The Structural Geology of the Saura Region, Nordland

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Plate   I. Geological and structural maps of the Saura region,
           Nordland.

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Abstract

The structural development is described of the Saura region, occupying part of the internal zone of the Caledonide orogenic belt in Nordland.

Two major rock divisions have been distinguished; a number of gneissic groups, holding more limited developments of metasedimentary rocks, underlie much of the southern and south-eastern sectors of the region whilst two metasedimentary groups are situated to the north-west. A major tectonic slide separates the gneissic groups from the metasedimentary groups, and the individual litho-structural units which comprise the major divisions have themselves often behaved as structurally independent entities. Rocks of all the groups are heavily veined by granite.

Two broad phases of deformation have been recognized. The early phase, with which the tectonic sliding is associated, consists of major recumbent folds and overfolds developed about E-W to NE-SW trending axes. These folds were formed during two closely related episodes, F_1 and F_2, but the majority are ascribed to the F_2 episode which was responsible for the inversion of the northern part of the gneissic groups and the now overlying metasedimentary groups. These structures have been refolded during the later phase of deformation (F_3) into a synform plunging gently towards the north-east and possessing a thick, steeply dipping eastern limb. The synform controls the present structural «grain» of the Saura region, most of which lies in the eastern limb of the fold and possesses an overall NE-SW trend. The structural relationships in the north suggest the possibility of continuity between the early and late phases of deformation.

The structure of the Saura region is discussed in the context of the tectonics of the wider area of Nordland outlined by Rutland and Nicholson (1965). The pattern and sequence of events that have been distinguished during the present work are repeated on a larger scale in the wider area considered by those workers and the structural evolution of the Saura region is ascribed to nappe-tectonics flanking a culmination of mobilized Precambrian basement to the north-east of the map-area.

Introduction

Saura is situated on the coast of northern Norway in latitude 67°
6′ N, longitude 14° 20′ E of Greenwich. It lies some 20 km south of
Bodø and is sheltered from the open sea by Sandhornøy (Fig. 1).

The Saura region forms a part of the internal zone of the Cale-
donide orogenic belt, lying to the west of the thrust front recognized
along the international boundary with Sweden. Strand (1961) has provi-
ded a useful account of the Scandinavian Caledonides as a whole. The
Saura region itself comprises a part of the 1 : 250 000 geological map
of Salta produced by Norges Geologiske Undersøkelse. Rekstad (1929)
summarized the available information in a report to accompany that
map and referred to geological features occurring within the Saura
region.

More recent published work on the geology of the coastal belt of
Nordland includes the results of a survey commenced in 1953 by a
team from University College London. Rutland (1959) published an
account of the structural geology of the Sokumvatn area which is
situated to the south of the Saura region and is separated from it by
the Beiartind range, whilst Nicholson and Walton (1963) have described
the geology of the Navervatn—Storglomvatn area which lies to the
south of the Sokumvatn area. Holmes (1966) published a description
of the structural geology of the area north of Ørnes and Wells and
Bradshaw (1970) have recently described the geology of the Sør-
finnset area; both of these areas are situated to the west of the
Sokumvatn area. Three short papers on various aspects of the geology
of the Glomfjord region have also been published (Ackerman *et al.*
1960; Hollingworth *et al.* 1960; Rutland *et al.* 1960).

Rutland and Nicholson (1965) presented an account of the tectonics
of the western part of Nordland between 66° 30′ N and 67° 30′ N. This
area, which includes the Saura region, comprises a basement of Pre-
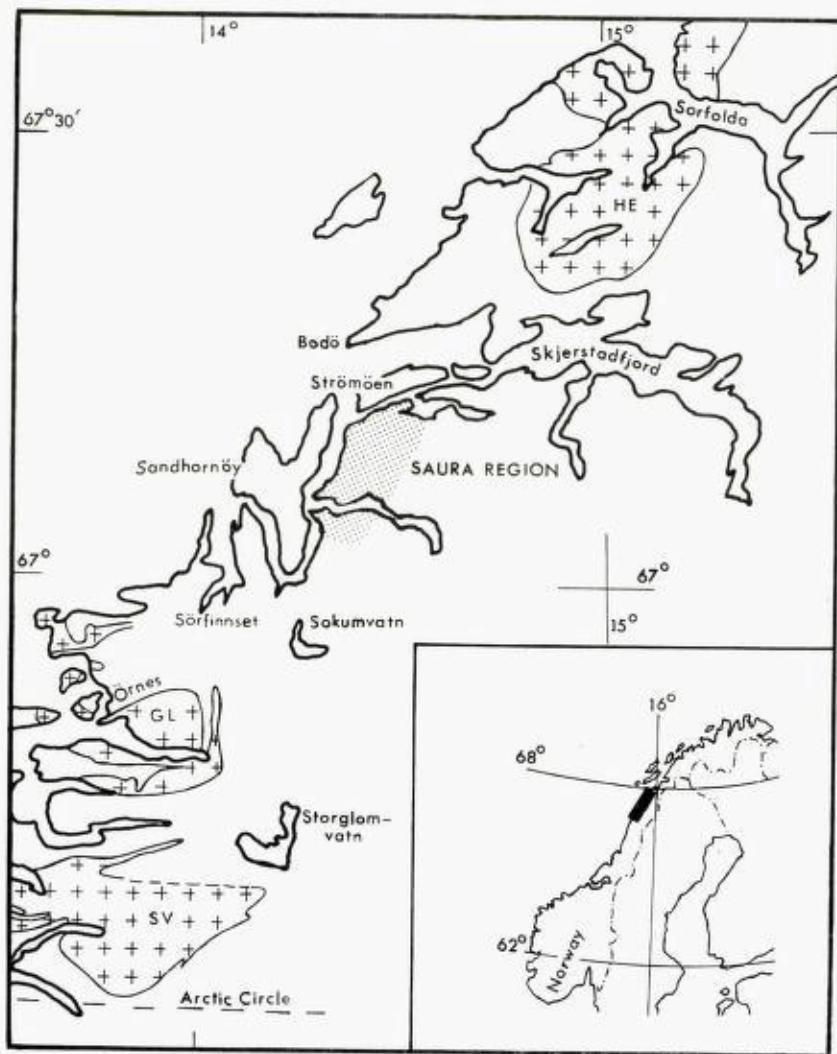cambrian granitic gneisses remobilized during the Caledonide orogeny

Fig. 1. Location of the Saura region. Crossed ornament signifies Precambrian basement massifs (Gl —— Glomfjord Massif; HE —— Heggmovatn Massif; SV —— Svartisen Massif).

(Rutland *et al.* 1960) and an overlying succession of metasedimentary and metavolcanic rocks of believed lower Palaeozoic age. Within the supracrustal succession a number of distinctive litho-structural units have been recognized which are commonly bounded by major tectonic slides (see Fleuty 1964). The tectonic development of the area has been considered in terms of nappe-tectonics and gravity-gliding off the culminations of the basement granites. These tectonic culminations are aligned broadly parallel to the main (NE-SW) Caledonoid trend.

The Saura region forms part of an extensive tectonic depression between basement culminations to the north-east (the Heggmovatn massif) and to the south-west (the Glomfjord and Svartisen massifs) and thus represents a high level in the structural succession. Lying obliquely across the depression is a belt of gneisses, believed to be of volcanic origin. At the southern end of the belt the gneisses (Harefjell Gneissic Group) lie in a late phase (F_3) synform above the Sokumfjell Marble Group (Rutland 1959). The gneisses were regarded as stratigraphically younger than the rocks of the Sokumfjell Marble Group by Hollingworth *et al.* 1960. Subsequently, as a result of their reconnaissance studies over a wider area of Nordland, Rutland and Nicholson (1965) have postulated that the gneisses form the base of a major F_1 disjunctive nappe complex which is now preserved in the principal tectonic depressions.

The Saura region is one in which several of the main structural units of the wider area considered by Rutland and Nicholson (*op. cit.*) come together. The relationships of these units are thus critical to their interpretation and the need to estabilsh them in detail was a major reason for undertaking the present work.

The Saura region was mapped during the three field seasons 1961—63, the work forming the subject matter of a Ph.D. thesis presented at the University of London (Bennett 1965). This paper represents a condensation of certain aspects of that work.

Outline of the geology.

Although the lithologies of the Saura region are often closely inter-developed on a small scale a number of major litho-structural units have been recognized in the field, each unit being characterized by a distinctive lithological assemblage. In most instances these units are separated by

tectonic slides. A major subdivision is apparent between a number of predominantly gneissic groups to the south and south-east and two metasedimentary groups to the north-west. In the absence of «way-up» evidence the stratigraphic relationships of the the units remain conjectural. A structural succession has been recognized, however, in which the highest litho-structural units lie to the north-west. In the following outline of the salient features of each unit, the units will be considered in ascending structural order.

The *Pallrakken* and *Framnes Groups* (Fig. 2, I and II) occur at the base of the succession. The former is named after a prominent mountain situated just east of the map-area, some 3 km from Eggesvik, whilst the Framnes Group forms a part of the Alsvik Group of Rutland and Nicholson (1965). These groups are unusual in that they are virtually monolithological, comprising migmatitic veined mica schists and gneisses which hold considerable amounts of sillimanite. The two groups have been correlated on lithological and structural grounds.

Overlying these rocks is the *Harefjell Gneissic Group* (Fig. 2, III; Rutland 1959), comprising massive and foliated dioritic gneisses, distinctive porphyroblastic gneisses and interbanded but generally subordinate metasedimentary rocks. The gneisses are regarded as granitized metavolcanic rocks, of which the quartz-monzonite gneisses possibly represent the most advanced stage, although it has been suggested (Professor R. W. R. Rutland, *personal communication* 1969) that original compositional variations may be partly responsible for the different rock types. The rocks of the group are extensively developed south of Beiarnfjord, but they have also been mapped on Ågdalsknubben to the north of the fjord. The metasedimentary rocks, in addition to forming discrete bands in the gneisses, also occur intimately mixed with the gneisses, for example on Kjellingfjell. To the south and west of Nubben the metasedimentary rocks become more extensively developed at the expense of the gneisses.

The last of the gneissic groups recognized, the *Røsnes Group* (Fig. 2, IV), holds biotite-hornblende-(garnet) gneisses of variable texture and appearance, and subordinate metasedimentary rocks. As such, it is not unlike the Harefjell Gneissic Group, but lacks the massive dioritic rocks and the porphyroblastic gneisses. The Røsnes Group has been extensively invaded by granitic material, but the style of the granitization has been conditioned by the structural state of the gneisses. The latter become
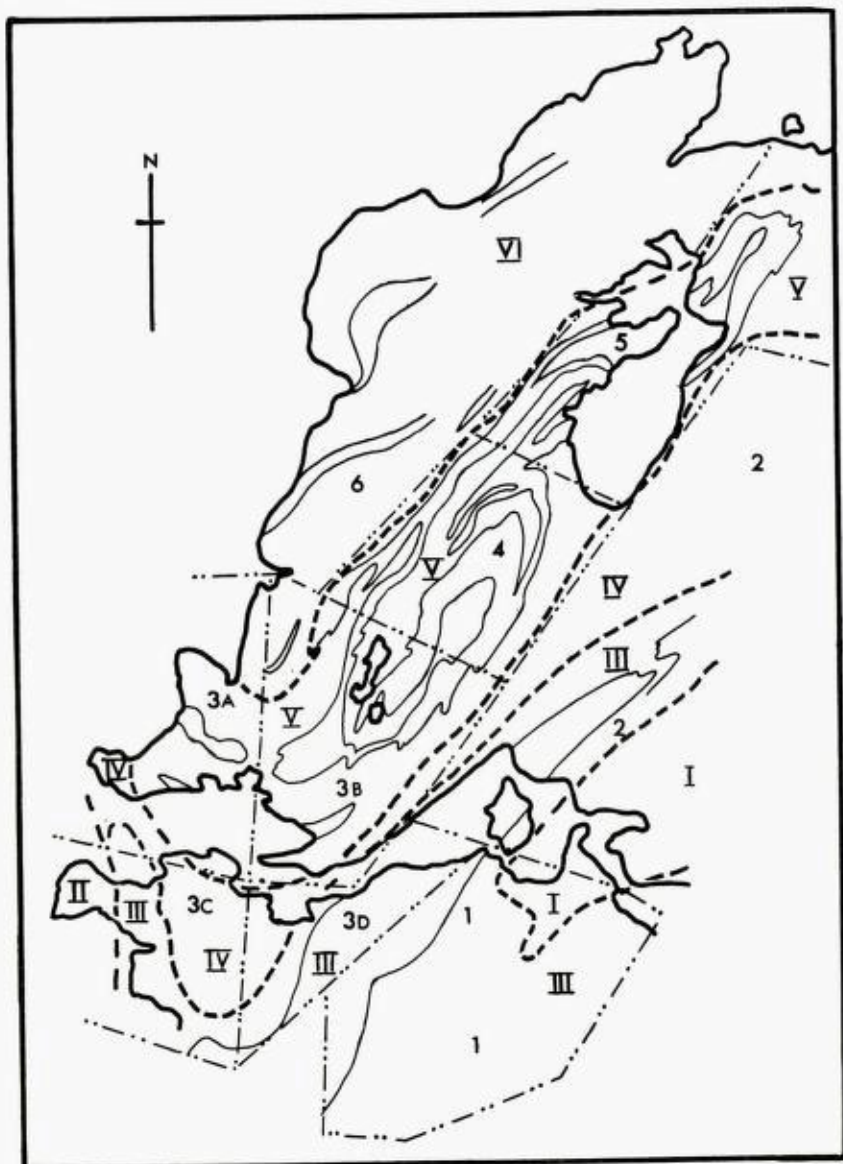
Fig. 2. Major litho-structural units and structural sub-areas. (Litho-structural units I—VI delimited by heavy pecked line; structural sub-areas 1—6 delimited by light pecked line; numbers referred to in text).

increasingly foliated to the south-west, paticularly at Røsnes where it is significant that the Skålsvik Slide and the postulated extension of the Framnes Slide are in close proximity.

The gneissic groups are separated from the metasedimentary groups to the north by the Skålsvik Slide. Overlying the Røsnes Group is a series of predominantly calcareous metasedimentary rocks referred to the *Saurvatn Mixed Group* (Fig. 2, V). The lithologies include veined pelitic (locally psammitic) schists and marbles, but banded calc-psammite and semipelitic schists and nodular calc-semipelitic schists are distinctive. Also noteworthy is a conglomerate consisting of flattened marble pebbles in a calc-silicate matrix which crops out at Skålsvik and at Saurneset. The correlation of these two outcrops is significant in determining the structural relationships at Saura. Amphibolite bodies, authough involved in major folding, occupy a sensibly constant horizon on the western and southern shores of the Saura peninsular. The rocks of the Saurvatn Mixed Group resemble those of the Meløy Group (Rutland and Nicholson 1965, p. 77).

The *Skånlandsfjell Marble Group* (Fig. 2, VI), situated in the north-west of the map-area, is the highest litho-structural unit mapped. In addition to marble, quartzites and pelitic schists occur in subordinate amounts and the major, although discontinuous, bands formed of these rocks have been differentiated on the accompanying map (Plate I).

Granitic rocks are extensively developed throughout the Saura region. The migmatization characteristic of the gneissic groups has been mentioned, but the rocks of the metasedimentary groups have also been affected. A sequence of granite emplacement reaching a climax in late to post-tectonic times has been recognized, the style of emplacement and also the distribution of the granitic material having been controlled by lithological and structural factors. With the exception of the migmatitic gneisses of the Pallrakken and Framnes Groups and much of the Røsnes and Harefjell Groups, those areas where emplacement has been most intense are indicated symbolically on the geological map.

The mineral assemblages developed throughout the gneissic and metasedimentary groups are consistent with regional metamorphism occurring under upper amphibolite facies conditions and reaching a climax after the early phase deformation (see below). Modification of the regional metamorphic assemblages by more hydrous mineral phases is ascribed to the widespread granitization.

I. Structural geology

1. Introduction

The structural evolution of the Saura region has been complex and rigorous. Two major phases of deformation have been recognized, the earlier of which can locally be further divided and the fold structures designated F_1 and F_2; the late phase folding is designated F_3.

The earliest folds known are isoclinal structures originally recumbent about approximately E-W trending axes (see section I, 2, A (b)). In suitable lithologies these folds possess a penetrative axial plane schistosity and are characterized by strongly lobate closures,* intrafolial and reverse folding (Turner and Weiss 1963, p. 117 and p. 473) and by thickening of the fold hinges and attenuation and elimination of the fold limbs (Fig. 3). Major F_1 folds have been mapped only in the Saurvatn Mixed Group.

The F_2 Folding is more widely developed. In the Saurvatn Mixed Group approximately coaxial refolding of the F_1 fold can be observed (e. g. the 269 Fold) but elsewhere the relationships are less straightforward. The F_2 folds are also overturned or recumbent about originally easterly trending axes but are less obviously intense than the F_1 folds and the schistosity can be traced around their hinges (Fig. 4). In some lithologies, however, differentiation between F_1 and F_2 minor structures has not proved possible and they have been mapped as undifferentiated early phase structures.

Tectonic sliding has accompanied all scales of the early phase folding which, as a result, is characteristically disharmonic. The attenuation and elimination of fold limbs has been noted and on a larger scale the individual litho-structural units are commonly bounded by major slides

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* The term «closure» is used to denote a complex of fold hinges such as is commonly developed in the F_1 isoclinal folds; «hinge» refers to an individual or «simple» turn-over.
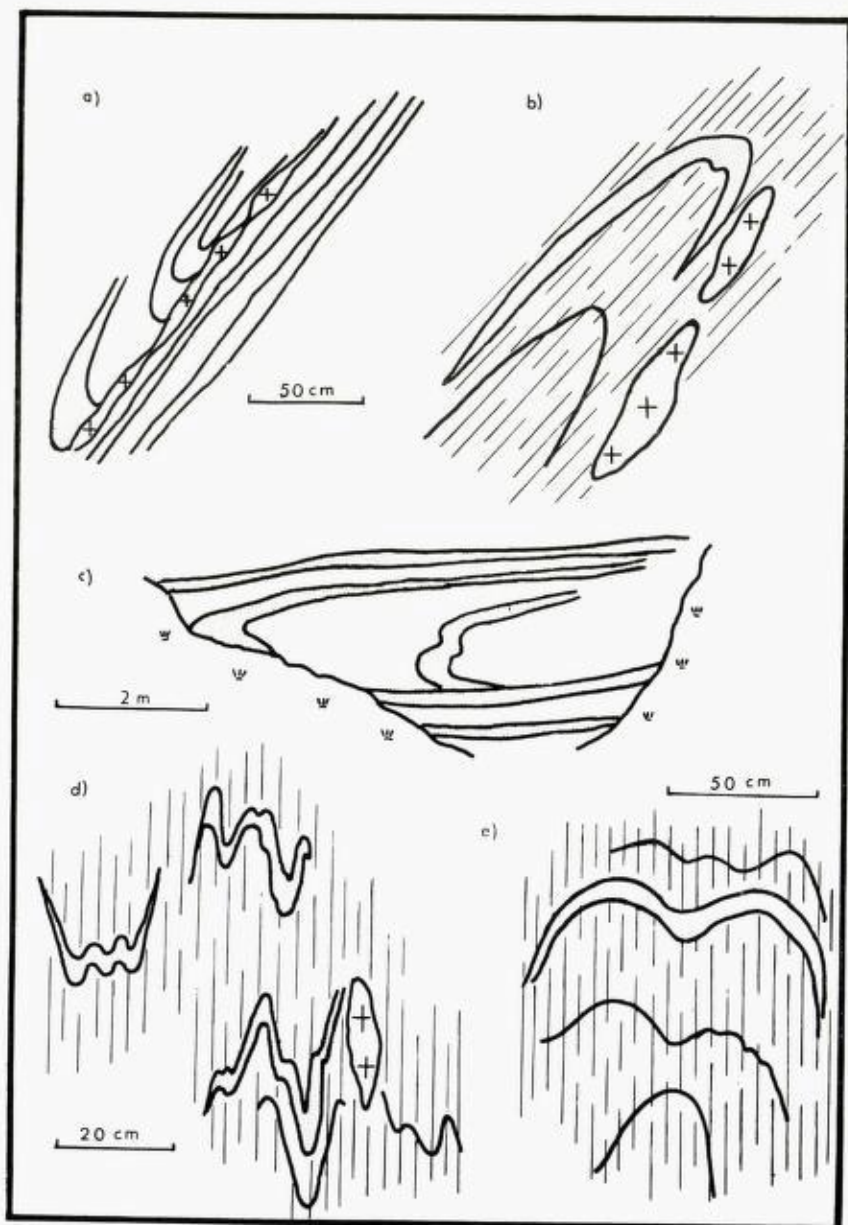
Fig. 3. Styles of minor folds (F₁) in the Isoclinal Fold Complex, Saurvatn Mixed Group.
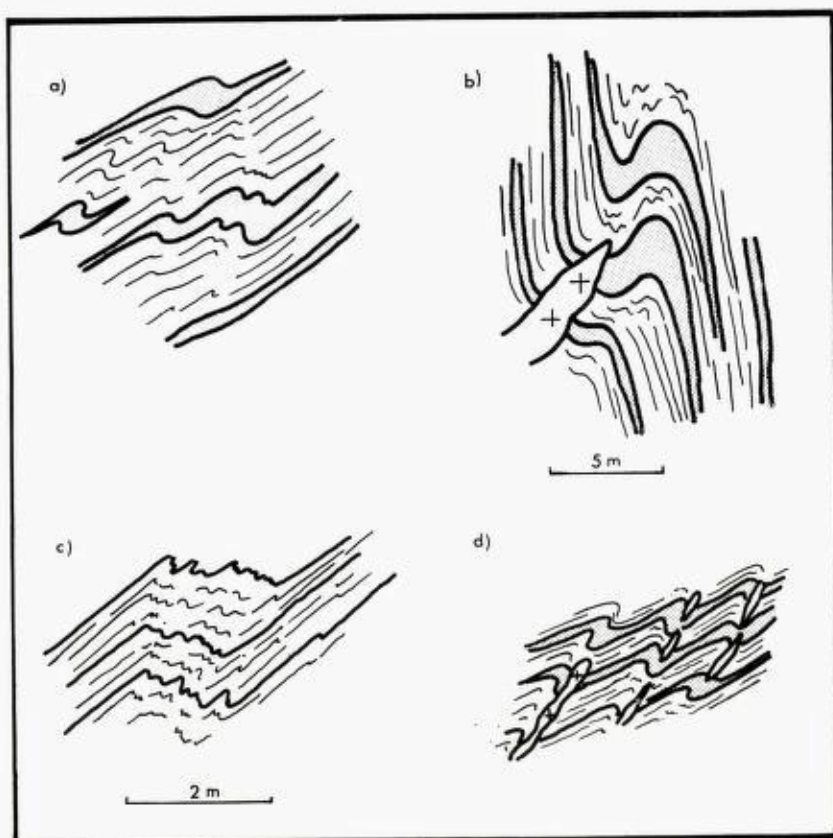
Fig. 4. Styles of minor folds (F₂) in the Isoclinal Fold Complex, Saurvatn Mixed Group.

and have acted as independent structural units. These zones of differential movement are sensibly conformable with the foliation over considerable distances and their recognition in the field may be difficult; often their existence can be determined only by mapping the large scale structural relationships, although in some instances the movement has given rise to zones of tectonic mélange. A quantitative assessment of the scale and importance of the sliding is hampered by the lack of adequate stratigraphic control.

The only major F_3 structure mapped is the Saura Synform which has refolded the early phase recumbent folds, overfolds and slides and

is responsible for the present «grain» of the country. Much of the Saura region lies within the thick, steeply dipping eastern limb of this fold. Minor structures associated with the late phase deformation are not strongly developed and are mostly weak, open folds and crenulations.

In the remainder of Section I of the paper the structural elements and their mutual relationships will be considered. Reference should be made throughout to Plates I and II which accompany the paper.

2. Structure of the Saurvatn Mixed Group: the Isoclinal Fold Complex

The Saurvatn Mixed Group is a lithologically varied group which has been mapped from Saura to beyond hill 613 in the north-east. It is bounded on each side by a major slide and prior to the F_3 folding behaved as an independent structural unit. The internal structure of the group is involved and is further complicated by refolding during the late phase deformation. Essentially it comprises three complementary F_1 isoclinal folds, now well-displayed in the steep limb of the Saura Synform. These folds and the traces of their axial surfaces were recognized largely on the basis of symmetrical lithological successions. The lack of such symmetry, in combination with other factors, has been taken as evidence for the existence of tectonic slides. The relationships of bedding and schistosity (Fig. 3) and, to a lesser extent, the style and attitude of minor folds have provided confirmatory evidence for the existence of the major folds near their closures.

The F_1 folds recognized are: the synformal *613 Isocline* to the north-west; the antiformal *Skålsvikfjell Isocline;* and the synformal *Skålsvik Closed Fold* to the south-east. The last mentioned fold is so-called because at Saura it adopts a closed «banana-shaped» outcrop pattern with inward-directed plunges as a result of refolding about the Saura Synform axis during the late phase deformation.

The mutual relationships of the F_1 folds are complicated by the refolding of the attenuated eastern closure of the Skålsvik Closed Fold back into the core of the Skålsvikfjell Isocline immediately east of Saurvatn. This, and a possible mechanism for it, will be discussed further in Section I, 2, B and I, 5. The result, however, is a coil-like structure caused by broadly coaxial F_2 refolding about the southerly plunging axis of the synformal *269 Fold*. The whole is referred to as the *Isoclinal Fold Complex*.

A. The F_1 folds and slides.

(a) *The 613 Isocline and the Ertenvågdalen Slide.*

The closure of the 613 Isocline is best-defined by the veined mica schist horizon on hill 613 and it resembles that of the Skålsvikfjell Isocline in style. These two folds share a common limb (again best-defined by the veined mica schists) and the 613 Isocline, with a southerly plunge, is synformal.

The banded schists which occupy the core of the 613 Isocline immediately south-south-west of the summit of hill 613 are pinched out further to the south-west (near lake 171) although occasional pockets of schist and amphibolite occur along strike in the veined mica schists. Some 2.5 km further to the south-west the horizon of veined mica schists bifurcates again. Thus, along this section the banded schists in the core of the fold have been eliminated by the merging together of the limbs of the 613 Isocline (as defined by the veined mica schists).

The geology of the south-western bifurcation is complex as this section comprises a tectonic mélange characterized by the strong attenuation, interdigitation and elimination of the various lithologies. The symmetry across the axial trace of the 613 Isocline has been destroyed here as a result and the location of the axial trace of the fold becomes more difficult to establish. Nonetheless, the normal succession from veined mica schist through banded schist and calc-semipelitic schist to conglomerate can still be recognized, but the succession has been progressively modified in a south-westerly direction. Thus, the banded schists, which further to the north-east form the core of the 613 Isocline, have been eliminated from the north-western limb of the fold and the veined mica schists brought into contact with calc-semipelitic schists to the east. Further south-west the veined mica schists themselves pinch-out and the calc-semipelitic schists lie in contact with marbles of the Skånlandsfjell Marble Group. Ultimately, these schists, too, have been eliminated and in the area south-south-west of Nygårdsjøen the calc-silicate conglomerate, which here occupies the core of the 613 Isocline, is overlain directly by marbles of the Skånlandsfjell Marble Group.

On the foregoing evidence a major structural discontinuity between the Saurvatn Mixed Group and the Skånlandsfjell Marble Group is postulated, and this will be referred to as the *Ertenvågdalen Slide.*

Further evidence for the slide is provided by the distribution of the quartzite and pelitic schist horizons in the Skånlandsfjell Marble Group. These are not symmetrically disposed about the axial trace of the Saura Synform but are more abundant to the west of it. The elimination of the bands to the east of the axial trace of the synform prior to the F_3 folding (which deformed the Ertenvågdalen Slide) is indicated (Plate II, Section A-B). To the north-east of Nordvik discordancy between the marker horizon in the Skånlandsfjell Marble Group and the Saurvatn Mixed Group is suggested and provides further evidence of a structural break, although frequently the relationships between the adjacent groups across the Ertenvågdalen Slide are sensibly concordant.

The significance of the Ertenvågdalen Slide is difficult to assess. The evidence supports the progressive elimination of the north-western limb of the 613 Isocline, particularly in the ground east and south of Nygårdsjøen, yet the conglomerate at Saurneset has not been eliminated. The slide is thus located above (i. e. to the north of) the conglomerate, rather than below. However, the conglomerate horizon in the Skålsvik Closed Fold south of Saura is also overlain by marbles which there form the core of the structure. If this marble horizon is correlated with the marbles of the Skånlandsfjell Marble Group no great stratigraphic or structural displacement is implied as a result of the sliding. However, it is considered that the Skålsvik marble represents an integral part of the varied lithological succession of the Saurvatn Mixed Group, and that the Ertenvågdalen Slide is accordingly of some extent and importance. Thus, on the southern shore of Skjerstadfjord the Skånlandsfjell Marble Group is in contact with the gneissic groups (Rutland and Nicholson 1965, Plate 12; and see Fig. 19 of this paper). The elimination of the Saurvatn Mixed Group to the north-east of the present map-area is implied.

The observed outcrop pattern and geometry of the 613 Isocline, in common with that of the other folds which make up the Isoclinal Fold Complex, is the result of later folding responsible for the formation of the Saura Synform. Owing to good exposure and considerable variation in relief, the nature of the 613 Isocline could be determined directly in the field as a synform plunging moderately towards the south. The plot of associated minor linear structures supports this observation (Fig. 5 a). Sensibly coaxial refolding of F_1 minor folds has been noted in the banded schists in the core of the major fold on the northern
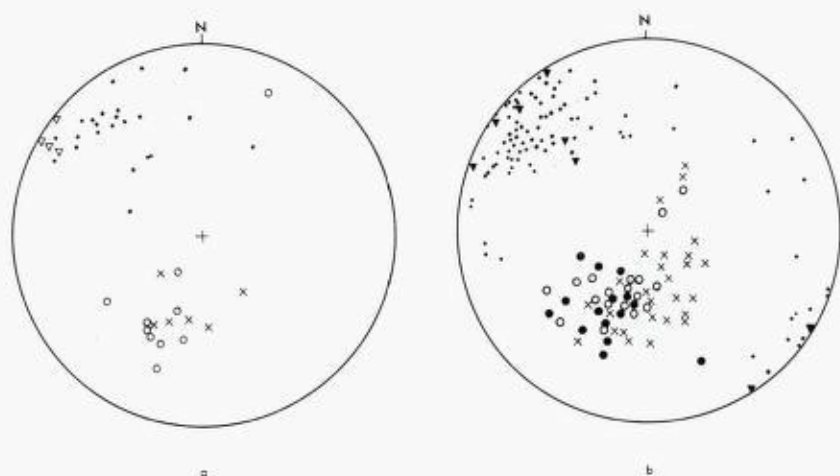
Fig. 5. Structural data, Isoclinal Fold Complex (1): (a) π S and B-diagram, the 613 Isocline, sub-area 5; (b) π S and B-diagram, the 269 Fold, sub-area 4. Symbols: — dot —— pole to foliation; open circle —— axis of F_1 fold; closed circle —— axis of F_2 fold in (b); cross —— mineral and intersection lineation; open triangle —— pole to axial surface of F_1 fold; closed triangle —— pole to axial surface of F_2 fold in (b).
All diagrams are Lambert equal area lower hemisphere projections.

shore of Valnesvatn. This is ascribed to the flexuring of the axial trace of the 613 Isocline by the 204 Fold, an antiform which plunges gently to moderately to the south and dies out rapidly to the north.

(b) The Skålsvikfjell Isocline and the Skålsvik Closed Fold.

The closures of these two folds are best displayed on and to the south-east of Skålsvikfjell, at Saura and at Skålsvik, where repetition of the succession as a result of the folding is evident. In addition, the relationships of bedding and schistosity (particularly in the banded and calc-semipelitic schists) and the development of congruent parasitic folds, notably to the west of Saurvatn and in the vicinity of Skålsvikfjell, provide further evidence of the existence of two major, complementary fold closures. Repetition of the successions is incomplete, however, and the southern, lower limb of the Skålsvik Closed Fold has been partially eliminated. The significance of this will be discussed in the following section.

The axial traces of these folds are well-defined at Saura, on Skåls-vikfjell and east of Røsnes on the basis of evidence noted above. Within the veined mica schists, however, precise location is less certain as the dominant planar structure is an axial plane schistosity preferentially followed by the granitic veining. Uncertainty also exists when an attempt is made to extrapolate the axial traces of both folds north-eastwards from Skålsvikfjell and Skålsvik. The axial trace of the Skålsvikfjell Isocline is envisaged as passing north-eastwards beneath the waters of Saurvatn, but the relationships are complicated by the refolding of the common limb between that fold and the Skålsvik Closed Fold about the F_2 269 Fold axis. It will be suggested in a later section (I, 2, B) that the development of the F_2 fold involved considerable differential movement in a zone of restricted width and the possibility of a simple or straightforward extrapolation of the F_1 axial trace in such an environment is accordingly felt to be unlikely.

The hinge of the Skålsvik Closed Fold south-east of Skålsvikfjell develops progressively into a typically lobate closure of F_1 style towards the north-east. This is defined by the repetition of the veined mica schists horizons in the ground north-north-east of lake 186. This process was accompanied by the pinching-out of individual fold hinges and, to the west of Bjerklien, by the total apression (or squeezing together) of the limbs of individual folds in a manner reminiscent of that occurring in the 613 Isocline west of lake 171. In the present case, however, it is probable that all these effects were accentuated during the F_2 refolding. As a result a number of F_1 axial traces have been recognized, only certain of which are indicated on the map for reasons of clarity. Recognition of the «main» axial trace and the detail of its continuity with that mapped at Skålsvik remains subjective. An attempt to indicate the «development» of the Skålsvik Closed Fold and the relationships described above is shown in a simplified fashion, with the effects of the F_2 refolding arbitrarily removed, in Fig. 6.

The relationship between outcrop and topography in the Skålsvikfjell —Skålsvik sector (Fig. 2, structural sub-area 3 b) indicates a moderate to steep south-south-westerly plunge for the Skålsvikfjell Isocline (which is thus antiformal) and for the eastern hinge of the Skålsvik Closed Fold (which is thus synformal). The plot of associated minor linear structures (Fig. 7 a) in general accords with this but some anomalies are apparent. These anomalies will be considered more fully below
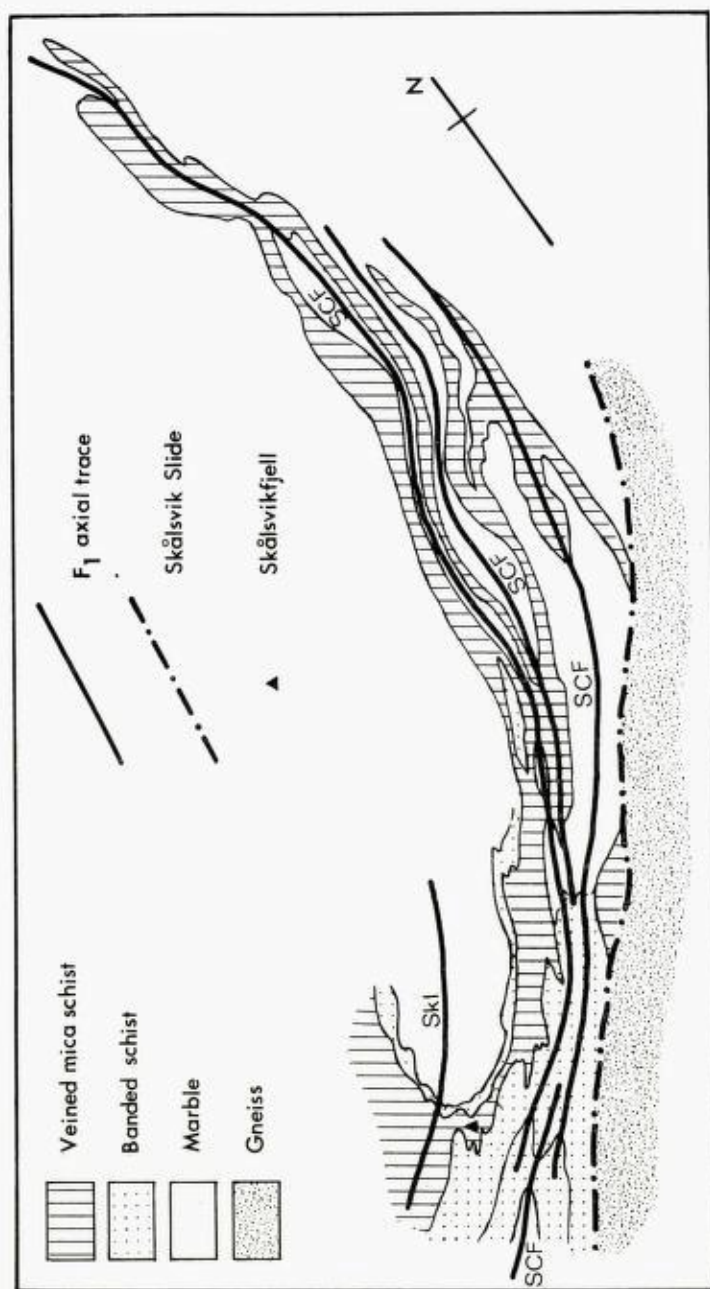
Fig. 6. Sketch reconstruction (not to scale) of the Skålsvikfjell Isocline (SkI) and the eastern sector of the Skålsvik Closed Fold (SCF) with the F₂ refolding (269 Fold) arbitrarily removed. To show the relationship of the F₁ folds and the development of the hinge of the Skålsvik Closed Fold into a complex fold closure.

(section I, 2, C) but it may be noted here that they are dependent partly on the position of the individual structures within the F_3 Saura Synform and in part are a result of pre-F_3 variation amongst the early phase linear structures owing to the lithologically varied and hence probably structurally heterogeneous nature of the Saurvatn Mixed Group (cf. Rutland and Nicholson 1965, p. 74). Dr. M. K. Wells (*personal communication* 1969) has noted a similar lack of structural homogeneity in a lithologically varied succession in the Sørfinnset area.

As the axial traces of the Skålsvikfjell Isocline and the Skålsvik Closed Fold are followed down from the higher ground towards the hinge of the Saura Synform the plunge of the minor linear structures lessens and becomes more westerly. This is not conspicuous in Fig. 7 a owing to the limited information available from the poorly exposed ground in the hinge area of the F_3 synform. However, on the northern shore of Skålsvik closed structures have been observed which form small scale replicas of the Skålsvik Closed Fold. These folds plunge gently to both east and west and as they occur virtually at the hinge of the Saura Synform may be taken as an indication of the original trend of the recumbent folds prior to the F_3 refolding.

The recumbent or gently inclined nature of the F_1 isoclines is preserved in the shallow-dipping western limb of the Saura Synform at Saura. The dip of the axial surfaces of these folds is low to moderate in a north-easterly direction (Fig. 7 c). The antiformal Skålsvikfjell Isocline closes towards the south and the associated minor structures plunge gently towards the south-east and east-south-east (Fig. 7 b). Similar trends have been noted at the western hinge of the Skålsvik Closed Fold east-south-east of Røsnes. In addition, however, numerous minor fold axes and mineral lineations possess a gentle east-north-easterly plunge. These are mostly interpreted as F_2 structures (similar structures having been recorded at Røsnes and Framnes) and are thought to be related to the development of the Framnes Fold (discussed in section I, 3, A).

c) *The Skålsvik Slide.*

In the previous section it has been noted that the repetition of the succession across the axial traces of the Skålsvikfjell Isocline and the Skålsvik Closed Fold is incomplete, inasmuch as part of the lower,
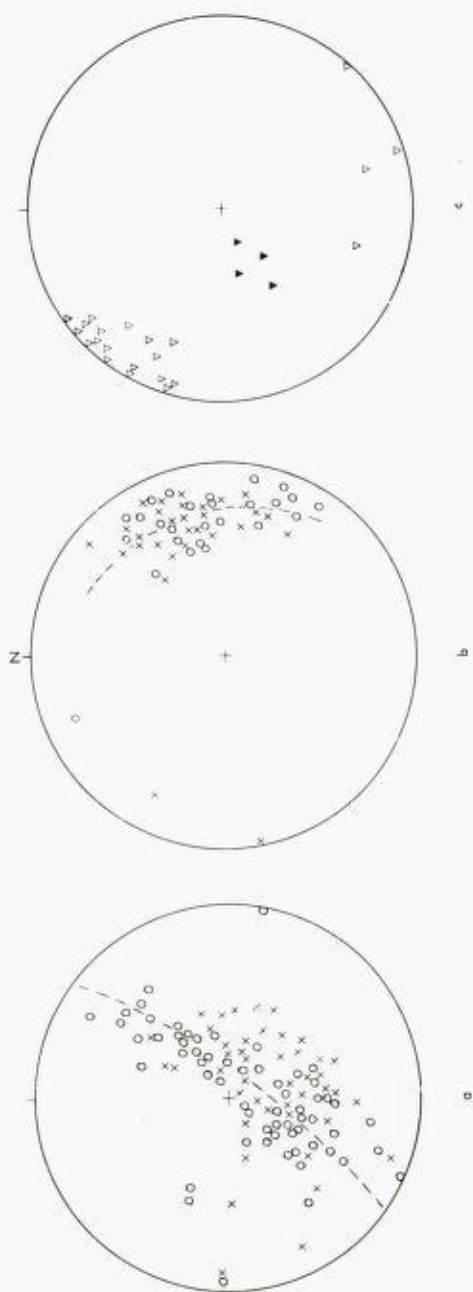
*Fig. 7. Structural data, Isoclinal Fold Complex (2): (a) B-diagram, sub-area 3b; (b)
B-diagram, sub-area 3a; (c) poles to axial surfaces of early phase folds, sub-areas 3a
and 3b. Symbols: —— open circle —— axis of early phase fold; open triangle —— pole
to axial surface of early phase fold, sub-area 3 b; closed triangle —— pole to axial
surface of early phase fold, sub-area 3 a. Other symbols as for Fig. 5.*

southern, limb of the latter fold has been partially eliminated since the expected veined mica schist horizon is virtually lacking from this limb. One isolated body of the schist has been mapped approximately 0.75 km south-west of lake 220 whilst a second rootless band occurs immediately south of Isvik (see also Fig. 6). As a result no complementary antiform to the south of the Skålsvik Closed Fold has been mapped (Plate II, section X—Y). These relationships are ascribed to the action of the Skålsvik Slide which separates the Saurvatn Mixed Group from the underlying gneissic groups to the south and south-east.

The Skålsvik Slide has been recognized to the east of Røsnes, north of Kjopstadnakken and thence to the north-north-east from Skålsvik. Granitic rocks are abundant along the line of the slide, particularly over the section between Skålsvik and Bjerklien. In addition to the criteria taken above as evidence for the slide, the following factors may be noted:

(i)   the obvious structural independence of the metasedimentary and gneissic groups and the contrast in structural style across the slide;

(ii) the structural discordancy which occurs on following the slide to the north-north-east, whereby different members of the Saurvatn Mixed Group are brought into contact with the gneisses; and

(iii) the thinning of the Røsnes Group south-south-west of Valnesvatn.

It is evident from the large scale relationships and from the examination of minor structures that the sliding is closely associated with the early phase folding. The Skålsvik Slide remained active throughout the early phase deformation as it has not been folded during the development of the F_2 269 Fold, now to be discussed. The slide has, however, been folded during the late phase deformation.

B. The F_2 refolding of the Skålsvik Closed Fold: The 269 Fold.

In the description of the Skålsvik Closed Fold the progressive development of the eastern hinge at Skålsvik into a lobate and complex fold closure further to the north-east has been considered. The repeated veined mica schist horizons and the associated penetrative schistosity have been traced around the northward-closing hinge of the 269 Fold
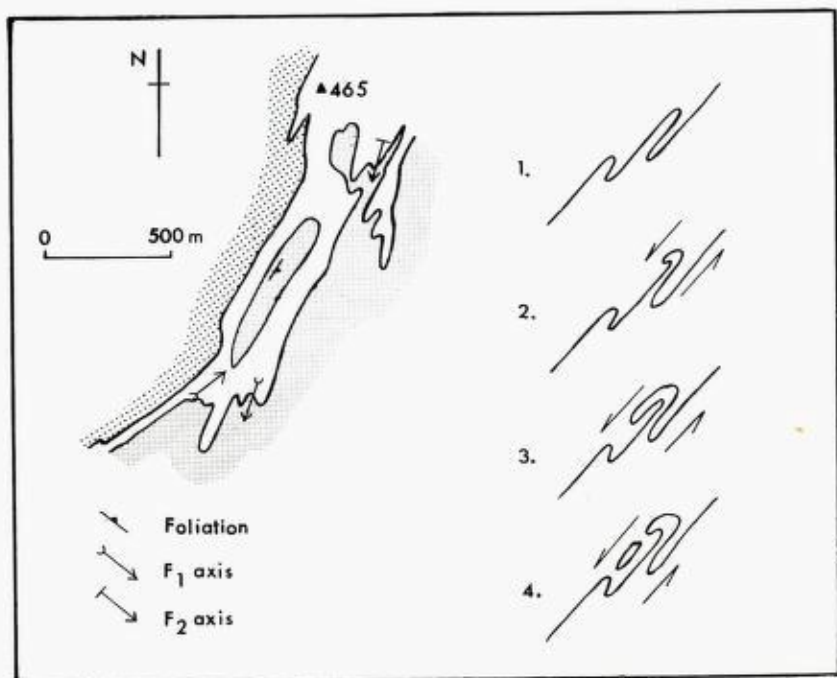
Fig. 8. *Interpretation of hill 465 fold complex (diagrammatic): (1)* ——— *F_1 parasitic fold; (2) and (3)* ——— *progressive development of F_2 fold and refolding of the F_1 fold by sinistral movement in a zone of restricted width; (4)* ——— *rupture of the F_1 fold. Stipple ornament signifies banded calc-psammite and semipelitic schists.*

on hill 269 and to the north-north-east of it. The folding thus post-dates the F_1 isoclinal folding. In addition, the F_2 fold, although tight, differs in style from the F_1 folds, lacking both the intensity of the F_1 structures and their compex fold closures. This distinction is enhanced by the recognition of minor structures of crenulation cleavage type associated with the 269 Fold. The minor fold axes and crenulation lineations plunge moderately towards the south (Fig. 5 b) and accord with the plunge of the 269 Fold as deduced from the dip relations in the hinge zone. The 269 Fold is thus synformal and, in the steep limb of the Saura Synform, is broadly coaxial with the earlier F_1 folding.

The effect of the 269 Fold has been to refold the attenuated eastern closure of the Skålsvik Closed Fold back into the core of the Skålsvik-

fjell Isocline, resulting in the coil-like structure indicated by the outcrop pattern in the steep limb of the Saura Synform. That the development of the 269 Fold occurred in a restricted zone accompanied by considerable differential movement is evident as the north-western limb of the Skålsvikfjell Isocline is virtually unaffected by the F_2 folding, apart from further to the north-east where flexuring (the 204 Fold) is envisaged as an accommodation feature formed during the evolution of the Isoclinal Fold Complex. On a smaller scale evidence for similar (sinistral) movement in a restricted zone is provided by the fold complex south-south-west of hill 465. The inclusion of banded schists in the veined mica schists is interpreted as an F_1 parasitic fold which has undergone refolding and detachment during the F_2 deformation (Fig. 8).

C. The F_3 refolding of the Isoclinal Fold Complex.

Under this heading the early phase minor structures associated with the Isoclinal Fold Complex in structural sub-areas 3 a and 3 b (Fig. 2) will be further analysed in an attempt to ascertain the nature and effects of the F_3 refolding. The description and geometry of the F_3 Saura Synform will be treated separately in section I, 4.

The plot of early phase linear structures (Fig. 7 a) from structural sub-area 3 b defines a maximum plunging between south-south-east and south-west which accords with the plunge of the major folds as deduced above. In addition, however, the linear structures form a great circle girdle of variable width which includes the Saura Synform axis (Fig. 9) but which cannot be directly related to the plunge of the early phase major folds. The attitude of the girdle is similar to that estimated for the axial surfaces of the major folds and to that indicated by the plot of the axial surfaces of associated minor folds (Fig. 7 c), both of which are controlled by the sheet dip in the eastern limb of the Saura Synform.

In attempting to account for this distribution pattern the following factors bear consideration:

(i) the extent to which the scatter reflects pre-F_3 variation in the attitudes of the linear structures; and

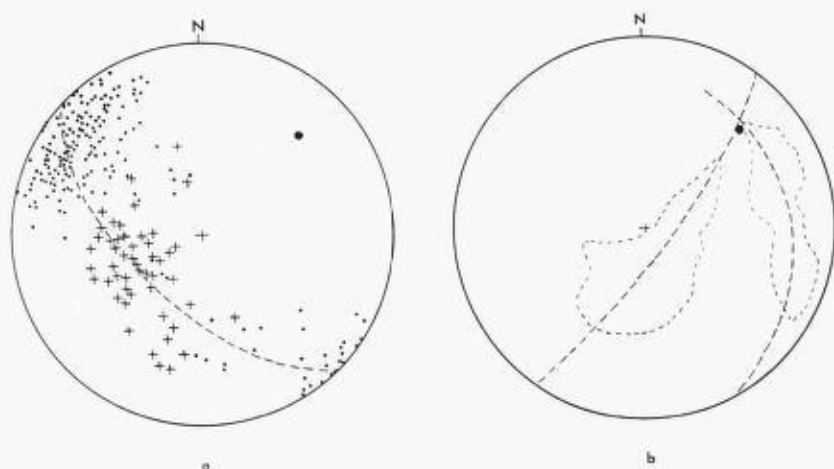(ii) the effects, if any, of the F_3 refolding.

Fig. 9. Relationship of the early phase linear structures to the F_3 refolding, sub-areas 3a and 3b; (a) πS diagram; (b) synoptic B-diagram (see Fig. 7a, b). Symbols: — upright cross —— pole to foliation, sub-area 3a; dot —— pole to foliation, sub-area 3b; closed circle —— F_2 axis and pole to πS girdle.

Relevant to the first of these factors is the lithologically varied nature of the Saurvatn Mixed Group which, it has been suggested, makes it unlikely that structural homogeneity will be achieved. Pre-F_3 variation in the attitude of the linear structures is thus probable.

A similar girdle distribution, although of different attitude, is also shown by the plot of early phase linear structures from structural sub-area 3 a (Fig. 7 b and Fig. 9). Here, the distribution pattern has been ascribed to an original angular difference between the F_1 and F_2 trends. In the steep limb of the Saura Synform the F_1 and F_2 trends, where distinguishable, commonly appear to be sensibly coaxial. Whilst some angular difference between them cannot be ruled out, it is felt to be unlikely that the girdle distribution can be due solely to this. Indeed, it may be conjectured that the apparent coaxiality in the steep, «upturned» (and, consequently, possibly more strongly deformed?) limb of the F_3 synform reflects a reduction of the original angular differences between F_1 and F_2 by a process of internal rotation during the F_3 refolding (however, see below).

It is suggested, therefore, that the scatter may largely reflect original sinuosity and inconstancy in the axial trend of the early phase folds

prior to the F_3 refolding. Although sinuous fold axes have not been directly observed on a small scale, local plunge reversals in structures of undoubtedly similar age have been noted which favours this contention. The interpretation of the Saura region in terms of nappe-tectonics and the complex spatial relationships between the early and late phase structures adds further support.

Nevertheless, the possible effects of the F_3 refolding should be considered. The scatter might have been caused by cross-folding either contemporaneous with or post-dating the F_3 deformation. Cross-warping about subhorizontal NW-SE trending axes is, indeed, suggested by the variation in plunge of the Saura Synform whilst the presence of such warps has been observed elsewhere in the map-area (e. g. the Evjenvatn Antiform) and beyond (Rutland 1959, p. 298). There is no evidence, however, that cross-folding of this type has been sufficiently strong to be considered as more than a contributory factor.

The plot of a limited number of early phase planar structures from structural sub-areas 3 a and 3 b (Fig. 7 c) shows a partial great circle girdle distribution with two maxima; the pole to this girdle compares favourably with the axis of the Saura Synform as determined from the π S plot (Fig. 9 a). The pattern indicates that the earlier planar structures have been deformed by external rotation during the F_3 refolding.

The relationship of the early phase linear structures to the F_3 deformation is less straightforward. The nature of the refolding mechanism is not immediately obvious from the diagrams (Fig. 7 a, b and Fig. 9 b) although the observations noted earlier in the paper concerning the plunge relations of the early phase minor linear structures on approaching the hinge of the Saura Synform remain valid and suggest an element of external rotation. However, it would appear to be unlikely that the spread of the early phase linear structures can be ascribed directly to the F_3 refolding. If the refolding involved only external rotation a small circle distribution about the F_3 axis would result, whereas if it involved internal rotation a single great circle distribution intersecting the axial surface of the F_3 fold would be expected. Pre-F_3 variation in the trends of the early phase linear structures is thus favoured by these relationships.

In conclusion it should be emphasized that the details of the pre-F_3 variation remain uncertain, but that lithological variety and the structural environment are considered to be controlling factors. Nonetheless,

the fact that both girdles intersect the F_3 axis (Fig. 9) and, furthermore, that on intersection the density of the early phase linear structures also decreases abruptly raises the possibility of more complex relationships (perhaps a closer genetic link?) between the early and late phase deformations than is readily apparent from the mapped relationships of the major folds.

D. Summary.

The main conclusions of the preceeding sections can conveniently be reiterated here:

(i)   the Isoclinal Fold Complex is restricted to the Saurvatn Mixed Group, is bounded above and below by tectonic slides and in effect forms a large rootless structure;

(ii) immediately prior to the F_3 refolding the Isoclinal Fold Complex comprised a recumbent pile of three complementary F_1 isoclinal folds with the 613 Isocline occupying the highest structural level and the Skålsvik Closed Fold the lowest;

(iii) the Skålsvik Closed Fold had been refolded about the 269 Fold axis during F_2, giving rise to the coil-like structure now displayed in the steep limb of the Saura Synform; and

(iv) major movement along the tectonic slides had been completed before the onset of the late phase folding.

3. Structure of the Gneissic Groups

With the exception of the Saura Synform all the major fold structures that have been recognized in the gneissic groups are ascribed to the second period of folding since the schistosity passes round their hinges and an earlier generation of minor folds has been distinguished locally. The structural analysis of massive gneisses is difficult, however, as these rocks do not in general provide the kind of evidence that layered metasedimentary rocks do. Accordingly, the detailed elucidation of the structural relationships is heavily dependent on the distribution of the metasedimentary marker bands. It is unfortunate that throughout much

of the south-western sector of the Saura region these bands are poorly developed.

As in the Saurvatn Mixed Group, the pre-F_3 folding has been accompanied by tectonic sliding.

A. The Framnes Fold and the Ågdalsknubben Synform.

These folds are located to the west and east respectively of the axial trace of the Saura Synform in the southern and south-western sectors of the map area. In the following sections the two folds will be described and their mutual relationships considered.

(a) *The Framnes Fold.*

The hinge of the Framnes Fold is most clearly observed to the south-south-west of Nubben where quartz-monzonite gneisses with a low to moderate northerly dip in the axial zone of the Saura Synform are folded quite openly but abruptly to the south-west. The dip of the gneisses in the western limb of the fold is low to moderate easterly.

Surrounding the gneisses in the core of the fold is a horizon containing marbles, schists and dioritic gneisses. This succession overlies the rocks of the Framnes Group and possesses a rather low easterly sheet dip in accordance with its position to the west of the axial trace of the Saura Synform. Direct mapping of the hinge of the Framnes Fold in the ground underlain by this succession to the west of Kjop-stadnakken was not possible owing to the limited exposure inland and to the lack of suitable marker horizons, although minor folding has been recorded along the fjord sections. Gneisses assigned to the Røsnes Group crop out along strike to the north of Beiarnfjord, however, and the rocks of the mixed succession are regarded as closing in a northerly direction beneath the waters of the fjord. The style of the Framnes Fold thus changes to the north of the quartz-monzonite gneiss contact. The resulting attenuation is ascribed to differences of competency between the quartz-monzonite gneiss and the mixed, predominantly calcareous succession surrounding it, and also to the «squeezing» effect caused by the convergence of the Skålsvik and Framnes Slides.
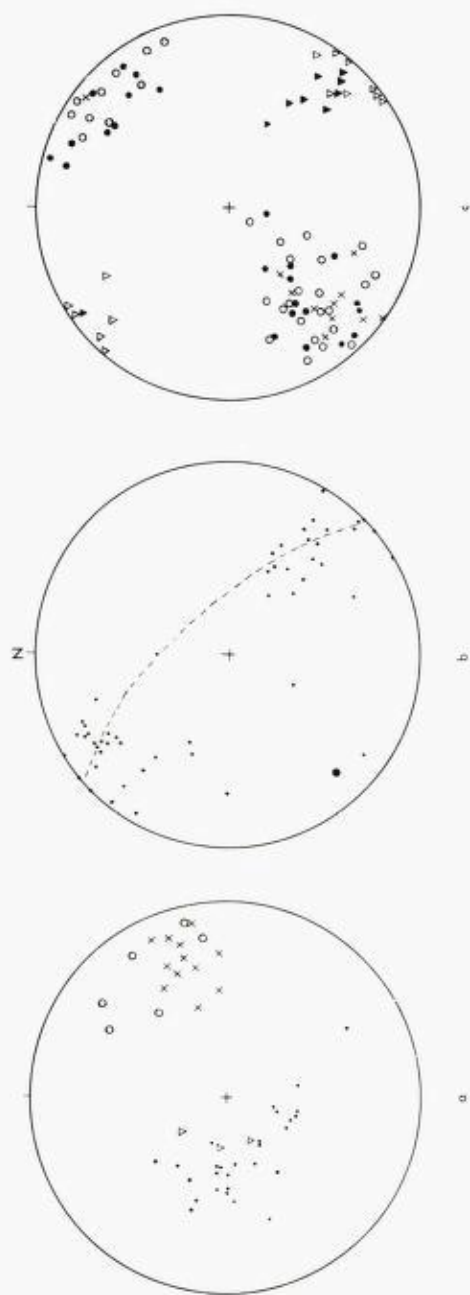
Fig. 10. Structural data, gneissic groups: (a) π S and B-diagram, the Framnes Fold, sub-area 3c; (b) π S diagram, the Agdalsknubben Synform, sub-area 2; (c) B-diagram and poles to axial surfaces of folds, the Agdalsknubben Synform, sub-area 2. Symbols: ——— dot ——— pole to foliation; open circle ——— axis of F_2 fold; closed circle ——— axis of ?F_1 fold in (c); large closed circle ——— axis of F_2 fold and pole to π S girdle in (b); cross ——— lineation; open triangle ——— pole to axial surface of F_2 fold; closed triangle ——— pole to axial surface of ?F_1 fold.

The dip relations and the attitude of the axial surfaces of minor folds indicate that the Framnes Fold is gently to moderately inclined, with an axial surface dipping in an easterly direction and sensibly parallel to the sheet dip. An east-north-easterly plunge for the fold is indicated by the plot of structural data (Fig. 10 a), the fold thus approximating a neutral or reclined structure, although possibly with a dominant antiformal component (Fleuty 1964, quoted in Ramsay 1968, pp. 358—60).

(b) *The Agdalsknubben Synform.*

Like the Framnes Fold, the Ågdalsknubben Synform is best defined by the quartz-monzonite gneiss which form a tongue-like outcrop on Ågdalsknubben. The north-western contact of these gneisses has been mapped south-westwards to Nubben where the same rocks form the core of the Framnes Fold, whilst the south-eastern contact has been traced south-south-westwards to Åsvatn. The recognition of the fold in the field was hampered by the lack of suitable marker horizons in the gneisses, particularly south of Beiarnfjord, and by the asymmetry across the structure, in particular to the north of Beiarnfjord (see also section I, 3, C).

Interfolding of the gneisses and metasedimentary rocks has been observed north of Ågdalsknubben, but the attenuated style of the gneiss contact, the discontinous nature of the metasedimentary horizons in the enclosing dioritic gneisses and the asymmetry across the structure indicate that the folding has been accompanied by differential movement and rupture.

The relationship between outcrop and topography and the attitude of the minor linear structures (Fig. 10 c) define the synformal nature of the fold and indicate its gentle south-westerly plunge. A subsidiary concentration which plunges gently between north-north-east and east-north-east is also apparent; consideration of this will be deferred until a similar pattern in structural sub-area 1 (Fig. 2) is considered. North of Beiarnfjord the dip relations confirm the nature of the fold. The western limb dips almost vertically whilst the eastern limb dips moderately to steeply towards the north-west (Fig. 10 b). However, south of the fjord the sheet dip is everywhere north-westerly and the fold is overturned to the south-east (Plate II, section E—F). The north-western limb of the fold is, therefore, inverted in this section.

(c) *Interpretation: the Framnes—Ågdalsknubben Overfold.*

The relative unsuitability of massive gneisses for detailed structural analysis has been noted and has rendered the intepretation of the Framnes Fold and the Ågdalsknubben Synform difficult.

Superficially, both folds might appear to be complementary to the Saura Synform, but in the case of the Ågdalsknubben Synform the synformal nature of the fold and its south-westerly plunge (as opposed to the north-easterly plunge of the Saura Synform) precludes this possibility. The detailed location of the axial trace of the Ågdalsknubben Synform is not known but a general convergence of the estimated trace with that of the Saura Synform is suggested which also renders this interpretation unlikely. More precise evidence against it is afforded by the overturning of the Ågdalsknubben Synform which increases in degree as the hinge of the F_3 synform is approached. The attitude of the Ågdalsknubben Synform thus depends on its position within the F_3 structure (Plate II, sections E—F and Y—Z) and accordingly pre-dates the F_3 folding.

Differences in attitude, trend and style between the Framnes Fold and the Saura Synform are likewise apparent and support a pre-F_3 age for the former. The axial surface of the Framnes Fold, which is sensibly parallel to the sheet dip, contrasts with the more steeply dipping axial surface of the Saura Synform (see below). As the sheet dip throughout the Saura region is controlled by the late phase folding, the axial surfaces of folds lying within the sheet dip will, by implication, also be so controlled. In addition, the style and trend of the minor structures associated with the two major folds differ.

As was the case with the Ågdalsknubben Synform, convergence of the axial traces of the Framnes Fold and the Saura Synform is suggested, favouring the refolding of the former during the late phase deformation. Unfortunately, reconnaissance traverses to the south of the map-area in an attempt to establish the relationships more certainly were not fully satisfactory owing to the difficulty of recognizing the axial trace of the Framnes Fold in the quartz-monzonite gneisses. The interpretation accordingly remains subjective.

However, additional support for the interpretation comes from beyond the Saura region. In the Sokumvatn area (Rutland 1959) no structure (in a similar position to the Framnes Fold) which could be

regarded as complementary to the Sokumvatn synform has been mapped immediately west of the synform. It will be shown later that the Saura Synform and the Sokumvatn Synform are different sections of what is essentially the same F_3 structure.

A pre-F_3 age for both the Framnes Fold and the Ågdalsknubben Synform is thus considered to be likely. The symmetrical distribution of the two folds to west and east of the axial trace of the Saura Synform suggests that the two folds are one and the same structure and owe their present disposition and outcrop pattern to the effects of the F_3 refolding. The likely convergence of the axial traces of the folds and the fact that the quartz-monzonite gneiss forms the core of both folds and that its northern contact can be traced from Ågdalsknubben around the hinge of the Saura Synform to the ground south-east of Framnes are significant in this respect, indicating a real continuity between the two folds. The attitude of the minor structures associated with the folds is consistent with this interpretation although information is sparse in the critical area at the hinge of the Saura Synform.

The recognition of the two folds as part of the same structure is important. It should be noted that the overfolding of the Ågdalsknubben Synform and the consequent inversion of the northern limb of that fold implies that the northern, upper, limb of the Framnes Fold is also inverted. The relationships are shown diagrammatically in Fig. 11 and the combined structure will be referred to hereafter as the *Framnes— Ågdalsknubben Overfold*. The realization that the northern, upper boundary of the gneissic groups is inverted as a result of the overfolding carries broader implications when the structural development of a wider area of Nordland is considered (section II, 1 and 2).

B. The Framnes Slide.

The attenuation of the Framnes Fold and the asymmetry across the axial trace of the fold to the east of Framnes provide the main evidence within the Saura region for the existence of the *Framnes Slide* which has been mapped from the north-east of Sandhornøy (Rutland and Nicholson 1965, Plate 12) to the Sokumvatn area (Rutland 1959) where it can possibly be correlated with the Staburfjell Slide Zone although Professor R. W. R. Rutland (*personal communication* 1969) has pointed out that it could equally well correlate with a slide occurring to the
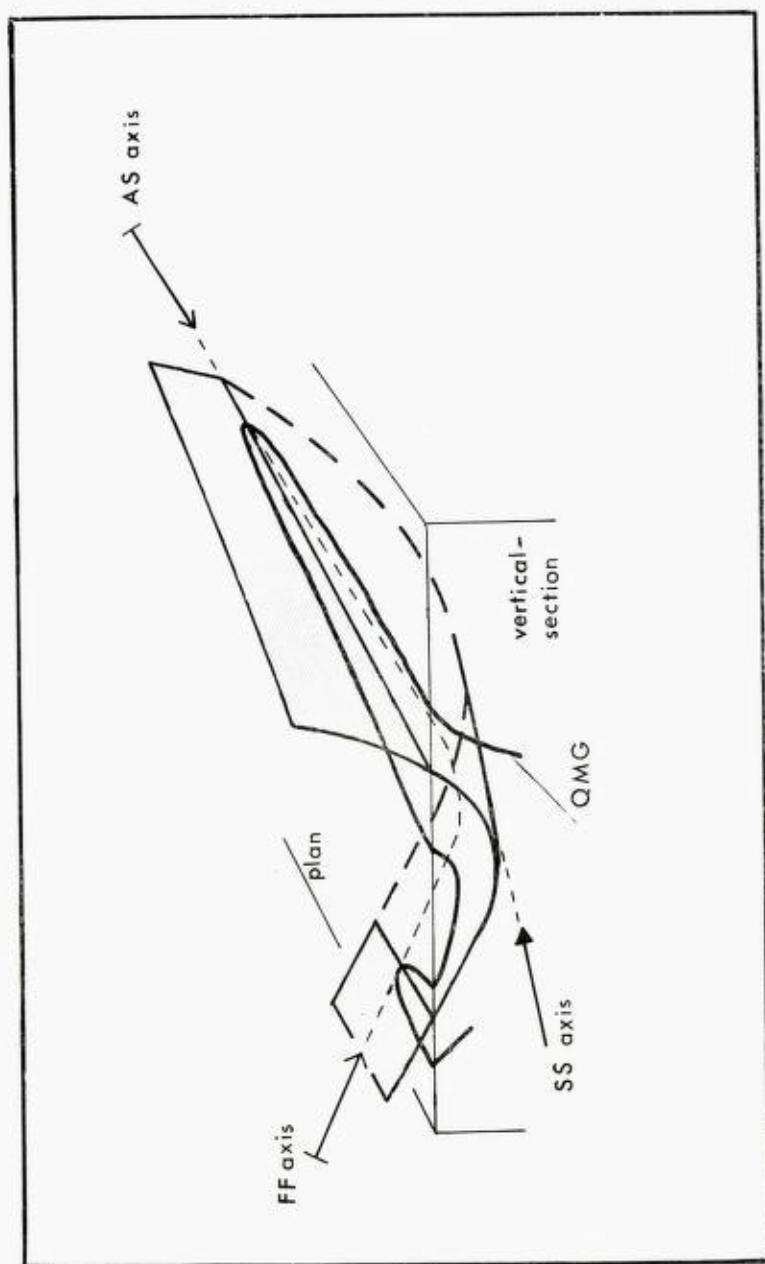
Fig. 11. The Framnes—Agdalsknubben Overfold; diagrammatic relationship of the Framnes Fold (FF) and the Agdalsknubben Synform (AS). Other symbols are: SS — Saura Synform; QMG — boundary of the quartz-monzonite gneiss «marker» horizon; stipple — axial surface of the overfold projected above the plan — section.

west of Fellvatn and below the Sokumfjell Marble Group (see also Rutland and Nicholson *op. cit.*, Plate 12).

At Framnes the succession passes upwards in an easterly direction from the Framnes Group through the mixed succession of marbles, schists and gneisses of the Harefjell Group (which here forms the core of the Framnes Fold) into the Røsnes Group. The Framnes Slide has been mapped along the upper contact of the Framnes Group and has eliminated the Røsnes Group from the lower western limb of the Framnes Fold (Plate II, Section E—F). Structural discordancy along the slide is suggested by the last observed trend of the quartz-monzonite gneiss in the core of the fold. If extrapolated southwards the gneisses would converge with the slide beneath the waters of the fjord and the enclosing «mixed» succession would, in consequence, be eliminated from the western limb of the fold.

Further evidence for the slide comes from Sandhornøy where the Røsnes Group has been eliminated by the convergence of the Skålsvik and Framnes Slides. Rocks of the Saurvatn Mixed Group, and further north of the Skånlandsfjell Marble Group are brought into contact with the northerly extension of the Framnes Group (shown as the Alsvik Group, Rutland and Nicholson 1965, Plate 12) along the eastern part of this island.

C. The Evjenvatn Antiform and Associated Slides.

The Evjenvatn Antiform is the last of the major folds which are specifically restricted to the gneissic groups. The hinge of the fold has been mapped in veined mica schists of the Pallrakken Group at Evjenvatn, where the schistosity has been followed around the fold hinge, and at the contact between the marbles and the massive dioritic gneisses of the Harefjell Gneissic Group to the south-east of Åsvatn (Fig. 12 f).

The antiform plunges gently in a south-westerly direction. At Beiarnfjord the fold is slightly asymmetric and possesses a steep north-westerly dipping axial surface, but further south the fold tends to become more tightly apressed and attenuated, although in part this is an apparent feature only, and has resulted from the interplay of topography and a low plunge. The dip on Kjellingfjell is easterly, but zones of higher and lower dip which reflect parasitic folding congruent with the main fold

Fig. 12. *Styles of minor folds (F₂), gneissic groups: (a) — (c), (e), (f)
—— the Evjenvatn Antiform; (d) south-east of Framnes.*

can be approximately defined. The flexures on the western limb of the fold, and particularly that immediately to the north-north-west of Evjenvatn, are accentuated by the shallow dip of the marbles there.

An analysis of the minor structures confirms the general structural pattern deduced from the major structure alone. The π S diagram (Fig. 13 a) shows a broad girdle distribution about a subhorizontal NE-SW trending axis. The width and attitude of the girdle is attributed to the undulating subhorizontal attitude of the foliation on hill 526 and to the easterly swing in strike to the north-east of Kjellingfjell. In addition, the presence of an initially anisotropic fabric prior to the folding responsible for the Evjenvatn Antiform may have contributed to the observed pattern. Evidence for the existence of this fabric is suggested by certain isoclinal minor folds (Fig. 12 e) which have been folded about axes essentially coaxial with that of the major fold, but which possess axial surfaces of variable attitude.

These plot as a partial great circle girdle suggesting that they have been refolded by the deformation responsible for the Evjenvatn Antiform (Fig. 13 b). (A similar relationship may be noted for the Ågdalsknubben Synform in Fig. 10 c.) The plot of linear structures (Fig. 13 c) amplifies the observation that the major fold plunges gently to the south-west, but a subsidiary maximum between north-east and east (cf., the Ågdalsknubben Synform) reflects weak cross-warping about subhorizontal north-westerly trending axes on hill 526, where the combination of this and the «Evjenvatn folding» has produced shallow closed structures in the marbles (Fig. 12 b).

The Evjenvatn Antiform is interpreted as an F_2 structure although there is no direct evidence on the large scale that it has refolded existing major structures. The schistosity relations in the veined mica schists have, however, been noted, as has the existence of a possibly earlier generation of minor folds. The development of a π S girdle rather than a point maximum is more consistent with an F_2 of F_3 age than with an F_1 age for the folding. The antiform, closing and plunging towards the south-west, bears no direct relationship to the Saura Synform and, therefore, an F_3 age for the structure is considered to be unlikely. The Evjenvatn Antiform is, in fact, an «internal» structure lying within the steep limb of the Saura Synform, and its axial trace is continuous with that of the Bjørnhatten Fold further to the south-west (Rutland 1959, pp. 300-1). Rutland has demonstrated that this fold pre-dates the
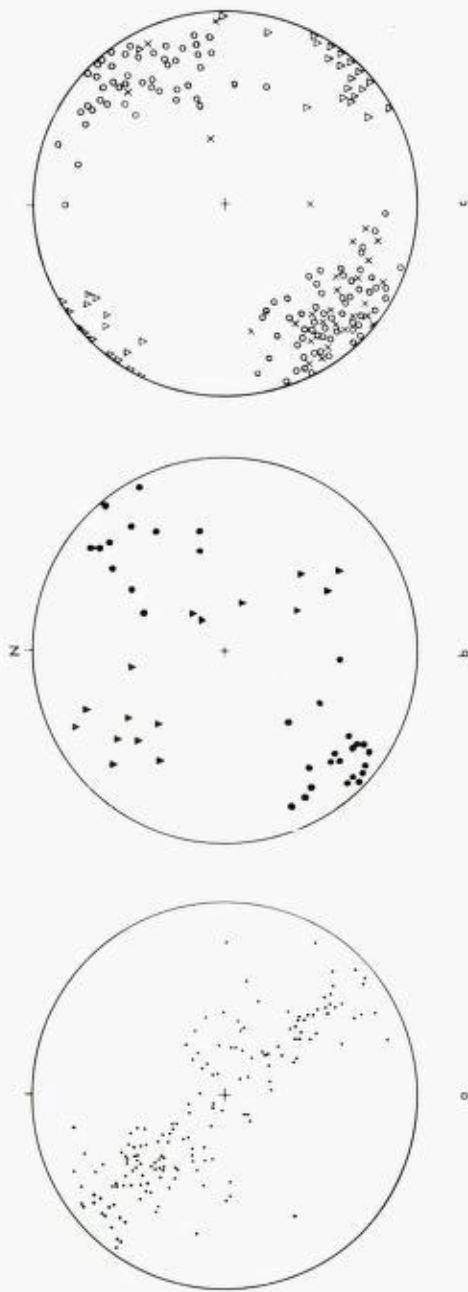
Fig. 13. Structural data, gneissic groups, sub-area 1 —— the Evjenvatn Antiform:
(a) π S diagram; (b) B-diagram —— F₁ folds and poles to axial surfaces of F₁ folds;
(c) B-diagram —— F₂ folds and poles to axial surfaces of F₂ folds.
Symbols as for Fig. 10.

later folding responsible for the formation of the Sokumvatn Synform. The fold is not, however, present in the western limb of the Sokumvatn Synform owing to its elimination by tectonic sliding (Rutland *op. cit.*, Figs. 2 and 11).

A similar relationship holds for the Evjenvatn Antiform which, like the two major folds already described in this section, is characterized by asymmetry across its axial trace. Thus, the predominantly gneissic succession to the west is not well-developed in the eastern limb of the fold. In the vicinity of Kjellingfjell massive dioritic gneisses pass upwards to the south-east into a zone of closely intermixed foliated dioritic gneisses and metasedimentary rocks in which the quartz-monzonite gneiss is only poorly developed. This zone eventually gives way to an extensive marble group termed the Sokumfjell Marble Group (Rutland 1959). The individual lithologies of the zone of intermixed gneisses and metasedimentary rocks tend to form discontinuous bands or lenticular outcrops and the whole zone has undergone strong deformation. On this basis, and on the asymmetry apparent across the antiform as a whole, the existence of the *Kjellingfjell Slide Zone* has been postulated. The succession and relationships in this zone are similar to those recorded by Rutland (1959) in the Staburfjell Slide Zone to the south which also separates the Harefjell Gneissic Group from the marble group to the east. The two zones are, therefore, correlated on both geological and geographical grounds.

Similarly, a slide (largely inferred in the map-area and named the *Åsvatn Slide*) limits the western extent of the Evjenvatn Antiform in like manner to that bounding the Bjørnhatten Fold. The present relationship between the antiform and the Ågdalsknubben Synform is not considered to be that of a complementary fold pair despite the similar plunge of the two structures. Immediately north-east of Åsvatn gneissic and metasedimentary rocks are complexly interdeveloped in a manner similar to that on Kjellingfjell. This zone of mélange has been recognized to the south-west of the map-area on reconnaissance traverses and effectively appears to limit the western extent of the Evjenvatn Antiform. To the north-east of Åsvatn the bands of foliated diorite are progressively thinned and eliminated whilst to the north of Beiarnfjord the lack of symmetry across the Ågdalsknubben Synform is accentuated by the rarity of these gneisses to the east of the quartz-monzonite gneiss outcrop. Similarly, the marbles overlying the veined mica schists of

the Pallrakken Group at Eggesvik and further to the north-east are not developed to any extent on the western limb of the Ågdalsknubben Synform. Further evidence for a structural discontinuity between the synform and the Evjenvatn Antiform can be drawn from beyond the limits of the Saura region. The Pallrakken Group has been mapped on the southern side of Skjerstadfjord but not on the northern, and shows no evidence of being folded round the hinge of the Ågdalsknubben Synform (Rutland and Nicholson 1965, Plate 12).

The Evjenvatn Antiform is thus included within the steep limb of the Saura Synform. The lithological similarity between the Pallrakken and Framnes Group has, however, been noted. The Evjenvatn Antiform, with the Pallrakken Group in the core, is accordingly envisaged as a rootless fold nose which became detached from the Framnes Group during the early phase deformation, with the convergence of the Åsvatn and Kjellingfjell Slides at depth (Plate II, section E—F). A comparable relationship is shown by the Bjørnhatten Fold (Rutland 1959).

D. Summary.

The salient features of the structure of the gneissic groups can be summarized as follows:

(i)   the Framnes Fold and the Ågdalsknubben Synform are regarded as parts of a single fold structure and owe their present relationship to refolding about the Saura Synform axis;

(ii) prior to the F_3 deformation the Framnes—Ågdalsknubben Overfold had been overfolded towards the south and the upper, northern limb of the structure inverted;

(iii) the Evjenvatn Antiform lies within the steep limb of the Saura Synform and its refolding by that structure is postulated although no equivalent fold has been recognized to the west of the axial trace of the Saura Synform; and

(iv) tectonic sliding has accompanied the folding.

4. The Saura Synform

The Saura Synform is the dominant fold structure of the Saura region, responsible for the major strike swing from a rather constant NE-SW trend over a large part of the region to a NW-SE trend in the extreme south-western sector. It is evident that the axial traces of the folds which comprise the Isoclinal Fold Complex and the associated tectonic slides have been involved in this strike swing, and thus early and late phases of deformation have been postulated. A similar relationship between the Framnes—Agdalsknubben Overfold and the Saura Synform has been argued.

The style of the Saura Synform varies from asymmetric or slightly overturned (to the north-west) to more tightly apressed and more strongly overturned in the same direction. The axial surface of the fold is sinuous, trending approximately N-S where the fold is relatively open and asymmetric and NE-SW where more tightly apressed. The fold is characterized by a thick eastern limb and a thinner western limb which dips gently to moderately towards the north-east.

The hinge of the synform is most clearly displayed at Saura where the early phase structures which comprise the Isoclinal Fold Complex have been traced around the hinge. In addition to this direct evidence of refolding the style and attitude of the Saura Synform contrasts with the early phase folds. The synform possesses an axial surface which dips moderately steeply towards the east. The axial trace of the fold trends N-S in this sector and dip values along the fjord-section to the south of Saura indicate a moderate plunge towards the north-north-east. Confirmation of this has been found to the south of Beiarnfjord where rocks of the Saurvatn Mixed Group dip moderately to the north-north-east.

The hinge of the synform has also been mapped on Kjopstadnakken and Nubben, but whereas the schist bands to the north have retained a constant thickness around the hinge, the gneisses of the Røsnes Group form a broader outcrop, due in part to a combination of topography and lower dip. Nonetheless, reconnaissance traverses to the south of the map-area show that to some extent this is also the result of deformation because on hill 714 a marker horizon in the quartz-monzonite gneiss indicates that there the synform is more tightly apressed (Plate II). It should be noted that the axial trace of the Saura Synform swings from
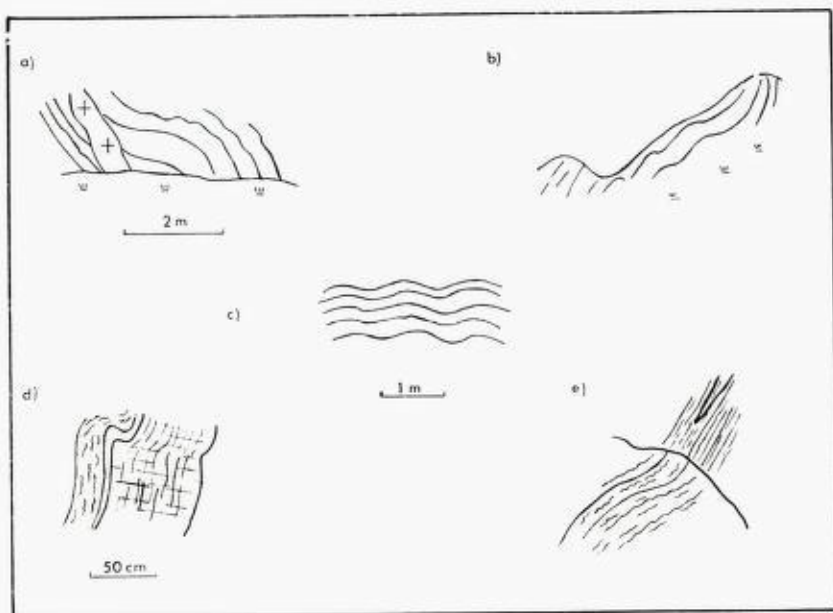
Fig. 14. Styles of minor folds (F₃), the Saura Synform, sub-area 3.

N-S to NE-SW here and that the increasingly apressed nature of the fold is consistent with a similar change in the style of the Sokumvatn Synform as that fold is followed north through the Sokumvatn area (Rutland 1959, Fig. 2).

The minor folds associated with the F_3 deformation are mostly weak and open, although dextral «drag-folds» congruent with the main structure have been observed, for example to the west of the southern end of Saurvatn (Fig. 14 b). Small-scale crenulations in suitable lithologies are, however, the most common minor structures that can be ascribed to this phase.

To the north-east of Nygårdsjøen the plunge of the Saura Synform decreases and the fold becomes more tightly apressed. Recognition of the hinge of the fold accordingly becomes more difficult, particularly in view of the lack of continuous marker horizons. The south-easterly sheet dip prevailing throughout the Skånlandsfjell Marble Group and the parasitic folding of the marker horizon to the west of the summit of Skånlandsfjell indicate that the axial trace lies to the south-east.

The veined mica schists of the Saurvatn Mixed Group which have been mapped from the northern end of Valnesvatn to Saura define the eastern limb of the fold, and the axial trace of the synform can thus be approximately located on these criteria. The resulting asymmetry shown by the marker horizons in the Skånlandsfjell Marble Group has already been noted in discussing the Ertenvågdalen Slide. The axial trace of the Saura Synform, therefore, adopts a north-easterly trend in the northern part of the map-area; it cannot be extrapolated northwards along the fjord as would have seemed probable from the relationships of the fold at Saura. Support for this conclusion from outside the map-area is provided by the Alsvik Group (equivalent to the Pallrakken and Framnes Groups of this paper) which has been mapped across the fjord from the northern part of Sandhornøy to Strømøen and shows no evidence of forming part of the hinge zone of the Saura Synform (Rutland and Nicholson 1965, Plate 12).

Throughout the northern sector the style and attitude of the Saura Synform varies from tight to more open, generally with a south-easterly dipping axial surface. The π S diagram (Fig. 16 a) indicates the varia-
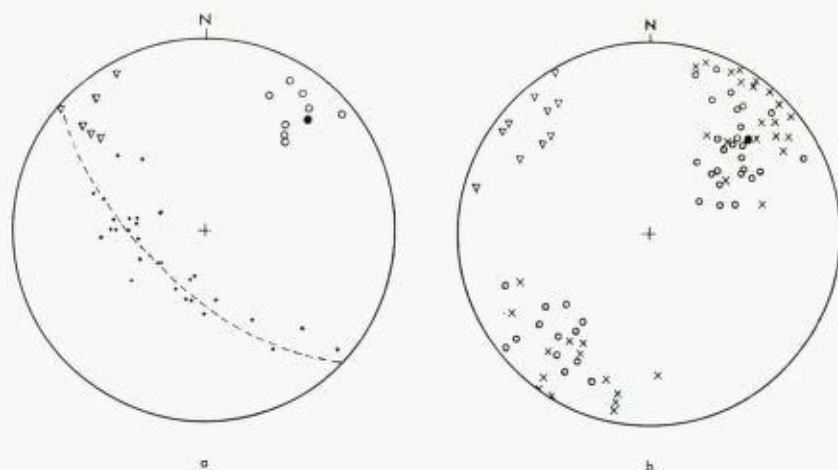
Fig. 15. Structural data (F₃), the Saura Synform, sub-area 3: B-diagram, also poles to axial surfaces of folds, and to π S girdle, sub-areas 3c and 3d; (b) B-diagram and poles to axial surfaces of folds and to π S girdle, sub-areas 3a and 3b. Symbols: — dot —— pole to foliation; open circle —— fold axis; closed circle —— F₁ axis and pole to π S girdle; cross —— crenulation lineation; open triangle —— pole to axial surface of fold.
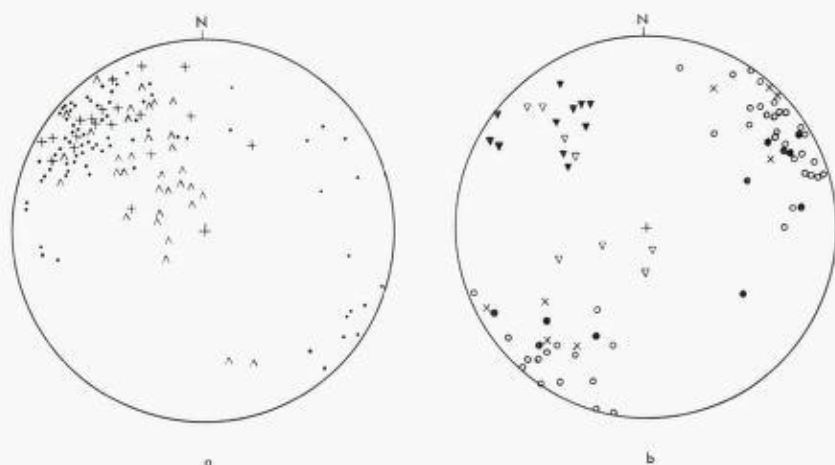
Fig. 16. Structural data (F₂), the Saura Synform, sub-areas 4, 5 and 6;
(a) π S diagram, sub-area 4 (dots), 5 (vertical crosses), 6 (inverted «v»);
(b) B-diagram and poles to axial surfaces of folds. Symbols: — closed circle
—— axis of fold of early phase style; closed triangle —— pole to axial
surface of fold of early phase style. Other symbols as for Fig. 15.

tion in trend of the fold and in the dip of the north-western limb. The
linear structures plunge gently between north-east and east-north-east,
but again show a subsidiary concentration plunging gently towards the
south-western quadrant (Fig. 16 b). Differentiation of the minor folds
(into F₁, F₂ and F₃ structures) has proved difficult in this sector, parti-
cularly in the marbles where the style of the folding varies from
isoclinal to open without obvious relationship to the age of the folding.
The marker horizons of quartzite and interbanded pelitic schist are
dominated by an open crumpling. An added complication is that the
folding of different styles has occurred about similar axes and the
divergency noted between the early and late phase trends (e. g. at Saura)
is not apparent here.

These relationships are ascribed to the more easterly trend and more
tightly apressed nature of the Saura Synform further north, the result
of which has been to render difficult the distinction of the early and
late phase structures and to reduce the divergency of their trends. It
is suggested that the changing style of the Saura Synform indicates
a link between the early and late phases of deformation and that the

more tightly apressed and more easterly-trending sectors of the fold reflect a dominant F_2 component. The significance of this will be considered more fully in section II, 2 of the paper.

In concluding this section the salient features favouring the correlation of the Saura Synform with the Sokumvatn Synform (Rutland 1959) can be outlined as follows:

(i) extrapolation of the axial traces of the two folds provides good geographical coordination;
(ii) both synforms show similar variations in style and attitude along and across their axial traces; and
(iii) both synforms appear to be of similar age and refold earlier recumbent folds.

5. The Structural Evolution of the Saura Region

In the earlier part of the paper the geometry of the folds within each of the main litho-structural units has been established. This has involved some discussion relating to the structural development of the Saura region and an attempt will be made here to briefly review certain aspects of this question. Minor modifications to the synthesis will be required when the region is finally considered in terms of the tectonic framework of a wider area.

Major fold structures ascribed to the early phase deformation have bee recognized in all the litho-structural units with the exception of the Skånlandsfjell Marble Group, and in the Saurvatn Mixed Group two episodes of this folding (F_1 and F_2) have been distinguished. Elsewhere only F_2 major structures have been mapped and some control over their distribution would appear to be indicated.

The recognition of the Framnes—Agdalsknubben Overfold is critical to any consideration of the structural development of the Saura region. It has been demonstrated that the rocks to the north of the axial trace of the structure are inverted and that the present structural top of the Røsnes Group along the line of the Skålsvik Slide in fact represents the inverted base of the group.

Direct evidence within the Saura region that the higher units of the structural succession, namely the Saurvatn Mixed Group and the
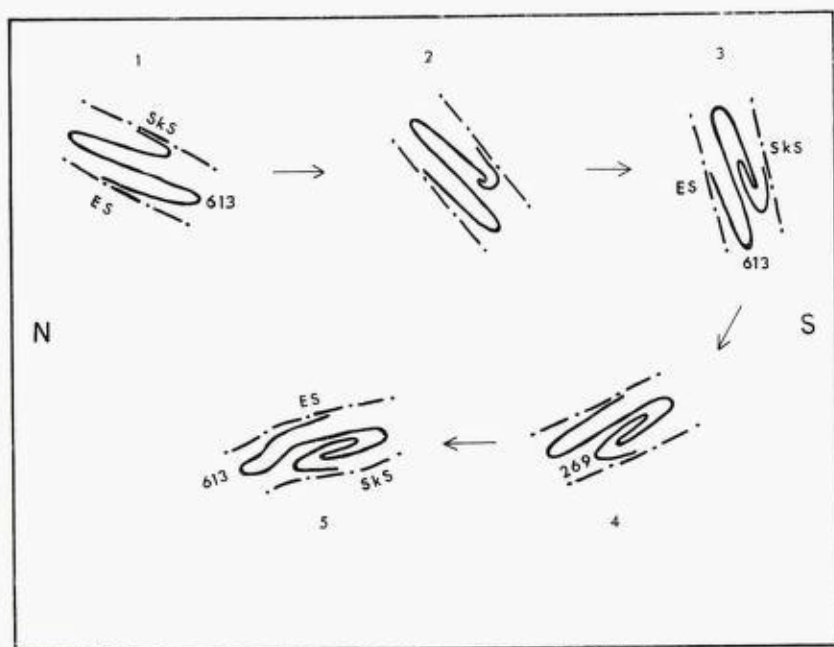
Fig. 17. The evolution of the Isoclinal Fold Complex (diagrammatic): (1)
—— F_1 «fold-pile» prior to F_2 inversion; (2) and (3) —— increasing south-
erly dip during inversion and progressive development of the 269 Fold; in-
version occurs between stages (3) and (4); (4) and (5) —— decreasing
dip after inversion, continued attenuation and flattening. ES —— Ertenvåg-
dalen Slide; Sl·S —— Skålsvik Slide; 613 —— 613 Isocline;
269 —— 269 Fold.

Skånlandsfjell Marble Group, are inverted is not forthcoming, as rocks
of these groups have not been observed on the lower limb of the F_2
inversion, that is of the Framnes—Ågdalsknubben Overfold. This is
partly ascribed to continued sliding during the F_2 inversion, with the
advance of the upper, inverted limb of the overfold. The result of this
has been to progressively eliminate the hinge of the overfold and to
weaken its symmetry. Evidence of this is provided by the convergence
of the Skålsvik and Ertenvågdalen Slides with the Framnes Slide on
Sandhornøy, whilst the close association between the sliding and the
early phase folding favours the juxtaposition of the rock groups involved
at an early stage in the structural history of the Saura region. When
a wider area is considered the distribution of the marble, schist and

gneissic groups favours the existence of inversion on an even grander scale (see section II, 2).

The F_2 inversion provides a mechanism for the evolution of the coil-like structure of the Isoclinal Fold Complex although the concept remains elementary and idealized. The postulated development is summarized diagrammatically in Fig. 17. Prior to the F_2 inversion the Skålsvik Closed Fold formed the highest structure in the pile of F_1 recumbent isoclines which then comprised the Isoclinal Fold Complex. During the F_2 inversion the Skålsvik Closed Fold is envisaged as moving forward and over itself, giving rise to what is now the 269 Fold and the resulting coil-like relationship. On a smaller scale this movement pattern is paralleled by the development of the 465 Fold. After the actual inversion the continued advance of the upper, inverted limb of the F_2 overfold emphasized the strong attenuation and associated sliding now noted in the eastern closure of the Skålsvik Closed Fold, whilst gravitational effects and load pressure caused the flattening of the Isoclinal Fold Complex and led to the development of the 204 Fold in a «structural void» created in the incompetent marbles which are believed to underlie much of Valnesvatn.

Late phase deformation then followed, accompanied by the upturning of these complex recumbent and overfolded structures and their associated slides (now essentially passive) into an asymmetric synform. In the southern half of the Saura region the relationships indicate the physical superposition of the F_3 synform on the earlier structures, with the implication of a time-break between the close of the early phase deformation and the onset of the late phase deformation. Further north, however, the relationships suggest the possibility of a genetic link between the early and late phases of deformation.

II. The Tectonic Setting of the Saura Region

1. Introduction

Frequent reference has already been made to Rutland and Nicholson's (1965) assessment of the tectonics of the Caledonides in part of Nordland, and the importance of the Saura region to their interpretation has been stated at the outset of this paper. The structural evolution of the Saura region having now been outlined, it is relevant to discuss the relationships of the region in the context of the wider area considered by those workers.

Many of the structural and lithological affinities which exist between the Saura region and the Sokumvatn area (Rutland 1959) have been raised already, and the salient features on which the structural correlation is based are shown in Fig. 18. The similarities afforded by the structures of the two areas are readily apparent.

An outline of the tectonic setting of the coastal belt of Nordland from Sørfolda in the north to the Arctic Circle in the south has been given in the introduction to this paper. The Saura region occupies part of an extensive tectonic depression which Rutland and Nicholson (1965) have envisaged as holding a large synformal klippe which they have termed the Beiarn Nappe and which they then regarded as an outlier and probable equivalent of the Rödingsfjäll Nappe (Rutland and Nicholson *op. cit.*, pp. 99—100; Kulling 1955; Fig. 19, this paper), although more recent work (Dr. R. Nicholson, *personal communication* 1969; Nicholson and Rutland 1969) now makes this direct correlation appear unlikely. The Beiarn Nappe is envisaged as being emplaced during the earliest (F_1) deformation, forming a disjunctive structure (Rutland and Nicholson *op. cit.*, p. 101), the base of which consists of granitized schists and gneisses.
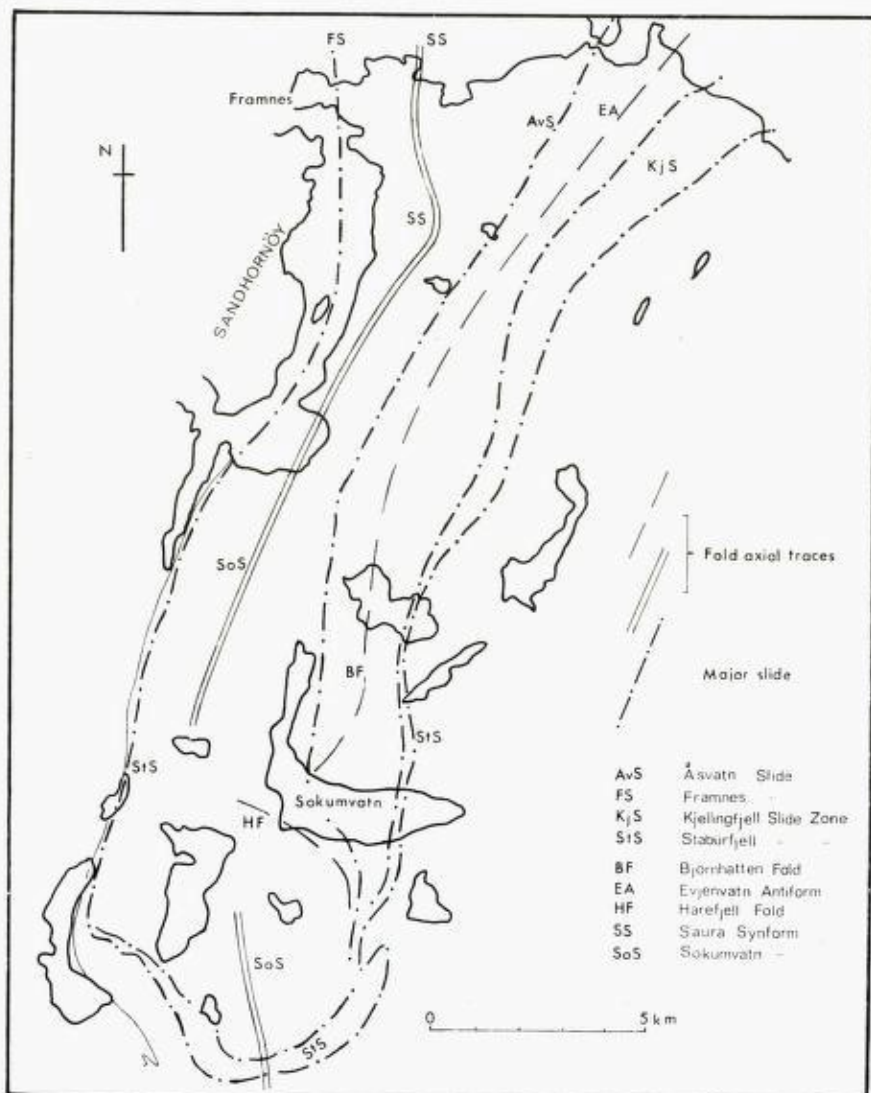
Fig. 18. Structural correlation with the Sokumvatn area (data from the Sokumvatn area after Rutland 1959, Fig. 11).
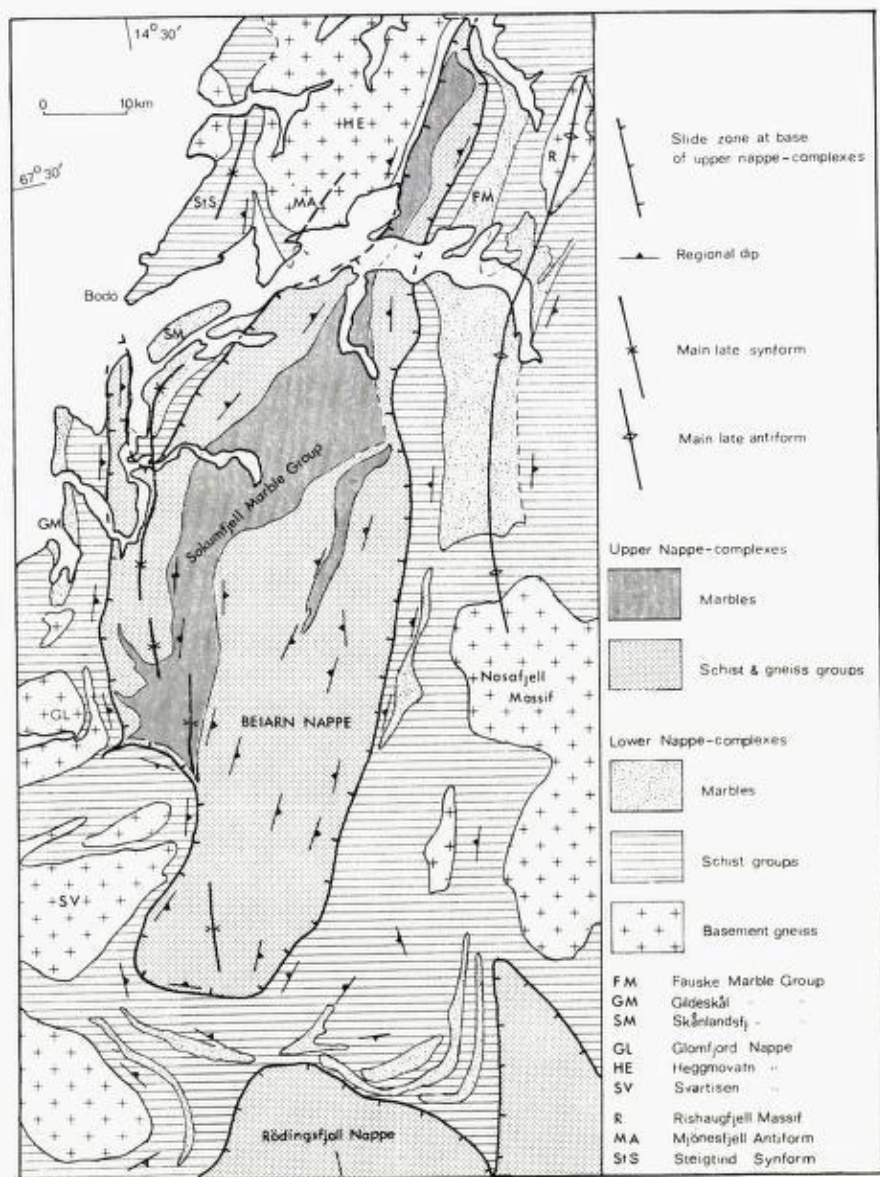
Fig. 19. *Tectonic relations of the Beiarn Nappe (after Rutland and Nicholson 1965, Fig. 8).*

A well-developed F_2 nappe complex affected both this «upper» nappe and the basement massifs and their envelopes. During this phase the massifs were mobilized and occupied the cores of the F_2 nappes which developed by movement off the basement culminations towards the tectonic depressions. Movement was thus to the north off the Svartisen and Glomfjord massifs (the Glomfjord and Svartisen Nappes) and to the south off the Heggmovatn massif (the Heggmovatn Nappe). As these nappes developed their closures «drooped» and some of the major synforms are, in fact, downward-facing *nappes de recouvrement*.

This phase of nappe formation is considered responsible for the inversion of the Beiarn Nappe in the north of the area where Rutland and Nicholson (1965, p. 99) have recognized the following sequence:

(i)   the emplacement of the Beiarn Nappe;
(ii) the F_2 inversion and the development of the Heggmovatn Nappe; and
(iii) the superposition of the F_3 folding.

The F_3 folding was ultimately responsible for the synformal disposition of the Beiarn Nappe. Further east the Rishaugfjell—Nasafjell belt forms a complementary antiformal zone, in which «external» massifs of Precambrian basement occur, comparable to the «internal» massifs noted above.

2. Discussion

The work in the Saura region has to a large extent substantiated the hypothesis proposed by Rutland and Nicholson (1965) to account for the tectonic development of a wide area of Nordland.

The sequence of structural events recognized in the Saura region is valid over a larger area where the earliest structures are restricted and are overshadowed by an approximately coaxial F_2 phase. In this context it is of interest to note that in the Sørfinnset area a dominant F_2 phase has been recognized (Dr. M. K. Wells, *personal communication* 1969; Wells and Bradshaw 1970) which has been subdivided into early F_2 and late F_2 components. A more restricted, earlier, F_1 phase has been largely obliterated during the F_2 deformation. It may be conjectured that the composite F_2 phase is analogous to the F_1 and F_2 folds recogni-

zed in the Saurvatn Mixed Group (as similarities certainly exist) and that certain of the lithological repetition within this group may reflect an even earlier deformation phase (that is, broadly equivalent to the F_1 phase of the Sørfinnset area). It is also of interest to note that the late F_2 phase of the Sørfinnset area overlaps in time with the broader F_3 warping (Dr. M. K. Wells, *personal communication* 1969).

The geometry of the postulated inversion of the Beiarn Nappe compares closely with the F_2 inversion occuring in the Saura region, whilst the refolding of the nappe into a N-S trending synformal belt finds a parallel in the F_3 refolding responsible for the Saura Synform.

The F_2 inversion was proposed by Rutland and Nicholson (1965) on both lithological and structural grounds. The Framnes—Ågdalsknubben Overfold provides the structural key although the F_2 inversion was originally attributed entirely to the Framnes Fold (Rutland and Nicholson *op. cit.*, pp. 98—99). The present work has placed that interpretation on a firmer basis by determining the geometry and relative ages of the Framnes Fold and associated structures.

Firstly, it has been shown that the Framnes Fold belongs to the same generation (F_2) as the other major structures mapped in the gneissic groups. This was inferred but not established by Rutland and Nicholson (1965, p. 97). In the Sokumvatn area Rutland (1959) had mapped the early phase structures but had not separated them into F_1 and F_2 episodes. It can now be postulated that the major fold structures in the Sokumvatn area are associated with the F_2 nappe formation and not with the F_1 disjunctive nappe emplacement.

Secondly, the recognition that the Framnes Fold and the Ågdalsknubben Synform belong to the same F_2 overfold on either side of the F_3 hinge allows the general trend of the axis of the F_2 inversion to be established. This is clearly north-easterly along the strike of the belt of gneisses and suggests a connection with the Valnesfjord Synform north of Skjerstadfjord (Rutland and Nicholson (1965, p. 93).

Further evidence for the F_2 inversion of the Beiarn Nappe is provided by the lithological similarities shown by the structural successions in three different localities. In the west the Gildeskål marbles pass upwards towards the east through the Meløy and Sundsfjord Group into the Alsvik Group (Rutland and Nicholson 1965, Plate 12). A similar succession passing upwards into gneisses in a westerly direction has been observed east of Bodø. In the Saura region the succession, although

similar, is reversed. Moreover, the gneissic groups in the south and south-east of the present ground are separated from the structurally higher groups by the Skålsvik Slide. It is these gneissic groups which are regarded as forming the base of the Beiarn Nappe. If the correlation of the successions outlined above is accepted then that in the Saura region is clearly inverted.

The existence of a major F_2 inversion in the Saura region has been argued on structural grounds although it has been noted that the symmetry of the inversion has been weakened by continued sliding and the advance of the upper, inverted limb during the inversion. Similarly, over the wider area the direct correlation of the three «type» successions has not proved possible as no major north-closing fold hinges, by which the F_2 inversion of the northern part of the Beiarn Nappe can be precisely defined, have been recognized. It is unlikely that the Framnes —Ågdalsknubben Overfold itself fulfils this role and the relationships in the Saura region suggest that it is also unlikely that the inversion of the northern part of the Beiarn Nappe will be a «simple» fold hinge.

The synformal nature of the Beiarn nappe is clearly the result of folding superposed on the F_2 inversion, and a similar sequence has been determined in the Saura region and also in the Sokumvatn area (Rutland 1959). In the Saura region, however, it has been suggested that the time-break implied by the term «superposition» may be misleading. This is substantiated when the relationships of the F_3 synform to the north of the Saura region are considered.

The easterly swing of the axial trace of the Saura Synform as it is followed to the north has been noted, and direct correlation with the Steigtind Synform (Fig. 19) is accordingly considered unlikely. The fact that the Saura Synform progressively adopts an «early phase trend» is considered significant and although data from the intervening ground is limited the geographical coordination with the Mjønesfjell Antiform (Fig. 19) is striking.

The Mjønesfjell Antiform is an asymmetric structure, overfolded towards the south and plunging towards the south-west. In order to correlate this fold with Saura Synform it must be regarded as developing further to form the «drooping» hinge of a downward-facing (synformal) anticline. It is thus similar to the *nappes de recouvrement* postulated by Rutland and Nicholson (e. g. the Glåmdal and Fondal folds, Rutland and Nicholson 1965, Figs. 2 and 3). As this drooping closure developed

divergence from the F_2 trend occurred, perhaps through the differential advance of the Heggmovatn Nappe, and in the southern part of the Saura region it refolds the early phase structures. A close link between the F_2 and F_3 folding is thus implied, the two being essentially continuous in time, although the spatial relationships are complex and control the sequence of structural events in any one area.

The present work has, therefore, largely substantiated the interpretation of Rutland and Nicholson (*op. cit.*) regarding the structural development of the western belt of Nordland. The structural pattern of the Saura region is reflected on a larger scale by the tectonic relationships of the northern part of the Beiarn Nappe.

3. Summary of the Structural History

The main conclusions arising from the present work are summarized as follows:

(i) Two major rock divisions have been distinguished in the Saura region — the gneissic groups to the south and south-east and the metasedimentary groups to the north and north-west.

The gneissic groups occupy the lower part of the structural succession in the map-area and are separated from the overlying groups by a major structural discontinuity.

The conclusion reached by Rutland and Nicholson (1965) that the gneissic groups form the base of the Beiarn Nappe is accepted by the writer.

(ii) The structural investigation of the Saura region has revealed a pattern and sequence of events similar to those elucidated in neighbouring parts of Nordland.

The rocks of the region have been involved in intense recumbent folding and overfolding about approximately E-W to NE-SW trending axes, designated F_1 and F_2. The F_2 structures are the more widely developed, and the recognition of a major F_2 inversion is critical to an understanding of the structural evolution of the region.

This early phase of deformation has been accompanied on all scales by tectonic sliding.

The early phase structures have been refolded about a gentle north-easterly plunging axis into a major synform (F_3) which

controls the structural «grain» of the region. The style of the synform varies from asymmetric to more tightly apressed and overturned.

The relationships of the synform in the north of the Saura region provide support for the theory that it represents the progressive development of an F_2 *nappe de recouvrement* of the type envisaged by Rutland and Nicholson (1965). A link between the early and late phases of deformation can be postulated.

Evidence of later «brittle» deformation is lacking on all but the smallest scale, and no major faults have been mapped. Master joints with a general south-easterly trend (approximately perpendicular to the regional strike) are locally well-developed throughout the area.

Acknowledgements

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Pl. 1.

GEOLOGICAL MAP OF THE SAURA REGION, NORDLAND.

LEGEND.

- Marble
- Banded Calc-psammite & semipelitic schists
- Calc-semipelitic schists (nodular) (dark)
- Calc-silicate conglomerate
- Amphibolite
- Quartzite & pelitic schist
- Veined mica schist
- Variable biotite-hornblende gneiss
- Massive diorite
- Foliated diorite
- Quartz monzonite
- Granite (intensive emplacement)
- Boundary, precise control
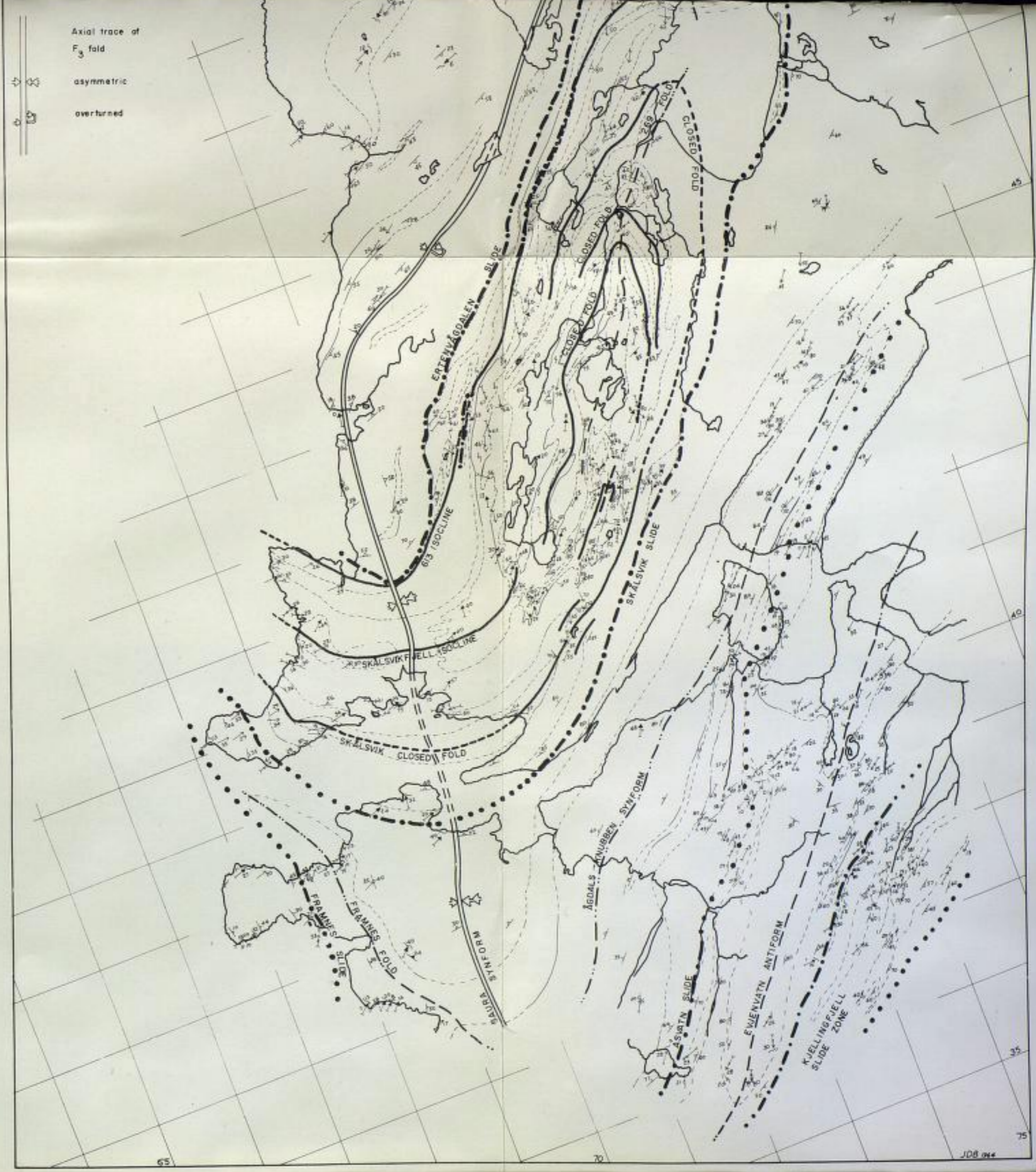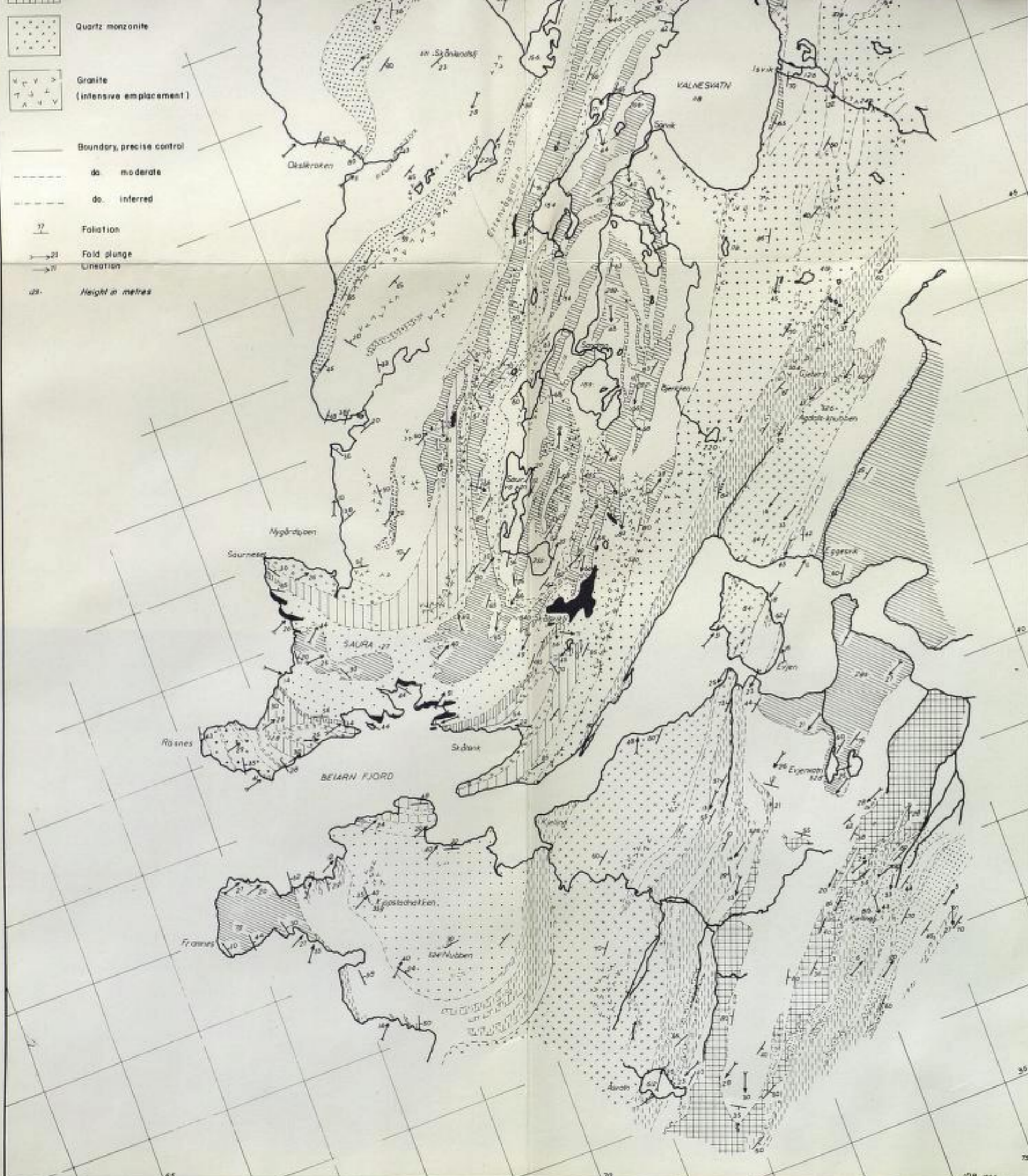- do. moderate
- do. inferred
- Foliation
- Fold plunge

N

SCALE
0   1   2km.

Valnes
Nordvik
Fakstoget
Skjönlandst
Isvik
VALNESVATN
Oksstraten

STRUCTURAL MAP OF THE SAURA REGION, NORDLAND.
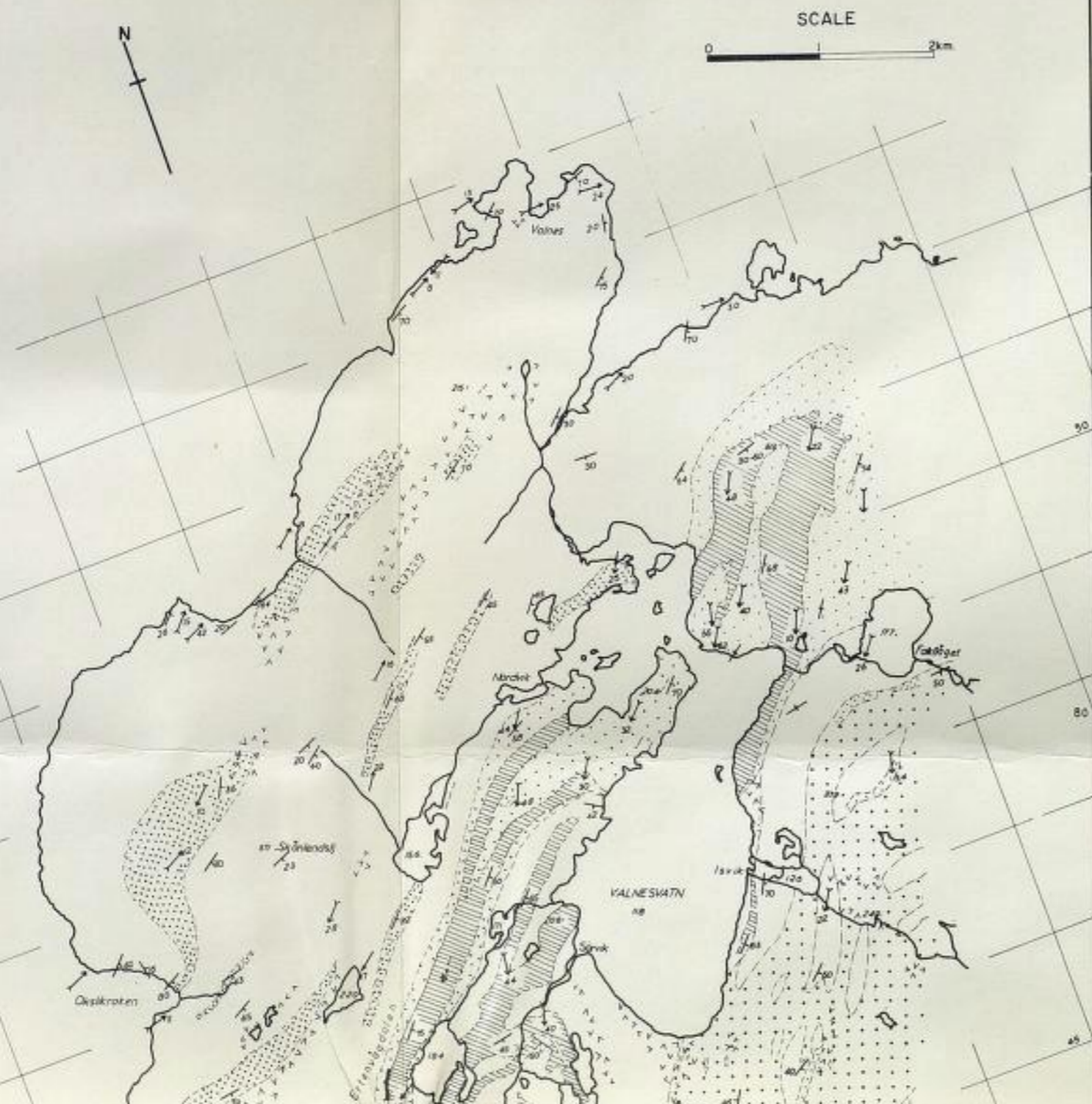
LEGEND

- Foliation

EARLY PHASE STRUCTURES.
- Fold Axis F_1
- " " F_2
- " " Undifferentiated.
- Lineation.
- Axial plane & axial plane schistosity to F_1 fold
- " " to F_2 fold
- " " to undifferentiated fold.
- Axial trace of F_1 fold.
- " " " " , inferred.
- Axial trace of F_2 fold.
- " " " " , inferred.
- Major Slide
- " " , inferred

LATE PHASE STRUCTURES.
- Fold Axis F_3
- Axial plane to F_3 fold
- False cleavage
- Axial trace of F_3 fold
- asymmetric
- overturned

N

SCALE
0   1   2km.

SAURA SYNFORM
FOLD
BIG ISOCLINE
CLOSED FOLD

Quartz monzonite

Granite
(intensive emplacement)

Boundary, precise control
  do.   moderate
  do.   inferred

Foliation
Fold plunge
Lineation

Height in metres

False cleavage

Axial trace of
F_3 fold
asymmetric
overturned

Pl. 2.

STRUCTURAL SYNOPSIS OF THE SAURA REGION, NORDLAND

CROSS-SECTIONS

LEGEND

SCALE

0   1   2 km

N

Marker horizons

Sheet dip

Generalised plunge of major fold axis :

F_1
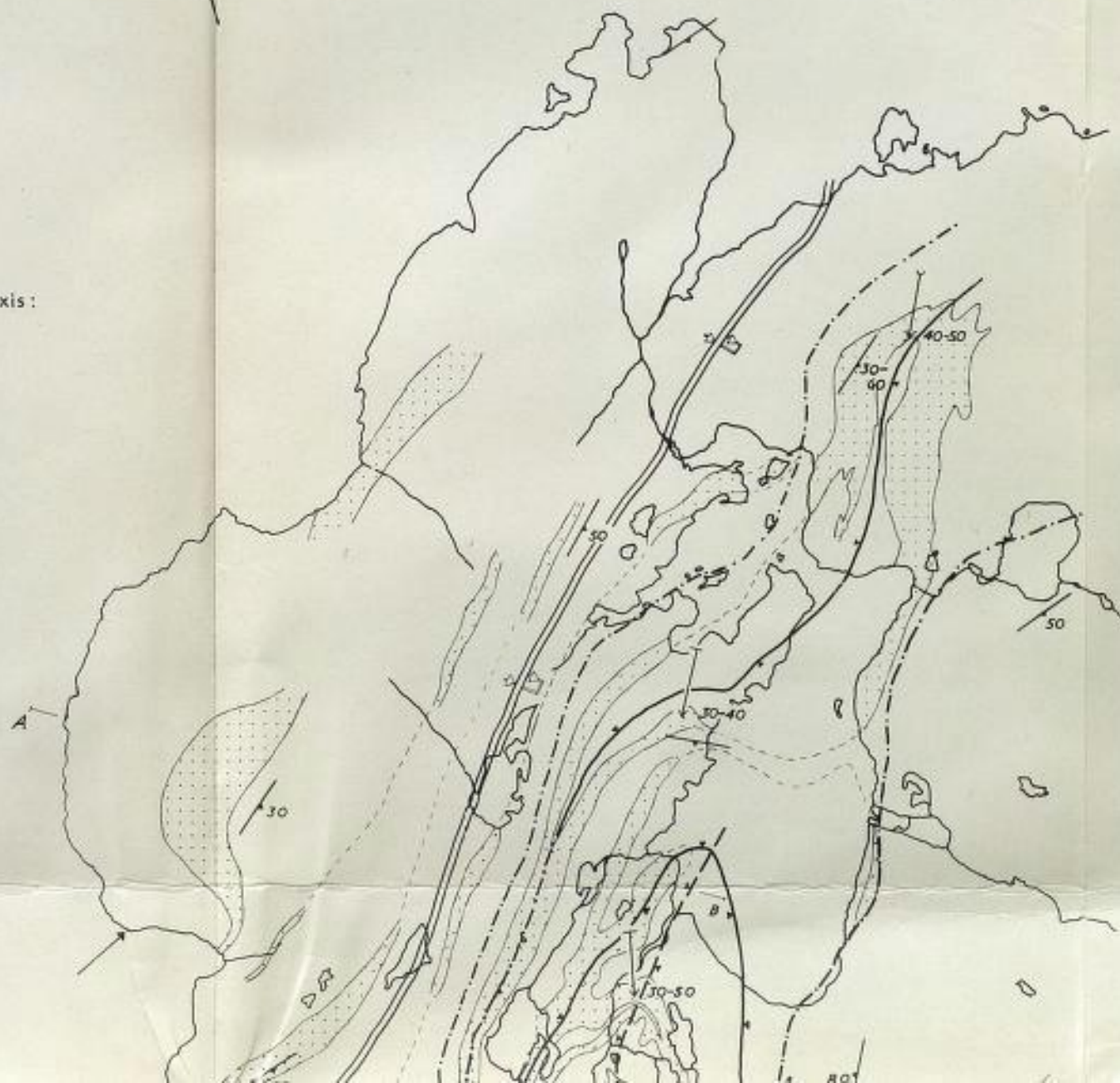
F_2 — Early phase

F_3 Late phase

Axial trace of major fold :

F_1

F_2
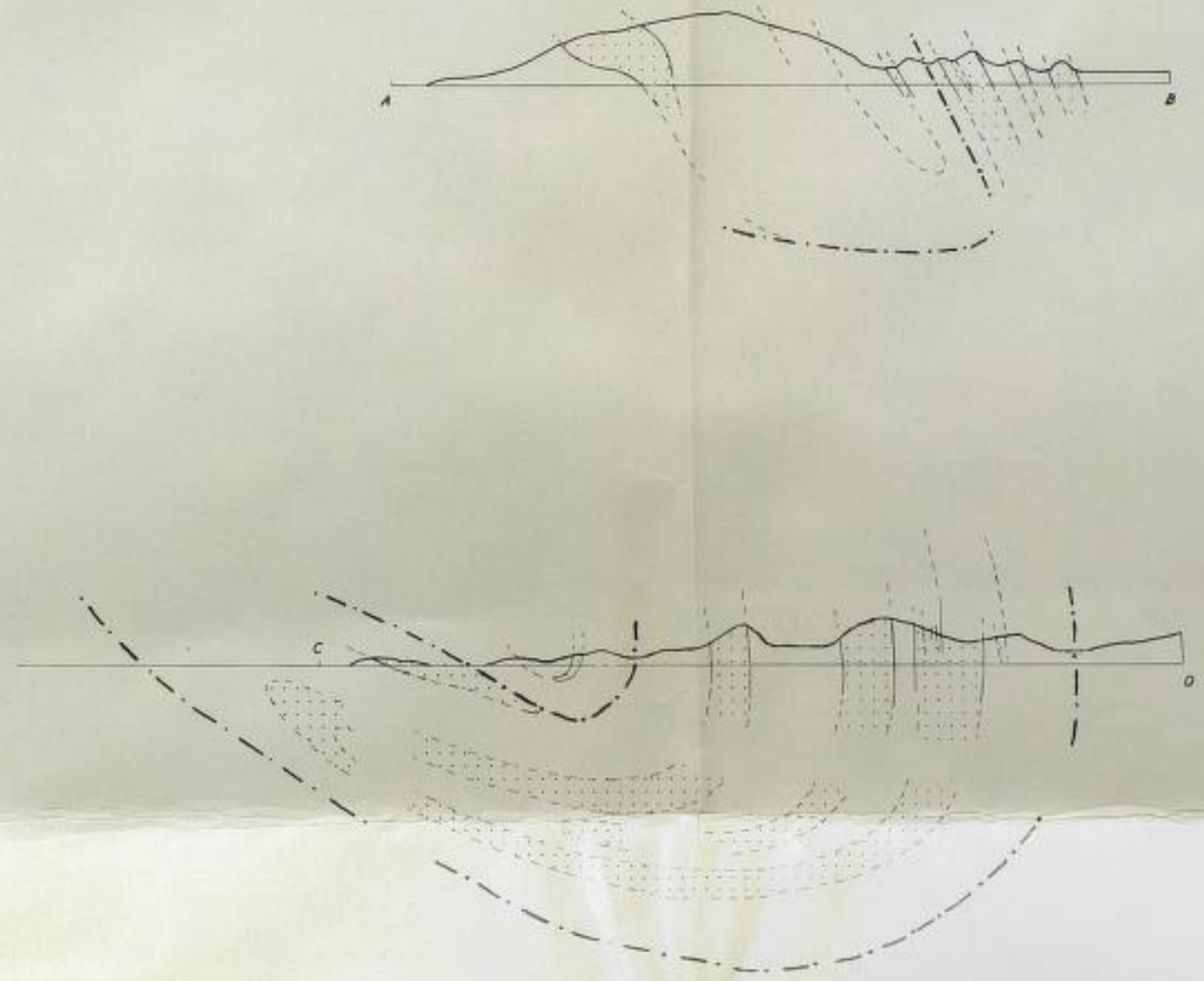
F$_2$

Antiform

       ,,   recumbent or overturned

Synform

       ,,   recumbent or overturned

F$_3$ Synform

       ,,   asymmetric

       ,,   overturned

Major slide :

J.D.B. 1969.