The Geology of the Løkken Area, Sør-Trøndelag

By

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Abstract

The paper describes the rock types and geological structure of the Løkken Area, near Trondheim. The area lies on the inverted limb of a nappe structure overturned to the north-west. This structure has been coaxially refolded. Chlorite grade basic metavolcanics of the Støren Group are perserved from erosion in the core of a synformal second fold, and are structurally underlain by sediments of the younger Hovin Group. Mica schists in the north, traditionally ascribed to the Cambrian Røros Group, are found to be, locally at last, equivalent to the Hovin Group sediments.

Foreword

This paper is the result of field investigations conducted in the Løkken Area in the summers of 1966 and 1967 by students from Imperial College, London, under the supervision of Dr. W. Skiba, who has contributed the following introduction.

Introduction

The Løkken Area is situated approximately 70 km south-west of Trondheim, and forms a westward continuation of the Fjeldheim-Gåsbakken Area, which was mapped by Chadwick, Blake, Rowling and Beswick in 1960 and 1961. Geologically the area is part of a broad structural depression in which metamorphosed Cambro-Silurian rocks have escaped erosion. The area is of considerable economic importance since it contains the Løkken concordant orebody of cupriferous pyrite, which is the largest of the many known occurrences in the Trondheim province.

The classical stratigraphic succession in this region was established through the work of numerous Norwegian geologists. Three main lithological groups are generally recognized:

Hovin Group	L. and M. Ordovician	Shales, sandstones and limestones.
Støren Group	U. Cambrian and L. Ord.	Metamorphosed Basic Volcanics.
Røros Group	Cambrian	Mica Schists.

The distribution of these groups was shown on the geological map by C. W. Carstens (1952) at a scale of 1 : 50,000.

In 1966 a team of student geologists from Imperial College received an invitation from Mr. P. Sandvik, of Orkla Grube Aktiebolag, the company which operates the Løkken Mine, to initiate detailed geological investigations in the Løkken Area. After a broad reconnaissance, it appeared that there were two main geological problems:

(a) Determination of the structural geometry and history of the area in relation to metamorphism and the Caledonian Orogeny. A detailed knowledge of the origin, geological history and structural control of the orebody is essential in the systematic development of the area and in future prospecting.

(b) The spilitic volcanic rocks of the Støren Group exhibit an almost overwhelming variety which has defied attempts to establish a stratigraphic or other subdivision on a petrographic basis. A geochemical sampling was therefore devised to study:

   (i) Variation of some major elements within individual lava pillows of different sizes.

   (ii) Variation between cores of pillows taken from different levels of the same flow.

   (iii) Variation between samples taken from comparable parts of different flows.

The opportunity is also being taken to establish any redistribution of major elements in pillow lavas in different states of strain. This study may contribute to the problem of the derivation of some of the chlorite schists in the area.

A geological map of the area has been made, a simplified version of which appears with this paper, and the general structure and range of rock types are described. The results of the geochemical investigations and the detailed study of deformation will form the subjects of further papers.

The field investigations were carried out in the summer months of 1966 by Messrs. E. H. Rutter, J. May and G. M. Kershaw, and in 1967 by E. H. Rutter, R. Chaplow and J. E. Matthews. The survey of the area considered is largely the work of E. H. Rutter, though the present synthesis drawn on the observations of all concerned.

The investigators are indebted to Messrs. Sandvik, Brøndbo, Nordstein and Sagvold of Orkla Grube Aktiebolag, who instigated the investigations, gave valuable advice on the area, and extended their hospitality which made the joint research possible. We also wish to gratefully thank Prof. T. Strand, Prof. J. Bugge, Prof. C. Oftedahl and Mr. F. C. Wolff for discussions of the Løkken problems.

W. J. Skiba.

Lithological Succession

Two distinct lithological groups are represented in the area:

(a) The Støren Group.

This group is predominantly composed of submarine basic lavas and tufface-ous sediments, with minor quantities of acid volcanic products and cherts. Rocks of this group are intruded by a number of gabbro masses.

(b) The Hovin Group.

This group is predominantly composed of sandstones and shales. Occasional intercalations of volcanic products occur near the base of the succession. Locally, a coarse polygenous breccia-conglomerate forms the basal unit of the Hovin Group. Because this conglomerate contains fragments of rocks typical of the Støren Group, it is inferred that the Hovin Group is stratigraphically younger than the Støren Group.

In the northern part of the area, structurally below the sandstones and shales of the Hovin Group, occurs part of a sequence of biotite mica schists and garnet mica schists which are traditionally regarded as comprising a third distinctive lithologic type in this area, the Røros Group. Because this group is structurally the lowest group of the area, it has in the past been assumed that it is also stratigraphically the oldest group of the area. Sedimentary structures in the Hovin Group sandstones and shales north of Løkken indicate that the rocks young consistently northwards, with no sign of any tectonic breaks in the succession. It thus appears that rocks previously attributed to the Røros Group in the Løkken Area are stratigraphically younger than the sandstones and shales of the Hovin Group.

The rocks of the Løkken Area were deformed and metamorphosed in the Greenschist Facies during the Caledonian Orogeny, but considerable variation in metamorphic grade and amount of deformation is observed across the area.

The Støren Group

The use of the term "Støren Group" to describe a thick sequence of basic volcanic products extensively developed in the Trondheim Region is now well established in the Norwegian Geological Literature, and will be followed here. Rocks of this group are widely developed in the Løkken Area, and are of particular economic importance and interest since the main Løkken pyrite orebody occurs within pillow lavas of this group. As may be seen from the map, these metavolcanic rocks form the core of a large synformal structure, here referred to as the Løkken Synform.

The greater part of the thickness of this sequence is made up of spilitic pillow lavas. There are also intercalations of basic pyroclastic materials, often showing primary sedimentary banding, pillow "agglomerates" and lenses of red jasper. Thin bands of pyritous black shale called "vasskis" are also quite common. Such bands are characteristically associated with the massive pyrite orebodies, though the converse is not always so.

Intercalations within the pillow lavas, and individual horizons within the pillow lavas themselves, are usually neither extensive nor very thick. This, coupled with poor exposure, has made it impossible so far to stratigraphically subdivide the Støren Group by the traditional techniques of geological mapping. A geochemical approach to this problem is currently being attempted, to determine whether zones of diagnostic chemical characteristics exist within the pillow lava series. It is hoped that this approach, coupled with further structural investigations, will lead to a useful stratigraphic subdivision of the Støren Group.

In the less deformed horizons of the Støren Group primary structures and textures are very well preserved, pseudomorphed by metamorphic minerals of the greenschist facies of regional metamorphism. In many cases the shapes of lava pillows can still be used to determine the local younging direction of the sequence. Within individual pillows concentric mineral zoning is generally well defined. The outer rims of the pillows consist of a thin zone, up to ½ cm in thickness, of chlorite. Then follows an epidote rich zone, up to about 2 cm thick, in which epidote filled vesicles can sometimes be distinguished. This zone passes into another made up of a fine grained intergrowth of actinolite and tremolite needles, albite, chlorite and epidote, which forms the entire core of the pillow. This region appears to be mineralogically homogeneous.

There is a restricted occurrence within the Støren Group of acid volcanic rocks. These rocks, as may be seen from the map, tend to form geographically separated areas of outcrop, but occur at about the same stratigraphic level. Two such outcrop areas appear in the area mapped, but it is also known that a similar outcrop occurs in the core of the Løkken Synform about 1 km west from the western extremity of the map.

Mineralogically, the acid rocks consist of a fine grained groundmass of quartz, albite, chlorite, muscovite and sometimes stilpnomelane. Set in this groundmass may be phenocrysts of fresh albite and quartz. Areas of non-porphyritic and porphyritic acid rocks can generally be mapped out on the ground. Following the nomenclature of spilites used for the basic rocks as a result of the omnipresence of albite as the main feldspar, the general richness in soda and the characteristic geological environment, the acid rocks are here referred to as quartz keratophyres.

The quartz keratophyres most commonly form lenticular intercalations within the basic metavolcanic rocks. They vary in thickness from one to twenty metres. Fine banding and fragmentary structures are quite commonly observed in the thinner members, which are generally of the non-porphyritic type. Such rocks are interpreted as acid pyroclastic rocks, whilst the more massive porphyritic rocks are tentatively interpreted as acid lavas or small, sill-like intrusions. Porphyritic acid rocks are also quite commonly observed to form small, cross cutting dykes.

Pillow lava breccias and small pockets of conglomerate are commonly observed within the Støren Group. However, only one such deposit can be truly compared with a volcanic agglomerate. This occurs about 2 km north-east of Storås. The rock is apparently undeformed, and consists of thoroughly angular fragments of basic lava. All the fragments make direct physical contact with their immediate neighbours. The outcrop is surrounded by a homogeneous mass of medium grained basic igneous rock, which is probably intrusive. This rock, which extends along the strike for some 10 km, is quite distinctive by virtue of rosette shaped clusters of actinolite set in a mass of euhedral epidote crystals, albite laths and interstitial chlorite. The rock is fresh and homogeneous in the east, passing through various stages of alteration until it is quite schistose in the west. It may represent a feeder dyke giving rise to the basic lavas, and has been described as albite dolerite on the map.

Finally, large bodies of massive cupriferous pyrite occur within the succession of pillow lavas of the Støren Group. A large, important deposit occurs at Løkken itself, and smaller deposits occur at Dragset and Høidal, etc. Pyrite is a universal accessory mineral in all rocks of this area.

The Hovin Group

Rocks of the Hovin Group which occur in the Løkken Area may be directly correlated with similar rocks in the neighbouring Fjeldheim Area to the east. The Hovin Group is comprised almost entirely of sedimentary rocks, although many of these are tuffaceous. In the Løkken Area the rocks are entirely unfossiliferous, but an Arenigian age is inferred for the group since Arenigian graptolites have been found in rocks at a stratigraphically equivalent level near Fjeldheim by Blake (1962).

The lowest member of the Hovin Group is a breccia conglomerate which immediately overlies the basic lavas of the Støren Group. The conglomerate is highly variable in lateral extent and thickness, and appears to have been derived from the rapid erosion of Støren Group lavas following a period of uplift. Petrographically, the conglomerate is entirely comparable to the laterally equivalent Fjeldheim Conglomerate which was described by Chadwick et. al. (1964).

In the Løkken Area the breccia-conglomerate is overlain by a series of sandstones and shales, which are often banded so that angular divergence between bedding and cleavage may be discerned. Occasionally, coarsening of grain size produces intercalations of conglomerate within this series. Most of the grains in the sandstones are lithic, and they are very poorly sorted. These rocks were clearly laid down in an unstable environment as evidenced by the common occurrence of graded bedding in the sandstone members.

The sandstone and shale series outcrops on both the northern and southern flanks of the Løkken Synform. In the south, these rocks are metamorphosed to chlorite grade and are almost undeformed, and primary sedimentary structures are very well preserved. In the south-west the highest part of the sequence becomes a hematite rich shale. On the northern flank of the Løkken Synform metamorphic grade is high chlorite, and deformation is much stronger. The shaly component of the sandstone and shale series are reconstituted to a chlorite schist. Metamorphic segregation of bands alternately rich in chlorite, calcite and epidote has taken place. The more massive sandstone bands, on the other hand, still exhibit well developed graded bedding. Northwards, the succession passes stratigraphically up into quartz-albite-mica schists via a transition group. Such primary structures as are preserved in the mica schists indicate that they were originally sediments poorer in basic volcanic material than the immediately subjacent sediments. Metamorphic grade reaches biotite subfacies in the outcrop of these schists, and in the extreme north-west of the area mapped almandine garnets begin to appear in the rocks. The way in which the metamorphic grade increases in the direction of stratigraphic younging suggests that the metamorphic isograds cut obliquely across the f_1 fold structures.

Intrusive Rocks

In an early stage of the orogenic activity of the area, possibly at the same time as their formation, the basic lavas of the Støren Group were intruded by a number of gabbro masses. The gabbros were metamorphosed with the country rocks, but the primary gabbroic texture has been preserved in the larger masses, pseudomorphed by new minerals. The smaller gabbro masses have been deformed and have locally developed a schistosity, but the larger masses do not appear to have responded to tectonic forces by internal deformation.

The gabbros were clearly originally composed mainly of calcic feldspar and augite pyroxene. Traces of primary pyroxene remain in some parts of the gabbros, but in most cases it has been completely pseudomorphed by a mixture of tremolite and a pleochroic amphibole which may be hornblende. The calcic plagioclase is replaced by an intergrowth of albite and epidote.

It has been found that the metagabbro masses are heterogeneous. To a greater or lesser extent, primary banding, an alternation of felsic and mafic layers, has been found in all the masses, particularly near the margins. Unfortunately, the metagabbro masses are very poorly exposed, and it has not proved possible to map out these features in detail.

A further interesting aspect of the heterogeneity of the metagabbro masses is the occurrence of coarse granophyric zones around some parts of their margins. Areas where this feature has been found are shown on the map.

To a very limited extent there occurs in this area a very distinctive basic porphyritic rock, which is very similar to the Hølonda Porphyrite described by Chadwick et. al. (1964), and which occurs very extensively several km to the east of Løkken. There exists a controversy as to whether these rocks are intrusive or lava flows. In the Løkken Area small stock-like masses and cross cutting dykes occur together with lenticular bodies, and only in the metavolcanic rocks of the Støren Group. In the Gåsbakken Area the Hølonda Porphyrites are most extensively developed in the lower part of the Hovin Group. Hence, either the Hølonda Porphyrites are entirely intrusive, or their development spans a considerable range of time.

Basic dykes are very common in the Støren Group metavolcanics. Because they are usually thin and exposure is poor, such dykes cannot be traced over great distances. One exception to this generalization is a thick dyke of a dark, fine grained basic rock which occurs some 3 km north-west of Storås, and which can be traced laterally for a similar distance.

Structural Geology

In this area it is possible to distinguish at least two phases of deformation, each of which is represented by a particular association of structures indicative of the particular dynamic conditions operative at that time.

(a) The Earlier Folds, f_1

The most obvious indicator of the early deformation in this area is the presence of a penetrative schistosity. This schistosity is seen to be parallel to the axial surfaces of small folds in rocks which exhibit primary banding particularly well. Such folds can only be seen on the scale of a single exposure where the bedding is thin (10 cm or less), as in the sandstones and shales, or where they affect quartz veins. Small scale folds of f_1 age are never seen in the thick metavolcanic rocks of the Støren Group. However, f_1 folds in these rocks of the order of 100 m wavelength can be inferred from mapped bedding-cleavage and way-up criteria.

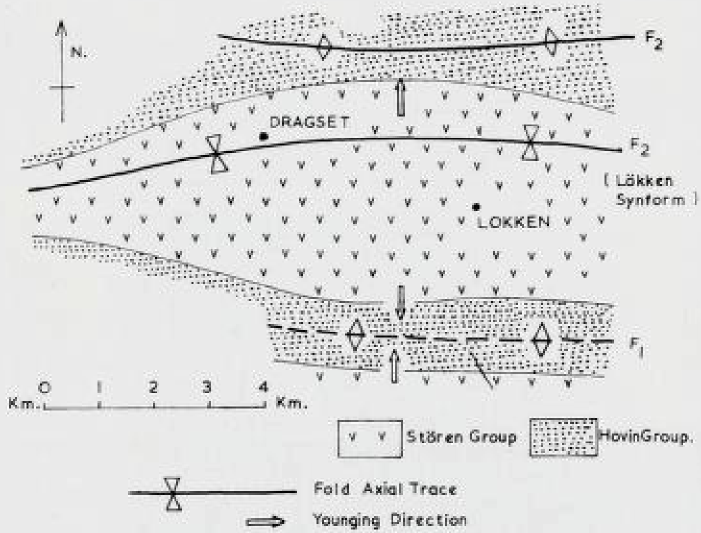
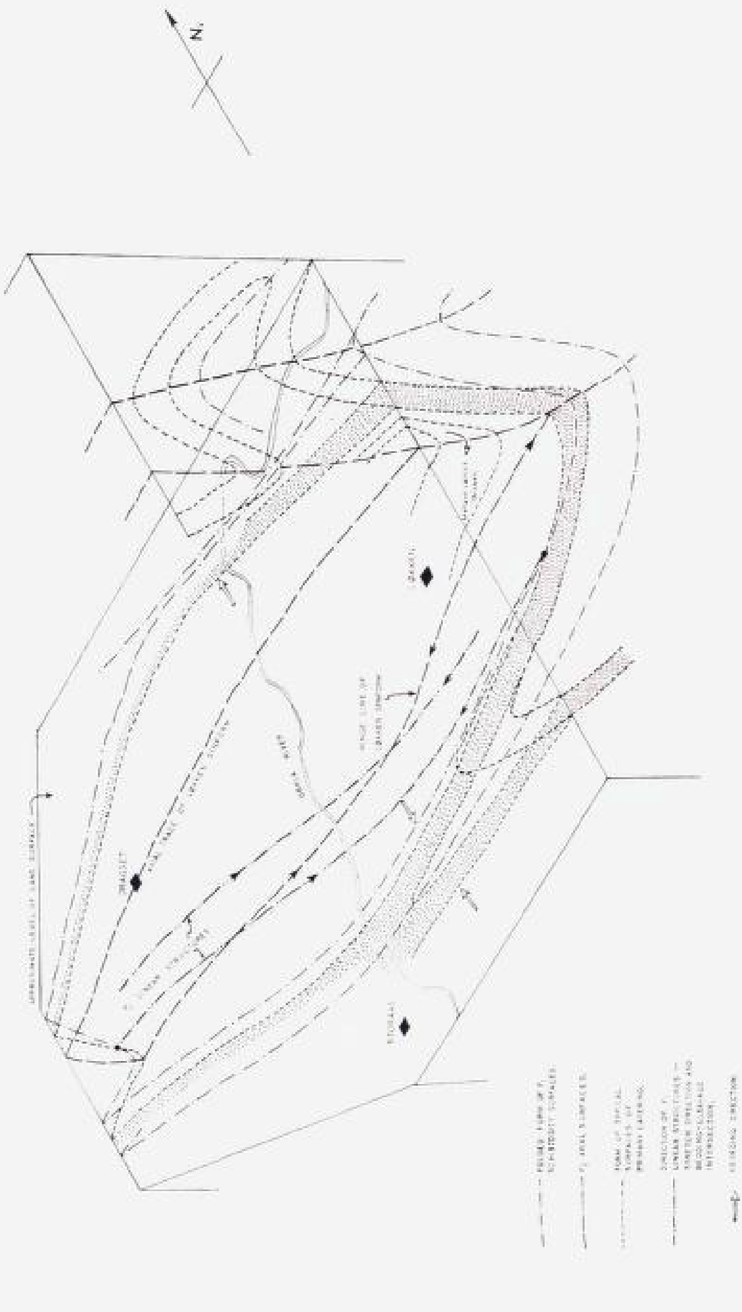


Fig. 1. Simplified sketch map showing the positions of the axial traces of the main f_1 and f_2 folds.

It is possible to map out a set of flat lying, nappe like f_1 overfolds which have been refolded by the f_2 movements. The axial traces of these major folds are indicated on a simplified map (Fig. 1). In the south of the area the form of a tight f_1 syncline in the Hovin Group sediments may be seen. This syncline is found to be antiformal, a fact which conflicts with the findings of Chadwick et al. (1964) along the eastward continuation of the same structure. Fig. 2 is a three dimensional representation of the structure of the Løkken Area. This is the interpretation found to be consistent with the structural data collected.

Only the f_1 phase of folding appears to have produced a significant amount of internal deformation of the rocks of the area, since deformed particles are flattened in the plane of the f_1 schistosity. Pillow structures, spherulites, gas vesicles and conglomerate pebbles are potential indicators of the amount of

Fig. 2. Schematic block diagram to illustrate the geometry of the fold structure in the Løkken Area. In the top right hand corner the vertical plane of the front of the block is extended upwards to show the interpretation of the closure of the f_1 nappe structure. The stippled area is a hypothetical continuous horizon at the base of the Hovin Group to show more clearly the geometry of the f_2 Løkken Synform.



internal strain suffered by the rocks. Such structures are, unfortunately, highly unlikely to have originally been spherical particles, and the non-spherical forms may have possessed an original fabric. Where tectonic strain is very high,

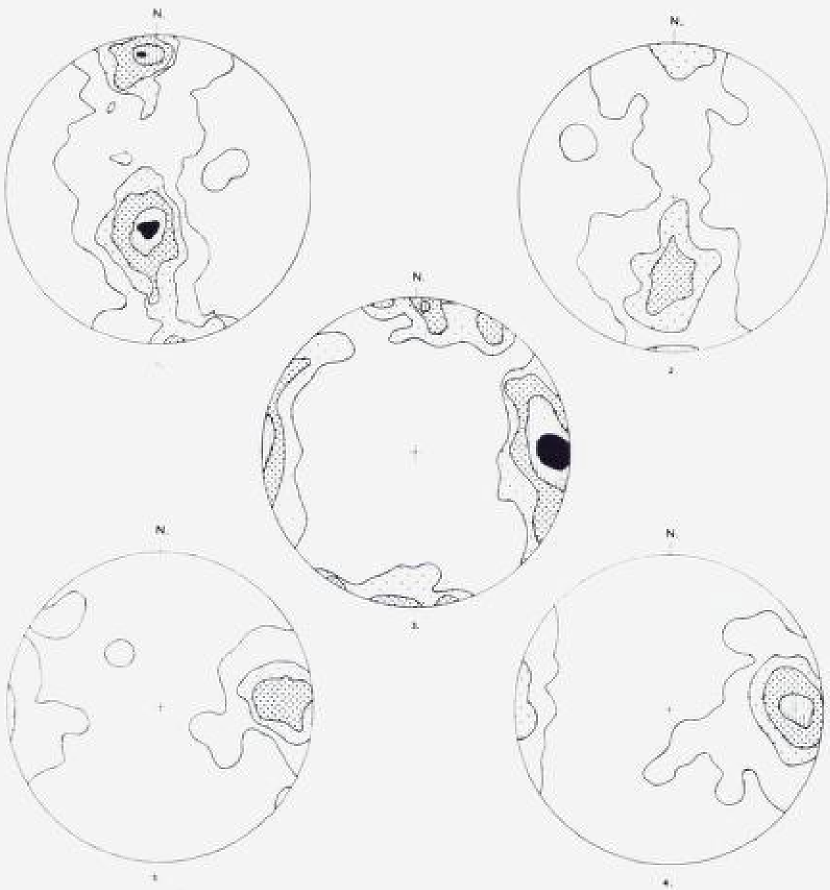


Fig. 3. Equal Area Projections, all lower hemisphere.

(1) Poles to f_1 schistosity surfaces west of the Orkla River. (328 readings)

(2) Poles to f_1 schistosity surfaces east of the Orkla River. (170 readings)

(3) Poles to barren joints over the whole area. (475 readings)

(4) Long axes of deformed lava pillows over the whole area. 174 readings)

(5) f_2 crenulation lineation over the whole area. (99 readings).

The scheme of shading used on all diagrams is: Black — over 30 points; Vertical ruling — between 20 and 30 points; Dense stipple — between 10 and 20 points; Light stipple — between 5 and 10 points; Blank — between 1 and 5 points, per 1 per cent of area of circle.

however, the long axes of the deformed objects may indicate the direction of maximum finite extension in the rocks. Measurements of the long axes of deformed objects, mainly lava pillows, are plotted in Fig. 3 (4). These are found to most frequently parallel the axial direction of the f_1 folds, as indicated by bedding-cleavage intersection lineations occurring in banded sedimentary rocks. Field measurements of the axial ratios of a number of approximately ellipsoidal lava pillows plot in the constriction field ($k>1$) of a deformation diagram of the type used by Flinn (1962). This gives rise to the pronounced linear fabric seen in strongly deformed pillow lavas.

A good mineral elongation lineation is conspicuously lacking in the rocks of this area. Although acicular crystals such as actinolite generally lie in the plane of the f_1 schistosity, they are, with few exceptions, randomly orientated, often producing a "Garben Skifer" texture.

When observations are made of the dip of a pillow lava flow or of a conglomerate outcrop, it is necessary to carefully distinguish primary layering from schistosity. Undeformed pillow lavas tend to be slightly flattened as a result of superincumbent load during cooling after eruption. This leads to a measurable "primary layering" of the flow. During deformation this is obscured and replaced by a flattening of the pillows in the plane of the schistosity, which may or may not coincide with the plane of the primary layering. Fig. 4 illustrates examples which are believed to represent successive stages in the deformation of pillow lavas. The earliest stage of deformation appears to be a rotation and interlocking of the pillows analogous to the packing of sand grains under pressure, and results in the formation of slickensides on the chloritic surfaces of the pillows. Further strain must be taken up by the internal deformation of the pillows. The whole pillow now begins to change shape, as also do internal structures such as vesicles. Eventually a penetrative schistosity is produced. All of these stages are observed in pillow lava flows in the Løkken Area. The pillow lavas are more often tectonically strained than not, and it is only in the south of the area, near Storås, that completely undeformed pillow lavas are found. The amount of deformation is observed to steadily increase northwards.

The basal conglomerate of the Hovin Group is always found to be deformed. It consists mainly of basic volcanic rock fragments and jasper fragments in a finer grained matrix of basic material. Because they are compositionally similar, the basic rock fragments appear to have deformed almost homogeneously with the matrix, producing good linear and planar fabrics. The jasper fragments, however, do not seem to have deformed at all, and the schistosity in the matrix is seen to be deflected around these rigid particles.

(b) The Later Folds, f_2

Unlike the f_1 folds, the f_2 folds do not appear to have produced strong internal deformation of the rocks. There was no associated metamorphism. The large scale flexure of the Løkken Synform (a synformal anticline) is the most important f_2 structure. In the north of the area lies a complementary antiform which is not so well defined as the Løkken Synform.

Angular relationships of the sufaces of the Løkken Synform are plotted in equal area projection in Figs. 3 (1) and 3 (2). These show the fold to be open, with an apical angle of about 85 degrees, essentially planar limbs, and a sharp hinge. The geographical distribution of dip values of the f_1 schistosity surfaces indicates that second order minor flexures of the order of 100 m wavelength occur on the more gently dipping parts of the f_2 major structures, for example on the hinge and southern flank areas of the Løkken Synform.

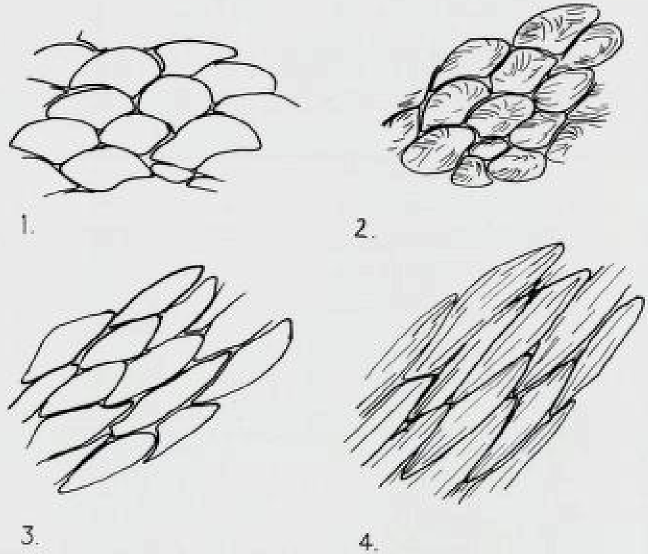


Fig. 4. Illustration of the proposed pattern of the progressive deformation of pillow lavas.

(1) Undeformed pillows slightly flattened in the plane of primary layering.

(2) Rotation and packing of pillows in the early stages of deformation. Slickensiding of chloritic rims.

(3) Internal deformation of pillows. Flattening produces a fabric which eventually overrides the primary fabric.

(4) Strong stretching and flattening of the pillows; imposition of a penetrative schistosity.

In the more schistose rocks a linear structure produced by crenulation of chlorite and mica flakes is consistently developed. This linear structure appears to be coaxial with the local plunge direction of the major f_2 folds, and measurements of this structure from over the whole area are plotted in equal area projection in Fig. 3 (5). It should be mentioned that other, less systematic, coarser crenulations have been observed in the schists. The significance of the latter structures is not yet understood.

In the flatter parts of the limbs of the complementary antiform north of the Løkken Synform is often observed a good crenulation cleavage which intersects the f_1 schistosity to form the f_2 lineation. This cleavage is almost vertical, striking east-west, and approximates to the axial surface of the f_2 folds. Small scale minor folds (wavelength less than one metre) of the f_1 schistosity are also quite common in the thinly laminated schists, in contrast to the absence of small scale folds in the more massive basic metavolcanics further south.

When crenulation lineation and schistosity measurements are analysed in subareas (defined by approximately north-south lines through Dragset, Storås and Løkken) it becomes clear that the plunge of the Løkken Synform varies from west to east. West of the Orkla River the fold plunges gently eastward. Between the Orkla River and Løkken the plunge is horizontal or gently westward, and east of Løkken the plunge is once more gently to the east. Similar variations are observed in the plunge of the f_1 structures.

The massive pyrite orebodies tend to occur along a line parallel to the f_1 linear structures, i.e. along a line connecting Dragset, Løkken and Høidal Mines. This line is slightly oblique to the hinge line of the f_2 Løkken Synform. The orebodies themselves are elongate in an east-west direction and tend to be flattened in the plane of the primary layering. It is probable that the marked east-west elongation of the Løkken Orebody is not a consequence of tectonic strain alone; it may reflect a surface feature present at the time of formation of the orebodies, for example, an east-west elongate trough.

It is clear from the asymmetry of the Løkken Synform that considerable variations in the thickness of the Støren Group volcanic pile exist within the area. The thickness of pillow lavas in the steeply dipping northern limb of the synform is considerably less than in the more gently dipping southern limb. It is concluded that the metavolcanics thin rapidly northwards and less rapidly westwards, and that this has led to a well defined axial surface trace of the synform very close to the contact between the metavolcanics and the structurally underlying Hovin Group metasediments.

(c) The Late f_2 Thrusts

The f_2 folds appear to have formed in a less ductile environment than the f_1 folds by a buckling process. A late stage in the formation of these was the development of thrust faults which allowed relief of material in their cores. Field evidence, in the form of drag folds, suggests that some of these thrusts have moved from south to north and others from north to south. It is possible that opposite senses of movement may exist on either side of some of the more extensive thrust planes. Fig. 5 illustrates diagrammatically the model proposed to describe the evolution of the f_2 folds and thrusts. The way in which thrusts cut across the f_2 fold structures is particularly well displayed in a quarry section near Svorkmo. The most extensive known thrust plane is the one which occurs in proximity to the Løkken orebody. This thrust, which dips gently westwards, intersects the mine workings at various levels. Low angle thrusts are observed at a number of exposures within the outcrop of the basic metavolcanics, but poor exposure makes it impossible to infer how these may be connected.

(d) Faulting and Jointing

The area is cut across by a number of north-south striking faults. These are relatively easily detected since they cross the strike of the rocks, often forming topographic depressions or fault line scarps. Where mappable lithologies meet such features, their contacts with surrounding rocks can often be shown to be displaced. Another well developed set of faults trends east-west, parallel to the local strike of the rocks. These are more difficult to detect, and are generally only shown on the map where they can actually be observed. Small faults are therefore probably a lot more common in this area than the map indicates.

Two systematic sets of joints are developed in the Løkken Area. The better developed set is the cross set, perpendicular to the local plunge direction of the f_2 structure (see Fig. 3 (3)). A systematic set of longitudinal joints is also developed, forming a significant concentration of poles in Fig. 3 (3). Other joints occurring in the area do not appear to be systematic.

Fig. 5. Illustration of the suggested progressive development of the late f_2 thrust faults as a response to the tightening of the f_2 buckle folds.

Summary

Rocks of the Støren Group are the oldest rocks occurring in the Løkken Area. They are preserved from erosion in the core of a synformal structure which trends east-west. The predominant rock type is basic pillow lava with associated volcanic sediments. The volcanic pile is intruded by a number of metagabbro masses.

The Støren Group is stratigraphically succeeded by a series of shales and greywacke sandstones, with the local development of a breccia-conglomerate. Higher in the succession, these sediments, which form part of the Hovin Group, become progressively poorer in basic volcanic detritus.

The entire sequence was deformed and metamorphosed in the Greenschist Facies during the Caledonian Orogeny. The metamorphic grade increases from chlorite grade in the south of the area to the lower part of the garnet grade in the north.

The geological structure is most conveniently summarized in the following outline of the geological history of the area:

(i) Eruption of pillow lavas of the Støren Group. Intrusion of gabbros

(ii) Uplift and erosion leading to formation of the sediments of the Hovin Group.

(iii) Burial by superincumbent sediments.

(iv) Earliest folding, f_1, tight to isoclinal folding. Development of nappe-type recumbent folds with east-west axes, overturned toward the north-west.

(v) Regional metamorphism in the Greenschist Facies. Development of schistosity axial plane to the large overfolds.

(vi) Refolding of the f_1 schistosity locally coaxial with the f_1 folds. Formation of the f_2 Løkken Synform.

(vii) Development of thrust faults in the late stages of the tightening of the f_2 folds.

(viii) Uplift, faulting and jointing.

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LEGEND
RIVER GRAVELS AND LARGER PEAT BOG AREAS
GARNET BEARING MICA SCHIST
BIOTITE BEARING MICA SCHIST
HEMATITIC SHALE
SHALES AND SANDSTONES
BRECCIA + CONGLOMERATE
HOVIN GROUP
BASIC PILLOW LAVAS AND TUFFS
ACID LAVAS, TUFFS AND MINOR INTRUSIVES
AGGLOMERATE
ALBITE DOLERITE
STÖREN GROUP
METAGABBRO
GRANOPHYRE
HØLONDA PORPHYRITE
BASIC DYKE
DIP OF F_1 SCHISTOSITY
F_1 PILLOW ELONGATION DIRECTION
F_2 CRENULATION LINEATION
FAULT
OBSERVED THRUST PLANE
LITHOLOGICAL BOUNDARY
MINE WORKINGS
SVORKMO
LAKSØYEN
DRAGSET
RIVER ORKLA
BJØRNLI
LØKKEN
HØIDAL
STORÅS
N.
GEOLOGICAL MAP OF THE LØKKEN AREA
SCALE
km. 1 0 1 2 3