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Tittel

A structural and stratigraphical study of the Furulund Group. Kartlegging. Geologi.

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Sammendrag

Furulundgruppen - strukturgeologi. På bakgrunn av detaljerte feltundersökelser er det forsökt å klarlegge om Furulundgruppens bergarter er invertert. Sedimentære strukturer, deformasjonshistorie (folder, lineasjoner, skifrighet) er undersökt. Övre del av Furulundgruppen er invertert som fölge av deformasjonsfasen D2. Meget vakre og detaljerte kart. Geologi. Kartlegging. Nordgruvefeltet.

A structural and stratigraphical study of the Furulund Group, Sulitjelma, Norway.

Report submitted to A/S Sulitjelma Gruber on fieldwork undertaken during 1980 and 1981.

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Project Aim

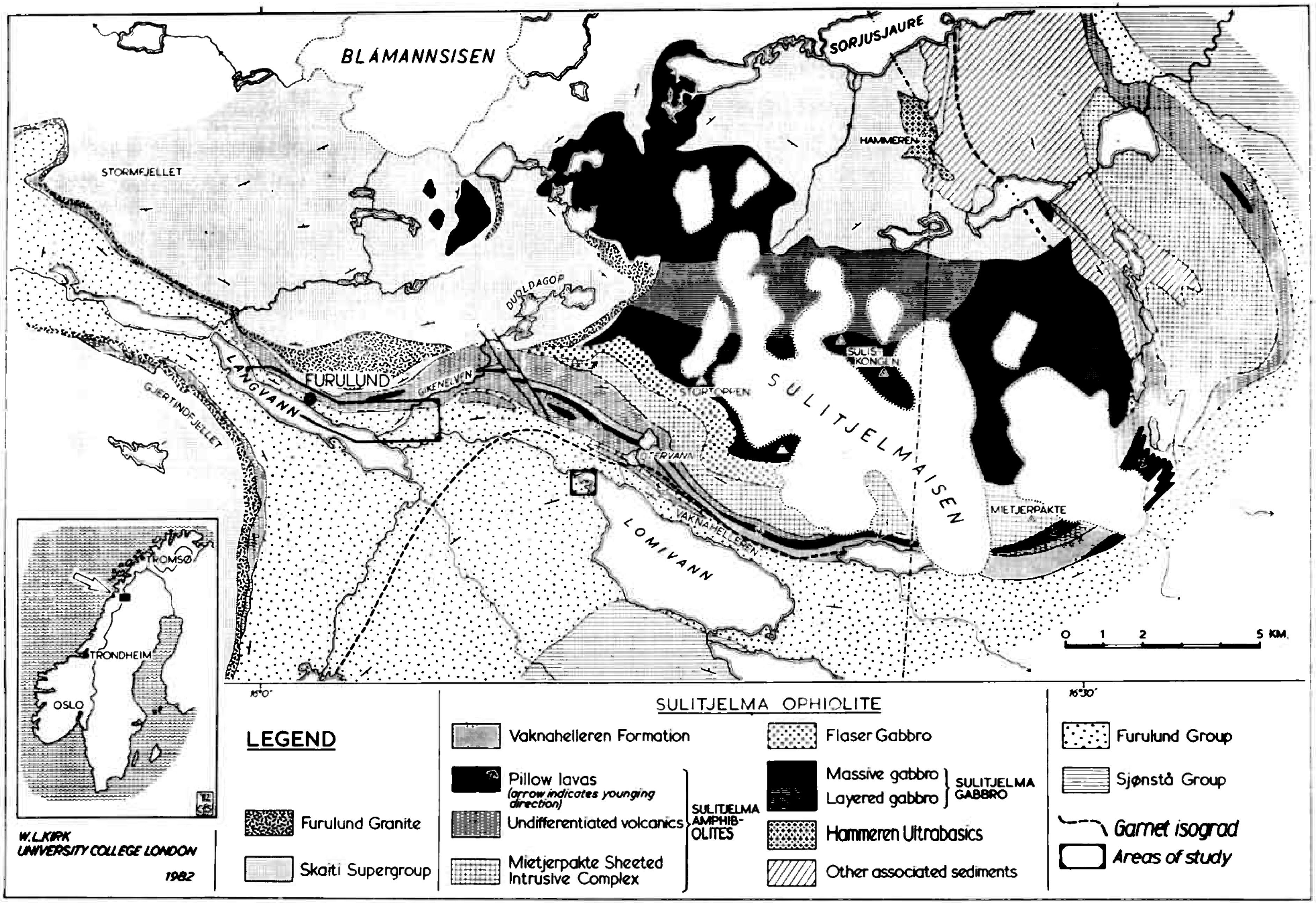
During the summer of 1980, a period of one month was spent making preliminary investigations into the lithologies and early structures in the upper part of the Furulund Group up to the contact with the overlying Sulitjelma amphibolites. Detailed work was conducted in a small area of good exposure and easy access in the northern ore field, north of Langvann. As results proved promising, a second field season of five weeks was conducted in 1981. Structural maps were made covering an area of about 1.5 sq. km. lying mainly west of Gikenelv, and a reconnaissance visit to the west end of Lomivann supported evidence from Giken for the structure of the area.

Introduction and previous research

The Sulitjelma region lies on the Norwegian/Swedish border, and comprises a series of Caledonian cover rocks lying in a tectonic depression between the Precambrian granitic-gneiss culminations of Tysfjord to the north, and Nasafjell to the south. It is a region of interest both geologically and economically, for it is an important copper-mining district.

Sulitjelma is well-known geologically, research having been started at the beginning of the nineteenth century. The first geological map was published by Sjögren in 1900, and early work has been summarised and reviewed in the classic memoir of Th. Vogt (1927). These early researchers all considered that the sequence at Sulitjelma was stratigraphically continuous and upright. A major challenge to this interpretation was made by Kautsky (1953); he postulated that the sequence lay in a number of allochthonous nappes, one of the major thrusts lying at the junction of the Furulund Group with the overlying Sulitjelma amphibolites. Considerable discussion has taken place since, both in favour of a nappe interpretation and against it. Recently, Geis (1978) and others have demonstrated that the Furulund Group and Sulitjelma amphibolites may be inverted, and in particular, Boyle (1979) has demonstrated that the amphibolites and the Sulitjelma Gabbro are part of a partially inverted ophiolite sequence (see also Boyle, Griffiths and Mason, 1979).

In the light of these recent discoveries, it has become important to the understanding of the regional geology and also to the search for strata-bound copper ores to determine whether any or all of the Furulund Group is inverted. Although the local lithologies and structures of the schists were studied extenisvely by Wilson (1968) and Henley (1968), and have been described in their regional context by Nicholson and Rutland (1969) it was deemed appropriate to re-examine in detail a small area with these recent discoveries in mind. The area chosen, mainly around Gikenelv, lies in the northern ore-field (Fig.1); lithologies and early structures were studied in the 250m. below the contact with the overlying Sulitjelma Amphibolite Group.


BLÅMANNSISEN
SORJUSJAURE
HAMMEREN
STORMFJELLET
DUOLDAGOP
FURULUND
LANGVANN
GIKENELVEN
GJERTINDFJELLET
STORTOPPEN
SULITJELMAISEN
SULISKONGEN
ØVERVANN
VAKNAHELLEREN
LOMIVANN
MIETJERPAKTE
TROMSØ
TRONDHEIM
OSLO
0 1 2 5 KM
15°0'
16°30'
W.L.KIRK
UNIVERSITY COLLEGE LONDON
1982
LEGEND
Furulund Granite
Skaiti Supergroup
SULITJELMA OPHIOLITE
Vaknahelleren Formation
Pillow lavas
(arrow indicates younging direction)
Undifferentiated volcanics
Mietjerpakte Sheeted Intrusive Complex
SULITJELMA AMPHIBOLITES
Flaser Gabbro
Massive gabbro
Layered gabbro
SULITJELMA GABBRO
Hammeren Ultrabasics
Other associated sediments
Furulund Group
Sjønstå Group
Garnet isograd
Areas of study

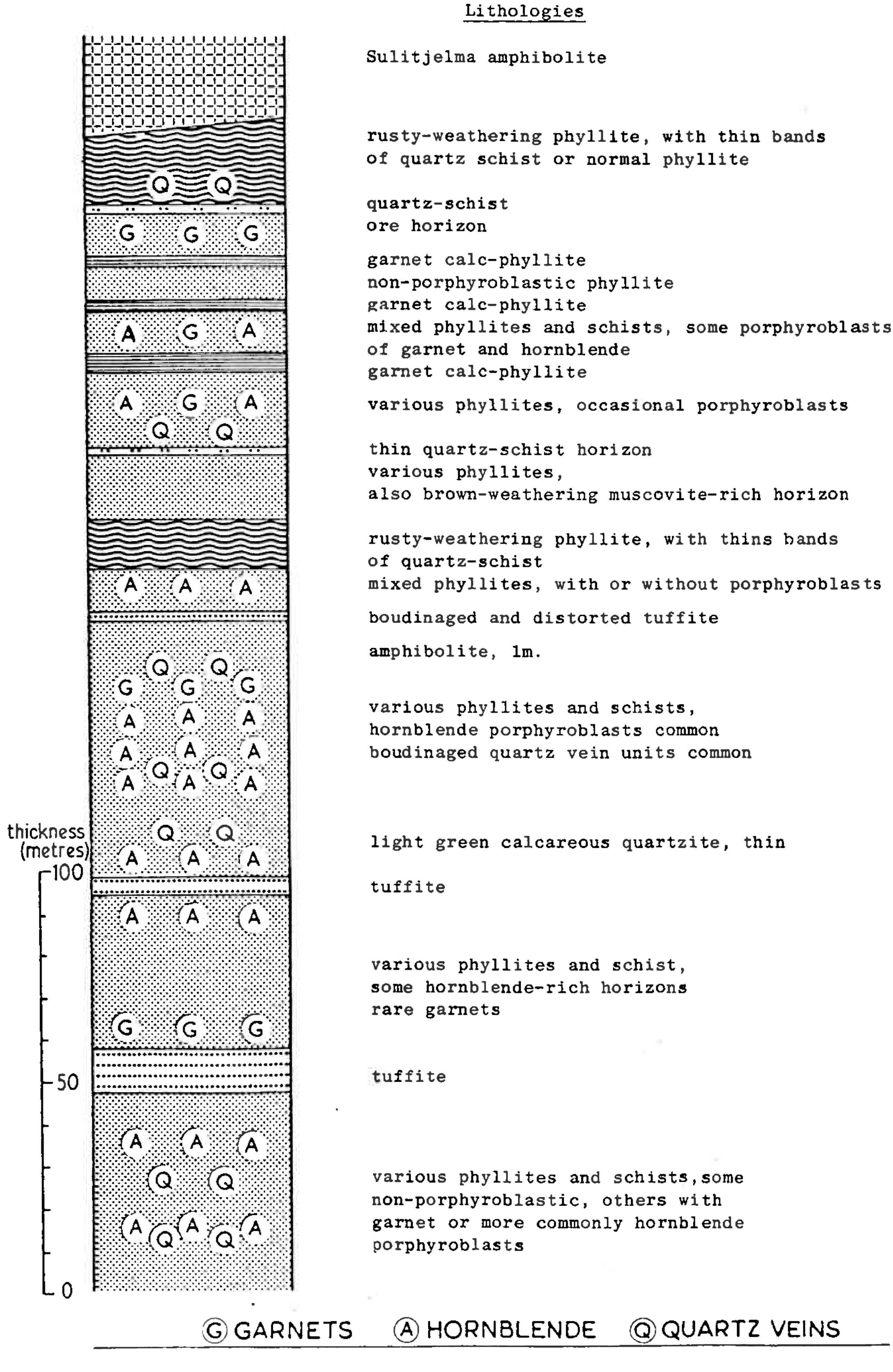
Furulund Group: Lithologies and sedimentary structures

The lithological succession has been described by Henley (1968, 1970) and Wilson (1968). It comprises a thick sequence of regionally metamorphosed pelitic and semi-pelitic sediments which are often calcareous. These have a well-developed schistosity and include thin bands and lenses of schistose amphibolites. The metamorphic grade increases from east to west across Sulitjelma so that at Giken the succession lies above the garnet isograd. The outcrops in this area form strips lying east-west (see accompanying maps), but thin and thicken along the outcrop due to intense post-schistosity boudinage. The upper 280m. were logged in detail up Gikenelv as far as the contact with the overlying Sulitjelma amphibolites. A generalised column section is shown in Fig. 2, and the complete detailed column section is included at the end of the report. Note that contacts between successive lithologies are usually gradational.

The lower part of the succession comprises various phyllites and schists which are often colour-banded. The banding, believed to represent bedding, occurs on the scale of a few centimetres and is usually parallel to the regional penetrative schistosity. Some horizons contain amphibole porphyroblasts up to 4cm. long, generally lying parallel to the schistosity surfaces; these needles may show a random orientation or garben structure, (Plate 1), or they may show a preferred orientation, lying parallel to the regional penetrative lineation. More rarely, horizons occur which contain both garnet (1-2mm.) and amphibole porphyroblasts. There are few horizons containing garnets alone. Intercalated with these metasediments are schistose amphibolite horizons, usually about 2 cm. thick, which are believed to represent tuffs (T. Hansen, pers. comm.). These often occur multiply, forming tuffites about two metres thick.

Attempts to follow these lithologies laterally proved almost impossible for several reasons: (i) because boudinage cuts out horizons completely from place to place (ii) although exposure is excellent, the lithological variations which are

Fig. 4 Furulund Group: Lithologies
Generalized column section up Gikenelv, through the uppermost 280 m. of the Furulund Group



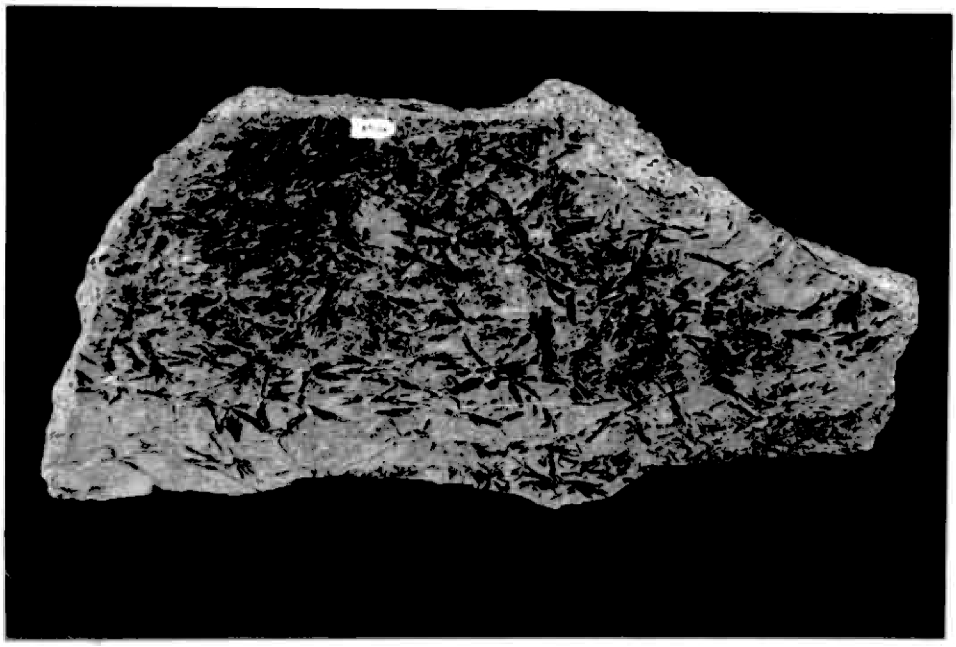


Plate 1   Garben structure in hornblende-rich phyllite

reasonably distinct in any one outcrop are not sufficint to enable recognition and correlation laterally (iii) the lithologies themselves vary laterally so that even in distinctive hornblende-porphyroblastic horizons, the porphyroblasts can be highly abundant in one part of the outcrop, yet totally absent in another (iv) outcrops often comprise vertical shear joints in which garnet or hornblende-rich layers are very difficult to recognise.

Quartz veins are very common in this part of the succession, occurring in the necks of boudinaged amphibolites, the quartz boudin scars often being flattened subsequently, and as boudins or folds cross-cutting schistosity. There is evidence for their intrusion at all stages in the tectonic history. These deformed quartz veins often occur together forming distinctive units perhaps 2m. thick, which are intimately associated with very hornblende- or biotite-rich layers, amphibolites and metasediments.

Non-porphyroblastic phyllites pass upwards without break into fine-grained rusty-weathering rocks, which are easily eroded and form the base of a 150m. waterfall at Giken. The rusty colour is due to weathering of contained pyrite. Some horizons are black and contain graphite, others take the form of grey and rusty banded rocks, which may have small (<1 mm.) porphyroblasts of garnet lying in thin layers. This rusty-weathering horizon can be traced readily to east and west, although the thickness varies considerably along the outcrop, presumably due to later extension and boudinage. Within these rusty phyllites are several fairly distinctive psammitic bands, approximately ½ m. thick.

Above the rusty-weathering phyllites lie generally non-porphyroblastic grey phyllites, although occasional porphyroblasts of garnet and/or hornblende do occur. This group of beds is known to form virtually the entire cliff feature above the bridge at Giken, but rapidly thins eastwards so that at the easternmost part of the study area, it has virtually disappeared. When traced westwards, it again forms cliff features which have not been examined in detail due to inaccessibility. Within this unit is a distinctive marker band of light-brown weathering quartz-biotite schist, which is about 2 m. thick at Gikenelv. It can be traced westwards intermittently, often occurring as two or three thinner bands, the repetition possibly brought about by early minor isoclinal folding. It has not been recognised east of the river or west of Leirelven.

Garnet calc-phyllites lie above this group, and at Gikenelv are interbedded with 'normal' phyllites. This unit is very distinctive, and occasionally contains hornblende as well. However, correlation of individual units across Gikenelv was not easy, particularly as the river was impassable in 1981, and the correlations are tentative. These beds are colour-banded, passing gradually from a light brown-brey to dark brown, and then abruptly to a light colour again, indicating the possibility of graded bedding (Plate 2). The garnets tend to be more abundant towards the darker layers.

Plate 2 Detail of colour-banding in garnet calc-phyllite, Glastunes

These bands pass upwards into phyllites which may contain porphyroblasts of garnet and hornblende, but not generally the latter alone. Above this lies another band of quartz-biotite schist which can be traced with certainty for 600 metres east of Leirelven, but correlations elsewhere are tentative. It is very similar both in hand specimen and in thin section to that already described.

Rusty-weathering rocks lie above these phyllites, forming the uppermost part of the succession. These are very similar to the lower rusty horizon, containing bands of graphite-rich phyllite, and also more psammitic units, which weather and crumble very quickly. In addition, a competent and finely banded unit (Plate 3) outcrops on the east of Gikenelv within the phyllites, forming a distinctive unit.

Some schistose amphibolite layers occur, but are less well developed than in the lower part of the succession. Quartz veins occur regularly throughout the upper hundred metres, and often occur as boudins up to a metre thick. The distinctive quartz-vein units of the lower part of the succession were not present.

Plate 3 Finely banded unit within rusty-weathering phyllites

Below the lower rusty-weathering horizon lie boudinaged amphibolites, termed the Kjeldvann metadolerites by Boyle et al. These are now distinct lenses, forming upstanding hillocks such as that found south of the road at Giken. Grain-size varies from coarse to medium, and at their margins they are often altered. They are geochemically dissimilar to the Sulitjelma amphibolites above (Boyle, Kollung, Mason and Søyland-Hansen, in press) and have been shown to cross-cut bedding over a wide area. They are therefore thought to be a deformed sill-like intrusion.

At the contact with the amphibolites occur keratophyric breccias, often associated with chloritic breccia. These tectonic breccias have been studied by Wilson (1968) whilst investigating the nature of the contact. In places, the junction between the Furulund Group and the amphibolites appears to be tectonic, but in one place, a thin layer of normal calc-phyllite, with some garnet porphyroblasts, lies above the rusty-weathering schists. Close by, normal calc-phyllites pass straight up into the amphibolites, and the contact appears to be stratigraphic.

Occurrence of ore

The ore occurs both massive, and as porphyroblastic cubes, often distorted and usually found in association with breccias at the contact. The main occurrence of massive ore lies above the Giken waterfall, some 20 m. below the contact. At one locality, the ore cuts across banding almost at right angles, although more generally it forms two or three bands sub-parallel to banding. This may be brought about through isoclinal folding. That this horizon has been worked in the past is shown by a number of old mine workings, now disused, as indicated on the map.

Lithologies in other areas

Reconnaissance visits were made to neighbouring areas, including Hellarmo and the western end of Lomivann. At Hellarmo, the schists are strongly banded, some horizons being black and mica-rich, whilst others are light-coloured and rich in quartz and feldspar (Plate 4). Although the banding repeated every few centimetres, and some bands looked graded as far as variation in mineralogy was concerned, no consistent way-up evidence could be found. At Lomivann, which lies to the east of the garnet isograd, outcrops are clean and freshly exposed due to a drop in water level brought about as part of a hydro-electric project. Exposure of non-porphyroblastic metasediments is excellent, with units obviously graded, and thicker than seen elsewhere, being up to two metres thick (Plate 5).

Plate 4   Banded schists at Hellarmo

Plate 5   Thick graded units at Lomivann, younging direction as shown.

Structural History

D2 Event

The Furulund Group has been subjected to polyphase deformation. Generally, the penetrative schistosity lies parallel to the banding, and both dip at about 20^{o} to the northwest due to later (D4) folding of the Langvann Antiform. Locally the banding shows tight to isoclinal S- and Z-folds to which the main schistosity is axial planar. They were assigned to a D1 event by Nicholson and Rutland (1969) and their terminology has been adopted widely. However, a recent appraisal by Boyle, Kollung, Mason and Søyland-Hansen (in press) has shown that these folds are coaxial with and belong to the same deformation event as the major Vaknahelleren syncline, which they have assigned to D2. This latter designation will be adopted in this report.

The axes of these folds trend between north and west in the Giken area, plunging between 0^{o} and 28^{o} (see Fig. 3a). They are best exposed within the garnet calc-phyllites, in which they occur abundantly, although since axial directions lie almost parallel to outcrops, they are not always determinable, and sections viewed are usually very oblique. Flame-like structures are sometimes developed, thought to be due to subsequent flattening. D2 structures are also developed to a lesser extent in other lithologies, particularly in the upper part of the succession. Typical fold structures are illustrated Plates 6a-6d. Chaotic folds occur fairly frequently in thin (1-2 cm.) schistose amphibolite bands in the lower part of the succession. These die out rapidly laterally and their significance is not understood. That pressure solution has occurred is illustrated by cutting out of parts of fold limbs against quartz veins lying parallel to axial surfaces, and by relics of transposed bedding/foliation (Plates 7a and 7b).

Although evidence of early folding at Giken abounds at outcrop scale, with amplitudes of a few centimetres to a metre or so, correlation of individual folds over a wider area has proved difficult so far. Correlation of individual synformal structures seen in outcrops all along the upper part of the

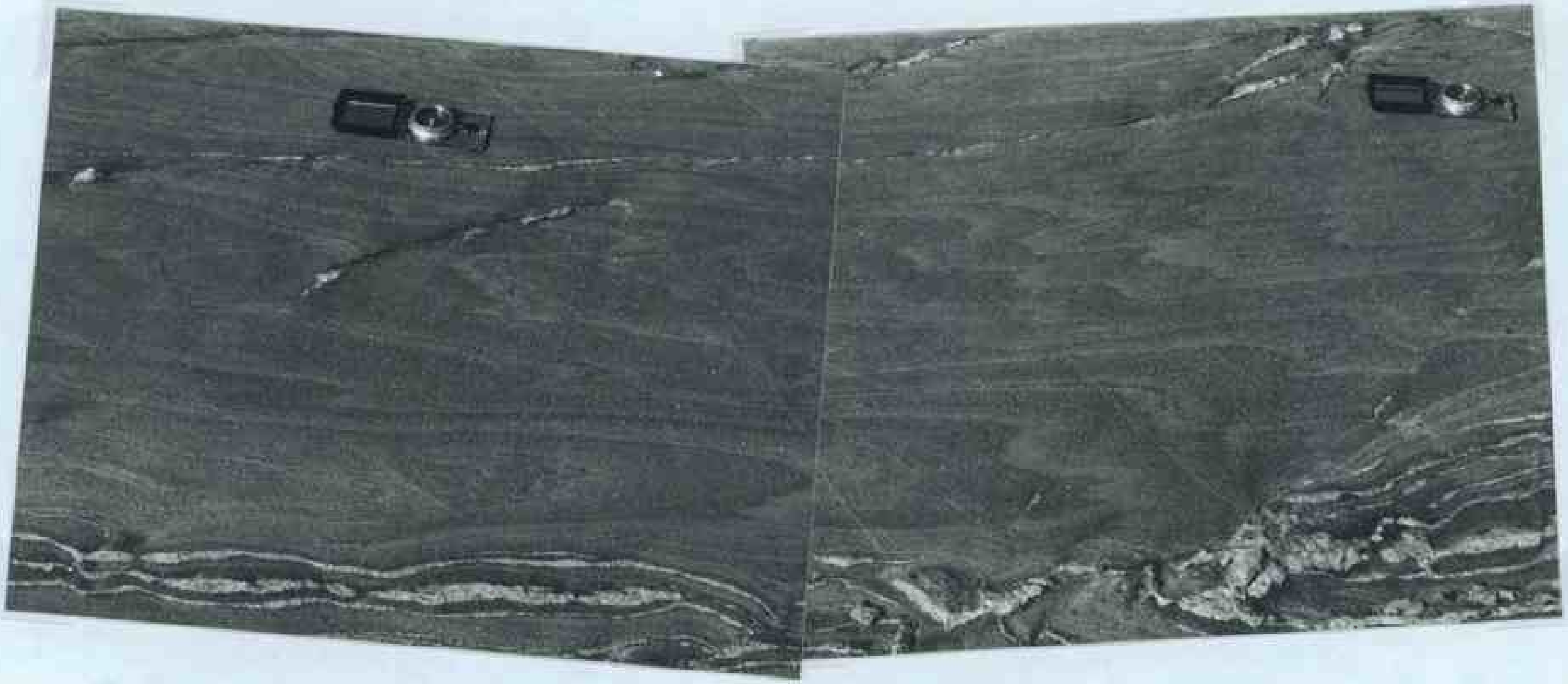


Plate 6a   Typical early fold development in garnet calc-phyllite, west of Gikenelv.
Folds plunge gently westwards to the left and slightly into the photograph.
Facing is downwards and to the north.

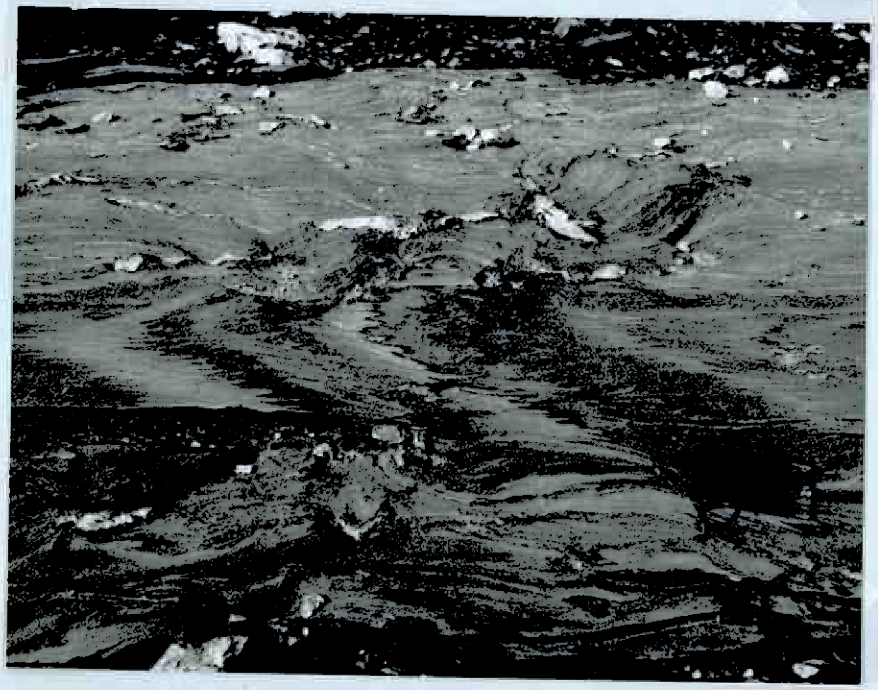


Plate 6b   Flame-like structures in D2 folds

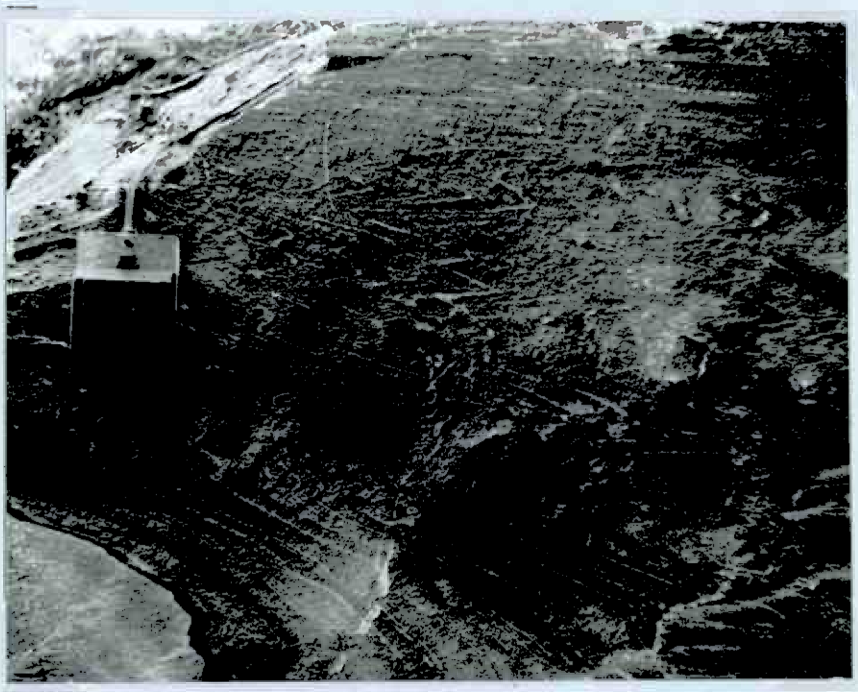


Plate 6c   D2 antiformal closure, east of Gikenelv and looking west. This closure has been refolded during D3 - see accompanying map, grid ref. -34 000Y 1 018 500X.

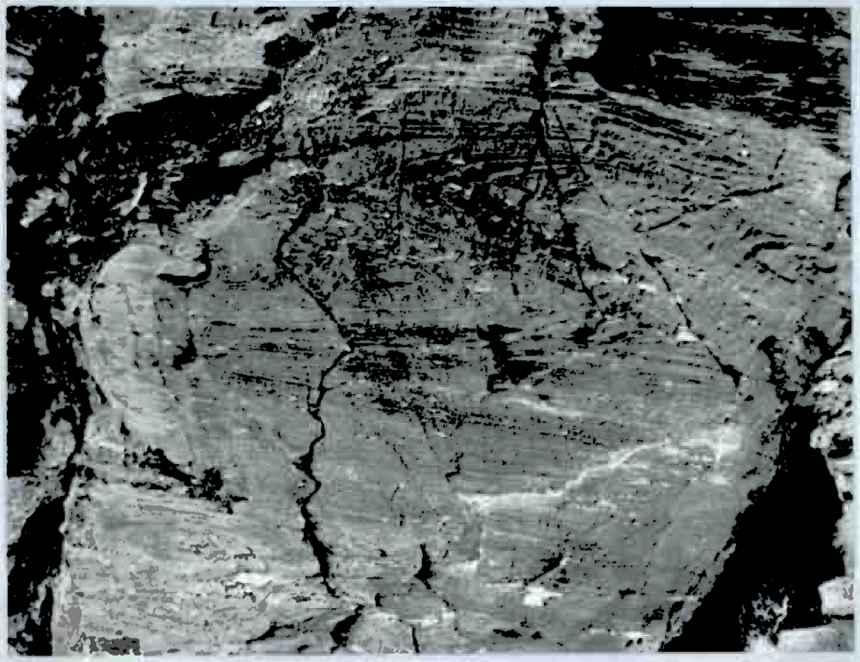


Plate 6d D2 fold exposed in joint face on western bank of Gikenelv. Note elliptical closure in bottom left-hand corner. Photo taken west - grid ref. -34 150Y 1 018 450X

Plate 7a Pressure solution effects in D2 folds. Note cutting-out of banding against boudinaged quartz veins. Photo taken west, 180 m. northwest of Giken

Plate 7b Transposed bedding, 120 m. WSW of Plate 6c

Plate 8a Downward-facing early fold west of Lomivann, plunging shallowly east-south-east towards the observer, and facing north-north-east. Note that the sense of asymmetry of minor folds on both limbs is the same, indicating formation during a subsequent (D3) event.

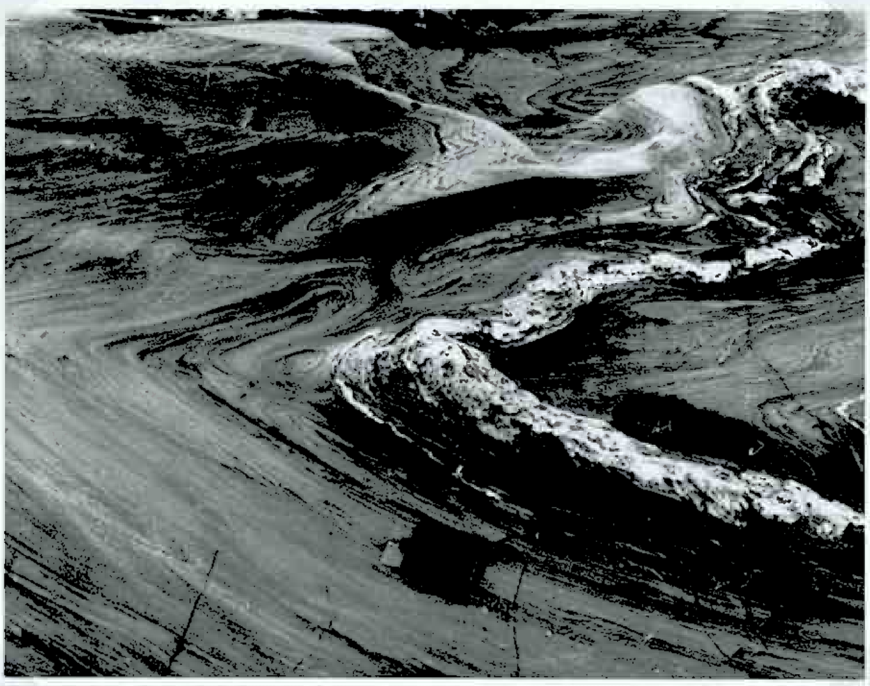
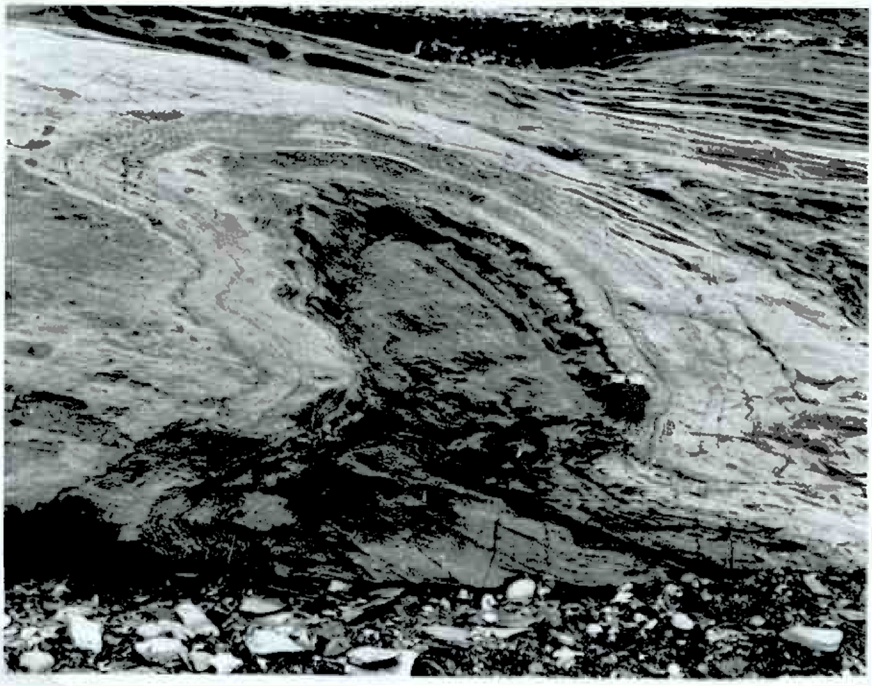
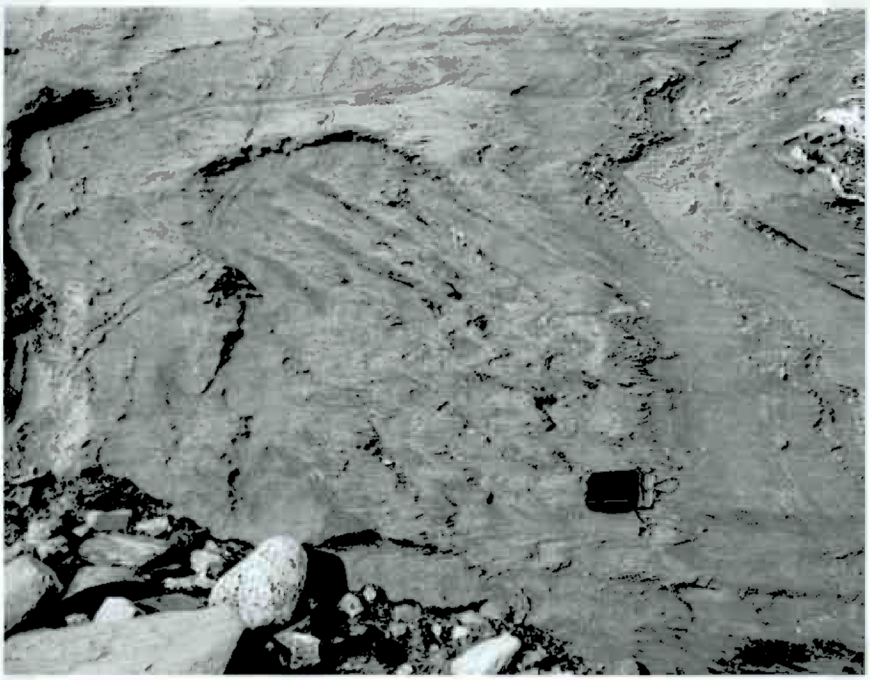


Plate 8b D2/D3 interference pattern, west of Lomivann



Plates 8c & 8d   D2/D3 interference patterns, west of Lomivann



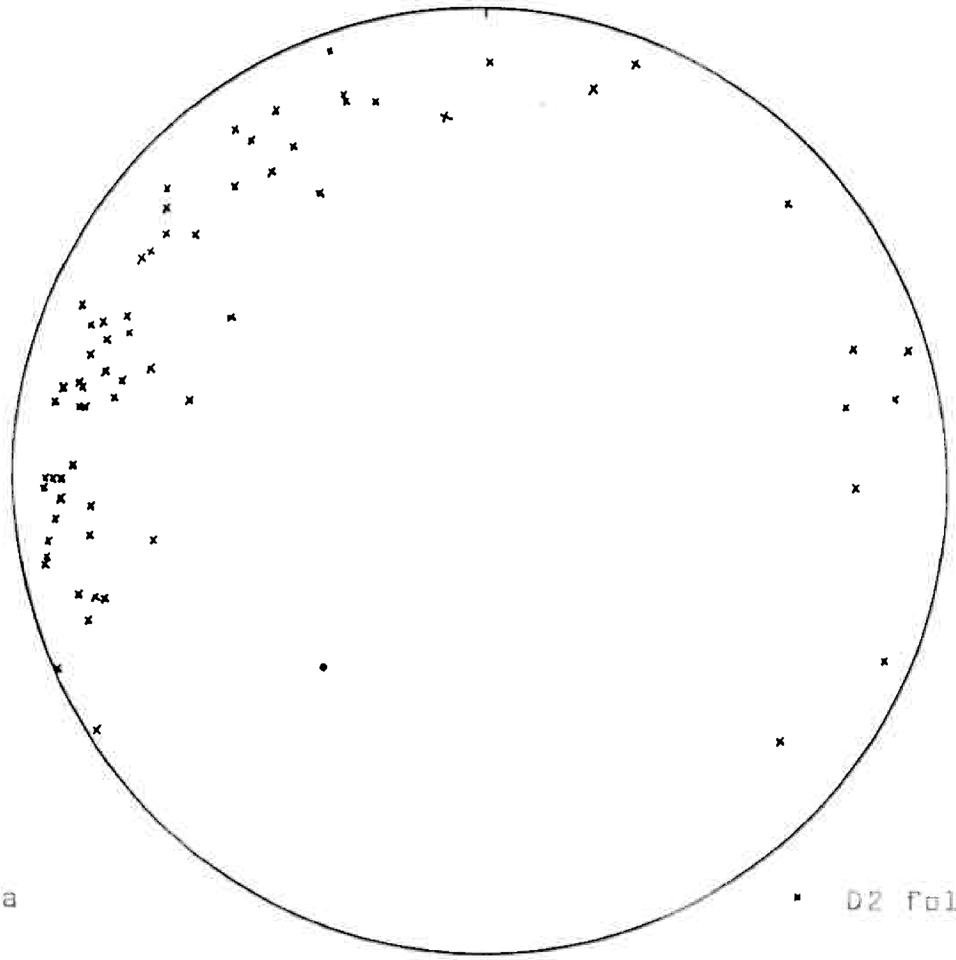
garnet calc-phyllite cannot be correlated with each other, nor is the significance of a beautifully preserved synform in a graphitic horizon just below the contact with the Sulitjelma amphibolites understood.

Evidence of D2 folding in the Lomivann region has been limited until recently due to lack of clean exposure. A drop in water-level as a result of an HEP project has revealed fresh outcrops showing outstanding interference patterns between D2 folds and later (D3) structures, as exemplified by Plates 8a-d. Note that the scale of the folds is greater than seen to the west at Giken and that the fold in Plate 8a plunges gently eastwards.

The symmetrical repetition of the lithologies between the two rusty-weathering schist horizons could be explained by a major D2 antiformal overfold when taken in conjunction with the predominance of S-folds in the uppermost part of the succession. However, there are then great problems accounting for the huge thicknesses of more 'normal' phyllites beneath, which this author believes is neither folded on a major scale, nor contains slides. Tectonic movements at the Furulund Group/ Sultitjelma amphibolite boundary are thought to be insufficient to cut out such a thickness.

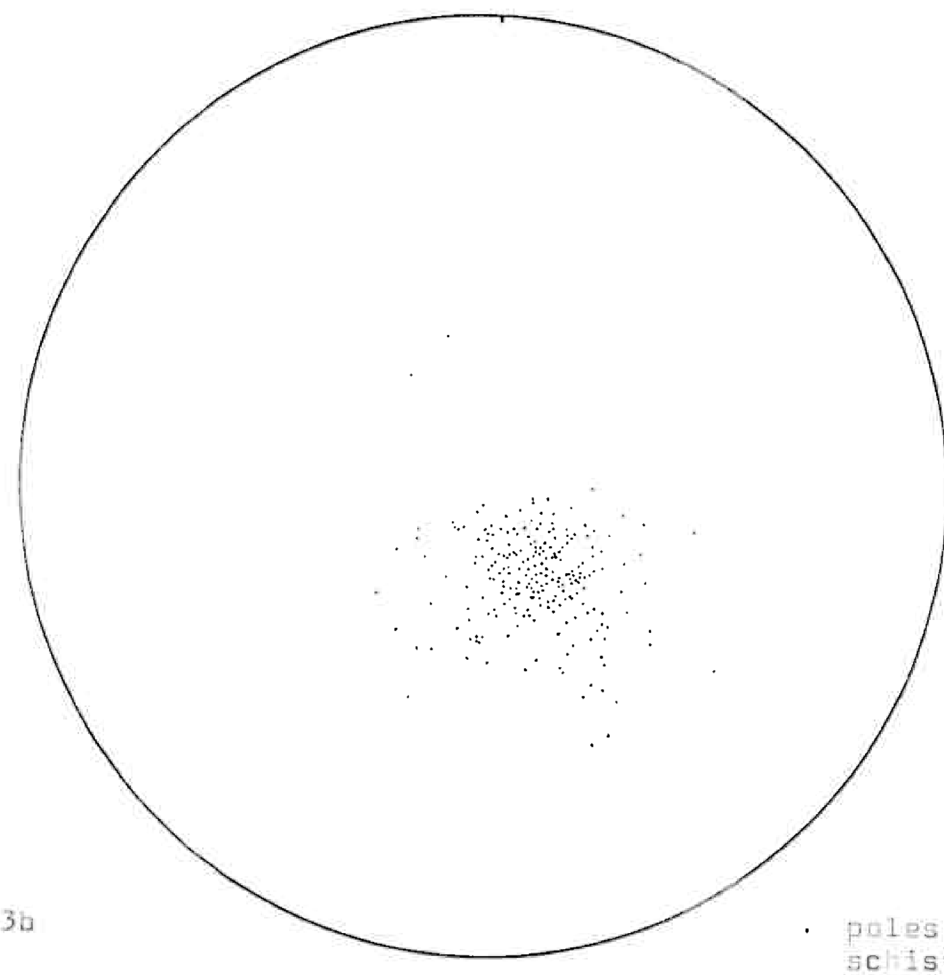
D2 fold axes are plotted in Fig. 3a, and form a great circle of the same orientation as the axial planar schistosity. This could have been brought by differential shear within the s-surfaces , which are plotted in Fig. 3b.

The main schistosity is accompanied by a lineation trending northwest (Fig. 3c), formed by the intersection of micas with the folded banding. This is nearly, but not quite, parallel with the main D2 fold direction. The hornblende porphyroblasts often show a preferred orientation parallel to this lineation. Both garnets and hornblendes show inclusion trails indicative of growth during or after the development of schistosity; many have rotated during growth, and are considered by Boyle et al to be partly synkinematic with D2. Subsequent flattening of schistosity around the porphyroblasts is assigned to a later



3a

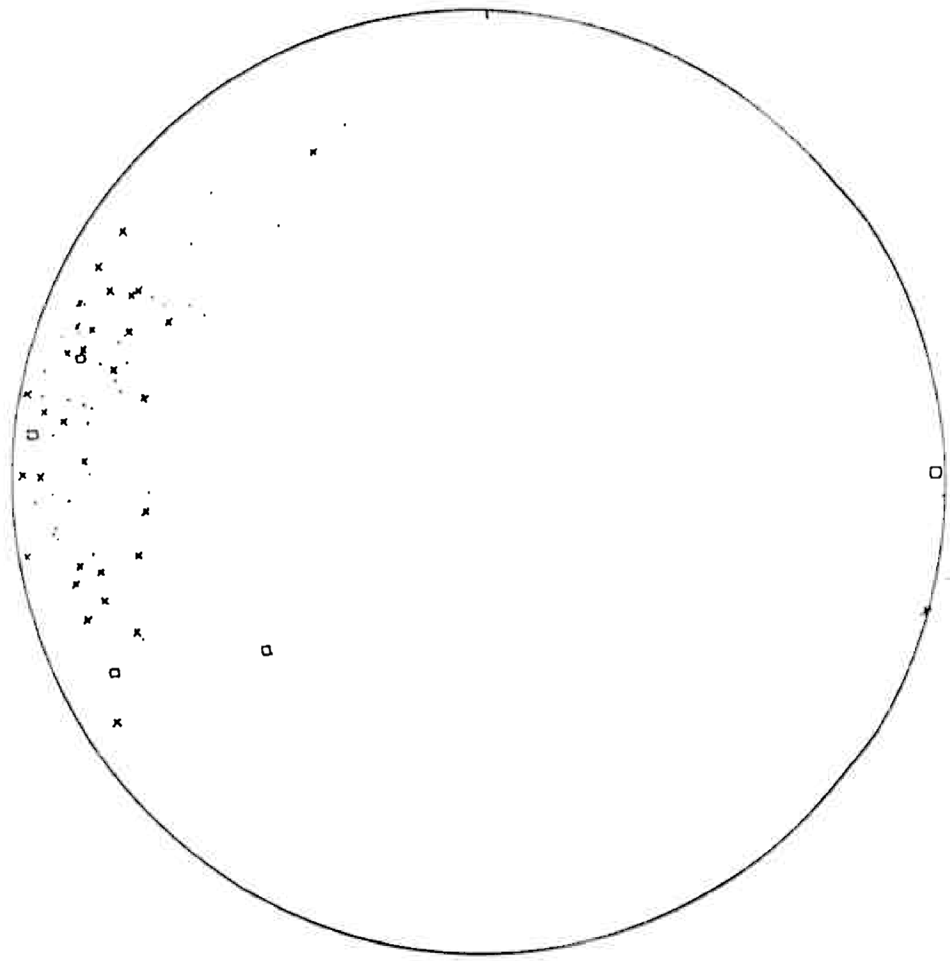
× D2 fold hinges



3b

· poles to main schistosity

Figs 3a & 3b Equal area nets showing D2 fold hinges, and poles to main schistosity



· penetrative lineation
× preferred orientation of hornblendes
□ crenulation around garnet porphyroblasts

Fig. 3c Equal-area plot of lineations at least partly synkinematic with D2 part of the same event, and appears to be synchronous with boudinage of quartz veins, hornblende porphyroblasts and amphibole-rich beds. Local variations in dip are probably caused by boudinage, post-schistosity folds on outcrop scale being rare in the main study area.

Plate 9 illustrates minor tight folds which have been picked out by weathering. These are discontinuous but obviously cross-cut the earliest folds, and have been assigned by Wilson (1968) using the terminology of Nicholson and Rutland (1969) to D2 along with the flattening of schistosity around the garnets, being the only folds that he recognises in his D2. This author suggests that they may represent carbonate vein material, originally cross-cutting banding, which has been folded synchronously with the earliest folds, and they are therefore not assigned to separate event.

Plate 9 'Weathered-out' folds, cross-cutting, but probably synkinematic with D2 folds of banding.

D3 Event

Although post-schistosity folds are not seen at Giken, folds of various styles and attitudes, with associated well-developed cleavage, have been described from the near vicinity by Wilson (1968) and assigned to D3. Pressure solution striping typical of these folds is illustrated in Plate 10. They are well-exposed at Lomivann, causing the interference patterns described above, but evidence of this event can be seen at Giken in the garnet calc-phyllites in the form of a marked cleavage cross-cutting the D2 folds. At one locality east of and above the waterfall, there is evidence that the D2 axis of Plate 6c is folded itself, reappearing with associated ore lower down the hill. Further west towards Bursi, kink folds in the rusty-weathering phyllites produce a striking cross-cutting foliation illustrated in Plate 11.

Later Structures

The northwest-southeast trending Langvann Antiform and the north-south trending Baldoaivve Synform are both attributable to D4, and it is the intersection of these major folds which produces the present outcrop pattern. Late-stage jointing is well-developed, and at one locality, the joints are folded (Plate 12).

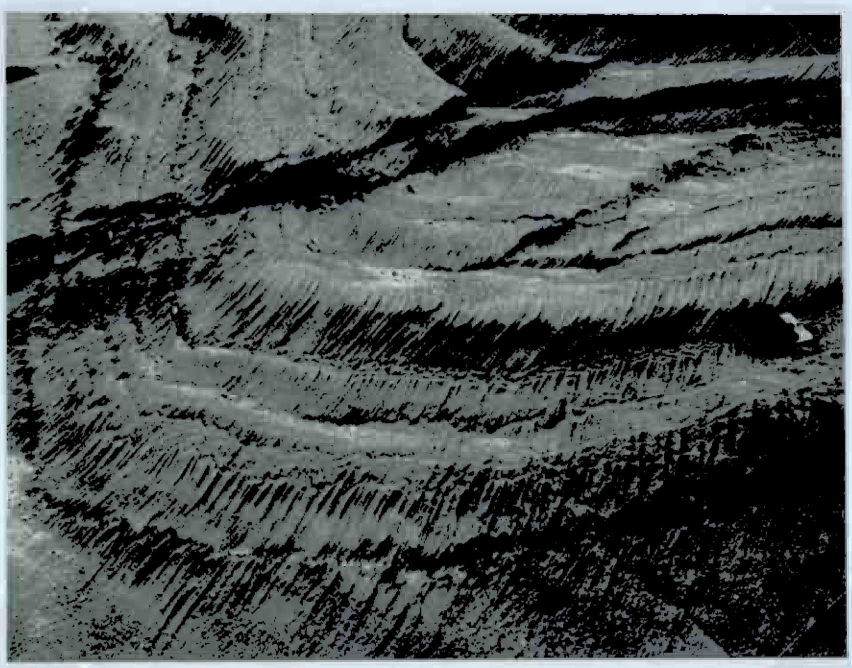


Plate 10 . Pressure-solution striping, D3 fold, Lomivann

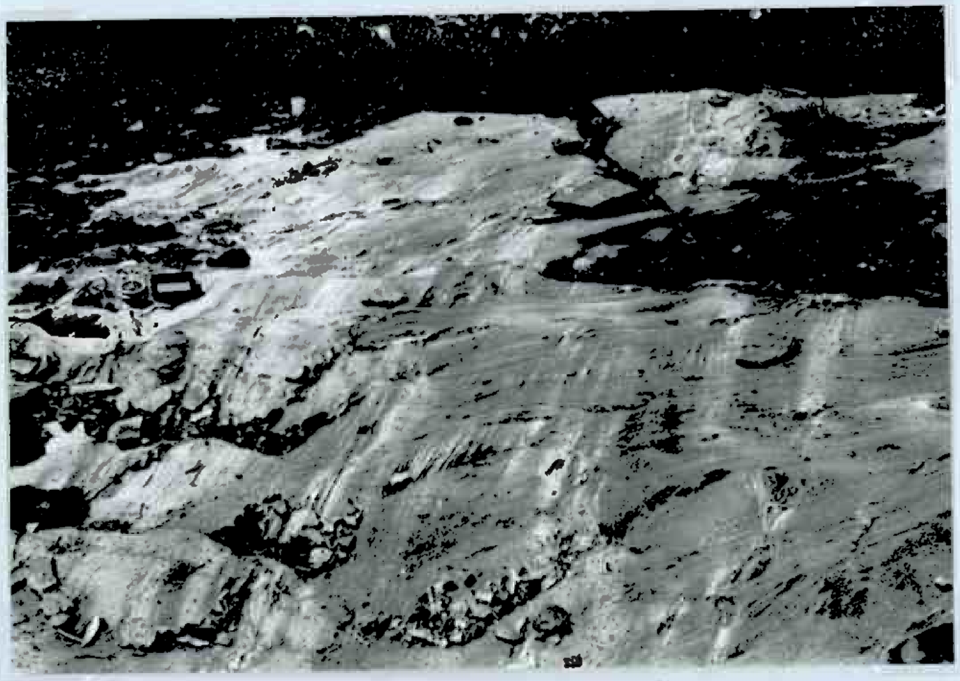


Plate 11   Kink-folds in phyllites, producing a marked cross-cutting fabric (D3)

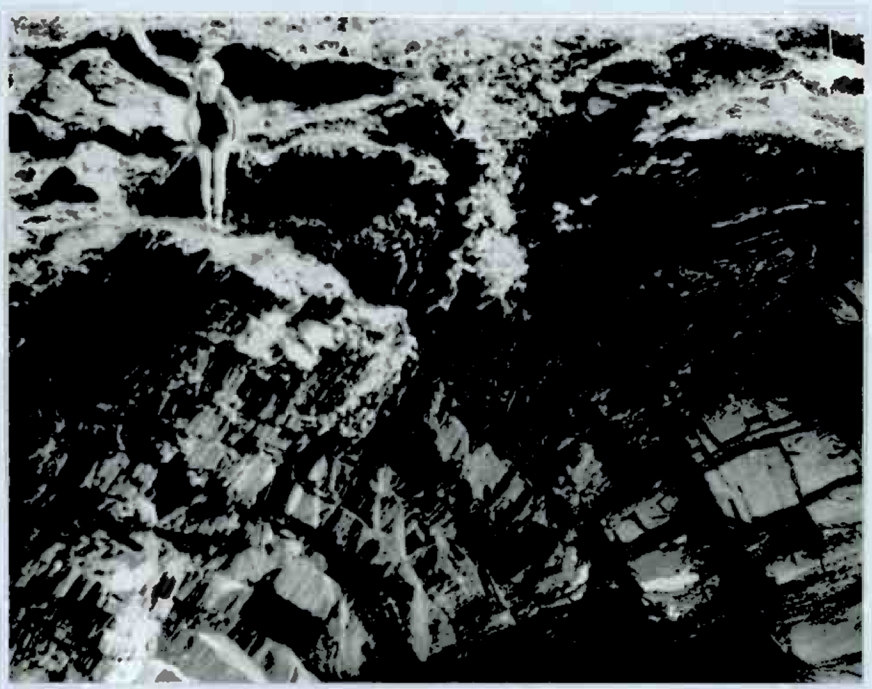


Plate 12   Folded joints, Giken, looking east

Evidence for the way-up of the Furulund Group

Before detailing the results of the present study of way-up structures in the Furulund Group, it is appropriate to outline evidence given by previous research workers for the way-up of the succession.

a) Regional

Early workers assumed that as the Furulund Group was bounded structurally above and below by different strata over a wide area, (the Sulitjelma amphibolites and Sjønstå Group respectively), the succession was continuous and upright. Nicholson and Rutland (1969) confirmed that the schists occupy the same position in the sequence regionally.

b) Local

Fossils occurring towards the base of the Furulund Group, and at the top of the Sjønstå Group below, were originally reported by von Schmalensee, working under Sjögren in 1898. Vogt (1927) produced the first detailed map of the occurrences and illustrates one colony, possibly the bryozoan Dianulithes petropolitanus of mid-Ordovician age, as being upright (but see also Spjeldnaes, pers. comm. in Wilson 1971). The area was subsequently mapped and the stratigraphy re-interpreted by Nicholson (1966).

Geis (1978) suggested that the whole sequence in the area might be inverted, giving examples of inverted graded bedding both in the schists and in sedimentary layers within the Sulitjelma amphibolites. He also cites examples of inverted graded bedding in Wilson's thesis (1968), which the latter found unacceptable as the grading could not be substantiated in thin section.

Recent research by Boyle has demonstrated that the Sulitjelma amphibolites comprise a sequence of pillow lavas and undifferentiated volcanics (termed the Otervatn Volcanics) and the Mietjerpakte Sheeted Intrusive Complex, which form, together with the Sulitjelma Gabbro Complex, the upper part of an ophiolite complex (Boyle 1979). Way-up evidence from the pillows has shown that whilst those to the north of the Vakna-helleren Schist are inverted (Fig. 1), those on the south side are upright, thus forming the lower limb of a syncline overturned towards the south (Boyle, Griffiths and Mason 1979). Thus much of the Sulitjelma phiolite is inverted.

c) Economic

The Sulitjelma ore bodies are massive sulphide deposits composed dominantly of pyrite, most of the ore bodies lying at or just below the junction of the Furulund Group and Sulitjelma amphibolites. Various hypotheses have been put forward to account for the origin of these ores in an upright succession (see Wilson 1973). However, if the top of the Furulund Group were inverted, this would suggest a more satisfactory exulanation, that the pyrite-chalcopyrite ores were of the Cyprus volcanic exhalative type.

<u>New way-up evidence for the Furulund Group</u>

a) Field evidence

Younging directions have been postulated from graded bedding which is particularly well shown in the D2 folds of the garnet calc-phyllites. This lithology has been traced for more than three kilometres to the west of Giken, and grading is well exposed in localities extending over tens of metres. Grading has been observed also in thick units at the western end of Lomivann. Younging directions have been used in conjunction with locally cross-cutting D2 schistosity to determine the direction of facing of the early structures.

The value of the concept of facing became apparent from Shackleton's (1957) work in unravelling the structures of the Iltay Nappe in the Dalradian Supergroup north of the Highland Boundary Fault. A fold is said to face in a direction normal to the hinge, along the axial surface, and towards the younger beds. If this direction plunges <u>down</u> the axial surface, the

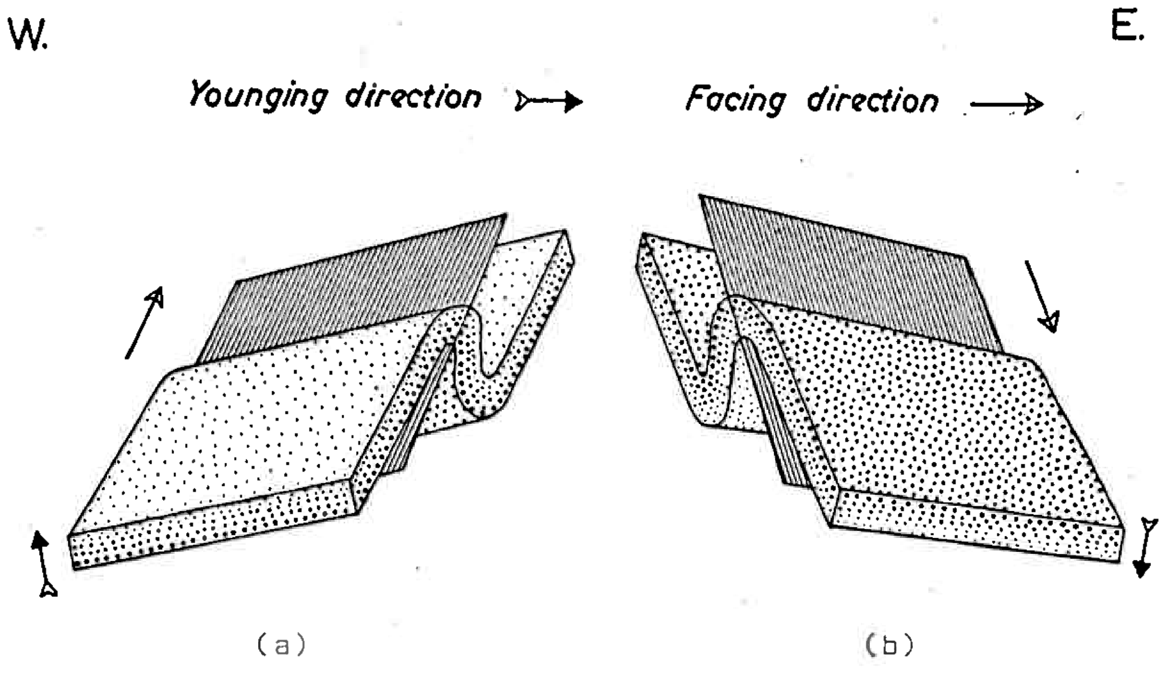


Fig. 5 Upward and downward-facing structures
(a) Upward-facing fold, facing towards the north
(b) Downward-facing fold, facing towards the south

structure is downward-facing, but if it is up the axial surface, the structure is upward-facing (Fig. 5).

Field evidence west of Giken has shown that D2 structures always face upwards and to the north or northwest (Plates 6a & 13) At Lomivann, northwards and downwards-facing structures occur, such as that illustrated in Plate 8a, but some folds are southwards and upward- facing. These data are mutually consistent if the former are envisaged as the product of refolding an inverted limb of an earlier formed structure, then the latter might be envisaged as being the smaller and upright limb of a minor fold on the parent structure. On the other hand, if a consistently northward- and downward-facing structure were subsequently refolded, then this would result in some northward and upward-facing structures. It would be interesting to see if this occurs on the other limb of the Langvann Antiform.

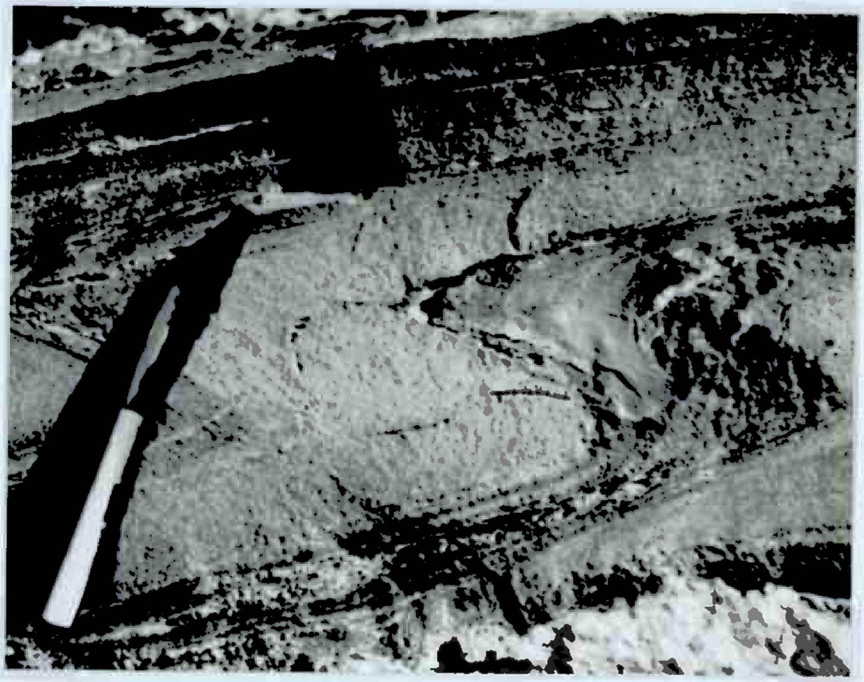


Plate 13 View up-plunge of a downward- and northward-facing Z-fold, Gikenelv. Photo taken eastwards.

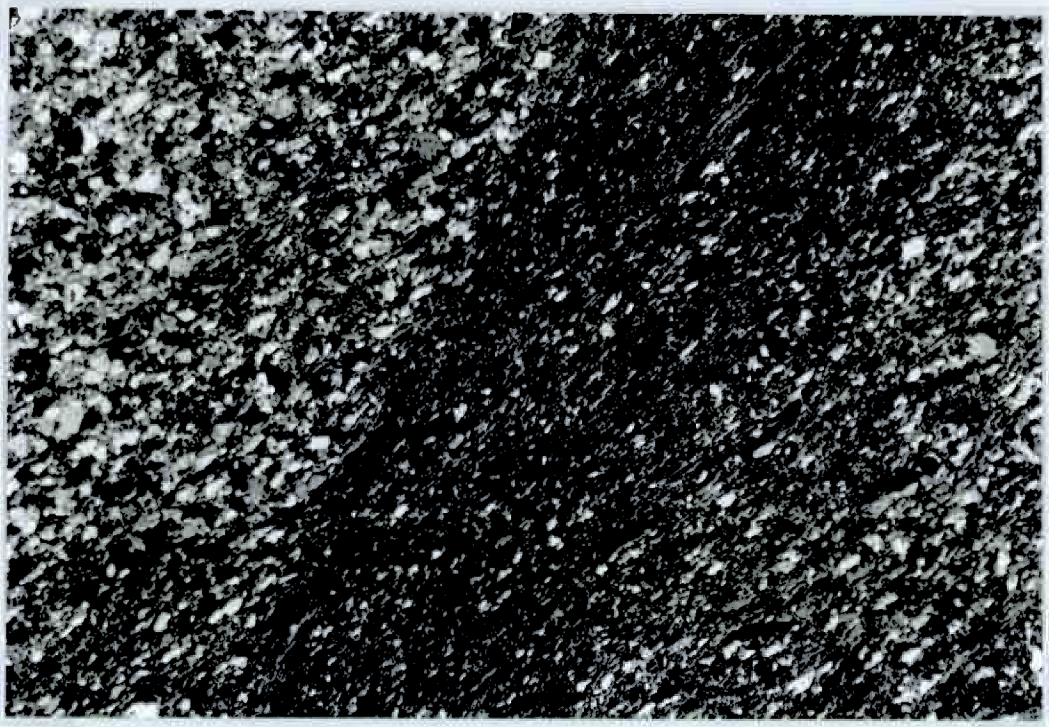
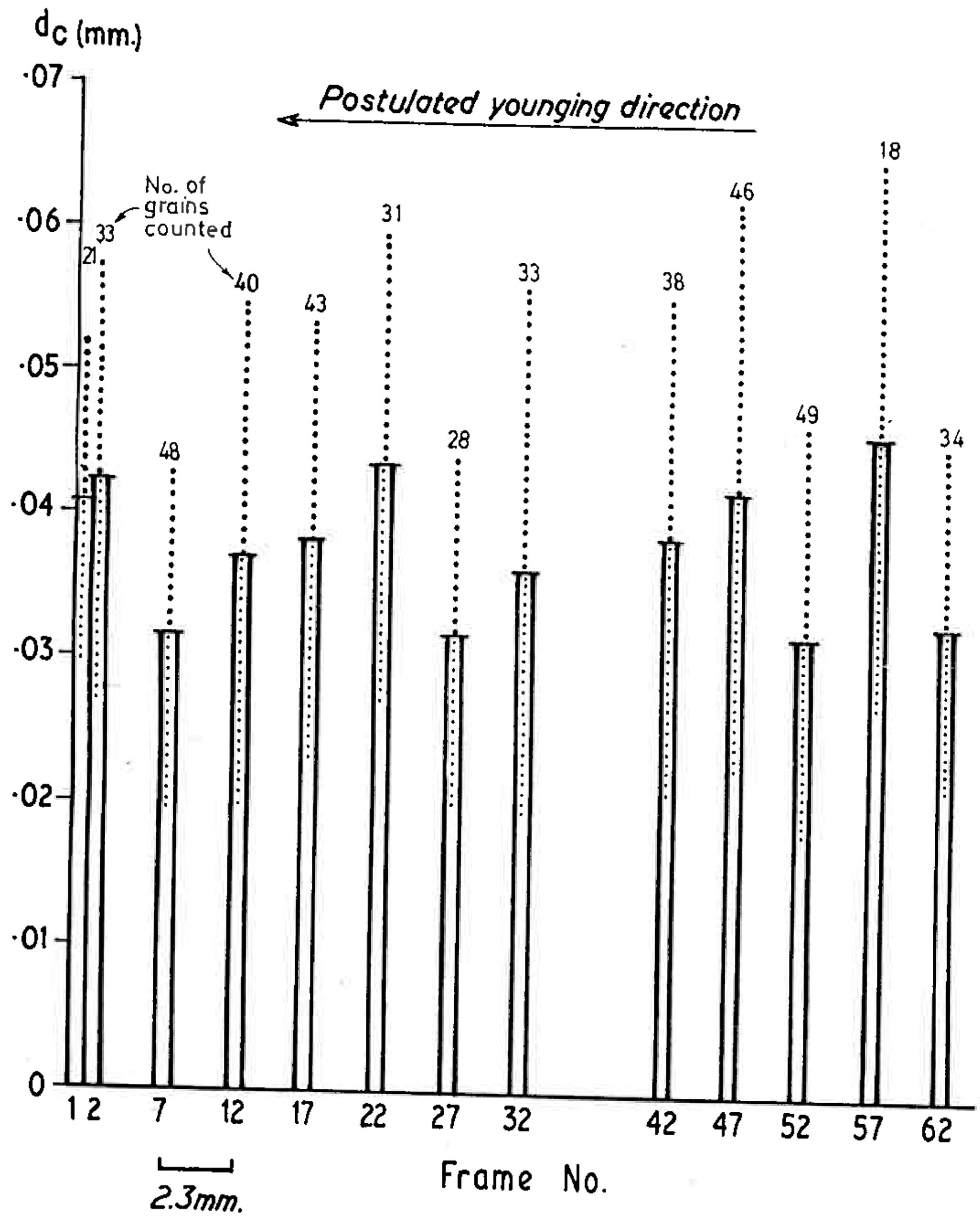


Plate 14 Photomicrograph (X22) of graded sediment from Jakobsbakken. Younging is towards the upper LHS

Fig. 5 Plot of d_c against distance, thin section of garnet calc-phyllite (WK 166/80).



<u>Evidence in thin section</u>

Obviously, the validity of the results depends on the ability to substantiate in thin section evidence of grading as determined in the field by colour-banding. To this end, an orientated thin section (WK 166/80) was taken through a garnet calc-phyllite at right angles to schistosity, nearly bu not quite perpendicular to the banding. Grading was not apparent by eye either from variation in mineral proportions or from change in grain size. A quantitative method of determining the latter was attempted therefore using a Kontron Videoplan, a semi-automatic image analyser, into which system was incorporated a petrological microscope. An area of the thin section 0.58 mm. X 0.46 mm. could then be projected onto a television screen at a magnification of 1:487. Boundaries were traced around all complete quartz and plagioclase grains visible in the frame, and for each grain the diameter of a circle of equal area (d_c) was computed automatically. The mean and standard deviation for d_c were determined for that frame. This was done for several frames, moving across the section normal to schistosity, and the results plotted in Fig. 6. Quartz and plagioclase were used under the assmmptions that (i) they are original clasts whose shape has been modified by solution and overgrowth during metamorphism to produce rod-shaped grains and (ii) there was only one peak of metamorphism (Henley 1970). Previous attempts to distinguish between the two minerals using the potassium rhodizonate staining method were unsuccessful, and abandoned.

The results indicate the existence of graded bedding, younging being towards the left of the diagram, in agreement with the direction determined in the field. One cycle occurs over a distance of about one centimetre, this according with the width of the colour bands. d_c varies in value between 0.009 and 0.09 mm., averaging about 0.038 mm; the change in value for d_c across one cycle of a centimetre is 0.02 mm.

Although these results are encouraging, several factors should be borne in mind when using this method: (i) it is essentially a two dimensional exercise only (ii) the number of grains counted per frame is small and varies, the number often being reduced by the presence of comparatively large garnet porphyroblasts, hence standard deviations are large, (iii) some bias is introduced insofar as larger grains are more likely to be partially out of view, and will not be counted. These limitations are not considered to invalidate the overall conclusion.

Further evidence of grading was found subsequently in thin sections taken from samples from Jakobsbakken, to the south of Langvann (A. Boyle, pers. comm.) and from Lomivann. A photomicrograph of the latter (Plate 14) shows a sharp boundary between the coarser-grained and quartz-rich base of one unit and the mica-rich and finer-grained top of the unit below. The planar fabric is thought to have formed during D3.

Conclusions

Field evidence along the northern shore of Langvann and at the western end of Lomivann indicates the presence of graded bedding and this has been confirmed by measurement in thin section. The relationship between younging directions thus determined and D2 fold structures shows that the Furulund Group is downward- and northward-facing near the top of the succession. This implies that the upper part of the Furulund Group was inverted prior to the D2 folding episode, and suggests that the stratigraphical inversion was earlier than the formation of the upward-facing Vaknahelleren Syncline. The structural evolution is thus more complex than that envisaged by Boyle et al. (in press).

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LEGEND

Sulitjelma amphibolites

Junction breccias

Keratophyre, often brecciated

Ore horizon

Furulund Group: Metasediments

Rusty-weathering phyllite, including more competent horizons

Quartz-schist

Calc-phyllite, often undifferentiated, occasionally with porphyroblasts

Garnet calc-phyllite

Mixed calc-phyllites, with or without porphyroblasts, thin schistose amphibolites

Calc-phyllites with garnet and amphibole porphyroblasts, rarely garnet alone

A Amphibole porphyroblasts

Intrusive

Kjeldvann metadolerite

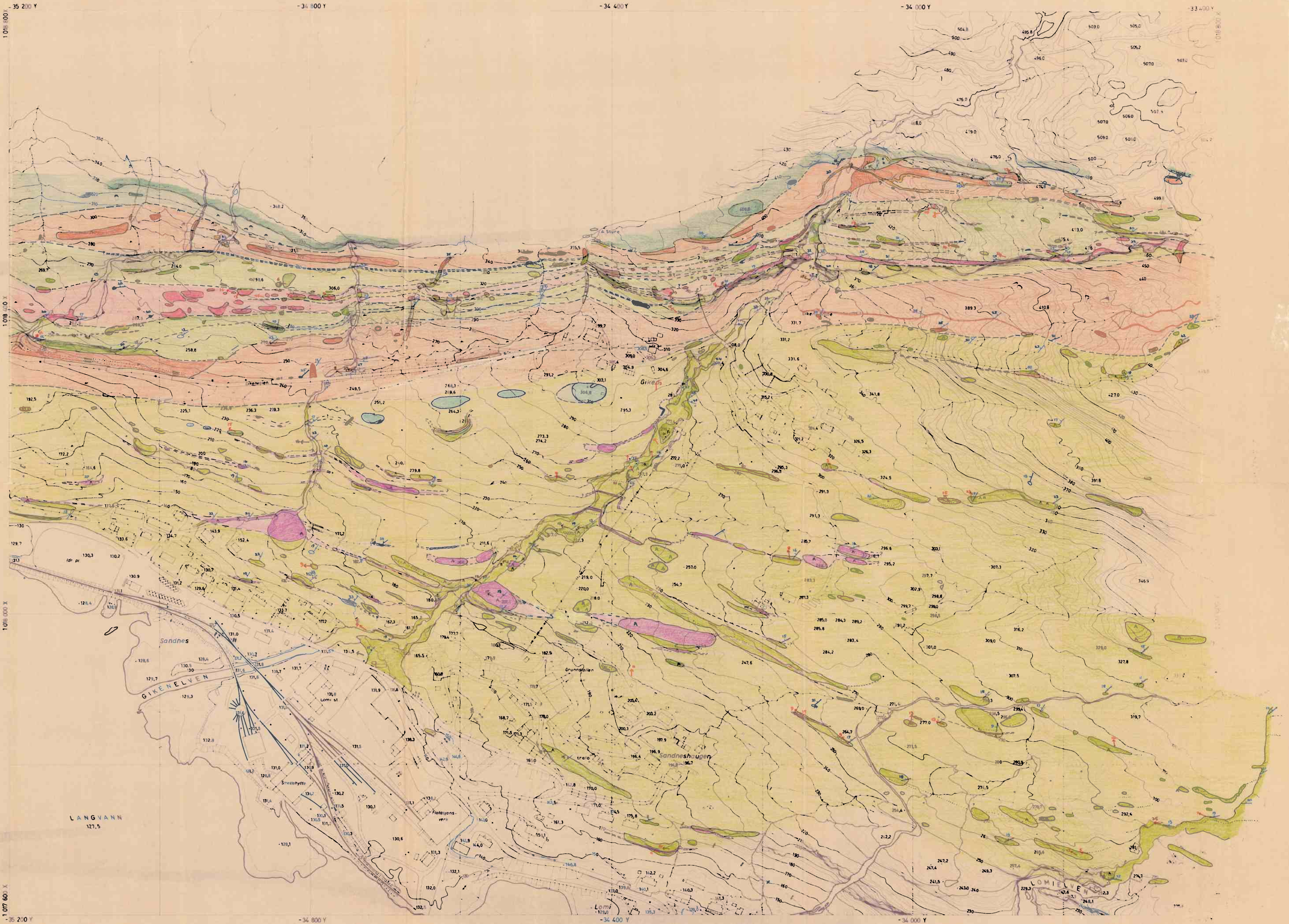
Main penetrative schistosity, dip in degrees

F_2 fold direction, plunge in degrees

Lineation direction, plunge in degrees

Geological boundary: known

Geological boundary: inferred



FJELLANGERS
OPPMÅLING OG LUFTKARTLEGGING
1968
utv 1974

Koord- og høydesyst nytt NGO

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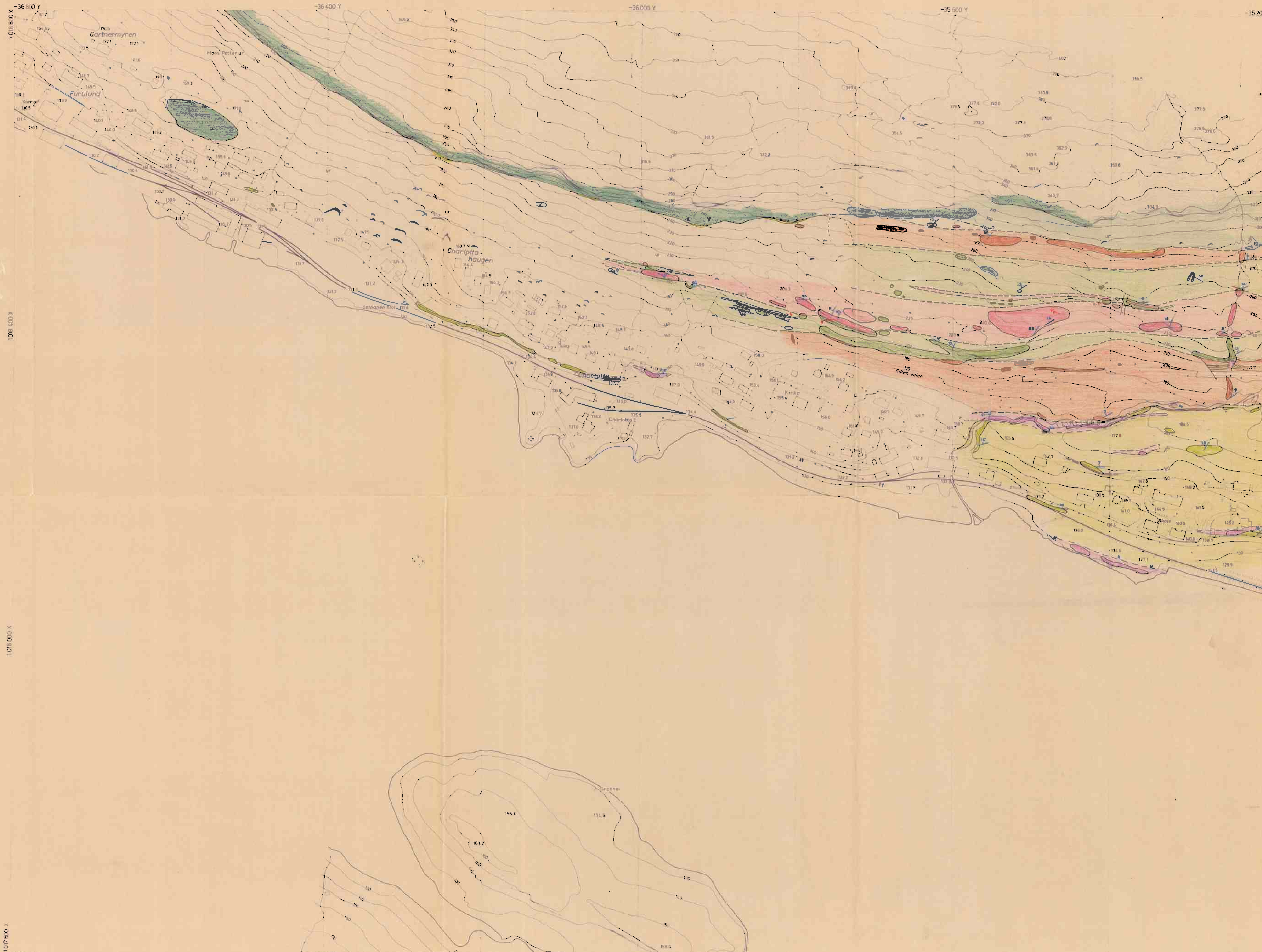
SULITJELMA M·1·

Ekv. 2m.



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SULITJELMA M·1:

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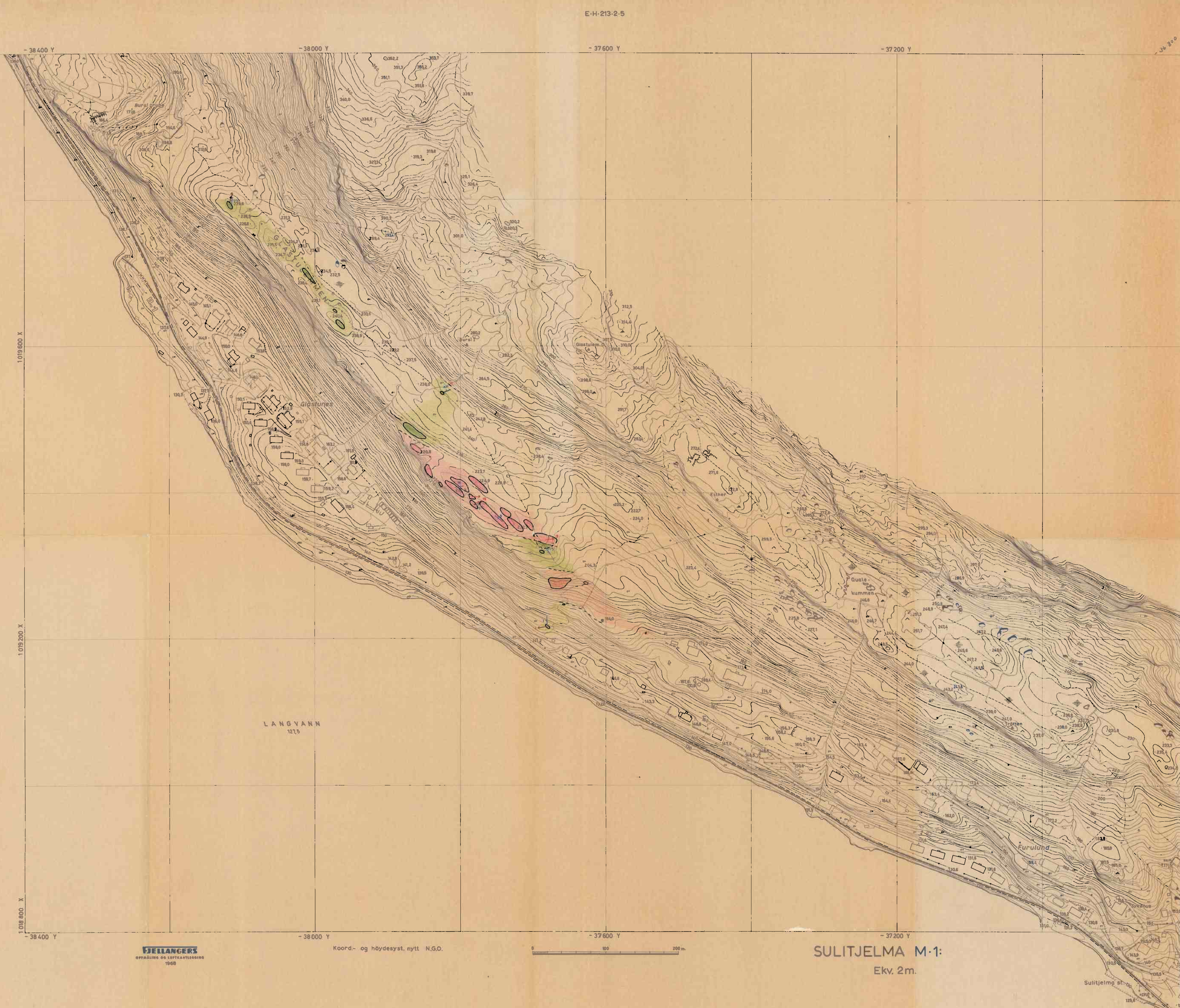
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Glastunes
LANGVANN
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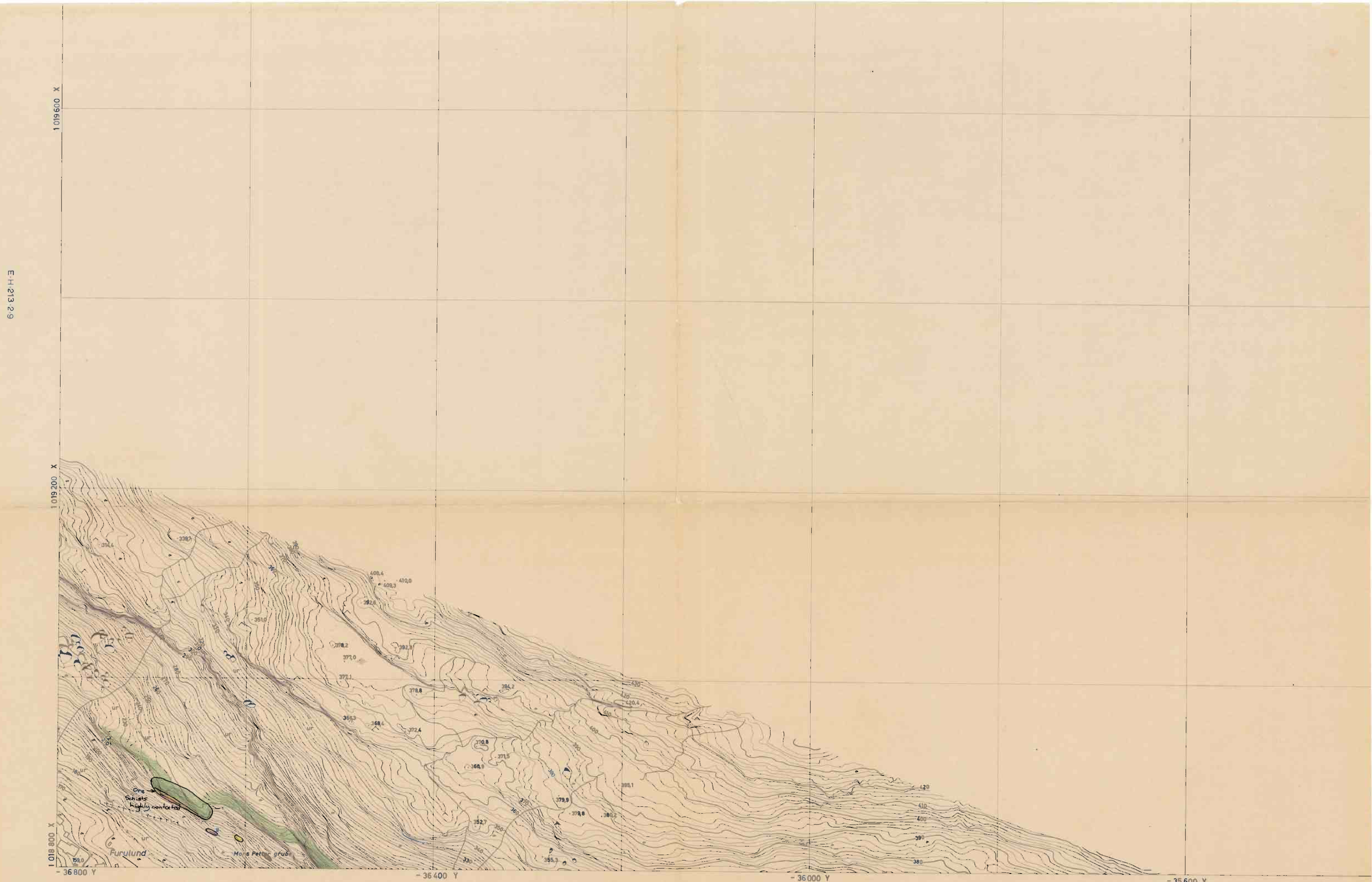

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