Geological investigations in the Snåsa—Lurudal area, Nord-Trøndelag

By
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Abstract.

Metasediments and meta-volcanic rocks of supposed Middle Ordovician age overlying a basement complex consisting predominantly of granite-gneisses, are described from an area near the north-eastern end of the lake Snåsavatn. A generalised succession (in ascending order) of mica schists, phyllite, limestone and greenstones with greenschist and pyroclastics has been recognized. Observations of the basement gneisses and their relation to the mica schists indicate that while a local concordance of banding is common, on a regional scale a very slight discordance would appear to exist, the various evidence favouring this as being a primary feature.

A tripartite division of the main Caledonian deformation is recognisable and the various minor structures are briefly described. Minor folds of the second generation are found to be of considerable value in positioning the axial plane traces of associated major folds.

Introduction.

The area under consideration is situated on the SW flank of the Grong culmination at the northern extremity of the Trondheim region, in the tract of ground between the NE corner of Snåsavatn and the valley of the Luru river, an areal extent of some 180 km². Metasediments and meta-volcanic rocks of the Snåsa Group are preserved in a major synclinal structure, the so-called Snåsa syncline (Carstens 1956). A granite-gneiss basement complex forms the north-western limit of the mapped area while similar rocks occur as a wedge-shaped outcrop on Kolåsfjell widening north-eastwards beyond Lurudal (Plate I).

Although no work dealing specifically with this particular area has been published, information either directly or indirectly relating to the geology immediately NE of Snåsavatn can be found in the papers of Carstens (1955, 1956), Oftedahl (1955, 1964), Birkeland (1958) and Peacey (1964). Carstens'

(1956) paper contains a large-scale map of the iron-ore district from Snåsa to Stjørna, the map terminating in the Snåsa-Kolåsfjell area. The present area lies partly on Foslie's 1 : 100,000 map-sheet "Sanddøla", published by NGU (no description available), but largely on the 1 : 100,000 rectangle sheet Overhalla; only the eastern part of the latter has so far been mapped (S. Foslie and H. Carstens manuscript map, NGU archives).

Fieldwork for the present study was carried out for Norges Geologiske Undersøkelse (The Geological Survey of Norway) in the summer of 1964 at the suggestion of statsgeolog Fr. Chr. Wolff, and was intended as a contribution towards the compilation of the new map-sheet Grong, shortly to be published on a scale of 1 : 250,000 by NGU. Partly on account of bad weather and partly because time was spent in the Sanddøla valley area examining the Limingen-Sanddøla and Eastern Cambro-Silurian Series, field mapping was restricted to less than 8 weeks. Field expenses were very kindly defrayed by Norges Geologiske Undersøkelse. Prior to commencing the work, mapping problems were described to the writer in considerable detail by Dr. Janet Peacey: for this valued advice, and the constant help and support given by statsgeolog Wolff, the writer is extremely grateful.

Geological setting.

The northern limit of the Trondheim region of Cambro-Silurian eugeosynclinal sediments is marked by the east-west ridge of Pre-Cambrian gneissic rocks referred to as the Grong culmination (Oftedahl 1955) — this, in effect, is the ridge connecting Asklund's (1955) 'Olden-Anticline' and 'West Norwegian basement rocks'. Part of this basement ridge has been called the 'Olden nappe'.

To the north of the Grong culmination Lower Palæozoic eugeosynclinal sediments continue as the Nordland facies (Strand 1960, 1961), and are dissected by several thrust planes and nappes of which the Seve nappe is the most extensive. The Cambro-Silurian sediments of the Trondheim region themselves constitute part of this Seve nappe which can here be subdivided into the main Seve nappe and an upper nappe, the latter recognised by Peacey (1964) in the Tømmerås - Hegsjøfjell region. It is more than probable that the bulk of the Trondheim region metasediments belong to this upper nappe (Wolff 1967, Roberts 1967), since its thrust plane is traceable down to the south of this region; in this regard, Wolff has suggested that the name 'Trondheim nappe' be adopted for this allochthonous metasedimentary pile.

Metasediments and volcanic rocks of the Snåsa - Lurudal area belong exclusively to the main Seve nappe. Collectively they are referred to the Snåsa

Group, since it is possible to trace several of the lithologies of this group from the Tømmerås-Snåsavatn area described by Peacey (1964) around the closure of the Snåsa syncline into the present area. Significant facies changes are, however, apparent. Furthermore, as the sequence does not reach up to the basal conglomerate of the Upper Hovin Group (Carstens 1956, 1960), the rocks for the most part almost certainly belong to the regional Lower Hovin Group, largely of Middle Ordovician age. Fragments of gastropods found in the Snåsa limestone (Carstens 1956, 1960) would appear to confirm this view. The age of the mica schists below the limestone is uncertain; these rocks quite possibly extend down into the Lower Ordovician.

While the Snåsa syncline dominates the structural picture in this area, two other less prominent major folds are present, mappable largely but not entirely on minor structural evidence. Both these folds and the Snåsa syncline deform the regional schistosity or foliation. South-east of the present area two major folds of considerable magnitude — the Tømmerås anticline and Verdal synform — have been described by Peacey (1964), both deforming the prevalent foliation and in the latter case deforming a major early isocline in the Hegsjøfjell area.

The lithological succession.

Evidence is more or less lacking in this area for the establishment of a chrono-stratigraphy. Just off the map in the extreme south the Steinkjer conglomerate, the supposed base of the Lower Hovin Group, is at least 15 m thick at Navlus (Peacey, 1964) but loses its identity north-eastwards along the strike; at Agle a granule conglomerate or coarse grit is thought to represent this horizon.

Difficulty also arises in tabulating an accurate litho-stratigraphical succession, primarily because of the facies variations encountered across the area. It is, nevertheless, possible to establish a generalized lithological succession. No sedimentary structures have been observed and consequently the sequence is based partly on tectonic structural evidence and partly on correlation with the successions recorded by Carstens (1956, 1960) and Peacey (1964). The generalized succession is as follows:

4. Greenschists, greenstones and hornblende schists.
3. The Snåsa and Kjennerås limestones.
2. Phyllite; with granule conglomerate in the south.
1. Mica schists.

1. The mica schists.

These rocks, regarded as the oldest member of the sequence, are exposed on either side of the Kolåsfjell ridge of basement granite-gneisses and leptites and also quite extensively in the north-west of the area striking NE-SW through Kultjern. While the north-western outcrop of mica schists is roughly lenticular in shape due both to folding and original sedimentary variation, those flanking the Kolåsfjell granite-gneiss are thickest in the east or north-east and appear to thin out westwards, eventually wedging out altogether so that greenschists come to lie adjacent to the gneisses.

Typically, this lithology is a grey or brownish grey, medium-grained biotite schist frequently containing garnet (and sometimes biotite) porphyroblasts and displaying a rusty-brown staining along schistosity planes. Garnets are usually small ($\leq$ 3 mm) and of variable abundance but examples have been found of rhombdodecahedra up to 1 cm across. Muscovite is infrequently present though certain horizons are muscovite-rich with a corresponding lack of garnet.

Hornblende schist bands are not uncommon particularly towards the top of the schist sequence where the boundary with the greenschist (where phyllite and marble are absent) is often quite graditional. In considering the strike extent of the mica schist from Troldvatn to Lurudal, a generalization is that the amount of amphibole decreases towards the north-east. At the same time garnet is generally more profuse in the east and north-east, but both this variation and that of the amphibole may be merely a reflection of original sedimentary character rather than metamorphic grade.

Thin graphitic phyllite bands sometimes weathering a sulphurous yellow colour are occasionally present in these schists. Bands of iron ore (pyrite and magnetite) occur sporadically but one 15 m thick ore horizon in the extreme north-east (Lurudal) is noteworthy. Other lithological variants include thin limestone and calcareous schist horizons E and NE of Kultjern and tuffitic or quartz-keratophyre bands — together with biotite-amphibole schist — in the vicinity of Kultjern. Tectonic inclusions of limestone are also distinguishable. In the basal part of the mica schists psammitic or quartz schist intercalations are present locally.

A notable feature of the schists, moreso in the north-west of the area, is their gradual induration and changing character towards the basement gneiss. The schist invariably becomes finer grained and massive or flaggy towards its base with micaceous leptite bands appearing, at first sporadically but becoming progressively more common, until the lithology is largely a fine-grained grey or pink-grey leptite or micaceous leptite. But even the more massive leptitic rock-type contains many intercalations of fine-grained biotite schist or amphibole schist, so that the field mapping of this transitional lithology can be somewhat frustrating. Although the precise origin of leptites and micaceous leptites has been the subject of much debate, the field evidence in this area would appear to point to a sedimentary derivation for at least the micaceous leptites. This is in agreeance with Peacey's (1964) suggested origin for the micaceous leptites of the Tømmerås area.

Quartz veinlets and segregations, often boudined, are ubiquitous in these mica schists throughout the northern and north-eastern parts of the area. These are invarably parallel to the dominant schistosity but are deformed by later folds. It is thought probable that much of this quartz is of metamorphic segregatory origin and as such is of fairly local derivation. On the northern border of the Kolåsfjell granite-gneiss, pegmatitic and granitic streaks, segregations and diffuse lenticles are present in the schist, again paralleling the recognisable banding and schistosity but deformed by second generation structures, such that an origin concomitant with the main foliation and metamorphism seems evident. Moreover, the greater part of this granitic material appears to be of replacive origin.

2. Phyllite.

This member of the sequence crops out in the south-eastern part of the area both N and NE of Sjysjøen and farther south beneath the Snåsa limestone in the Agle district, on the northern and southern limbs of the Snåsa syncline respectively. On Foslie's "Sanddøla" map the southern outcrop of phyllite extends north-eastwards from Agle for some 13 km until the pattern of outcrop suggests the presence of a major fold closure. The phyllite outcrop is then severed by an apparent tectonic break (trending ca. 060-065°), re-appearing some 4 km to the south-west on the north side of this line. The present writer, agreeing with Peacey's (1964) assumption, regards this line of discontinuity as a fault.

As a distinctive lithology the phyllite is a grey biotite-muscovite phyllite frequently containing conspicuous pyrite with or without magnetite. It is sometimes of greenish grey colour moreso where it grades into the typical greenschist. Quite often, where the grain size is slightly larger, it is best described as a phyllitic schist, but all gradations from phyllite into the underlying mica schist can be found. On the south side of the Snåsa syncline, the phyllite is generally darker grey and graphitic; thin limestone and quartzitic ribs are sometimes present.

At Agle, some 30-50 m below the base of the Snåsa limestone, the phyllite contains a distinctive schistose granule conglomerate. Difficulty arises in choosing a name for this rock-type, moreso as particle size varies across the strike. Where particles, closely packed and constituting the bulk of the rock, are always less than 3 mm across, it can be described as a schistose grit but such a size restriction is uncommon since particles in many bands measure up to 5 or 6 mm and sporadic pebbles of greenstone up to 3 cm are present. In view of this variation a middle course has been chosen and Twenhofel's (1950) term 'granule conglomerate' adopted for the lithology of this horizon.

Particles consist mainly of a blue or bluish feldspar, white quartz and pale grey quartzite with subordinate fragments of greenstone, greenschist and, rarely, jasper. Larger pebbles always appear to be of greenstone or a similar schistose amphibolitic rock-type. This is very interesting since it indicates that the sequence from which the pebbles were derived - the Støren Group - was probably somewhat metamorphosed prior to the deposition of the conglomerate. The matrix is normally a dark phyllite or schist. Although a three-dimensional study of the various particles was not attempted on account of the poverty of exposure, a stretching direction is perceptible which is oblique to the trend of local minor folds. These small folds, varying from microfolds up to structures of 3 m wavelength and amplitude, deform the regional schistosity and also appear to post-date the particle lineation: the fold axes plunge towards 260°-270° whereas the lineation of small fragments is towards 050°-060°. On the other hand, a transverse section though these minor folds often shows ca. 60-70 % of particles flattened parallel to the axial planes — yet the orientation of particle c-axes does not accord with that of the fold axes.

Nearer the boundary with the main limestone in this same small area, a calcareous schist is found to contain intercalated psammitic ribs which have frequently been sheared and dissected into lenticular or discoidal fragments. At times this lithology resembles a highly tectonized conglomerate though it is clearly not of primary origin. Some 4 km further NE along the strike, due south from Sjysjøen, a calc-phyllitic schist contains many thin quartzitic ribs, there only partially disrupted by shearing.

Returning to the granule conglomerate, it is almost certain that this lithology is the strike continuation of the Steinkjer conglomerate which is so well-developed further south-west. A gradual thinning, together with important facies changes accounts for the character of the lithology at Agle (here more of a coarse grit than a true conglomerate).

About 2 km north-east from the Agle occurrence along the same stratigraphical horizon, a rather poor exposure of gravelly phyllite has been observed. The particles here are of quartzite and greenstone. Many pseudo-pebbles of quartz are present, these having originated tectonically by shearing and rotation.

This above-mentioned gravelly phyllite would appear to be the last vestige of the Steinkjer conglomerate when the latter is traced north-eastwards on the southern limb of the Snåsa syncline. No lithology resembling either a true conglomerate or a granule conglomerate as that described from Agle has been found on the northern limb of the syncline. However, two localities situated some 800 m apart just below the limestone in the vicinity of Kolåstjern display interesting features which are suggestive of a possible correlation with the Steinkjer conglomerate horizon. Both these exposures are of greenish grey schist which contains scattered but fairly abundant drawn-out fragments, granules or very small pebbles of either greenstone or a pale grey psammitic rock-type: these are up to 5 mm across. While the phyllitic member of the sequence is absent hereabouts it is significant that the stratigraphical position of these granule-bearing schists corresponds quite favourably with that of the Steinkjer conglomerate. Considering the facies variations inherent in this conglomeratic horizon on the southern limb of the Snåsa syncline, correlation of the Kolåstjern granule-bearing schist with the Steinkjer conglomerate is therefore, not too improbable a suggestion.

3. The limestones.

The Snåsa limestone occurs on the southern border of the mapped area trending ENE towards Agle and becoming progressively thinner. Beyond Agle this limestone thins gradually; on Foslie's "Sanddøla" map it disappears due east of Sjysjøen.

A second major limestone outcrop is that in the vicinity of the farm Kjennerås, south-east of Kultjern. The rapidly varying thickness of this limestone is partly primary but largely ascribed to tectonic causes. Whereas to the south-west of Kjennerås this limestone extends into Aadalen beyond Troldvatn, it thins out quite rapidly north-eastwards. Other thinner bands of limestone (up to 60 m thick) occur prominently within the greenstone-greenschist sequence.

Since the position of the Kjennerås limestone in relation to the mica schist and greenstone-greenschist members of the sequence is more or less identical to that of the Snåsa limestone in the Snåsa-Agle area, correlation of these two limestones seems highly probable and this assumption is supported by lithological similarities. Both are fairly well-banded, blue-grey, recrystallized limestones often containing thin dark grey or dark blue stringers of graphitic phyllite giving the rock a striped appearance. Finely disseminated pyrite may be observed. The boundaries of the limestone are frequently gradational into the adjacent schists, either through progressive increase of pelite content or alternations of limestone and schist which cannot be indicated on the present map. Within relatively short distances along the strike, lithological variations are perceptible, these clearly being of a primary nature. Near Kjennerås farm the limestone is locally coarsely crystalline and poorly banded.

Lithological facies variations are indeed of appreciable importance in this part of Nord-Trøndelag, not least in a consideration of the geology of this Snåsa - Lurudal area. Peacey's (1964) remarks concerning the Snåsa limestone can perhaps be quoted here — "... 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 polygenous Middle Ordovician conglomerates, whilst north-east along the strike it thins to nothing and its place is taken by greenschists and amphibolites".

4. The greenschists, greenstones and hornblende schists.

This member of the sequence constitutes the greater part of the Snåsa synclinal basin, also extending north-eastwards to beyond Flåtjern. The lithology is, for the most part, a green or pale greyish-green, poorly schistose rock though with a pronounced linear element always noticeable in the field. Where a schistosity is pervasive the rock-type can be referred to as a greenschist; otherwise, greenstone is the accepted terminology. At times the lithology is massive and essentially a tuffitic greenstone but all transitions to quartz keratophyres, rhyolite tuffs and keratophyre - agglomerate appear to be present, though not common. On the map (Plate I) only the more prominent tuffaceous or keratophyric bands have been indicated.

Towards Troldvatn and in a belt north-eastwards to beyond Flåtjern the lithology is more of a hornblende schist or mixed hornblende schist - greenschist than the typical greenstone - greenschist. Hornblende is certainly the predominant porphyroblastic mineral in this northern area and intercalated bands of hornblende-garbenschiefer are mappable with amphibole up to 16 cm in length though generally $\leq$ 10 cm. It is noteworthy that these garbenschiefer horizons, many of which have had to be omitted from the map, invariably occur close to limestone bands. In the area between the two thin but extensive limestone bands in the central part of the area and the wedge of basement granite-gneiss, hornblende schist is very abundant and thin impersistent limestone ribs are not uncommon. Limestone ribs, and occasionally bands up to several metres thickness, are also demonstrable in the Snåsavatn area, just above the main Snåsa limestone.

Pyrite and magnetite are common minerals throughout the greenstone-greenschist sequence, sometimes in segregations or thin ore-bodies but often as disseminated crystals showing excellent cubic (pyrite) and octahedral (magnetite) form. Magnetite is usually present in quartzitic bands. Detailed descriptions of the ore can be found in Carstens' 1956 paper. Epidote and quartz-epidote-calcite segregations are also present in this greenstone-greenschist; epidote veinlets occur locally. West of Kolåstjern the greenschist immediately above the main limestone band contains abundant biotite porphyroblasts, some up to 5 mm across.

Just to the west of Flåtjern a finely banded tuff or keratophyre can be seen to change laterally into a rubbly tuffitic greenstone and then into a conspicuous agglomerate. This latter rock-type, and to a lesser extent the adjacent massive rhyolite tuff, is densely net-veined with quartz and felsitic veinlets (some of only 1 mm thickness) which stand out as ribs on the white-weathered surface. Disoriented schist fragments up to 2·5 cm in length are present within this pyroclastic lithology while yellow-weathering concentrations of pyrite are not infrequent.

Evidence as to the origin of the bulk of the greenstone tends to be masked by the metamorphism, but tuffs, tuffaceous greenstones, rhyolitic tuffs and keratophyre-agglomerates leave no doubt as to their volcanic derivation. The typical greenschist or partially schistose greenstone is less easily accounted for. Occurrences are found of transitions from limestone through calc-schists to greenschists and even tuffaceous or keratophyric greenstone so that a sedimentary origin would here appear incontrovertible. The bulk of the greenschists and some of the poorly schistose greenstones therefore probably represent reworked lava detritus. The iron-ore bands are also almost certainly of sedimentary origin, but the association of pyrite with the pyroclastic material near Flåtjern leads one to consider the possibility that gas exhalations connected with the volcanism may have supplied some of the elements constituting the ore-mineral segregations, as suggested by Oftedahl (1958).

The amphibolite situated within mica schists north of the Kolåsfjell granite gneiss is regarded as a meta-gabbro. In the central parts of the body it is typically a black to dark green, coarse-grained, garnetiferous meta-gabbro: garnets up to 5 mm across are quite prominent. Towards its margins this basic sheet is more of a fine-grained schistose amphibolite, almost a true schist in part, containing abundant small garnets.

South of Kolåsfjell, and again within mica schist, another amphibolite sheet is present. This is broadly similar to that occurring north of the granite-gneiss except that garnets are now quite uncommon. Moreover this amphibolite is, at best, less coarse-grained than the northern one and tends to be more schistose. Despite these differences it would appear that the two amphibolites are related and quite feasibly represent segments of an originally more extensive and possibly continuous gabbroic intrusive sheet. The structural evidence for this point of view is presented later.

The basement complex.

Rocks of this group, which underlie the metasediments and volcanics of the Snåsa Series, are largely of granitic composition and have been regarded by various authors as being of Pre-Cambrian age. As can be seen from the map (Plate I), basement rocks occur in two separate areas. On tracing these occurrences in a general easterly direction onto Foslie's Sanddøla map-sheet, they are found to link up into one extensive area of 'gneissic granite'. This broad E-W belt of granitic rocks forms part of the Grong culmination and while the larger part of this belongs to the so-called Olden nappe, a marginal zone is referable to the Seve nappe.

On the present Snåsa - Lurudal map no distinction is made between rocks of these two tectonic units. In the time available, and since investigations were purposely and basically concerned with the Cambro-Silurian sequence, little work has been attempted on the basement rocks.

Granite-gneiss is the most widespread rock-type occurring in this basement complex. Typically it is a pink or greyish pink, medium- to coarse-grained gneiss of granitic character. Feldspars are often prominent as porphyroblasts with biotite as the chief mafic mineral. Some zones of granite-gneiss are muscovite-rich and are correspondingly whiter in colour.

Grain size is sometimes observed to be extremely variable. Where the lithology is of finer grain, it is often difficult to differentiate between a gneiss and a leptite, moreso where gradations occur.

Augen gneiss is notable only to the north-east of Kolåsfjell in Lurudalen. In one locality feldspars (chiefly microcline) up to 6 cm in length were observed but this is quite exceptional as most porphyroblasts rarely exceed 1·5-2 cm. Growth of secondary feldspar tends to have been quite irregular in distribution and porphyroblastic feldspars also occur sporadically in the schists adjacent to the basement rocks.

Leptite is here taken to mean a pinkish grey, fine-grained (rarely medium-grained), banded or massive rock, consisting mainly of feldspar and quartz with subordinate amounts of micas, epidote, garnet, sphene and zircon. It may be rather flaggy and is generally brittle and closely fractured. Wafer-thin biotitic stringers are sometimes present, particularly nearer the overlying schists. Micaceous leptites are also distinguishable, and gradations both into true leptites and mica schists have already been described. Furthermore transitions into gneissic granite are recognisable.

Nowhere throughout the area could any sharp contact be traced between either granite gneiss and leptite or leptite and mica schist; a transitional boundary is invariably present. In a railway cutting some 2.6 km north of Lurudal Station the contact between basement rocks and mica schists is excellently exposed. As far as dips and strikes are concerned the sequence is conformable, the mica schists being separated from the leptite or leptitic gneiss by a zone of augen gneiss. The full sequence shows a fine- or medium-grained granite-gneiss becoming perceptibly more leptitic towards the north; this is followed by a 30-35 metre thick zone of leptitic augen gneiss with feldspars up to 1 cm across. North of this, for 3-5 metres, feldspar augen become smaller and more scattered, the bulk of the rock now of darker colour and finer grain and more of a true biotite schist: then follows the ordinary biotite schist but this is also found to contain sporadic small feldspar porphyroblasts over a distance of at least 40 m — the exposure is then discontinued. Thin leptite bands and intercalations of hornblende schist are present in the mica schist at this locality.

Without a thorough petrological examination of the leptites it is difficult to comment on their precise origin. Based on field criteria alone — the gradations into micaceous leptites and schists, local rapid alternation with indubitable metasediments and fairly regular 'stratification' parallel to that in the sediments — a sedimentary origin would not appear improbable. Peacey (1964), while putting forward arguments for a possible volcanic interpretation, leaves the question of their origin quite open. At this stage the present writer also feels inclined to remain uncommitted on this question.

The basement contact.

The basement contact — the contact between the basement rocks and the overlying Cambro-Silurian metasediments — is rarely exposed well enough for an appraisal of its precise nature. Commonly the critical few metres of contact are not sufficiently well exposed, or else a gradational boundary appears to exist which quite often may be partially masked by secondary effects.

The earlier mentioned section exposed along the railway line north of Lurudal provides the only really clear-cut profile displaying the boundary relationships in this area. There, it will be recalled, the sequence from schist to granite-gneiss is conformable but an augen gneiss separates these rocks: feldspar porphyroblastesis is also pervasive in the schists hereabouts, so that the original nature of the contact cannot be stated with any certainty. It is noteworthy that augen gneiss occurs only in this Lurudal area on the northern side of the Kolåsfjell basement complex. In the coarsest type of augen gneiss, the groundmass between the feldspar augen has an appearance not unlike some mylonitic lithologies. From this it is possible to suggest that the present concordance between basement and cover in this particular small area is secondary. It is necessary, however, to consider other points before generalizing on this important relationship.

Partially transitional boundaries between schist and leptite and leptite and granite-gneiss have been mentioned previously. These are particularly wide in the W and NW of the area but are observed elsewhere on a lesser scale. Sharp contacts have not been found though the boundary may be located within a distance of two or three metres. Despite this apparent concordance measurements of banding in both schist and gneiss (or leptite-gneiss) in any one locality adjacent to this narrow contact show interesting discrepancies. These are quite systematic and cannot therefore be dismissed as errors of measurement. Seven such localities show that while strikes are broadly comparable in schist and basement, dips of banding in the basement granitic rocks are always steeper than in the stratigraphically overlying metasediments by anything up to 12°. Only in the rail-cut locality north of Lurudal Station is there an absolute concordance of banding. Considering the profile A-B (Fig. 3) across the area, if the major folds responsible for the present pattern of outcrops are unrolled until the metasediment banding is horizontal, the banding in the gneisses is found to dip gently and quite constantly in a south-easterly direction, thus suggesting the presence of a slight, regional, primary unconformity. It must be stressed that this slight discontinuity is a regional feature — it has not been possible to place ones finger on any angular unconformity in the field. On studying the map (Plate I) the wedging out of the mica schist both on the north and the south sides of the Kolåsfjell basement area could also be taken as evidence of a large-scale unconformable relationship between basement and cover.

In recent years a certain amount of controversy has surrounded the question of the nature of the basement contact in the Trondheim region; the papers of Birkeland (1958), Oftedahl (1964 and 1965), Peacey (1964) and Holmsen (1965) provide a fair range of views on this subject. While not wishing to take sides on this matter, at least not at this stage, the present writer can only point to the observations from this comparatively small Snåsa-Lurudal area, and the conclusions reached from the investigation cannot be said to hold for other parts of the Central Norwegian Caledonides. In summary, the salient features of the basement contact in this area are that, firstly, there is little evidence (except possibly in a small area NNW of Lurudal Station) for the existence of a general pseudo-conformity, i.e. a Caledonian tectonized contact.

Secondly, while the basement-cover boundary is concordant on outcrop scale, measurements point to a very slight discordance. This, together with the larger scale Kolåsfjell gneiss-schist relationship as seen on the map, would suggest that on a regional scale a very slight unconformity exists, the implication being that the basement rocks were tilted very slightly (in a general south-easterly direction) but unfolded at the time of deposition of the sediments and volcanics of the Snåsa Group.

These conclusions would appear to confirm, to a large extent, the findings of Peacey (1964) from the Tømmerås area south of Snåsavatn. Moreover they are broadly consistent with Oftedahl's (1964) opinion that "the Pre-cambrian rocks were essentially flat-lying und unfolded" at the commencement of Eocambrian or Cambrian sedimentation, but the present writer does not subscribe to the view of the basement surface being perfectly horizontal. Considering both Peacey's conclusions from Tømmerås and the present investigations, a gently undulating Pre-Cambrian surface is the more likely case. A final point is that in stating these conclusions the writer regards them as applicable only to the extreme northern part of the Trondheim region. To the south and west of this extensive region, it is known that prior to the Eocambrian - Silurian sedimentation the basement gneisses were subjected to a complex sequence of deformation, intrusion and metasomatism (see e.g. Banham and Elliot 1965). With regard to the nature of the basement and its boundary with the cover rocks it is clearly unsafe to generalise over an area as broad as that of the Trondheim region.

Structure.

The major structure, the Snåsa syncline, can be followed far beyond the limits of this small area, particularly in a south-westerly direction. To the north-east, some 12-13 km NE of the lake Sjysjøen to be exact, the closure of this fold can be readily identified on Foslie's "Sanddøla" map. A brief description of the structural features of this Snåsa syncline closure area have been given by Peacey (1964, pp 78-80) and Fig. 34 of that paper illustrates the general situation, and the relationship of the Snåsa syncline to other major folds, quite adequately.

In the Snåsa - Lurudal area the Snåsa syncline is an asymmetrical structure the axis of which plunges in a general WSW direction. This is reflected in an overall convergence of lithologies towards the ENE. The synclinal axial plane, the trace of which is depicted on Fig. 1, dips steeply in a NNW direction — the northern limb of the fold dips steeply, at times near vertically, to the SSE whereas the southern limb is generally inclined at a moderate angle

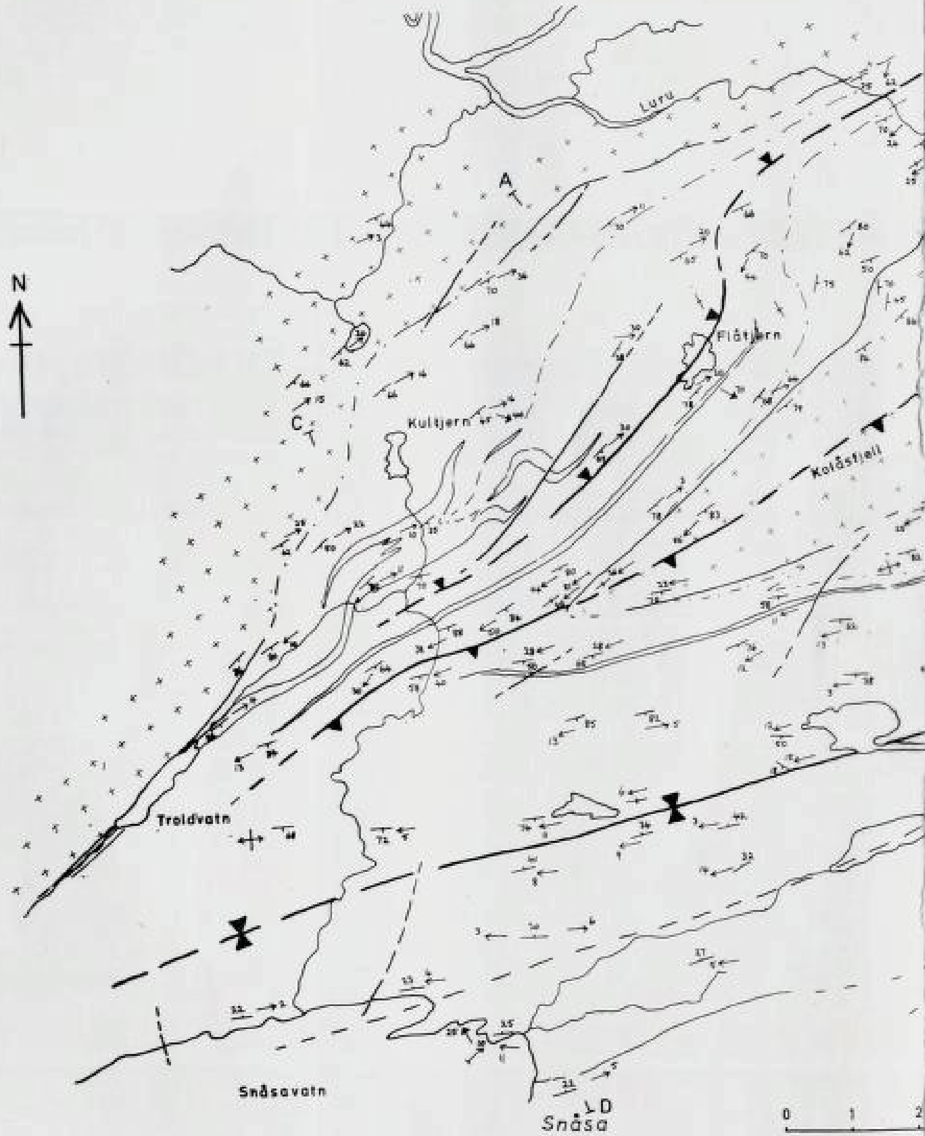
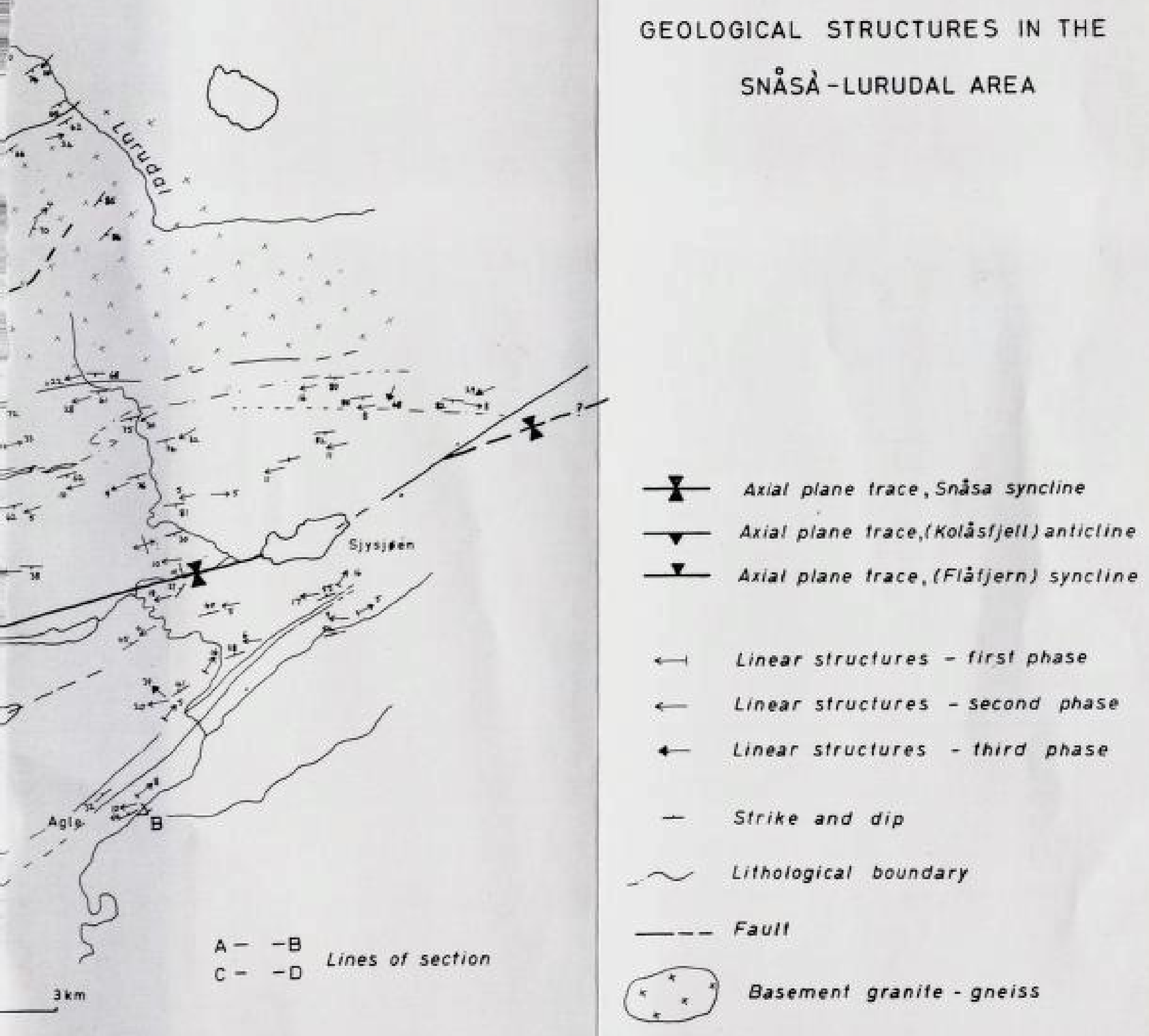


Fig. 1. Map of axi



al plane trends and representative linear elements in the Snåsa - Lurudal area.

(30° - 50°) towards the NNW. Minor folds, clearly related and congruous to the main syncline, show variable axial plunges generally WSW but locally horizontal or ENE.

Before considering the structures in the northern part of the area it is important here to note that the Snåsa syncline, and its parasitic minor folds and phyllitic crinkles, deforms the main schistosity which is present in almost all the metasediments. Rarely, in calc-silicate schists, tight or isoclinal folds are found, the pervasive schistosity being axial planar to these folds. In several places, minor folds related to the Snåsa syncline (or other major folds occurring further north) deform an earlier linear element. From this it will be appreciated that the deformation which produced the Snåsa syncline was not the first to affect these metasediments.

The northern half of the area is characterised by steep-dipping metasediments and granite-gneisses, but it is nevertheless possible to demonstrate the existence of a further two major structures with the aid of minor structural evidence. The disposition of the various metasediments and basement rocks to the SW of Kolåsfjell would appear to indicate the presence of an anticlinal structure complementary to the Snåsa syncline. Although no indubitable fold hinges were discernible, a study of the minor folds and their relative vergence reveals the presence of a tight fold closing upwards (Fig. 2), thus confirming the stratigraphical indications. South of the axial surface trace of this fold, minor folds deforming the schistosity are overturned towards the NNW — this is also the northern limb of the Snåsa syncline. Immediately north of the axial trace the direction of fold overturning is reversed, but folds become inconspicuous away from the hinge zone of this anticline.

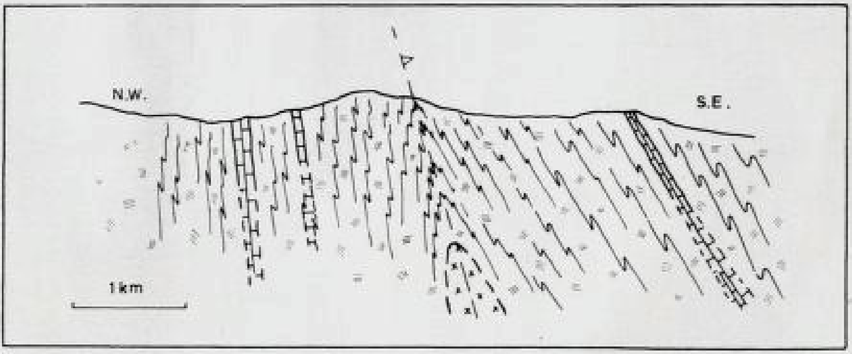


Fig. 2. Diagrammatic profile (SE of Kjennerås) depicting anticline axial plane located by congruous minor folds.

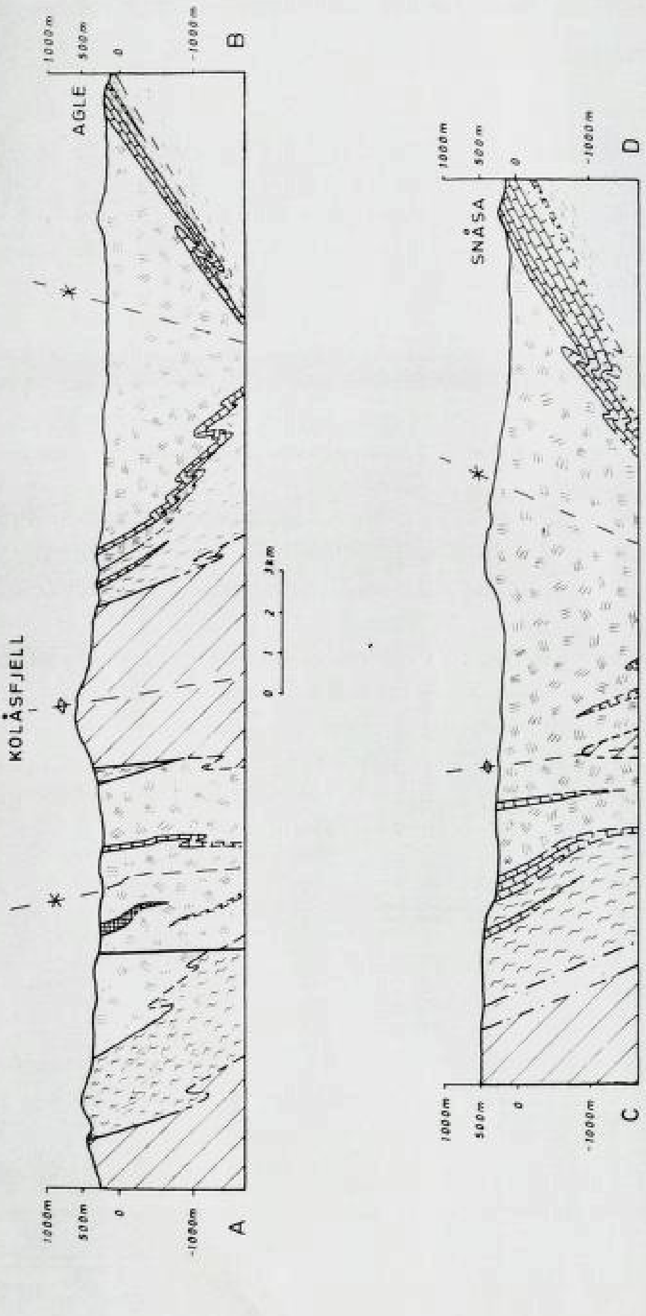


Fig. 3. Geological sections across the area.

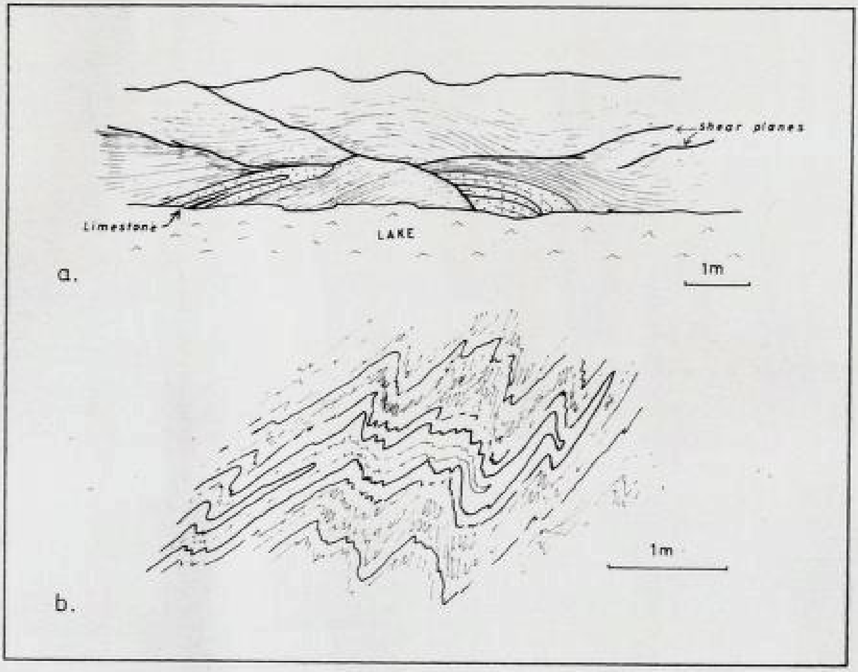


Fig. 4. Early (first episode) structures. (a) Sheared isocline with third phase warps. Calcareous greenschist and limestone, NE shore of Snåsavatn. (b) Isocline deformed by second phase folds. Limestone, Troldvaselven.

Further to the north-west minor structural indications are that another fold, this time synclinal, is present within the greenstone-greenschist sequence (Figs 1 and 3) the axial surface trace extending north-eastwards beyond Flåtjern and separating the two outcrops of mica schist in the extreme NE part of the area. This again supports the stratigraphical evidence. To the south-west, west of the Bruvoldelven valley, it has not been possible to trace this fold.

The changing style of the regional major folds is rather interesting; in the northern part of the area the 'Flåtjern syncline' is a very tight structure while the anticline further south is only slightly less acute. In comparison the Snåsa syncline is a relatively open structure. This trend — of progressively more open style to the S or SE — is continued if the Tømmerås anticline is brought into the picture (Peacey 1964).

Though a systematic analysis of minor structures and lineations was not possible in the time available, their observation has shown that three main episodes of deformation have affected the rocks in this area. Faulting may be counted as a possible fourth phase of the deformation history.

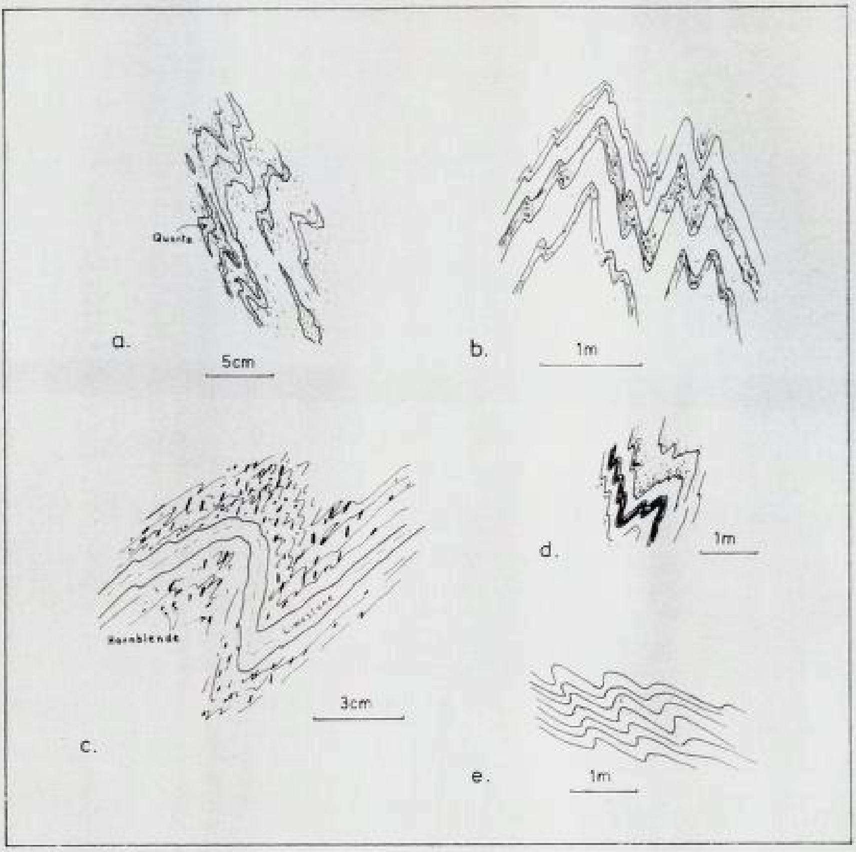


Fig. 5. Second episode structures. (a) Mica schist with vein quartz. (b) Interbanded leptite and schist. (c) Hornblende schist with limestone ribs. (d) Greenschist with psammite bands. (e) Greenschist.

The most abundant structure representative of the first episode of deformation is the schistosity or foliation displayed by metasediments, volcanic rocks and gneisses. Folds to which this folation is axial planar are quite uncommon, tending to be restricted to interbanded limestone - calc-silicate schist and some greenschist lithologies (Fig. 4). Where present they are essentially of isoclinal type. Boudinage and stretching phenomena constitute an associated linear element as does the alignment of small granules and pebbles in the conglomerate within the phyllite member of the succession. Major first episode folds have not been recognised.

Second episode folds and lineations are prominent over most of the area. Minor

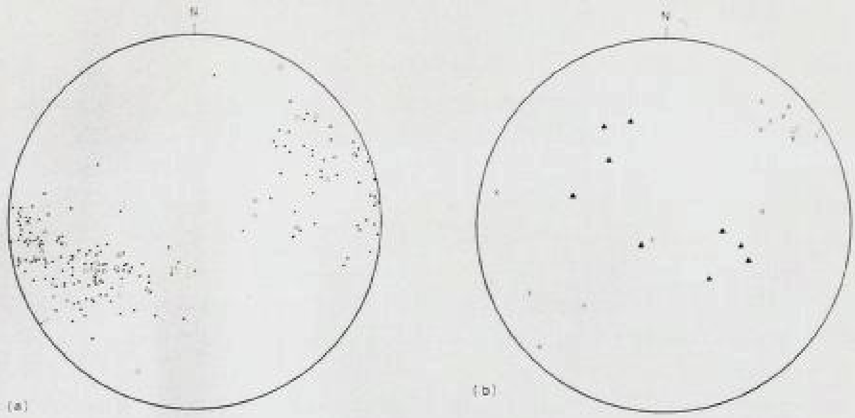


Fig. 6. Stereographic projections of linear elements (Wulff net, lower hemisphere). (a) Second episode structures; dots — folds axes and phyllitic lineation; open triangles — mineral lineation; circles — lineation in basement rocks. (b) First and third episode structures; crosses — first episode fold axes and lineations; ellipse — pebble elongation (first episode); full triangles — third episode fold axes.

folds vary considerably in style, a variation which is only partially dependent on lithology, since in the south these folds tend to be less acute than in similar greenschist farther to the N-NW. In the limestones a maximum style variation is observed, from quite open to near-isoclinal structures.

Minor folds axes and lineations belonging to this generation are depicted on the stereogram, Fig. 6. The variation of trend is largely a reflection of the attitudes of the major structures of this second episode and only to a minimal extent by later deformation. In the south, for example, both in the hinge zone and on the southern limb of the Snåsa syncline, minor fold axes generally plunge at low angles to the W-WSW; locally however, plunges are to the east. Moving N and NW away from the axial trace of the syncline the angles of plunge of these minor folds steepen until, in the closure zone of the adjacent anticline, they are in the range 30° - 50°. At the same time the direction of plunge moves round close to SW.

Within this same anticlinal hinge zone away from the Kolåsfjell gneiss, second episode minor folds and lineations plunge less steeply and towards Troldvatn the direction of plunge is often ENE. An ENE fold plunge is also common in the mica schist and limestone in the north-western part of the map area. It would thus appear that the steeper lineations and fold axes in the hinge zone of the 'Kolåsfjell anticline' just to the SW of the wedge of gneiss are a consequence of granite-gneiss acting as some kind of buffer during the deformation, so resulting in a deviation of linear elements developing in the less competent metasediments.

In the Flåtjern area, lineations of this generation are quite irregular in trend swinging round to N-S and then reverting to the general WSW plunge in the extreme north-east of the area. While this deflection appears to be due to a later episode of deformation, impression of linear elements on a pre-existing irregularity cannot be entirely ruled out.

Boudinage is also found associated with second episode folds. In some places two orthogonal directions of boudinage may be observed, moreso where conjugate shear planes disrupt the picture: this latter case, with boudins aligned in 'a', is not uncommon in the greenstone-greenschist lithology. Fold mullions are demonstrable in the mixed leptite-schist lithology west of Kultjern — these are parallel to the local second phase fold axes.

Acicular hornblende frequently displays a preferred lineation paralleling the second fold axes, but cases of two amphibole lineations in the same rock have been observed in the hornblende schists of the Kolåsfjell anticline hinge zone. Where this occurs, the earlier lineation is only weakly developed and is quite oblique to the prominent later element.

A crude linear element, essentially of quartzo-feldspathic material, is manifest in the granite-gneisses: this appears to be parallel to the second episode lineation developed in neighbouring metasediments.

Third episode structures are relatively uncommon, at least as minor folds. Where recognisable they are quite open folds or warps, although locally in phyllitic lithologies they may be represented by kink folds or strain-slip cleavage.

Distortions of earlier lineations on a large scale may also be attributed to this deformation phase. In general the trend of these late warps or folds is somewhere between NW-SE and WNW-ESE and is, therefore, more or less normal to the dominant second phase lineation.

Faulting appears to be a relatively insignificant feature over this small area. The few faults present show a marked NE-SW trend, although the major fault in the south and south-east varies from ENE to NE. This fault may quite feasibly be an extension of the major strike-fault present just north of Snåsavatn (Peacey 1964), but further investigations are needed before a definite opinion can be voiced.

Since the faults are representative of a notably brittle deformation, they are probably largely of fairly late development. As several of them are strike faults or oblique faults, they could be envisaged as developing simultaneously with the upheaval of the Grong culmination, itself a late structural feature (Oftedahl 1955). Downthrows along these faults are noticeably to the SE or SSE, an observation which would seem to accord well with Oftedahl's postulate of a late upheaval of the basement to the north of this Snåsa area. On the other hand, minor slides in the limestones, associated with the second episode of folding, are often seen to develop into faults along the same dislocation. These faults sometimes exhibit features indicative of horizontal displacement. While most faults over the area appear to be normal, the major fault in the south which displaces the Snåsa syncline axial trace may have an additional tear component, but the evidence for this is indistinct.

The penetrative schistosity or foliation seen in all lithologies in this area has been shown to have developed concomitantly with the first folding. Although this would appear to restrict the main metamorphism and recrystallization to this deformation phase, the picture is not so straightforward. The second generation structures deform the foliation but they also deform quartz veins and segregations and granitic material locally pervading the mica schist which can be shown to post-date the first folds and foliation.

Vein and segregatory quartz, while usually paralleling the banding of schistosity, is not infrequently seen to transsect these S-planes. It is however strongly deformed, often boudined, by the second folds. Similarly, granitic and pegmatitic material occurring in the mica schist near the basement contact has been emplaced ensuing the development of schistosity and is clearly of replacive origin. This too is affected by the second folding. These phenomena suggest, therefore, that metamorphic and metasomatic processes continued into the static interval separating the first and second deformation phases but a precise dating of the acme of the metamorphism cannot be given until a thorough petrographical study has been carried out. While this accounts for the main regional metamorphism, it is quite likely that the pre-Lower Hovin rocks were also affected by an earlier metamorphic event, as noted previously.

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