
2. Development of hydrothermal convection systems associated with the intrusion of the ultramafic, gabbroic and dioritic rocks.
3. Remobilisation of both basement and supracrustal cover during the Caledonian orogeny.

It has been possible to recognise several types of mineralisation, some of which may be closely related.

a. Ulveryggen Mineralisation

Here low grade copper sulphide mineralisation is present in a tightly folded and sheared zone within the Steinfjell Formation. The ore bodies are composed of zones of comparatively rich ore (average 0.75% Cu locally rising to 3% Cu) separated by walls of leaner ore, or barren zones. Reitan describes the mineralisation as being 'scattered patches or grains interstitial to the clastic grains of the country rock'. The ore bodies are aligned SW-NE parallel to the axial planes of the major folds of this district. It seems that copper bearing hydrothermal solutions migrating upwards from the lower levels of the greenstone sequence during the Precambrian metamorphism may have found here conditions which favoured the precipitation of the copper. The ore bodies appear to be discordant to the bedding, so this environmental control seems unlikely to have been a sedimentary feature such as grain-size, content of fine-grained sediment etc. The primary sulphides,bornite and chalcopyrite, have been identified in sandstones of all types from conglomerates (in matrix) through to very fine-grained sanstones. Almost certainly, the control is a structural one, the ore having been precipitated in zones of granulation or shearing, perhaps not obvious on the macroscopic scale. Later remobilisation of the copper may have produced the irregular veinlets and coated joint surfaces.

b. <u>Hogfjell Mineralisation</u>

A number of veins of chalcopyrite and pyrite with a gangue of quartz and calcite (the pyritic paragenesis of Vokes, 1957) occur in the volcanics of the Hogfjell Formation. Most are orientated normal to the bedding and the first cleavage S_1k, but their age relationship with the Ulveryggen copper ores is not certain.

c. Mineralisation associated with the intrusive suite

Many gabbroic intrusives have traces of sulphide mineralisation. For example, at the Lappish ritual stone on the road between Neverfjord and Kvalsund, cooling joints and fractures in a medium grained gabbro are coated with epidote, which are in turn cut by calcite veins bearing copper sulphide. The gabbro is itself very rich in disseminated copper sulphide. In this case therefore, mineralisation clearly post dates emplacement of the gabbros, and similar relationships have been observed at Ulveryggen where gabbroic intrusives have been intruded up the weak axial zones of folds.

d. Other disseminated deposits in Precambrian rocks

Disseminated sulphides have been found in small quantities in most of the Precambrian rocks, especially the greenstones.

e. Mineralisation of Caledonian age

There is also evidence for remobilisation of sulphides during (or later than) the Caledonian orogeny. West of Porsavann, below the base of the Caledonian parautochthonous nappe there is a small prospect into the Lomvann Formation. Every hand specimen collected from the associated spoil heaps contains at least a little sulphide. Copper and iron pyrite occur as segregations and veinlets which are transgressive to to bedding and cleavage, and not flattened by the latter, so mineralisation is clearly later than the first Caledonian phase of folding. In this case, remobilisation of sulphides may have been a consequence of high pore fluid pressures during the overthrusting of the Caledonian nappe pile. Mineralisation does not extend into the Caledonian rocks above the thrust plane. Although the amount of mineralisation present here is very small, it is interesting in that it is possible to demonstrate a Caledonian (or younger) age for it.

Conclusions on mineralisation

Although the age relationships are as yet poorly understood, it is however clear that several distinct phases of mineralisation have occurred, each perhaps scavenging sulphide from the previous cycle. It is hoped that the detailed geochemical analysis which is being carried out at the moment will help shed further light on these problems. In particular it is hoped to define zones which have acted as sulphide donors and receivers so that a geochemical model can be derived from mineralisation within the window.

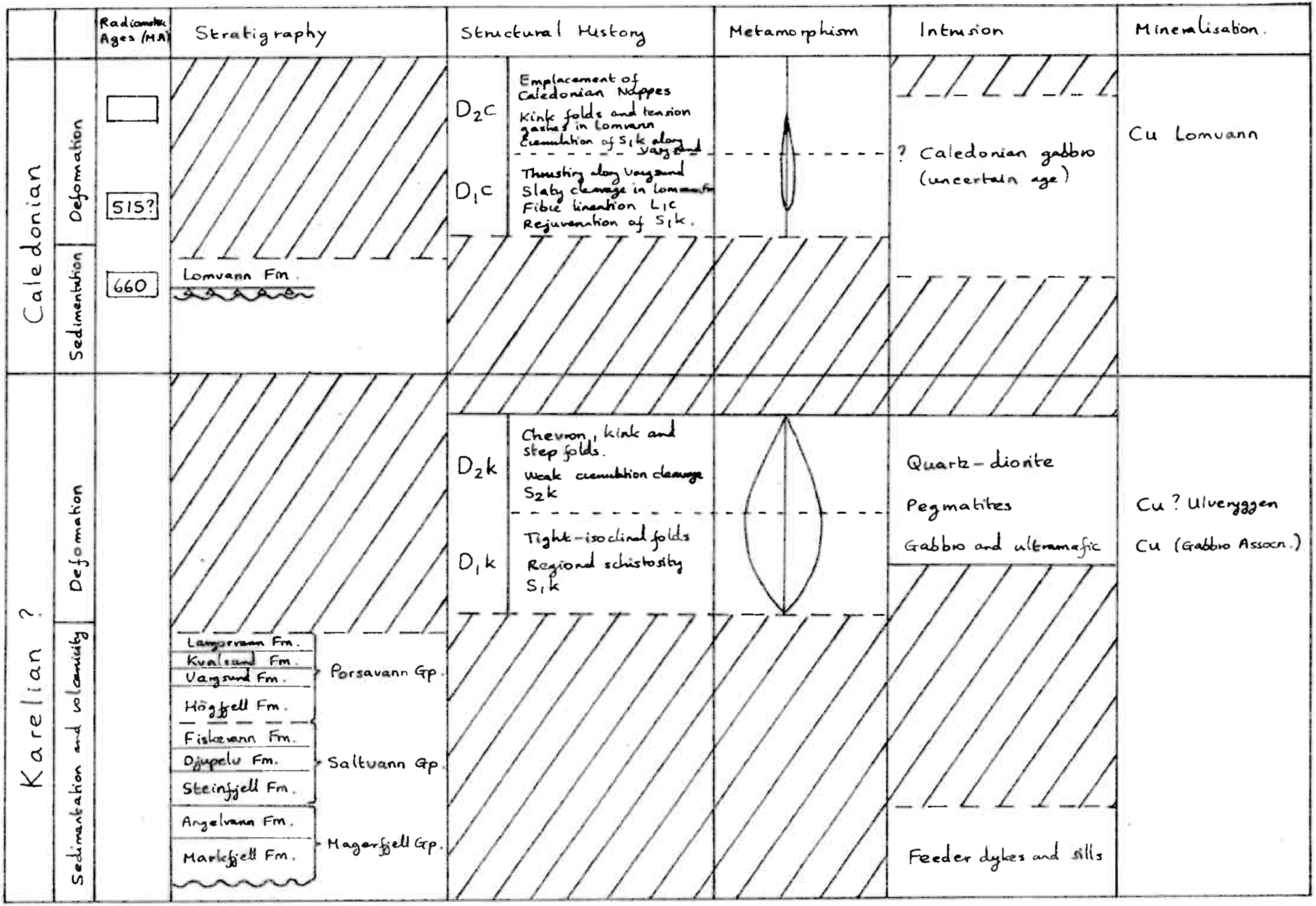


Fig. 15 Brief Summary of Geological History.

Future work and aims

In the final year of this studentship the information on the structural, metamorphic and mineralisation history gained by conventional techniques will be integrated with data from geochemical analyses being carried out at present. Trace element data, in particular, should shed considerable light on the environment of origin of the volcanic rocks, and show how the chemistry of the rocks has altered throughout their geological history.

In addition it is intended to carry out Rare Earth Element studies to investigate the petrogenic evolution of the rocks of the area. Radiometric dating will be used to date certain key events in the district.

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Stratigraphic Column

Parautochthonous Nappe	Caledonian	
Kalak Thrust		
Finely bedded sandstone siltstone and shale Quartzite Quartz conglomerate Tillite (local development)	Lomvann Formation	EOCAMBRIAN
Unconformity		PRECAMBRIAN
Tuff lava, ash etc Shale, limestone, sst Tuffaceous conglomerate	Langorvann Fm.	Porsavann Group
Black carbonaceous shale	Kvalsund Fm.	Porsavann Group
Cross-bedded quartzite Dolomite (stromatolitic, nodular locally) Quartz conglomerate	Vargsund Fm.	Porsavann Group
Agglomerate Pillow lava Graded tuff Limestone Quartz breccia	Hogfjell Fm.	Porsavann Group
? ? Relationship uncertain		
Conglomerate with purple porphyry pebbles	Fiskevann Fm.	Saltvann Group
Greenstone conglomerate	Djupelv Fm.	Saltvann Group
Vein quartz Arkose, feldspathic sst Greenstone conglomerate	Steinfjell Fm.	Saltvann Group
Unconformity ?		
Graded tuff Pillow lava Breccia Basaltic tuff Tuff with limestone or dolomite horizons Lava with relict pillow texture	Angelvann Fm.	Magerfjell Group
Tuff with limestones Greenstone pebbles in a tuffaceous matrix " " " " with increasing content of gneiss pebbles	Markfjell Fm.	Magerfjell Group
? ? Gneissose and granitic basement at depth ?		

Intrusive Rocks

- Metagabbro
- Serpentinite
- Quartz Diorite
- Pegmatite

Geological Symbols

Precambrian				Caledonian			
	S_0				S_0		
	S_1		F_1		S_1		F_1
	S_2		F_2		S_2		F_2

General

Axial plane	Joint plane	Constructed Schistosity	Younging Direction
Cataclastic Fabric	Thrust	Caledonian Basal Thrust	Sense of Displacement
Crenulation Lineation	Fibre Lineation	Pebble Extension	
Lithological Boundary	Inferred Boundary	Gradational Boundary	
Raised beach	Fluvioglacial		
Prospect	Copper Opencast	Settlement	


KOMAGFJORD TECTONIC WINDOW
North-Central District
Finnmark, Norway
Scale 1:20,000
0
1
2
3 Km
N
Neverfjord
Vargsund
Middagstind
Porsa
Saraby
Sarabytind
Gutsvikklumpen
Porsavann
Grubevann
Indrevann
Hermanvann
Midtfjell
N. Saltvann
Saltvann
Steinfjell
Ulveryggen
Fiskevann
Breidalsvann
A
B
C
D
A1
B1
C1
D1