The Precambrian rocks of the Telemark area in south central Norway XIV:

STRUCTURE AND METAMORPHISM OF PRECAMBRIAN ROCKS EAST OF FYRESVATN

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Two generations of folding believed to have developed at different tectonic levels during the Sveconorwegian orogeny are recognized in sillimanite zone schists and gneisses east of Fyresdal in south central Norway. The earlier folding involved the emplacement of a large recumbent fold whose initial development was contemporaneous with the thermal maximum of metamorphism. The deformation and metamorphism, spanning a time interval between approximately 900–1200 m.y., affected all rocks in the Telemark Suite. The presence of a regional unconformity at the base of the Nape Amphibolite suggests an even earlier deformation possibly related to the Svecofennian recrystallization recognized elsewhere in southern Norway. This implies that the oldest supracrustal rocks in the Telemark Suite may be older than 1700 m.y.

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The rocks of the Precambrian Telemark region of south central Norway belong to a supracrustal sequence which presumably extends from beneath the Caledonian belt southward perhaps as far as the southern coast of Norway (Holtedal & Dons 1960). Collectively, the rocks are part of the Sveconorwegian Province of the Baltic Shield (Magnusson 1965) and have been thoroughly recrystallized 1000–1200 m.y. ago (Michot & Pasteels 1969, Kratz et al. 1968). In contrast to Sveconorwegian rocks north of the Caledonian belt, rocks within the Telemark region have been apparently unaffected by the Caledonian recrystallization.

The metamorphic grade within the Telemark region generally increases from north to south. Low grade mafic and felsic volcanics interbedded with arkosic sandstone and conglomerate are in the epidote-amphibolite facies near Dalen (Hasan 1971), whereas further south in the Fyresvatn area, the same sequence has clearly recrystallized in the sillimanite zone (Stout 1972a, Venugopal 1970). The metamorphic grade continues to increase southward to hornblende granulite facies west of Åmli (Ploquin, written comm. 1971) and near the lake Vegår (Touret 1968), to granulite facies along the Skagerrak coast (Bugge 1943). Concomitant with the southerly increase in grade, granitic gneisses and granites of probable anatectic origin become volume-

trically more abundant relative to obvious metasediments. This fact in addition to the general difficulty of correlating rock units across isogradic surfaces has made extension of the low grade Telemark stratigraphy (Dons 1960, 1962) southward into high grade terrain difficult at best. However, a few of the quartzo-feldspathic rocks and particularly the more refractory amphibolites and quartzites found in the Fyresvatn area have recently been shown (Stout 1972b, Venugopal 1972) to be not only of supracrustal origin but correlative with lower grade rocks in the Telemark Suite.

The regional distribution of supracrustal rocks in the Telemark Suite compiled by Dons (1960) reflects the complexity of their evolution. Moreover, the presence of regional unconformities within the Suite indicates that the oldest rocks represented have been subjected to multiple deformation. Structural analyses following the now classic works of Ramsay (1962, 1967), Weiss (1959) and others are exemplified in the Telemark region by the recent studies of Mitchell (1967), Martins (1969), Cramez (1970) and Venugopal (1970). The latter two authors attribute the apparently complex deformation of gneissose rocks east and west of Fyresvatn in terms of three and four periods of folding, respectively. A similar interpretation is possible in the Fyresvatn area (this paper) based on interference patterns alone. The presumed stratigraphic constraints in the Fyresvatn area, however, suggest a more substantial interpretation that not only simplifies the geologic history but may also bear on the structural development of high grade rocks elsewhere in the Telemark region.

Summary of stratigraphic and structural problems

The predominant structures shown on the geologic map of the region east of Fyresvatn (Stout 1972b, fig. 2) are three conspicuous folds. Fig. 1 of this paper shows their distribution as outlined by the Nape Amphibolite. All of the formations, collectively representing portions of the Rjukan, Seljord and Bandak Groups within the Telemark Suite (Dons 1960), are involved in the folding. The most northerly fold, the Roan fold, is geometrically a synform but its core is occupied by the Dyrvatn Gneiss, the oldest formation recognized in the area. The next large fold to the south, the Nape antiform, is flanked by older formations and thus is structurally inverted. The most southerly of the three folds, the Fyresdal synform, has the older Litjørn Formation in its core and the younger Nape Amphibolite and Fjellstøl Gneiss on its flanks.

The overall distribution of the Nape Amphibolite and adjacent formations is relatively simple. It can be interpreted as an interference pattern produced by two, possibly three periods of folding. In view of the postulated unconformity (Stout 1972b) at the base of the Nape Amphibolite, an even earlier folding event may be evident. The geometric and temporal relationships between these fold events and their interpretation within the framework of the regional stratigraphy is the subject of this communication.
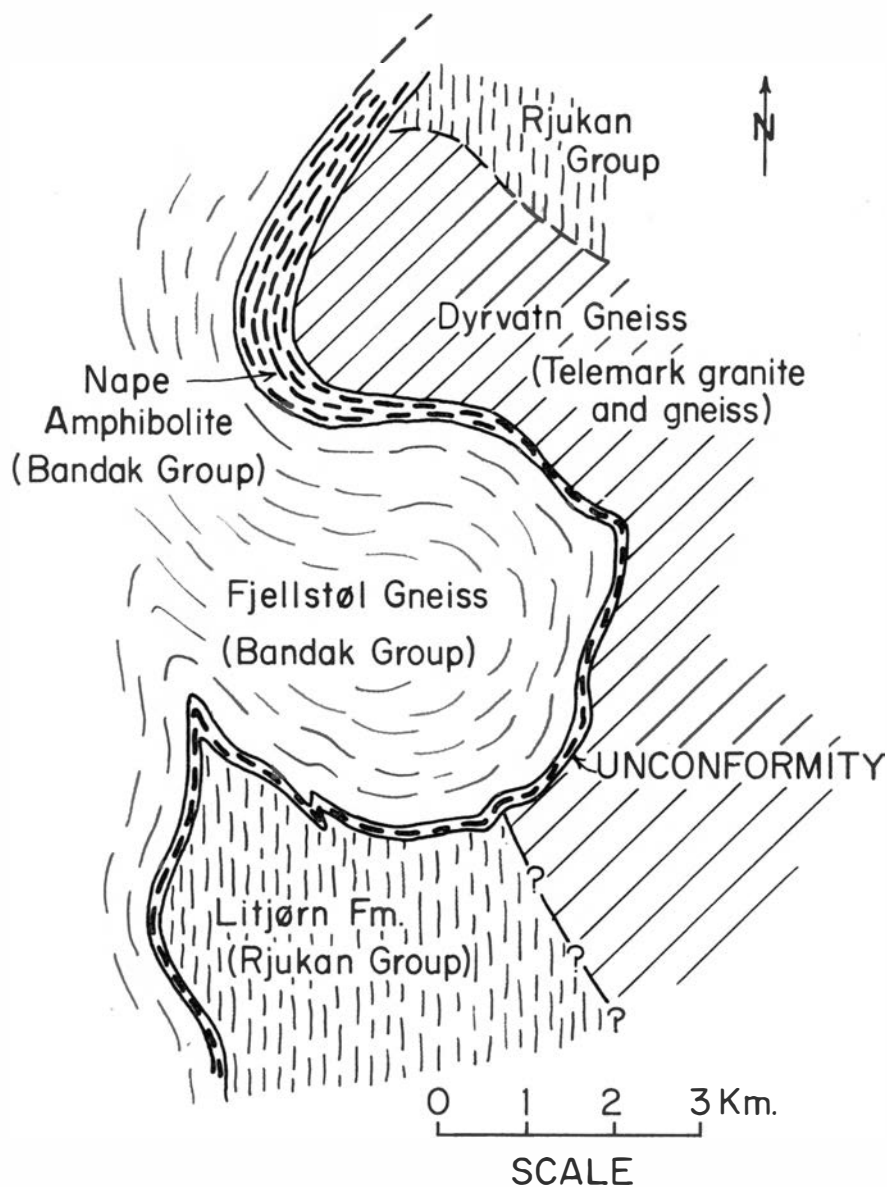
Fig. 1. Sketch map of formations in the Fyresvatn area and their probable equivalents in the Telemark Suite (after Stout 1972, fig. 3). The Dyrvatn Gneiss and the Litjørn Formation are the oldest formations and are unconformably overlain by the Nape Amphibolite and the Fjellstøl Gneiss in that order.

Geometry of folding

Roan fold

The Roan fold (Fig. 2) is the most spectacularly exposed of the large folds. Its geometry is best illustrated by the distribution of the Dyrvatn Gneiss
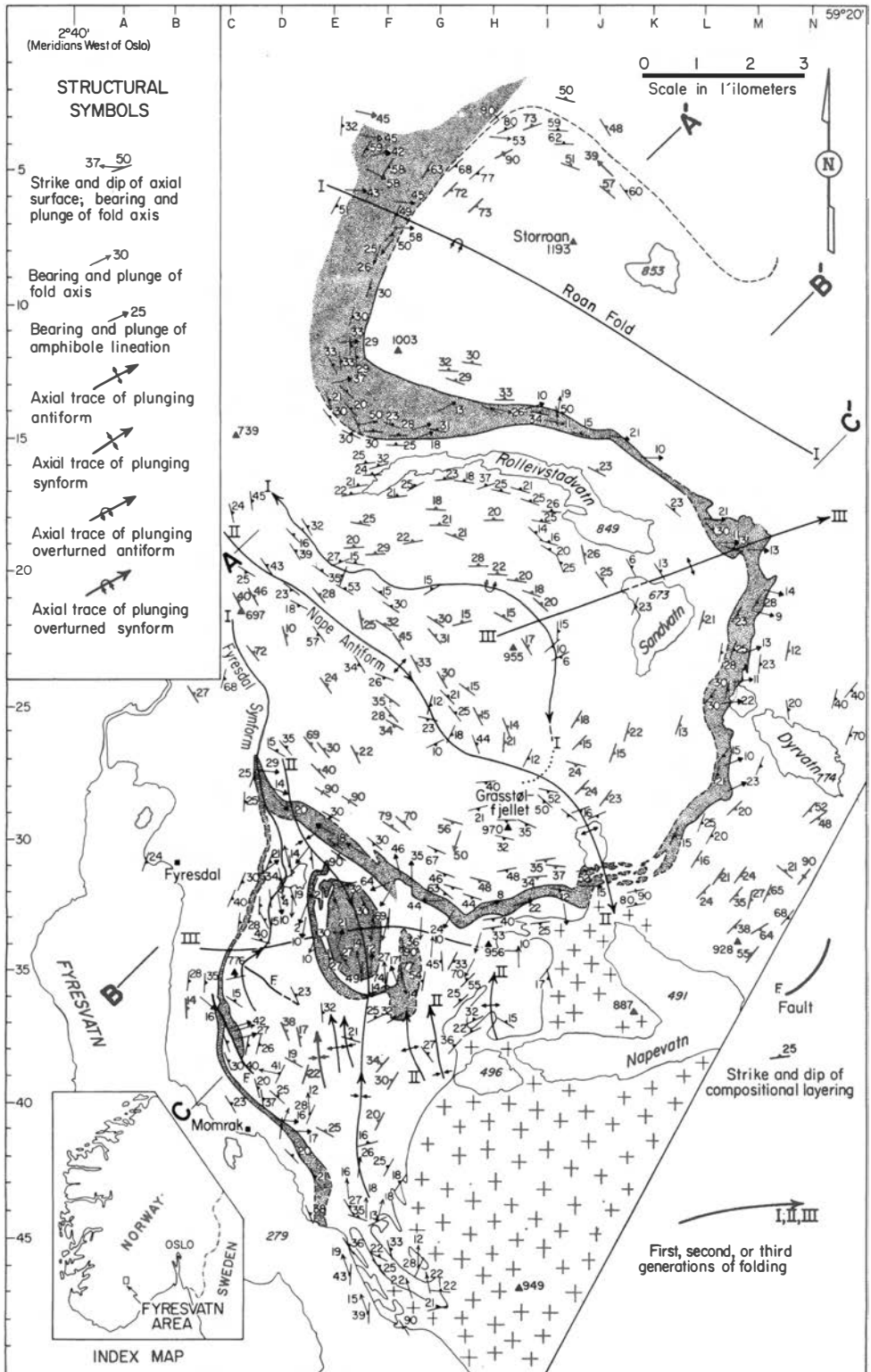
Fig. 2. Aerial photograph of the Roan fold in the northern part of the Fyresvatn area. The axial trace trends from northwest to southeast.

from the northeast corner of Fig. 3 to the north side of Rolleivstadvatn (Sector H–16). The northern limb of the fold dips on an average more steeply (60 degrees) than the southern limb (30 degrees). This suggests at first a simple synform overturned to the southwest. The stratigraphy indicates that a normal sequence of beds is found on the northern limb.

Systematic measurements of foliation and bedding along the limbs and hinge indicates that the fold as a whole is not cylindrical (Fig. 5). The general form of the fold, however, is characterized by two regions of max-

Fig. 3. Structure map of the Fyresvatn area. Shaded formation is the Nape Amphi-bolite. The Fyresvatn Granite (+ symbol) is shown in the southern part of the area. Structure sections A–A′, B–B′ and C–C′ are given in Fig. 4. A geologic map at the same scale (Stout 1972, fig. 2) is available.

Structural map of the Precambrian rocks east of Fyresdal, showing structural symbols, axial traces, and fold generations. Includes index map of the Fyresvatn Area, Norway.
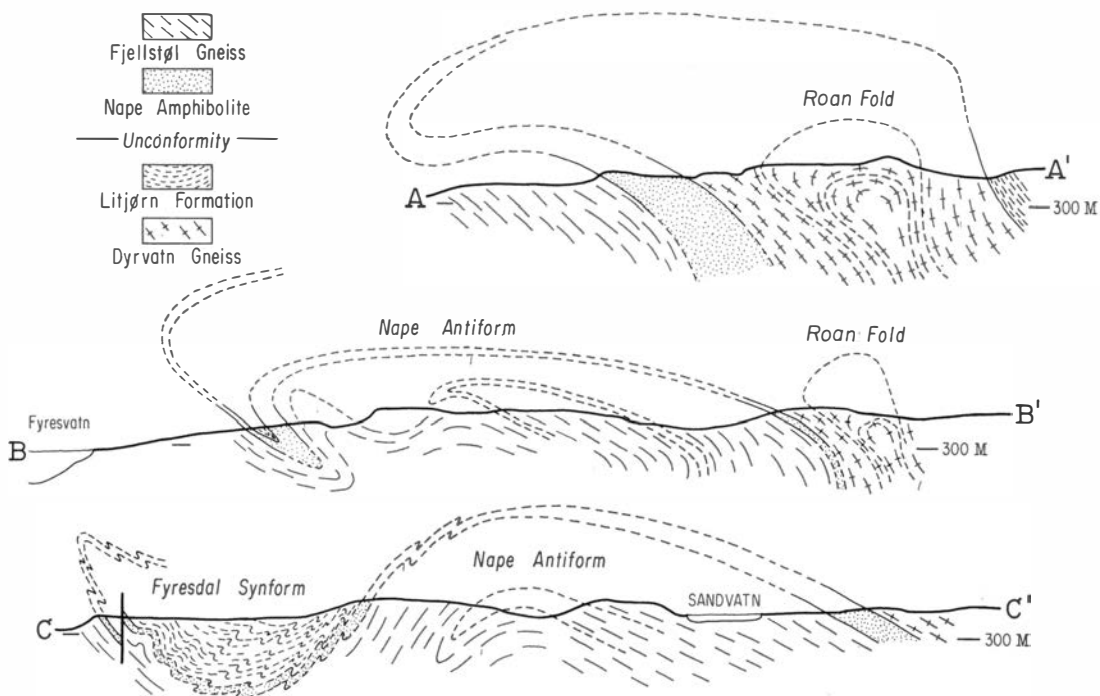
Fig. 4. Structure sections for Fig. 3. Note inverted stratigraphy.

imum curvature, and fold axes calculated from each of these (Fig. 6) are approximately normal to the northwesterly trending axial trace (Fig. 3). Steepening of dips across the fold from south to north coupled with the apparent convergence of fold axes with depth suggests that the fold in profile (A–A', Fig. 4) is somewhat fan-shaped.

The quartzo-feldspathic gneisses within the core of the Roan fold are characterized by a well-developed foliation. Minor folds whose axial surfaces are generally parallel to the foliation typically exhibit extreme thinning along their limbs and thickening in their hinges. Tectonic thinning may also account for the general form of the Roan fold on a regional scale (Fig. 1 and Fig. 3), suggesting that the fold as a whole was formed under conditions where deformation was primarily by passive flow. There is no indication of an axial plane fabric either in the Dyrvatn Gneiss or in the Nape Amphibolite, yet individual horizons in each of these formations have approximately the same configuration and radii of curvature.

The average axial plane of the Roan fold is oriented N.60°W. with a 40° dip to the northeast. This was determined from the linear axial trace of the fold in Fig. 3 and from average fold axes from Fig. 4. A similar overturned sense is observed in the other large folds in the Fyresvatn area as well as in the early generation folds described by Venugopal (1970) west of Fyresvatn.
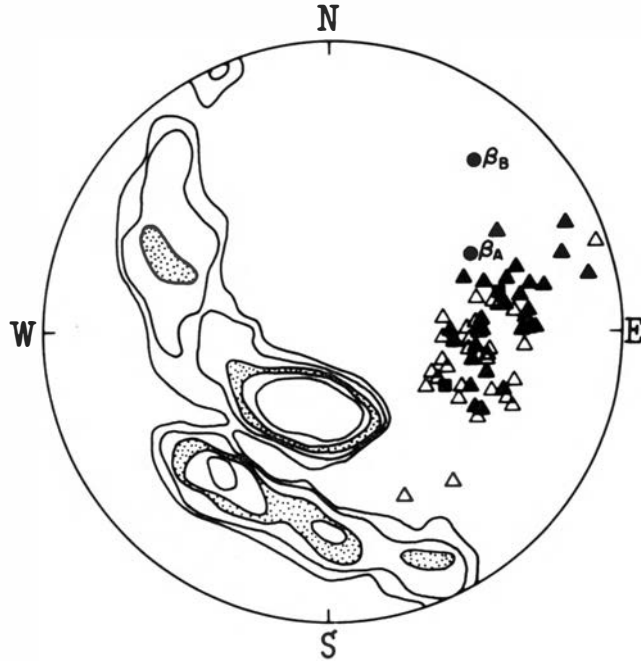
Fig. 5. Stereogram of poles to compositional layering and hornblende lineations from domains A and B (Fig. 6) of the Roan fold. Closed triangles are hornblende lineations from domain A; open triangles are from B. Closed squares are pebble lineations. 181 poles to compositional layering are contoured at 2, 4, 6, 8 and 10 percent.

Fyresdal synform

The Fyresdal synform, located east of the village of Fyresdal (Sector D–28), is outlined by the Nape Amphibolite in Fig. 3. Its geometry differs from that of the Roan fold in several respects, although its development may be con-
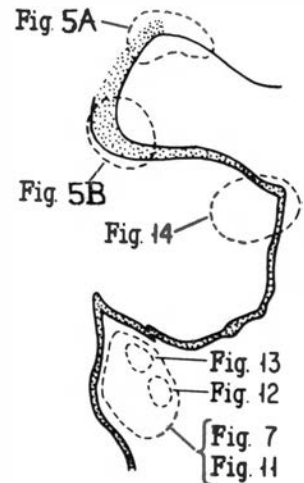

Fig. 6. Index map to domains for stereograms in Figs. 5, 7, 11, 12, 13 and 14.

Fig. 7. Superposed folds in the Litjørn Formation. Axial trace of first generation fold extends from lower right near hammer to the top of the outcrop between the two trees. Axial traces of second generation folds extend from middle left to upper right parallel to a prominent joint set. Figure is drawn from a photograph taken looking north.

temporaneous. Unlike the Roan fold, the north end of Fyresdal synform is tight and overturned to the southwest. South along its axial trace, the synform assumes an open form characterized by gentle plunges to the north and south. Axial traces are apparently terminated against the northeasterly trending Fyresvatn Granite.

The style and complexity of folding in the core of the Fyresdal synform differs from that observed in the adjacent Nape Amphibolite and Fjellstøl Gneiss. This may be due in part to the abundance of biotite schists within the Litjørn Formation (Stout 1972b, p. 29). There is evidence for two generations of folding and these will be referred to as first and second generation folds.

First generation folds are characterized by:

Overturned to recumbent attitude with tight to isoclinal form.

Hinge lines that trend north-south and plunge variably to the north and south at low angles.

Axial surfaces that strike north-south and dip variably to the east and west parallel to bedding.

Development of axial plane schistosity and amphibole lineations in rocks of appropriate composition.

The presence or absence of a penetrative fabric related to the last mentioned above is controlled in part by the mineralogy of the folded rock. Many isoclinal or sub-isoclinal folds whose axial surfaces are parallel to recognizable bedding are believed to be of first generation origin because of their relationship to later folds, yet there is so little biotite or amphibole in the rock that a conspicuous axial plane fabric is lacking.

Second generation folds in the Fyresdal synform are characterized by:

Inclined to overturned attitude with open to tight form. Folds are generally asymmetric with a consistent Z-shape when viewed north along plunge (Fig. 4 and Fig. 7).

Hinge lines that trend north-south and plunge variably to the north and south.

Axial surfaces that strike north-south and dip exclusively west at low to moderate angles.

External rotation of schistosity and amphibole lineations.

The distribution and orientation of second generation folds across the Fyresdal synform is shown in structure section C–C′ in Fig. 4. A systematic variation is seen from low westerly dipping axial surfaces in the western part of the synform to vertical dips in the eastern part. It is perhaps noteworthy that the angular relationship between second generation axial surfaces and bedding remains relatively constant even though both surfaces steepen eastward to the vertical.

Relationships between first and second generation folds
Both generations of folding are clearly visible in several outcrops within the Fyresdal synform. The relationships shown in Fig. 7 are typical. Bedding
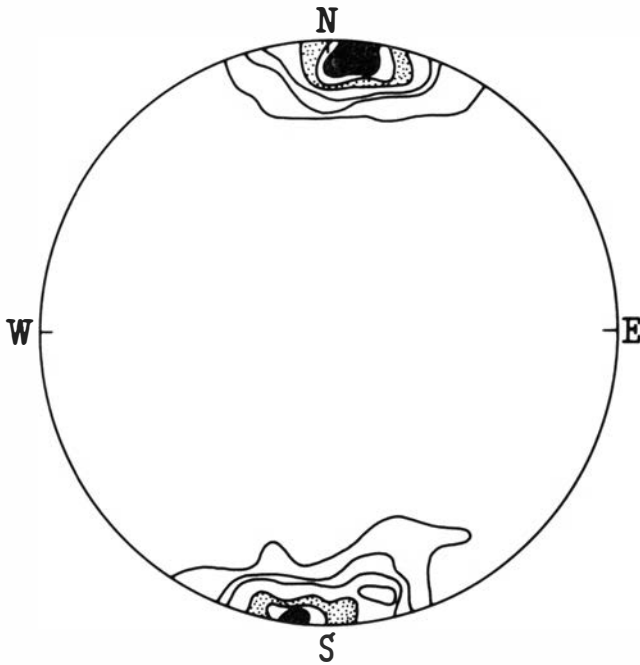
Fig. 8. Stereogram of 408 hinge lines measured in the Litjørn Formation within the core of the Fyresdal synform. Contours are 2, 4, 6, 8, 10 and 12 percent.
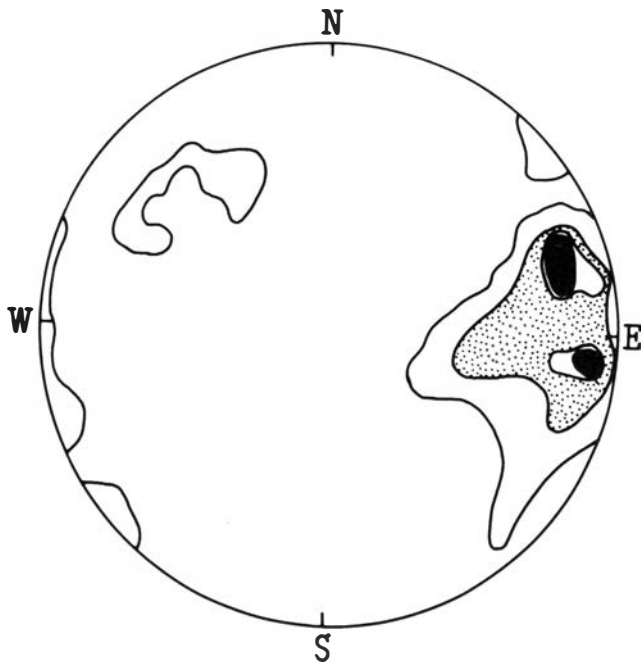

Fig. 9. Stereogram of 265 hornblende lineations from the Nape Amphibolite. Contours are 4, 6, 8 and 10 percent.

and schistosity are generally parallel and trend from the lower right to upper left. The axial trace of a conspicuous first generation fold extends in a parallel manner from below the hammer to the top of the outcrop between the two trees. West-dipping axial traces of second generation folds extend from left to right parallel to a prominent joint set. The axial surfaces of the two fold generations have the same strike, and their hinge lines are homoaxial. For these reasons, intersecting axial traces are rarely observed on the near horizontal outcrop surfaces so commonly exposed in the region.

In general, the relative orientations of hinge lines cannot be used to distinguish between first and second generation folds. Nearly all hinge lines from the Fyresdal synform have the same orientation. This is shown in Fig. 8 in which over 400 hinge lines of both generations are represented. The only reliable criterion for identifying fold generations was found to be the attitudes of axial surfaces, and these were best revealed by seeking out east-west trending vertical exposures.

Nape antiform

The Nape antiform, located in the central portion of Fig. 3, is flanked to the south by the Fyresdal synform and to the north by the Roan fold. Intersecting axial traces within the antiform are attributed to two, or possibly three generations of folding. The earlier generation, probably the same as first generation folds in the Fyresdal synform, is represented by a doubly plunging antiform within the Fjellstøl Formation. The axial trace from Haugeheil (Sector E–19) to Hyttetjørn (Sector I–24) has an arcuate shape probably due to later folding. The axial surface is strongly overturned to the southwest so that it parallels folded compositional layering in the gneisses. Fold axes plunge to the northwest and southeast not far removed from the strike of the axial surfaces.

Another antiform, designated as a second generation fold in Fig. 3, occurs adjacent to and southwest of the overturned fold discussed above. The fold is upright and symmetric, and its axial trace can be traced for several kilometers. In the absence of an intervening synform, a plausible interpretation consistent with a multiple folding hypothesis is shown in structure section B–B′ (Fig. 4). There is no indication from the distribution of the Nape Amphibolite that the axial trace of the earlier isoclinal fold passes through that formation. The alternative is for the earlier trace to be totally contained within the Fjellstøl Gneiss as inferred in Fig. 3. The resulting interference pattern (Ramsay 1962) would be similar to that in which the kinematic *a* direction of the later fold makes a high angle with the axial surface of the earlier fold.

Third generation folding

The variation in plunge of all folds in the Fyresdal synform may be related to a third generation of folding. The sense of rotation is about an east-west trending axis. This is shown just south of Litjørn (Sector E–34) where a
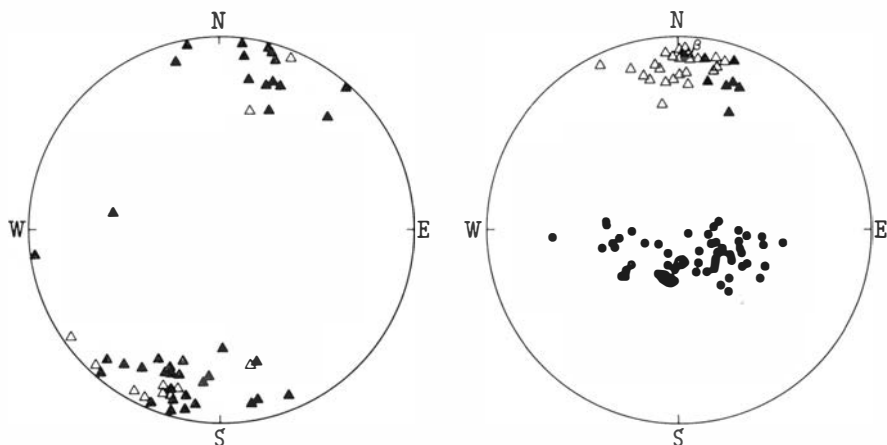
Fig. 10 (left). Stereogram of hornblende lineations (closed triangles) and gedrite, antho-
phyllite and cummingtonite lineations (open triangles) from the Litjørn Formation.

Fig. 11 (right). Stereogram of poles to compositional layering (solid points), hinge lines
(open triangles) and hornblende lineations (closed triangles) in the southern part of the
doubly-plunging synform (Fig. 6).

doubly plunging synform or elongate basin is evident. Attitudes of com-
positional layering from the southern part of the basin are plotted in Fig. 11
and reveal a fold axis that plunges north at a low angle. This coincides with
hinge lines measured in the same area. Similarly, Fig. 12 represents com-
positional layering and hinge lines from the northern part of the basin. They
plunge south but at somewhat steeper angles.

In the Nape antiform near Mosnetten (Sector M–18), the rocks exhibit a
strong curvature that could also be related to a third generation folding.
Four kilometers west the axial trace of the doubly plunging first generation
antiform (Fig. 3) has an arcuate shape convex to the east. A line trending
N.70°E. passes through points of maximum curvature and is interpreted
geometrically as the axial trace of a third generation fold. Poles to composi-
tional layering along this trace define a girdle (Fig. 13) whose pole trends
N.70°E. and plunges gently east. Thus the axial surface is vertical. It should
be noted that hornblende lineations (Fig. 3) related to first generation
folding are apparently undeformed about the axis of this third generation
fold. This is possibly due to deformation about an axis corresponding to
the direction of the earlier lineations.

Some minor structures within the Nape Amphibolite and the Litjørn For-
mation may be associated with possible third generation folding. Kink bands,
almost exclusively developed in amphibolites, are common in some east-
west trending zones. The zones range from a few meters to perhaps 50 meters
in width, and within each zone, kink bands may be closely spaced (a few
mm) or separated as far as one meter. Individual bands average five mm in
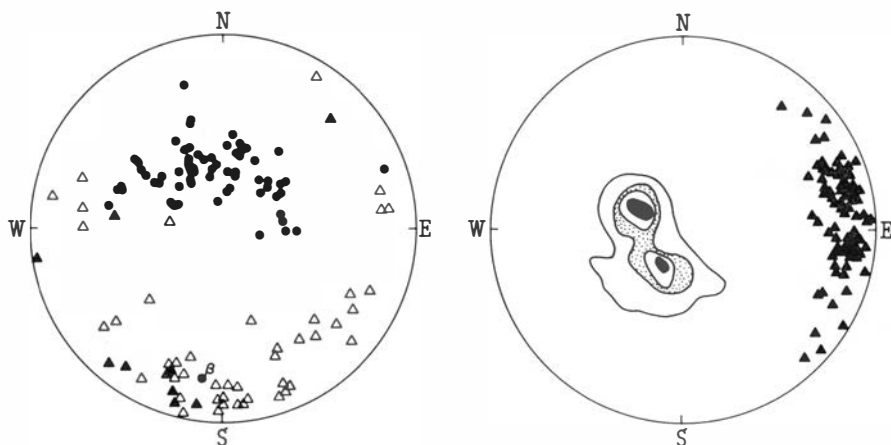width and appear to have vertical axial surfaces.

Fig. 12 (left). Stereogram of poles to compositional layering (solid points), hinge lines (open triangles) and hornblende lineations (solid triangles) from the northern part of the doubly-plunging synform (Fig. 6).

Fig. 13 (right). Stereogram of 231 poles to compositional layering and 81 hornblende lineations (solid triangles) for the third (?) generation fold in the Nape antiform (Fig. 6 for domain). Contours are 5, 10, 15 and 20 percent.

The possible third generation fold episode in the Fyresvatn area plays only a small part in the development of the overall structure. A similar late deformation with the same orientation has also been observed by Cramez (1970) in the Nisser area, Venugopal (1970) in the area west of Fyresvatn, and by Martins (1969) in the Vrådal area.

Amphibole lineations

Nearly all of the amphibole-bearing rocks in the Fyresvatn area show a pronounced lineation defined by the parallel alignment of hornblende, cummingtonite and rarely, gedrite. The mineral lineations are restricted to certain compositional layers controlled by original deposition or flow. The c crystallographic axes of the various amphiboles correspond to their direction of maximum elongation and are never observed to cut across compositional layering.

Several investigators have demonstrated that prismatic minerals tend to align parallel to the direction of maximum finite extension (Ramberg 1966, Schwerdtner 1970). In the general case, that direction will be oblique to compositional layering such that amphiboles, for example, subjected to the same extension would be expected to align obliquely to layering as well. Because of the apparent compositional constraint of the original layering in the Fyresvatn area, lineated amphiboles may diverge from the direction of maximum extension. In view of this fact, it is remarkable that hornblende lineations in the Nape Amphibolite show such a pronounced preferred orientation in an approximately east-west direction. In the hinge zone of the Roan

fold lineations are approximately normal to the strike of compositional layering (Fig. 3). As one follows the amphibolite around to an east-west strike just north of Rolleivstadvatn (Sector H–16), the lineations are approximately parallel to the strike of compositional layering. Similarly, as one follows the amphibolite around the Nape Antiform the hornblende lineations retain a generally eastward plunge whereas the strike of the amphibolite again changes through 90 degrees. It is only until the northern limb of the Fyresdal synform is reached that departures from this relationship are found, and these are believed related to later folding.

Several thin, discontinuous lenses of metaconglomerate within the Nape Amphibolite northwest of Storroan (Sector F–4) contain quartzite pebbles and cobbles that are strongly elongated in an approximately east-west direction. Typical cross sections normal to the elongation direction appear as flattened ellipses whose long dimensions are two or three times their shortest dimension. The elongation dimension, however, is commonly as much as 20 times the long dimension of the cross section. Some discussion has arisen in the literature regarding the origin of flattened and elongated cobbles in other localities within the Telemark Suite. Singh (1968, 1969) and more recently Hasan (1971) argue that the shapes are primary, whereas others (Roberts 1969) favor an origin by deformation. Near Storroan, the elongated cobbles are parallel to local hornblende lineations (Fig. 3) suggesting that both linear elements were formed in response to the same stress field at the same time. If the deformed cobbles are a reliable strain guage, it suggests that at least locally, the amphibole lineations correspond to the direction of maximum extension during folding.

The data of Figs. 3, 5 and 10 indicate that there is a somewhat variable angle between megascopic fold axes and hornblende lineations measured around the three major folds in the area. In contrast, amphibole lineations within the core of the Litjørn Formation are strictly parallel to hinge lines of first generation folds as defined earlier. These lineations plunge at low angles to the north and south (Fig. 10) nearly perpendicular to amphibole lineations in the Nape Amphibolite. The reason for this is not clear, but it may be related to an original anisotropism due to deformation in the Litjørn Formation prior to the deposition of the Nape Amphibolite and younger formations (Stout 1972b).

Structural interpretation

Based on geometric considerations alone, the overall distribution of the Nape Amphibolite and adjacent formations may be interpreted as an interference pattern ('type 2', Ramsay 1962) due to intersecting axial traces of first and second generation folds. Similar patterns are described by White & Jahns (1950) in New England and by Ramsay (1967). The location of the axial traces of each fold generation according to this interpretation is shown in Fig. 3. A third generation is shown, but it only slightly modifies

the interference pattern of the earlier folds. If the inverted stratigraphy (Stout 1972b) is correctly understood, however, a strong argument may be made for the existence of the large recumbent fold shown diagrammatically in Fig. 14. Only the lower limb of the fold as outlined by the Nape Amphibolite is extensively exposed in the Fyresvatn area. The upper limb is exposed only on the north flank of the Roan fold (Fig. 3) and possibly in the core of the Fyresdal synform.

The mechanism of emplacement of the recumbent fold and the reason for its apparently folded axial surface (as evidenced by its folded lower limb) is not well understood. Because of the apparent temporal relationship between first and second generation folding and the Fyresvatn Granite discussed in the following section, a model such as that represented in Fig. 15A may not be unreasonable. The model implies that first and second generation folds in the Fyresdal synform formed during a single phase of deformation. The term 'synchronous refolding' (Wynne-Edwards 1963) has been used to describe relationships of this sort brought about by a change in the local direction of flow during the deformation of high grade rocks. A distinction between this type of refolding and superposed folding due to separate deformations may in general be made provided there are linear elements such as hornblende lineations related to an early deformation. Superposed folding in this case results in the deformation of the earlier-formed lineations in a systematic manner (Ramsay 1960) except in the special case where the later fold axes and the lineations are homoaxial. In the case of synchronous refolding, early-formed lineations related to directions of flow may retain their orientation as the folding progresses.
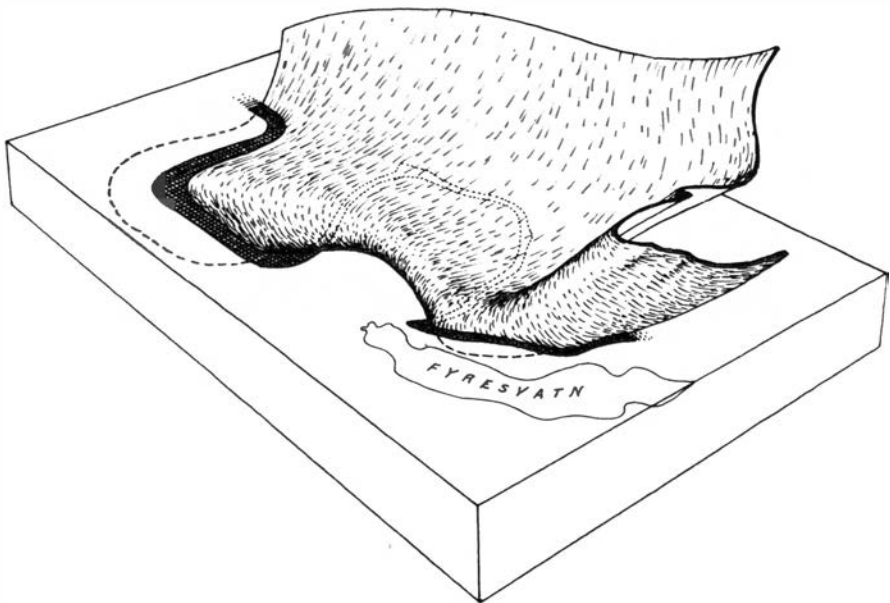

Fig. 14. Three dimensional representation of the large recumbent fold whose folded lower limb traces out of the Fyresdal synform, the Nape antiform and the Roan fold.

The remarkably simple pattern of hornblende lineations in the folded Nape Amphibolite suggests synchronous refolding in such a manner that the Nape antiform formed simultaneously or nearly so, with the emplacement of the large recumbent fold shown in Fig. 14. The structural style is remarkably similar to that of basal gneiss culminations observed in the Scandinavian Caledonides (Ramberg 1966), Greenland (Haller 1955, Berthelsen 1960) and New England (Thompson et al. 1968). In such areas, quartzo-feldspathic gneisses commonly occur in the cores of mushroom-shaped domes and as cores of recumbent folds and nappes. Structures of this sort have their experimental counterpart in the works of Ramberg (1964, 1966).

If the easterly plunging amphibole lineations are not far removed from the direction of maximum finite extension, it may be concluded that the *general* direction of flow during the formation of the early folds was in an east-west direction. This interpretation follows regardless of whether refolding was synchronous or a result of separate deformations. The root zone of the fold shown in Fig. 14 lies to the east of the Fyresvatn area, implying a westward direction of flow. Geologic mapping by the author between the Fyresvatn area and Nisser (Stout 1970 and especially Stout 1972, fig. 1), has shown that the Telemark stratigraphy is repeated again in that area. The gradual steepening of dips in the Dyrvatn Gneiss (Fig. 3) to vertical attitudes from the Nape Amphibolite eastward to the margin of the map is mirrored by a gradual steepening from east to west from the Nisser area. The zone of convergence lies within the Dyrvatn Gneiss as a linear zone trending approximately north-northwest. The details of these relationships will be the subject of a later communication.

Relation of folding to metamorphism

In outcrops where both first and second generation folds are seen, the older of these shows a predominent axial plane schistosity or *b* amphibole lineation in rocks of appropriate mineralogy. A detailed study of the mineral chemistry and phase petrology of the amphibole-bearing rocks in the Fyresvatn area (Stout 1972a) clearly demonstrates that the amphibole-bearing assemblages have approached equilibration under the pressure-temperature conditions of the sillimanite zone. In particular, homoaxial intergrowths of cummingtonite and hornblende, cummingtonite and anthophyllite, and cummingtonite and gedrite are invariably lineated parallel to hinge lines of first generation isoclinal folds. The systematic distribution of major and minor elements between gedrite and both garnet and cordierite indicates that the latter two phases also equilibrated with the amphibole during the deformation.

A similar relationship is observed between recrystallized quartz fabrics and first generation folds in highly deformed quartzites near Litjørn (Sector D–32, Fig. 3). The stable mineral assemblage is primarily quartz with minor amounts of garnet, clinopyroxene and epidote. The preferred crystallographic orientation of quartz grains is extremely well developed in the limbs of

small isoclinal folds. The conclusion is inescapable that a thorough recry-
stallization accompanied first generation folding in an environment in which
quartzo-feldspathic compositions were partially melted and deformation of
more refractory rocks was by flow.

Such an environment is in contrast to that inferred for the formation of
second generation folds. Schistosity and amphibole lineations are deformed
by external rotation which indicates, lower temperatures and probable
formation at a higher tectonic level. There is some evidence to suggest that
rocks such as those shown in Fig. 7 have passed from a deeper to a shal-
lower level environment in a relatively short period of time rather than
having been subjected to two separate orogenic events. The Fyresvatn Gra-
nite shown in the lower half of Fig. 3 is believed to be at least in part a
partial melt product of the Dyrvatn Gneiss during the regional metamor-
phism. The incorporation of muscovite-bearing portions of the Fyresvatn
Granite into first generation folds (Stout 1970) supports this hypothesis,
particularly in view of the demonstrated relationship between early folding
and metamorphism. Muscovite ($\pm$ garnet) bearing pegmatites traceable
into the marginal portions of the Fyresvatn Granite south of Momrak (Sector
E–45, Fig. 3) commonly intrude the axial surfaces of second generation folds
developed in the Litjørn Formation a few kilometers to the north (Fig. 4).
Moreover, the regional truncation of axial traces of both first and second
generation folds by the granite as shown in Fig. 3 demonstrates that the
intrusive activity extended after the development of the later folds.

The cooling age of the Fyresvatn Granite south of Momrak is given by
Venugopal (1970) as 868 $\pm$ 50 m.y., but it is clear that the granite was in-
volved in a complex history prior to that time. Since the Fyresvatn Granite
apparently retained its mobility from the time of regional metamorphism and
first generation folding to some time during or after second generation fold-
ing, it suggests that all events are related to the same orogeny. If the dating
of the regional metamorphism by Michot & Pasteels (1969) at 1100 m.y. is
correct, then the Sveconorwegian orogeny is characterized not only by
regional metamorphism and the production of granite but also by a kine-
matic episode involving folding at progressively higher levels in the crust
between approximately 1100 and 900 m.y. This timing is consistent with
radiometric age determinations from all of southern Norway published by
Neumann (1960), Kulp & Neumann (1961) and Broch (1964). More re-
cently, O'Nions & Baadsgaard (1971) and O'Nions et al. (1969) have shown
that the thermal maximum of the Sveconorwegian orogeny in the Bamble
area was attained at about 1170 $\pm$ 50 m.y.

The age of the rocks of course must predate the orogeny. There is no
indication from the systematic petrography in the Fyresvatn area of an
earlier metamorphic event, although Venugopal (1970) and Ploquin (written
comm. 1971) have found presumably relict assemblages in nearby areas. A
very early period of deformation quite separate from the Sveconorwegian
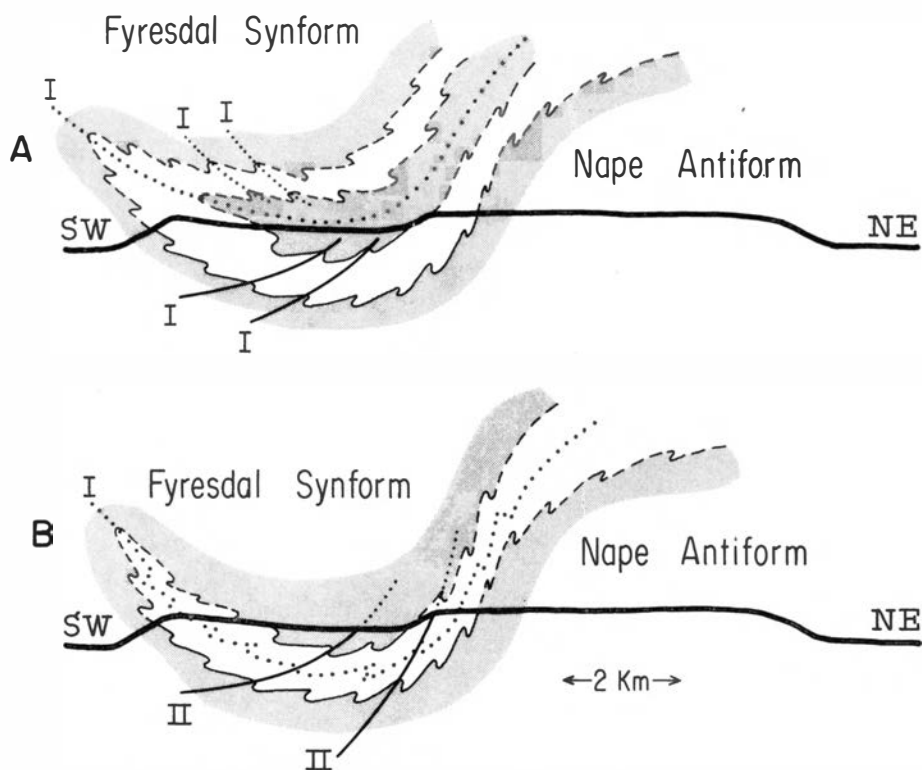orogeny may be inferred from rocks stratigraphically below the regional un-

Fig. 15. Two possible interpretations of the fold relationships in the Fyresdal synform. A. Interpretation that upper limb of recumbent fold is not exposed, and second generation folds are synchronous drag folds. B. Interpretation that upper limb of recumbent fold is exposed and second-generation folds are later.

conformity at the base of the Nape Amphibolite (Stout 1972b). There is increasing evidence in southern Norway for an earlier period of metamorphism at approximately 1700 ± 100 m.y. (O'Nions & Heier 1972) considered to be of Svecofennian origin. In view of the petrologic similarities between the Kongsberg-Bamble Province and the Telemark Province (Touret 1962, 1967, 1968), it would not be surprising to see the effects of the Svecofennian recrystallization and deformation in the Telemark area. If further studies prove this to be the case, the Bandak Group of the Telemark Suite (Dons 1960) may be younger than Svecofennian, and the Rjukan Group along with the Dyrvatn Gneiss may be older than 1700 m.y.

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