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Studies in the Trondheim region, Central Norwegian Caledonides

The nature of the basement contact

By Christoffer Oftedahl

Reconnaissance of the Tømmerås Anticline

By Janet Springer Peacey

Stratigrapical position of the Gudå conglomerate zone

By Fredrik Chr. Wolff

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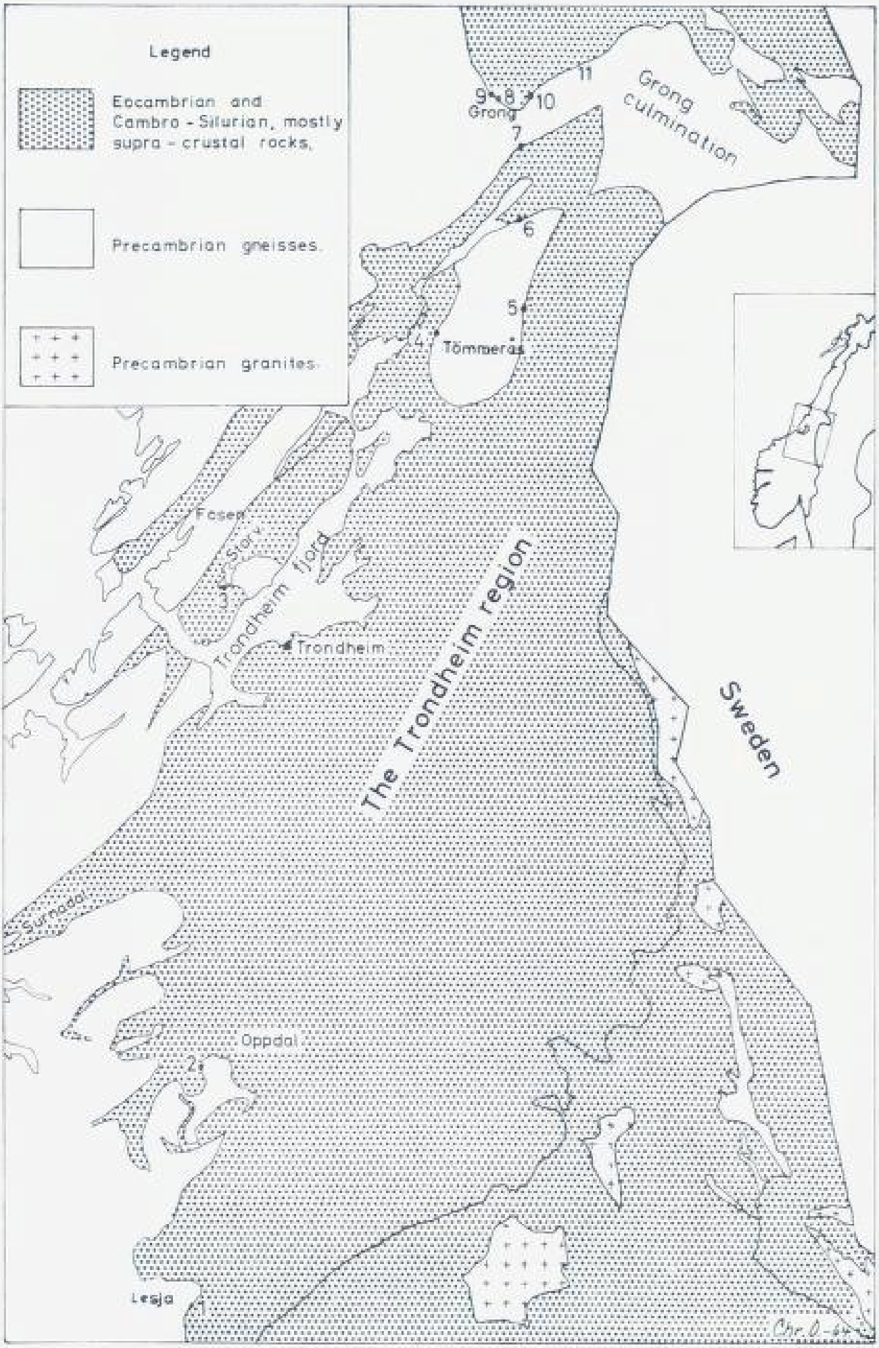
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Fig. 1.

THE NATURE OF THE BASEMENT CONTACT.

By *Christoffer Oftedahl.*

Abstract.

The gneisses below the Cambrian schists or Eocambrian flagstones in the central Norwegian Caledonides have been considered of Precambrian age, but the fact that the contact is always concordant has been explained as due to Caledonian tectonization. The author describes shortly a number of localities of this contact and concludes that a more likely explanation is that the rocks are really close to concordant, e.g. the Precambrian rocks within the Trondheim region were essentially flat-lying at the begin of Cambrian time.

Introduction.

In the last century the contact between the Precambrian basement and the overlying sediments of Eocambrian or Cambro-Silurian age presented no serious problem to the geologists. The Trondheim region (Fig. 1) and its continuation through Jotunheimen, Sognefjord and Hardangerfjord was considered as the main Caledonian zone. Southeast of this zone a very marked angular unconformity was known. The gneisses northwest of the zone were considered to be of Precambrian age. This situation lasted until the 1930 years, when O. Holtedahl in several papers took up the problem, see the summary by Strand (1960, p. 230—235). The most important conclusion was that the northwestern gneisses (western part of Fig. 1) represent a mixture of older Precambrian basement and highly metamorphosed (eventually granitized) Cambro-Silurian rocks, all rocks now showing Caledonian metamorphism.

The rocks overlying the Precambrian basement gneisses consist either of Cambro-Silurian sediments, mostly of some Cambrian age, and arkoses, the so-called sparagmites. The latter rocks have a lowermost Cambrian or uppermost Riphean age or both ("Eocambrian"), depending on definitions used. In the area west of Oppdal the gneisses are overlain by a flagstone belonging to the sparagmitian complex and in this area O. Holtedahl (1938) made his field observations which led to his general conclusions. Holtedahl also observed that besides being folded together with Eocambrian and Cambro-Silurian sediments, the basement gneisses had a conformable contact to the younger sediments. This presented another major problem to him, and his interpretation was that since there is no angular unconformity, the concordant gneisses necessarily have to be sparagmitic flagstones granitized or migmatized by the "caledonization" of all rocks involved. This process of caledonization produced what Holtedahl called "basal gneisses" and the importance of these basal gneisses were emphasized by Strand (1960, p. 230—245) in his summary of the Norwegian Caledonides by specifically describing "the region with basal gneiss in the northwestern part of southern Norway".

The present author has his main field experience within the Norwegian Caledonides from the Grong area, but has made more cursory observations in many other parts of the Caledonides. The contact relations were studied in a number of localities, and the obtained observations on the schistosity and layering of the Precambrian concordant with the overlying metasediments suggest clearly that the layering is a primary feature. This means that the Precambrian rocks were essentially unfolded when the Cambrian beds were deposited in the central part of the Norwegian Caledonides. It is rather surprising that this view has appeared as an alternative working hypothesis only shortly mentioned in one paper (Strand, 1949, p. 32).

In the following observations from 11 localities are shortly described, then the results are discussed.

Observations.

1. *Lesja.* 5 km SE of Lesja the contact is observed in the mountains. The best exposure has only the five meters of the very contact lacking. Here beds of flagstone steeply dipping to the west are overlying finegrained and schistous leptite. The structure is interpreted as a primary sedimentation feature. T. Strand (1949, p. 31—32) has studied this area by survey field mapping and thin section work. He is the first who has considered both possibilities for explaining the banded character of the gneisses: "The banding of the gneisses can be interpreted in more than one way, the interpretation of the banding will imply also an interpretation of the genesis of the rock. Thus the banding may be a primary feature ... In other cases the banding may recall banding in a supracrustal rock (Figs. 2,3). In this case the banding may be

influenced by the metasomatic processes or by metamorphic diffusion within the rocks, still it may be a structure prescribed by the bedding." Later Strand (1951, p. 13) published the following statement concerning the basement contact from Lesja southwards to Otta-dalen: "The gneisses have sharp contacts to the overlying sparagmites, but there is no unconformity at the contact."

2. *West of Oppdal.* Along the main highway from Oppdal westwards granitic gneisses are beautifully exposed in long road cuts west of Lønnset (see Holtedahl, 1938, p. 34—41). The banding looks distinctly sedimentary and is parallel with the bedding of the overlying sparagmitian flagstones. Holtedahl's interpretation was that the gneisses represent metamorphosed (and granitized) Eocambrian sediments. Rosenqvist (1944, p. 123) thinks that the conformity must be a pseudo-conformity and that all structures are Caledonian in origin. The interpretation that the gneisses are Precambrian with their primary features retained, is offered as an alternative explanation.

3. *Storvatnet.* On the southwestern side of Storvatnet, 20 km NW of Trondheim, both the Precambrian gneisses and the overlying Cambrian micaschists are well exposed in long road cuts, although some hundred meters are missing in the contact zone. The strike is persistant and parallel in both complexes, so that a rough parallelism in undoubtful. The gneisses consist of a mixture of finegrained leptitic bands, mediumgrained granitic gneiss and augen-gneiss. Persistant dark schlieren and amphibolite zones with thickness up to one meter lieve little doubt that these planar features which are parallel to the general schistosity represent the primary bedding of the gneiss complex. The area around Storvatnet has not been spesificly described earlier, but the area immediately to the west has been studied by Ramberg (1944). Here gneiss cores are conformably underlying metamorphosed sediments of Cambro-Silurian age, and the cores are interpreted as zones where the migmatite front has risen much higher than in the Synclines. The author prefers a purely stratigraphic interpretation. Then the gneiss anticlines should be basement anticlines where leptites have recrystallized to granitic gneisses of various kinds during the same metamorphism that altered the overlying Cambro-Silurian rocks.

The Tømmerås anticline consists of more or less leptitic rocks. The author thinks he has observed what looks like parallel contacts at localities 4, 5 and 6. This is in a general way verified by Dr. Janet S. Peacey (see her article in this volume).

7. *Agle.* About 1 km south of Agle station a long railroad cut exposes the contact between leptitic gneisses and overlying Cambro-Silurian micaschists. The leptite beds are parallel with the overlying micaschists. The upper two meters of the leptite are schistous and contain feldspar porphyroblasts, 2—3 cm in size, while the underlying leptitic gneisses contain more scattered and smaller porphyroblasts. In a small road cut close by, however, there seems to be a clear angular unconformity between the two complexes. More extensive field investigations are necessary in order to find out if this is a strictly local phenomenon or is more regional.

8. *Grong station.* 1.0 km north of Grong railroad station the contact between Precambrian and overlying younger rocks is exposed over a flat area of elevation 275 m. Below the micaschists there is a transitional zone which is usually a few meters thick. Both in the transitional zone and the underlying regular granitic gneisses the foliation is parallel to that of the overlying micaschists. Since the gneisses are rather homogenous without clear bedding features, one might well suppose for this locality that the foliation could be of secondary origin.

9. *Medjå Bridge.* This locality is mentioned rather because of easy access. Road cuts at the main northern highway and exposures along the adjacent River Namsen show highly deformed and folded gneisses and overlying micaschists. Although there is no knifesharp contact to be inspected, there is parallelism between the micaschists and the underlying granitic gneisses, where aplitic to felsitic leptite beds are still visible.

10. *East of Formofoss station.* A very instructive section is found along the creak that runs down to river Sandøla just west of Trangen, ca. 5 km northeast of Formofoss station. The Precambrian consists of thick beds of red leptite, forming beautiful steps in the landscape with thickness 1—2 meters. Between the beds are found layers of hornblende schists to micaschists of thickness 10—100 cm. These beds, as well as the bedded appearance of the leptite, are considered indicative of primary sedimentary bedding. Only occasionally traces of Caledonian metamorphism is seen, in the form of feldspar porphyroblasts in size up to 5 cm. The beds have a constant strike and dip, and although the stratigraphically most important 20 m of the contact are lacking, it is easily seen that the regional strike and dip of the overlying micaschists is the same as in the leptite.

11. *The Grong culmination.* The Grong area and the Precambrian of the Grong culmination is well known from the geologic maps of S. Foslie. From his own field work in this area, the author finds that much larger areas than those mapped by Foslie as containing leptite or quarz porphyries may be seen to have consisted of such rocks, although Caledonian recrystallization has transferred them in part to fine-grained or medium-grained gneisses or augen-gneisses. In general the author finds that there is a marked conformity between the bedded leptites and the overlying phyllites or micaschists throughout the Grong area. This is most beautifully seen in the Sandøla River Valley (Loc. 11).

From the literature only one paper should be cited, otherwise the reader is referred to the survey by Strand (1960, p. 230—245). The Surnadal Syncline culminates a little west of the area shown by Fig. 1, and further west the so-called Molde-Tingvoll syncline is mapped and shortly described by Hernes (1955). The most striking feature is that the syncline of greenstone and micaschists of undoubtedly Cambro-Silurian age is underlain by a huge syncline of Precambrian gneisses with no unconformity anywhere. All gneisses show more or less marked sedimentary features. Although the features indicative of a primary or a secondary origin of the concordant basement schistosity are too shortly described, both modes of origin seem possible in this area.

Discussion.

Three viewpoints seem to be responsible for the fact that the previous authors have been so reluctant to discuss the concordant basement contact as possibly primary. The first is the view that a typically granitic gneiss is mostly formed by complex metamorphism and granitization of older rocks. But waterlain pyroclastic tuffs and tuffites of some granitic composition or other form a very common group of rocks in the Precambrian. This is recognized long time ago i Sweden, where they are mostly called leptites, but much less so in Norway. When such rocks are exposed to regional metamorphism, they recrystallize very easy to form granitic rocks with banded appearence.

Secondly it is assumed that the Precambrian rocks in the Norwegian Calendonides got a completely new Caledonian structure during the main Caledonian orogenic phase. But the author thinks that it is necessary to distinguish rather carefully between the secondary schistosity or foliation of a gneiss and its layering or banding. Only a minute differential movement may be necessary to produce a completely new mineral orientation within a gneiss, whereas very extensive plastic flow with differential flow gradients between 10 up towards 100 or more may be necessary to change one heterogeneous rock into another with a new and tectonic layering which looks like sedimentary bedding. There is no need to go into any detail on these problems, because they are excellently treated in a recent publication by J. A. Redden (1962), and only one sentence needs to be quoted. After interpreting sharply banded and layered gneiss rocks as meta-sedimentary, Redden states: "I believe the burden of proof must be on the geologist who contends that such structures are *not* bedding." From Norway there is only one good description of a clearly Caledonian deformation of the Precambrian. From the southwestern part (Hardangerfjord) Kvale (1945, p. 15) has described a locality where a tectonic schistosity is seen in Precambrian quarzite. This structure may be seen many hundred meters down in the Precambrian, but the origional bedding is still clearly preserved.

Third is the view that Precambrian rocks must be folded. However, considerable areas in adjacent Sweden are covered by virtually flat-lying and unfolded Precambrian, called Sub-Jotnian Dala porphyries, Jotnian Dala sandstone, and Olden porphyries.

Much more field work is necessary in order to arrive at a certain conclusion, but in view of the fact that only the basal gneiss hypothesis is mentioned in general treatises like "Norges geologi" by O. Holtedahl (1953) and "Geology of Norway" (Chapter on Caledonides by T. Strand (1960)) it seems justified to the present author to advance a tentative hypothesis as the more likely conclusion, namely that the basement contacts of the central Norwegian Caledonides are what they look like, namely concordant. More explicitly expressed, this means that the Precambrian rocks were essentially flat-lying and unfolded at the begin of Cambrian or Eocambrian sedimentation. This hypothesis covers the Caledonides from Ottadalen in the south to the Grong culmination in the north, a distance of 350 km. Even if the assumption by Holtedahl (1938) that the gneisses underlying some of the flagstones are Eocambrian in origin, they again have a basement contact which seems to be concordant.

The problems discussed have only been treated in one paper and with a result which is completely opposite to the hypothesis here presented. Birkeland (1958, p. 412) reports that "the junction between the basement complex and the overlying formations could in many cases be readily recognized as an unconformity . . .". This unconformity also appears in his general map, but there are no descriptions of localities where such unconformities may be inspected. Until such descriptions have been published, the author thinks that Birkeland's conclusions are wholly unsubstantiated and can be overlooked.

If the advanved theory proves to be probable by further work, the consequences to Precambrian geology are quite important. The flat-lying Precambrian complex consists mostly of leptitic rocks with quite small admixtures of ordinary clastic sediments. The leptites may be waterlain pyroclastic sediments or in cases also rhyolitic lava flows. In the Grong area the leptites continue into the Olden porphyries. As to the southern half of the Trondheim region, it seems natural to consider the originally flat-lying Precambrian to represent a continuation of the Dala porphyries. Recently the age of the Dala porphyries as well as the Olden porphyries has been increased from the earlier 700—800 mill. years to at least 1200—1300 mill. years (Magnusson, Lundqvist, and Regnéll, 1963, post-printed addition). Possibly the Dala sandstone may have an age approaching 1600 mill. years (Geijer, 1963, p. 134). However, the suggested comparison may be erroneous, because there is no trace of the Dala sandstone in the leptitic gneisses in the southern Trondheim region. Anyhow, if the hypothesis of flat-lying Precambrian between Ottadalen and the Grong culmination is accepted, it is clear that this area was not hit by a later Precambrian orogenesis. This means that the Gothian (Dalslandian) orogenic zone in Sweden and the Gothian or "Telemarkian" orogenic zone in southern Norway trends southwest of the said area,[1]) whereas the Sveco-Fennian zone of middle and northern Sweden trends northeast of the area or below the rocks of the said area.

The problems discussed for the central Caledonides also exist for the northern part. Thus there is a clear angular unconformity between the Precambrian and overlying Cambrian in the Rombak window, 20 km east of Narvik (Th. Vogt, 1941). But the basement only 35 km west and southwest of Narvik is concordant in nature, the problems of which have been discussed by Foslie (1941). Even here a primary concordance may be assumed.

[1]) Note added in proof. — This is recently confirmed by I. McDougall and D. H. Green (Norsk Geol. Tidsskrift, vol 44, 1964, p. 183—196). They find that two classical eclogites from Sunnmøre seem to be 1800 m.y. old, with metamorphism probably at 900—1100 m.y. and certainly at 400 m.y.

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RECONNAISANCE OF THE TØMMERÅS ANTICLINE

By J. Springer Peacey

Abstract.

A granitic basement dome, overlain with sedimentary unconformity by Palaeozoic and perhaps Eocambrian rocks, is described. The flat-lying "leptites" and intercalated sediments, which comprise the basement, were little affected by events earlier than the Caledonian orogeny, and formed a gently-domed ridge against which the later sediments were deposited.

It is probable that the Caledonian fold-pattern of northeast-trending synclines and anticlines reflects the distribution of the sedimentary basins. The relative displacement of the basement blocks upwards and the troughs downwards has been continued by the later faulting.

The three main tectonic units are:

(1) the Tømmerås basement anticline and its autochtonous Palaeozoic cover, which are overlain with tectonic unconformity by

(2) further Palaeozoic rocks on the eastern flank of the anticline. Units (1) and (2) lie structurally above

(3) the Olden nappe (cf. Oftedahl, 1956), which is exposed along the median ridge of the Grong culmination.

After their emplacement they have been folded together into a series of southwest-plunging synclines and anticlines.

INTRODUCTION

Every so often in the unravelling of the geology of a region circumstances conspire to produce a rapid evolution of ideas, and great progress in the understanding of the local problems. This may come about by deliberate intensive study, but often it happens that, by fortunate coincidence, independant fragments of evidence are found to fit together to make a complete and complementary whole.

In Norway, the region north of Trondheim and the adjacent parts of Sweden have been the subject of such an evolution during the last ten years. This has been due partly to the work of H. Carstens (1955, 1956 and 1960) and Wolff (1960), partly to publication of the late S. Foslie's maps and their descriptions by Oftedahl (1955) and Strand (1956), and partly to the intensive tectonic studies undertaken in the border area of Sweden (see e.g. Asklund, 1960, for summary). Compilation of individual work began in connection with the International Geological Congress in 1960 when regional descriptions were brought out, both in Norway and Sweden, to accompany maps at a scale 1 : 1000,000; simpler descriptions by H. Carstens and Asklund were used as excursion guides. In Norway, the compilation continues, and the new map sheet, "Grong", which is shortly to be published by the Norwegian Geological Survey at a scale of 1 : 250,000, will show some of the results.

The area considered in the present study overlaps the south-west corner of the Grong sheet and stretches south and westwards of it (Fig. 1); it lies partly on the 1 : 100,000 rectangle sheets Snåsa, Verdal, Steinkjer and Levanger, between the parallels 63° 45′ N and 64° 15′ N, and at a median longitude 1° 20′ E Oslo.

The Tømmerås anticline, mentioned in the title of this paper, is a window of granitic rocks, marked on the map by Dons and Holtedahl (1960) as "Caledonized basement". It is shown in Fig. 1, and the following is a short description of the main geological features of the region.

Regional setting.

The Palaeozoic rocks of the northern part of the Trondheim synclinorium abut against an arcuate ridge of granitic gneisses exposed in the Grong culmination (Oftedahl 1956). This ridge, which runs east-west and then south-east across the grain of the Caledonian fold-belt forms a major divide, separating the main outcrop of the Cambro-Silurian into two parts; north of it the Lower Palaeozoic rocks continue in a series of thrust nappes and to the south they form a pair of narrow synforms, which unite south-westwards as the Trondheim synclinorium.

The maps, Figs. 1, 34, show the structures south of the Grong culmination, a pattern of ridges and troughs whose axial traces trend north-east. The northerly trough, the Snåsa syncline, is separated from its structural counterpart, the Verdal syncline, by the Tømmerås anticline; and whilst, in general, the synclinal troughs plunge steadily south-west from the Grong culmination, the anticlinal axis shows a local plunge culmination which results in a dome-like outcrop of granitic rocks forming the main Tømmerås massif.

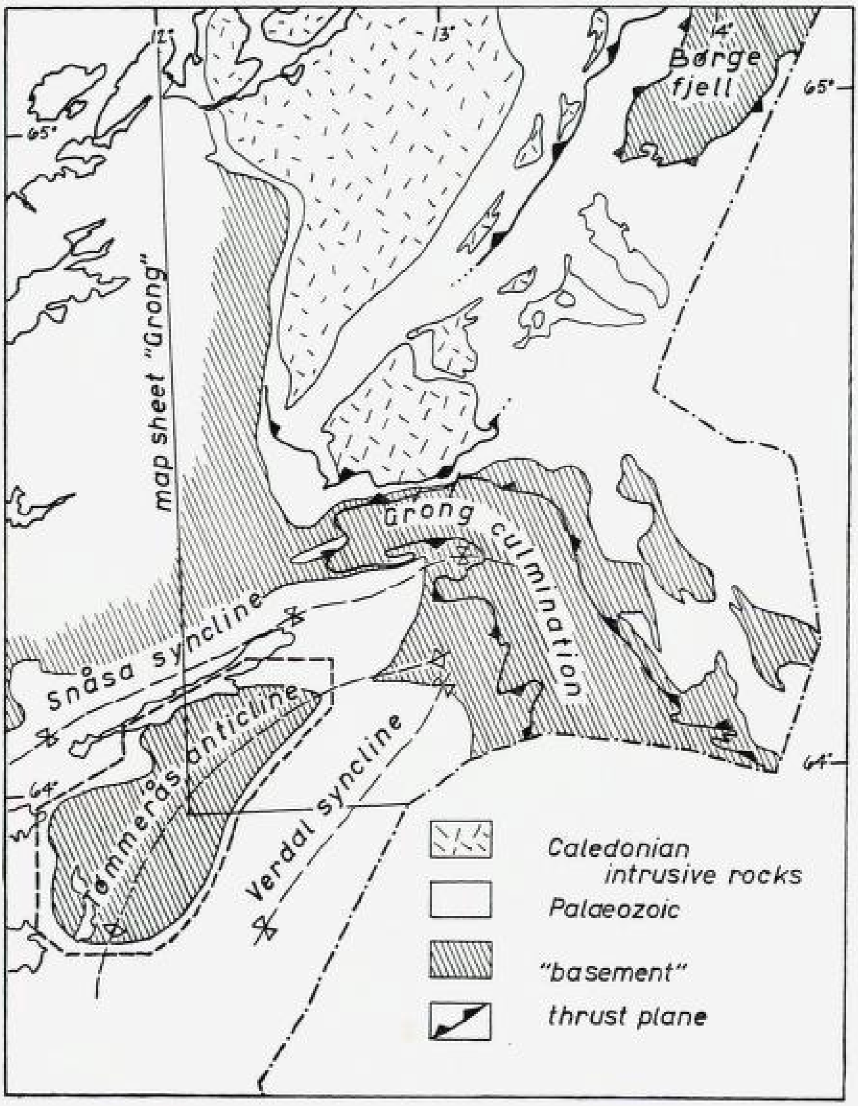


Fig. 1. Simplified geological map of the north part of the Trondheim region.

Previous work.

The northern part of the Trondheim synclinorium has been visited by numerous geologists previously; parts of it are described by T. Kjerulf and K. Hauan (1876), A. E. Törnebohm (1896), G. Holmsen

(1919), and C. W. Carstens (1920). But the most important sources of literature in the later years have been works by Oftedahl (1956), H. Carstens (1955, 1956, 1960), Birkeland (1958) and Wolff (1960), and the summaries given in "Geology of Norway" by Strand (1960). The geological maps by S. Foslie on the sheets Jaevsjø and Sanddøla have been invaluable, as have data from the manuscript maps on the sheets Overhalla and Snåsa, which were kindly loaned by Norges Geologiske Undersøkelse.

The mapping and laboratory study.

Field maps, at a scale 1 : 500,000, were made using Kodatrace overlays on aerial photographs. The final map shows both field measurements and the data obtained by interpretation of the air photos; the information from the different sources is indicated by separate symbols. Readings are given in 360°.

This has been only a reconnaissance and the data are therefore often both incomplete and unsystematic. Many of the investigations which belong to a complete regional study have been left out. Although more than five hundred thin sections of the rocks have been examined, detailed petrographic description of them is limited to those of the Leksdalsvann Group. The study of the leptites could usefully have been supplemented with modal and chemical analyses, in order to see how these rocks compare with modern rhyolites and the Swedish and Finnish leptites.

But in spite of these defects, it is possible to draw some conclusions from the available data, and, by using the information already published on the map sheets "Jaevsjø" and "Sanddøla", to suggest how they may be fitted into a broader regional picture.

The stratigraphy.

The litho-stratigraphic scheme used in this account has been based, as far as possible, upon those of earlier workers, and new names have been introduced only when this would simplify description. The rocks can be divided into four major units, three of which form an undisturbed stratigraphic sequence, and a fourth, which is separated from them by a plane of tectonic dislocation. Their relationships are schematically represented below; the evidence for these assertions and the reasons for the nomenclature are given in the following paragraphs.

Age	Western flank	Eastern flank
Lwr. Palaeozoic (Cambrian—M. Ord.)	Snåsa Group	the 'allochthonous Palaeozoic'
possibly Eocambrian	Leksdalsvann Group	
older Pre-Cambrian	Tømmerås Group	less T.P.

1. The Snåsa Group.

The rocks on the west side of the Tømmerås massif belong to the southern limb of the Snåsa syncline. They have been mapped by H. Carstens (1956, 1960) who, on fossil evidence and by correlating similar rock types, e.g. conglomerates and volcanic rocks, has been able to fit the litho-stratigraphy into the classic scheme established in the Hølonda-Horg area (Th. Vogt 1945).

The following table (Fig. 2) is modified from Carstens' 1960 description; it shows Vogt's five litho-stratigraphic groups and the lithological equivalents in the Hølonda and Steinkjer areas. To it have been added the étage numbers, which show Henningsmoen's tentative stratigraphic correlation of the Trondheim region with the detailed successions in the Oslo province (1960).

If Carstens' correlation is valid, then the deposits of the Snåsa syncline span the time range from the base of the Cambrian to the Upper Ordovician. He considers, however, that the succession has been disturbed by large-scale gliding and thrusting in the northern part of the syncline, since the Steinkjer conglomerate and the polygenous equivalent of the Volla conglomerate are missing here (Carstens 1956). He also points out that, on the southern limb south of Steinkjer, the major portion of the greenschists lie below the Steinkjer conglomerate, whilst farther north-east along the strike their thickest development lies above it.

The present investigation on the southern limb on the Snåsa syncline has, however, shown no litho-stratigraphic discrepancy which cannot be reasonably explained by lateral facies change and local faulting. It is therefore considered that these deposits form a tectonically-undisturbed, normal succession "younging" north-west towards the centre

Age	Group name	Hølonda—Horg area	Steinkjer—Follafoss area
Lwr. Silurian 6—7c	Horg	sst. and shales	sst. and shales
		Lyngestein qtzite cong.	
Upper Ord. 4c—5a	Upper Hovin	rhyolite sst.	
		Volla polygenous cong.	polygenous cong.
Mid. Ord.- uppermost Lwr. Ord. 3b—4c	Lower Hovin		sst. rhyolite tuff Snåsa, Lund lsts. greenschists, keratophyre schist
		Venna cong.	Steinkjer cong.
Lwr. Ord. 3a—3b	Støren	greenstones	greenstones
Camb.-lowest Ord. (possibly uppermost Eocamb.) 1—2c	Røros	mica schist	mica schists amphibolites

Fig. 2. Table to show the stratigraphic correlation between the Hølonda—Horg and Steinkjer areas.

of the syncline. Further, on the south side of Snåsavann, where the rocks rest directly upon the "basement", although there is thinning of the lower lithological units, there is no sign of secondary disturbance. This boundary is considered to be a primary sedimentary unconformity; the evidence for this assertion is more fully discussed under the heading "The rocks of the Snåsa Group".

By using marker horizons such as the Steinkjer conglomerate and the Snåsa limestone, this succession can be extended north-east along the strike to join up with rocks known as the Snåsa Group on Foslie's map sheet "Sanddøla". The data given on Carstens' 1956 map have been amplified in the present investigation and it is now possible to follow characteristic lithological units to the northern extremity of the syncline, and to correlate them with Foslie's lithological members (Fig. 34).

It is also possible to demonstrate that the sedimentary rocks shown on the north-west corner of the sheet "Jaevsjø" are part of the same sequence (Fig. 34).

At this northern end of the Snåsa syncline, however, there is too little evidence to warrant the establishment of a chrono-stratigraphy. The only marker horizon of reasonable certainty is the Steinkjer conglomerate, which has been traced beneath the Snåsa limestone as far as Navlus on the sheet "Snåsa"; this may represent a fairly constant time-plane, but the limestone itself is certainly diachronous since near Kvam it occupies the whole span of the Lower Hovin Group as delimited by the Steinkjer and the polgenous Middle Ordovician conglomerates, whilst north-east along the strike it thins to nothing and its place is taken by greenschists and amphibolites (Fig. 34).

Since one cannot establish a stratigraphy it is convenient to treat these rocks as a single litho-stratigraphic entity, and in this account the term, "the Snåsa Group", will be used for those rocks of the Snåsa syncline which lie south of Snåsavann on the sheet "Snåsa". They are considered to be equivalent to the Snåsa Group on the sheets "Jaevsjø" and "Sanddøla", their probable age range is Cambrian to Middle Ordovician since the Upper Hovin Group seems to be missing on the south side of the lake.

2. The Leksdalsvann Group.

On the south-west side of the Tømmerås massif is exposed another thick sequence of sedimentary rocks, lying beneath the Snåsa Group. In earlier descriptions of the area these rocks have been variously included with other groups. Although Törnebohm's map (1896) shows them as a crystalline series separate from the Palaeozoic rocks above and the granite below, C. W. Carstens (1920) included them with the Røros Group, whilst G. Holmsen (1919) confined them to the lower part of this group. Birkeland (1958) considered them to be metasedimentary rocks belonging to the basement complex, and his descriptions are illustrated by a photograph of quartzofelspathic gneiss, showing cross-bedding.

In the present investigation these rocks have been distinguished as a separate lithostratigraphic entity and the name "the Leksdalsvann Group" is proposed for them. The grounds for dividing them from the Snåsa are that they are distinctive in composition and texture; they seem to represent a different sedimentary environment and even, perhaps, a different provenance.

In the Snåsa Group great thicknesses of amphibolites and "greenschists" (mineral assemblages rich in Ca, Fe and Mg, and containing amphibole, chlorite and epidote) are thought to represent metamorphosed basic volcanic material. Some rocks, in which amphibole is abundant, may be almost wholly derived from this source; but even in those rocks which are clastic in origin, the admixture of volcanic débris has caused them to be unusually rich in the cafemic constituents and to differ from ordinary detrital rocks. Well-sorted clastic rocks and those of a coarser grade (i.e. quartzites and sandstones) are uncommon in the Snåsa Group, and if detrital felspar is present, it is as often plagioclase as potash felspar.

Fig. 3. Cross-bedded sandstones in the Leksdalsvann Group. South end of Lekdalsvann.

The rocks of the Leksdalsvann Group which are principally impure, microline-bearing sandstones and sandy siltstones are in sharp contrast to this. Amphibolites are thin and very local, and there is no sign that the detrital material has been mixed with volcanic debris. A characteristic feature is the abundant evidence of sedimentary depostition (Fig. 3); cross-bedding, grading and primary segregations of such minerals as epidote, magnetite and quartz-felspar are widely developed, particularly near the top of the sequence. Wherever it is possible to determine the "way-up" of the strata they young consistently south, or southwest showing that they have a normal stratigraphic position. The base of the Leksdalsvann Group is marked by the junction to the rocks of the Tømmerås massif. No angular unconformity can be observed directly, but on a larger scale it is seen that the rocks wedge out against the "basement" block (Fig. 32). There is no reason to believe that this

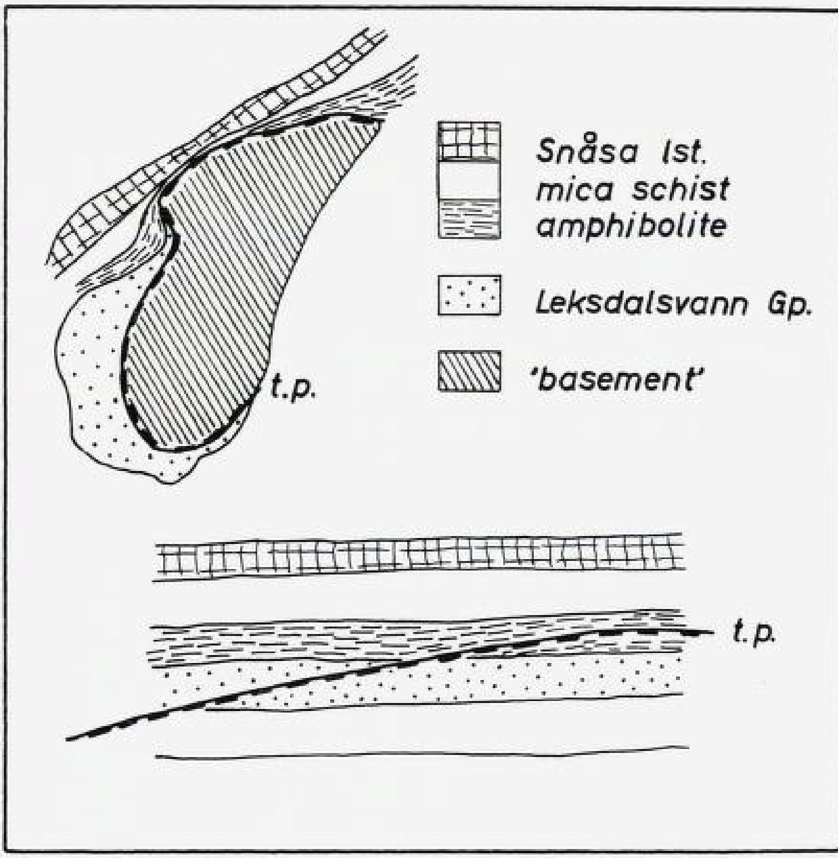


Fig. 4. Diagram to show the upper boundary of the Tømmerås massif interpreted as a thrust plane.

boundary represents a thrust plane against which the lower lithological members are cut out (Fig. 4) and, in both this group and the one above, there is evidence, more fully discussed later, that it is a primary sedimentary unconformity.

Little can be said of the age of the group. A tenuous analogy might be made with areas farther south where the Eocambrian comprises feltspathic sandstones and siltstones. But apart from this and its position beneath rocks of known Palaeozoic age, there is no means of establishing its age. The rocks might even be the lowest member of the Palaeozoic sequence, and equivalent to the basal quartzites of the Snåsa Group.

3. The allochthonous Palaeozic Group.

The sedimentary sequence on the eastern flank of the Tømmerås massif has been assigned in age to the Lower Palaeozoic by most authors, but the lack of fossil evidence and the scarcity of reliable marker horizons have meant that only litho-stratigraphic correlation has been possible. The rocks show a lithological development rather different from that in the Hølonda type-area, and this, combined with the obvious structural complexity of the area (shown on the maps of Holmsen (1919), Foslie (1959) and Wolff (1960), have made conclusions about the more detailed stratigraphy both tentative and at variance with one another. The rocks also differ in sedimentary facies from the Snåsa Group. The two sequences on either side of the Tømmerås massif cannot be readily correlated; and since those on the eastern flank can be shown to lie with tectonic discontinuity upon the Snåsa Group, they will be distinguished as a separate lithological group, known as "the allochthonous Palaeozoic".

The most recent work in the region is by Wolff (1960), who was able to make a detailed lithological subdivision of the rocks which stretch east from the Tømmerås massif to the Swedish border, on the sheet "Verdal". By means of conglomerate marker bands, and by comparison of lithological types he was able to correlate the sequence with Vogt's stratigraphy from the Hølonda area. However, a recent reassessment of the stratigraphical position of the Skjaekerstøtene conglomerate (Wolff (1964) – see accompanying paper in this volume), has made necessary a revised correlation. The two alternatives shown in the table below.

System	Group	Verdal 1.	Verdal 2.
Lower Silurian	Horg	Strådal schist Vera schist Sul schist Hyllfjell gabbro zone	
	Lyngestein cong.	Skjaekerstøtene con	
Upper Ordovician	Upper Hovin		Vera schist Strådal schist Sul schist black shales
	Volla cong.		Tromsdal 1st.
Mid. Ord & uppermost Lwr. Ord.	Lower Hovin	Tromsdal 1st.	
	Venna cong.	Bjøllo cong.	Bjøllo cong.
Lower Ordovician	Støren	Storstadmarka greenstones	Storstadmarka greenstones, Hyllfjell gabbro zone
			Skjaekerstøtene cong.
Lowest Ord. & Cambrian	Røros	Skjaekerdal, Malsådal schists	Skjaekerdal, Malsådal schists

Fig. 5. Table to show alternative stratigraphic correlations in the Verdal area.

In the sketch map (Fig. 6) Wolff's current interpretation of the stratigraphy and structure on the sheet "Verdal" and their continuation onto the sheet "Snåsa" is shown (Wolff 1964 and also personal communication). There follows a short summary of the main points of his opinion.

The Palaeozoic rocks in the east side of the Tømmerås massif are in a normal stratigraphic succession above the "basement". The Malsådal schists, the equivalent of the Røros Group, are followed above by the Storstadmarka greenstones, and then, by the Bjøllo jasper conglomerate, thought to be the equivalent of the Venna conglomerate at the base of the Hovin Group. The Tromsdal limestone and an overlying series of shales represent the Hovin Group. This sequence is seen in the southwestern part of the area, preserved in a synclinal trough, plunging south-west. The axial trace of this structure runs north-east on the east side of Mokkavann and the plunge changes to north-east, such that the same three groups are again exposed; near Lustadvann, the Røros Group is very thin and seems to die out northwards.

Farther east the Røros Group (now represented by Skjaekerdal schists) is exposed in the core of an anticline, and on its eastern flank the base of the Støren Group (here called the Hyllfjell gabbro zone) is marked by a quartzite conglomerate, which is correlated with the Svorkmo conglomerate (Wolff 1964), near Løkken. The Hyllfjell gabbro zone is overlain by the Sul and Vera schists, equivalents of the Hovin Group, and at the eastern border there is a sharp junction where they rest upon a complex of high-grade metamorphic rocks the Strådal schists. The lithological divisions used in the present account are substantially the same as those above, and a general term "the allochthonous Palaeozoic"

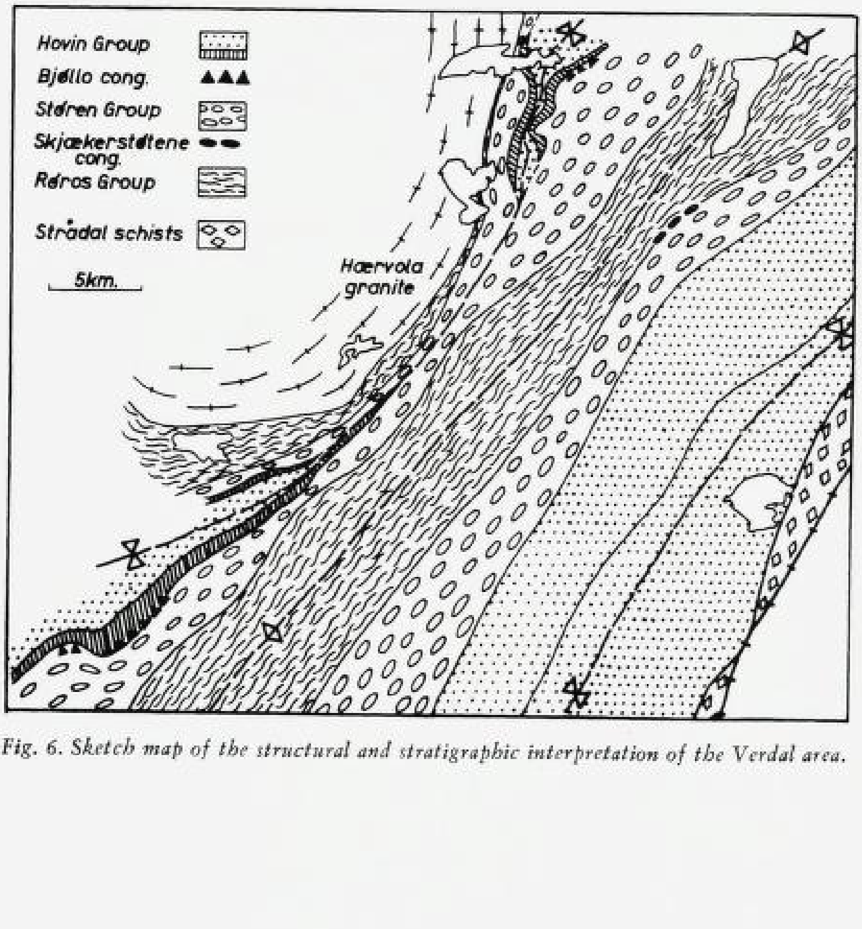


Fig. 6. Sketch map of the structural and stratigraphic interpretation of the Verdal area.

is used to refer to the whole of the sequence. The range of the Malsådal schists is slightly different from the original definition, since the unit was found to include the quartzites and mica schists that belong to a thin development of the Leksdalsvann Group.

Another important observation recorded in Wolff's work (1960) concerns the relationship of the "basement" to the sedimentary series above. Both Carstens (1920) and Holmsen (1919) believed that the Haervola granite, which forms the substratum between Kjesbuvann and Mokkavann, was younger than the mica schists above, and therefore Caledonian in age. Wolff recognised the boundary between the granite and the Palaeozoic rocks as a mylonite zone and that the crosscutting veins and apophyses, thought previously to be igneous injections, were in fact of tectonic origin. He attributed the crushing to differential slip between the basement and the cover rocks during the Caledonian folding, and concluded that the granite is a pre-Cambrian rock, partly modified by the later orogenic processes.

The mylonite zone can be followed along the eastern border of the Tømmerås massif between Mokkavann and Lustadvann (Wolff 1960) and, in the present study, has been traced from Lustadvann farther north to Vesterås in the Jørstad valley (Fig. 33). On the south side of Lustadvann the mylonites overlie rocks of the Leksdalsvann Group but southwards the effects of crushing become less obvious until, near Blokko in the river Malså, the junction between the Palaeozoic and its substratum is undisturbed. On the north, south and western boundaries there is no sign of crushing. Hence this mylonite zone cannot simply be due to the relative movements of the cover rocks during the Caledonian folding, and at Vesterås there is evidence that it represents a plane of tectonic dislocation. Here the rocks of the "eastern Palaeozoic" are found to rest successively upon the basement and then upon the lower members of the Snåsa Group (Fig. 32). The junction is marked by shearing and thinning of the stratigraphic units. Farther east the position of this thrust plane can be guessed from the data on Foslie's map "Jaevsjø"; the continuation of the Snåsa Group strikes beneath the "allochthonous Palaeozoic", bringing these rocks to rest on the basement again (Fig. 34). This is more fully discussed later with the major structures and regional correlation.

4. The Tømmerås Group.

The lowest lithological unit in the area, upon which the other three units rest, has so far been referred to as "the basement". Since, however, the term places a genetic connotation on the age and position of the unit, it is convenient to have a term which is purely descriptive. "The Tømmerås Group" is herewith suggested as a name for these rocks. It comprises those called "granite" by earlier authors, the Haervola granite on the eastern border of the outcrop, and part of Birkeland's "basement complex", including both metasedimentary and granitic types. The distribution of the group is best seen from the map, Fig. 32. Although it must be older than the Snåsa and Leksdalsvann Groups, there is at present no direct means of establishing its age.

SUMMARY

Four major lithological units are distinguished in the area, three of which form a normal undisturbed succession, and a fourth, which is separated from them by a thrust plane.

1. On the western flank of the Tømmerås massif the uppermost unit is the Snåsa Group. The rocks are equivalent to Carstens' sedimentary sequence, below the polgenous Upper Hovin conglomerate, and to the "Snåsa Group" on the sheets "Jævsjø" and "Sanddøla". They are considered to form an undisturbed normal succession, younging northwest, on the south limb of the Snåsa syncline, and to rest with primary unconformity on the Tømmerås Group. Scarce fossil evidence and correlation by marker horizons suggests that the age span of the rocks is Cambrian to Middle Ordovician.

2. The Leksdalsvann Group follows beneath the Snåsa Group with unbroken sedimentary continuity, and in a normal stratigraphic position. It is older than the Snåsa Group, but otherwise it can not be directly dated. It might possibly belong to the Eocambrian. It is primarily unconformable upon the Tømmerås Group.

3. The Tømmerås Group comprises the metasedimentary and granitic rocks, commonly termed the "basement". It is stratigraphically the lowest unit in the area and must be older than the Snåsa and Leksdalsvann Groups. It is probably also older than the allochthonous Palaeozoic, but there is otherwise no direct evidence of its age.

4. The rocks on the eastern flank of the Tømmerås massif are probably comparable in age with the Snåsa Group. They rest with

tectonic discordance upon the other three units. Although they are Palaeozoic in age, they cannot be readily correlated either with the Snåsa Group or with the type succession at Hølonda. Marker conglomerates, which may be equivalent to the basal Støren and basal Hovin, or basal Hovin and basal Horg, may indicate ages of Cambrian to Middle Ordovician or Cambrian to Silurian. In the present account the question of age is waived; and the rocks are considered as a tectonically separate lithological unit, and termed "the allochthonous Palaeozoic".

The rocks of the Snåsa Group.

Their main outcrop lies west of the Tømmerås massif and south of Snåsavann (Fig. 32). They strike north-east and dip gently north-west. Although these rocks have been subject to folding and regional metamorphism they preserve signs of their sedimentary origin and a well-differentiated sedimentary sequence is still apparent.

The outcrop is divided naturally into two parts by a gap where the "basement" rocks stretch down to the shore of Snåsavann between Grønøra and Tangen. This present division seems to reflect an earlier partial separation into two areas of sedimentation, for although the same lithological units can be identified without difficulty in the eastern and western parts of the outcrop, they often thin markedly as they are traced towards the gap. This is particularly noticeable in the mica schists which underlie the Steinkjer conglomerate, and in the banded amphibolites below them (Fig. 32).

If a rough calculation of the thickness is made, based on the average dip of the rocks and the width of the outcrop, then a section south-east from Medjås (north of the gap), or Gustad (south of the the gap) gives a thickness of about 2 km for the rocks between the bottom of the Steinkjer conglomerate and the "basement", whilst at Tangen the total thickness in 350 m. Not only do the individual units thicken away from the junction at this point, but the rocks become finer-grained as they are traced along the strike; the several bands of conglomeratic rocks developed in the eastern part disappear or become less coarse-grained north-east-wards (Fig. 32). Finally, near Tangen, where the base of the Snåsa Group is exposed in contact with the substratum, a conglomerate containing fragments of the "basement" rocks is developed.

The apparent thinning of the lithological units might be a secondary feature or could be explained by postulating a plane of tectonic discontinuity between the "basement" and the overlying sedimentary sequence, such that the lower members of the succession are cut out against it towards the base (Fig. 4). There is, however, no sign of

Western outcrop		Eastern outcrop
Greenschists Snåsa limestone	6.	Greenschists & amphibolites with thin st. horizons Snåsa limestone
Steinkjer conglomerate	5.	Steinkjer conglomerate
	4.	Greenschists
Hornblende-biotite-muscovite schists		Gritty feltspathic sst., partly quartzite-greenstone conglomerate
Dark biotite-quartz schists		Greenschists
Greenschists		Conglomeratic greenschists
		Greenschists
		Dark biotite-quartz schists
Banded amphibolites	3.	Banded amphibolites
Biotite schists Amphibolite Banded quartzites Biotite schists	2.	Dark biotite schists Felspathic quartzites
Leptite conglomerate	1.	

Fig. 7. Comparative lithological developments in the eastern and western outcrops of the Snåsa Group.

disturbance or mylonitisation at the boundary; and in contrast to this, many sedimentary features, in both this group and the one below, argue for its being a primary unconformity with overlap of the Palaeozoic rocks against the older substratum. Birkeland (1958) has already put forward this idea.

The table below is a summary of the principal lithological divisions in the two parts of the outcrop; for comparison they can be simplified to six main units. A more detailed description follows upon it.

(a) *The western outcrop*

1. *The leptite conglomerate*

The base of the Snåsa Group is exposed in the road section slightly east of Tangen on the south side of Snåsavann. Here a succession of leptites and thin hornblendic sheets is overlain by 1½ m of dark chlorite-biotite schists containing small slabs and subangular fragments

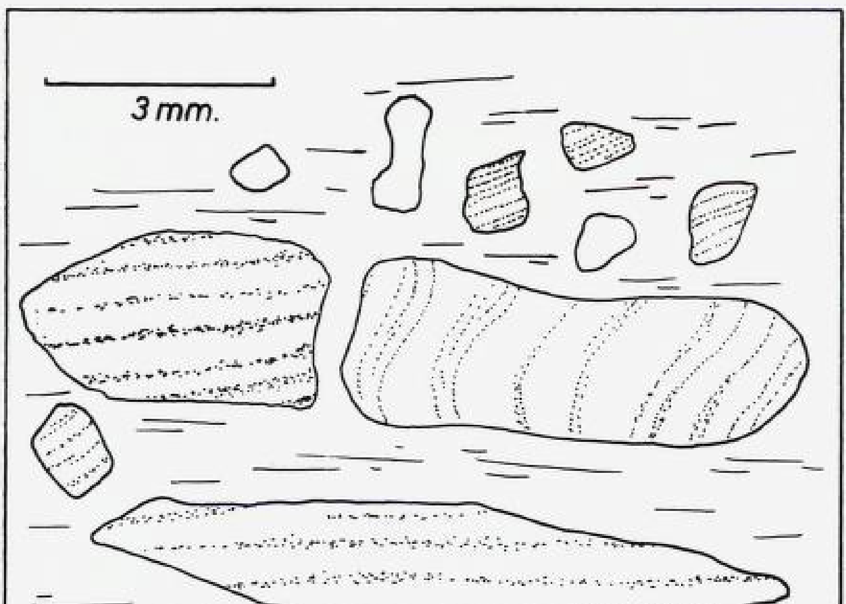


Fig. 8. Fragments in the leptite conglomerate.

of the leptite. Towards the junction the leptite fragments are larger, and seem to have been little moved from their original position. There is no visible angular discordance; the banding in the slabs of leptite is parallel to that in the "solid" rock beneath; in the smaller fragments, however, the banding shows a random orientation (Fig. 8). There is no sign of tectonic disturbance of mylonitization.

The leptite conglomerate is considered to be the basal conglomerate of the Snåsa Group and to show that the group rests with normal stratigraphic relations upon the "basement" rocks at this point. If the earlier conclusions are correct, that the Palaeozoic rocks are thinning against the substratum along the boundary between Tangen and Grønøra, then this is the most favorable stretch for the formation of a conglomerate, where the "basement" rocks have been least protected by deposition. The fragments are hardly rounded, and it is probable that the conglomerate is of very local occurence; it has not been found elsewhere in the area.

2. *The basal quartzites and mica schists*

Above the conglomerate follows a thin horizon of biotite-quartz-garnet schists, then banded quartzite, a horizon of chlorite-amphibolite and further biotite-muscovite-garnet schists. The total thickness is 16,5 m. These rocks are presumably metamorphic derivatives of clastic rocks, impure sandstones and sandy siltstones. In the eastern outcrop the amphibolitic rocks are normally well-separated from the underlying quartzites and mica schists, but here 5 m of amphibolite are intercalated in this unit.

3. *The banded amphibolites*

These rocks are principally amphibole-epidote schists, occasionally amphibole-garnet schists, and there may also be amphibole-garnet-mica schists near the base of the section. It is difficult to be certain of their origin; much of the amphibole schists are rather uniform in composition although they show some banded variation. They have no relict igneous textures, but their composition suggests that hey may perhaps have been basic volcanic material. Since the unit behaves as a litho-stratigraphic entity, they might be water-laid sub-aerial effusives or submarine lavas. The amphibole-mica schists could well represent clastic sediments with an admixture of derived volcanic material.

The strike of the western outcrop turns southwards at the western border of the area and the rocks of the Snåsa Group can be followed in a broad arc as they strike around the outcrop of the Tømmerås massif (Fig. 32). South of Steinkjer this group has not been mapped in sufficient detail to enable its division into lithological units; the lower boundary of the group has, however, been mapped and with it the immediately adjacent rocks.

Continuous sections of the basal members of the Snåsa Group can be seen along the south shore of Leksdalsvann, and in the River Malså, west of Blokko, both on the sheet "Verdal". In the first instance, there is an even gradation downwards from amphibole-mica schists and amphibolite horizons, through biotite-garnet schists with thin quartzites to the flaggy quartzites and gritty felspathic sandstones, which form the upper members of the group below. There is no evidence of an hiatus or a tectonic break in the section, which has the appearance of a normal sedimentary transition. At this locality the Snåsa Group rests with original conformity upon the underlying group and it can be seen from the map (Fig. 32) that a considerable thickness of rocks separate, it from the upper boundary of the "basement".

In the Malså river section the mica schists are not developed at all and here banded amphibolites directly overlie the flaggy quartzites of the group beneath. The boundary is sharp within 5 m but in this zone the two rock types are delicately interbanded. This seems to be a primary feature and there is no sign of shearing, which might have accompanied tectonic interbanding. Once again the base of the Snåsa Group is separated by a thickness of other rocks from the top of the "basement".

At other localities where the lowest members of this group are exposed the junction is not visible but it appears that the amphibolites follow directly upon the rocks below. Examples of this are the road sections north-east from Røiseng and east of Edberg, on the sheet "Snåsa".

4. *The mica schists*

The fourth unit of the Snåsa Group is a variable succession of mica schists. In the section near Tangen dark biotite-quartz-amphibole schists are followed upwards by paler muscovite-biotite-amphibole schists; near Edberg, and in the section west of it, the lower members are green, gritty muscovite-epidote-amphibole schists whilst those above are dark grey biotite-muscovite schists with occasional garnet and amphibole. Compositional differences expressed by amounts of light and dark minerals, and by the presence of different micas give the rocks a very variable appearance.

5. *The Steinkjer conglomerate*

The ridge, which runs south-west from Tangen to Gustad is principally composed of this rock type, and exposures of it occur both in the road section and along the shore of Snåsavann (Fig. 9). Near Tiltnes it has a calculated thickness of 45 m and near Gustad perhaps as much as 70 m, although it is not so easy to fix its limits here.

Fig. 9. The Steinkjer conglomerate at Tiltnes.

At these localities the conglomerate directly underlies the Snåsa limestone and the two units are so intimately associated that it is difficult to tell whether the lenses of limestone in the conglomerate are elongated fragments or thin bands. In the eastern outcrop at Navlus the conglomerate is interbanded with the base of the limestone.

At Tiltnes the fragments comprise yellow-white limestone, chlorite-amphibole schists, greyish quartzite, medium-grained quartz-plagioclase rocks, pinkish quartz-biotite-felspar rock (perhaps gneiss?) small grains and aggregates of plagioclase, and porous, yellow-green, fine-grained, epidotic rocks, which are reminiscent both of the epidote-rich lavas and the fine epidotic segregations seen in the Støren Group farther south. The fragments are mostly strongly flattened parallel to the schistosity (i.e. the secondary foliation formed during regional metamorphism) (Fig. 24), and sometimes show a weak elongation roughly parallel to the regional lineation; often, however, they lie at random in the schistosity.

The fine epidotic rocks seem least affected by the flattening and it is probable that the fragment shapes are partly original; the quartzites, chlorite-schists and limestone would anyway have weathered as slabs or flakes, whilst the massive epidotic rocks would form more equidimensional cobbles and boulders. The size and degree of flattening of some

		Size in cm (a:b)	Flattening ratio, b/a
TILTNES	Epidotic rocks	30 × 50	2,1
		14 × 18	1,7
		7,0 × 15	1,4
		3 × 4	1,3
	Other types	1,5 × 22	22,0
		1,0 × 22	22,0
		0,5 × 10	20,0
		1,1 × 8,0	17,5
		0,4 × 7,0	17,5
		1,5 × 6,0	14,0
BERG	Jasper epidotic rocks	15 × 40	8,3
		15 × 35	2,06
		3 × 25	2,03
	Other types	a : b : c	b/a : c/a
		0,5 × 0,9 × 10	1,8 × 20,0
		0,4 × 0,6 × 7,0	1,5 × 17,5
		0,6 × 0,9 × 1,4	1,5 × 2,3

Fig. 10. Size and deformation of pebbles in the Steinkjer conglomerate.

fragments from two localities, one in the western and one in the eastern outcrop, are given below. At Berg, in the eastern outcrop, the pebbles are often strongly elongated parallel to the regional lineation and the last value of the size and flattening ration expresses this dimension.

The matrix of the conglomerate is generally a dark biotite-chlorite schist. The pebble material varies both along and across the strike of the unit; sometimes the epidotic rocks form the bulk of the fragments; downwards across the strike the limestone is not represented. The coarseness also varies, and in the finer bands the largest fragments, principally quartz and felspar, may be not more than 1 cm across. It is remarkable that none of the pebbles seem to be of "basement" rocks; no granite, gneiss, or leptite is represented.

6. *The Snåsa limestone.*

The uppermost unit of the "stratigraphy" in the western outcrop is the Snåsa limestone, a grey-blue rock in which Carstens (1956) has found an assemblage of fossils of Middle Ordovician type on the north side of Snåsavann. In sections north-west across the strike from Tiltnes, it seems to occupy the whole of the Lower Hovin Group, from the Steinkjer conglomerate to the polygenous equivalent of the Volla conglomerate. In both directions along the strike, however, it is partly replaced by other rock types; south-westwards, a thin wedge of chlorite schists and biotite-muscrovite-epidote schists appears below the limestone west of Gustad and thickens along the strike; to the north-east, the limestone thins away and its place is taken by banded "greenschists" (muscrovite-chlorite-quartz-plagioclase) with thin limestone horizons.

(b) *The eastern outcrop.*

An almost complete section through the "stratigraphy" of the eastern outcrop can be seen on the road south-east along Jørstaddal from Finsås towards Gifstad. The Steinkjer conglomerate is exposed behind the farm, Rein and the lower units along the road from here to Gifstad. The most easterly extension of units 2 and 3 can be seen in the road from Vesterås, south-west along Roktdal. At this last locality the rocks of the Snåsa Group are tectonically overlain by these of the allochthonous Palaeozoic and the effect of this disturbance is the reason for the sheared and platy appearance of the quartzites.

2. *The basal quartzites and mica schists.*

As the leptite conglomerate is absent, the lowest rocks of the Snåsa Group in this part of the area are the basal quartzites and mica schists. West of Gifstad they are developed as well-banded, gritty, felspathic quartzites with clastic grains up to 10 x 8 mm in size, both plagioclase and potash felspar, and with numerous secondary augen of potash felspar, and locally, plagioclase, The quartzites are overlain by a thin horizon of biotite-quartz-garnet schists; and in general, wherever this unit is seen it becomes more pelitic near the top. The calculated thickness at this point is 20 m. It is possible that the coarsely felspathic quartzites characterize an environment, i.e. the position directly above the "basement" rocks, rather than a particular phase of deposition. They may correspond to a "basal arkrose", and therefore be of varying age (see "Leksdalsvann Group" p. 44).

The outcrop can be followed continuously south-east along the north side of Jørstaddal, and the unit increases slightly in thickness. Sections across the strike by Gifstad, Kjenstad, and north of Vesterås measure 25 m, 30 m and 50 m respectively; south of Vesterås the thickness is only 10 m, reflecting secondary thinning beneath the thrust plane.

The basal quartzites rest directly upon the "basement" rocks, but nowhere is an angular unconformity visible; on a larger scale, however, it can be seen that the layering in the substratum makes a small angle with the base of the quartzite unit, such that the yonger rocks rest successively upon different horizons. This is illustrated on the map (Fig. 32) on the north side of the Jørstad river.

3. The banded amphibolites also thicken south-eastwards, but the outcrop appears unnaturally broad north of the Jørstad valley where they are exposed at the centre of an anticline. Farther east this unit can be followed south of the valley where it thins and is finally cut out under the thrust plane (Fig. 32). In texture and mineralogy the rocks are not noticably differ from their couterparts farther west.

4. The micaschists, which in the western devolpment are uniform and monotonous, are here diversified by two conglomeratic horizons, one of which seems soon to die out north-east along the strike and the other, which can possibly be traced sufficiently far to be correlated with a quartzite horizon on Foslie's sheet "Sanddøla" (Fig. 34).

The bottom of the unit is exposed in a cliff section, in the road west from Gifstad. The rocks show well-developed compositional banding, which is expressed by the varying proportions of light and dark minerals. The dark bands constist om amphibole-biotite-epidote or biotite-chlorite- epidote-amphibole whilst the lighter ones contain quartz-epidote-felspar-muscovite, with or without amphibole and biotite. Near the top of the cliff the rocks are finer-grained chlorite-biotite schists, and in this matrix are scattered platy fragments of grey quartzite and light plagioclase-amphibole rock together with lumps of the fine epidotic material seen in the conglomerate at Tiltnes.

At another exposure of this horizon, in the road from Medjås to Gifstad, the matrix is a chlorite-biotite schist and the pebbles consist of quartzite, pale quartz-plagioclase rock, massive epidotic rock and grains or aggregates of opalescent bluish plagioclase. This band is similar in general composition to the Steinkjer conglomerate except the it contains no limestone.

Farther west in the road, i.e. up the succession, are exposed gritty rocks, consisting principally of plagioclase, quartz, biotite and chlorite. The grains of quartz and blue opalescent felspar are obviously clastic in origin. The band is separated from the conglomerate previously mentioned by biotite-chlorite-amphibole greenschists.

South-west along the strike, in the road west of Gifstad, the gritty horizon is less distinctive, but consists of a quartz-rich epidote-biotite-chlorite rock. North-east along the strike, at Nymoen on the road south-east from Snåsa, there occurs a similar quartz-rich band at roughly the same stratigraphical level. Here it is conglomeratic and contains lens-like fragments of white, grey or bluish quartzite and pinkish or olive-green epidotic material in a quartz-biotite-chlorite matrix. There are no limestone fragments and the whole rock is much more quartz-rich than the Steinkjer conglomerate. On the sheet "Sanddøla" at this horizon there is marked a band of quartz-schist, which may be its continuation. The upper members of the unit are greenschists, consisting of varying amounts of epidote, biotite, chlorite, muscovite and amphibole with quartz and felspar as the light constituents.

5. *The Steinkjer conglomerate.*

Exposures of this rock type occur in the main road south-east of Jørstad station, on the peninsula, Tynestangen, behind Rein on the Jørstad–Snåsa road, south of Berg on the Agle road and by Navlus (Fig. 32). Rock types peculiar to the eastern development of the conglomerate are jasper and grains of bluish, opalescent felspar. But, in general, it is little different from that in the western outcrop.

At Berg, in addition to the usual rock types, there occur slabs of pale jasper, together with chips of blackish chlorite schist and grains of blue felspar, 2—3 mm across. The pebbles of less competent material are strongly drawn out parallel to the regional lineation and the axial plane cleavage cuts through them (Fig. 24). Farther north-east along the strike the conglomerate is interbanded with lenses of limestone several metres thick.

At Navlus the jasper is purplish-blue or bluish, and the pebbles are flattened parallel to the axial plane cleavage of folds, which accompany the regional lineation. South across the strike and down the thickness of the conglomerate, coarser and finer bands are intercalated with lenses of limestone. The lowest exposure of the conglomerate contain no limestone, but there are plentiful grains of white quartz and bluish felspar.

By Jørstad station the fragments are relatively small (5—10 cm); the opalscent felspars occur again. But at Tynestangen they are absent. The latter is a poor development of the conglomerate and quartz-felspar schists, striped chlorite-amphibole schists and porous greenstone layers form the bulk of the rock. Occasional fragments of pale jasper are, however, present.

6. *The Snåsa limestone.*

A typical blue-grey limestone is the uppermost member of the stratigraphy; its place is partly taken by greenschists north-eastwards along the strike. Certainly its continuation on the sheet "Sanddøla" is considerably thinner, and above it, for example at the head of Snåsavann, are exposed banded greenschists with thin limestone horizons. The rocks consist of assemblages of muscovite, plagioclase, quartz, chlorite and epidote. They seem to be of mixed clastic and basic volcanic material, partially sorted. There are poorly-developed examples of cross-bedding.

The rocks of the Leksdalsvann Group.

The extent and distribution of the Leksdalsvann Group is shown on the map, (Fig. 23). The rocks have a crescentic outcrop, whose maximum with occurs on the south-west side of the Tømmerås massif; north-east and westwards, along the outcrop in either direction, the group wedges out, and is hidden by overlap of the younger rocks onto the Tømmerås Group.

The rocks lie conformably beneath the Snåsa Group and no stratigraphic break can be found between the two (see p. 31). They can be divided into two lithological units, (a) an upper unit of impure, felspathic sandstones and (b) a lower unit of dark, sandy siltstones, but there is no sharp junction between them; they pass gradually one into the other by an even compositional variation, and this seems to be a primary sedimentary effect.

Other signs of their sedimentary origin are the abundant depositional features e.g. cross-bedding and grading, seen in the upper unit (Fig. 3), and the primary mineral segregations and delicate compositional banding found in both upper and lower. Wherever the "way up" of the rocks can be determined, they young south-west or west, and there is no doubt that they are in a normal sedimentary position. It was not possible to collect enough readings of current directions to make the data statistically valid.

A section from the Snåsa Group, through both units of the Leksdalsvann Group is seen along the road, on the south and east shores of Leksdalsvann; on the west side, the road runs through the upper unit only. The crescentic outcrop of the individual units echoes that of the whole group; each of them thins against the Tømmerås Group, and at both ends the lower unit is overstepped by the upper one.

(a) *The upper unit.*

The rocks are distinct in texture and mineralogy from those of the lower one. They are coarse- to medium-grained felspathic sandstones, occasionally developed as gravelly sandstones, where the fragments are larger than 1 mm. They are pinkish, or pale greeny-grey in colour.

The calculated thickness of the Leksdalsvann Group shows a systematic change along the length of the outcrop, and, if upper unit is taken as an example, the thickness at various points is as shown in the sketch map below (Fig. 11). At the northern extremity of the outcrop, east of Edberg (Fig. 32), the Snåsa Group rests directly on the Tømmerås Group, but gradually, thin members of the Leksdalsvann Group appear between the two, and their thickness increases southwards until it reaches a maximum of 300—350 m between the south end of Leksdalsvann and Kjesbuvann. Then it begins to decrease again, and the unit turns northwards and disappears beneath the thrust plane, near Holmlitjern; it is exposed again locally in Ogndal, south of Lustadvann and here has a thickness of only 15 m. The values at Vistvik and Kjesbuvann are not as accurate as the others, since contour data from the rectangle sheet, and not measured heights, were used for calculation. At the south-western end of the outcrop it is not obvious how much the thrusting has affected the thickness, but certainly the unit begins to thin long before this could be attributed to secondary tectonic effects.

An exactly similar pattern is shown by the outcrop of the lower unit. Other sedimentary characters also show a systematic change; the coarsest and least-sorted detrital material is found at the thickest part of the

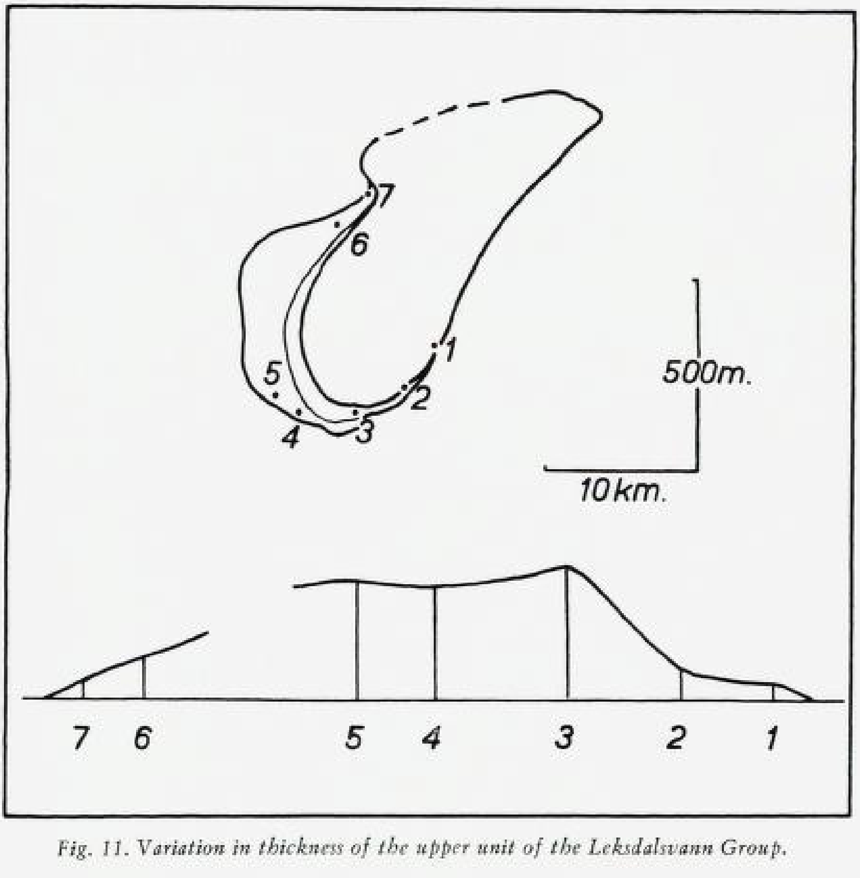


Fig. 11. Variation in thickness of the upper unit of the Leksdalsvann Group.

outcrop, and here cross-bedding and grading are best developed; laterally the rocks become thinner-bedded and better-sorted, and depositional structures less common.

There is no sign that these changes are anything but primary features and, although it is still not impossible that the junction of this group with the Tømmerås Group is a tectonic one (see p. 21), it seems as reasonable to believe that it represents a primary unconformity, with the younger members showing overstep onto the substratum. If this is so, the Tømmerås Group is truly the "basement" for the two younger groups.

The variation in sedimentary grade is shown in greater detail by Figs. 12 and 13. The average grain size for seven groups of specimens in the upper unit, distributed geographically along the outcrop, has been plotted; this is seen in the histograms (Fig. 12). The grade classes are those used by the U.S. Bureau of Soils, (quoted by Pettijohn 1949, p. 16) and are as follows:

	fine gravel
1,0 —0,5 mm.	coarse sand
0,5 —0,25	medium sand
0,25 —0,1	fine sand
0,1 —0,05	very fine sand
0,05 —0,025	coarse silt
0,025—0,001	medium silt

The total sample contains only 34 specimens and this is, therefore, not a comprehensive study, but the data available show that whilst at the thickest part of the outcrop the most samples fall into the fine gravel, coarse sand and medium sand classes, these at the extremities of the outcrop are contained principally in the range of medium and fine sand. The actual size range and the averages are listed in table Fig. 13. The grain sizes of rocks from the lower unit are also quoted, and it will be seen from the relevant histogram that these are mostly fine and very

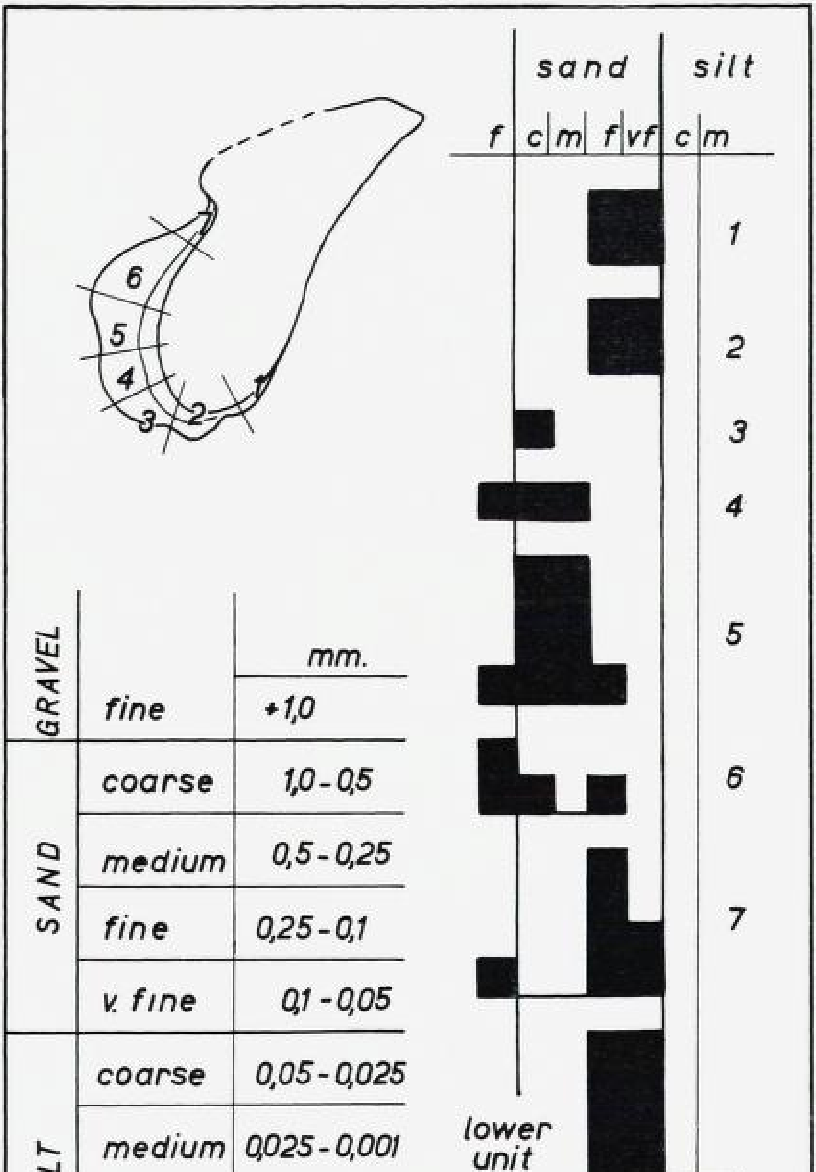


Fig. 12. Grain size variation in the upper unit of the Leksdalsvann Group.

fine sand, and coarse and medium silt. The lower unit is thus markedly finer-grained than the upper one.

The variation in coarseness in the upper unit is associated with differences of mineralogy and composition. In the coarsest rocks the quartz and total felspar contents are about equal, and only 10—15 % consists of other minerals. The felspar is both plagioclase and microcline, and there are composite fragments of quartz-Kf-plagioclase. The grains and fragments are angular or subangular, and the finer-grained matrix now consists of quartz-epidote or quartz-epidote-muscovite, although it may originally have been quartz and calcite.

This rock type falls within the definitions of an arkose quoted by Pettijohn:

"a sandstone containing 25 % or more felspars derived from the disintegration of acid igneous rock of granitoid texture" (Committee on Sedimentation), and "a highly felspathic (30 % or more of felspar) sediment derived from a granite and having the appearance of a granite" (Krynine 1940).

The source of the felspar material, in this case, is probably the plagioclase-microcline granitic gneisses, which form parts of the Tømmerås massif; the microtextures of the felspars are certainly very similar in the two types of rock.

Laterally the rocks grade into felspathic sandstones, in which the felspar content is less and quartz becomes the dominant mineral; they are finer-grained and better sorted, and the grains seem better rounded although they are still sub-angular.

Typical mineralogical assemblages from the arkose are; plagioclase, microcline, quartz, muscovite and epidote, with rutile, magnetite and orthite as accessories, or microcline, plagioclase, quartz, epidote, magnetite and muscovite, with accessory orthite, biotite and chlorite. The darker bands are concentrations of magnetite and epidote or rutile, muscovite, and epidote; magnetite and rutile seem to be sedimentary concentrates. The "cement" for the fragments is quartz-epidote, or quartz, epidote and muscovite. The felspathic sandstones are typicaly represented by the following minerals: quartz, microcline, plagioclase, muscovite, biotite and magnetite, or quartz, plagioclase, muscovite, microcline, epidote and accessory rutile. Clastic potash felspar is peculiar to the upper unit of this group and another distinction is the lack of ferro-magnesian minerals; the principal mica is muscovite, and biotite and chlorite appear only as accessories or where there has been sec-

THE UPPER UNIT

	Size range mm.		Average
GROUP 1.	0,01	0,58	0,29
	0,03	0,0	1,51
	0,019	0,58	0,299
	0,015	0,28	0,147
	0,02	0,96	0,491
	0,019	0,76	0,389
	0,015	0,48	0,247
	0,019	0,665	0,342
	0,019	0,25	0,134
GROUP 2.	0,019	0,25	0,249
	0,02	1,44	0,73
	0,02	4,5	2,26
	0,01	2,5	1,30
GROUP 3.	0,02	1,63	0,82
	0,02	0,96	0,49
	0,02	0,96	0,49
	0,02	0,385	0,202
	0,02	0,65	0,33
	0,038	0,76	0,524
	0,019	0,96	0,489
	0,02	1,34	0,68
	0,02	2,0	1,01
	0,02	1,54	0,78
GROUP 4.	0,02	1,54	0,78
	0,02	0,96	0,49
	0,035	2,0	1,02
GROUP 5.	0,02	1,73	0,87
GROUP 6.	0,02	0,5	0,26
	0,02	0,29	0,19
	0,02	0,29	0,19
GROUP 7.	0,015	0,29	0,152
	0,02	0,96	0,49
	0,015	0,58	0,297
	0,02	0,49	0,25
	0,02	0,58	0,30
	0,02	0,76	0,39

THE LOWER UNIT

Size range in mm		Average
0,015	0,125	0,07
0,01	0,076	0,043
0,019	0,29	0,134
0,019	0,125	0,072
0,01	0,038	0,024
0,019	0,076	0,047
0,01	0,192	0,101
0,019	0,096	0,057
0,01	0,038	0,024
0,019	0,125	0,072
0,038	0,38	0,209
0,038	0,076	0,057
0,038	0,192	0,115
0,015	0,114	0,064
0,019	0,29	0,104
0,019	0,192	0,105
0,019	0,192	0,105
0,01	0,038	0,024
0,01	0,058	0,034

Grain sizes in the Leksdalsvann Group.

Fig. 13. Table of grain sizes.

ondary fracturing. This contrasts with the rocks of the lower unit where biotite is one of the most important minerals.

The rocks of the upper unit are considered to be the little-transported débris from the weathering of a granitic terrane. The present outcrop is visualized as a section through a deposit which thins towards the edges and lies unconformably upon the Tømmerås Group (Fig. 23). Both units are banked against the Tømmerås massif, and it is probable that the weathering of this basement provided the detritus to form the upper unit. If this is so, it means that, during the deposition of the lower unit, the Tømmerås Group was undergoing erosion only very slowly or not at all; this or a different provenance could account for the finer-grained, better-sorted rocks, and the differences in composition between the two.

It is notable that both within the Tømmerås Group and at the base of the Snåsa Group in the eastern outcrop, there occur rocks similar in composition and texture to those of the upper unit; all three occurrences characterize the same environment and represent times when the granitic rocks were subject to erosion. Thus it is that the sedimentary rocks immediately above the basement may be identical but widely separated in time.

(b) *The lower unit.*

The lower unit is exposed on the east side of Leksdalsvann along the road north of the Lund river, and the junction between this unit and the rocks of the Tømmerås Group is seen in the road east from Tiller-eng, on the footpath east to Henningsvann, and north of Kjesbuvann. On the sheet "Snåsa", it can be seen on the footpath south-east from Fjesem, and in Ogndal on the road north-east from Støen.

An angular unconformity between the two is not found anywhere; the boundary is sharp within five metres, but its details are blurred by secondary effects. The metamorphic grade seems to increase downwards in the unit, so that near the boundary the rocks are coarse, granular schists, often with augen of potash felspar or quartz-plagioclase-Kf. The increase of grade, shown by coarser recrystallization of the minerals, is an effect which appears gradually and is spread over a wide distance, but the growth of felspar augen is strictly limited to the few metres directly above the contact. It is difficult to know whether the felspar represents recrystallization of the original potashbearing constituents of the schist, or whether material has been introduced from the felspathic rocks below.

The lower unit differs from that above in texture, sedimentary grade and composition; and although, because of its composition, it has been more readily affected by metamorphism, it is still possible to recognize primary sedimentary features, particularly at the top of the unit.

The least metamorphic rocks are dark, fine-grained sandy siltstones with thin, pale bands or lenses of sandy, calcareous material. Cross-bedding and grading are not developed, and the rocks are fairly well-sorted. It has here been assumed that, although the micaceous minerals may recrystallibe relatively easily, the quartz and felspar remain stable longer; from textural evidence in thin section, this appears to be true, and on this basis the average grain size has been calculated. The results are plotted in Figs. 12 & 13, and they confirm that the bulk of these rocks are considerably finer-grained than those of the unit above, and fall mostly into the size range of the finer sands and the coarser silts.

Because of the better sedimentary differentiation, the mineral assemblages tend to fall into two groups, corresponding to (a) the dark sandy siltstones and (b) the pale calcareous lenses. Typical assemblages from the former group contain biotite, (quartz and plagioclase), garnet and epidote, or biotite, (quartz and plagioclase), garnet, apatite, muscovite and zircon. The quartz and felspar are reckoned together since frequently they cannot be easily distinguished; much of the plagioclase is untwinned albite. One notable difference from the upper unit is that potash felspar does not occur as a detrital mineral.

The quartz, felspar, zircon and apatite are probably primary detrital minerals; the quartz, felspar and mica, partly recrystallized, whilst garnet is a secondary metamorphic product.

In the latter group, (b) the calcium of the rock may be present in as primary or secondary minerals; in the first case typical assemblages would be (quartz-felspar), biotite, epidote, calcite, and garnet with accessory apatite and magnetite, or (quartz-felspar), epidote, biotite, calcite, garnet; in the second case the paragenesis would typically be hornblende, biotite, epidote, (quartz-felspar), calcite.

SUMMARY

The Leksdalsvann Group rests unconformably upon the Tømmerås Group in a normal stratigraphic position above it. The systematic variations along the outcrop of sedimentary characters e.g. thickness, grain size, sorting, composition, and incidence of depositional structures, are considered to be a primary feature, which shows that the deposition of the group is directly related to the Tømmerås massif, upon which basement the rocks were deposited. Thus the unconformity is a primary discontinuity.

The Snåsa Group follows conformably above and oversteps the Leksdalsvann Group. These rocks together presumably mark a period of marine transgression.

The two units of the group are distinct in texture and mineralogy. The lower one consists of fine, dark, sandy siltstones with pale calcareous bands. Biotite, amphibole and calcite are characteristic minerals; potash felspar is absent as clastic grains. The upper unit, which shows abundant grading and cross-bedding, consists of coarse to medium-grained felspathic sandstones, which occasionally are developed as gravelly arkoses. The rocks are considered to represent material derived by weathering of the Tømmerås massif. The presence of microline is diagnostic, and there is characteristically very little ferromagnesian mineral.

The rocks of the allochthonous Palaeozoic.

The allochtonous Palaeozoic rocks have been separated into the lithological units shown below, and their lateral equivalents in Verdal (Wolff 1960, 1964) are given for comparison:

Structural sucession on the sheet 'Snåsa'	Verdal
"Quartz keratophyre"	
Greenstone	Storstadmarka greenstone
Bjøllo conglomerate	Bjøllo conglomerate
Tromsdal limestone	Tromsdal limestone
Dark phyllite	
Malsådal schists	Malsådal schists

A marker horizon in the present area is the jasper-bearing Bjøllo conglomerate (originally found by Wolff 1958, personal communication); it is presumably the lateral equivalent of the Bjøllo conglomerate, and can probably be correlated with the Lower Hovin Venna conglomerate. There are, otherwise, no horizons of undoubted age and, as yet, no evidence of the "way up" of the rocks; thus the author considers it unsafe to treat the succession as anything but a structural one. Although lithologically the units are equivalent to those established by Wolff, no attempt is made to correlate them with the Røros, Støren, and Hovin Groups.

The Malsådal schists.

The Malsådal schists, structurally the lowest of the eastern Palaeozoic succession, are a series of "greenschists" with subordinate amounts amphibolite and quartz-felspar schist. They are well-banded, on scales ranging from a few millimetres to several metres, and are very variable in composition. Sections along the north shore of Lustadvann or on the east coast of Mokkavann show a rapid alternation of dark or medium green rocks, consisting principally of amphibole, epidote, plagioclase and quartz, with paler plagioclase-quartz or quartz-plagioclase-muscovite-chlorite rocks. Amphibole is the commonest mafic mineral, and the composition of the darker bands might suggest that they are metamorphosed basic igneous rocks, but only occasionally does the distribution of light and dark minerals resemble igneous textures. Instead, most of the greenschists, in thin section, appear as an ill-sorted, little-recrystallized aggregate of large amphibole and plagioclase crystals in a finer matrix of plagioclase-quartz and epidote. This seems to be the clastic débris derived from the weathering of basic igneous material, and the rocks are perhaps the water-laid products of explosive vulcanism (tuffs), or re-worked submarine lavas.

The lighter bands are of two kinds: firstly, there are those which show large twinned crystals of plagioclase in a finer matrix of plagioclase and quartz. They are very similar in texture and composition to the rhyolites and rhyolite tuffs, which Carstens has reported from the Hovin Group in the Hell-Frosta area (H. Carstens 1960, excursion guide); they might be either acid lava flows or their fragmented material. The second type are quartz-plagioclase-calcite rocks with muscovite, biotite or chlorite, and generally epidote. From their apperance they seem to be normal psammitic or semi-pelitic sedimentary rocks. Other rocks types found in the unit are brown biotite-muscovite schists with large scales of mica up to a centimetre across.

The amounts of the different types present varies from place to place, but there are often a higher proportion of mica schists near the top of the unit, whilst near the bottom, the rocks are principally amphibolites and felspar-quartz schists. The banding also becomes better developed towards the base, but this may be partly tectonic. This unit rests directly upon the thrust plane (Fig. 14) and in the northern part of the area, near Vesterås, it seems to be cut out against it; here the blackish-green phyllites of the unit above are these immediately against thrust.

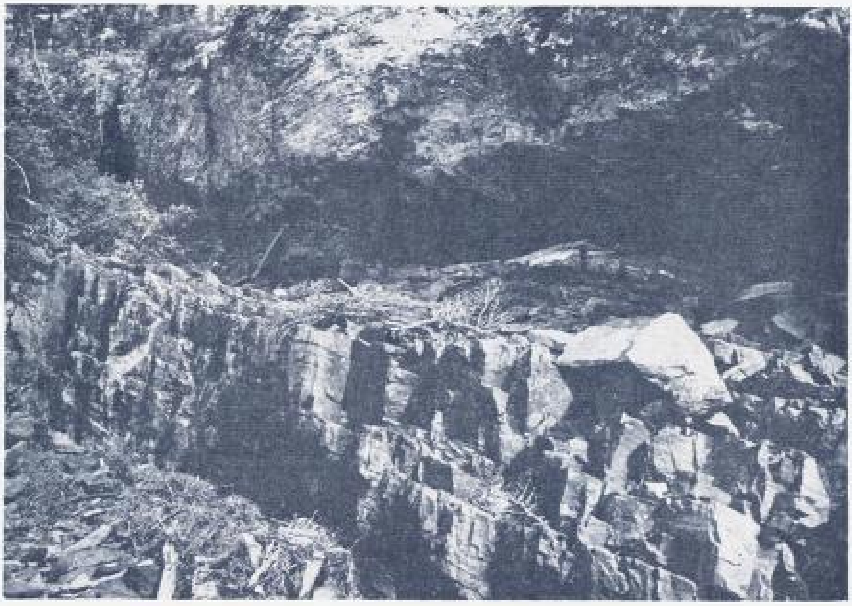


Fig. 14. The Malsådal schists of the allochtonous Palaeozoic, resting upon a thrust plane above banded leptites belonging to the Tømmerås Group. South coast of Mokkavann.

The Tromsdal limestone.

Between Mokkavann and Lustadvann the Malsådal schists are overlain by limestone shales or by calcareous chlorite schists belonging to the Tromsdal limestone unit. North-east of Lustadvann the limestone splits into two, enclosing a wedge of dark phyllites (Fig. 32) and both horizons thin northwards. South of Mokkavann this unit also seems to divide into several horizons and to die out.

The limestone is a pale grey or bluish, well-banded rock, which in spite of its fissile appearance, contains little but calcite; there are scattered flakes of muscovite or grains of quartz and felspar. Near the base it is little recrystallized; the calcite grains may average only 0,02 mm in size, but towards the top, large crystals of secondary calcite may be up to 3—4 mm across. The texture is, however, patchy and varies rapidly in any one outcrop. South of Lustadvann green caleareous chlorite scihsts are the lowest member of the unit.

The dark phyllites.

Near Mokk the total thickness of outcrop between the Malsådal schists and the Storstadmarka greenstones above, is occupied by limestone, but south of Lustadvann, dark grey or greenish-grey phyllites divide the limestone into two, and their outcrop thickens northwards. Finally the lower limestone horizon disappears altogether, and the phyllites rest directly upon the Malsådal schists. On the north and east sides of the lake a section through both limestones and the phyllite is exposed. Immediately above the lower limestone lie green chlorite schists, which are followed by black phyllites. Similar green schists are found locally throughout the phyllites and in thin section show clastic fragments of quartz and felspar set in a matrix of chlorite and muscovite. The phyllites are often delicately banded; the darker bands consist of clastic quartz and felspar in a chlorite-muscovite groundmass, whilst in the lighter ones the chief minerals are plagioclase, quartz and epidote. Near the base of the upper limestone there is an even transition from one rock type to the other and here calcite is also present with the other minerals.

The Bjøllo conglomerate.

In the hillsides north of Mokk and east of Lustadvann the limestone is overlain by a jasper-bearing conglomerate, whose thickness varies up to 15 m. It is found sporadically along the upper boundary of the limestone and continues eastwards out of the present area (H. C. Seip, personal communication), but it is difficult to tell whether it is a series of lenses, or whether the exposure is patchy.

The conglomerate is variably coarse, and the largest fragments may reach 35 x 15 cm; jasper is always present and the other "pebbles" consist of fine, banded greenschist, pale limestone and dark porous greenstones, which look like lavas. Near the top and bottom the conglomerate is finer-grained with sparse jasper fragments; at the base, conglomeratic chlorite schist and the limestone are interbanded; at the top, there is an even transition to the banded greenstones which form the lowest members of the Storstadmarka greenstone unit.

The Storstadmarka greenstones.

This is structurally the highest unit of the succession dealt with here. The rocks are principally pale green, massive amphibolitic rocks with rare banding. There are great thicknesses of light, more felspar-rich types, some of which show igneous textures and phenocrysts of quartz. The latter are grouped together under the general term "quartz keratophyre".

The succession, which here is treated as five separate units in ascending structural order, is considered by Wolff (1960, 1964) to consist of three units repeated across a synclinal axis; hence the dark phyllites are the youngest rocks, the limestone appears twice on the different limbs of the fold, and the Malsådal schists are equivalent to the Storstadmarka greenstones (see Fig. 6). This interpretation may be correct although there are a number of points which suggest that the distribution of the rocks could be explained by facies variation:

1. the jasper conglomerate has not been found below the lower limestone horizon,

2. the Malsådal schists are much thinner than the greenstones; they are also lithologically distinct, with better banding and greater compositional variation than the latter.

The alternative theory would explain the division and final disappearance of the limestone by gradual facies change, such that the limestone is replaced by the phyllites. These two would then be partly equivalent in time. If it is valid to compare this succession with that of the Snåsa Group, it is possible that the sequence is upside down; the Mokk limestone and the conglomerate are reversed in order when compared with their lithological equivalents in the Snåsa Group. Then the succession would be, in ascending stratigraphical order:

the Malsådal schists

the Tromsdal limestone and dark phyllites
the Bjøllo jasper conglomerate
the Storstadmarka greenstones.
This, however, is very speculative.

The rocks of the Tømmerås Group.

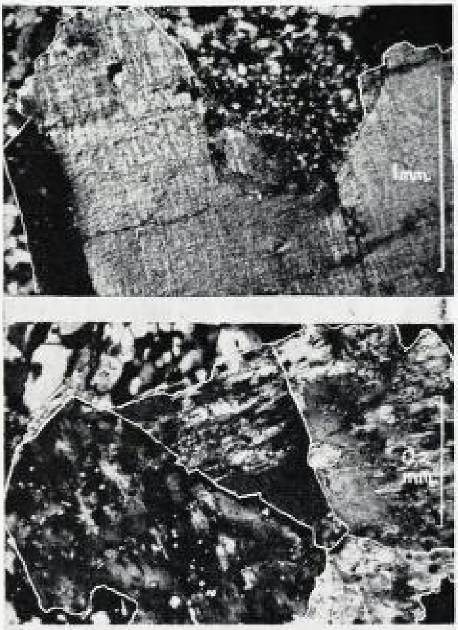
Their origin.

Most of the rocks of the Tømmerås massif are granitic in compositon, but they are sufficiently diverse in texture and grain size to make possible the mapping of broad lithological units. The principal rock types are "leptites", granite-gneiss, micaceous leptites and mica schists, both muscovite and biotite-bearing. The term "leptite" is here used to mean a pale grey or pinkish, fine- to medium-grained, banded or massive rock, consisting principally of felspar and quartz, with lesser amounts of such minerals as biotite, muscovite, epidote, garnet, sphene, and zircon. No genetic connotation is placed upon the term; there is no certain evidence to show the origin of these rocks.

The leptites.

But although this is so, there are a number of features that suggest that the rocks are not normal sedimentary types and might more readily be expained as acid volcanic material:

1. Many of the leptites are fine-grained and show a high degree of sorting. For example, the fissile Mokkavann leptites, which outcrop between Lustadvann and Mokkavann, consist of large, euhedral or subhedral corroded crystals of plagioclase and perthitic alkali felspar averaging 1,2 mm across set in a finer-grained matrix of felspar and quartz, which averages 0,04 mm (Fig. 15); there is very little material of intermediate size. There is no sign that the fine grain is due to crushing and that the large felspars are secondary; in fact, the complex twinning often developed is on those twin laws supposed to characterize igneous rather than metamorphic felspars (Gorai 1950, Turner 1951). The twinning of the alkali felspar is often a distinctive combination of Carlsbad and Baveno individuals (Figs. 15, 16); these twinned felspar are so characteristic and so stritcly confined to the Mokkavann leptites that they can be used as an "index fossil" for this horizon. If supposing the grain size and distribution is a primary feature, the rocks are considered as water-laid deposits, then they show an unusual



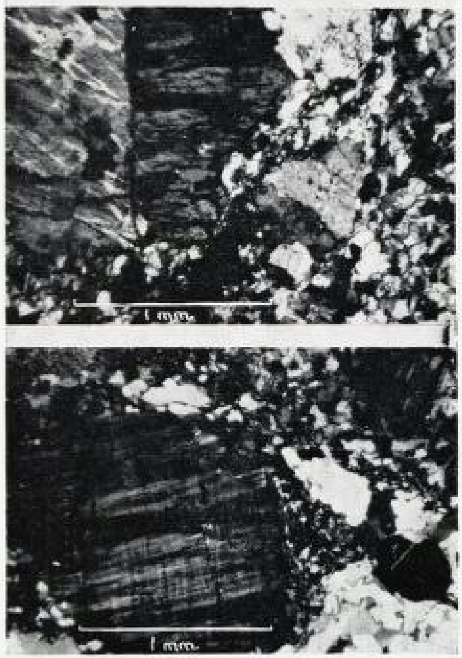


Fig. 15 a. (i) Corroded crystal of alkali felspar, (ii) showing complex twinning. From the fissile leptites on the north shore of Mokkavann.

Fig. 15 b. Photographs to compare the textures of (i) the Haervola granite and (ii) the Leksdalsvann arkoses.

size-roundness relationship of the grains. Pettijohn (1949, p. 404) has recorded that, in such deposits, the greater effect of abrasion on the larger fragments ensures that they are better rounded than the smaller grains. Where the combination of large, irregularly-smoothed material with small rounded grains occurs, it implies a dual source for the material. On the other hand, in volcanic rocks the occurence of phenocrysts or crystal fragments in a finer groundmass is fairly common; and, in texture, these leptites compare well with the rhyolite and rhyolite-tuffs described by Carstens from the Hovin Group (1960).

2. Another feature, which would make these leptites uncommon as sedimentary rocks, is their grain size relative to composition. The

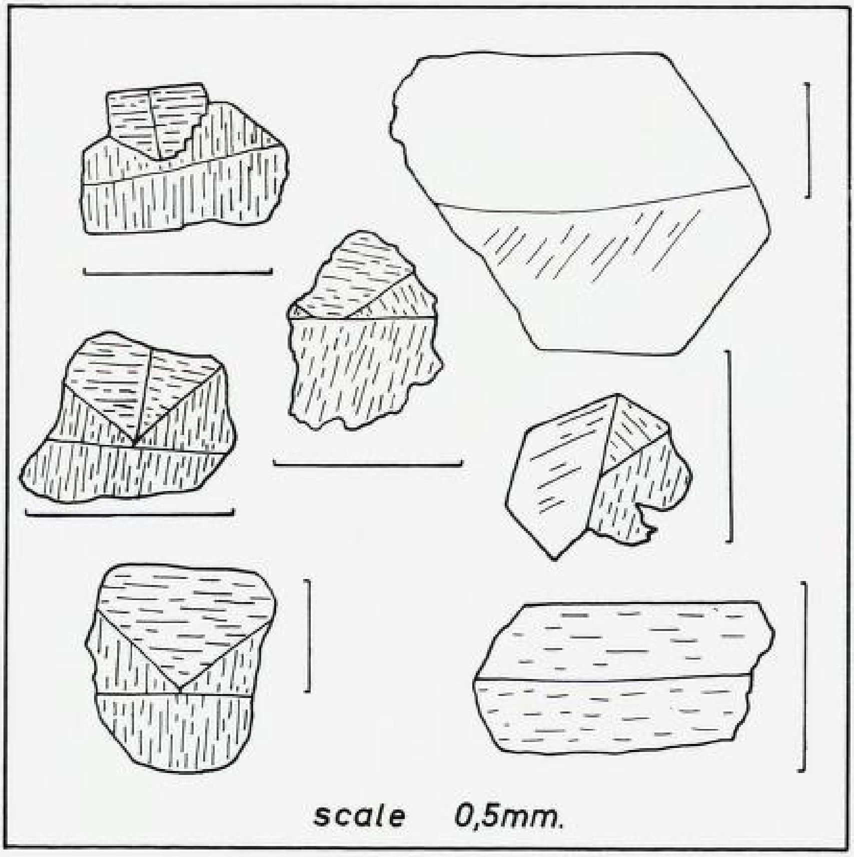


Fig. 16. Twinned alkali felspars in the leptites.

Mokkavann leptites, are for example, are very pure felspar-quartz rocks with generally less than 15 % of other minerals. The fine, even grain size of the bulk of the rock would imply a mature polycyclic sediment, and therefore the chief mineral would probaply be quartz; in fact it is felspar. Secondly, at this grain size (0,04 mm) which falls into the silt class, it would be normal to have a higher proportion of clay minerals or their micaceous derivatives, c.f. the lower unit of the Leksdalsvann Group.

These arguments are, of course, not at all conclusive, but may serve to show that the leptites could be more reasonably interpreted as acid volcanic rocks than as felspar-quartz sediments.

But whatever their origin, it is clear that the lithological variations within the leptites are disposed in a regular, stratified manner, and that this stratification is parallel to that of undoubted sedimentary horizons. The most extensive marker horizon in the massif is the Bjørntjern schist band, (Fig. 32) which runs in a semicircular outcrop from Tangen, north-east to Nordslettjern, and then south on the west side of Roktdal; its probable continuation can be followed west from Kjesbuvann. This band consists principally of muscovite schists and miceous leptites, but interbanded with them are graphite schists, limestones (Skorovass A/S, personal communication) and very pure, sugary quartzites.

The micaceous leptites.

There are also other more local horizons of quartzites (e.g. west of Roktdal) interbanded with micaeous leptites, and the association of the two rocks types suggests that the micaceous leptites may themselves be sedimentary. Slight support for this theory is given by the fact that when they are interlayered with, or immediately adjacent to the Mokkavann leptites, they too contain the characteristic twinned felspars. There are several interpretations of such an occurence, or it might be purely coincidental, but one explanation could be that the micaceous leptites are the weathering products of the Mokkavann leptites, and that the twinned felspars are derived from the latter. The higher proportion of mica in these rocks could then be explained by the weathering and secondary formation of clay minerals by breakdown of such primary constituents as felspar and magnetite. And it would then not be strange that many of the micaceous leptites resemble both parts of the upper unit of the Leksdalsvann Group, and the basal felspathic quartzites of the Snåsa Group; if all three are derived by weathering of granitic rocks, small wonder that they look alike.

The granite gneisses.

In some cases it seems that the granite-gneisses, or augen gneisses as they are sometimes developed, are a variant of the micaceous leptites, produced from them by the re-growth of potash felspar during metamorphism. On the western side of the massif, for example, the uppermost rocks of the sequence are mica-rich leptites which, along the strike, are patchily developed as granite-gneiss or augen-gneiss. The growth of secondary felspar is a phenomenon, which also affects the base of the Leksdalsvann Group (see p. 44), and, in the road section north-east from Støren in Ogndal, the different types can be examined. There is an even transition from the brown biotite-garnet-muscovite-amphibole schists which belong to the Leksdalsvann Group, through biotite-bearing augen schists to muscovite-biotite augen-gneisses, which finally rest against the massive, pink rocks with conchoidal fracture that are characteristic of the "true" leptites.

Biotite- and amphibole-sphene-bearing varieties of granite-gneiss seem to be derived from local horizons of biotite schist and amphibolite within the leptites. Such rocks cannot be explained as the weathering products of leptites and must represent thin intercalations of sedimentary and volcanic rocks. The amphibolitic variety is confined to the eastern border of the massif; the "parent" rocks can be seen beneath the bridge across the Mokka river on the main road west of Mokk, and their gradual transformation to streaky granite-gneiss can be followed in the river and road sections westwards. On the western border of the massif, in the river section at Støien, are exposed other sedimentary rocks which form the highest members of the Tømmerås Group; they are well-banded felspar-quartz-muscovite-epidote rocks with accessory sphene and secondary chlorite.

One type of granite-gneiss, which does not fall into the above category, is that which makes up the main Haervola granite. This mass has been mentioned by G. Holmsen (1919) and C. W. Carstens (1920), who considered it to be a Caledonian intrusive rock. Wolff (1960), however, was able to show that the cross-cuting veins, thought to be igneous, were tectonic origin, and he suggested that this was a pre-

Cambrian granite, impressed with Caledonian structure. It is a coarse-grained, ill-foliated rock, with crystals of plagioclase, microcline and microcline-perthite up to 5 mm across, set in a finer quartz-plagioclase matrix (Fig. 15 b). The quartz has an uneven distribution and, in hand specimen, appears as large bluish patches against the pink or white felspar. The other minerals generally comprise less than 15 % of the rock; they are biotite, muscovite, chlorite, sphene, epidote and magnetite. Structurally above the Haervola granite lie amphibole- and biotite-bearing gneisses which can be traced continuously from the Mokka river, along Malsådal and west towards Kjesbuvann. There is a blurred transition from one to the other.

The granite itself seems to have a narrow, lenslike form; north of Kjesbuvann it thins out and its place is taken by leptites; similarly it thins northwards, but disappears beneath the thrust plane to the east.

It is the felspars from this rock that compare so favourably with those in the arkoses of the Leksdalsvann Group (see Fig. 15 b); perhaps a limit is set on the possible coarseness of the arkoses by the grain size of the granite. On the other hand, the Haervola granite might itself be a slightly recrystallized arkose; it woul be exceedingly difficult to distinguish this from a coarse-grained foliated granite. No opinion is expressed by the author about the origin of this rock.

SUMMARY

The rocks of the Tømmerås Group fall into three main groups, and evidence for the origin and derivation of the different rock types is given above:

(a) sedimentary rocks and micaceous leptites

Thin zones of mica schist, limestone, graphite schist and pure quartzite are interpreted as sedimentary differentitates. The mica-rich leptites which are interbanded with them are also considered to be sedimentary, derived by weathering of the leptites.

(b) "True" leptites are distinctive fine-grained, felspar-rich rocks which, from the foregoing discussion, may perhaps be more readily interpreted as acid volcanic rather than sedimentary rocks. The arguments are, however, inconclusive. The lithological variants are found to occur as regular stratified units parallel to the banding of sedimentary horizons; these rocks may thus be acid lava flows or tuff deposits.

(c) The effect of metamorphic segregation upon the sedimentary rocks and the mica-rich leptites has been to produce patchy developments of granite-gneiss. All stages of the transformation can be seen. One type of granite-gneiss, however, which cannot be explained in this way is the Haervols granite: its origin is uncertain. It seems to have been the source material for the arkoses of the Leksdalsvann Group.

Basic rocks intrusive into the Tømmerås Group.

A minor constituent of the Tømmerås Group are the numerous thin metadolerite sheets, which are found amongst the predominantly granitic rocks of the massif. The least altered examples of these are coarse-grained, massive rocks showing ophitic texture and cross-cutting relations to the country rocks. They show all stages of alteration from the partial replacement of the original pyroxene by amphibole, through amphibole-plagioclase-epidote rocks to biotite-amphibole, chlorite-biotite-amphibole and finally chlorite schists.

In all three other groups there occur amphibolites (very rarely in the Leksdalsvann Group), but although there are bodies of comparable size and thickness to the metadolerites, ophitic or other typically plutonic textures have never been observed. This suggests that the origin of the two types may be different and that this coarse-grained type of basic igneous rock is restricted to the Tømmerås Group. Hence the intrusion of the swarm of dolerite sheets is probably an episode which predates the deposition of the other three groups. On this assumption, they are treated as part of the Tømmerås Group.

In texture, the basic sheets range from ophitic gabbro to medium-grained dolerite, but since the degree of secondary alteration is roughly proportional to the thickness of the body, it is not possible to tell whether there were originally any finer-grained types. The largest of them are up to 450 m in thickness and, in general, are elongate lenses in shape; a typical example is seen on the west coast of Mokkavann, is 150 m thick but at least 2,5 km long. At the edges and along fracture planes, the patchy ophitic texture of the rock becomes streaky and finally disappears altogether, whilst the pyroxene and amphibole are replaced by chlorite. On the ground it is not possible to see any discordance, but on a larger scale the body is found to taper and cut across the banding of the leptites; this can, for example, be observed on the aerial photographs.

Fig. 17. Discordant sheets of chlorite schist in the leptites.

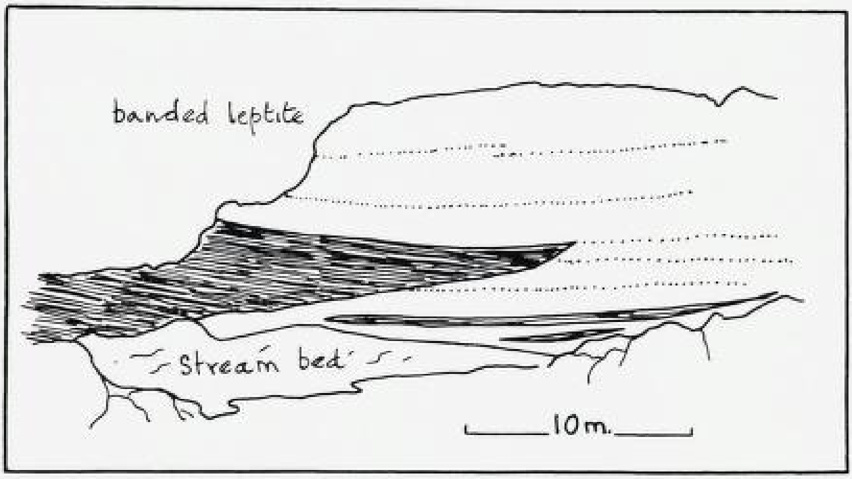


Fig. 18. Discordant metagabbro in the Tømmerås Group near Bjørntjern.

Locally, however, discordance can be seen even in quite thin basic bands. Fig. 17 shows lenses of chlorite schist a few centimetres thick, which cut across the banding; and Fig. 18 shows a thicker discordant body in which the development of regional cleavage can be seen.

These sheets have had a long history and it is not surprising that they show many complex features. From their field relations it can be established:

1. that they were originally intrusive, and at least partly discordant,
2. that, since they have developed a schistosity parallel to the regional cleavage, they pre-date the regional deformation, and
3. that, as there is strong recrystallization parallel to the axial directions of the regional structures, the two are synchronous, and hence, the sheets have also been subject to the regional metamorphism.

The schistosity shown in Fig. 18, is a product of that regional deformation and recrystallization. Frequently the schistosity and the banding in the leptites are virtually parallel and differential slip along the layering has produced incredibly intricate boundary relations between the two rock types. The basic material appears to send tongues and apophyses into the country rock, parallel to the banding, but this is a secondary discordance of tectonic origin. An example of this is shown in Fig. 19 and with it a sketch to show illustrate how a simple lensoid body may be deformed by differential slip of this kind.

The distribution of these metadolerites is uneven and seems to be partly controlled by the physical properties of the country rock. In the fissile Mokkavann leptites, for example, there are tens of small sheets, only a few centimetres thick, exposed along the shores of Lustadvann and Mokkavann. Elsewhere they seem to occur as local swarms of thicker bodies; examples are seen near Vesterås, between Løvvann and Mokkavann, east of Støen and near Bjørntjern (Fig. 23). The broadly circular outcrops north of Hatlingvann and Løvvann are the intersection of flat-lying sheets with the topography.

'Stratigraphy' of the Tømmerås Group.

Lateral variation of the lithological units makes it difficult to establish a stratigraphy for the whole of the massif, although it is clear from their outcrop that the units show a regular disposition parallel to

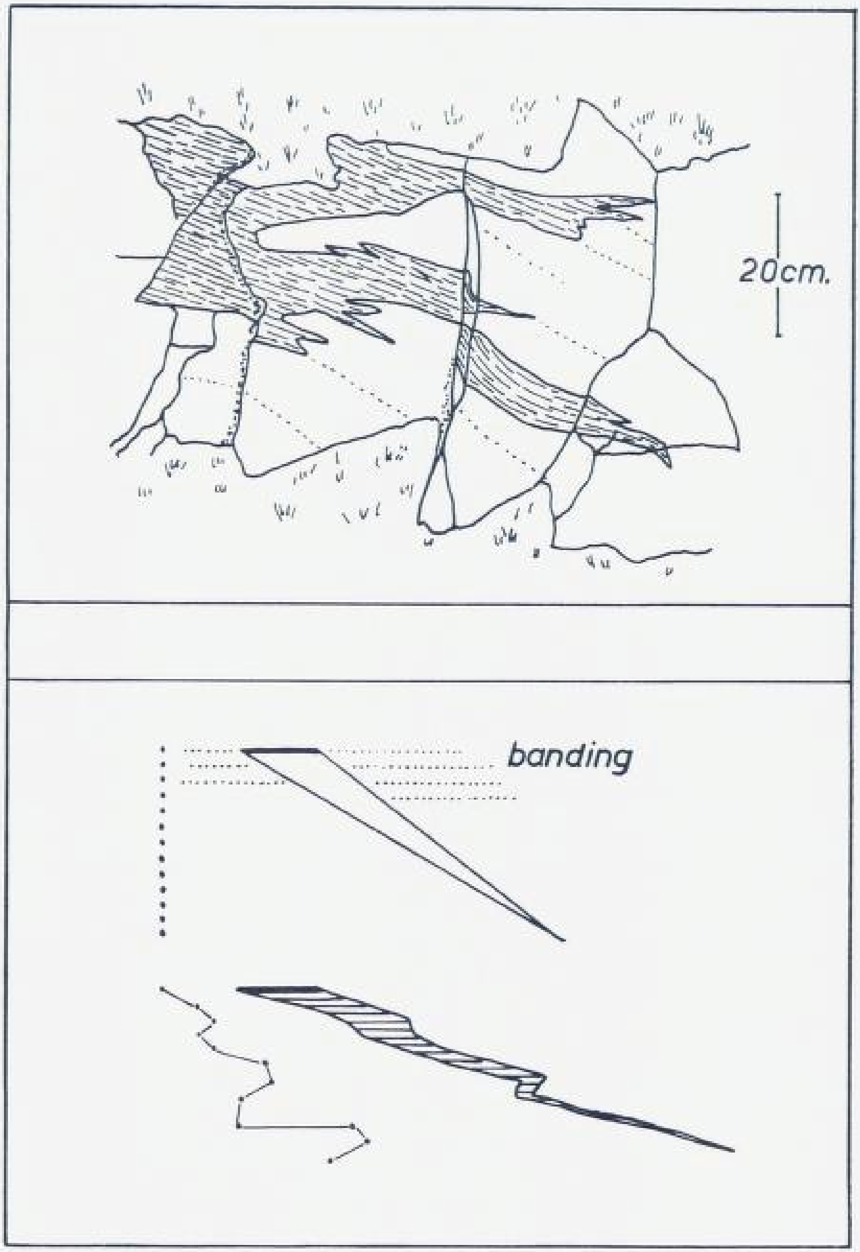


Fig. 19. Deformation of the basic sheets. Jørstaddal.

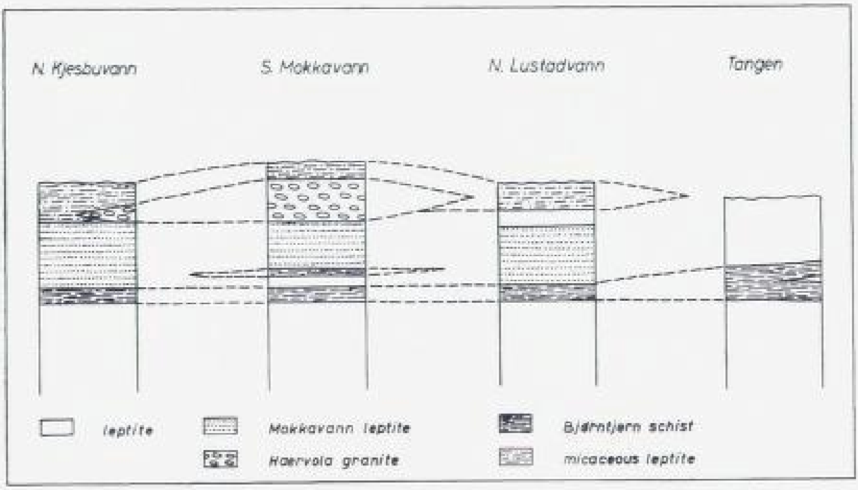


Fig. 20. "Stratigraphy" of the Tømmerås Group.

the sedimentary bands, which may represent time planes or time zones. There is no means of discovering which way up the succession is.

But by using marker horizons it is possible to make a rough division of the rocks (Fig. 20). The Bjørntjern schist is the most important of these; the Mokkavann leptites and the Haervola granite are also useful, although more local in extent. The field mapping has been supplemented with photogeological data, and by study of the aerial photographs it has been possible to pick out lithological variations in the leptites, which, on the ground, can hardly be distinguished. In this way an imperfect structural succession can be built up; it, and the distribution of the broader lithological units is shown in Figs. 20, 21. It demonstrates the lens-like character of many of the horizons. The mica-rich leptites, which so often are the highest unit of the succession, may represent a "basal arkose", a deposit following the pre-Palaeozoic form of the massif; this would explain their slightly discordant relations to the other lithological units.

The earlier history of the basement block.

If the arguments of the foregoing chapters are valid, and there exists an almost-undisturbed primary unconformity between the Snåsa—Leksdalsvann Groups and the Tømmerås Group, it must then follow that the substratum has been equally little affected by subsequent events. Hence it will show the original erosional surface, and its banding will be as it was before the sedimentary rocks were deposited on it. In these circumstances it should be possible to work out the appearance of the basement block, and its history prior to the deposition of the Snåsa and Leksdalsvann Groups.

One event which in exclusive to the history of the basement is the intrusion of the dolerite dyke-swarm, which has been discussed previously. It is obviously earlier than the deposition of the Leksdalsvann Group, but later than the formation of the Tømmerås Group itself.

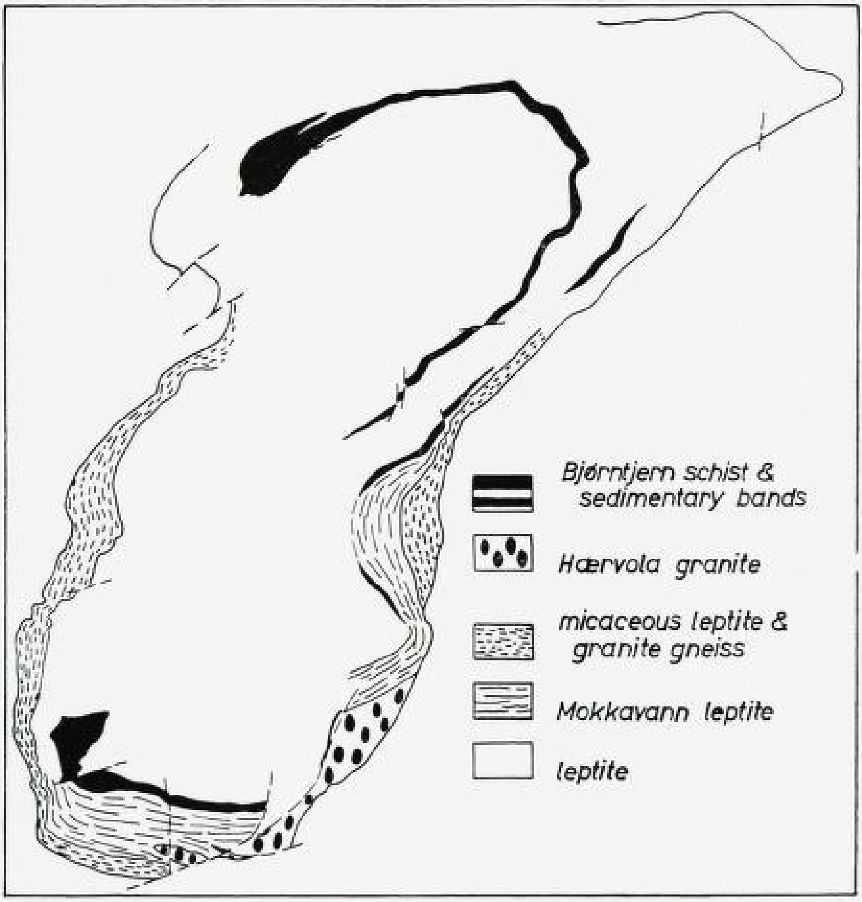


Fig. 21. Map of the lithological variation in the Tømmerås Group.

It has already been argued that the banding in the Tømmerås Group is a primary feature and that it can be considered as a rough stratigraphy. If a plane of erosion forms the upper limit of the group, it would be reasonable to expect that the stratigraphy be truncated by it, and for there to exist a "double discontinuity"; i.e. that relative to the erosion plane, the rocks both above and below would be discordant.

The actual boundary relations, seen in Figs. 21 and 32, are unexpected. The outcrop of the lithological units in the basement is substantially parallel to that of the erosion surface; only occasionally, for example on the north side of Jørstaddal, is there a small angular discordance visible. This must mean that, at least in the "strike" section that can be seen today, the banding of the leptites was virtually parallel to the topographic surface of the basement at the time of the deposition of the Leksdalsvann Group. For this reason a profile through the Tømmerås massif shows a simple, shell-like structure (Fig. 22). If the dip of the erosion surface were considerably different from that of the banding the effect of this would appear in the outcrop pattern, and therefore it is reasonable to assume that in this direction also the two surfaces are roughly coincident.

An implication of this conclusion is that the leptites formed a rather gently-dipping substratum for the sediments of the Caledonian cycle; even now, after being folded across the axis of the Tømmerås anticline, the dip of the surface is rarely more than 20° in any direction. The idea of flat-lying pre-Cambrian basement rocks is not new; Oftedahl (1964, see paper in this journal) has already suggested it, and considers it is a general feature of the pre-Caledonian substratum. The only unusual thing about the present occurrence is that this is a case where the concordance of the basement rocks and the surface of discontinuity can demonstrably not be secondary.

The Tømmerås Group cannot, however, have been perfectly horizontal; the Leksdalsvann and Snåsa Groups are plainly banked against the erosion surface. It seems probable that the Tømmerås massif was already established as a stable crustal area at this time, even if not as a dome of positive movement; and that this tendency has influenced the location of the present Tømmerås massif. Thus the fold-ridges and troughs of the Caledonian orogeny simply accentuated an older pattern of sedimentary domes and basins, already established.

Although the massif must probably have been an submarine ridge, its axis need not have been coincident with that of the present structural

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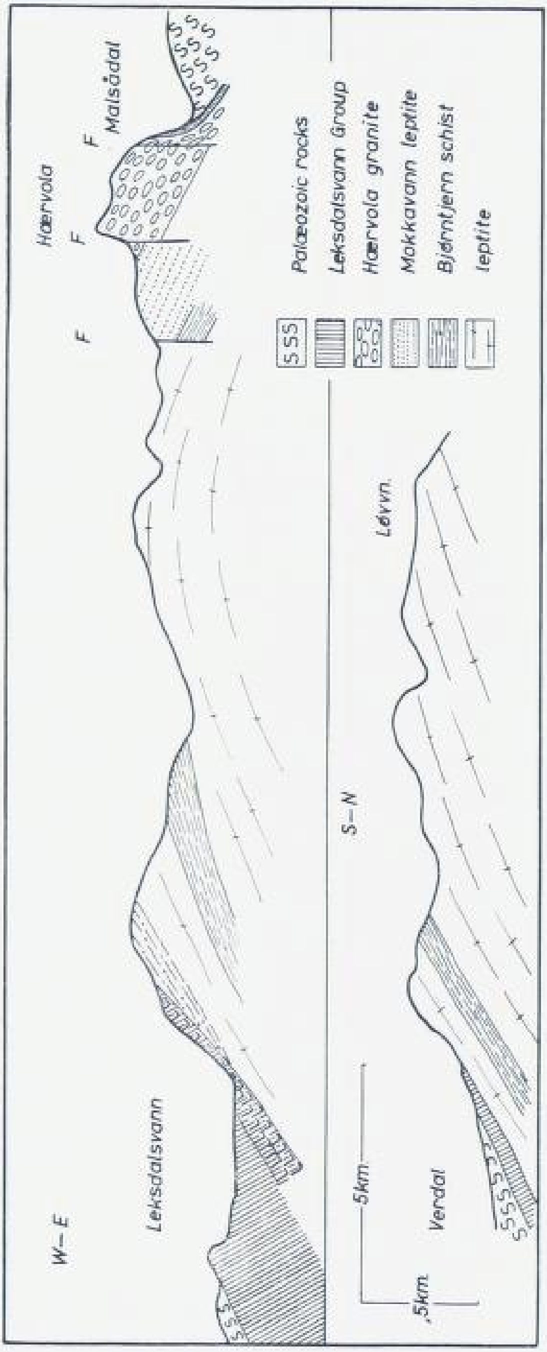

Fig. 22. Profiles across the Tømmerås anticline.

feature. In fact the outcrop patterns of the different units in the two groups suggest that it ran in a more north-south direction, and slightly west of north roughly along a line joining the extremities of the Leksdalsvann Group. If it were possible to discover accurately the kind of deformation which has produced the Tømmerås anticline, and, more important, the direction of tectonic transport, (the "a" direction) within this fold, it would be possible to correct the secondary deformation of the erosion surface, and so to arrive at its original orientation. The author has not been able to do this although it may be feasible. Instead a hypothetical case has been constructed, conforming as nearly to the known conditions as possible, to test the hypothesis that: the section exposed today on the ground surface is a profile through a lens-like deposit, which was banked against a surface striking roughly north-south, and dipping west; the sedimentary rocks thin in three directions, towards the east up the dip, and both north and south along the strike. This is easier to visualize if the shore-line is imagined to be concave westwards. The deposit has later been folded across the axis of an anticline, plunging south-west; and part of the shore-line eroded away.

Fig. 23 is a stylized example of this. To simplify construction the trace of the axial plane has been made at right angles to the supposed shore-line; the first runs N.E.–S.W. and the second N.W.–S.E. The deposit is treated as being as simple semicircular shape, which is alike in profile along the three principal directions, down the dip of the erosion surface and in both directions towards the thickest part of the deposit parallel to the shore-line (see Fig. 23 b) Fig. 23 a is a plan of the deposit and shows the boundary of the upper sedimentary unit, A with the basement; the profile beneath shows how the deposit is made up of two units both thinning towards the shore; as the lower one, B is of lesser extent it does not initially appear on the ground surface (datum plane 0). The two surfaces, one the junction of A and B, and one the erosion surface of the basement, have been contoured to show the regular dip of the planes. The dip on the erosion surface is an arbitrary angle of 16,5°, and that of the surface A-B, 3°. The axial plane of the later fold is taken as being both a symmetry plane of the deposit (i.e. it runs down the centre at the thickest part) and as being normal to the datum plane 0; it therefore appears on the plan as a straight line, and the plane rises vertically out of the page. The axis of the fold, however, which lies within the plane, plunges at 30° E.W. (i.e. from the shore-line towards the sea).

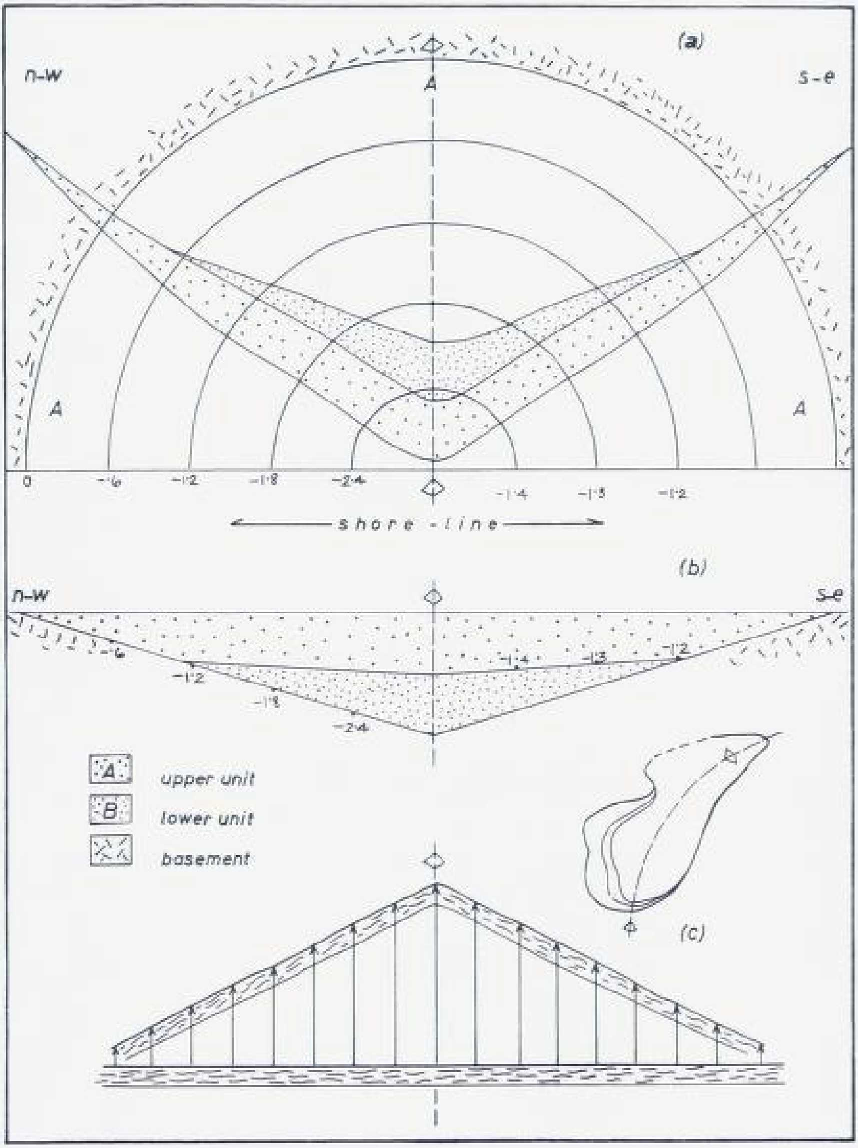

Fig. 23. Diagram to illustrate folding of the basement and its sedimentary cover.

Fig. 23 c is a cross-section of that fold, normal to the axis, to show the mode of deformation by shear-slip of the rock-mass along planes parallel to the axial plane. The "a" direction is, in this simple case, a line contained with in the axial plane and rising vertically out of the page. By superimposing this deformation on the known shape of the sedimentary deposit, it is possible to arrive at the final outcrop shapes for the two units. As the deformation causes the units to be partly lifted above the datum plane 0, it is convenient to plot the out-crop patterns on this plane.

The final result is shown by the arcuate plan shapes seen in Fig. 23 a. These are very similar to the actual outcrop patterns of the Leksdalsvann Group, and it would therefore seem that it is reasonable to visualize deposition of the Leksdalsvann and Snåsa Groups against a roughly north-south trending ridge.

The structural history.

The deformational history of the area is surprising in a number of ways. Firstly, there seems to have been no folding in the basement prior to the deposition of the overlying sedimentary units; the regional deformation is common to all the rocks. Secondly the folding has been rather gentle and produces a simple regular pattern of structures; and thirdly, the faulting has substantially modified this simple pattern.

The deformation can be divided into three phases; two episodes of folding followed by the development of faults and fractures:

(a) the regional folding, which is accompanied by widespread recrystallization and regional metamorphism,

(b) later folding, which is a brittle, mechanical deformation, and

(c) faulting.

The three phases are separated in time, but there is no means of telling how long the intervals may have been. The regional folding affects middle Ordovician rocks and must therefore be Caledonian or later in age.

(a) *The regional folding.*

The dominant linear and planar structures in the area, which are seen to some degree in all the rocks, belong to this period.

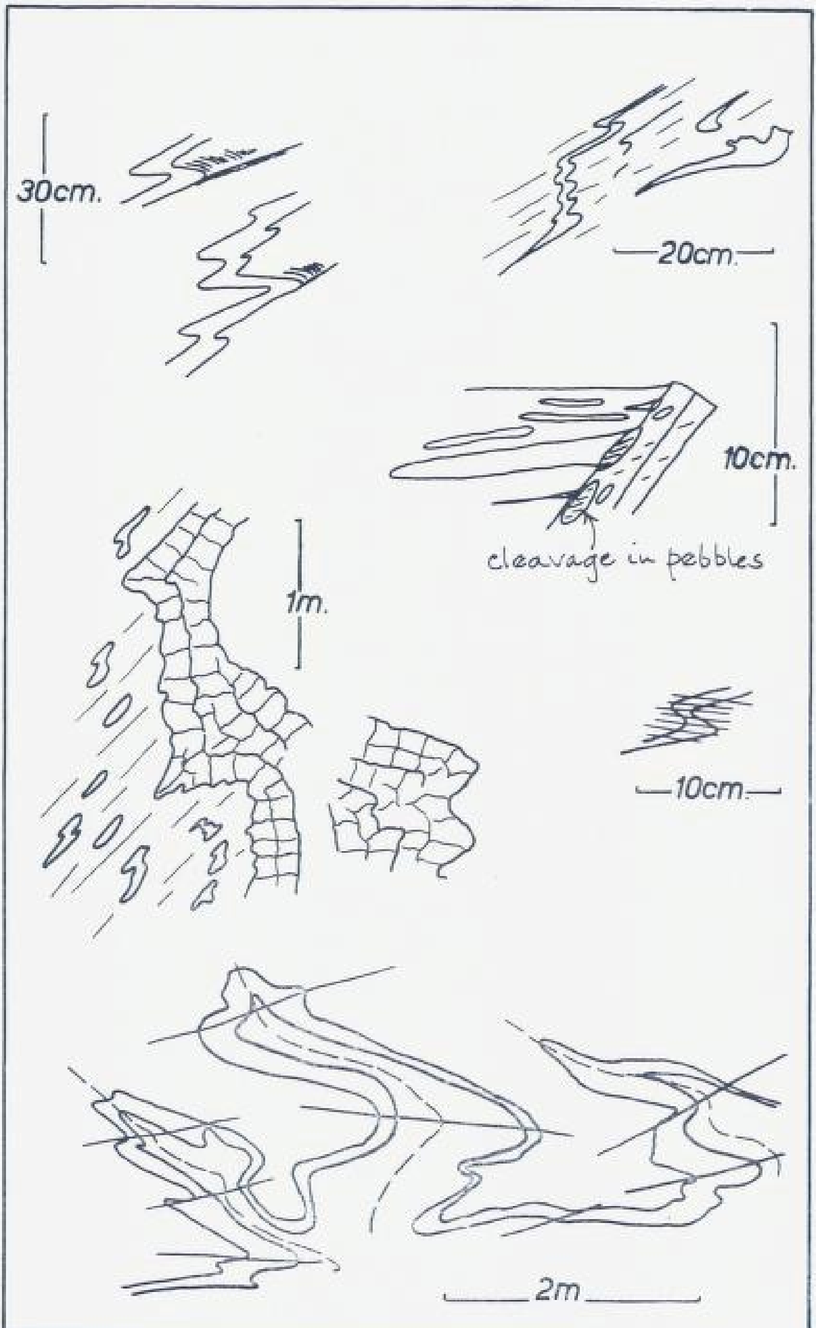

Fig. 24. Structures formed during the regional folding.

They are accompanied by regrowth of minerals, and the lineations comprise the outcrop of cleavage (schistosity) on bedding, marked by such minerals as mica or shape-oriented amphibole and quartz aligned parallel to the axial plane, or linear elements, which may be picked out by elongated quartz or acicular amphibole. In the Steinkjer conglomerate the pebbles are sometimes aligned parallel to the axial plane schistosity, and may be elongated in the direction of the regional lineation (Fig. 24).

The intensity of the structures varies according to the rock type and according to the position in the stratigraphic sequence; for example the massive leptite and the felspathic sandstones show very weak lineations, whilst the higher members of the succession seem less deformed than those near the base. This does not necessarily mean that the intensity of folding decreases upwards, although this may be so; both effects might be partly conditioned by the regional metamorphism, i.e. because of their composition the felspathic sandstones and some of the leptites are not strongly affected by metamorphism and therefore show a weak lineation; similarly the metamorphism itself seems to die out

Fig. 25. Regional folds and quartz-felspar segreations on the north shore of Mokkavann.

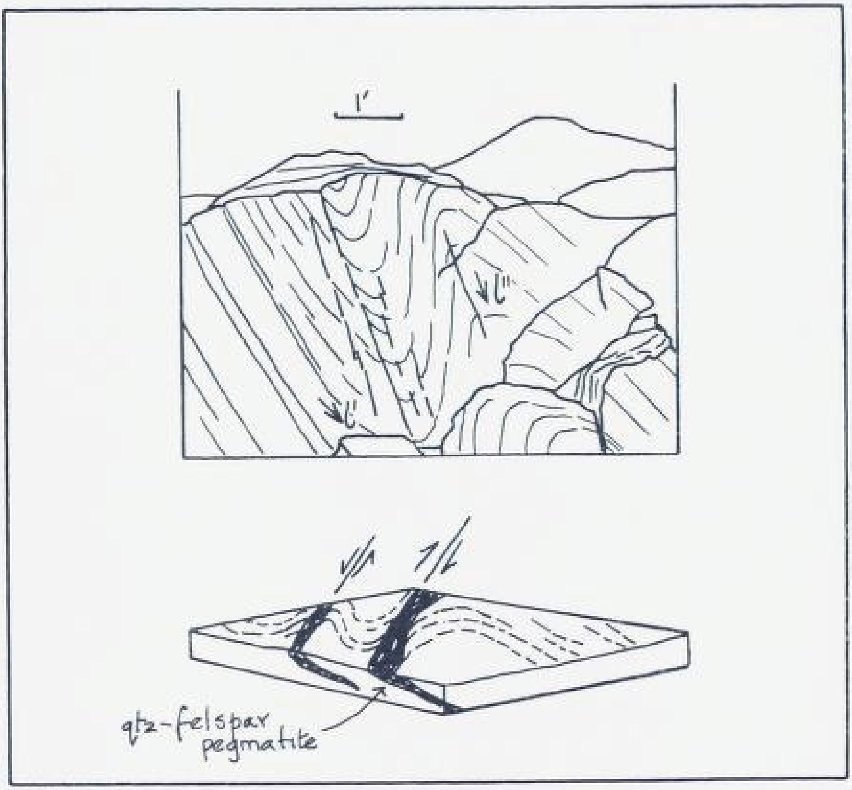

Fig. 26 a. Deformed lineations produced when the "ab" plan is coincident with foliation. (from Ramsay, 1960).
Fig. 26 b. Comparable structures near Bjørntjern.

upwards, and thus the visible evidence of the deformation would be less.

Lineations are the dominant structure of this phase. Folds are uncommon (Fig. 25), and although a schistosity, presumably parallel to the axial plane direction, is widespread, it forms so small an angle with the layering that it is not sensibly different. In the basement rocks the best development of cleavage is seen in the metadolerites (Fig. 18, 19).

The relationship of cleavage and bedding in such examples as that shown in Fig. 19 suggest an explanation for the lack of folds. Ramsay (1960) has reported instances of folding in which the "a" direction and the "ab" plane are coincident with the foliation. As the transport of material, parallel to the "a" direction, is contained within the foliation, deformation produces a lineation but no folds.

If there is an earlier lineation this will be deformed. Fig. 26 a is Ramsay's drawing of such an instance; it shows the earlier lineation (1') lying on an unfolded bedding plane, and crossed by the later lineation which is parallel to the "a" direction.

If, instead of being perfectly coincident, the planes were inclined to each other at a small angle, the effect would, in theory, be to produce folds of very small amplitude, but in practice these would be too gentle to be visible. It is suggested that the regional lineations in the area have been formed in this way, and that this mechanism could explain the lack of associated folds.

A parallel instance is seen in the area, where locally the regional lineations are affected by movements on fracture planes, filled with quartz-felspar pegmatite. These planes make a very small angle with banding in the leptites, such that no displacement is visible; the effect on the lineations, however, is very marked and they are thrown into a series of sine-wave folds, lying in the bedding plane (Fig. 26 b).

However, this hypothesis for the explanation of the regional linear structures is not entirely consistent. Fig. 33 shows the distribution of the lineations; if the hypothesis is valid and the lineation direction is coincident with the "a" direction, then it has varied considerably from place to place in the area. Whilst the lineation trends roughly N.W.–S.E. in the part south of Ogndal and along Roktdal, in the northern half between Tangen and Snåsa it swings north-south and finally become coincident with the trend of the Snåsa syncline.

The reason for this may be that the present fold structures are an accentuation of earlier ridges and troughs, and hence the deformation was superimposed, not on a simply-dipping sequence of rocks, but upon an already-established pattern of structures. Alternatively, the difficulty of interpretation may be caused because structures from two phases are being treated as one. The possibility of this mistake is inherent in the method of distinguishing the regional lineations; if there were an earlier phase of strong deformation producing, for example, a lineation running N.W.–S.E., crossed by a weaker, sporadically-developed set of structures running N.E.–S.W., and with the latter or both phases accompanied by metamorphism, they would be very difficult to distinguish.

If this alternative is the correct explanation, then the majority of lineations in the area, those trending N.W.-S.E., belong to an earlier phase which affected both basement and cover rocks. The folding which produced the Tømmerås anticline was accompanied only locally by linear structures, and this deformation has distorted the earlier ones so that they plunge east and west from the axial plane of the major fold. Arguments against this alternative are that it does not explain the lack of folds in both phases, and that it seems difficult to believe that, for example, the stretching of pebbles in the Steinkjer conglomerate is caused by one phase when they are oriented down the dip of the foliation (near Gustad) and by a quite different phase if they are aligned along the dip (near Navlus), particularly as there seems to be an even variation of plunge from the one orientation to the other.

But if the minor structures show a complex pattern, that of the major folds is relatively simple. The Tømmerås anticline is a broad shallow ridge, whose axial plane trends north-east.; the dip of the limbs is between 20° and 30° on either side. The main axis of the fold has a gently wave-like form (Fig. 22); and, because the fold is so nearly symmetrical, it lies within the axial plane. If it is followed northwards from Verdal, the south-westerly plunge of up to 20° gradually decreases and north of Ogndal, the axis is roughly horizontal. Farther north near the lake, Øiingen it begins to plunge north-east and finally reaches between 20° and 30° in Jørstaddal. The continuation of this fold can be followed on the sheet "Jaevsjø", and subsequently it will be shown that a chance disposition of topography and an axial depression has led to the geographical separation of the "basement porphyries" from the rocks of the Tømmerås Group. It is difficult to tell whether the axis was originally variable, or whether the present arrangement of domes and basins has been brought about by gentle flexuring along axes belonging to the second phase of folding.

North of the Tømmerås anticline the complementary syncline is the Snåsa syncline. Little of it is shown on the map, Fig. 32 but it will discussed more fully later under the heading "Regional synthesis". Part of its south-eastern limb is seen in the north of the area, and near Snåsa the dip is very gently north-west. A dip of up to 20° is generally more common on other parts of this limb, and the unusually small values at this point seem to be a secondary effect caused by flexure across a later axis. The axis of this fold too shows a wave-like form; although along the coast near Tangen it plunges gently south-west, at

Navlus it is virtually horizontal. The southerly complement to the Tømmerås anticline, is the Verdal syncline. Little of it is seen in the present area, and it will therefore be discussed in the chapter on the regional synthesis.

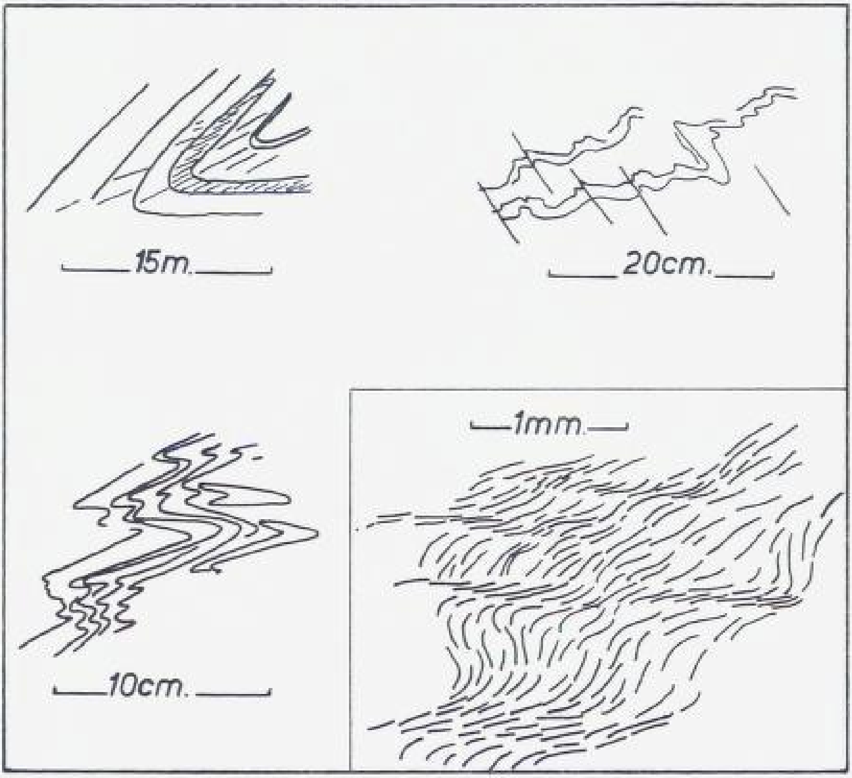

Fig. 27. Later fold structures.

(b) *The Later folding.*

Structures of this age (seen in Figs. 27, 28) comprise open folds and lineations, which are due to a mechanical alignment or rupture of minerals, or to minute crinkling of the foliation. Parallel to the axial plane there may be a "strain-slip" cleavage, which in thin section shows as a "herring-bone" arrangement of micas or a dragging of the minerals into planes parallel to the axial structure, but there is no recrystallization of minerals parallel to this direction. In the felspathic sandstones the axial plane may be marked by fractures spaced 0,5—1 m apart. Folds of this age distort the regional lineations on both a minor and a major scale (Fig. 33, see Later fold west of Hatlingvann); they are therefore younger than the latter. They are developed sporadically over the area (Fig. 33) on axial planes which trend east-west or slightly south of east, and the axes seem to take their orientation from the position of the earlier fold limbs; thus on the west side of the Tømmerås axial plane, the limb dips west and the folds plunge in the same general direction. On the east side of the anticline the later folds plunge east, whilst at the crest of the fold they are horizontal. The amount of plunge is variable and does not seem to show a systematic pattern.

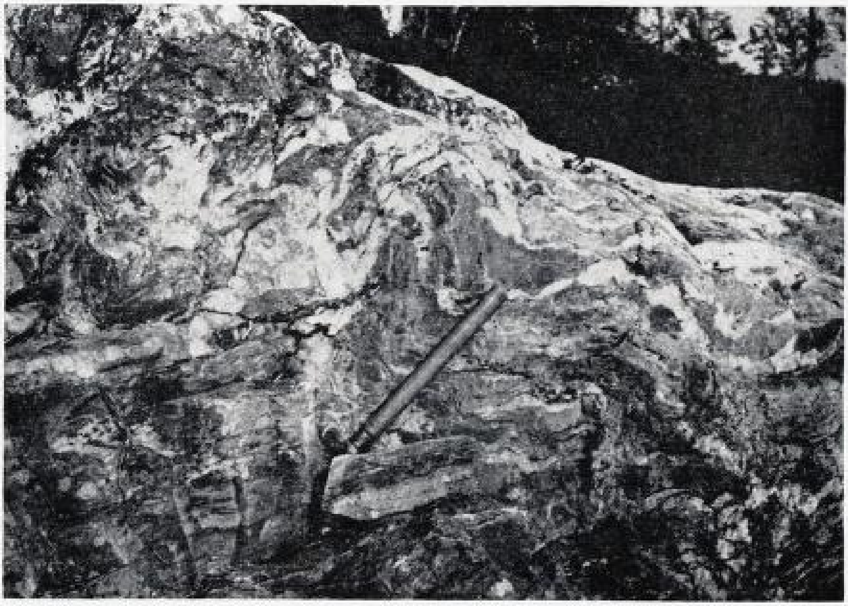

Fig. 28. Later folds on the south shore of Mokkavann.

(c) *Faulting.*

A systematic study of the fracture pattern has not been undertaken, but the directions of the main faults is evident from the displacements seen on the map, Fig. 33. They can be resolved into two sets, one trending 10—25° and the other at 60—75°; a few fractures at an intermediate value of 45° are found. A sketch of the chief faults and their sense of movement is shown in Fig. 29. The amount of vertical or horizontal displacement cannot be determined, but if the disturbance to the regional strike direction is any indication of the element of tear movement, then most of the displacement is concentrated in a vertical sense. Only along the eastern border of the Tømmerås massif is there distortion of the regional strike, which seems to indicate a sinistral component of drag in both sets of fractures.

The 45° set is the least widespread, and one of its chief representatives is the fault which causes repetition of the nose of the Later syncline, west of Hatlingvann. The south-eastern block is downthrown. The boundary between the upper and lower units of the Leksdalsvann Group in Ogndal is another fracture belonging to this set. A topographic fault-line scarp marks the edge of the raised southern block.

Both the other two sets are represented by numerous fractures. Those belonging to the 10—25° set are well-developed along the south shore of Snåsavann and on the east side of the Tømmerås massif. In general, the eastern block is raised relative to the other on the north-west side of the massif; on the south-east side, the sense of movement is the reverse. There is often strong crushing in zones up to several metres thick along these planes.

The 60—75° set are perhaps the most important fractures; they may be many kilometres long, and members of this set can be identified on the sheets "Sanddøla" and "Overhalla". They are also accompanied by mylonitization, and, as with the previous set, their sense of movement seems to depend on their position relative to the basement block. Thus, in general, on the south-east side of the Tømmerås massif the downthrow side of the fault lies to the south, whilst on the north-east side it lies to the north.

Many of the faults are marked in the present landscape, and because of this the edges of the massif are often bounded by cliffs. The block is topographically a raised feature. This is probably not a coincidence. Fig. 29 shows how the faults are arranged around the Tømmerås block, and, that in nearly every case, the displacement on them is such that the massif is raised at the centre relative to the sides. The pattern can be simplified to show the block enclosed in a parallelogram, so that on all sides the surrounding rocks lie at a lower level.

It is probable that the shape of the basement massif, elongated along a N.E. axis, has been still further distorted by slip along these fault

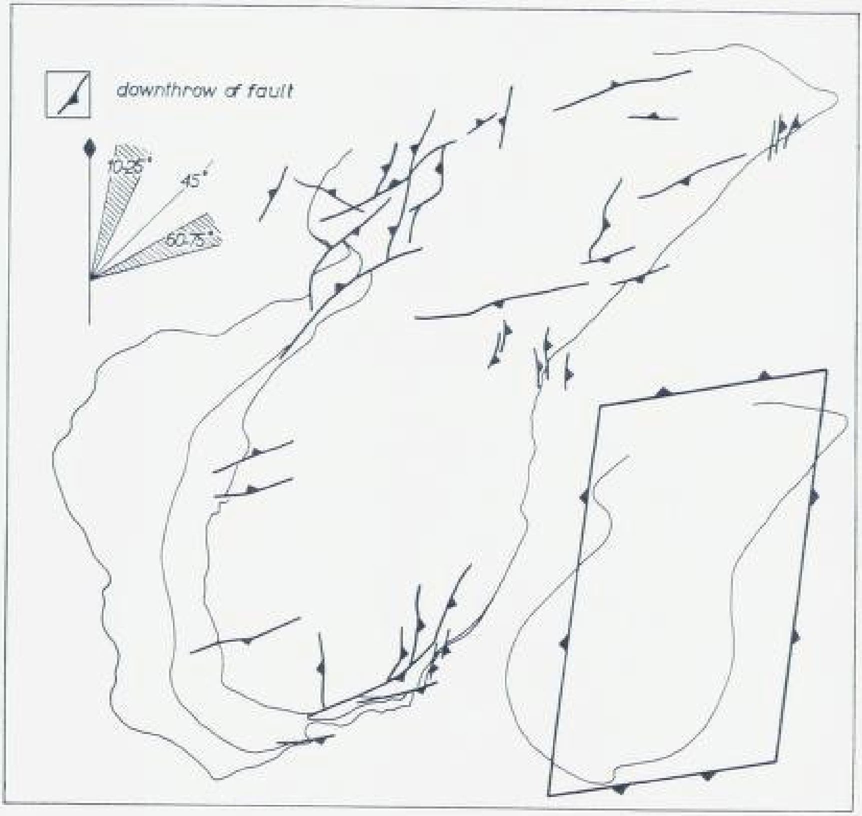

Fig. 29. Fault pattern showing uplift of the Tømmerås basement block.

planes, which, in theory, corresponds to a cumulative extension of the block in a north-easterly direction. On the north side of the Snåsa syncline, two important members of the 60–75° set show a downthrow on the south side; once again the basement is raised relative to the younger rocks, and the synclinal troughs lowered still further. It is interesting to speculate how much these later movements reflect a long-established pattern of vertical displacement.

From the history that can be built up in the present area, the Tømmerås block existed as a submarine ridge before Caledonian sedimentation began; its trend and probably those of the sedimentary troughs were already established, as Carstens (1955) has suggested. This pattern was apparently simply accentuated by the Caledonian fold

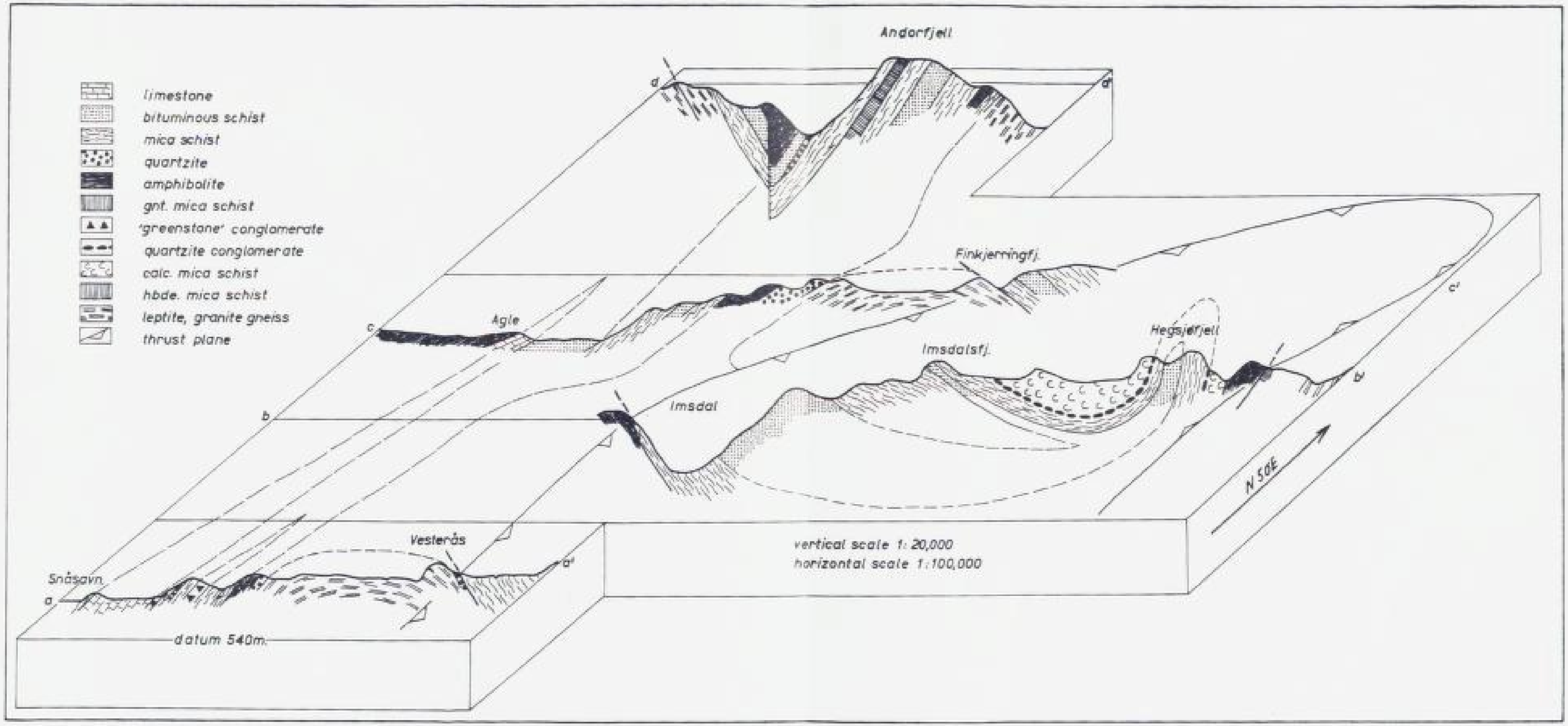

Fig. 30 Sections across the Tømmerås and Verdal folds.

structures, and in the most recent episode of deformation the same sense of displacement, with rising basement blocks and sinking troughs between them, has continued to influence the faulting.

Mineralization.

The principal minerals found as fillings along the fracture planes are chlorite, quartz, felspar and calcite. The particular mineral present is dependant largely upon the composition of the country rock; thus quartz-felspar or quartz-calcite assemblages are common in the leucocratic rocks, whilst quartz or chlorite and quartz are most frequent in the greenschists or amphibolites. The only occurence of economic interest is the Roktheia lead-zinc deposit, which is located along fractures belonging to the 10—25° set, perhaps the continuation of those which distort the eastern boundary of the Tømmerås Group, north of Lustadvann. The gangue mineral is quartz.

The metamorphism.

The petrology and chemistry of these rocks has not been sufficiently well examined for any detailed conclusions to be reached about the metamorphism. The only observations which will be recorded here are those which have been made in the field, and are of a quite general nature.

It has already been mentioned that the regional recrystallization is synchronous with the main Caledonian folding, and that the degree of metamorphism seems to decrease upwards in the succession. This is obviously much influenced by differences of composition, but in, for example, the lower unit of the Leksdalsvann Group, where it would be reasonable to assume a fairly constant composition, this seems to be true.

One metamorphic effect, which is related to composition, is the formation of augen, lenses or veins of quartz-felspar pegmatite. This is seen in all the quartzo-felspathic rocks; in the leptites and gneisses of the Tømmerås Group (Figs. 25, 28), in the upper unit of the Leksdalsvann Group, and in the felspathic quartzites at the base of the Snåsa Group. It is most frequent in the basement and might be mistaken for evidence of "mobilization" or of the igneous origin of these rocks. It may certainly indicate that, locally, partial mobilization took place in rocks of the right composition during the metamorphism, (see for example, the "blurring" of the upper boundary of the Tømmerås Group against the Leksdalsvann Group), but similar segregations of quartzo-felspathic pegmatite, found filling the late-stage fractures, suggest that a non-magmatic origin is the more likely explanation for these features.

Regional synthesis.

The Tømmerås anticline can be placed in a broader regional context by considering the geology of the areas immediately adjacent to it. To north-west lies the area described by H. Carstens (1956), and to the east, the areas covered by Foslie's two map sheets "Sanddøla" and "Jaevsjø", published by N.G.U. Although there is no description to accompany these sheets, the detailed observations recorded on them make it possible to infer something of Foslie's opinions. For example, on the sheet "Sanddøla" there is distinguished a unit called the Snåsa Group; on the sheet "Jaevsjø" the group is not mentioned by name in the legend, but it is clear from the lettered symbols for the lithological units that firstly, rocks of this group continue onto the north-west corner of the sheet, and secondly, that they are different from the Palaeozoic rocks farther to the east.

Fig. 34 is a composite map showing the areas mentioned above. The outcrop of the thrust plane, which delimits the Olden nappe, is taken from Oftedahl's paper on the Grong culmination (1955); the boundaries are those of the original authors, but the other major structural lines are based upon an interpretation for which the writer takes full responsibility.

1. *The Snåsa syncline.*

It has already been established that on the southern limb of the Snåsa syncline the broader lithological divisions of the Snåsa Group can be followed from one side of the Tømmerås area to the other, in spite of local variation. When the rocks are traced farther north, the same is found to be true.

The thin horizon of greenstone and amphibolite, which overlies the Snåsa limestone, becomes better developed as it is traced along the strike, and simultaneously the limestone dwindles and finally disappears. The Steinkjer conglomerate has not been recognized on the sheet "Sanddøla", but this is probably a mapping error rather than a lack in the stratigraphy since at Navlus at the northern border of the Snåsa sheet, it is at least 15 m thick.

Unit 4, the mica schists, is diversified by bituminous and calcareous horizons and there are two quartzite bands, the upper one of which is probably equivalent to the conglomeratic quartzite in the Tømmerås area (see p. 36). Units 3 and 2 are also present; the amphibolite (unit 3) thins northwards and disappears, whilst mica schists become the most important rock type in unit 2. It is possible that the basal conglomerate, unit 1, is also represented; Birkeland (1958) mentions a quartzite conglomerate at the base of the Cambro-Ordovician sequence 2 km south of Agle on the north side of the syncline.

Lateral variations continue north-eastwards around the nose of the Snåsa syncline, making it difficult to trace a continuous stratigraphy; but it is probable that asymmetry of this fold is principally due to structural causes. On the northern limb of the syncline the rocks are abruptly terminated against a straight line, which strikes at 62°, and the boundaries seem to be displaced sinistrally along this line for several kilometres; the displacement on the boundary of a bituminous schist horizon, for example, is 4 km. These observations could be reasonably explained by the presence of a fault belonging to the 60–75° set, (such as have been described from the Tømmerås area) on which there has been a relative vertical displacement of the northern block upwards. If this is assumed the two halves of the structure are found to fit together to make a simple synclinal fold, in which the northern limb is rather more steeply-dipping than the southern one (section dd, Fig. 30).

The presence of another fault belonging to this set can be deduced from the data shown on Carstens' maps (1956, 1960). A steep-sided narrow valley which runs unbroken along the north side of Snåsavann, from Holem south-westwards as far as Hjellebotn, marks the position of a line along which the geology is interrupted. Across this line the rocks change abruptly, and the Cambro-Ordovican sequence seems to be trucated against it.

Carstens has explained the narrow outcrops of Upper Hovin Group as small synclines, with greenschists below it on either side (1956, sections), but they could also be a simple syncline which is truncated by a fault, such that the northern limb is missing; this would explain for the absence of the basal conglomerate of the Upper Hovin Group on the northern limb. The movement on this fault has also raised the northern block relative to its southern counterpart, and the Upper Hovin rocks have been removed by erosion.

The difference in width of outcrop on the two limbs of the Snåsa syncline is due partly to these faults, but also partly to the shape of the fold itself. Near the nose the northern limb is almost vertical, whilst the southern one dips at 60—70°; farther south-west the northern limb remains very steeply-dipping, but the southern one flattens out and is finally bent across the Tømmerås anticlinal axis.

The effect of the two faults can be seen from Fig. 34. On the first, the displacement of the axial-plane trace is relatively little since the two lie so close together, but for a long distance (at least 30 km) along the second fault the crest of the Snåsa syncline is missing altogether.

2. *The Tømmerås anticline*

As the rocks of the Snåsa Group are traced south-east along Jørstaddal their northerly dip becomes less and less until finally they begin to dip south-east (section aa', Fig. 30). This anticline is the continuation of the Tømmerås anticlinal fold, and near Vesterås the axis has been depressed by intersection with a number of small Late folds. The intersection of the fold depression with the topography has preserved the lower units of the Snåsa Group as a cover above the Tømmerås Group, which, in this way, is separated by chance from its continuation, the "leptites and porphyries", on the sheet "Jaevsjø". The axial trace of the anticline turns north-east again north of Imsdal, and finally the fold is lost as it abuts against the Grong culmination. The effect of the Later folds is marked all along the north side of Imsdal, where the intersection of gently-plunging structures with the hummocky terrain, produces a complex pattern of outcrops.

The Verdal synform.

The section (aa', Fig. 30) across the northern end of the Tømmerås massif shows the rocks of the Snåsa Group truncated by a thrust plane and overlain by those of the allochthonous Palaeozoic. The tectonic discontinuity is marked by a zone of shearing, and on the sheet "Jaevsjø" it can be found again in Imsdal, where the sheared leptites are quarried as flagstones. Farther east the position of the plane can be inferred from the discordant strike readings, and from the way in which lithological units are abruptly terminated. Its tentative position is marked on Fig.

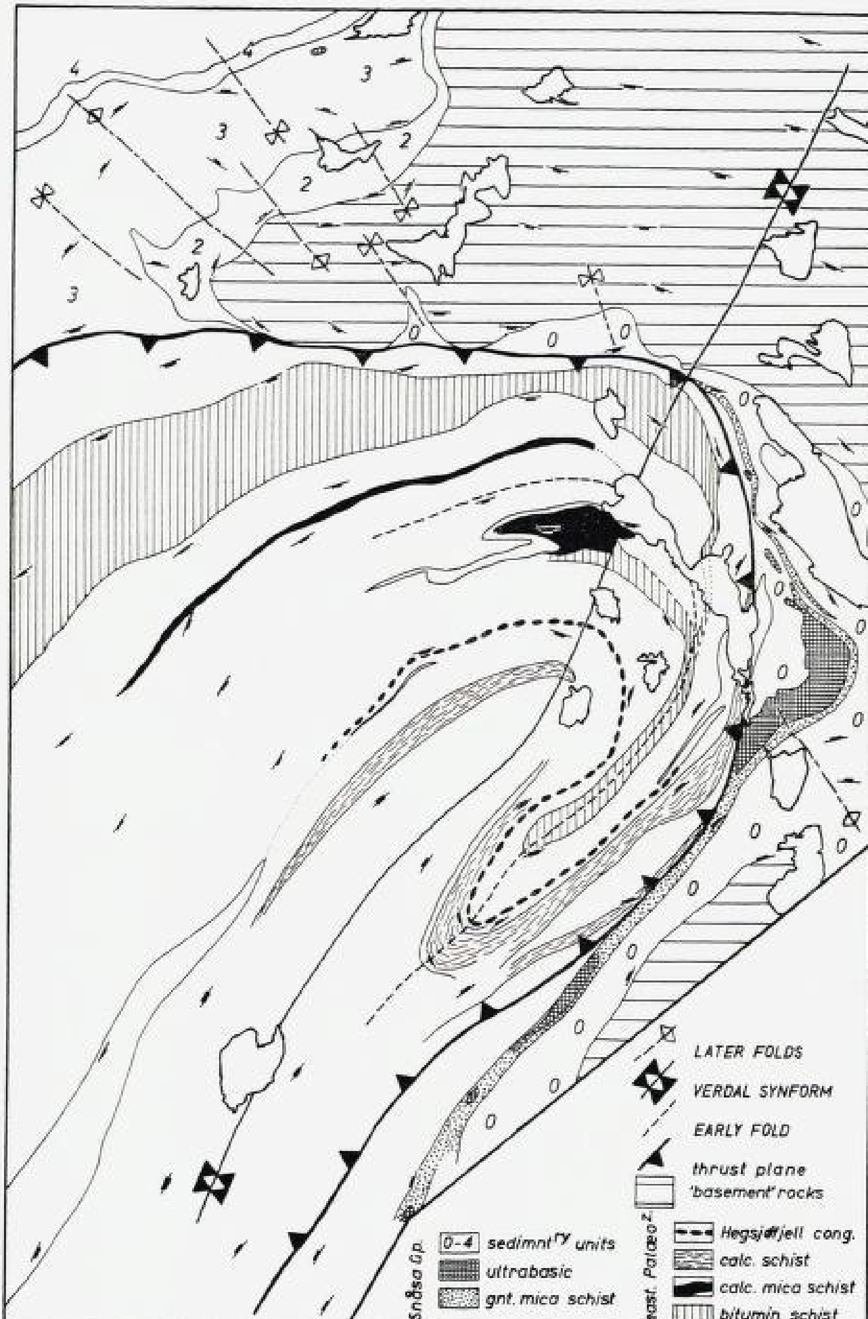

Fig. 31. Simplified stratigraphy of the Verdal synform to show the early fold.

34. It runs east, then turns south and finally south-west, separating an arc of the Snåsa Group rocks from the allochthonous Palaeozoic above. It is interesting that a similar distribution is marked on Holmsen's map (1919) but no explanation is given.

The thrust plane has been folded across the axis of the Verdal synform and so it dips inwards in all directions towards the axial trace. The allochthonous Palaeozoic sequence shows a similar pattern; but the Hegsjøfjell conglomerate, which forms a good marker horizon, indicates that this folding is not the earliest deformation of these rocks. This band is repeated across the Verdal synform, but appears twice on the southern limb, repeated across an antiformal fold (section bb', Fig. 30).

If the stratigraphy is carefully redrawn to show this pair of structures (Fig. 31) it is found that the closure of the latter fold bends around the Verdal synform, and must therefore be earlier than it. The final shape of the structures must then be that shown in Fig. 30 section bb'. The early fold is a recumbent structure, closing eastwards, whose axis plunges south-west; until the stratigraphy is established with certainty, it is not possible to say whether it is an anticline or a syncline. Part of its outer limb, i.e. the one that forms the broader arc nearest the thrust plane, is truncated by the thrust plane.

The Verdal synform, which has deformed the early structure, is an asymmetrical fold about an axis which plunges 30—45° south-west. Near the closure the southern limb is vertical or dips steeply north-west, whilst the northern limb dips 40—45° south-east. North towards the thrust plane, the dip decreases to between 20° and 30° as it approaches the Tømmerås anticlinal axis. Farther south along the axial trace of the Verdal synform, a cross section would show that both limbs are vertical or steeply dipping, but the southern one becomes flatter towards the southern outcrop of the thrust plane.

It is clear from the map that the nappe of allochthorous Palaeozoic rocks had been emplaced before the formation of the Verdal synform; both they, the rocks of the Snåsa Group and the underlying basement have been folded together in this structure, and the fold trace runs continuously across all three.

SUMMARY

The principal tectonic units (Fig. 34) of this region are, therefore:

(a) the Olden nappe (Oftedahl (1956)), consisting mainly of coarse-grained granites and leptite, with thin remnants of a Palaeozoic sequence resting upon them. This sheet forms the lowest visible unit, exposed along the spine of the Grong culmination. From evidence on the Swedish side of the border, Asklund considers it to be a far-travelled nappe (1938).

(b) Above this lies a sheet consisting both of "basement" and of Palaeozoic rocks; it comprises the Snåsa and Leksdalsvann Groups, which are separated by a primary depositional contact from the Tømmerås Group.

(c) The highest unit of the three consists only of Palaeozoic rocks, and comprises those termed the allochthonous Palaeozoic. Although on the map sheet "Jaevsjø" the allochthonous Palaeozoic is separated from the Snåsa Group by a tectonic discontinuity, it is possible that the two form a continuous sequence farther south, for example in Verdal. This has not been fully investigated, but it would support Carstens' hypothesis (1955) that even at the sedimentary stage the development of the two synclinal troughs has been different.

These three tectonic units were emplaced before the main Caledonian folding, which has given rise to the major fold structures of the area. They are a pair of synforms separated by the Tømmerås anticline; their axial planes trend south-west and their axes, which initially plunge south-west from the Grong culmination, are locally flexed up over a northwest-southeast trending anticlinal axis, before they again plunge south-west.

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This work was carried out partly at the Norwegian Geological Survey, Trondheim and partly at the Department of Mineralogy and Petrology, Cambridge during the tenure of Fellowships from the D.S.I.R., London, the N.T.N. Forskningsråd, Oslo and Newnham College, Cambridge. The Norwegian Geological Survey has been very kind in providing aerial photographs, equipment and field expenses. I am most grateful to all the Survey officers, particularly Directors Ingvaldsen and Bjørlykke and Statsgeolog Wolff for their help and support; and to Professor T. Strand, of Oslo university, who has undertaken critical reading of the manuscript. Finally, the field work would have been impossible without the kindness of the many people in Nord Trøndelag, who have provided me with accommodation.

STRATIGRAPHICAL POSITION OF THE GUDÅ CONGLOMERATE ZONE

By Fredrik Chr. Wolff.

Abstract.

The Gudå conglomerate zone has been considered to be of Upper Ordovician to Lower Silurian Age. The main argument for this conclusion has been that the conglomerates of this zone have the same pebble composition as some proved Ordovician — Silurian conglomerates. The author describes shortly a number of localities in the Gudå-conglomerate zone, and by comparison with descriptions on localities of conglomerates of known age, he concludes that the former conglomerates are more likely of Lower Ordovician age.

1. Introduction.

In most areas in the Norwegian part of the Caledonian mountain-chain fossiliferous horizons are scarce, and stratigraphical correlation has therefore had to be based on stratigraphical succession or lithological units only. This has led to (and will probably also in the future lead to) attempts to correlate horizons from widely different time periods. Conglomerate horizons have often been misused in this manner. There has been an extended tendency to think that conglomerates of similar pebble-compositions are deposits of the same age. This concerns for example the correlation between the quartzite conglomerates of Vojtja, Lyngestein, Kjølhaugen, Portfjell, Hegsjøfjell, Skjækerstøtene and Gudå, which all have been considered to be of Upper Ordovician to Lower Silurian age.

In the following the stratigraphical position of these and some other quartzite conglomerates are discussed. Their adjacent rock types are also taken into account.

2. Conglomerates of undoubted Upper Ordovician to Lower Silurian Age.

a) The Vojtja quartzite conglomerate (in the Swedish Caledonides northeast of the Trondheim region) is overlain by the Slätdal limestone containing Holorhynchus (Kulling 1933), which is characteristic of stage 5b, the top of the Upper Ordovician in the Oslo region. On top of this limestone follows a series of quartzite and black shale.

b) The Lyngestein conglomerate (plate 2) rests on the Hovin sandstone, which is considered to extend up into the lower portion of the Upper Ordovician (Kiær 1932). This opinion is based on findings of Nitulites and Theca in the Hovin sandstone, indicating a Caradocian age.

c) The Kjølhaugen conglomerates (plate 2) is overlain by sandstone and black shale containing Rastrites (Getz 1890) indicating the upper part of Lower Silurian.

These three conglomerates have the following features in common:

1. They are dated by findings of fossils to upper part of the Upper Ordovician or lower part of Lower Silurian.
2. They lie in lowgrade metamorphic rocks and are usually not seriously deformed.

3. Conglomerates of Lower Ordovician age.

At Svorkmo north of Løkken Mine (plate 2), just below the greenstone lavas of type Støren group, a deformed quartzite conglomerate is present (Carstens 1954). This conglomerate lies in a series of micaschists of the Røros group, where zones of crystalline limestone also are intercalated. Here is a case of a quartzite conglomerate, which is demonstrably older than the lowest Ordovician.

Foslie (1923) describes the Portfjell conglomerate (Kjerulf 1876). This conglomerate, which also is associated with crystalline limestone and greenstone, lies in a sequence so strongly deformed that it is difficult to decide whether the layering is normal or inverted. Foslie (1959) considered this conglomerate to be contemporaneous with the Swedish Vojtja conglomerate by comparison of the quartzite pebbles of the two conglomerates.

Kulling (1955) opposed this correlation and considered the Portfjell conglomerate to be much older and to represent the Ropen quartzite conglomerate of the Ro series in the Swedish Caledonides northeast of the Trondheim Region.*) Kulling also points out that the Ropen quartzite conglomerate and similar conglomerates in this part of the

*) After the present paper had gone to press T. Strand published a note in which he arrives at the same conclusion as Kulling. See NGU nr. 223.

Caledonides lies in high-grade metamorphic schists with trondhjemitic intrusions.

These two conglomerates have the following features in common:

1. They are overlain by greenstone lavas of the Støren group and associated with limestone.
2. They are lying in high-grade metamorphic rocks and are strongly deformed.

4. Conglomerates of unknown age.

a) In Hegsjøfjell (plate 2) a strongly deformed quartzite conglomerate is found. This conglomerate is resting on a garnetiferous micaschist and is overlain by micaschist and amphibolite.

These data are taken from a map made by Foslie (Jævsjø) published by Oftedahl (Foslie 1959). Foslie considered this conglomerate to be contemporaneous with the Portfjell conglomerate, which he supposed to be contemporaneous with the Vojtja conglomerate (Silurian).

If Kulling's opinion is correct, and Foslie's parallelism between the Hegsjøfjell and the Portfjell conglomerates holds, the Hegsjøfjell conglomerate must then be equivalent to the Ropen conglomerate.

b) The Skjækerstøtene conglomerate lies along strike from Hegsjøfjell, less than 20 km southwest (plate 2). This conglomerate is also a strongly deformed quartzite conglomerate where the pebbles are drawn out to long rods. It also rests on a garnetiferous micaschist and is overlain by amphibolite. The present author (Wolff 1960) correlated this conglomerate with the Portfjell and by accepting Foslie's opinion suggested a Silurian age.

c) Following the zone of the Hegsjøfjell — Skjækerstøtene conglomerates about 60 km southwest we find the Gudå conglomerate (plate 2). This quartzite conglomerate is so seriously deformed, that its conglomeratic character has been doubted (Bäckstrøm 1890) and the name "kvartskakelag" (meaning quartzcake layers) has been applied. A similar name has also been applied to the Portfjell conglomerate by Hauan (Foslie 1923). The Gudå conglomerate has later been proved to be a real conglomerate (Kautsky 1947), and the same holds for the Portfjell conglomerate (Foslie 1923).

West of the Gudå conglomerate lies a series of quartz-biotite-kyanite-schists with hornblende and garnet. About 10 km north of Gudå, in the mountain Blåstøten a limestone horizon is found somewhat to the west of the level of the conglomerate. At Gudå a limestone layer is intercalasted in the conglomerate. East of the conglomerate an amphibolite zone of 6 km thickness is found.

d) The Bukkhammer — Usmadam metaconglomerate (Kisch 1962) lies in the same zone about 40 km southwest of Gudå (Plate 2). West of this quartzite metaconglomerate in a series of micaschists containing staurolite and kyanite, a zone of crystalline limestone (the Vollfjell limestone) is located. To the east of the conglomerate lies an amphibolite group, which acording to Kisch consists of "metabasites, in part metamorphosed tuffs, or reworked tuffs, oligoclase-amphibolite and other amphibolitic varieties". He considers it to lie below the conglomerate, and therefore, under the assumption that the amphibolite group is equivalent to the Støren greenstone in the west, to be contemporaneous with the Venna conglomerate (Table I). The main reason for this conclusion seems to be that the schistosity dips towards west, and therefore gives the impression that the conglomerate rests on the amphibolite group. The present author thinks that Kisch's assumption, that the amphibolite group is equivalent to the Støren greenstones is correct, but that the metaconglomerate is not equivalent to the Venna conglomerate. The arguments for this will be presented later (paragraph 5).

The conglomerate mentioned in this paragraph have the following features in common:

1. They are adjacent to amphibolites (metabasites): volcanics.
2. They lie in high-grade metamorphic rocks and are seriously deformed.

5. The distribution of the different stratigraphical units in the northern part of the Trondheim region.

The discussion above has been based on stratigraphical correlations only. In the following the general geological map (Plate 2) of the northern Trondheim region and sections across it (Plate 1) are discussed. This discussion leads to the assumption that the conglomerates of unknown age occupy a low position in the stratigraphical sequence.

The map (Plate 2) and the profils (Plate 1) of the region in question are now discussed. Section A-B shows the following profile from west to east: Micaschist, crystalline limestone, quartzite-conglomerate, and michaschist of the Røros group. Then greenstones of the Støren group, then in a double syncline beds of the lower Hovin group and farther to the east again greenstones of the Støren group. In the easternmonst part of the profile in the Gauldalen valley, beds from the lower and upper Hovin group overlain by the Lyngestein conglomerate and the Sandå beds of the Horg group occur. Section C-D, shows in the western part of the Stjørdalen valley, beds of the upper Hovin group, consisting of sandstones, polygenous conglomerates (Volla/Hopla), and rhyolite tuffs. To the east, the lower Hovin beds of dark shales, rhyolite, limestone, sandstone, and at the bottom the Stokvola breccia (Venna-conglomerate) occur. Both in the limestone and the shale of this group, fossils are found indicating the lower Hovin group (Middle Ordovician) (Carstens 1960). Below the Stokvola breccia lie the greenstones of the Støren group. This section shows still older layers from west to east, although the layers are dipping in an easterly direction. The beds are therefore probably overturned. Further to the east we find micaschists, which the author believes is a continuation further down in the sequence. They are most likely belonging to the Røros group. These micaschists are frequently intruded by trondhjemitic sills, and also at one locality, Dyrehaugen (Plate 2), by a noritic intrusion, these traits might suggest a low position in the Cambro-Silurian sequence.

At the Swedish border, the black shales at Kjølhaugen are dated by Rastrites (Silurian). To the west of Kjølhaugen sandstones, chlorite schists, and limestone (farm Brenna) occur. In this group no fossils are found, but they most likely lie below the Silurian beds at Kjølhaugen, and therefore belong to the Hovin group (upper and lower part). Just west of the limestone at Brenna, lie the amphibolite zone, which the author considers to be metabasites of the Støren group. The layers are here dipping towards west, but are again probably overturned. The arguments for this assuption is based on lithostratigraphical correlations only. In that the conglomerate here is associated on one side of a persistent zone of amphibolite, limestone and chlorite-schists, which again are overlain by evident Silurian beds, and the other (below) of micaschist. This succession fits so well into the stratigraphical scheme from other parts of the Trondheim region, that it would be reasonable to make the above mentioned assumption.

According to this profile, the Gudå conglomerate is located on the border between the Røros and the Støren group (Table I). Near the zone of the conglomerate trondhjemitic sills frequently occur, such intrusives also occur near the Ropen and contemporaneous conglomerates in Sweden, as pointed out by Kulling (1955). It should here be remembered that the Ropen conglomerate also is supposed to be of the age here mentioned for the Gudå-conglomerate (Lower Ordovician).

Along the Swedish border a tectonic break is found. The various rock types east of this line are considered to belong to an other tectonic unit and are therefore beyond the scope of this discussion.

6. Conclusion.

There are two points of importance in the discussion of the age problem of the conglomerates of paragraph 4:

a) The interpretation of the geological maps and sections suggest a Lower Ordovician age.

b) In trying to fit the sequence of the conglomerate and its adjacent rocks into the established stratigraphical schemes of other well known parts of the Caledonides, we find that our sequence is in agreement only when the conglomerates are placed in the Lower Ordovician (Table I).

The earlier conclusions to this problem are based on:

a) Comparison of pebble composition of this and some proved Silurian conglomerates.

b) That the conglomerate possibly overlie a similar rock type as does a known conglomerate (Venna) in an other area.

To the present author these two last arguments seem so weak compared with the two first ones, that he is convinced of the Lower Ordovician age of the Hegsjøfjell-, Skjækerstøtene-, Gudå-, and Bukkhammer – Usmadam conglomerates, whilst no better counterarguments are presented.

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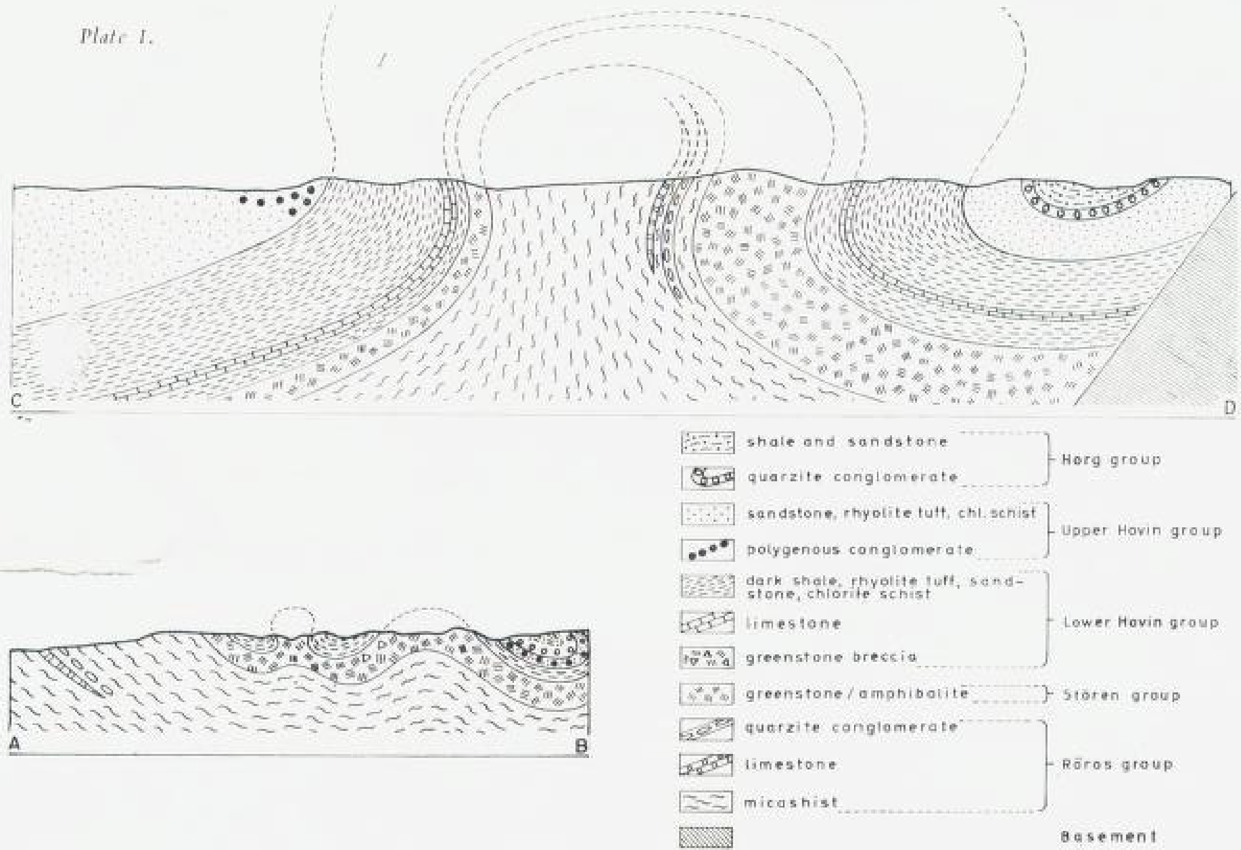
Table I. Correlation table for beds of some Scandinavian Cambro-Silurian areas.

	Svorkmo — Lundamo Section A—B Carstens 1954 — Vogt 1945	Stjørdal — Meraker Section C—D Carstens 1960, Wolff 1964 — Getz 1890, Wolff 1964		Västerbotten the southern part of Södra Storfj. Kulling 1955 and others
Horg group	Shale and sandstone (The Sandå beds) Quartzite conglomerate (Lyngestein)	Absent	Shale and sandstone Quartzite conglomerate (Kjølhaugene)	Arenitic calcareous shale Shale Limestone Quartzite conglomerate (Vojtja)
Upper Hovin group	Rhyolite (Grimsås) Sandstone Polygenous conglomerate (Volla)	Polygenous conglomerate Rhyolite tuff Polygenous conglomerate and sandstone alternating Polygenous conglomerate (Hopla)	Sandstone Absent	Absent
Lower Hovin group	Dicranograptus black shale Rhyolite tuff (Espehaug, Hareklett) Sandstone and shale (Krokstad) Limestone (Holonda) Fossiliferous shale (Langeland) Greenstone conglomerate (Venna)	Dark shale Rhyolite tuff (Muruvik) Sandstone Limestone (Tautra, Forbordfj., Flora) Fossiliferous shale (Leksdal) Greenstone breccia (Stokvola)	Chlorite schist Limestone (Brenna) Chlorite schist Absent	»Tuffitic rocks«? Greentones and tuffs with ceratophyre and sediments intercalated. Intermitent conglomerate Arenitic shales (in west calcareous) Shales and polygenous conglomerate Polygenous conglomerate
Støren group	Greenstones	Greenstones	Amphibolite	Greenstones
Røros group	Micaschist Quartzite conglomerate (Svorkmo) Crystalline limestone Micaschist	Micaschist Absent Absent Micaschist	Micaschist Quartzite conglomerate (Hegsjøfj. Skjækerstøtene, Gudå and Bukkh. — Usmadam) Crystalline limestone Micaschist	Quartzite conglomerate (Ropen) Crystalline limestone Shale, arenitic shale etc.

Plate I.



Profiles across the central and northern part of the Trondheim region.
Section A—B from Svorkmo to Lundamo. Section C—D from Stjørdal to Storlien.

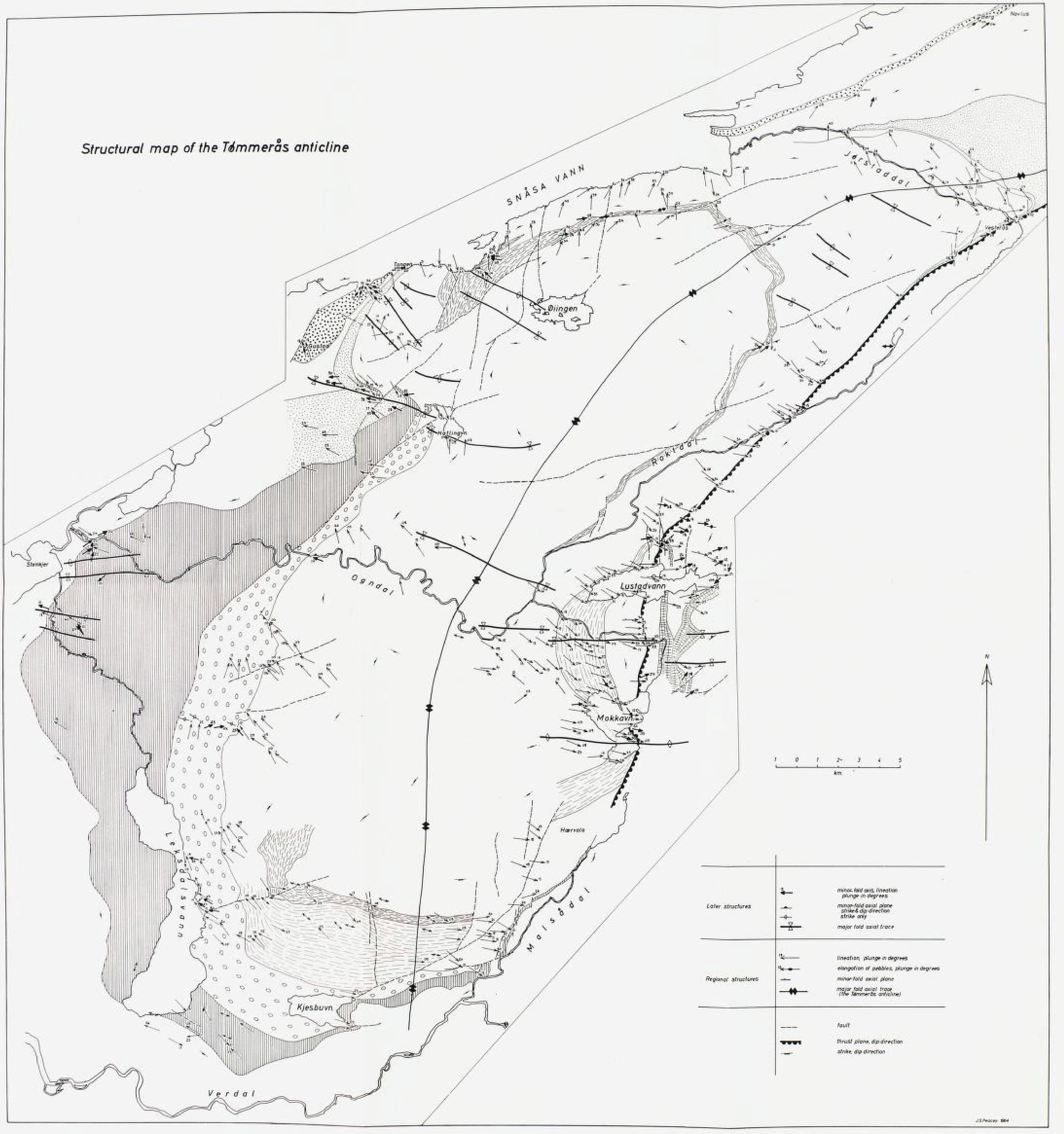


Fig. 33. Structural map of the Tømmerås anticline.

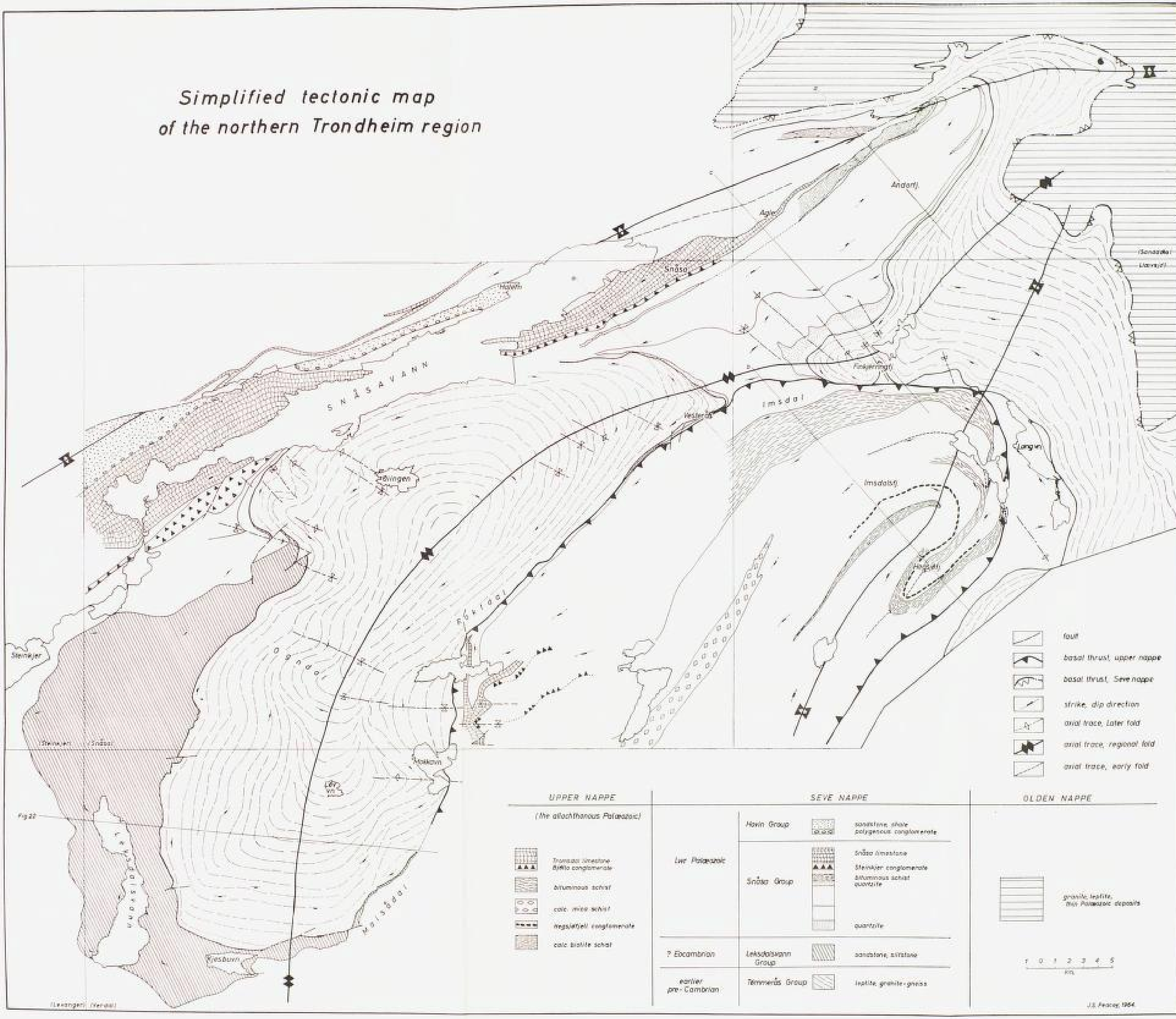


Fig. 34. Simplified tectonic map of the northern Trondheim region.

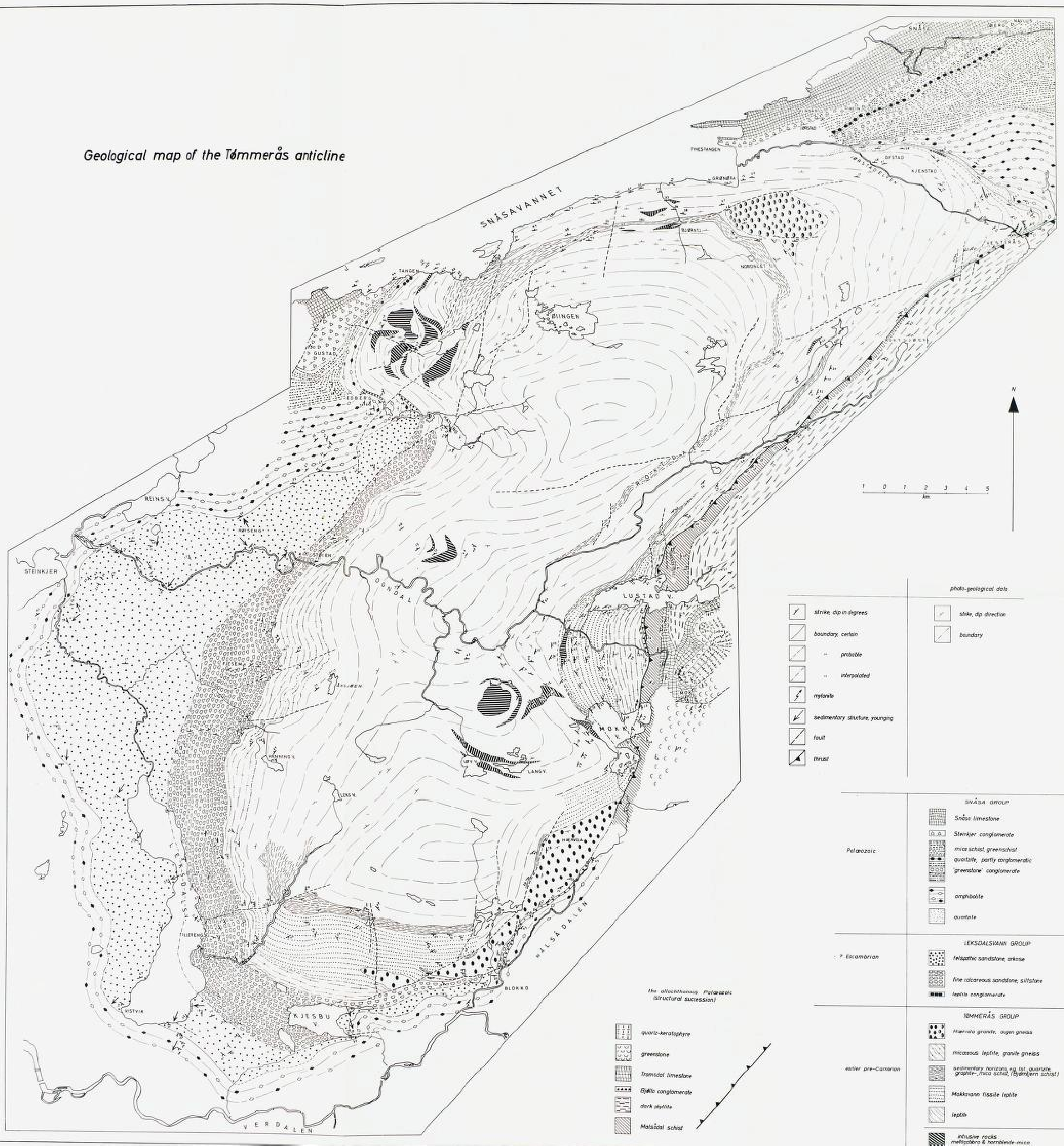
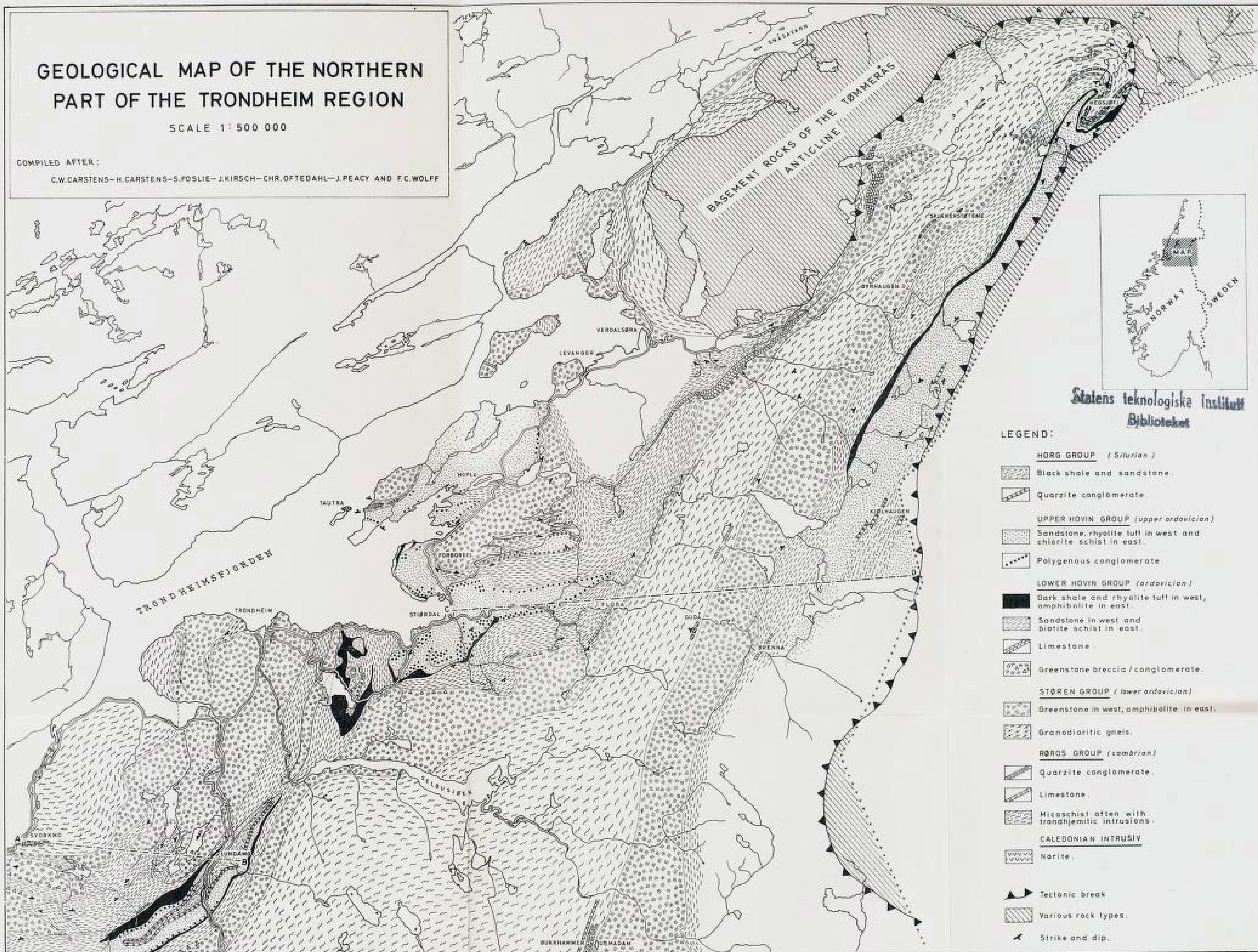


Fig. 32. Geological map of the Tømmerås anticline.



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