NORGES GEOLOGISKE UNDERSØKELSE Nr. 262

Multiple Folding in the Sørfinnset area of Northern Norway

By

M. K. Wells
Dept. of Geology, University College London

and

R. Bradshaw
Dept. of Geology, University of Bristol

OSLO 1970
UNIVERSITETSFORLAGET

Editor:
Magne Gustavson

Sentrum Bok- og Aksidenstrykkeri, Trondheim

CONTENTS

ABSTRACT

120 km² of the Norwegian Caledonides have been mapped on aerial photographs on a scale of approximately 1 : 15,000.

Detailed correlation between the folded schist successions has enabled the effects of the earliest movements to be distinguished and assessed more completely than in adjoining areas. This F_1 deformation comprised large-scale, pre-metamorphic nappe development, probably on E-W axes, accompanied by extensive sliding and may be compared with that postulated by Rutland and Nicholson (1965) as forming the basis of the Beiarn nappe which impinges on the eastern margin of the Sørfinnset area.

Most of the more obvious structural components of the Glomfjord nappe complex developed during the succeeding F_2 and F_3 deformations which were accompanied by metamorphism. F_2 comprised two or perhaps more overlapping phases, the earlier of which was particulary intensive giving isoclinal folds again with more or less E-W axes.

Basement gneisses were involved in these folds and provide the core to the F_2 nappes which have envelopes of sparagmite and a wide variety of schists of the Meløy Group.

Late-F_3 open folds with steep axial planes and a gentle plunge to the SSW have given the earlier folds an easterly to southeasterly plunge over much of the area and a southwesterly plunge over the rest. Accompanying this late folding there was local tightening in a zone up to a kilometre wide which gives south southwesterly plunging minor structures.

During the late F_2 and F_3 movements a microfolding (strainslip cleavage) was developed.

INTRODUCTION

The Sørfinnset area covers about 120 km² and is situated in the heart of the Caledonides in the Nordland region of northern Norway, about 50 km north of the Arctic Circle and 40 km south of Bodø. It lies in the administrative district of Gildeskål, a town about 10 km northwards up the coast of Sørfjord from Sørfinnset. The name Sørfinnset relates to a group of small villages and farmsteads individually recorded on the 1 : 100,000 topographic map (Meløy sheet) as Finset and Gilset, occupying the only appreciable area of gently undulating low ground in the vicinity. Most of this low ground, and particularly the cultivated part, is underlain by marbles. Elsewhere the relief is marked. It is dominated by outcrops of granite-gneiss which give rise to bare and sometimes vertical rock faces on Bjellatind and Høgstjerna, south and west of Sørfjord respectively, and by alternations of differentially weathered schists and marbles, giving a topography of strike ridges and valleys east of Sørfjord.

The results of reconnaissance survey of the geology of the area made by Holmsen, on a scale of 1 : 250,000, were published in 1932, (Rana sheet) and showed the boundaries of the main formations of granite, gneiss, schist and marble, together with a generalized representation of the regional strike and dip.

The present investigation is based on aerial photographs on a scale of approximately 1 : 15,000. It forms part of a detailed study of the Glomfjord region (covering about 900 km^2) which was mapped mainly between 1952 and 1960 by a number of geologists from University College London, working under the direction of Professor S. E. Hollingworth and Dr. M. K. Wells.

Detailed structural studies of parts of the Glomfjord region adjoining the present area have already been published (Rutland, 1959; Nicholson and Walton, 1963; Holmes, 1966). The area described by Rutland (mapped in part by Ackermann (1960)), provided the first examples of multiple folding to be recognized in the region.

An interim summary of the geology of the whole of the Glomfjord region was presented by the writers in collaboration with Professor Hollingworth to the Norden Geological Congress (1960). More recently Rutland and Nicholson (1965) have published a synthesis of the structure of a much wider area (about 4,000 km^2) which incorporates the Glomfjord region. This has had two important advantages as far as the present work is concerned. Firstly, only a wide-scale review provides adequate means of visualizing the really major structures such as nappes, in proper perspective; and secondly, during its preparation the present authors were able to contribute and discuss their own detailed evidence and the development of their ideas against the broad background that Rutland and Nicholson were providing. It is appropriate therefore to use their review as the starting point and to adopt the major structural/stratigraphical units recognized by them as the basis of the outline map, Fig. 1.

Since no fossils have been found in the intensely deformed and metamorphosed rocks of the area, any stratigraphical correlation has to be based

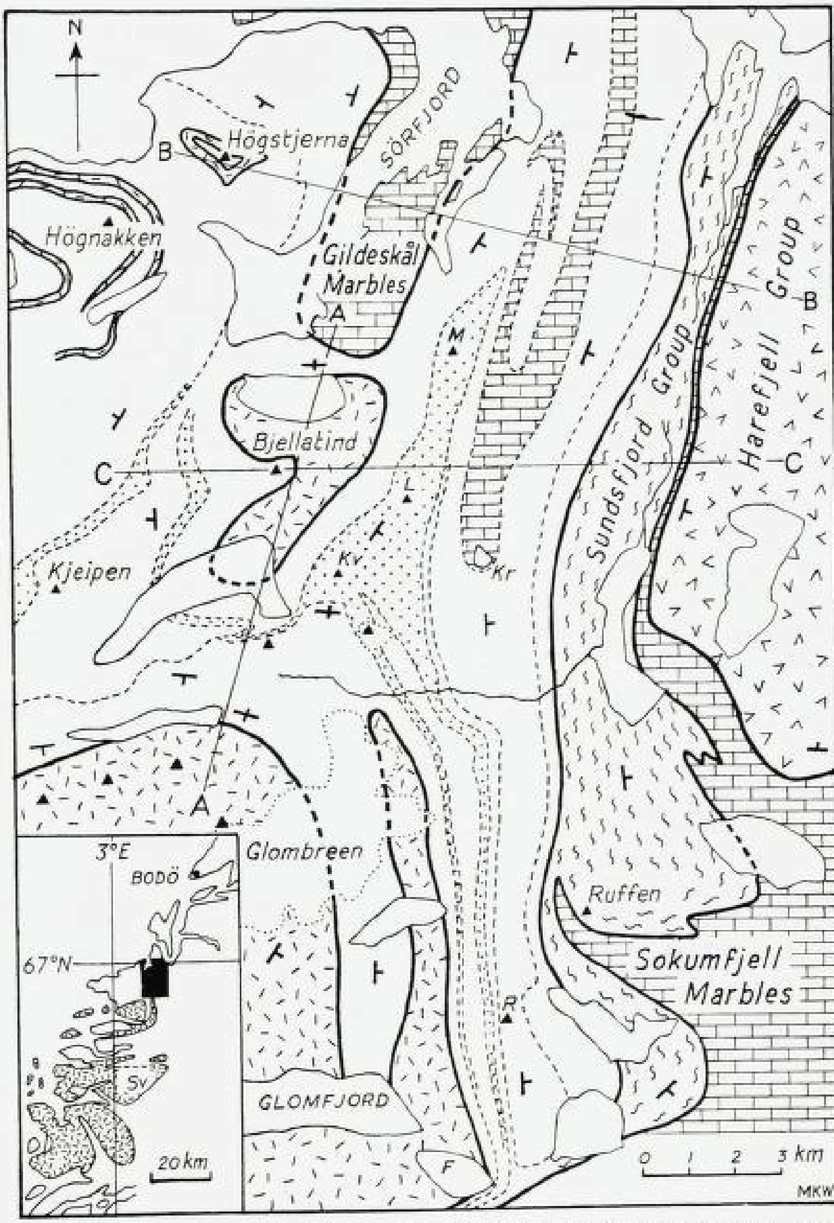


Fig. 1. Tectonic setting of the Sørfinnset area (based on Rutland and Nicholson. 1965).

on broad lithological comparisons with the succession in fairly distant parts of Norway and Sweden. Much of the succession in the following table is based on a comparison with the Oppdal region of central Norway (Rosenqvist, 1941, 1942; O. Holtedahl, 1948).

TABLE 1

Top:	*Harefjell Gneissic Group;* massive and schistose dioritic gneisses and quartz-monzonitic gneisses of presumed volcanic origin.	Ordovician?
	Sokumfjell Marble Group; pure and impure marbles with subordinate pelitic and quartzitic bands.	Ordovician?
	Meløy Group; upper part mainly pelitic with subordinate calcareous schists mainly and marbles; lower part mainly semipelitic and psammatic.	Cambrian and Eocambrian?
Base:	*Glomfjord Granitic Gneiss*	Precambrian?

The Table is taken from the paper by Rutland and Nicholson (1965, p. 77) which also includes a reasonably full discussion of the evidence for original stratigraphy. Additional comment is therefore required on only a few points particularly relevant to the Sørfinnset area. The first concerns the Sundsfjord Group shown in Fig. 1, but not included in the Table. The rocks of this group are pelitic and semipelitic schists with very subordinate thin marble layers. They may very well be related to the upper part of the Meløy Group in an original stratigraphical sense but they seem to form a distinct tectonic unit separated from neighbouring groups by slides. A certain amount of disharmonic movement has almost certainly occurred along most of the contacts between formations of contrasting lithologies, but the positions of major slides and the extent of the movement involved are hard to define.

The second point for discussion concerns the age of the masses of granitic gneiss in the area. Although the greater part of the Glomfjord Gneiss may be derived from Precambrian basement rocks, as indicated in the Table and argued convincingly by Rutland *et al* (1960), it seems likely from the local evidence that the outermost part of the Glomfjord mass (in contact with the envelope of schists), together with the Bjellatind, Fykan and Høgstjerna Gneisses, are granitized representatives of Eocambrian Sparagmite, and therefore possibly related to rocks included in the lower part of the Meløy Group (p. 24). This interpretation does not affect the major structural conclusion that the granitic gneisses form the basal members of local successions and appear in the cores of anticlinal structures.

These and other matters of correlation (e.g. the position of the Gildeskål Marbles shown in Fig. 1) are discussed in some detail in the paper, particularly in relation to the effects of early folding upon the succession.

The structure of the Sørfinnset area is the result of three major phases of deformation referred to as F_1, F_2 and F_3. Favourable exposure and a varied and distinctive series of lithologies have combined to produce an area in which the complexities of the folding can be unravelled with some certainty. Certainly the evidence for the full sequence of deformations is more complete and detailed around Sørfinnset than in any other part of the Glomfjord region, particularly in regard to the earliest phase of isoclinal folding. Knowing that this would form a major part of the present account, Rutland and Nicholson (1965) touched on it only briefly in their review.

OUTLINE OF THE MAJOR STRUCTURES

All three episodes of folding have given rise to major structures, but only those of the later episodes, F_3 and F_2, are at all obvious at first sight. The existence of the F_1 folding becomes apparent much more from its effect in repeating and inverting parts of the local stratigraphical successions than from the evidence of any distinctive structures that may have survived the later deformations. For this reason the folds are introduced in the reverse of their chronological order, and only the conspicuous structures, of F_3 and F_2 age, are outlined in the present section. This is followed by a discussion of the stratigraphical and structural position of the granite-gneisses: a necessary preliminary to an understanding of the complex relationships involving the F_1 deformation (p. 26).

The characteristics of the three episodes of folding may be summarized as follows:

F_3. Large and open folds with steep axial planes and gently plunging axes trending approximately north-south over the greater part of the area. This episode is the one most obviously responsible for determining the regional dip and strike, and as such is the easiest to appreciate from an outline map (Fig. 1). Associated minor folds are scarce exept in a few localities, and generally have the form of concentric drag-folds. These are accompanied by strain-slip phenomena (microfolding) affecting the schistosity of some pelitic schists. F_3 folding overlaps in time with the later phases of F_2.

F_2. The episode mainly responsible for structural development of the major recumbent folds and nappes. This involved very plastic deformation under deep-seated conditions associated with high-grade metamorphism. Most of the minor folds of the area are attributed to this phase: they are similar-style folds, often tightly compressed and grade into ones that are isoclinal. Plunges tend to be more or less parallel to the local directions of regional dip and vary in attitude with the latter: east of Sørfjord the trend is mainly ESE and west of the fjord it is to the SW.

F_1. Completely isoclinal folds or parts of folds, generally accompanied by evidence of extensive shearing and sliding, found in the limbs of F_2 folds or refolded in the closures of the latter. Much of the evidence derives from the detailed stratigraphical relationships as already noted. Because of the extreme intensity of the F_2 deformation, F_1 minor structures are difficult to interpret, but the available limited evidence suggests that the original trend was approximately E-W.

The main F_3 structure of the area is the *Sørfjord* or *Bjellatind Antiform.* This can best be appreciated looking southwards across the low ground formed by the Gildeskål Marbles around Sørfinnset. Along the axis of the fold lies the granite-gneiss massif of Bjellatind (Fig. 2), with a horizontal capping of schists and with traces of concordant foliation or jointing running across the sheer north-facing wall of the corrie which bites deep into the mountain. To the west the schists dip gently westwards off the gneisses: the different lithologies have been etched out by erosion giving a terraced surface and a serrated skyline to the arete of Galtskarttind (see the main map, Plate 1). West of Sørfjord rise the twin peaks of Høgnakken and Høgstjerna which must have formed nunataks during the period of ice cover, and which are separated by a perfect U-shaped valley (Fig. 3). Towards their summits there are thick sheets of granitic gneiss which are very gently inclined to the west, the one on Høgstjerna obviously linking with the lower of the two sheets on Høgnakken. The sheets of gneiss mark the western limit of the Antiform. Further west they are warped into the shallow *Storvik Synform* which plunges gently southwestwards. This is a complementary structure to the Sørfjord Antiform.

The whole of the eastern half of the area lies in the eastern limb of the Antiform, giving a regional dip which, with only a few local exceptions, is consistently towards the east at angles which are mostly between 30° and 50°. East of Sundsfjorddalen the dip flattens and the rocks of the Harefjell Group lie in the broad *Sokumvatn Synform* (Rutland, 1959). The latter is obviously of the same age as the Sørfjord Antiform, it has a similar trend and it refolds earlier structures with approximately E-W trends.

Viewed from Sørfjord, the eastern limb of the Antiform appears to be dominated by a steep scarp feature which extends unbroken from Middagshaugen in the north to Kvittind in the south (see Fig. 1). The ridge

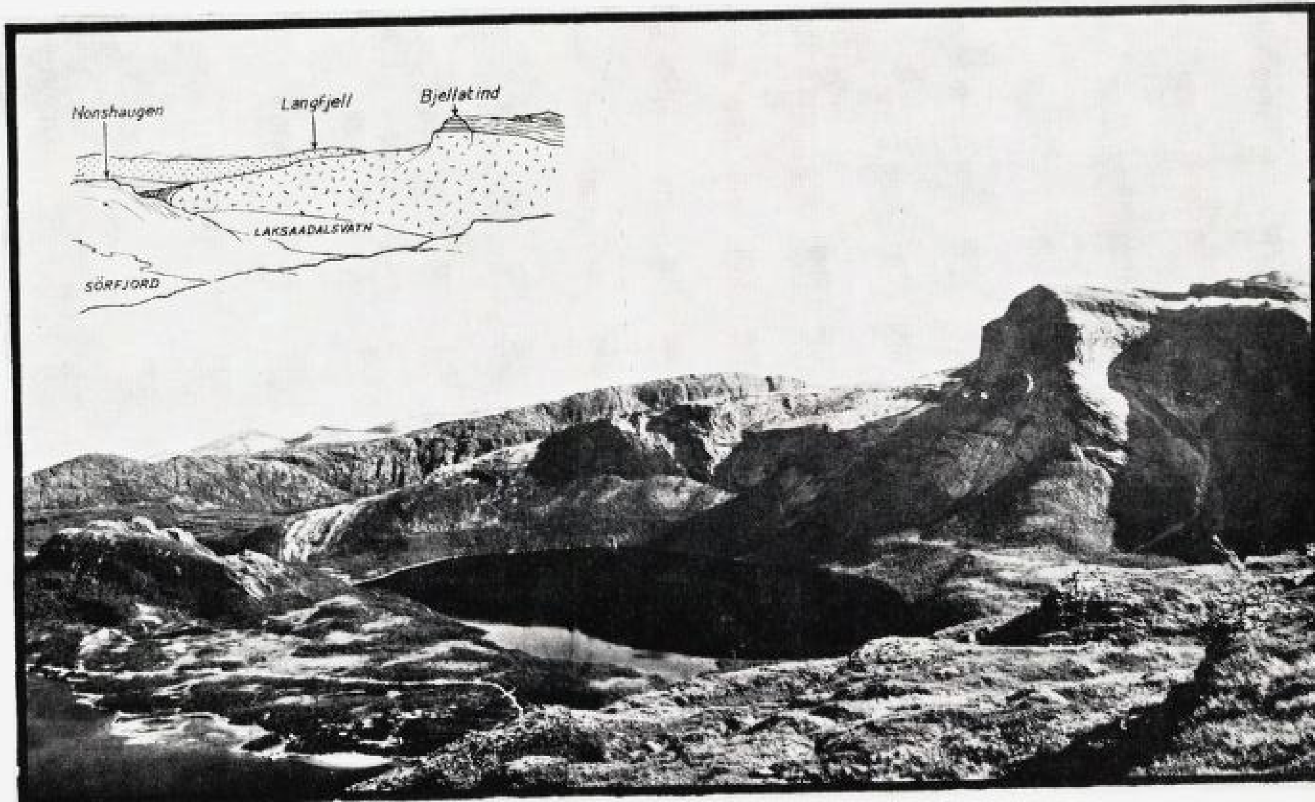


Fig. 2. Panorama looking southeastwards showing the Nonshaugen Fold. The Laksådalen Fold occupies the valley between Langfjell (Silty Schists stippled) and the spur of Bjellatind Gneiss (dashes) which backs Laksådalsvatn.

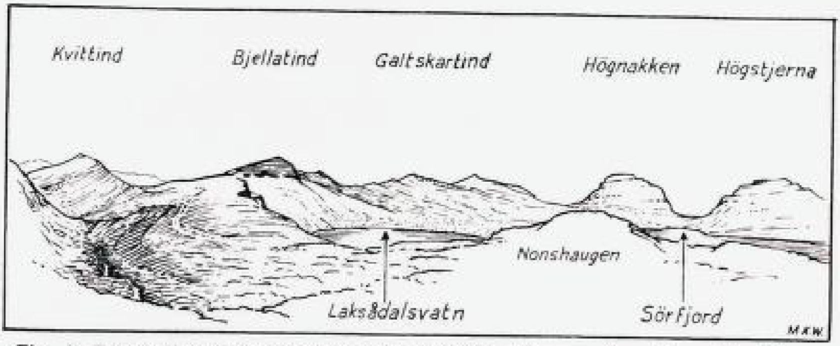


Fig. 3. Panorama of the southern end of Sørfjord drawn from Skavoldknubben.

is capped by an outcrop of bare rock which consists of grey-weathering and massively "bedded" schists that are siliceous and somewhat feldspathic. For convenience these will be referred to as the Silty Schists throughout this account. They are the local representatives of the semi-pelitic and psammitic schists which are recorded in Table 1 as being the main members of the lower part of the Meløy Group succession. Between the Silty Schists and the Gildeskål Marbles, a variety of mainly pelitic and calcareous schists of the Meløy Group outcrops along the lower slopes of the Middagshaugen-Kvittind ridge. This part of the area is difficult of access, being densely wooded and in places mantled with a coarse boulder-scree.

There are many points of comparison between these outcrops with their overlying Silty Schists to the east of Sørfjord, and similar outcrops of mainly pelitic and calcareous schists capped by the thick sheet of granite-gneiss of Høgstjerna west of the fjord. At first sight it appears as if the Silty Schists might be equivalent to the gneisses and should be linked with them over the crest of the Antiform, except that the former rocks are uniformly grey and the latter are tinged with pink. In fact, no such simple relationship exists because of the complicating effects of F_1 and F_2 upon the successions.

Before describing these earlier structures, brief reference should be made to the remaining part of the eastern limb of the Sørfjord Antiform occupying the area east of the Middagshaugen—Kvittind ridge. As already mentioned, the dips and strikes of this part are remarkably uniform except locally near the closures of pre-F_3 folds which are mainly isoclinal. The original sediments constituting the Meløy Group were well differentiated, and as a consequence of metamorphism and repetition of the sequence

Fig. 4. Ridge and valley topography of the Krokvatn Fold, marble belts forming the low ground. The lakes are Djupvatn and Langvatn.

by the early isoclinal folding, they have given rise to a rapid alternation of contrasting lithological types of schists and marbles. Erosion has been extremely selective so that beds only a few metres thick form distinctive features that may be traced with scarcely any interruption over the full length of their outcrops, i.e. for distances of up to 10 or more kilometres. The thicker and more homogeneous schist formations have given rise to long and unbroken ridges, while the valleys have been eroded from the marbles and more fissile schists (Fig. 4). The ridges are mostly steep-sided and the western scarp faces, in particular, may be precipitous. Since the position of each lithological unit can be traced with confidence, the area is ideal for the study of the complex structures that occur.

Rutland and Nicholson (1965) assigned all the structures in the area west of the margin of the Sundsfjord Group, to the Glomfjord Nappe complex. In the outline description which follows, only the major recumbent folds of the complex will be dealt with. These are predomi-

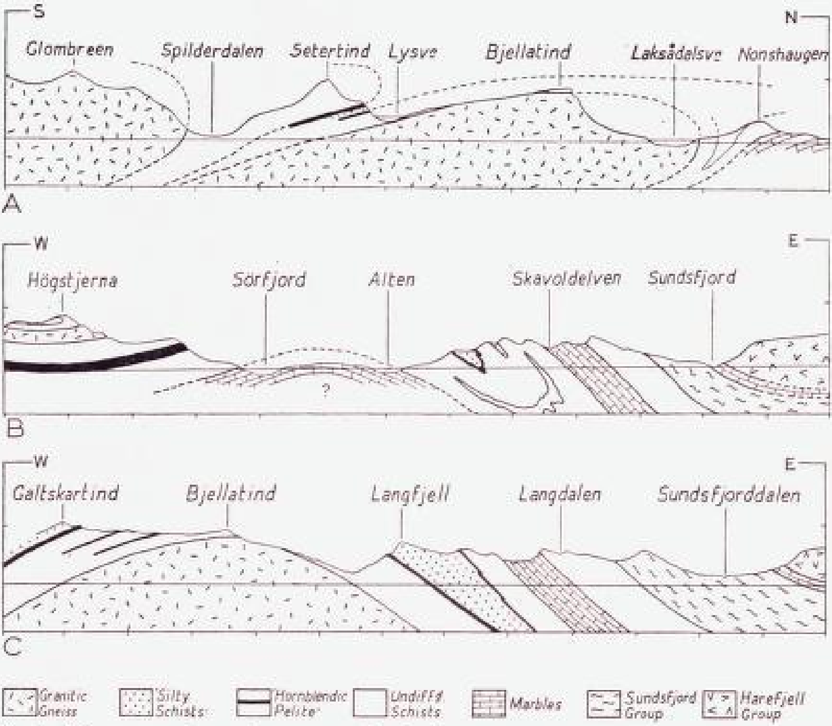


Fig. 5. Diagrammatic sections across the Sørfinnset area. Lines of sections are shown on Fig. 1.

nantly of F_2 age and characterized by sensibly E-W axes. For simplicity it will be assumed that these developed entirely before the F_3 folding and were re-folded by the latter, although, as indicated in the summary above (p. 9) the F_2 and F_3 phases almost certainly overlapped in time. In addition at this stage, the F_1 structures will be ignored for reasons given above, though they also contributed to the eventual form of the nappe structures.

In this account we are only concerned with the envelope of the Glomfjord Nappe complex, and particularly with the part that lies in the eastern limb of the Sørfjord Antiform. An outline of the structure of the whole complex was given by Rutland and Nicholson (1965), and more recently Holmes (1966) has described the core and western part of the envelope in some detail.

The core of the nappe is formed of the Glomfjord Gneisses. These are folded into a large recumbent anticline overturned to the north, as shown in the N-S section of Fig. 5. (This figure also shows the closely comparable structure formed by the Bjellatind Gneiss, over which the main part of the Glomfjord Nappe has ridden).

Although the closure of the *Spilderdalen Fold* is impressively displayed at the eastern end of Spilderdalen, the position and structure of the fold have (in the main) to be inferred. Because of the easterly plunge, the hinge-zone extends above ground-level westwards, and the schists which border the gneisses along the greater part of Spilderdalen lie in the underlimb of the fold and hence dip to the south.

It is difficult to determine the position of the axial-plane with any certainty inside the gneissic massif, partly because of inacessibility of the north-facing slopes of Glombreen and the Spilderhesten range in which much of the critical evidence lies, and partly because of scarcity of distinctive marker-lithologies. In general however, the plane must be inclined to the east, at least as far as the Glombreen part of the structure is concerned. Once the axial-plane passes from the gneiss northwards into the rocks of the envelope, however, its position becomes easier to define. This is particularly true of the extension on the eastern side of the Sørfjord—Bjellatind axis. The axial-plane undulates to some extent, but remains essentially horizontal when traced northwards from the head of Spilderdalen through Steffodalen, Setertind, and Kvittind to Middagshaugen (see Plate 1). The axial-plane passes through, and is shared by, a sequence of closures developed in some of the highly distinctive lithologies of the Meløy Schists. Although these are in a sense all parts of a single great fold, two of them are sufficiently important from the point of view of structural analysis to justify being given separate names. The *Setertind Fold* plunges gently to the ESE and is roughly coaxial with the Spilderdalen Fold. It can be studies in three dimensions: the complete profile-section of the closure is exposed in the scarp face between Kvittind and Tverfjell (Fig. 6), while the core is exposed on Setertind. Furthermore, in the high-level valley or col known as Steffodalen, just south of Setertind, the valley floor has been eroded exactly parallel to the plunge for a considerable distance. This has given rise to an apparently simple sequence of schists with relatively straight and parallel outcrops, despite the fact that local profile sections show the folding to be intensive and exceedingly complex. The Setertind Fold is outlined by distinctive calcareous and hornblende schists which, as explaned on pp. 27-29, play a critical part in the unravelling of the earliest folding history.

The second of the closures in the Meløy Schists to share its axial-

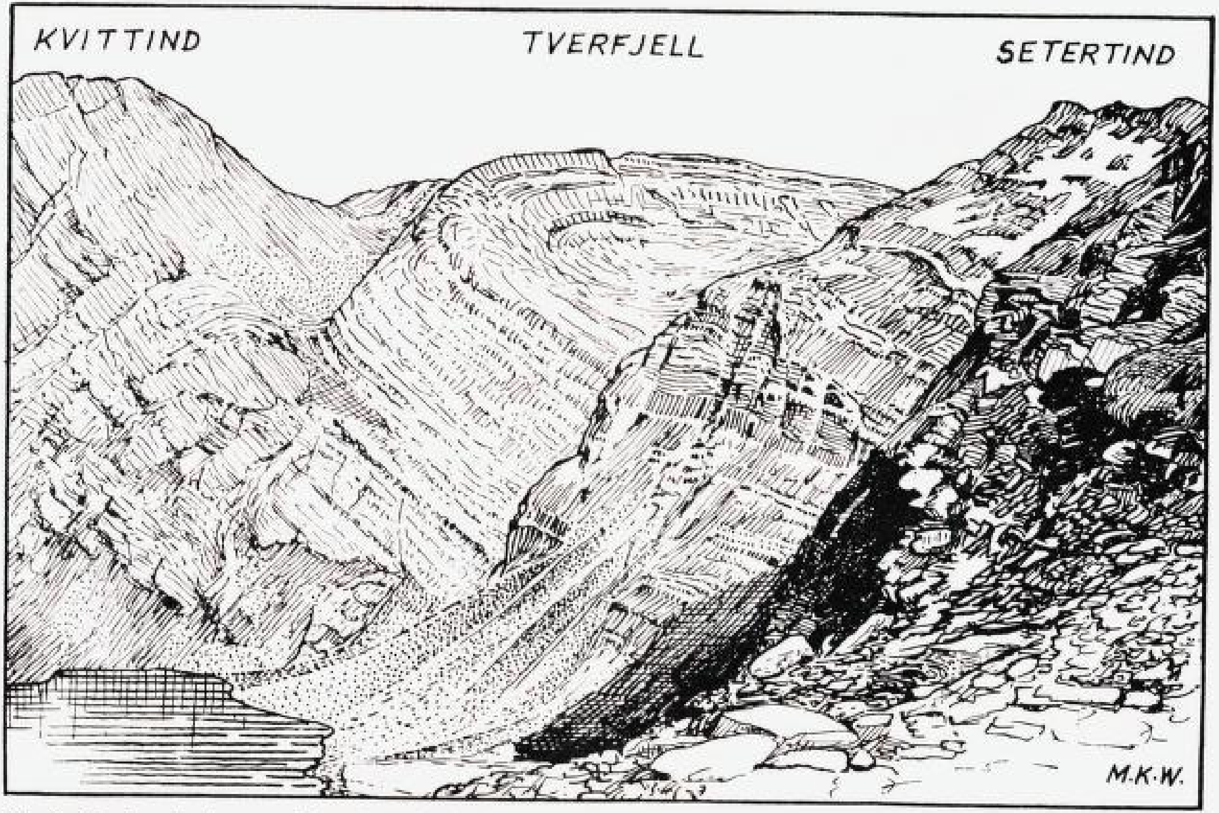


Fig. 6. Northwards closure of the Setertind fold in the vicinity of Kvittind and Tverfjell. View looking eastwards from south of Lysvatn.

plane with the Spilderdalen Fold is termed the *Middagshaugen Fold*. It wraps around the northern end of a core formed by the Silty Schist division of the Meløy Group, whose outcrop is outlined in Fig. 1. Despite continuity of the axial-plane, the plunge of the Middagshaugen Fold is different from that of the Setertind and Spilderdalen Folds, being towards the SSW rather than ESE. This is due not to a gradual swing of the axial trend of a fold belonging to a single generation but to the re-moulding of an earlier fold, essentially of F_2 age and with an approximately W-E axis, by a later deformation, F_3. F_3 drag-folds which plunge gently about 200° become conspicuous in the Middagshaugen area and this part of the major structure has developed the shape of a synform with a southerly plunge. In fact when the original description was written (Hollingworth *et al*, 1960) and before the writers had completed the mapping that links Middagshaugen to Setertind, the whole structure was assumed to have a N-S axis and was referred to as the "Middagshaugen Synform". Reinterpretation of this structure forms a critical part of the present account and is considered in detail on pp. 70—73.

The structure of the envelope of the Glomfjord Nappe east of the Sørfjord—Bjellatind axis can most easily be appreciated from a profile projected down the dominant F_2 plunge to the ESE (Fig. 7). As a glance at the lineation map (Plate 2) shows, the major and minor structures represented in the profile are approximately homoaxial, with the exception of the northern part of the Middagshaugen Fold noted above. The drawing of a profile is only valid here on the assumption that the southerly plunging structures around the Silty Schist are superficial and restricted.

Overlying the Middagshaugen and Setertind structures is a spectacular and perfect isoclinal fold with closures directed towards the south. This is the *Krokvatn-Rebenfjell Fold*. The first name refers to what is probably the most conspicuous fold-closure in the area, where thick marbles of the core are wrapped round by the schists. The marbles have been eroded to form a natural amphitheatre with Krokvatn in the bottom. The second name relates to the extension of the fold southwards into the area mapped by Walton and described by Nicholson and Walton (1963). Both the major and minor folds plunge to the ESE more or less down the dip of the axial plane at angles of between 40° and 50°. There is no doubt from the direction and style of the minor structures, that the Krokvatn-Rebenfjell Fold was formed contemporaneously with the Setertind Fold (i.e. it is essentially of F_2 age), and that is constitutes an integral part of the Glomfjord Nappe complex. In the original account (Holling-

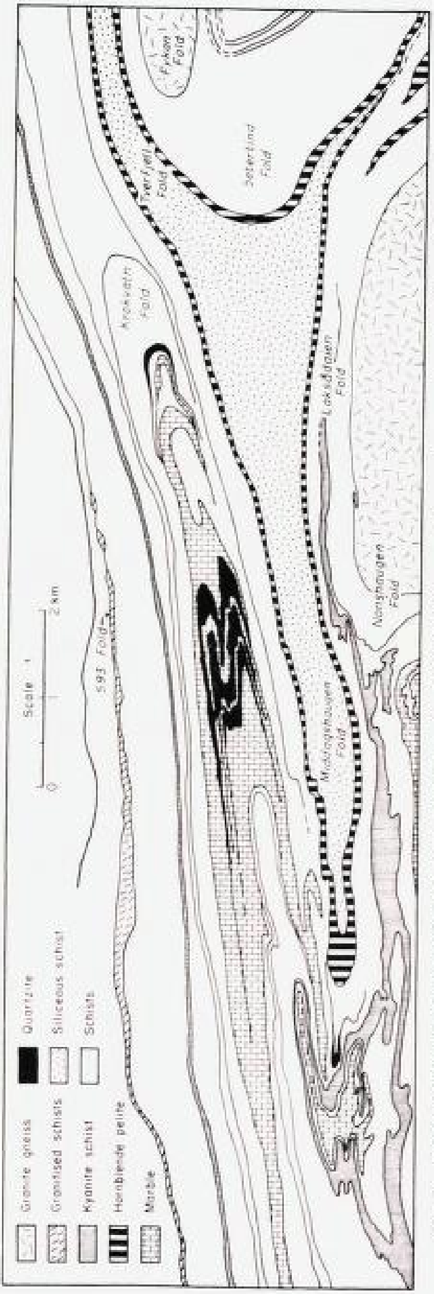


Fig. 7. Profile projected downplunge to a direction of 125° 40', bounded on the west by the line ABC on Figure 9. If the profile were extended to the south, the Glomfjord Gneiss would occur below the Fykan Gneiss in the core of the Setertind Fold. (See Holmes, 1966, Plate 2 B).

worth *et al*, 1960) this relationship was not recognized, largely because the critical Setertind area had not been mapped completely. The Krokvatn-Rebenfjell Fold was then regarded as the outstanding example of an "F_1" isoclinal fold, one that was re-folded by the adjacent N-S Middagshaugen Synform, which was considered to be an "F_2" structure.

The first serious doubt about the very early age of the Krokvatn-Rebenfjell Fold was raised by Nicholson and Walton (1963) from their examination of the relationship between folding and schistosity in the part of the structure south of Rebenfjell. Their experience from the area southeast of Glomfjord was that the relics of the earliest folding were invariably accompanied by an axial-plane schistosity. In the case of the Rebenfjell Fold, however, the schistosity is folded with the bedding in a way that is characteristic of F_2 or later deformation.

Details concerning the Krokvatn-Rebenfjell Fold are given on pp.66-70, and it is only necessary to say at this point that the objections raised by Nicholson and Walton have been sustained and confirmed by the evidence provided by our completion of the present mapping. As indicated, contemporaneity with the Setertind Fold (of F_2 age) has been established and, more important, convincing evidence of an earlier phase of isoclinal folding has been found in both the Setertind and Krokvatn structures (see pp. 29-33). In effect, the discovery of the earliest isoclinal folding has meant that all the later folding has had to be moved up one place compared with the chronological sequence given by Hollingworth *et al.*

Reverting now to consideration of the projected profile (Fig. 7), it is evident that the *Laksådalen Fold* which underlies the Middagshaugen and Setertind structures is similar in many ways to the Krokvatn Fold above them. It also closes southwards and has minor folds which plunge mainly ESE, and show the typical characteristics of the F_2 deformation. However, the fold lineations are sufficiently scattered to suggest that evolution of the fold probably extended from F_1, through the F_2 phase and modified in F_3. The main interest in the Laksådalen Fold lies in its position between the great thickness of massive Silty Schists in the core of the overlying fold and the even more massive Bjellatind Gneisses below. Not surprisingly, the fold is compressed and the greater part of the lower limb has been sheared out by the Lysvatn Slide. Although sliding has had a marked effect on the successions in many parts of the area, this instance is worth noting as being the only one that appears to be cross-cutting (see p. 41; Holmes, 1966).

The Bjellatind Gneisses outcrop in the core of the lowest structural unit in the area. This is formed by the intersection of the Sørfjord-Bjellatind Antiform with a major recumbent fold which is overturned towards the north. This recumbent structure is named the *Nonshaugen Fold,* since the closure is marked by a belt of vertically dipping schists just north of the gneiss boundary and passing through the small hill of Nonshaugen (Plate 1).

Credit for the initial realization of the significance of the Nonshaugen Fold must go to Professor Hollingworth. When the mapping was in its early stages he pointed out the strong similarity that it shows to the Spilderdalen Fold (p. 15), both being great recumbent structures with cores of granitic gneiss. He suggested that analogies might exist with the Pennidic Nappes of the Alps. Subsequent mapping, largely by Holmes and the writers, confirmed the essential truth of the suggestion. The Nonshaugen Fold is not represented on the structural map of Rutland and Nicholson, and because of the choice of line for their section passing through Bjellatind (1965, Fig. 5 A) the recumbent nature of the fold is not revealed. The possibility of distinguishing a "Bjellatind Nappe" from an overlying Glomfjord Nappe was not considered. As far as the core of the structure is concerned, such a distinction might well be justified since only the exposed tip of the gneissic mass can be seen but this may extend in depth to form a unit of a size and structural significance quite comparable with the Glomfjord Gneisses. However, no structures are visible that might be related to the envelope of a "Bjellatind Nappe" in the way that the Setertind and Middagshaugen Folds are related to the Glomfjord Nappe. Because of lack of positive evidence, therefore, it is best to regard the Nonshaugen Fold and Bjellatind structures generally as being integrated with the Glomfjord Nappe complex.

The Nonshaugen Fold plunges both eastwards and westwards beneath other structures, so that the axial plane only outcrops in a limited area over the immediate crest of the Sørfjord-Bjellatind Antiform. Consequently the attitude of the axial plane is difficult to determine and its portrayal on a map is almost impossible. The position of the axial trace shown in Fig. 9 must therefore be regarded as merely diagrammatic, designed to illustrate its relationship to that of the N-S Bjellatind Fold. The axial plane cannot be traced from the gneisses into the adjoining schists because of disharmonic movements near the junction and the effects of multiple folding in the schists. This can be appreciated from the triangular area of very complicated structure that has been mapped just east of Nonshaugen. Symmetry of the geology suggests that an area of similar complexity probably exists west of Nonshaugen but it is covered with drift.

Although the Sørfjord Antiform bends the Nonshaugen Fold and is in this sense the younger structure, it is evident from the uniform character of the foliation throughout the Bjellatind gneissic dome that deformation must have continued round the Nonshaugen axis during much of the time the Antiform was developing. The problem of age relations of the folding is dealt with in the concluding discussion (p. 85).

Both to the north and south of the gneisses and their immediate mantle of schists, the structures lying more or less on the axis of the Sørfjord Antiform are difficult to relate to those already described, due partly to the complex interplay of F_1 with the later folding. The areas concerned —

i.e. the lower ground of Gildeskål Marbles and associated schists around Sørfinnset, and the complex mountainous country immediately south of Lysvatn — are described separately in later sections.

Even greater difficulties exist in interpreting the structures occurring on the western flank of the Sørfjord Antiform and associated with adjoining Storvik Synform. Exposures are interrupted by extensive drift and vegetation cover on the low ground while considerable areas of higher ground are inaccessible because of the steep cliffs formed by the sheets of granite gneiss. In parts of the area the schists are crumpled and tightly folded with the development of a prominent microfold lineation plunging gently to the southwest. It should be noted that this direction — which is characteristic of the whole area west of Sørfjord and Bjellatind — is not what might be expected if it had been derived from a later re-folding by the Sørfjord Antiform of F_1 and F_2 structures originally sharing common geometry and trends with folds of these ages in the east (p. 85).

The intensity of the minor folding in parts of the western area suggests proximity to major fold closures. There is, for example, a suggestion of an overturning of rusty-weathering schists near the summit of Høgstjerna above the thick sheet of granitic gneiss in an area difficult of access.

About 2 km west of Lysvatn, Holmes (1966, p. 68) has located the hinge zone of a large recumbent fold. This is his *Kjeipen Synform,* essentially an F_2 structure lying between, and in a sense complementary to, the Spilderdalen and Nonshaugen Folds with their cores of granitic gneiss. It closes southwards and because of its rather flat but undulating axial plane it gives rise to a sinuous axial trace shown in Fig. 8. The fold is surprisingly inconspicuous and its geometry is difficult to determine in the field. This is due to the combined effects of a gentle plunge to the SW, an axial plane which coincides very roughly with the ground surface, and the fairly open nature of the closure. In any given outcrop approaching the closure, the dip changes from a westerly direction in the lower limb, through the vertical to a south or south-easterly dip in the upper limb. There is, however, hardly any deflection of strike. According to this interpretation all the rocks in our area between Høgstjerna and Galtskartind are in the lower limb of the Kjeipen Synform.

The structure is best appreciated from a projected profile (Holmes, 1966, Plate 2 A). This illustrates the great thickness of schists involved in the overturning — of the order of 4,000 m — and also shows how this thickness is made up of only a limited sequence of beds which have been repeated by earlier isoclinal folding and then refolded by the Kjeipen

Synform. The early folding is exemplified by the Galtskartind Fold of Holmes (*op. cit.* p. 73).

Thus the Kjeipen Synform is of composite origin. As in the case of structures east of Sørfjord such as the Middagshaugen Fold, it comprises isoclines of F_1 age and possibly early F_2 which have been refolded in later F_2 times. During this later folding the forces responsible for the F_3 trend shown by the Sørfjord Antiform must also have exerted a considerable influence on the resulting geometry of the structure. In these circumstances it is easy to see why one cannot make any simple correlation between the F_2 structures on the two sides of the Antiform.

Before the earliest deformation, F_1, can be interpreted it is necessary to establish a basis for the primary stratigraphical succession of the area. For this purpose the relationships between the grantic gneisses and surrounding schists need brief consideration.

STRATIGRAPHICAL SIGNIFICANCE OF THE GRANITIC GNEISSES AND THEIR RELATIONSHIP TO THE SILTY SCHISTS

The case for regarding the granitic gneisses in the region as being derived from Precambrian basement rocks has been argued by Rutland *et al* (1960) and recently Holmes (1966) has reviewed the relationship of the gneisses to the metasediments. It is therefore only necessary to emphasize special points relating to the Bjellatind, Høgstjerna and Fykan Gneisses occurring in the present area.

These are all petrographically very similar and compare closely with the gneisses forming the marginal facies along the northern and eastern sides of the Glomfjord massif. Jones has shown that this facies differs from the gneisses forming the interior of the Glomfjord mass and that a narrow belt of more variable rocks, including metasediments such as quartzite, separates the two facies along part of their boundary (Rutland *et al*, 1960).

All who have written about the marginal gneisses of Glomfjord and the sheets of granitic gneiss outcropping round the coast have emphasized their layered character. This is especially well seen in the Høgstjerna sheet, where parallel and well-marked biotite-rich layers maintain individual continuity throughout the full extent of a cliff section over two km in length. There can be little doubt that this feature has been derived from original bedding and that these pink microcline-rich gneisses are of sedimentary origin, as suggested by previous writers. On the north face of the Spilderhesten range which forms the northern margin of the Glomfjord massif, a large recumbent isoclinal fold is picked out by the micaceous layers (see Fig. 8 and Holmes, 1966, Pl. 5). This combines with evidence of refolding of minor structures in the interior of the Glomfjord mass to show that the gneisses have been involved in a tectonic history quite as long as that affecting the surrounding rocks. The history of at least part of the gneisses may, of course, be even longer and more complex than that of other rocks of the area.

Identity of the marginal Glomfjord Gneisses and the Bjellatind Gneisses is suggested not only by their petrographic similarity but also by the fact that they form the cores of almost identical folds (Fig. 5 A) and are mantled by rather similar groups of rocks. A reasonable case can also be made for a close relationship existing between the Glomfjord and Fykan Gneisses, the latter occurring in an early-formed isoclinal fold of probable F_1 origin (Fig. 1). The rocks surrounding the northern closure of this fold appear to be similar to those mantling the Glomfjord massif: the two groups meet to form an isoclinal synform between the gneisses.

No such direct link can be established between the Glomfjord Gneisses and the sheets of granitic gneiss round the west coast. There is little doubt, however, that the conjectural line shown as linking these gneisses in Fig. 8 (after Holmes, and Rutland and Nicholson) is fundamentally correct in its intention if not in local detail. Holmes, (1966, p. 73) considers that a similar sequence of rocks occurs both above and below the thick sheet of granitic gneiss on Skjeggen, suggesting that, like the Fykan Gneiss, this lies in the core of an isoclinal fold. It seems likely that the effects of the early isoclinal folding extended to the Høgstjerna Gneiss. The sequence of rusty weathering mica schists, calc-schists and marbles immediately beneath the Høgstjerna Gneisses is sufficiently similar to the sequence above the Bjellatind Gneisses that one may well be the inverted equivalent of the other.

Therefore the gneisses can be regarded generally as having maintained an original stratigraphical relationship to the adjacent schists despite the extreme tectonism to which the boundary must have been subjected. Gneisses are therefore considered to form the stratigraphical base to all the local successions in which they are involved. In no case, however, can such a succession be followed outwards for any distance from a gneiss boundary before it is affected either by a major slide or a reversal due to isoclinal folding. This is well illustrated by the inversion of the Høgstjerna assemblage compared with that of Bjellatind, the beds between

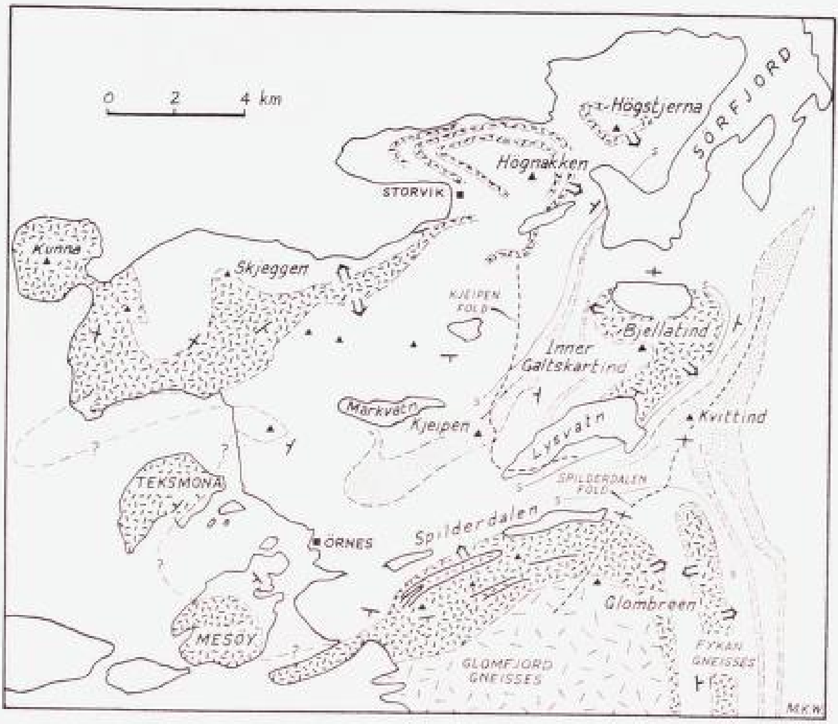


Fig. 8. Map showing the relationship of the granite-gneisses and Silty Schists, based largely on Holmes (1966, Fig. 2) and Rutland *et al.* (1960, Fig. 1). Structural data relevant to the present discussion only is shown, namely the axial traces of the Spilderdalen and Kjeipen Folds, and position of the major slides (S - S). Arrows indicate the stratigraphical order at the margin of the gneisses.

the two gneisses having been affected by a number of early isoclinal folds as shown by repetitions of the succession which crosses the Galtskartind ridge (Fig. 8). This folding — F_1 or early F_2 age, or both combined — accounts for the great thickness of beds refolded by the Kjeipen Fold of late-F_2 age mentioned on p. 21. The extent and significance of sliding in the early deformation is discussed on p. 36. Three of the slides which were recognized by Holmes and which extend into the Sørfinnset area are shown in Fig. 8.

Lastly there is the relationship between the gneisses and the formations of semipelitic to psammitic rocks that occur in the lower part of the Meløy Group and which are regarded as equivalent to Eocambrian Sparagmite. Throughout the Glomfjord region representatives of this formation lie

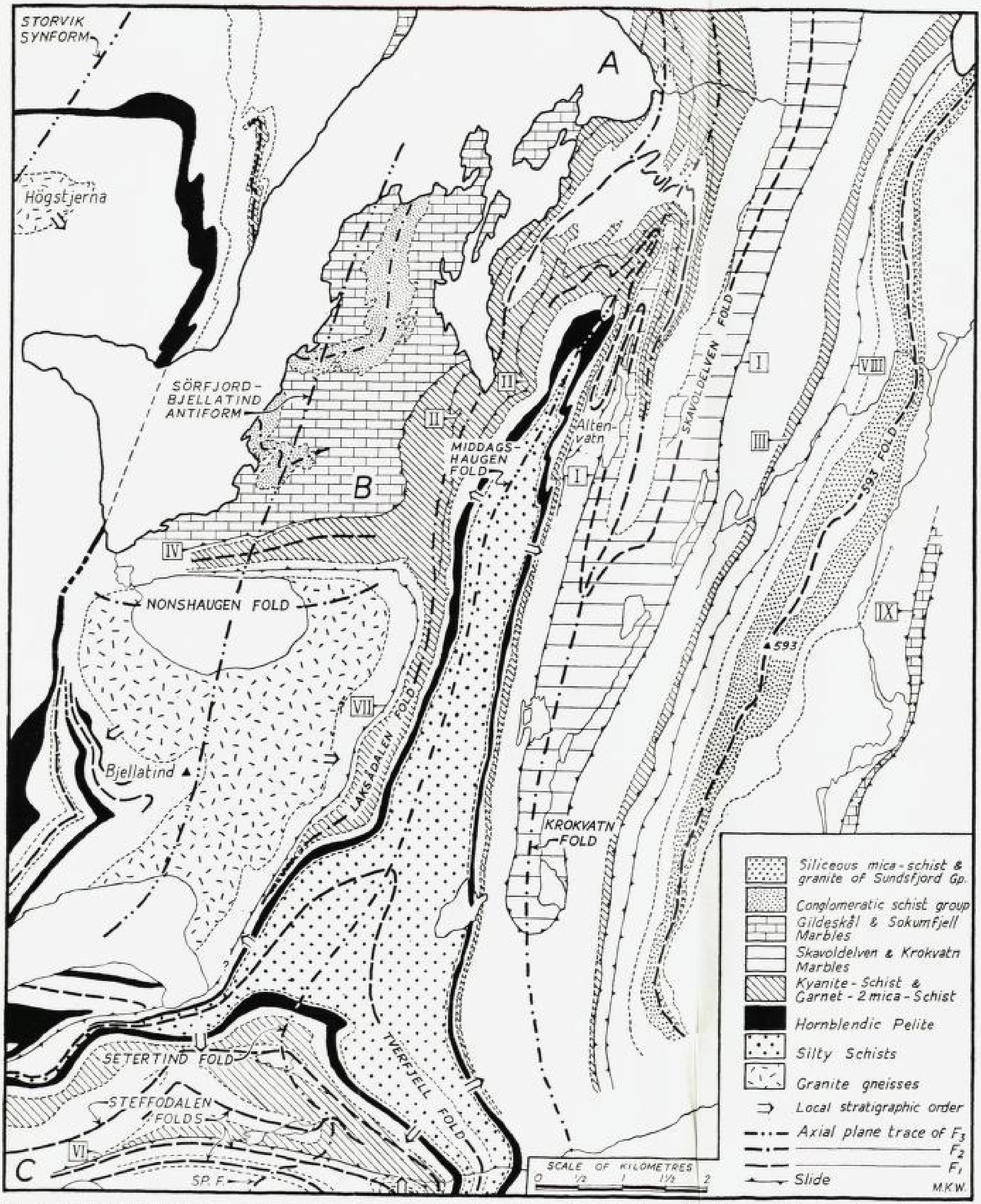


Fig. 9. Analysis of the major structures, showing axial traces of F_1, F_2 and F_3 folds; the main slides; and local orders of succession in the Meløy Group. SP. F. = Spilderdalen Fold.

close to the boundaries of the gneisses as befits a group of sediments thought to have been deposited directly on basement rocks. In the Sørfinnset area the presumed Sparagmite is represented by the Silty Schists of Kvittind (Fig. 8), and although these occur relatively close to the Glomfjord, Bjellatind and Fykan Gneisses, everywhere they are separated from the gneisses by isoclinal folds and slides. The Laksådalen Fold and Lysvatn Slide are the only relevant structures so far discussed (p. 19). It seems, therefore, as if the cover rocks have in part been torn away from the basement as a result of early thrusting and folding. This inevitably throws some doubt on the original stratigraphical proximity of the two formations.

Our recent studies of the Bjellatind and Fykan Gneisses have provided evidence, however, that removes most of these doubts. It has been found that the outermost part of the Fykan body consists of rocks identical with the Silty Schists of the main Kvittind outcrop, and only the central part is the typical pink microcline-rich gneiss. It appears that the schists grade into gneisses with increase in K-feldspars. Incompletely feldspathized schists comparable in lithology to the Silty Schists have also been found in the heart of the Bjellatind mass where they are in the course of conversion to typical gneisses. This kind of evidence makes us revert to a conclusion that was suggested very tentatively in the original paper (Hollingworth *et al*, 1960, p. 34), namely that the marginal gneisses of Glomfjord and those round the Sørfinnset area are the granitized equivalents of originally arkosic sediments (i.e. of the Silty Schists).

The arguments given by Rutland *et al* (1960), Holmes (1966) and recent chemical data by Rutland and Sutherland (1967) all favouring a pre-Sparagmite origin for the gneisses merit more attention than they can be given in this paper. In view of this and the fact that our own evidence includes petrological detail inappropriate in the present account, we have discussed this problem in a separate paper (in manuscript).

The question of the origin of the gneisses does not materially affect the conclusion that the Silty Schists were originally closely related to the gneisses in a stratigraphical sense. These schists can therefore be regarded in the same way as the gneisses as forming the stratigraphical base of adjacent successions.

RELATIONSHIPS BETWEEN STRATIGRAPHY AND STRUCTURE DUE TO THE EARLIEST FOLDING

Although the effects of the later (i.e. F_2 and F_3) movements in folding the boundaries between the rock groups are immediately apparent, evidence of the F_1 deformation is generally hard to detect. This is the main reason why formerly the tendency has been to regard the effects of F_1 deformation as strictly limited, being confined within each major formation as a kind of localized drag-folding which has not substantially re-ordered any major part of the succession (see, *e.g.*, Nicholson and Walton, 1963. p. 31).

Evidence has emerged from a study of the Glomfjord Nappe in the present area, however, which the authors regard as proof of folding on an impressive scale, inverting major parts of the succession before the development of the F_2 and F_3 structure outlined on pp. 9-22.

Major and minor structures of F_1 age are difficult to distinguish from the early phases of F_2 because of the intensity of the latter deformation. Although axial-plane schistosity has been regarded as the diagnostic characteristic of F_1 it appears reasonably certain that with suitable lithologies a comparable structure is developed in the early-F_2 deformation as seen in the Krokvatn Fold (p. 56). On the other hand, there are one or two major isoclinal structures such as the Fykan Fold mentioned in the previous section, which are of F_1 origin but have the schistosity folded round the closure. This may well be due to the fold having continued to develop during the F_2 deformation. Whatever the explanations may be, the phenomena show that the structures alone are inadequate for distinguishing the categories of early folding. There may be an overlap in time between the F_1 and F_2 deformations as there is between F_2 and F_3. There is very little evidence on this point except that microfolded trails of fine-grained inclusions in the porphyroblasts of some rocks of the Glomfjord region suggest that the earliest deformation was essentially pre-metamorphic (Ackermann *et al.*, 1960). This may be taken to indicate that an interval separated F_1 from the synmetamorphic F_2 events.

In view of these uncertainties, the only criterion which is absolutely diagnostic of F_1 major structures is the occurrence of sequences of beds that have been repeated by folding and which occur in the limbs of F_2 folds. In such positions the repetitions cannot be due to the F_2 folding, but must be of earlier origin. To unravel structures in this way with any certainty requires an original stratigraphical sequence of very distinctive rocks. Such a sequence is provided by part of the Meløy Group of schists which surround the Silty Schists of Kvittind and follow the latter in the stratigraphical succession. Two of the thicker units are outstanding as markers: namely the Hornblendic Pelite and a distinctive garnet-two mica-schist which over much of its outcrop is closely associated with a kyanite-schist and boudins of a garnet-hornblende-schist. Since these two units serve to reveal the structure over the whole area west of the Sundsfjord Group (Fig. 1), they and their associated rocks are described in some detail. Most of the rest of the Meløy Group is less distinctive: it includes alternations of schists and marbles as well as the thick marbles that occur within the Krokvatn Fold.

Only the major distinctive formations are included in the following descriptions. Marbles and various kinds of schists form thin intervening layers, as indicated in Fig. 9. Formations in the sequence *a* to *e* can be traced unbroken round both limbs of the Middagshaugen Fold, though the whole succession is attenuated to a thickness of only a very few metres near the closure east of Dorryvatn. Along the whole of the eastern limb of the Middagshaugen Fold, in fact, individual beds are rarely more than a few metres thick and although their boundaries are generally visible there is insufficient space to put more than the limiting beds *a* and *e* on the map. Bed *f* (a kyanite-schist) has not been identified in the eastern limb of the fold, due it is thought to be effects of F_1 folding and sliding. In this area, however, the alternative possibility has to be considered of attenuation of a bed beyond the limits of recognition.

(a) *Hornblendic Pelite.* A pale grey-brown, massive schist with an irregular and poorly-defined foliation and a characteristically pitted surface. Bronzy biotite is the main component, associated with quartz and plagioclase. Irregularly shaped crystals of rather pale garnet are seen in thin section to be rich in inclusions of quartz and calcite, the latter being fairly abundant. The most distinctive component is a rather pale green amphibole occurring as fairly well-shaped porphyroblasts with a somewhat elongated, tabular habit. These are widely spaced and measure about 5 mm across and 1-2 cm long. Whether seen on outcrop scale, in hand specimen or thin section, this is a most distinctive rock and forms the most valuable marker of the area.

(b) *Pelite with euhedral garnet.* This dark schist outcrops in layers only 1-2 m thick and carries an abundance of perfectly shaped dark rhombdodecahedral almandines. Kyanite and staurolite also occur in some parts of the outcrop.

(c) *Calc-schist with quartz laminae.* This has some features in common with the hornblendic pelite. However it contains a different and much darker amphibole and has a dark grey (sometimes slightly greenish) weathered surface which is smoother and less pitted. A distinctive feature is the occurrence throughout of sharply defined laminae of quartz. These are up to 2 or 3 cm thick and extend laterally for several tens of centimetres.

(d) *Biotite-hornblende-gneiss.* This is a more massive rock with slabby jointing parallel to the foliation, and has a light grey weathered surface which on closer inspection appears speckled black and white. The small dark hornblende prisms of this essentially dioritic rock are often lineated. A useful feature for mapping is a tendency for outcrops to be coated with an orange brown lichen. A close similarity in petrography should be noted between this rock and some of the dioritic gneisses of the Harefjell Group (Rutland, 1959) and also with two formations in the Sundsfjord Group (see p. 34). Around Sørfinnset it has proved second only to the hornblendic pelite in value as a marker, and has been given the field term of "hornblendic rock". Because of contrasting competence, unusual boudinage phenomena have developed at the contact between the gneiss and underlying marble in the western limb of the Middagshaugen Fold (Bradshaw and Wells, 1964).

(e) *Garnet-two mica-schist.* A massive brown-weathering and uniformly textured schist, characterized by evenly scattered small garnets (1 or 2 mm diameter) and approximately equal amounts of biotite and muscovite in parallel sheaves finely interbanded with the quartz and feldspar. The texture and mineralogy are favourable for development of a very characteristic kinked puckering of the schistosity, described on pp. 58-64. Ovoid and strongly lenticular segregations of white quartz, 10 or more centimetres across, are characteristic and are particularly well developed around Dorryvatn. These segregations, which occur at intervals of the order of a metre, are difficult to measure in three dimensions; but they appear to have a preferred direction of elongation in this area.

At some levels the garnet-two mica-schists grade into layers of more siliceous and striped schists and even thin quartzites, some of which are large enough to be shown on the map (see e.g. in the closure north of Dorryvatn). These may well be the result of folded repetition. Occasional masses of pegmatite, ranging in diameter from a few centimetres to 1 or 2 metres, are also widely dispersed through the schists; while saddle-shaped bodies of pegmatite up to 3 m thick, split and distend the main quartzite near the closure, the pegmatites being thickest whereover the outcrop is flexured by drag folding (see Plate 1 where the pegmatite bodies are left blank).

(f) *Kyanite-schist.* Even in the absence of kyanite this can generally be distinguished from its neighbour, the garnet-two mica-schist, because the garnets may grow up to about a centimetre across and are more unevenly scattered. Kyanites are generally abundant and conspicuous as bladed porphyroblasts 5 mm across and up to about

3 cm long. They are sometimes slightly bent, but generally straight and idioblastic and often show signs of preferred orientation. Just like the garnets of (b) above, the kyanites are often collected in pockets of soil on the frost-shattered rock. Sometimes, as for example on Nonshaugen, the kyanite occurs in sheaves of prismatic crystals up to 10 cm long, in segregations with quartz. It may be noted that the crystals are blue in all outcrops west of Middagshaugen and around Skavoldknubben; but in what is believed to be the same formation in the eastern limb of the Krokvatn Fold (see Plate 1 and Fig. 9), they are generally colourless to white.

It should be noted that the Hornblendic Pelite is separated from the Silty Schists by a thin group of schists and marbles occupying a gulley only 20-30 m wide round the Silty Schist outcrop. The beds are exposed in only one or two places, such as east of Kvittind where they comprise the following:

1. Silty Schists
2. 5 m lenticular impure marbles
3. 1 m flaggy mica-schists
4. 0.6 m fissile black hornblende-schist
5. 3 m mica-schist
6. 4 m marble
7. ? m hornblende-schists
8. 0.3 m quartzite
9. 15 cm marble
10. 1.3 m siliceous mica-schist
11. 0.6 m striped hornblendic calc-schists
12. 2-3 m coarse garnet-mica-schist
13. Hornblendic Pelite

It seems likely that these beds, shown on the map as a single outcrop, have suffered extreme attenuation. They are correlated tentatively with the much thicker sequence of mica schists, hornblendic calc-schists and impure marbles which have been noted on pp. 22-25 as marginal to the Bjellatind and Høgstjerna and possibly Fykan Gneisses. This would accord with the suggestion that the Silty Schists are stratigraphically equivalent to the gneisses.

The Tverfjell Fold

The first indication of a major phase of intensive folding pre-dating the recumbent and in part isoclinal folding of Krokvatn and Middagshaugen came with the discovery that the whole of the succession *a* to *e* described above occurred in ascending order above the Silty Schists on Tverfjell and in descending order below it. This unequivocal repetition all occurs in the upper limb of the Setertind Fold. The upper Hornblendic Pelite sequence can be traced round Middagshaugen outside the Silty Schist outcrop, while the lower sequence margins the other side of the Silty Schists round the Setertind closure (see Fig. 7). *Thus the great recumbent F_2 fold complex involving the Middagshaugen and Setertind closures has a series of rocks forming its envelope identical with those in its core. This can only mean, that before this fold developed, part of the rock succession had already been inverted by a major F_1 fold.* The core of this latter structure is formed dominantlv of the Silty Schists

This F_1 fold is named after Tverfjell since a series of varied mica- and calc-schists which split the Silty Schist outcrop, terminate in what appears to be a northerly closure of the fold near the summit of the mountain, much of which is covered by a snow-field. However, near the inferred axial-plane of the fold between Tverfjell itself and Ruffudalen, there is an abundance of minor isoclines refolded by tight F_2 folds. Because of the intensity of the refolding it is impossible to determine how far the plunge of the relict F_1 structures differs from that of the F_2 minor folds. The limited evidence available seems to suggest that the F_1 folding had an approximately E-W trend. Apart from the refolded isoclines just mentioned it is difficult to find and identify minor structures of undoubted F_1 age. The sequence of beds duplicated by the Tverfjell Fold extends in parallel and unbroken outcrops for more than 12 km southwards to Fykanvatn, giving the impression of a simple concordant succession (see Fig. 1).

The position of the axial plane of the Tverfjell Fold has not been determined within the great thickness of Silty Schists where it is refolded round the Setertind Fold closure, but is easily located again in the lower limb of the Setertind Fold. Once again the axial plane lies in a layer of Silty Schists sandwiched between opposed sequences of the Hornblendic Pelite group outcropping in the cliff section south-east of Lysvatn where it is inclined gently southwards, eventually to pass beneath the Glomfjord Gneisses.

The Skavoldelven Fold

Evidence for the Skavoldelven Fold (Fig. 9) is not so complete as it is for the Tverfjell example, but is of a similar kind. The structure is preserved in a re-folded form within the Krokvatn Fold, and once again the evidence consists of beds that occur in the envelope of the latter reappearing in the core. This F_1 duplication of beds is revealed mainly by members of the group of kyanite and garnet-two mica-schists noted above.

A thick group of marbles lies between the duplicated schist formations in the Skavoldelven valley and forms the presumed core of the F_1 fold. If the sequence of beds from the Silty Schists through the Kyanite-Schists, etc., to these marbles is a stratigraphical one as seems likely, then the marbles are the youngest members of the Meløy Group in the area and the Skavoldelven Fold can be regarded as a syncline.

Its axial plane is assumed to lie in the Skavoldelven marbles and to be folded with the latter round the Krokvatn Fold and into the narrowing tongue of marbles north of Altenvatn. This is regarded as essentially an F_1 fold, though modified by F_2 deformation. Although the structure hereabouts is very complex and exposure is not good enough to be sure of detail, it seems fairly certain that having reached this F_1 closure of the marbles, the axial plane enters the surrounding garnet-two mica-schist and then passes round the Middagshaugen closure.

Further consideration of the position and significance of the Skavoldelven Fold is made easier by a brief digression into the way our ideas have developed concerning the structure of this area.

Our original interpretation of the complex interference pattern of refolding in the area north of Middagshaugen and around Skavoldknubben mentioned briefly on p. 18. (Hollingworth *et al* 1960, p. 40 and Fig. 2) was based on only two phases of deformation and on this basis the Altenvatn fold was an anomaly. We had not then examined the areas which provided the evidence for the Tverfjell Fold and did not suspect the presence of analogous F_1 structures in the present area. All that had been appreciated, but not explained at that time, was the fact that the layer of garnet-two mica-schist — which forms such a distinctive unit round the Silty Schist core of the Middagshaugen fold — bifurcated on reaching the tongue of marbles near Altenvatn, and that one branch extended round the schists in the core of the Krokvatn Fold while the other branch continued along the upper limb of the Middagshaugen Fold. (Realization that the latter branch extended round the envelope of the Krokvatn Fold came later).

In the heart of the Skavoldknubben structures is a convolute outcrop of marbles completely enclosed by schists. The outcrop is roughly crescentic. The two "horns" of the crescent are formed of southward-closing folds, the eastern one coinciding with the Krokvatn Fold and the western one similarly lying on the line of the Laksådalen Fold (see Fig. 9 and Plate 1). The convex part of the crescent is formed by the Skavoldknubben Closure. In a sense this is obviously a northward extension of the Middagshaugen Fold, but it embraces both the latter and the adjacent

Altenvatn Fold: this is what constituted the anomaly of the Altenvatn fold in the original interpretation. The anomaly disappears if this fold is based on an older (i.e. F_1) structure which has been refolded during development of both the Middagshaugen and Skavoldknubben closures in the F_2 and F_3 phases.

Although the diversity of styles and directions of minor folds in the area suggests the possibility of the three phases of deformation postulated, in general the intensity of the early F_2 movements has been such that typical F_2 minor structures have become predominant even in the case of major fold closures which on other evidence must almost certainly be of F_1 origin. It seems likely that where the angle between the trends of earlier and later folding was sufficiently small and the geometry of the F_1 fold was appropriate, it was "taken over" and developed on almost its pre-existing pattern, instead of being re-folded in any obvious way, by the F_2 deformation. This seems a likely explanation of some features of the Krokvatn Fold described on p. 68, and of much of the Skavoldknubben Fold complex described on p. 75.

Because of this, 'stratigraphical' criteria are critical for establishing the identy of F_1 folds. The case for recognizing an extension of the Skavold-elven Fold — crossing the Middagshaugen axis and becoming involved in the Skavoldknubben complex — rest almost entirely on whether or not the schists and the core of marbles forming the closed outcrop of Skavoldknubben are the inverted equivalents of any of the beds surrounding the Silty Schists of Middagshaugen. This would confirm and extend the evidence provided by the garnet-two mica-schist already noted.

The repetition of the beds should be apparent in a traverse along the line of the Middagshaugen Fold, from the marbles in the core of the Skavoldknubben fold complex towards the Silty Schists in the Middags-haugen core.

From the marbles the sequence is:

1. Skavoldknubben marbles
2. Biotite-hornblende-gneiss
3. Impersistent, thin marble
4. Thin, impersistent development of varied siliceous schists and garnet-two mica-schist
5. Kyanite-schist
6. Garnet-two mica-schist with a layer of pure quartzite in about the middle of the formation
7. Thin development of varied schists
8. Thin marble
9. Biotite-hornblende gneiss
10. Impersistent thin marble.

It appears that beds 1 and 10, 2 and 9, 3 and 8, and 4 and 7 are probably equivalent. The main objection to these correlations might be the great differences of thickness shown *e.g.* by the biotite-hornblende-gneiss, bed 9 being only a few metres thick around Middagshaugen and bed 2 reaching a thickness of one or two hundred metres on the west side of the Skavoldknubben complex. Similarly the marbles in the core of the latter must reach a thickness of at least a hundred metres as shown by the fact that a system of caves and deep swallow holes is developed in them. This is compared in the proposed correlation with a marble that is probably not more than a metre or so thick. Thickness, however, is not really a significant factor in this tectonic environment: the Skavoldknubben biotite-hornblende-gneiss (unit 2) itself shows an enormous variation in thickness when traced round the core of marbles, thinning to only about a metre on the eastern side of the complex. When this evidence is considered with the splitting of the garnet-two mica-schist round both sides of the Altenvatn tongue of marbles described above, it must be concluded that the succession has been repeated by F_1 folding and that this has played a most significant part in the structural evolution of the region.

Evidence provided by the Tverfjell Fold, and with slightly less certainty by the Skavoldelven Fold, thus establishes the importance of a distinct and separate earliest phase of deformation which preceded the development of the conspicuous syn-metamorphic recumbent folds and nappe structures of the F_2 and F_3 phases. This earliest episode affected the rock succession on a scale sufficient to justify the conclusion that it involved the development and transport of nappes (see pp. 38-45), at least in the formations overlying the Basement. Because of the tectonic element introduced into the local successions by F_1 only the earliest folds can properly be designated as anticlines and synclines. If our interpretation of the relative ages of the rocks is correct, the Tverfjell Fold is anticlinal and the Skavoldelven Fold synclinal. One is only justified in referring to the main Glomfjord Nappe structure as anticlinal (*cf*: Rutland and Nicholson, 1965, p. 87) in the sense that the presumed basement rocks which form its core were not significantly involved in the development of the fold until the F_2 deformation. Otherwise the Glomfjord Nappe must be regarded as a re-folded complex of older anticlines and synclines.

There are many indications that the Tverfjell and Skavoldelven Folds or their equivalents extend into the western part of the area. However, the problems involved in separating the effects of the F_1 and F_2 deformations are so great (as discussed on pp. 9-22) and the evidence is so fragmentary that detailed descriptions are not justified.

593 Fold

The possibility was noted in the preliminary account (Hollingworth *et al.* 1960) of there being a folded repetition of beds which are well exposed on the un-named ridge (593 m) west of Storvatn and Sundsfjorddalen. The rocks are all in what Rutland and Nicholson (1965) distinguished as the Sundsfjord Group (p. 8). The suggestion was originally rather tentative because, as a structure, the fold is unconvincing, particularly by comparison with the magnificent Krokvatn Fold, then regarded as also being of F_1 age. Now that we know that this is not a valid comparison and also, from the Tverfjell Fold, that the evidence for the earliest folds is almost entirely stratigraphical, the 593 Fold seems much more convincing.

The fold-core is regarded as being formed of a coarsely crystalline quartz-garnet-two mica-schist which is rich in feldspar, and approaches a pelitic augen-gneiss in composition and texture. Micaceous foliae wrap round the garnets and feldspathic patches which are uniformly distributed through the rock, so that the schistosity is irregular and wavy. This rock forms an outcrop of fairly uniform width (50-100 m) except just north of the 593 m summit where it widens to extend down the eastern flank of the ridge on a spectacular dip surface, and south of the summit where the outcrop breaks up into a series of lenticular masses separated by the effects of F_2 shearing (see p. 42).

Characteristics of the beds on both sides of the core can be summarized as follows:

1. Ten or so metres of gneiss containing abundant granite in discrete lenses and large augen, and, in the western outcrop particularly, characterized by intensive and irregular folding to give 'swirly' foliation.
2. Thin hornblende- and hornblende-biotite-schists.
3. A considerable thickness (up to about 100 m) of semi-pelitic to siliceous mica-schists, in part slightly calcareous and containing little or no garnet. A striking feature of these otherwise undistinctive schists is their association with numerous concordant sheets and lenses of granite which are often several metres thick and tens of metres long. Examples shown on the map are typical of the whole length of both outcrops. There is no intermingling of the schist and granite components. A very distinctive hornblende-biotite gneiss occurs in a 10-20 m thick layer in the western limb of the fold, west of Sirivikfjell. This is closely comparable to the Hornblendic Rock previously described. Similar rocks occur, often as tectonic inclusions, in the eastern limb.
4. A calcareous group comprising rather flaggy mica-schists with a little hornblende, calc-schists, and four or five fairly thick marbles (some

rich in tremolite) are well exposed on the eastern dip slopes of the 593 ridge and again on Sirivikfjell in the north. They are rarely visible in between. Aggregate thickness is of the order of 100 m. The corresponding western outcrop is split by a narrow ridge of schists in its southern half, the western belt lying in the Tveråen valley; but in the northern half two belts cannot be separated and jointly occupy a dry valley extending to Vindvik. Again there is a combination of mica- and calc-schists (the latter including conspicuous tremolite-rock in the western belt) and several marbles (possibly 5), each a metre or so thick. Sheets of granite and pegmatite are present throughout the calcareous group.

5. A 2-3 m quartzite is associated with the eastern-most marble of the eastern belt, and a thin quartzite has also been mapped near part of the western boundary of the western belt.

This marks the end of the sequence which provides positive evidence suggestive of fold repetition. It also marks the limit of the Sundsfjord Group along the western boundary, for it is here that the calcareous series rich in granite adjoins the granite-free schists of the Meløy Group.

On the eastern side of the 593 Fold, the calcareous unit and quartzite, 4 and 5, are again followed by predominantly pelitic schists. These differ from possible counterparts in the Meløy Group by being granitized (Fig. 10). However, although it may be coincidence, it is worth noting that the pelites which outcrop due south of Ågnes are the only ones in Sundsfjorddalen which have been noted as rich in kyanite, and they occur at the appropriate level to be equated with the kyanite-schist (f) of the Meløy Group.

There are considerable grounds for thinking that the Sundsfjord Group is stratigraphically closely related to the Meløy Group as mentioned in the Introduction. This suggestion is made despite the fact that the rocks show distinctive properties of minor structure and texture, and particularly in regard to their association with granite. There can be little doubt that a slide separates the two Groups; but the thrust rocks may not have travelled as far as these structural differences suggest. It appears that any early sliding that occurred was preceded or accompanied by large scale interfolding of the rocks now distinguished under the headings of the separate Groups. Having described the evidence for this early folding it is appropriate next to turn attention to the role of sliding.

Fig. 10. Granitized pelites in Sundsfjord Group south of Storvatn.

TECTONIC SLIDES

No faults or obviously cross-cutting structures have been found in the area which has been dominated by extremely plastic deformation throughout F_2 and F_3 times. Though litological units vary enormously in thickness as a result of deformation, cohesion has in general been maintained between adjacent units which have therefore retained their relative positions and continuity throughout great lengths of outcrop. It is obvious that all lithological boundaries, though based on original bedding, are now tectonic in some degree. The problem is to distinguish (1) instances where no major dislocation is involved and movement has been sufficient merely to meet the demand of differences of plasticity during the F_2 and F_3 deformation, from (2) cases involving extensive dislocation and transposition (Whitten, 1966), particularly during the earliest deformation. Because of the intensive nature of the F_2 and F_3 deformations, all direct evidence of early thrusting and faulting is efficiently masked. Original cross-cutting relationships have been drawn out to give tectonic concordance, while evidence of cataclasis has been largely recrystallized and lost in new schistosity.

E.B. Bailey's non-genetic term 'tectonic slide' is used for all the major dislocations in the area because of uncertainties about their origin. Fleuty (1964, p. 454) has aptly summarized the characteristics of slides, saying that each is a kind of dislocation which is "formed in close connection with folding, which is broadly conformable with a major geometric feature (either fold limb or axial surface) of the structure, and which is accompanied by thinning and/or excision of members of the rock succession affected by the folding".

In the Meløy Group the rock successions affected by the folding are sufficiently distinctive for significant gaps to be identified and for these to be related with reasonable confidence to the affects of early dislocations. It is evident that the earliest folding (e.g. the Skavoldelven Fold) was accompanied by extensive thrusting and it seems probable that the early structures had the form of nappes involving considerable transport. These were probably pre-metamorphic structures which are unrelated, except indirectly, to the present form of the Glomfjord nappe complex. All the boundaries between the Meløy Groups and adjoining formations seem to involve slides. The slide relationship between the Meløy Group and the granitic gneisses with their enveloping schists has been noted briefly in Section 3. Slides can also be postulated along the boundaries with the Gildeskål Marbles and the Sundsfjord Group (Fig. 1). Details of some of these slides are given below and their positions are indicated in Fig. 9.

In the eastern part of the area where the dip and strike is fairly uniform, the criteria used in the west for recognizing gaps in the succession are largely absent. The only large-scale folding is that provided by the conjectural 593 Fold. On the other hand, small-scale structures and the fabric of the schists and gneisses of the Sundsfjord Group indicate that the whole estern belt has been involved in intensive shearing, probably initiated in the F_1 phase and certainly continuing into the F_2 and F_3 phases. Evidence of cataclasis, and even mylonitization, has not been so completely obscured by the late-F_2 and the F_3 recrystallization which characterizes the much-folded rocks to the west.

Because of their differences it is convenient to discuss the western and eastern slides under separate headings.

Slides associated with the Meløy Group

Evidence for a slide (Slide I, Fig. 9) associated with the Skavoldelven Fold is best appreciated from the main map. This shows that while members of the pelitic series — the kyanite and garnet-two mica-schists (p. 28) — occur in both limbs of the F_1 folds, certain other formations are confined to one limb only. This applies to a series occurring between the pelitic series and the marbles round the *envelope* of the Krokvatn Fold (F_2). This series has not been recognized between the pelites and marbles in the *core* of the Krokvatn Fold, that is, in the other limb of the Skavoldelven Fold (p. 30). For the present purpose this group of rocks is referred to as the "semipelitic series". It comprises striped, semipelitic schists, thin quartzites, and garnet-mica-schists. Two members are especially distinctive: a massive, dark garnet-mica-schist containing a little calcite which weathers to give a pitted surface; and a fissile, muscovite and siliceous schist which contains pyrite and is easily weathered to give long strike-hollows on both sides of the Krokvatn Fold (shown by a fine stipple on Plate 1).

The semipelitic series reaches a great thickness on Stepperne where it is in the hinge zone of the Krokvatn Fold; but it dies out just north of Altenvatn.

The northern tip of the outcrop of the semipelitic series is wrapped round by the Skavoldelven marbles in the Altenvatn Fold. As indicated above (p. 30) this has the style and geometry of an F_2 structure modified by F_3, but the relationship between the marbles and the surrounding pelitic schists in this structure was established primarily by the F_1 Skavoldelven Fold. Similar considerations apply to the relationship between marbles and the semipelitic series. Although the latter is locally intensively crumpled (with lineations plunging at about 40° SE) as befits its position in the core of the Altenvatn Fold, the series as a whole does not appear to be repeated by the folding. Thus one can trace the Skavoldelven marbles from south of Altenvatn where they lie structurally *above* the semipelitic series, westwards round the northward-closing Altenvatn Fold and the adjacent S-closing structure when the marbles apparently *cut across* the series, until the marbles — now very much attenuated — link up with a single thin layer of marble which lies structurally *under* the greater part of the semipelitic series. There seems little doubt that the semipelitic series has been cut out against the marbles as the result of an early dislocation associated with the Skavoldelven Fold.

It is impossible to tell how much of the succession has been cut out by the faulting, and what were the original relative positions of the semipelitic series and the main group of marbles in the Skavoldelven Fold. These difficulties arise because of uncertainty as to the exact position of the axial plane of the fold. If this is situated in the main group of marbles as suggested in our initial description (p. 31), then the semipelitic series is confined to one limb. The single layer of marble noted in the previous paragraph would represent a different stratigraphical horizon from the main marbles, and the junction between them would be a faulted one. Alternatively the axial trace of the Skavoldelven Fold may be just within the semipelitic series. Then the single marble layer beneath the latter would be stratigraphically equivalent to some part of the main group of marbles above them: the contrast in thickness of marbles in what would now be the two limbs of the Skavoldelven Fold would be due largely to the combined effects of F_1 faulting and folding.

It appears that with either interpretation, the main dislocation must lie close to the axial trace. Speculation on their positions in the area between Altenvatn and Middagshaugen becomes pointless because of the extreme attenuation of F_1 structures induced by the F_2 and F_3 deformations hereabouts (see p. 31). However, the dislocation probably crosses the axis of the Middagshaugen-Skavold fold systems (Fig. 9), just as the axial trace of the Skavoldelven Fold is assumed to do. Evidence for this is provided by the gap in the succession between Middagshaugen and Skavoldknubben which has been repeated by the Skavoldelven Fold as listed on p. 32.

This brings us to consideration of the tetconic nature of the junction between the kyanite-schist and garnet-two mica-schist of the pelitic series, indicated in Fig. 9 as Slide II.

Evidence of sliding is provided by the distribution along the contact of widely spaced boudins, or more correctly, tectonic inclusions (Rast, 1956). These are formed of a distinctive rock of dark hornblende and deep-pink garnets which average about a centimetre in diameter. They are lenticular or rounded masses of the order of a metre across, and are found scattered at intervals varying from a few metres to several hundred metres along the whole boundary between the kyanite-schist and the garnet-two mica-scist. They have been found all round the Skavoldknubben outcrops, on both sides of the kyanite-schist outcrop which lies west of Middagshaugen, and into Laksådalen. They also occur in association with the garnet-two mica-schist which outcrops on Setertind, helping to confirm that this belongs to the same formation even though its outcrop is quite separate within the area investigated.

The inclusions indicate that there has been appreciable transposition along the boundary between the two schists, but give no indication as to the extent or tectonic significance of the movement. Near Opsal, however, the rock forming the inclusions is associated with a group of rather fissile and striped siliceous schists which intervene between the kyanite- and garnet-two mica-schist (stippled on Plate 1). The same group occurs in much greater thickness both in the extreme north of the area and in the south on Setertind and in Steffodalen (see Plate 1). In the former case the garnet-hornblende rock forms layers interbedded with the siliceous schists. It is therefore concluded that along much of the kyanite-schist/garnet-two mica-schist boundary, shearing has eliminated a considerable thickness of beds, leaving only the garnet-hornblende rock as "balled-up" relics of the most competent rock-type.

Although movement may have started early, as for Slide I, the nature of the tectonic inclusions shows that it extended into the period of metamorphism associated with F_2.

More precise data about the time of at least the later effects of transposition is provided by Slide III. Again this concerns tectonic inclusions and the kyanite-schist, this time the latter's upper boundary in the eastern limb of the Krokvatn Fold. The main component of the tectonic inclusions is a tremolitic rock, and the two largest examples are big enough to appear on the map, due east of Krokvatn. Although the boundary surface of the kyanite-schist is an un-warped plane, schists above are rucked into drag-folds with amplitudes of 10-20 m, and with the tremolite rock and a garnetiferous schist squeezed in to form the cores. The folds plunge SSE at about 25°, and have typical late-F_2 characteristics. Although this proves movement along the slide during late-F_2 times it gives no evidence of possible earlier movement. It is just possible that Slides II and III may be related since they affect similar formations on each side of the Krokvatn Fold.

No special mention will be made of Slide IV separating the Meløy Group from the Gildeskål Marbles since the reasons for its existence are self-evident from the map.

The slides which separate the isoclinally-folded Meløy schists from the granitic gneisses and their immediate envelopes of rusty-weathering garnet-mica-schists, calcareous schists etc., have been referred to on pp. 24-25. Little need be added to information given by Holmes (1966) in whose ground these slides are mainly developed. They comprise Slide V, the Galtskartind Slide which underlies the rocks associated with the Høgstjerna and other sheets of granite gneiss outcropping near the coast; Slide VI, the Steffodalen Slide bounding the Glomfjord and Fykan gneisses and their immediate envelope; and Slide VII, the Lysvatn Slide which partly or perhaps wholly isolates the Bjellatind Gneisses and their envelope from the rest of the Meløy Group. The systems of early folds which repeat some parts of the Meløy Group successions adjacent to these slides are respectively the Galtskartind, Steffodalen and Laksådalen Folds. It is worth noting that in each case the beds which have been folded and are cut out by the slides include, or are close to, the Hornblendic Pelite. Since these phenomena concern stratigraphically related rocks which are now in widely separated structural positions in the Glomfjord nappe complex, it is suggested that they may be relics of a single earlier, or F_1, structure.

All of the more obvious structural evidence of these slides, however, relates to renewed movement during F_2 and F_3 times. This is well illustrated by the Lysvatn Slide, the only example in the area which can be picked out from a distance. Seen in this way it appears to cut across a fold which Holmes (1966, p. 70) identifies as part of the Kjeipen Synform. Closer inspection, however, fails to reveal any actual dislocation and the slide merges into the attenuated limb of the fold.

The slide can be traced into Laksådalen where it cuts out most of the beds in the inverted limb of the Laksådalen Fold. The dioritic gneiss (p. 28) can be traced round the closure; but beds outside it, notably the hornblende pelite, do not reappear in the lower limb. In the Nonshaugen area (see Plate 1), very striking effects of disharmonic folding are apparently associated with transposition in the slide zone. It seems as if the massive core of Bjellatind Gneisses expanded northward during the later phases of F_2 and into the F_3 movement, crumpling the Meløy schists that lay in its path.

An exactly analogous relationship is shown between the broadly-folded Glomfjord and Fykan Gneisses separated by the Steffodalen Slide from the tremendous complexity of folding of the Meløy schists in the Steffodalen area.

Slides associated with the Sundsfjord, Sokumfjell and Harefjell Groups

As mentioned in the introduction to this section, there are several features concerning the small-scale and microscopic structures of the eastern belt of uniformly dipping rocks which distinguish them from the

Meløy Group, and which indicate the influence of intensive and long-continued shearing. The coarse, feldspathic garnet-mica-schist forming the core of the 593 Fold illustrates a characteristic style of deformation, being drawn out at the southern end of the outcrop into a series of separated lenticular masses (see Plate 1). Tectonic inclusions are widespread. The most distinctive feature, however, is the abundance of granite in various forms throughout the eastern groups, as discussed below.

In order to understand the significance of these features in terms of structural history it is necessary to consider evidence from outside the present area. This has been ably reviewed by Rutland and Nicholson (1965), and before describing the eastern slides in detail, their relevant conclusions will be summarized.

They have been able to show that the distribution and correlation of the main formations east of and including the Sundsfjord Group, can best be explained as a result of their transport in an early nappe. This is called the Beiarn nappe and covers an area of about 120 km from north to south and about 40 km from west to east, extending to the antiformal regions of Nasafjell and Steinfjell where sensibly autochthonous rocks of the basement are brought to the surface. It is suggested that the Beiarn nappe is an extension of the Rödingsfjäll nappe of eastern Norway and Sweden (see Strand, 1955, 1958, 1960, 1961, Oftedahl, 1966).[1]) The Beiarn nappe is considered to be disjunctive, i.e. its emplacement — almost certainly prior to the main metamorphism — materially affected the stratigraphical relationships with neighbouring formations. After its emplacement the nappe was subjected to F_2 and F_3 folding similar to that described in relation to the Glomfjord nappe complex. The final result has been to preserve the nappe in a complex synformal structure which is overturned to the east. This has become separated from the nearest part of the Rödingsfjäll nappe by the effects of erosion over the intervening antiformal structure of Steinfjell.

A point which has an important bearing on the structural interpretation of the eastern part of the Sørfinnset area is that in the Rödingsfjäll nappe, Kulling (1955, p. 92) recognizes a lower, or migmatite, series with intercalated amphibolites; a middle or limestone series; and an upper series of garnet-mica-schists. Rutland and Nicholson suggest that, among the formations in the Beiarn nappe with which we are concerned, the Sundsfjord

---

[1]) Recently Nicholson (1968) after detailed studies in the Sulitjelma region has questioned this correlation.

and Harefjell Groups may be correlated with Kulling's lower series, and the Sokumfjell Marbles with his middle series. If this correlation is valid it means that the Sundsfjord and Harefjell Groups are, at least in part, equivalent, and must have suffered early folding or faulting to bring them into their present positions, one on either side of the marbles.

Rutland and Nicholson did not follow up the consequences of this correlation; but it appears that all the conditions can be satisfied by the local evidence.

Firstly, the characteristics of microscopic fabric of the schists, the small-scale structures, and the association with granitic rocks which distinguish the Sundsfjord from the Meløy Group, all make their appearance along a sharply defined line. This coincides with a narrow belt of thin marbles, calc-schist and various kinds of mica-schist, some of which approach granitic compositions. The various rock units in this belt all show signs of tectonic disturbance. The most striking instance is provided by a line of boudin-like masses of a coarse tremolite rock associated with pegmatite. This belt forms the obvious choice as a boundary of the Beiarn nappe and is regarded as an important slide zone (Slide VIII in Fig. 9).

Secondly, in Sundsfjorddalen the Sokumfjell Marbles are much attenuated compared with their main outcrop south of the Harefjell Group (see Fig. 1), where they constitute an almost self-contained complex of re-folded folds. Some of these folds cannot be traced into the surrounding schists, and all of them are disharmonic in some degree (see Nicholson and Walton, 1963, for details). Sundsfjorddalen represents one of three localities round the main outcrop where the marbles are reduced to layers only a few metres thick which nevertheless extend for many kilometres along the strike. From Nicholson's mapping of the one example which is satisfactorily exposed — a narrow spur of marble extending from the main outcrop southwards through Storglomvatn — it seems that the structure is analogous to that of the Laksådalen Fold and Lysvatn Slide. In the Storglomvatn example it is the marble which is drawn out into a tight isoclinal fold between two massive and unrelated formations of schist: the Meløy Group on the west and Vegdal Group on the east side (*cf.* Bjellatind Gneisses and Kvittind Silty Schists). The boundary between the marbles and Vegdal Group is rgearded as a slide.

Whether or not this is a reasonable model, and the marbles in Sundsfjorddalen represent the attenuated and sheared remnants of an isoclinal fold, it is inevitable that the boundaries of the marble layer should be largely tectonic. Exposure is very poor in the floor of Sundsfjorddalen,

Fig. 11. Gneisses in the Sundsfjord Group near Ågnes.

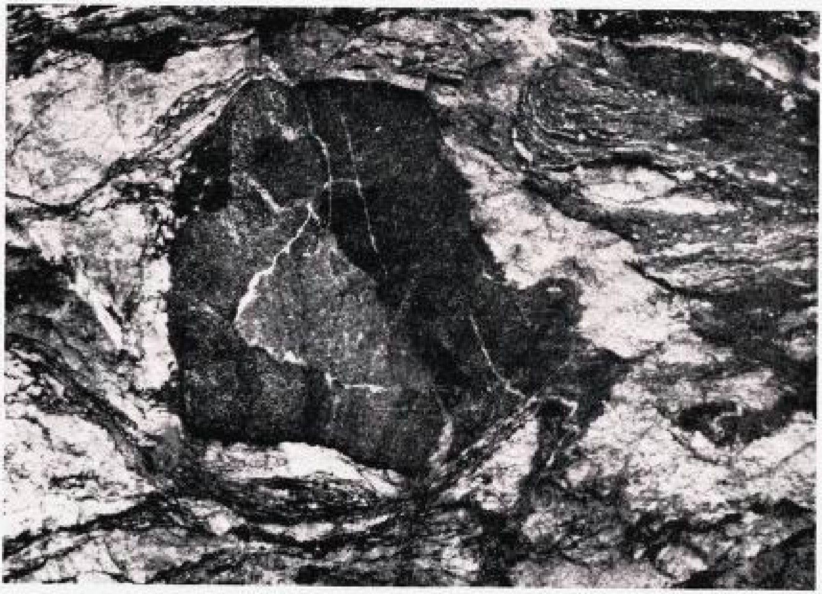


Fig. 12. Tectonic inclusion of amphibolite in gneisses, Ågnes.

but it seems that the whole width of the valley can be regarded as a slide zone (IX in Fig. 9), with extensive shearing and granite injection. This links up with the Staburfjell Slide Zone recognized by Rutland (1959, p. 293), separating the Sokumfjell Marbles from the Harefjell Gneisses in their type areas. Its effect in the Sørfinnset area are best seen in a rock-cutting near the head of Sundsfjord, where there is a tectonic melange with blocks of hornblendic gneiss enclosed in heterogeneous pelitic schists and gneisses in various stages of granitization. The assemblage is cut by a network of shear planes and granitic veins (Figs. 11, 12). Many of the blocks of hornblendic gneiss have suffered rotation, with their foliation discordant to that of the host rocks, thus proving that movement and migmatization followed a phase of high grade metamorphism.

The hornblendic rocks are of interest in another sense. They are quite extensively developed in the Sundsfjord Group, both as isolated tectonic inclusions and as continuous thick sheets, one west of the 593 core north west of Ågnes, and another west of the core and outcropping in the floor of Sundsfjorddalen just north of Storvatn. All of these rocks are closely similar to dioritic gneisses which constitute one of the dominant rock types of the Harefjell Group and which Rutland (1959, p. 289) considers to be metavolcanics. The Storvatn outcrop noted above is only separated by a relatively small thickness of other rocks — including the layer of Sokumfjell Marbles — from the main outcrop of Harefjell dioritic gneiss and it may well be that these rocks, although united for want of definite knowledge as the Sundsfjord Group, are related to the Harefjell Group. This possibility would find support from other features which the Sundsfjord Group has in common with the Harefjell Group and particularly with those parts of the latter which are marginal to the Sokumfjell Marbles and involved in the Staburfjell Slide Zone.

Granitic rocks associated with the Sundsfjord, Sokumfjell and Harefjell Groups

Granitic rocks are widely distributed in these eastern groups in marked contrast to the Meløy Group which is virtually devoid of granite. In the Sundsfjord Group the mode of occurrence and amount of granite varies systematically according to the nature of the host rock and the latter's structural position in the 593 Fold (p. 34). By their nature and distribution, the granitic rocks throw considerable light on the deformation history.

In schists the granite occurs in laminae, in augen, and in lenticular

Fig. 13. Lenses of granite in schists of the Sundsfjord Group south of hill 654.

bodies which may be several tens of metres long. It is common to find layers showing pinch-and-swell structures or for numbers of separated lenticular bodies to be strung out along a common foliation plane (Fig. 13), indicating boudinage of once continuous layers. Schistosity is partially deflected round the granite bodies in such a way that the components and texture of the granite generally merge into those of the enclosing schist. There are broadly two kinds of granite; a trondhjemitic variety with dominant sodic plagioclase and a microcline-rich variety. The former is generally less conspicuous and tends to be more intimately interspersed through the schists and gneisses which are granitized to varying extents. The trondhjemitic rocks have passed through much the same history of cataclasis and metamorphic crystallization as the host rocks. The potassic granites, however, tend to be more sharply segregated, with occasionally cross-cutting relationships, and often with an undeformed pegmatitic texture. Some of the largest bodies of pegmatite occur as sheets one or two metres thick in the marbles.

These facts suggest that the trondhjemitic granites were emplaced prior to, or during, development of the 593 Fold, and have been deformed and partially or wholly recrystallized during subsequent shearing. The microcline-granites, however, did not finally crystallize until after most of the deformation had ended. In this respect they compare with the microcline-rich facies of the Bjellatind Gneisses.

Granitic bodies of one kind or another are found throughout Sundsfjorddalen, and in scattered vein-complexes in, or fairly close to, the Staburfjell Slide Zone round the Harefjell Group and into the type area of Sokumfjell Marbles (Rutland *et al*, 1960, Fig. 2). Here Ackermann and Rutland have been able to establish a well-defined chronology of deformation and granite emplacement. The structural relationships between the marbles and the network of various kinds of veins and dykes is particularly instructive and is described by Rutland (1959, p. 330) as follows: "The early trondhjemitic granites . . . emphasize the difference in time between the two fold episodes. They were emplaced essentially after the first folding as planar intrusions parallel to the axial-plane of the Sokumfjell Fold. Subsequently they were boudined and dragfolds were produced on their margins during the second folding". The later potassic dykes were generally only slightly deformed by the second folding and in places cut across gaps between the trondhjemite boudins. The contrast in mode of occurrence of these frequently discordant granites compared with their counterparts in Sundsfjorddalen proves the importance of shearing and of slide tectonics in the latter area, extending in time throughout the F_2 phase, producing tectonic concordance and generally disguising the origin of the granites as minor intrusions.

MINOR STRUCTURES

Under this heading are considered the styles and attitudes of the various kinds of minor folds in the area, but excluding the microfolding or strain-slip 'cleavage' which is described in the next section. Mineral lineations are plotted on the map (Plate 2) and in the projections but they are not discussed in detail here since they are being considered elsewhere. Although tectonic inclusions are common in some formations and have been discussed in relation to sliding, more conventional boudinage phenomena are relatively uncommon. We have, however, previously described a special kind of boudinage which is developed in the hornblende-biotite-gneiss (p. 28) in contact with underlying marble to the south-west of Dorryvatn (Bradshaw and Wells, 1964).

In view of the excellent exposure of the area above the valley bottoms, examination of the minor structures, and in particular an anlysis of stereo-

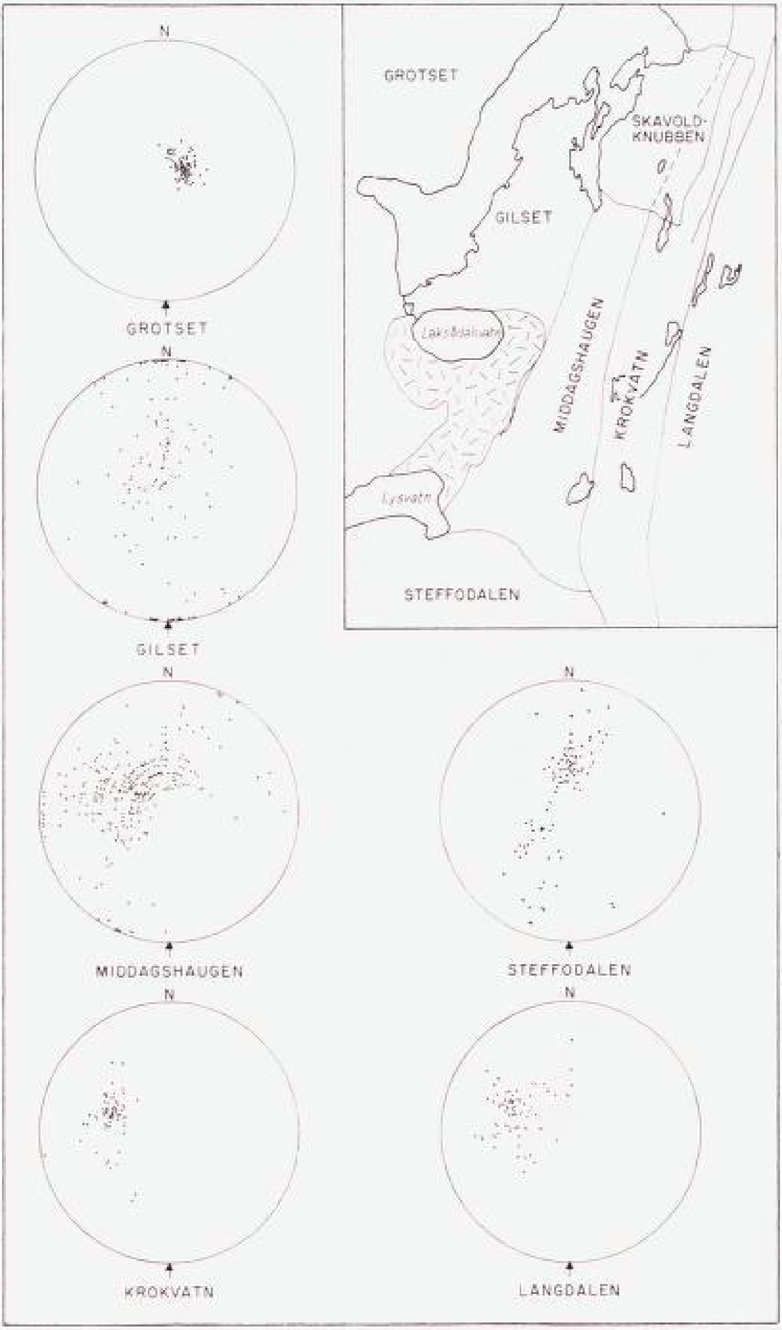


Fig. 14. Poles to foliation for sub-areas (lower hemisphere projection). The Skavoldknubben sub-area is plotted with Middagshaugen and Krokvatn sub-areas respectively.

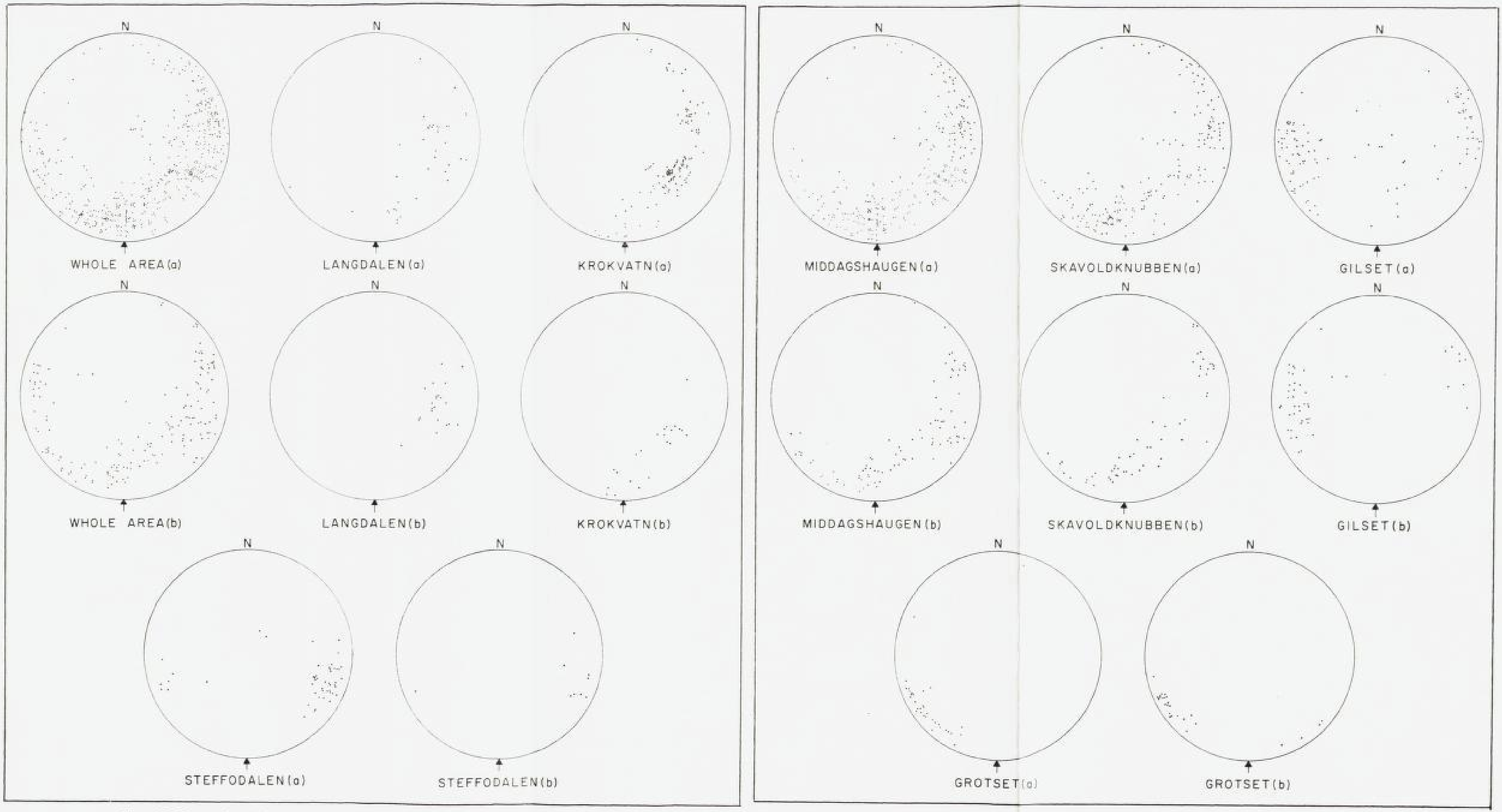


Fig. 15. Lower hemisphere stereographic projections of structural data for the subareas outlined on Fig. 14. For each region (a) is the plot of minor-fold axes and (b) the plot of mineral lineations.

graphic plots of the data, often adds relatively little to the interpretation of the major structures, as pointed out by Rutland (1959) for the neighbouring Sokumvatn area. The main advantage of the projections lies in being able to show *all* the data recorded for the various sub-areas selected for analysis, while only a selection of data can be shown on the map.

A plot has been made of all the available linear structures data of the area (Fig. 15). This shows a rather surprisingly even scatter of lineations with moderate to gentle plunges in all directions from a little north of east, through south to south-west.

When the map is examined it is seen that the lineations, in fact, fall into three main groupings. East of the axis of the Bjellatind-Sørfjord Antiform the scarce ?F_1 lineations and the dominant F_2 ones plunge generally to the E or SE. West of the axis, lineations of similar ages plunge generally to the SW. A belt in which southward-plunging minor folds are important, and locally dominant, extends from north of Skavoldknubben through Middagshaugen to Kvittind. This includes the latest folds (F_3) and is believed to be related to the Bjellatind-Sørfjord Antiform.

Orientations of poles to the bedding and/or foliation (Fig. 14) and linear structures (Fig. 15) are largely self-explanatory and only brief summaries need be given of the sub-areas to which they relate.

Data for the belt of fairly uniform dip and strike east of Langdalen is sparse because the foliation varies so little that a single measurement suffices for relatively large areas, and in the case of linear structures because of the scarcity of measurable folds. Among the fairly large spread of results there are probably some F_1 lineations and others more certainly of early F_2 age which plunge mainly between E and SE. The later F_2 and possible F_3 folds of this area plunge generally SSE or S.

The Krokvatn data show three quite distinct elements: a plunge to NE, probably of F_1 age; a fair spread of F_2 lineations with those of an earlier F_2 age being mainly ESE to SE, and later F_2 more commonly between SE and SSE; while F_3 minor folds plunge S or just W of S. Folds giving this last concentration occur mainly towards the west and north of the area, associated with the neighbouring Middagshaugen Synform.

In the area of Setertind and Steffodalen deformation has been particularly intense since relics of the Tverfjell and other F_1 folds are re-folded by the Setertind Fold whose axial plane lies close to ground level over much of the area, with a corresponding intensity of F_2 minor folding. The F_1 isoclines are re-folded by recumbent and near-isoclinal F_2 folds, and these in turn by undulating folds with fairly steep axial planes (?F_3), all sensibly coaxial (Fig. 16).

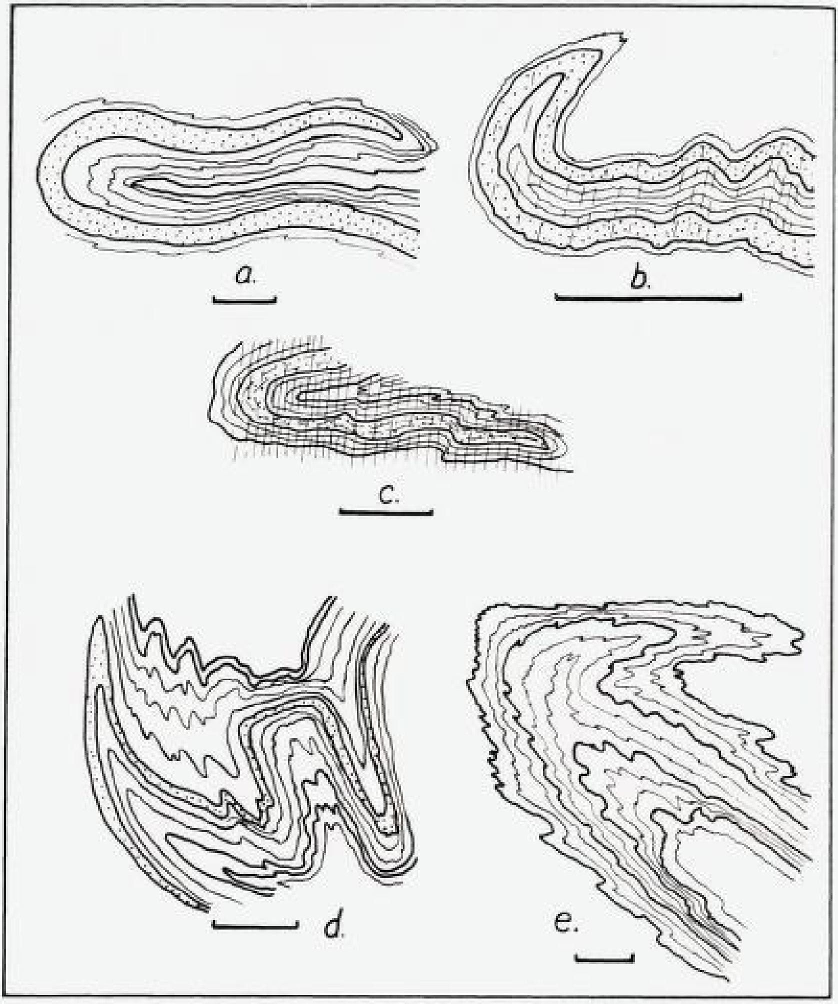


Fig. 16. Approximate profile sections of easterly-plunging F_1 isoclines refolded by F_2 folds with similar trend, both refolded by open folds also with an easterly trend and an almost vertical axial plane parallel to which new strain-slip planar structures are sometimes developed. Semi-pelitic bands dotted; scale is 30 cms. All folds from the Steffodalen col.

The Middagshaugen area is a relatively large one for analysis, but it was considered best to treat it as a unit since the three main phases of deformation are so closely interwoven. The area embraces the local core of the Glomfjord Nappe in the form of the Setertind Fold (dominantly

F_2 with ESE to SE plunge); the Middagshaugen Synform which modifies the recumbent fold in its northern part (dominantly F_3 with a southerly plunge); and the Laksådalen Fold which shows a fairly wide scatter of minor fold axes of F_1 and probably early- and late-F_2 ages. Data for the refolded complex of Skavoldknubben has been included in the Middagshaugen area, but it has also been plotted separately in Fig. 15.

Characteristics of F_1 structures

No examples are known which have not been intensively deformed by the F_2 and F_3 movements. The most certain relics are in the core of the Tverfjell Fold where re-folded isoclinal closures of banded calc-silicates occur, the F_2 re-folding being itself of a relatively tight character. In the Setertind and Steffodalen regions similar re-folded isoclinal relics are preserved in siliceous mica-schists. Examples are illustrated in Fig. 16. It may be noted that microscopic "drag-folds" seen in the micaceous layers of the Setertind example show anomalous vergence attributable to the multiple deformation. Isolated and fragmentary examples of axial plane schistosity are widespread throughout this area.

This is a characteristic feature of F_1 deformation. The micas or occasionally other minerals which define the schistosity have of course, grown during the metamorphic period, i.e. probably during F_2, and it is only the planes in which the minerals have grown that can be regarded as of F_1 origin. If, as we suppose, the F_1 deformation was essentially pre-metamorphic the planes may at that time have had the character of slaty or fracture cleavage.

Relics of axial plane schistosity are quite common in the complex folding around Laksådalselven, and in parts of the Krokvatn Fold and the Skavoldknubben complex (Fig. 17, d, g). The main difficulty in interpreting these examples lies in the fact that a similar axial plane schistosity appears to be generated under some conditions by early F_2 deformation as described below. Probably in the case of the Skavoldknubben complex, both F_1 and early-F_2 folding have played their part in the deformation because the outcrop pattern and particularly the great variations of thickness shown by the hornblende-biotite-gneiss are difficult to account for without this.

The isoclinal style of F_1 structures must be, like the schistosity, partly a secondary character. Even if at the end of the F_1 deformation the folds were relatively open, they would have become tightened to an isoclinal state by the end of the extreme F_2 deformation.

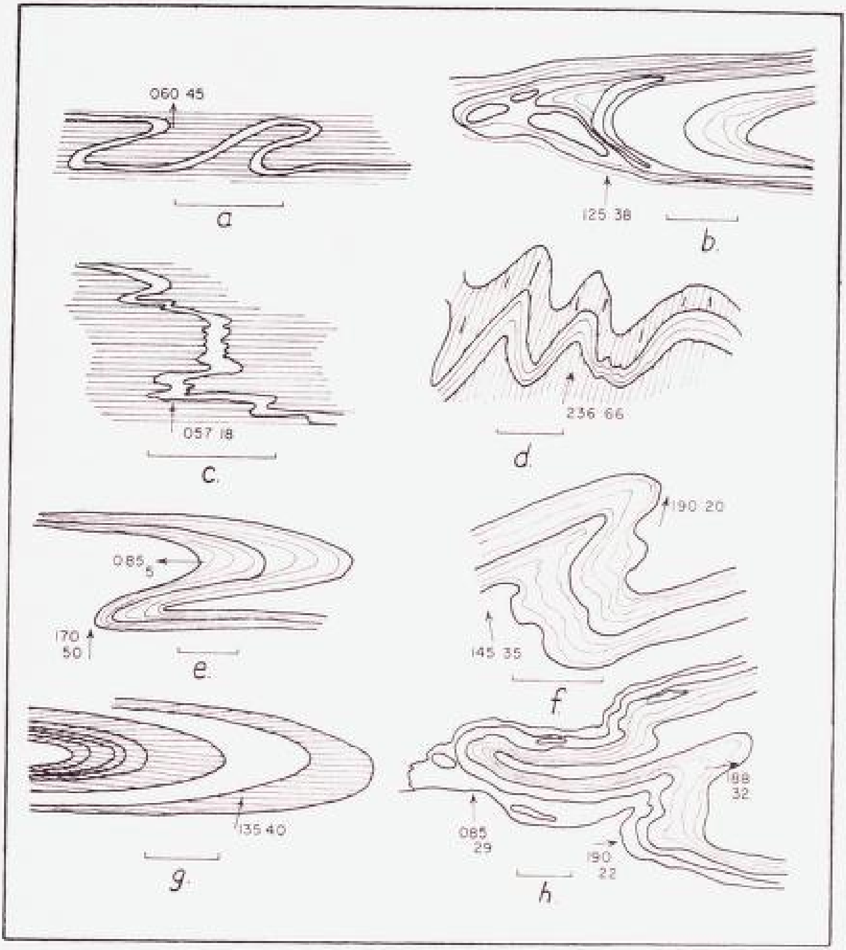


Fig. 17. F_1 and F_2 folds showing varying styles and axial trends. Axial plane schistosity develops in earlier folds while in later ones the schistosity is folded round. The more silty beds are stippled. Scale is 30 cms.

Similarly, of course, the trends of F_1 lineations must all have been severely modified. All that can be said is that the earliest isoclinal minor folds and lineations which may be of F_1 origin are generally easterly plunging in all examples east of the Sorfjord-Bjellatind axis.

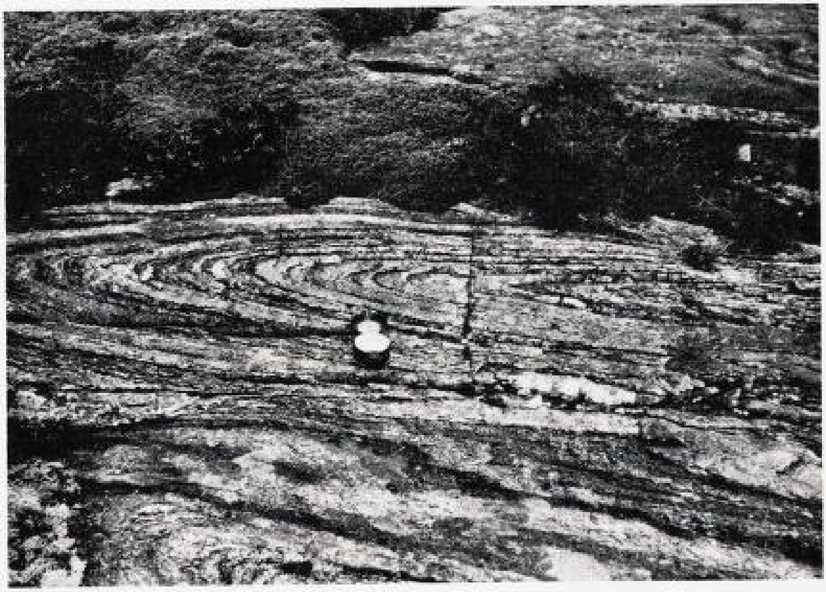


Fig. 18. Early F_2 fold in quartzite and semi-pelitic schist.

Characteristics of F_2 structures

It seems probable that the great majority of the minor structures whose geometry is related in some congruous fashion to the mappable major folds relate to the F_2 and F_3 phases. The former has been dominant in its effects and appears to have involved a gradual evolution from early and very intensive folding of an isoclinal or almost isoclinal style, to a still recumbent but more open style. There may be considerable uncertainty whether the earliest lineations and minor fold axes in any area are early-F_2 or relics of F_1. This is the case, for example, with early lineations in the Sundsfjord belt which plunge almost exactly down dip to the east or just north or south of east. The fact that tightly-compressed drag-folds, commonly developed in quartz lenticles, have a predominantly sinistral sense of movement (Fig. 22) leads to the conclusion that these are of early-F_2 origin, and later than the 593 Fold (p. 34).

In the Krokvatn Fold and less commonly in other parts of the area, the early-F_2 deformation has produced a very distinctive structure in which large numbers of minor isoclinal folds of short wave-length but relatively great amplitude are tightly packed together over the crests or troughs of the major structures. This isoclinal packing was referred to briefly by

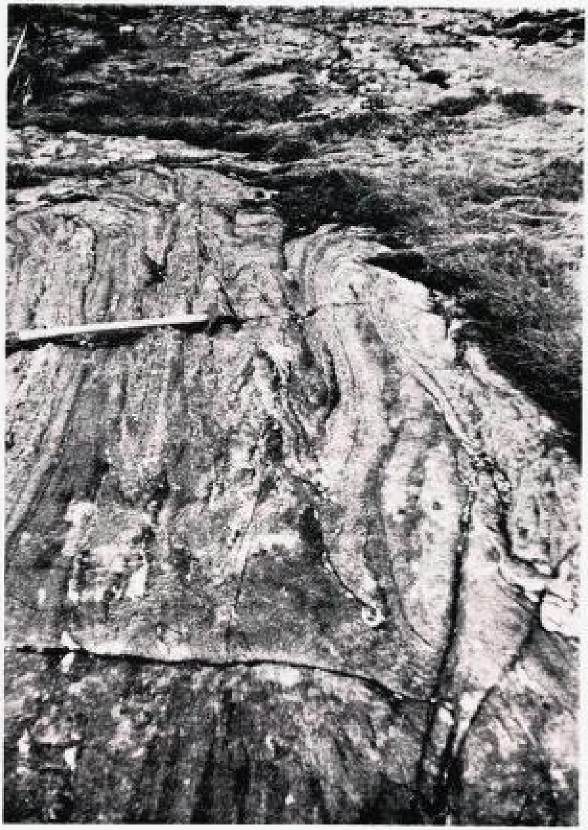


Fig. 19. Early F_2 fold in pelitic and semi-pelitic schists from the core of Krokvatn Fold.

Hollingworth *et al* (1960, p. 38) as an example of early folding, and it was pointed out that individual folds might be only a metre thick (i.e. in "wave-length"), but between 20 to 100 metres in amplitude.

Details of this kind of folding can only be worked out if the rocks involved are thinly bedded with distinctive lithologies, as is the case, for example, in some banded micaceous and hornblendic schists which occur at three levels in the schist-core of the Krokvatn Fold east of Altenvatn (cross-ruled on Plate 1). As the crest of the main fold is approached, layers which are only a metre or so thick in the limbs are folded back upon themselves a great many times as shown diagrammatically in Fig. 23. The net result is to increase the effective thickness of each lithological unit by up to a hundred-fold where the apparent thickness measured in the axial plane of the main fold becomes equal to the amplitudes of the minor folds.

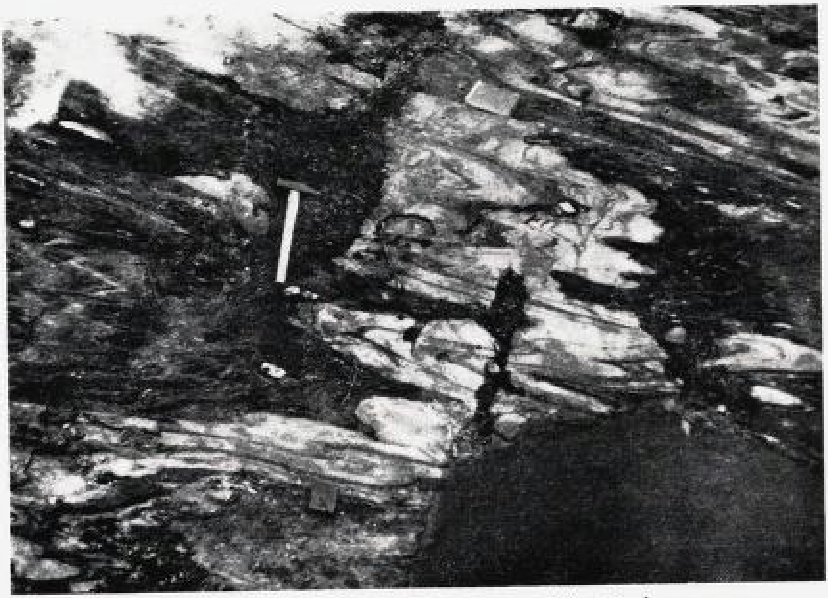


Fig. 20. F_2 fold in marbles and pelitic schist, Krokvatn.

Fig. 21. F_2 fold in pelitic schist. NW of Ågnes.

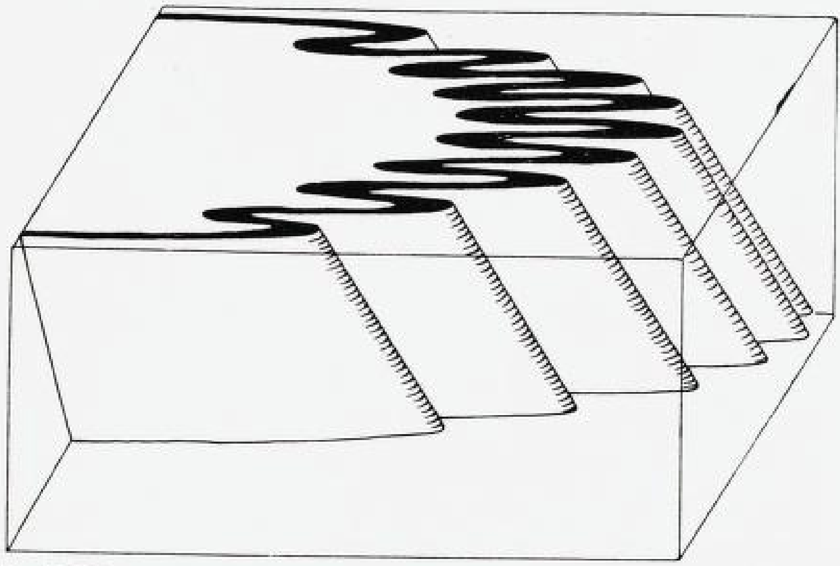


Fig. 23. Diagram of isoclinal folding as seen in the core of Krokvatn Fold. Note that with schists, the amplitudes of individual folds may be relatively much greater and the packing tighter than shown.

This style of folding is also well displayed where the distinctive sequence of schists enveloping the marbles of the Skavoldknubben complex forms a semi-circular closure just south of Skavoldknubben, and again in the extreme north of the map by the outlet of Skavoldelven. In the latter case the folds are on a big enough scale to show on the map which, though partly diagrammatic hereabouts, in no way exaggregates the amplitudes of the folds. Other examples occur in the Laksådalen Fold and in the vicinity of the bend of Laksådalselven.

Throughout the Skavoldknubben and Krokvatn Folds minor structures of this kind plunge ESE or SE.

One further point about these folds is worth making. If the rocks involved are all of one kind of mica-schist, individual isoclines virtually disappear and one is left with a homogeneous unit of schist, showing great thicknening round the major fold closure, with the dominant schistosity parallel to the main axial plane. Without traces of bedding being visible, it may be very difficult to distinguish the pseudo kind of "axial plane schistosity" induced by intensive folding from the true variety. Although this kind of structure is typically best developed in schists, it is most difficult to portray from these rocks.

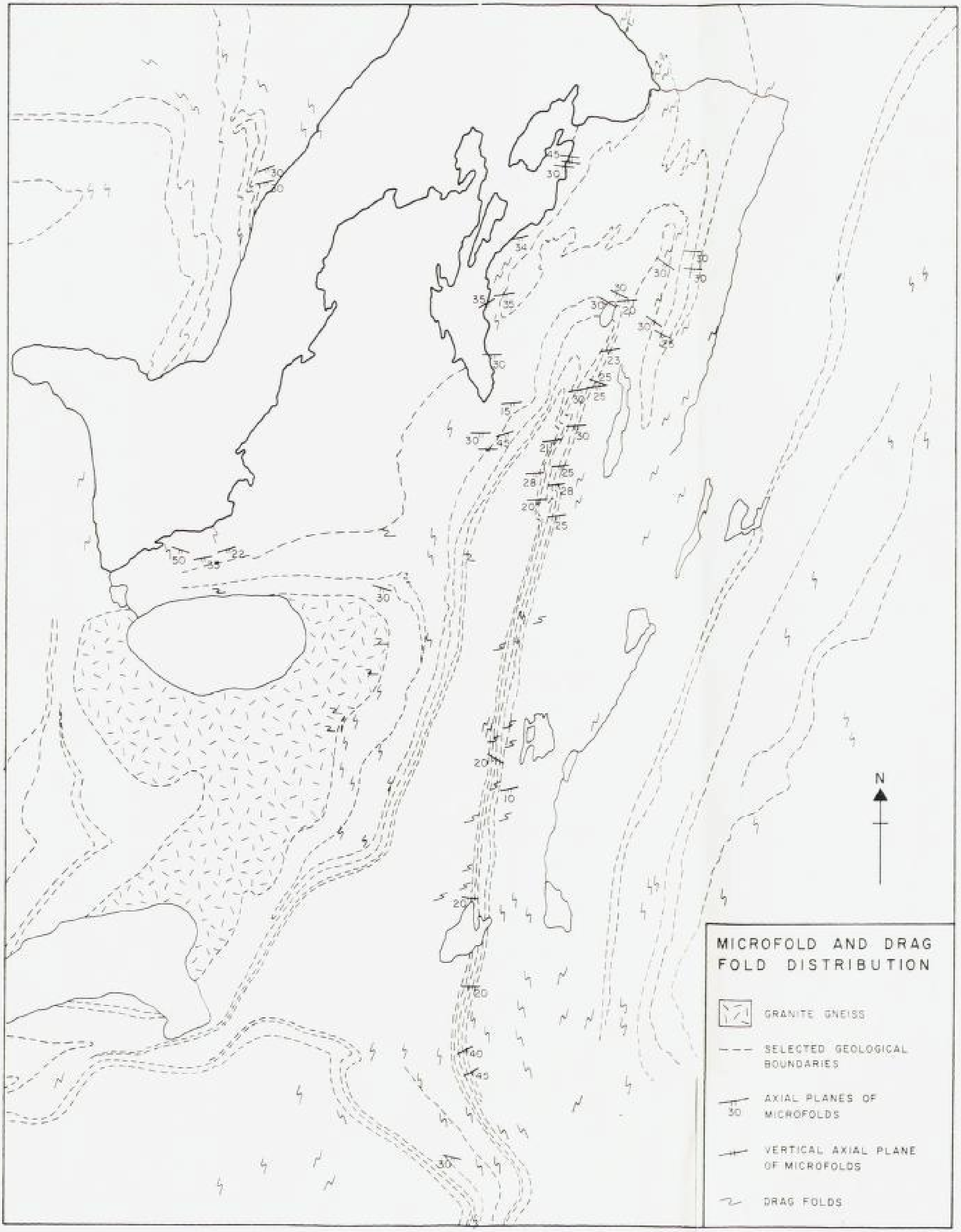


Fig. 22. Distribution of planes of strain-slip cleavage (axial planes of microfolds) and of drag folds.

Variations of the fold styles with lithology and the significance of the early-F_2 isoclinal folding in the development of major structures are both discussed in relation to the Krokvatn Fold (p. 68).

There is every gradation from the early-F_2 isoclinal folds associated with both true and apparent axial plane schistosity to later F_2 folds which are sufficiently open in character for the folding round of schistosity to be readily visible. These are often asymmetrical drag folds of sinistral or dextral character which are congruous with the major F_2 structures. Although less marked than in the earlier F_2 folds, there is still appreciable thickening of beds at the closures. East of the Bjellatind-Sørfjord axis the later folds have a more southerly trend than the earlier ones, plunging between SE and SSE.

Characteristics of F_3 structures

The youngest minor folds over much of the area are roughly parallel to the Sørfjord-Bjellatind Antiform and are therefore regarded as related to this. They are sparsely distributed compared with F_2 structures and only achieve a comparable intensity and concentration with the latter in a belt extending from north of Skavoldelven southwards to Kvittind where the plunge is about 200°/15°.

Typical late-F_3 folds are relatively symmetrical and open with generally steep axial planes and gentle plunges, either to the SSW or to the E. They show an approach to a concentric style, though even in these the marbles may show considerable flowage into the fold cores. Examples which are most nearly concentric and demonstrate by their distinctive style as well as their trend that they are of really late-F_3 origin may also demonstrate this fact by their warping of earlier structures. A good example is provided by a minor fold plunging almost due south at about 5° on the east flank of the Middagshaugen Synform. This refolds an earlier lineation by simple rotation from a SE plunge on its eastern limb, steadily changing over the crest to NW on its western limb.

The majority of folds having what are regarded as typical F_3 trends, however, often show little if any evidence of having refolded earlier structures. This is the case for instance, north of Skavoldelven, where a concentration of sensibly N-S folds occurs, individual examples often adjoining and passing into minor folds plunging to the ESE or SE. The adjoining folds may have rather comparable styles and share common axial plane directions. It is reasonably certain in this case that the two trends developed by contemporaneous cross-folding.

Fig. 24. F_3 folds involving hornblendic rock above and marble below. Western limb of the Middagshaugen Fold, northwest of Skavoldknubben.

The style and attitude of the latest folds in each area is obviously governed very considerably by the geometry of the earlier structures and by the disposition of the major lithological units. The control that the massive core of Silty Schists exercises on the development of the Middagshaugen Synform and its associated minor folds is described as an example of this on p. 70.

When they are traced southwards, the southerly-plunging folds die out and by the time the Setertind Fold is reached all the folding is about ESE axes. This is partly the result of the strong disharmony between the thinly-bedded calc-schists and the massive Silty Schists which they envelope.

MICROFOLDING

Microfolding or puckering of the schistosity is very pronounced in some parts of the area, particularly near major fold closures. Schistosities are sharply kinked in such a way that the axial planes through the crests and troughs of the microfolds form sets of roughly parallel and evenly spaced planes at intervals of a few millimetres or up to about a centimetre. These planes have been termed "fracture cleavage" by Rutland (1959), Holmes

(1966) and other workers, but as there is usually no actual break, this is not really appropriate. The question of nomenclature of similar phenomena has been discussed by, among others, Wilson (1961) who suggested that the term "strain-slip cleavage should be used for the secondary or false cleavage developed in those rocks which already possess a primary schistosity, or which are so thin-bedded that the formation of the cleavage causes them to become plicated". Knill (1960) in a discussion of cleavage classification, and after describing the details of strain-slip cleavage, suggests the term crenulation cleavage. There is no doubt, however, that microfolding or puckering of the micas is a most prominent feature of this structure and it might be best to follow Nicholson and Walton (1963) in the use of this term. As has been pointed out by Wilson (1961), it is difficult to say whether the planes parallel to the axial planes of the microfolds are the cause of the folding or whether the folding produced the shear planes.

The relationship is particularly well displayed around the closure of the Middagshaugen Fold. Here the 'cleavage' planes appear to be related to many of the later F_2 and F_3 congruent drag folds of this structure, as illustrated in Fig. 25 a & f, but it is clear they are not parallel to the axial planes of these structures. The later drag folds plunge at about 25° in a direction of 200°. If the 'cleavage' planes are shear planes, their intersection should coincide with the direction of intermediate stress during their formation. There is no consistent pattern of intersection, but there is a maximum in a direction between 170° and 220° with a plunge of between 15° and 30°, shown by the stereographic projections of Fig. 26 a and b. This direction is roughly parallel to the plunge of the Sørfjord Antiform and to many of the minor folds associated with the Middagshaugen Fold, as noted above. It is fairly obvious from this evidence that the microfolding developed at the same time as the drag folds.

Despite this agreement between the 'cleavage' intersections and the plunges of minor and major folds, the 'cleavage' planes are not parallel to the axial planes of the major folds with which they are associated. The Sørfjord Antiform, for instance, has an almost vertical axial plane, while those of the Middagshaugen, Krokvatn and Laksådalen Folds are inclined at about 45° to the east. In other parts of the area away from the Sørfjord and Middagshaugen Folds with their prominent southerly-plunging component of the late folding, the attutides of the microfold axes and the larger folds with which they are associated differ from those noted above. In the Steffodalen area, for example, between the Spilderdalen and

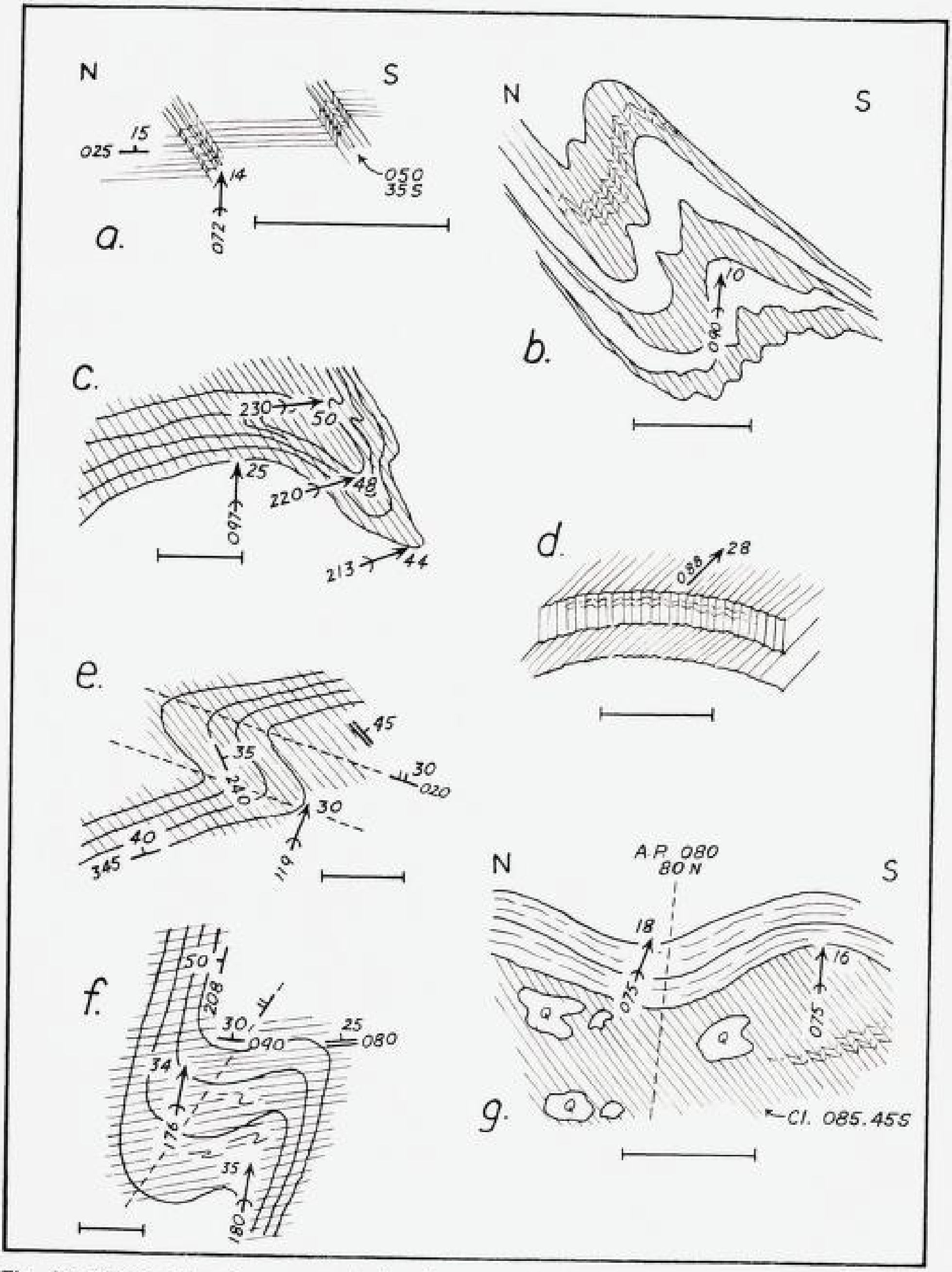


Fig. 25. Relationships between strain-slip cleavage (microfolding) and various styles of folds; a, b and g are approximate profile sections. Scale is 30 cms.

Setertind closures of the main Glomfjord nappe structure, folding on all scales — including microfolding of the garnet-two mica-schist — is directed towards the ESE. On the eastern shore of Sørfjord and in the Steffodalen col, 'cleavage' has been recorded with more or less vertical orientation parallel to the axial planes of open flexures plunging at 095° 20° (Figs. 16 b, c and 25 d). There is little doubt that all this microfolding is of the same general character and age of formation. In other words, the latest deformation gave rise to drag folding and the 'cleavage' type of microfolding with widely different trends in different parts of the region. This is in accordance with other evidence discussed on pp 9-22, that there was an overlap in time between the development of the structures with trends and characteristics typical of F_3 and of the later components of equally typical F_2 ones.

This helps to explain why microfolding in areas surrounding Sørfinnset has been described as associated with different ages of folding. The closest analogy to the situation in the Sørfjord and Middagshaugen Folds is probably provided by the Sokumvatn and Sokumfjell Folds described by Rutland (1959, especially Fig. 6). In the western limb of the Sokumfjell Fold there are many minor folds, with long straight limbs dipping steeply westwards, and puckered short, flat limbs, with plunges of 25° to the SSW, whereas the plunge of the major fold is nearly vertical. Although the

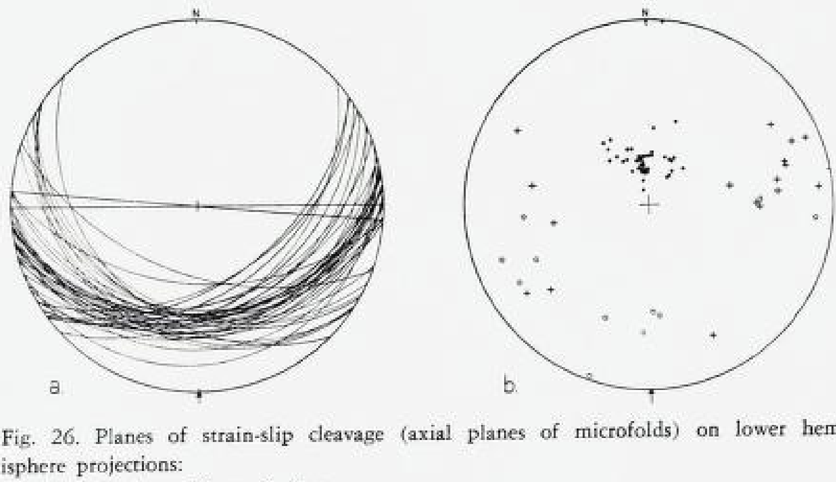


Fig. 26. Planes of strain-slip cleavage (axial planes of microfolds) on lower hemisphere projections:

(a) Cyclographic projection.

(b) Poles to strain-slip cleavage planes (dots); intersection of these planes with foliation (circles) and plunge of the microfolds (crosses).

Fig. 27. Fold plunging 090° 10° with zig-zag folding of schists in core and some development of axial-plane strain-slip cleavage.

axial plane of the Sokumfjell Fold is nearly vertical, those of the minor folds and the strike of the strain-slip cleavage planes parallel to them cut across both limbs of the fold in the same direction. Their axial trend suggests a correlation with the formation of the Sokumfjell Synform (cf. the F_3 Sørfjord Antiform) but their sense is not appropriate to congruous drag folds in relation to the synform.

Holmes (1966) states that microfolding is well developed in the hinge-zone of the Kjeipen Synform, the trend of the crests of the mica puckers plunging SW at about 15°. This is parallel to the plunge of the major fold which Holmes regards as an F_2 structure comparable with the Krokvatn Fold. We would now prefer to regard it as essentially F_2 and retaining the F_2 trend for this area, but with F_3 characteristics imposed on it by deformation which continued into the latest phase.

Finally, it may be noted that Nicholson and Walton (1963) record puckered and microfolded schistosity in the southward extension of the Krokvatn Fold which closes in Fykandalen. There is no doubt in this case that the Krokvatn Fold is essentially an F_1 and early F_2 structure. It appears, however, as if the microfolding must be of later origin. Evidence for this is provided from our own area by the drag folding and associated microfolding on both sides of the Skavoldknubben marbles which form

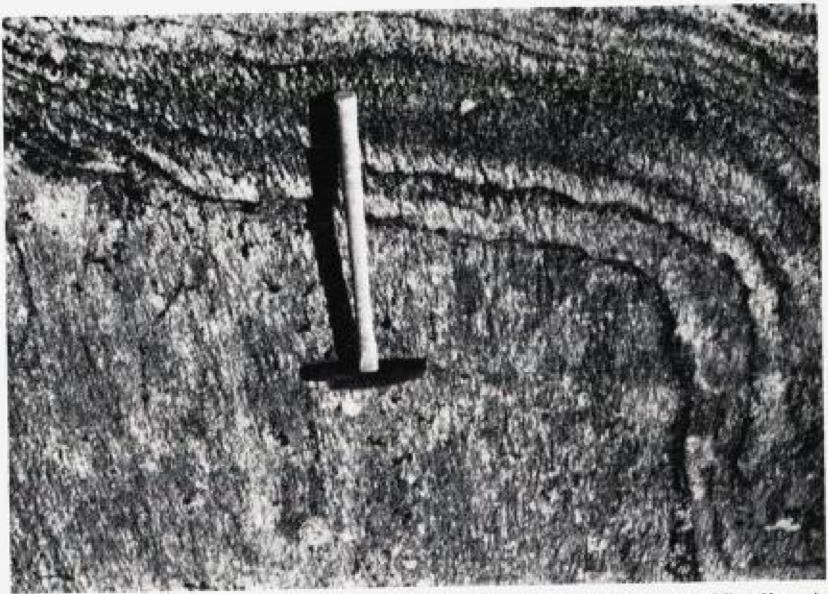


Fig. 28. Microfolding (strain-slip cleavage) northwest of Middagshaugen. The lineation is E-W approx. and is the intersection of a horizontal foliation surface and the cleavage planes.

the core at the northern end of the Krokvatn Fold (p. 68): on both limbs the southwards-plunging drag-folds are sinistral and obviously superimposed after the main folding.

There is some similarity between the relation of the strain-slip planes and the folding described here and that discussed by Wilson (1961, p. 454-7 and Fig. 16) following Muff (1910) and Mead (1940). Mead suggested that this type of cleavage may occur as a late shear phenomenon on two sets of shear planes produced by the same compressive forces as those which gave rise to earlier folds. Monoclinal wrinkles of the type that Mead claims to be formed by this means are found to the west and northwest of Middagshaugen (Fig. 25 a). These wrinkles are all sinistral indicating an over-riding of the upper beds towards the north. Mead (op. cit. p. 1019) stated that if the principal stresses remain constant in direction during and after the folding, then the planes of maximum shearing stress may be expected to be orientated symmetrically to the fold axial plane and their intersection to be parallel to the fold axis. If, however, the stress distribution changes during the development of a fold then the planes of maximum shearing stress, and hence the shear-cleavage planes, may lie in any position relative to the fold. The relations of the strain-slip cleavage round Sørfinnset suggest that the orientation of the stresses has varied locally but that on the whole the cleavage has been produced by the same stresses as those giving rise to the Sørfjord antiform and related structures.

Somewhat similar considerations apply to the production of conjugate shear systems and related strain-slip cleavage described by Ramsay and Sturt (1963) from Sørøy in northern Norway.

STRUCTURE OF INDIVIDUAL AREAS

Now that the characters of the main episodes of folding have been described, it is appropriate to examine their combined effects in selected sub-areas. These have been chosen because they illustrate distinctive structural features; but of course, any sub-division of a refolded complex like the Glomfjord Nappe is arbitrary to a certain degree because of the interpenetrating nature of the folds.

The sub-areas are as follows:

(a) Outcrop of Sundsfjord Group
(b) Krokvatn Fold
(c) Outcrop of the Silty Schists of Middagshaugen, Langfjell and Kvittind
(d) The Skavoldknubben complex
(e) Setertind-Steffodalen area
(f) Sørfinnset

Outcrop of Sundsfjord Group

Little needs adding to descriptions already given under the headings of '593 Fold', 'Tectonic Slides' and 'Minor Structures'.

Although this belt of uniform strike and dip has escaped the plastic type of folding on the major scale with characterizes F_2 and F_3 in the remainder of the area, it by no means escaped deformation during these periods. This is shown by the lensing of many of the units, notably the widely-distributed sheets of granite and the augen-schist or augen-gneiss which is regarded as lying in the core of the presumed-F_1 593 Fold; and also by tectonic inclusions, particularly of amphibole-rich rocks which, by their wide spacing at certain horizons in the schist sequence, indicate a considerable degree of lateral extension and corresponding flattening.

Although the thin marbles and occasional unusually-fissile schists have provided planes of accentuated transposition, in general, deformation has been relatively homogeneous throughout the group because the schists are of fairly uniform competence. An elegant demonstration of this is provided by the characteristics of three or four granite dykes located along the ridge of plane-foliated schists which forms the eastern margin of the Krokvatn Fold. Strictly these are outside the Sundsfjord Group but illustrate aspects of deformation which extend to the latter. The dykes are all only 5 - 10 cm thick and individually maintain constant attitudes for some tens of metres as they cut obliquely across the foliation from one schist lithology to another. They are gently dipping to the northeast and have obviously been involved in deformation since their original emplacement, with development of a penetrative schistosity, probably considerable thinning and certainly a bodily and consistent rotation (compare re-orientation of Scourian dykes by Laxfordian movements described by Sutton and Watson, 1956; and Watson, 1967, p. 217).

In keeping with the general uniformity of deformation, the tightly compressed, and usually very small, drag-folds (seen most commonly in quartz laminae) appear to be uniformly sinistral. This is the case even with the earliest microfolds and mineral lineations which plunge to the east or a little north of east. If these are of F_1 age their uniform sense of movement throws doubts on the reality of the 593 Fold as an F_1 major structure. It seems more likely that the minor structures are of early-F_2 age.

Towards Storvatn a family of later F_2 or F_3 drag-folds becomes prominent. These plunge to the SSE and cause undulations of the local dips on a sufficiently large scale to be mapped. The relationship of this folding to contemporaneous slide displacement has been discussed above (p. 40). It is probable that the folds are outer ripples of deformation which reaches its peak in the major fold closures of Ruffen to the south, mapped by Walton (1959), and indicated in the outline map of Fig. 1. The description given by Nicholson and Walton (1963, p. 32) of these folds, referred to as the Ruffen Synform and Antiform, contains much information which is relevant to the present discussion. They show that the schistosity and the earlier (sodic) granites were folded during development of the main closures while the later (potassic) granites, concentrated in the northern limb of the Ruffen Synform, were emplaced during and after the main folding. From these facts and the geometry of the folds it is inferred that the Ruffen Synform and Antiform belong to the later phases of deformation, being of the same age as, or perhaps younger than, the adjoining Krokvatn-Rebenfjell fold.

Where pelitic rocks of the Sundsfjord Group are folded round the Sokumfjell Marbles in the main closure of the Synform (see Fig. 1), the axial plane strikes approximately E-W and is inclined gently to the north. The plane is curved, however, and the axial trace swings into a more N-S direction north of Ruffen. Poor exposure prevents any detailed analysis of its extension northward into the pelitic schists. This is most unfortunate in the present context because the axial trace looks to be heading for the line of the 593 Fold. Although the possibility of the two folds being related has had to be considered, the fact that they may meet and in part have common trends is regarded as largely coincidental. The proper correlation should be between the Ruffen Folds and the drag folds and later features of the slide tectonics of the Sundsfjord belt on the one hand, and possibly between the 593 Fold and some of the re-folded isoclinal structures in the Ruffen area which Nicholson and Walton have noted, on the other. Granitic rocks extending through both regions provide a common time-control for the various events.

Krokvatn Fold

This is a reclined fold, an example of an isoclinal fold with the axial plane dipping eastwards at about 40° and the plunges of the main fold and the dominant major and minor drag-folds approximately following the direction of dip at 140°/40°.

The main closure around Krokvatn forms the most impressively displayed fold in the region because of the deep erosion of the marbles which here form the core. Along both limbs erosion has etched the topography so that the various layers of schist and occasional thin quartzites form features which can be traced for hundreds of metres on the ground and on the aerial photographs. Similar conditions prevail in the tongue of schists which forms a whale-back ridge at the core of the fold in its northern part. The marble outcrops, by contrast, are largely covered by grass or dense birch scrub.

Folding is largely confined to the hinge-zone along the whole length of the structure. Only a few metres outwards from the zone of intensive folding, the rocks have planar schistosity which gives no hint of the proximity of a major isoclinal fold-closure. Over a large part of the structure the crestal and drag-folds are sensibly homoaxial, and since the latter show appropriate dextral and sinistral characters in the eastern and western limbs respectively, it appears at first sight as if all the folding belongs to essentially the one phase of deformation, responsible for development of the whole structure. In fact, this is an over-simplification.

The age of the dominant folding can be deduced by comparison with the adjacent northwards-closing Setertind Fold to which Krokvatn forms a complementary southwards-closing fold. Since the two structures show comparable styles and share a common ESE trend, they must be essentially of the same age.

This age is confirmed as F_2 in the case of the Setertind Fold because the latter re-folds the F_1 Tverfjell Fold. It may also be the case for Krokvatn if evidence for the Skavoldelven Fold is accepted, because this is certainly refolded by the Krokvatn Fold.

As pointed out on p. 17 this conclusion differs from that which was reached originally (Hollingworth *et al*, 1960). At that time the Tverfjell region had not been mapped in detail so there was no knowledge of the Tverfjell Fold, the Skavoldelven structure or, indeed, of what we now regard as the F_1 phase generally. The mapping then completed suggested that the Middagshaugen Synform (presumed to be of F_2 age) folded the Krokvatn Fold, making the latter to be apparently of F_1 age. This view was strenghthened by the fact that the ESE trend of the main Krokvatn folding agrees fairly well with that of the earliest folds recognized by Rutland and Ackermann in the Sokumvatn area east of Sundsfjord, and designated as F_1 by Rutland (1959).

The main objection to the original suggestion of an F_1 age for the Krokvatn Fold and for its southward extension known as the Rebenfjell Fold, lay in the style of the folding and its relationship to schistosity. This varies considerably from one part of the fold to another and depends a lot on the lthological units involved. Truly penetrative axial plane schistosity is subordinate to schistosity which is folded round the closures.

This is in complete contrast to the situation which Nicholson (1960) found to apply to F_1 structures in the Storglomvatn region. One fold in particular gives strong evidence of its F_1 origin: this is a single isoclinal closure forming an isolated and incomplete relict structure in the limb of one of the F_2 folds, and having a plunge which is unrelated to any other structure in the vicinity. The most important feature of this fold relates to its schistosity which is entirely of a penetrative axial-plane character. When faced with the evidence of the folded schistosity in the Rebenfjell Fold at its closure near Fykanelven, Nicholson and Walton (1963) naturally concluded that the Krokvatn-Rebenfjell Fold must be, in large part at least, of post-F_1 origin.

Evidence from the folding/schistosity relationships thus confirms our own conclusions based on the evidence of refolding of the Skavoldelven and Tverfjell Folds.

This still leaves open the question of the age of some of the structures, such as axial plane schistosity and isoclinal minor folding with the "older" E to SE trends, incorporated in the Krokvatn Fold. Are any of these structures of F_1 age or do they belong to an early phase of F_2? Because for several years we thought that the Krokvatn Fold was of F_1 age it was perhaps natural that when the stratigraphical evidence of the Skavoldelven and Tverfjell folding emerged we should initially have tried to correlate this with at least the oldest looking of the Krokvatn structures. However, we have now been forced to the conclusion already expressed on p. 54, that most if not all the structures under consideration owe their present shapes and trends to the various phases of F_2 deformation. The reason for this view is simple: virtually all the older types of structure and notably the isoclinal packing of minor folds are concentrated in the hinge zone where they achieve their optimum development. They are thus genetically related to the development of the Krokvatn Fold and not to the earlier Skavoldelven and Tverfjell Folds.

This is not to say that the F_1 phase did not make any contribution to the form adopted by some of the later structures. The most likely place for F_1 to have played a significant part in the structural evolution appears to be in the north of the Krokvatn Fold approaching the refolded Skavoldknubben complex. A branch of the marbles that lies at the centre of that complex extends southwards into the core of the Krokvatn Fold. South of Greftvatn, schists form a closure round these marbles which is very different from closures further south. In the first place it is knife-sharp, with the marbles attenuated to only a centimetre or so before they disappear. Where the schists meet, only the fact that their opposed sequences match one another reveals the existence of a fold at all, because the schistosity extends southwards at this point parallel to the axial plane and with no sign of flexure over the crest.

Minor folds which locally plunge at about 30° in directions between 165° and 180° are relatively open drag-folds of the late-F_2 types, associated with strain-slip microfolding. It is quite obvious that they are younger than, and unrelated to, the main isoclinal closure, since they warp the axial plane of the latter and have the same sinistral sense of movement in both limbs.

This refolding established the fact that the Greftvatn closure is of an early-F_2 or even F_1 age, and its distinctively attenuated character suggests that it may be older than closures further south which share the same axial plane. The possibility of the Greftvatn closure having started to develop in the F_1 phase is discussed further in connection with the Skavoldknubben complex. It seems just as likely, however, that the Greftvatn closure developed contemporaneously with more rounded closures further south and that its form was governed by its position in the Krokvatn Fold and by the nature of the rocks involved.

Similar considerations may apply to variations in the fold trends. In the northern part of the structure the southerly-plunging late-F_2 folds are dominant, with the F_3 influence apparent in some parts; while in the vicinity of Krokvatn itself, the folding is virtually homoaxial with the typical earlier F_2 plunges to the ESE or SE. Possibly the southern part of the structure remained inert while the late-F_2 folding took place in the north; but it seems more reasonable to suppose that movement occurred contemporaneously in the south which was constrained to develop structures along previously established axes. This would agree with several different kinds of evidence in the region to show that so-called early- and late-F_2 (or alternatively in some cases, F_2 and F_3) structures and trends overlapped considerably in their ages.

While it is probable that the fold trends have been subject to some degree of lithological control, there is no doubt that the thickness and competence of the sequence of schists and marbles has completely dominated the style of folding.

In successive closures southwards from Greftvatn the following characteristics may be noted:

1. Tightly-packed isoclinal folding of the kind described on p. 54 characterizes each of the schist formations which embraces the Greftvatn marbles. Although this folding reaches its greatest amplitude near the crest, it is also found in the major drag-folds mapped just east of the crest (note the example shown on Plate 1 due south of Greftvatn and east of Altenvatn). The outlines of the drag folds drawn on the map are clearly seen in aerial photographs, but on the ground they cannot be picked out because isoclinal folding causes the foliation to pass through the area of the folds without apparent deflection.
2. The following sequence comprises a considerable thickness of impure marbles alternating with thin layers of schist. It may have been the regular character of the alternation which allowed a uniform amount of slip to develop between schist and marble throughout the sequence, and thus gave rise to a similar-type fold with a relatively sharp hinge west of Djupvatn.
3. In the next part of the sequence, the thicknesses of the schist and marble layers are greater and more variable, with the marbles generally predominating. This has led to development of some

large-scale drag-folds of a convolute type, and with considerable disharmony between folds. One schist layer immediately north of Krokvatn gives the impression of a ptygmatic type of folding as though the schist has been squeezed into the yielding marble in accomodating to the confines of the main fold. It is possible that the structure is a result of re-folding.

4. The semicircular shape of the main Krokvatn closure results from the combination of a fairly massive, pure marble adjoining a very thick envelope of schists.
5. Contacts between the various schists which form this envelope on Stepperne and south to Ruffudalen are easy to see from aerial photographs, and follow simple curves as shown on the map. Within each schist formation, however, there is an approach to the packed isoclinal minor folding described previously. This also shows on aerial photographs, as a striation parallel to the foliation which is mostly parallel to the axial plane.
6. From Ruffudalen southwards for several kilometres into the area mapped by Walton, the Krokvatn - Rebenfjell Fold continues without any visible closures. The core is formed of homogeneous schist with a sensibly planar foliation. The folded structure only becomes apparent again when other lithologies are involved, notably in the region of Fykanelv.

One of the most impressive features of the Krokvatn deformation is the amount of material transported towards the crest of the fold. This is shown by the thickening of all the beds, but perhaps most clearly by the occasional quartzites. Not only is the thickness several times greater than in the limbs, but the purity of the quartzites seems to be increased, due to metamorphic differentiation that must have accompanied the recrystallization during deformation.

All the structure are indicative of extremely plastic deformation under deep-seated conditions of high-grade metamorphism. This constitutes one more reason for believing that the fold is mainly of F_2 origin.

Outcrop of the Silty Schists of Middagshaugen, Langfjell and Kvittind

Lithological control of structural evolution, as seen in the Krokvatn Fold, is equally apparent in the present case, and the contributions of the three main phases of deformation are even easier to distinguish. Each phase has produced a distinctive major fold of which the Silty Schists formed the core: the F_1 Tverfjell Fold, F_2 Setertind Fold, and F_3 Middagshaugen Synform. Actually the Synform is only in part an F_3 structure as explained below.

F_1 deformation was responsible for overturning the original succession so that rocks of the Hornblendic Pelite group were repeated on either side of a folded core of Silty Schists. The form of the original structure is completely unknown: but it seems from the evidence described on pp. 22-25 that the earliest folding was accompanied by thrusting which was responsible for at least a partial separation of cover rocks — including the then unmetamorphosed forerunners of the Silty Schists — from the basement gneisses. This suggests that, for the cover rocks, some form of pre-metamorphic nappe tectonics prevailed.

Intensive F_2 deformation has largely obliterated any actual fold structures of F_1 phase apart from occasional tightly re-folded and small-scale isoclines whose trends cannot be distinguished from those of the refolding, now plunging ESE. Similarly the core of the original major fold has been deformed almost beyond recognition to produce layers of Silty Schists of almost uniform thickness sandwiched between opposed sequences of the Hornblendic Pelite group in the upper and lower limbs of the Setertind Fold.

F_2 deformation followed the pattern seen in the Krokvatn Fold. In the relatively uniform lithology of the Silty Schists, tightly-packed isoclinal folding is virtually impossible to make out, though intensive folding of this general character is revealed on Kvittind where thin layers of mica-schist are intercalated amongst the more typical siliceous rocks. Some of the latter are strongly banded and were examined for evidence of graded bedding; but in fact the "grading" repeatedly reverses its direction even in limited outcrops, due to the intensive folding. On Middagshaugen the Silty Schists show a uniform lithology and are apparently evenly and rather massively bedded, with planar foliation and partings along more micaceous layers spaced at intervals of the order of 10 cm. In view of the intensive folding in the schists further south, this apparent lack of deformation is almost certainly illusory. Foliation probably follows the axial planes of isoclinal folding and can only be very indirectly related to original bedding (*cf.* the explanation given by King and Rast (1955) for similar phenomena in rocks of the Central Highlands of Scotland).

In addition to causing great thickening of the Silty Schists towards the axial plane of the embryonic Glomfjord Nappe, the early-F_2 deformation folded the normal and inverted rocks of the Hornblendic Pelite sequence to form an outer and inner closure which, between them, almost enclose the Silty Schists. At this stage the developing Setertind and Middagshaugen folds were probably relatively flat-lying with WNW - ESE axes.

Sometime during F_2, however, further extension of the folds towards the north was affected by the cross-folding due to emergence of the Sørfjord Antiform. In the main this caused a rotation of previously-formed structures so that with the steepening of the easterly dip, for example, original fold axes plunging gently ESE became re-orientated to a steeper SE plunge. Around the massive core of the developing Middagshaugen Fold, however, rotation was accompanied by locally intensive folding with an approach to a new N-S trend and relatively gentle plunge. As these late-F_2 folds gave way in time to strictly F_3 folds, so the style of folding became more perfectly concentric and the plunge reduced to only a few degrees in a direction of about 200°.

Disharmony between the massive Silty Schists and the surrounding sequence of thinly-bedded and very variable schists and marbles (i.e. the rocks between the Silty Schist and Hornblendic Pelite on p. 29) has caused the deformation to be concentrated in the fold envelope with scarcely any effects penetrating the core. Movement of the core has been upwards relative to the envelope so that the drag-folding is sinistral and dextral in the eastern and western limbs respectively. Since these S to SSW-plunging drag-folds are locally the dominant minor structures they make it appear that the whole structure is that of a synform with a similar plunge, and a similarly late-F_2 to F_3 origin. This impression is strengthened by the downward convergence of dip of the two limbs. In fact, there is no corresponding evidence of a major synform in the fold core: S-plunging minor folds are very sparsely represented and the almost unwarped foliation dips steadily eastwards right across the fold.

A second anomaly is provided by dips of the rocks in the envelope. Along the axis of the foldd near Dorryvatn these should approximately equal the plunge of 5°-10° SSW, whereas in fact they are mostly about 30°. This must be due to the varying attitudes of beds before the latest folding (*cf.* Ramsay's (1958) description of this kind of relationship shown by refolded structures in the Monar area, Scotland).

According to our present interpretation, therefore, the Middagshaugen Synform is not a major structure formed in the last phase of folding as we originally thought; but essentially an F_2 structure analogous to the Setertind Fold, and moulded rather superficially and to only limited extent by F_3 deformation.

It seems likely that during the general tilting which accompanied the growth of the Sørfjord Antiform, the rocks surrounding the Silty Schist core of the Middagshaugen Fold (in its early-F_2 state) became more tightly compressed and were able to deform more readily than the core itself.

Relative movement of core and envelope produced the "synformal" pattern of drag-folding.

The influence of N - S folding dies out towards the south, probably because the increased thickness of the Silty Schists inhibited the development of deformation other than parallel to existing trends. Effects of the disharmonic relationship between the Silty Schists and the Hornblendic Pelite group round the Setertind closure are discussed on p. 81.

Skavoldknubben Complex

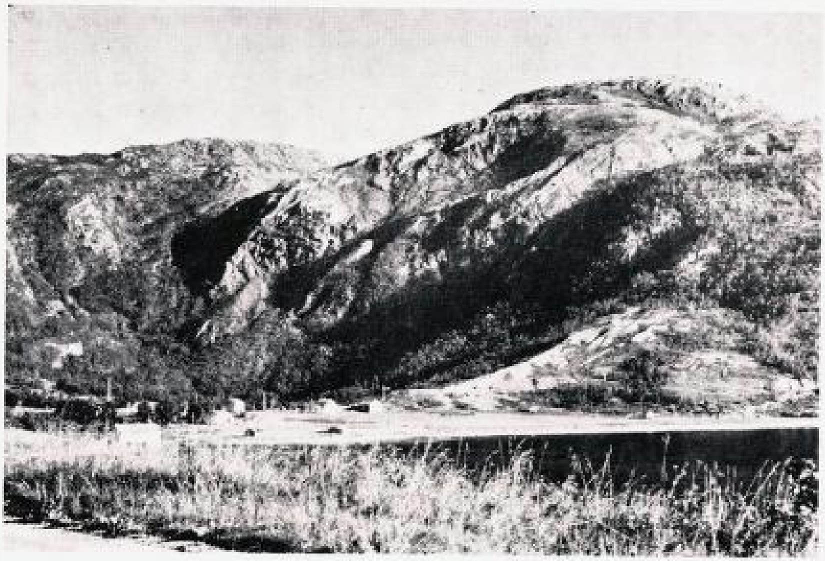
The outcrop pattern of this complex speaks more eloquently of multiple folding than probably any other feature of the region, and has played an understandably important role in the development of a folding hypothesis (see e.g. p. 17). The ground rises to a height of 529 m in just over a kilometre from the fjord and is truncated on its northern flank by the Skavoldelven which cuts a gorge in part of its E-W course. A threedimensional picture of the structure is thus presented (Figs. 29 and 30).

A grey marble forms the core of the closed outcrop confined to the region round Skavoldknubben itself. This is surrounded by a distinctive group of rocks, of which the most important are the hornblende-biotite-gneiss and kyanite-schist described on p. 28. Thickness of the prominent hornblendic rock varies from a few metres in the east to several hundred metres between the summit and the fjord, and like the marbles, it also forms an outcrop closing in all directions. The kyanite-schist behaves in a similar fashion, being quite thin in the east but thickening appreciably to the west of the summit and closing to the north just beyond the limits of the map. A closure to the south lies west of the Middagshaugen fold and constitutes a part of the Laksådalen Fold. The other main southward closure is that of Greftvatn, forming part of the Krokvatn Fold on the east side of Middagshaugen.

Minor folds associated with the two main southward closures generally have an eastward component of plunge, while the main northward closure is dominated by S- or SSW-plunging structures.

A history of double folding which these facts at first suggest — *i.e.* Middagshaugen "F_2" refolding Krokvatn "F_1" (cf. Fig. 2 of Hollingworth *et al.* 1960) — has been shown to be much oversimplified by evidence that has already been discussed in the context of other structures. For convenience, the main items are summarized as follows:

1. Rocks forming the closed outcrop are not tectonically isolated from others in the vicinity, but are related by F_1 folding (Skavoldelven



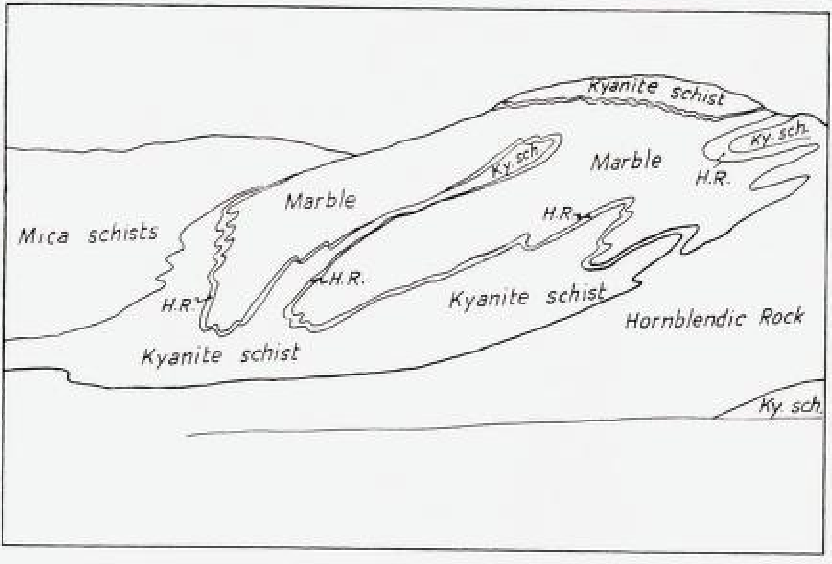


Fig. 29. Skavoldknubben complex viewed from the northwest.

Fold) to another part of the succession which is closer to the Silty Schists and wraps round the Middagshaugen core. The same folding initiated the Altenvatn Fold and helps to account for the otherwise anomalous position of the latter adjoining the Middagshaugen Fold so that both are now embraced by the Skavoldknubben structure.

2. The Krokvatn Fold is essentially an F_2, not an F_1 structure.
3. The Middagshaugen Fold is largely complementary to Krokvatn and formed at the same time. Any deformation it may have suffered after formation of the Krokvatn fold was limited in its effects and could not have caused a bodily overturning of any earlier structure.

Repetition of the hornblendic rock and kyanite-schist north and south of the marble core enables the axial trace of the earliest folding of the complex to be drawn as in Fig. 30. It is intricately folded by a whole series of tight F_2 folds whose axial planes are more or less parallel but which fan out somewhat in the nose of the Glomfjord nappe.

The large angle that this relationship indicates as existing between the early and later fold axes suggests that the early folding belonged to F_1 rather than some preliminary phase of F_2. This would accord with the other local indications of F_1 folding noted in (1) above.

It is impossible to obtain any precise idea of the nature and geometry of the original fold, particularly from those parts of the structure where the later deformation has been most intensive, such as in the core of the Krokvatn Fold and on the western side of the Skavoldknubben complex. Here the F_1 axial trace can only be shown as converging with the later folds, though it would probably be nearer the truth to show a more complex pattern of intersecting lines as in the mathematically derived patterns of refolding presented e.g. by Ramsay (1967). Unless the early fold was very tight or isoclinal in its own right, there is no real reason why its axial trace should pass out of the marbles into the enclosing rocks via any of the present tight folds, since these may all be of exclusively F_2 origin. Bearing this possibility in mind one can appreciate the difficulty involved in determining what components of the present disposition of the rock is due to F_1 and what to F_2 in e.g. regions like that between Alten and Nonshaugen (see Plate 1).

It seems probable that the great thickness of the mass of hornblendic rock west of Skavoldknubben is due to its having been folding in the core of the F_1 structure and then in an F_2 one. This may explain why the outcrop is terminated by closures both to the north and south.

Foliation dips consistently ESE with only very localized exceptions throughout this outcrop and in adjoining rocks. Folding is therefore of a

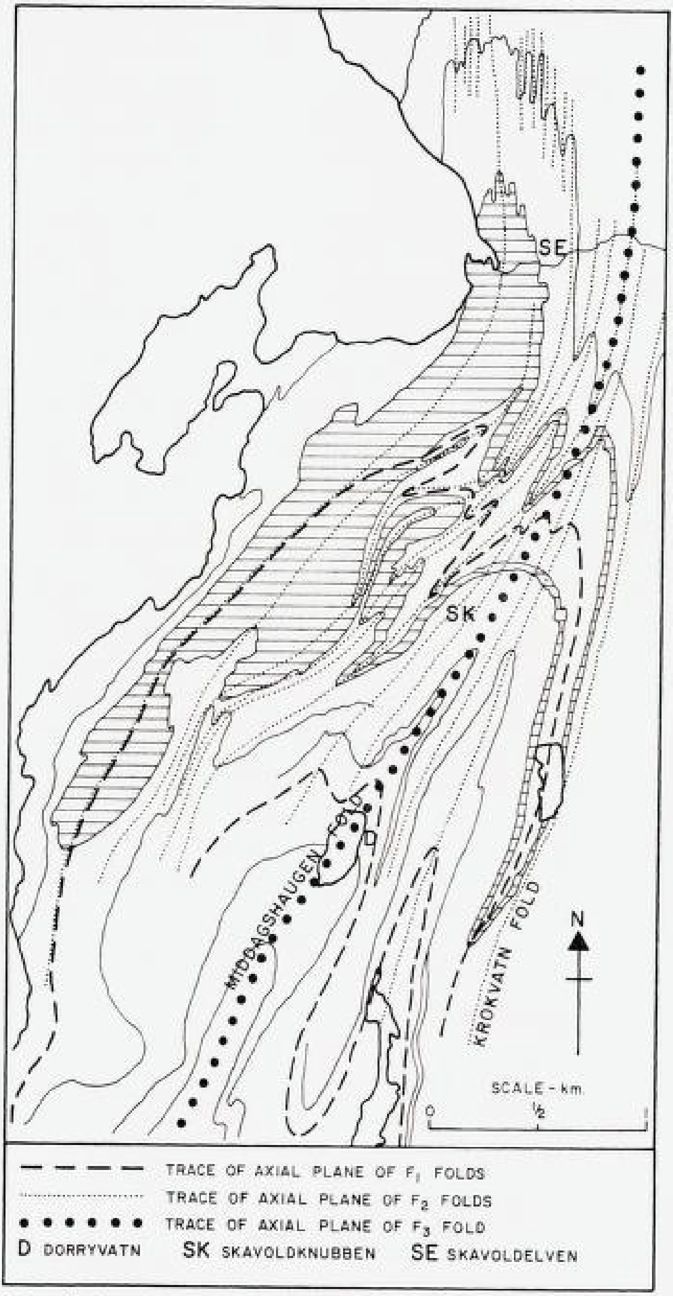


Fig. 30. Map of the relations between F_1, F_2 and F_3 folds around Skavoldknubben.

tightly packed isoclinal character. This is clearly seen in thin quartzite layers in the garnet-two mica-schists which surround the hornblendic rock. Folds in the quartzites show a diversity of plunge directions, e.g. 085°/60°, 145°/30°, 150°/40°, etc.. Lineations in the quartzite tend to have a more north-easterly component of plunge, between 055° and 069°/25°. As elsewhere the tendency is for the easterly or northeasterly plunges to be confined to very compressed small-scale folds, while the 150° set may be more open, on a larger scale and of a determinable sense of movement. These latter folds are dominant and are regarded as belonging to the early-F_2 phase, while the former more fragmentary occurrences are related to F_1. Both the hornblendic rock and quartzites show penetrative axial plane schistosity in places.

Effects of the F_2 folding are conspicuous throughout the complex with earlier folds plunging east or southeastwards and later ones more to the south. In part the two sets developed contemporaneously as shown by the common occurrence of adjacent, minor folds sharing common axial planes but having widely divergent plunges (Fig. 17 e, h). The two sets of folds have comparable styles and there is generally no evidence of the one kind refolding the other. This relationship is particularly well seen in banded siliceous schists forming a plateau north of the Skavoldelven gorge. Some of the most impressive isoclinal folds of the whole region are those which affect the northern margin of the Skavoldknubben marbles deeply infolded with the hornblendic rock and marginal schists, as shown in Fig. 29. The large amplitude of folds of this kind can be appreciated in the northward closure of the kyanite-schist north of Skavoldelven.

Although in Fig. 30 the F_2 axial planes are drawn right through the marble core of the complex, they cannot be identified as such in the marbles, and it is evident that the latter have introduced a disharmonic component into the later folding.

Finally reference must be made to the zone of most intensive F_3 deformation which extends along the Middagshaugen axis to the NNE. It is oblique to the trends of the main isoclinal folds, and probably its main effect has been to deform and rotate these earlier structures. This is seen north of Skavoldelven where the beds have locally been tilted into the vertical and where the major structure in the zone of intensive F_3 deformation is apparently a southward-closing antiform, contrasting with the Middagshaugen Synform further south, and indicating that formation of the folds is largely independent of the F_3 phase.

Fig. 31. Refolded ? F_1 isoclines in siliceous schists, Steffodalen Col.

Setertind - Steffodalen area

This comprises rocks between the Setertind and Spilderdalen closure of the Glomfjord nappe (Fig. 7). As in the previous area there is abundant evidence of isoclinal folding before the main Setertind Fold developed. Since refolding has been on approximately parallel axes, there are no distinctive closed outcrop patterns. Instead there is abundant evidence from tightly refolded isoclinal minor folds (Fig. 16) as also described and illustrated by Holmes (1966).

Mapping conditions are difficult except in Steffodalen which is part of an old valley "hanging" between the overdeepened part of Ruffudalen to the east and a corrie to the west, bounded on the north by a steep face of Setertind and on the south by the outer bastions of the snow-covered Glombreen mass.

The area is however critical mainly because of the evidence it provides of the stratigraphical and structural relationship between the granitic gneisses and the surrounding schists, particularly the Silty Schists. Having found that the Silty Schists along their outer margin face the Bjellatind Gneisses across the (in part) F_1 Laksådalen Fold and its accompanying Lysvatn Slide, it was important to see whether along their inner margin the Silty Schists were similarly facing the gneisses — this time of Glomfjord and Fykan. It was anticipated that this would be the case because both Holmes and M. Jones (personal communication) had reported calcareous schist similar to the Hornblendic Pelite as occurring close to the margins of the Glomfjord and Fykan Gneisses respectively. If these rocks should prove identical with the Hornblendic Pelite, then the latter would be known to be close neigbours to both the gneisses and Silty Schists, thus greatly strengthening the case for correlation of the latter formation as suggested in Section 3. Isoclinal F_1 folds separating the Silty Schists and Fykan and Glomfjord Gneisses would be proved at the same time (see Figs. 1 and 6).

In the event it was found that the calcareous schist was *not* sufficiently similar to the Hornblendic Pelite to justify correlation, but there is abundant other evidence to prove the duplication of a substantial part of the succession between the Silty Schists and Glomfjord and Fykan Gneisses. Much of this duplication is due to pre-Setertind structures which we shall refer to as the *Steffodalen Folds* whose axial traces are show in Fig. 9.

The plunge is now impossible to distinguish from that of later folding at about 10° ESE. This coincides with the ground slope over much of Steffodalen so that beds outcrop in numerous parallel strips which fluctuate in dip but otherwise give little indication of the complexity of the folding. This is seen in gulleys eroded along ac-joints and in the east face of the corrie which truncates Steffodalen to the west. These profile sections show small isoclines (associated with occasional relics of axial-plane schistosity) folded by tight recumbent folds that are congruous with the main Setertind closure and are themselves warped by folds of small amplitude with generally steep axial planes. Strain-slip microfolding is associated with the later folds in some of the schists (Fig. 16).

Determining the geometry of the major first fold amidst this complexity is obviously difficult. Outcrops are locally repeated by all three kinds of folds; but it is possible to distinguish what may be described as a first-order duplication of significant parts of the succession due to the Steffodalen Folds. The main formation duplicated in this way is the garnet-two mica-schist, which outcrops on Setertind and again near the southern rim of Steffodalen. In both outcrops it has layers in which occur tectonic inclusions of the distinctive garnet-hornblende rock described on p. 39. Equally conspicuous are belts of pale grey siliceous schists which are prominently banded with biotite- and, in part, hornblende-rich layers. This rock has a pronounced minor and microfold lineation and is the best rock locally for revealing the small-scale refolded isoclines. Other valuable markers include actinolitic calc-schists and tremolite marbles.

Attitudes of the early Steffodalen structures depend on their position in the Setertind closure. On Setertind itself their axial planes are steep and the thick mass of garnet-two mica-schist, intensively interfolded with banded siliceous schists and feldspathic schists, form the core of a first-fold antiform. The closure itself is exposed rather inaccessibly in the corrie west of Setertind. A subsidiary flanking antiform ouctrops south of Setertind whose core comprises a sequence of quartzites and schists formed by repetition of only one or two beds a few metres thick. The outcrop terminates down plunge where the axial plane becomes folded round the hinge of the Setertind Fold. Although the axial plane of the latter lies just above ground level over most of Steffodalen, at this locality the ground rises to interesct the plane and give a twist to the outcrop as shown on the main map.

On the south side of Steffodalen the dip steepens and beds are much less crumpled as they come under the stretching influence of the core of Glomfjord Gneisses in the Spilderdalen Fold (just south of the area mapped). There is striking disharmony at the level of the more northerly of the two layers of tremolite-marble shown close to the southern boundary of the main map. The marbles can be traced from where they cross a lake on Steffodalen col (160 m) to a local summit of Glombreen (1046 m) in steep and smoothly curved outcrops (shown by broken lines) round the Spilderdalen closure. By contrast, schists which succeed the marbles to the north are thrown into sinistral F_2 drag-folds which occur for some distance down the mountain side.

Because of the greater simplicity of F_2 structure in the southern part of Steffodalen, the effects of the earlier folding show up more clearly. A key to these is provided by the outcrops of tremolite marble, all of which appear to be formed of one original bed. Although this is involved in the antiformal parts of the structure of northern Steffodalen and Setertind its outcrop is mainly confined to the corrie face west of Steffodalen. Here it shows sinistral drag-folds consistent with the marble turning down into a tight synform before it reappears, folded back on itself, as the northern one of the twin outcrops already referred to.

These provide the simplest and at the same time the most striking evidence of an F_1 fold in the area. The core of the fold is formed of a nodular-weathering calcareous pelitic schist with big garnets, forming a layer some tens of metres thick flanked by prominent and identical looking outcrops of rusty schist which are exposed from Steffodalen col to the summit of 1046 m on Glombreen. These are followed in turn by garnet-mica-schists, laminated siliceous schists, minor developments of rusty-weathering schists and then the grey tremolite-marbles. Such a symmetrical arrangement suggests repetition by folding but it must be said that no convincing supporting evidence from minor structures has been found for a major fold.

The remaining rocks between the tremolite marbles and the Glomfjord Gneisses are mostly either covered or inaccessible in this area (see Holmes, *op. cit.* for further details). Some of these rocks are similar to the garnet-two mica-schist which would be appropriately placed from our reading of the structure — but limited exposure make identification very uncertain.

The antiformal F_1 structure of Setertind and northern Steffodalen can be traced eastwards round the F_2 Setertind Fold into the belt of mica-schists which separate the Silty Schists of Tverfjell from the rocks in the Fykan fold.

A slide — the Steffodalen Slide (Figs. 8 and 9) postulated by Holmes *(op.cit)*. — must separate the main part of the schists in this belt from those which close round the Fykan Gneisses. As noted above, the latter cannot be matched exactly with any of the rocks close to the Tverfjell Silty Schists (i.e. the group containing the Hornblendic Pelite) though there are some similarities: both groups include a variety of calcareous schists, and the marginal "gneisses" are actually of Silty Schist lithology. The Fykan fold has a typical F_2 closure with schistosity folded round. However, its relationship to the Steffodalen and Tverfjell Folds shows that it must have originated in F_1 times and been moulded by F_2 deformation. The slide must similarly have been active over a long time. Although the slide cuts out much of the fold, the axial trace of what remains is believed to continue, with the slide, into the "synformal" part of the F_1 structures of south Steffodalen. It is suggested that the slide corresponds with the plane of disharmonic folding described above. Finally, the southernmost member of the Steffodalen F_1 folds, which duplicates the tremolite-marbles, follows round the Spilderdalen closure into the schist belt which separates the Fykan and Glomfjord Gneisses (Figs. 1 and 9).

Influences which produced the late N-S minor folds of the Middagshaugen Synform failed to penetrate beyond the boundary of the Silty Schists into the Setertind Fold. However, the structures are influenced by a broad warping along an approximately N-S extension of the Sørfjord

Fig. 32. Late-F_2 folds in schists showing variable plunge, south of Opsal.

- Bjellatind axis, causing plunges west of Steffodalen to be mainly south westerly. Occasional minor folds with plunges of about 165°/30° occur in the region of warping.

The Sørfinnset area

The Gildeskål Marbles of this region form low-lying pasture in which exposure is limited, while the central schists form slightly higher ground of poorly drained heathland. By contrast, the encircling schists outcropping in the lower slopes of the Middagshaugen - Kvittind ridge to the east and Nonshaugen to the south are largely wooded and partially obscured by coarse boulder screes.

Lack of adequate relief makes it difficult to build a three-dimensional picture of the central schist unit. This forms two main outcrops separated by marbles, the pattern being a result of isoclinal and recumbent folding about sensibly E - W axes refolded by F_3 folds plunging gently SSW. In keeping with a position on the crest of the Sørfjord Antiform, dips are dominantly low, though there are narrow belts of steep dip produced by asymmetrical F_3 folds. In the latter case the strike is roughly NNE-SSW while in intervening areas it is approximately E - W with a southerly dip consistent with the F_3 plunge. Such variation gives a complex pattern of outcrop whose full interpretation would require more perfect exposures than are available. On the eastern margin of the northern outcrop, the schists and marbles interpenetrate as a result of the isoclinal folding and the narrow belts so formed are sharply bent by the re-folding. The form of the eastern contact is governed mainly by F_3, though at one point a marginal facies of the schist group penetrate deeply into the schist outcrop as a result of the earlier folding.

The key fact about the southern outcrop is that the marbles dip *beneath* the schists along the northern boundary, while marbles lie *above* the schists along the southern one. Although the details are not clear, the schists must therefore outcrop in some form of fold closing to the east, and related to early recumbent folding.

Confirmation that the schists lie in the hinge-zone of an early-F_2 (or possibly, originally F_1) structure is provided by stratigraphical evidence. The same group of marbles is in contact with the same schists which are repeated along both margins of the northern outcrop and all round the southern one.

A few feet of a very distinctive siliceous and pyritous schist adjoins the marbles: this is almost white when fresh, but weathers to a rusty brown.

Next occurs another thin schist containing inconspicuous pale garnets, followed by an impersistent layer of impure tremolitic marble. The core of the schist belt is a sparsely garnetiferous and unusually fine-grained mica-schist with a pitted surface due to segregations of carbonates associated with muscovite.

These carious-weathering schists grade into a conglomerate which is well exposed near the shore and in road cuttings through the southern outcrop, and also to a limited extent in the northern outcrop north of Finset. The most conspicuous pebbles are all of marble, rimmed by dark green reaction skarns. Details of the deformation will be given in a separate publication: most of the pebbles are flattened, some are elongated, and in some cases folded into shapes of irregular cross-section.

Rocks belonging to the schist group occur as trains of tectonic inclusions in the marbles around the inlet of Alten and north of Finset, but their relationship to the main outcrops cannot be assessed. The inclusions reach lengths of several tens of metres, and are characterized by an unusual diversity of minor fold styles and trends. Some of this is presumably due to deformation accompanying the boudinage process; but it seems likely that being enclosed in very plastic marble, the schists have been cushioned against the full effects of the later phases of deformation and consequently may retain more steps of the earlier deformation.

CONCLUDING DISCUSSION

The Sørfinnset area is divided by a slide separating formations in the east, (the Sundsfjord, Sokumfjell and Harefjell Groups) which are included within the Beiarn Nappe of Rutland and Nicholson (1965) from complexes of granite-gneisses and their envelopes in the west. These latter constitute the Glomfjord Nappe complex of Rutland and Nicholson, though there are grounds for separating the gneisses and envelope of Bjellatind and regarding them as forming a lower nappe structure.

The Bjellatind and Glomfjord nappes together with that of Svartisen further south form a series of recumbent to isoclinal folds which are overturned to the north and have predominantly E-W trends. They are essentially anticlinal, with cores of granitic gneisses which are probably in the main derived from Precambrian basement rocks, though from new evidence outlined in this paper, gneisses in and near the Sørfinnset area seem more likely to be formed by granitization of Eocambrian (Sparagmite) sediments that originally rested unconformably on the basement. Involvement of basement rocks in the formation of these nappes is comparable to that in Morar (Kennedy, 1955) and Glenelg (Ramsay, 1958).

Conditions during formation of the Bjellatind and Glomfjord nappes were those of deep-seated plastic deformation with high grade metamorphism and localized granitization and granite emplacement.

Structural evolution of the two nappes during the F_2 and F_3 phases has been dominated by the folds round the gneisses, i.e. the Nonshaugen and Spilderdalen Folds. The former plunges east and west from a culmination caused by intersection with the N-S Sørfjord Antiform, but the latter is deflected to the south-west and dies out so that it does not have a comparable effect in warping the Spilderdalen Fold which therefore plunges consistently eastwards throughout its length (Holmes, 1966). Consequently the "anticlinal" Nonshaugen and Spilderdalen Folds have roughly parallel plunges east of the Sørfjord axis, but divergent plunges on the west side. A complementary "syncline" formed of envelope rocks — the Kjeipen Synform described by Holmes (op. cit.) — occupies the resulting gap between the nappes. This gap narrows eastwards and the synform is largely cut out along the Lysvatn Slide. For these reasons the Setertind and Middagshaugen Folds of the Glomfjord Nappe on the east flank of the Sørfjord Antiform do not reappear on the west flank.

Lack of symmetry across the Sørfjord axis is due to two main factors: (1) overlap in time between F_2 and F_3 deformation; (2) a legacy of F_1 movements in giving the rocks significantly varied attitudes and distribution before the start of the synmetamorphic F_2 and F_3 phases.

Evidence suggests that much of the warping of the Sørfjord Antiform occurred simultaneously with the northward movement of the nappe fronts. The dominantly southwesterly plunges of the western part of the area may perhaps be regarded as a compromise direction produced by deflection of would-be E-W folds off the flank of the rising antiform. East of the Sørfjord axis the interplay of F_1, early- and late-F_2, and F_3 has given an interference pattern of folding which is perhaps no more complex, but is certainly more conspicuous, than in the west. The most striking effects are seen where localized intensification of the late-F_2 and F_3 N-S folding occurs in a zone extending several kilometres north from Middagshaugen. This reorientates structures in the Middagshaugen closure of the Glomfjord Nappe and gives it the form of a S-plunging synform.

The highly distinctive sequences in the Meløy Group have provided critical evidence to show that before folds of the Glomfjord nappe complex began to develop their present form, the rocks had already been subjected to extensive folding and thrusting. This constitutes an F_1 phase of nappe development. The extent and condition under which the F_1 movements occurred are difficult to determine because of intensity of the later deformation. It is inferred, however, that the F_1 structures were premetamorphic and characterized by roughly E-W trends.

Detailed studies of other areas in Northern Norway show a general sequence of folding which is similar in many respects to that around Sørfinnset (e.g. D. M. Ramsay and Sturt, 1963; I. B. Ramberg, 1967: Roberts, 1968). It is hoped that radiometric age determinations will eventually make correlation of the phases of deformation possible.

The constant association of the granitic gneisses and the Meløy Group throughout the region has prompted the suggestion that their original stratigraphical relationship has not been desroyed (see *e.g.* Hollingworth *et al*, 1960; Rutland and Nicholson, 1965, p. 78). Our opinion on this has changed during the last few years, however, as the significance of the latets mapping has become apparent. We now regard the Meløy Group not as a stratigraphical entity but as a composite unit formed of F_1 nappes. These appear to be at least parautochthonous, if not allochthonous, in character.

The lowest F_1 unit is also the best authenticated, incorporating the Tverfjell Fold with an anticlinal core of meta-Sparagmite. The original inverted limb faces the granitic gneisses of the area across a series of essentially synclinal folds and slides. Whether or not our suggested correlation between local gneisses and "Silty Schists" is accepted, there appears to be no escape from the conclusion that a major structural break separates the gneisses and adjacent rocks that were tied to the original basement from "Silty Schists" and other formations in the Meløy Group. If this separation was fairly complete it would help to explain why one part of the original Sparagmite became granitized — by maintaining contact with the basement complex throughout the F_2 metamorphic period — while the transposed part mostly escaped granitization.

It is quite likely that movement during the early phase was confined largely to cover-rocks, though no direct evidence of this is available in the area.

A major effect of early movements on the remaining rocks included in the Meløy Group is the emplacement of Skavoldelven Marbles into the sequence by a combination of F_1 thrusting and folding. Because of their tectonic emplacement, these rocks must be related to other marbles in the vicinity. The situation is analogous to that of the Skavoldknubben Marbles discussed on p. 33. The Gildeskål and Sokumfjell Marbles are the most obvious possibilities for such correlation. Taking into account the duplication of the intervening schists due to F_1 and F_2 folding, and also effects of slides bounding the marbles, a reasonable case can be made for linking the Skavoldelven and Gildeskål Marbles. Too many unbridgeable gaps in the evidence exist to suggest with conviction that a similar relationship may apply to the Sokumfjell Marbles, though this is a possibility through the agency of the 593 Fold. A major complication in this case is the presence of intervening slides which are known — from evidence of tectonic inclusions with rotated schistosity — to have been active well after the start of metamorphism.

Whatever the correct interpretation of these relationships may be, the fact remains that one has to look outside the Meløy Group for stratigraphical equivalents of the Skavoldelven Marbles and for a continuation of the F_1 structures with which they were associated. This suggests the interesting and likely possibility that up to the end of the F_1 phase, the Beiarn and Glomfjord nappe complexes shared some structural elements in common. Disjunctive relationships that existed at this time became largely obliterated during subsequent development of the Glomfjord Nappe but remain as a recognizable legacy in the Beiarn structure.

Rutland and Nicholson have commented on the significance of the E-W trends in the nappes in the Glomfjord complex, suggesting that they are deep-formed crossfolds which have in part moved northwards under gravity from off the Svartisen culmination towards the depression between it and the Heggmovatn culmination to the north. These crossfold trends die out well to the north of the Sørfinnset area and also to the east of the Sokumfjell marble group where more 'normal' N-S trends predominate. Thus while the Glomfjord nappes may have a trend almost at right angles to the main Caledonoid trend they are not crossfolds in this immediate locality (see Rast and Platt, 1957, p. 159).

H. Ramberg (1967) has pointed out that structural deviations from the main Caledonoid trend are common, particularly near basal gneiss complexes where strikes are parallel to the outline of the complexes as *e.g.* in Tysfjord (Foslie, 1941). Similar features were achieved by Ramberg in an interesting series of experiments using dynamic models with centrifugal force to simulate gravity. The experiments suggest that basement culminations produced as a result of crustal forces in the early history of the Caledonian fold-belt would, when mobilized, rise as a result of vertically buoyant forces and produce much of the horizontal compression as a secondary effect. Cover rocks would then flow away from the culminations into the surrounding depressions, becoming recumbently folded in the process and perhaps developing flat-lying schistosity as they spread under their own weight. The easterly-trending pre-metamorphic nappes of the Glomfjord area may thus be gravity controlled structures related to the uprise of the Svartisen culmination early in the deformation cycle.

ACKNOWLEDGMENTS

The work was mainly carried out as part of a research project under the leadership of the late Professor S. E. Hollingworth of University College London whose friendship and stimulating discussion both in the field and the laboratory we remember with gratitude.

Thanks are due to colleagues who mapped adjoining areas — Professor R. W. R. Rutland, Drs. K. J. Ackermann, M. Holmes, R. Nicholson, B. J. Walton and Mr. M. Jones for their help and companionship in the field and to Professor Rutland and Dr. Nicholson for discussion on the structure.

We are also grateful to many Norwegian friends in the Sørfinnset and Bodø areas who helped in many ways to make the work possible.

The research was financed by the Central Research Fund of the University of London, the former Department of Scientific and Industrial Research, the Royal Society and the University of Bristol to whom our thanks are given.

REFERENCES

Abbreviations:

NGU = Norges Geologiske Undersøkelse

NGT = Norsk Geologisk Tidsskrift

SGU = Sveriges Geologiska Undersökning

ACKERMANN, K. J. 1960. Mineral paragenesis of the metasediments invaded by granite in the area around Sokumvatn, Gildeskål, Norway. *Unpublished Thesis, University of London.*

ACKERMANN, K. J., NICHOLSON, R. and WALTON, B. J. 1960. Mineral development and deformation in metasedimentary rocks in the eastern part of the Glomfjord region, Northern Norway *Int. geol. Congr. 21 (19),* 54-63.

BRADSHAW, R and WELLS, M. K. 1964. Boudinage-type Structures at Sørfinnset, Gildeskål, North Norway. *Geol. Mag. 101,* 484-495.

FLEUTY, M. J. 1964. Tectonic Slides. *Geol. Mag. 101,* 452-456.

FOSLIE, S. 1941. Tysfjords Geologi. Beskrivelse til det geologiske gradteigskart Tysfjord. *NGU 149,* 1-298.

HOLLINGWORTH, S. E., WELLS, M. K. and BRADSHAW, R. 1960. Geology and Structure of the Glomfjord Region, Northern Norway. *Int. geol. Congr. 21 (19),* 33-42.

HOLMES, M. 1966. Structure of the area north of Ørnes. Nordland, Norway. *NGU 242,* 62-93.

HOLMSEN, G. 1932. Rana. Beskrivelse til det geologiske generalkart. *NGU 136,* 1-107.

HOLTEDAHL, O. 1948. Deep-seated Crustal Deformation in the Northwestern part of the Caledonides of Southern Norway. *Int. geol. Congr. 18 (13),* 135-140.

KENNEDY, W. Q. 1955. The tectonics of the Morar anticline and the problem of the North-West Caledonian Front. *Quart. J. geol. Soc. Lond. 110,* 357-390.

KING, B. C. and RAST, N. 1955. Tectonic styles in the Dalradian and Moines of parts of the Central Highlands of Scotland. *Proc. Geol. Ass. 66,* 243-269.

KNILL, J. L. 1960. A Classification of Cleavages, with special reference to the Craignish District of the Scottish Highlands. *Int. geol. Congr. 21 (18),* 317-325.

KULLING, O. 1955. Beskriving till Berggrundskarta över Västerbottens län. 2. Den Kaledoniska Fjällkedjans Berggrund inom Västerbottens län. *SGU Ser. Ca, 37,* 101-296.

MEAD, W. J. 1940. Folding, rock flowage and foliate structures. *Journ. Geol. 48.* 1007-1021.

MUFF, H. B. in EACH, B. N., KYNASTON, H. and MUFF, H. B. 1910. The geology of the seabord of Mid-Argyll. *Mem. Geol. Surv. Scotland.*

NICHOLSON, R. 1960. The Metamorphic Rocks of the Storglomvatn Area, Northern Norway. *Unpublished Thesis, University of London.*

NICHOLSON, R. 1968. A section across the Norwegian Caledonides — Bodø to Sulitjelma. *Geol. Soc. Lond. Circular 146,* 1.

NICHOLSON, R and WALTON, B. J. 1963. The structural geology of the Navervatn-Storglomvatn area, Glomfjord, Northern Norway. *NGT 43,* 1-58.

OFTEDAHL, C. 1966. Note on the main Caledonian thrusting in Northern Scandinavia. *NGT 46,* 237-244.

RAMBERG, H. 1967. The Scandinavian Caledonides as studied by Centrifuged Dynamic Models. *Bull. geol. Inst. Univ. Uppsala 43. (4-5),* 1-72.

RAMBERG, I. B. 1967. Kongsfjell-områdets geologi, en petrografisk og strukturell undersøkelse i Helgeland, Nord-Norge. *NGU 240*, 1-152.

RAMSAY, D. M. & STURT, B. A. 1963. A study of fold styles, their associations and symmetry relationships, from Sørøy, North Norway. *NGT 43*, 411-430.

RAMSAY, J. G. 1958. Superimposed folding at Loch Monar, Inverness-shire and Ross-shire. *Quart. J. geol. Soc. Lond. 113*, 271-307.

RAMSAY, J. G. 1958. Moine-Lewisian relations at Glenelg, Inverness-shire. *Quart. J. geol. Soc. Lond. 113*, 487-523.

RAMSAY, J. G. 1967. *Folding and Fracturing of Rocks*. New York.

RAST, N. 1956. The origin and significance of boudinage. *Geol. Mag. 93*, 401-408.

RAST, N. and PLATT, J. I. 1957. Cross-folds. *Geol. Mag. 94*, 159-167.

ROBERTS, D. 1967. Geological investigations in the Snåsa-Lurudal area, Nord-Trøndelag. *NGU 247*, 18-38.

ROBERTS, D. 1968. The Structural and Metamorphic History of the Langstrand-Finfjord Area, Sørøy, Northern Norway. *NGU 253*, 1-100 .

ROSENQUIST, I. T. 1941. The Lønset anticline in the Opdal Area. *NGT 21*, 25-48.

ROSENQUIST, I. T. 1942. Metamorphism and metasomatism in the Opdal area (Sør-Trøndelag. Norway). *NGT 22*, 106-202.

RUTLAND, R. W. R. 1959. Structural Geology of the Sokumvatn area, North Norway. *NGT 39*, 287-337.

RUTLAND, R. W. R., HOLMES, M. and JONES, M. A. 1960. Granites of the Glomfjord area, Northern Norway. *Int. geol. Congr. 21 (19)*, 43-53.

RUTLAND, R. W. R. anl NICHOLSON, R. 1965. Tectonics of the Caledonides in part of Nordland, Norway. *Quart. J. geol. Soc. Lond. 121*, 73-109.

RUTLAND, R. W. R. and SUTHERLAND, D. S. 1967. The Chemical Composition of Granitic Gneisses and Sparagmitic Meta-Sediments in the Glomfjord Region, Northern Norway. *NGT* 47, 359-374.

STRAND, T. 1955. Sydøstligste Helgelands geologi. *NGU 191*, 56-70.

STRAND, T. 1958. Greenschists from the southeastern part of Helgeland, Norway. their chemical composition, mineral facies and geologic setting. *NGU 203*, 112-129.

STRAND, T. 1960. The pre-Devonian rocks and structures in the region of Caledonian deformation. *In Geology of Norway, O. Holtedahl ed., NGU 208*, 170-284.

STRAND, T. 1961. The Scandinavian Caledonides. A Review. *Am. J. Sci. 259*, 161-172.

SUTTON, J. and WATSON, J. 1956. The pre-Torridonian metamorphic history of the Loch Torridon and Scourie areas of the North-West Highlands and its bearing on the chronological classification of the Lewisian. *Quart. J. geol. Soc. Lond. 106*, 241-296.

WALTON, B. J. 1960. The metamorphic and structural geology of the Navervand Region, near Glomfjord, Northern Norway. *Unpublished Thesis, University of London.*

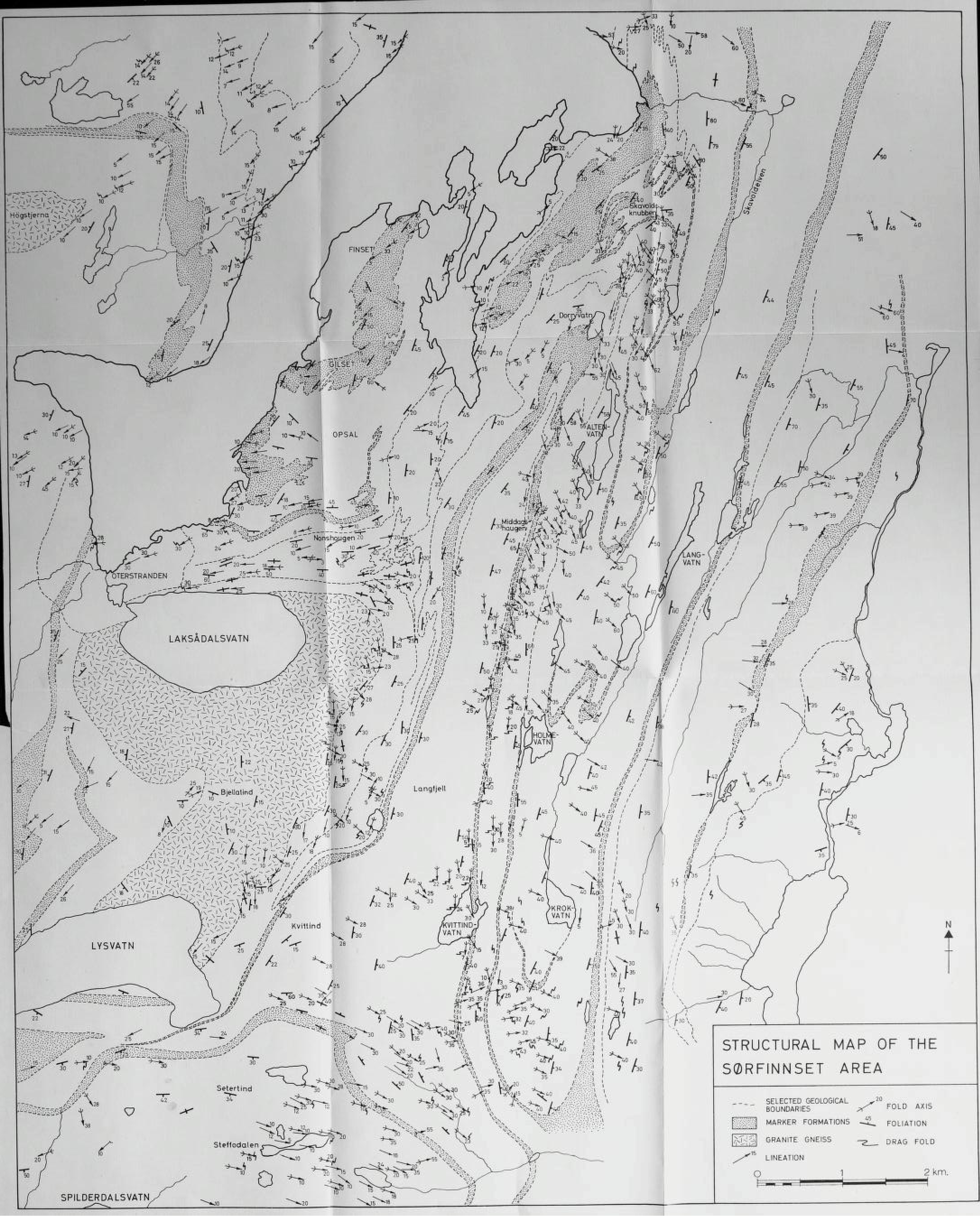
WATSON, B. J. 1960. Evidence of mobility in reactivated Basement complexes. *Proc. Geol. Ass. 78*, 211-235.

WHITTEN, E. H. T. 1966. *Structural Geology of Folded Rocks.* Chicago.

WILSON, G. 1961. The Tectonic Significance of Small Scale Structures and their importance to the geologist in the field. *Annls Soc. géol. Belg. 84*, 423-458.

Manuscript received June 1969.

SÖRFJORD
AUSEN
ALTEN
FINSET
GILSET
OPSAL
Nonshaugen
OTERSTRANDEN
LAKSÅDALSVATN
LYSVATN
Bjellatind
Galtskartind
Kvittind
KVITTIND-VATN
Lang-fjell
Laksådalen
Middags-haugen
Stepperne
KROK-VATN
HOLME-VATN
Langdalen
Rúffudalen
Tverfjell
Setertind
Steffodalen
SPILDERDALSVATN
MARGIN OF FYKAN GNEISSES
FORSVATN
Högstjerna
LANGVATN
Grötset-tind
GRÖTSET
PLATEAU OF MARBLES, SILICEOUS & CALC-SCHISTS
MICA-SCHISTS WITH STRONG LINEATION AND MICROFOLDING
GILDESKÅL MARBLES
DORRYVATN
ALTEN-VATN
DJUP-VATN
Skavold-knubben
Skavoldelven
SKAVOLDELVEN MARBLES
Hestdal-fjell
KJERSLET-VATN
LANG-VATN
Tverden
VINDVIK
Sirivik-fjell
DENSELY WOODED DIP-SLOPE
INJECTED AND SHEARED GNEISS
ÅGNES
Sundsfjorddalen
SOKUMFJELL MARBLE GROUP
HAREFJELL GNEISS GROUP
SAMEL-VATN
593
MAINLY PELITIC SCHISTS & GNEISSES OF SUNDSFJORD GP.
STOR-VATN
N
Schists
Marble
Quartzite
Pegmatite
SUNDSFJORD GROUP
Mica & calc-schists with tremolite marbles
Mica-schists with granite lenses
Felspathic garnet-mica-schist
MELÖY GROUP
Banded hornblende-mica-schist
Garnet-mica-schist with quartz laminae
Pyritous quartz-muscovite-schists
Calcareous garnet-mica-schist
Kyanite-schist
Silic schists with garnet-hornblende rocks
Garnet-2 mica-schist
Biotite-hornblende-gneiss
'Hornblendic Pelite'
Calc-schists, hornblende-schists, marbles etc.
Felspathic garnet-mica-schist adjoining Gneiss
Calc-schists, etc in core of Tverfjell Fold
BASAL ROCKS
'Silty Schists'
Granite Gneisses
0 ½ 1 1½ 2 km
Foliation dip
Lineation plunge
M.K.W.


STRUCTURAL MAP OF THE SØRFINNSET AREA
SELECTED GEOLOGICAL BOUNDARIES
MARKER FORMATIONS
GRANITE GNEISS
LINEATION
FOLD AXIS
FOLIATION
DRAG FOLD
0
1
2 km.
N
Högstjerna
FINSET
GILSET
OPSAL
Skavoldknubben
Skavoldelven
Dorrivatn
ALTEN-VATN
LANG-VATN
Middagshaugen
Nonshaugen
ØTERSTRANDEN
LAKSÅDALSVATN
HOLME-VATN
Langfjell
Bjellatind
Kvittind
KVITTIND-VATN
KROK-VATN
LYSVATN
Setertind
Steffodalen
SPILDERDALSVATN