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Geology of the coast-region from Lofoten to Loppa, with special emphasis on faults, joints and related structures

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REPORT

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Title:
Geology of the coast-region from Lofoten to Loppa, with special emphasis on faults, joints and related structures

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Summary:

Lineament patterns in the coast-region from Lofoten to Loppa, is investigated. Exposures of fault-rocks show a variety of modes of deformation from ductile to brittle. Relative movements are indicated in some places, showing small strike-slip components and large vertical components. The area represents an elevatet substratum for post-Caledonian basin-sediments.

Keywords: Fault	Pseudotachylite	
Extensional	Breccia	
Joint		

CONTENTS

1 INTRODUCTION

This part of the present report has the purpose of giving supplementary information about the faults in the actual segment of the coast, based on data from on-shore bedrock-mapping during the last twenty years.

A further object was to conduct sampling for paleomagnetic age determinations in the area, and to supply the petrophysical lab. with representative sample material and magnetic measurements in situ. These, in turn, form the basis for the petrophysical database.

The area was subdivided into two provinces, partly because most geological relationships seem to be somewhat different north and south of the Senja Fault Zone, and partly because of the simple fact that the two present authors have been working in each their province.

2 METHODS AND SOURCES OF DATA.

2.1 Fieldwork. Both authors have been working in the area since early 1970`s, mainly with general bedrock mapping at a scale of scale 1:250000. This mapping has not been aimed particularly at fault tectonics. During the summer of 1992, however, the authors had the opportunity to spend one week in the field for this particular project, mainly with the purpose of finding exposures of fault-zone rocks, and eventually describing and sampling these.

2.2 Sample analysis.

Microscope, XRD and microprobe analysis has been applied to the samples, as far as this has been necessary for identification of minerals and micro-features.

2.3 Lineament tracing.

This work has been done on the basis of several topographic maps, air photos approximately of scale of 1:40000, satellite images at a scale of 1:1 mill. Unfortunately, no bathymetric data has been available.

In the Lofoten - Vesterålen Province, only those lineaments with fault rocks, or otherwise showing evidences of consentrated tectonic movement, have been depicted. A more complete tracing of lineaments has been done only in restricted areas; in the northeastern part of Vestfjorden (See "K" in map sheet 2.), and the island of Anda ("O" in map sheet 2). This gave more time to study the complicated petrography of the fault-rocks in the area, as well as making the map-display of details easier.

In the Senja-Loppa Province, both geomorphological relationships and the presence of the Caledonian front, made an analysis of lineaments the most promising method for reaching conclusions on fault movements, fault geometry and relative ages.

For classification and interpretation of lineaments, no special statistical methods or computer programmes have been used. Preliminary interpretations were carried out with the help of the structural symmetry patterns for faults given by Freund (1974). The paper by Woodcock & Fisher (1986) has also been useful in this respect.
Lineaments were transferred to tophographic maps at a scale of 1:50,000. These maps were then photo-reduced to scale 1:250,000.

3 DISCUSSION AND RESULTS

3.1 The Senja-Loppa Province.

For the Senja-Loppa Province, the resulting lineament-pattern is shown in map sheet 1.

Two groups of lineaments have been recognized, which differ in orientation, character and age. The older group is thought to be of Precambrian age. The younger group is considered to be mainly of post-Caledonian age, but these lineaments locally follow older structures. This is particularly the case for the faults in the Nordreisa area; these appear to be mainly Caledonian in age even though several generations of faults have been recognised.

During the project meeting of January 1992, Roy Gabrielsen of Norsk Hydro suggested that two types of Precambrian faults were present in the Tromsøy region - high-T, NW-SE trending ductile shear zones which largely follow rock boundaries, and high-angle faults parallel to Precambrian dolerite dykes. It has been found that the first type is dominant in the northern half of the island of Senja, whereas the second type is common on Ringvassøya.

3.1.1 Precambrian structures on Senja and Kvaløya.

The Precambrian shear-zones on Senja and the southwestern part of Kvaløya define a ca. 30km-wide, NW-SE trending linear zone which we here refer to informally as the Senja Shear Belt. From the interpretation of aeromagnetic and gravimetric maps the Shear Belt appears to be a direct continuation of the Precambrian Bothnian-Senja Shear Zone (Henkel 1991). The Shear Belt consists of possible Archean supracrustals and younger mafic and felsic plutons with a minimum Rb-Sr isochrone age of 1746 Ma (quartz diorite, Krill & Fareth 1984) or 1706 Ma (Ersfjord Granite, Andresen 1980).

The southwestern border of the Senja Shear Belt is defined by the several km wide Svanfjellet Shear Zone (SSZ) and the northeastern border by the 1.5 km wide Torsnes Shear Zone (TSZ).

Within the belt the gneissic foliation and faults/shear zones form a coherent pattern suggesting some form of mutual relationship (map 1). The rocks are mylonitised in narrow shear zones, the most prominent of which is the 800 m-wide Astridal Shear Zone (ASZ) in the Hekkingen area. In the less strongly deformed rocks the minerals are partly reduced in grain size and recrystallised into lensoid mineral aggregates forming a foliation of augen gneiss character. The original dark-coloured feldspar and the dark blue quartz of the granulite paragenese, have changed to a pale gray colour caused by retrogression.

Within the shear zones the rocks are mylonitised and recrystallised, appearing as fine-grained garnet-biotite and hornblende gneisses and locally even as schists. The grain-reduced felsic minerals are recrystallised into a granoblastic polygonal texture (see Zwaan 1991 for the Torsnes Shear Zone). The mafic minerals are enriched in thin parallel bands and display a random, non-schistose orientation. The felsic minerals are microcline and mainly twin-free oligoclase. The mafic minerals are green to brown pleochroic biotite and green to blue pleochroic amphibole. Accessory minerals are sphene and apatite. In places, an older, granulite-facies, mineral assemblage is preserved.

3.1.2 Precambrian structures on Ringvassøya.

A prominent system of faults with a predominant N-S trend is restricted to the mid-western part of Ringvassøya. The fault system appears to be consistent with the deformation of the Ringvassøy Greenstone Belt into a recumbent synform (Zwaan 1989). The faults are parallel in strike to the Precambrian dolerite dyke swarm. Detailed mapping in a small area in the western half of the island has revealed that the faults and the dykes are related in some way. The dykes are older than the Ersfjord Granite which has a Rb-Sr minimun age of 1.7 Ma (Andresen 1980).

3.1.3 Caledonian and Post-Caledonian structures in the Nordreisa map area.

The fold and fault structures in the Nordreisa map area are considered to have formed during the Caledonian orogeny. From the geological map a mainly dip-slip movement down to the northwest is deduced for the two main faults, the Kvænangen-Langfjord Fault (KLF) and the Lyngen-Rotsund Fault (LRF). Locally, strike-slip movement is inferred from Caledonian regional open folds, indicating different deformation intensity on either side of the fault. The folds are thought to be related to the updoming of the Precambrian Kvænangen window. Olesen et al. (1990) concluded that the raised domal position of this window is "a consequence of gravitational instability during the Scandian orogeny" However, the faults, which may well have originated during Caledonian time, are symmetrical with the abundant post-Caledonian faults in the Tromsø map area and discordant to the Caledonian tectonostratigraphy.

A thin-section of a mylonitic rock taken from the Lyngen-Rotsund Fault at Rotsund (see Map 1.) displays a mylonitic texture which has recrystallised in lower greenshist facies. This texture and mineral association are similar to those in mylonitic rocks occurring along the post-Caledonian faults in the Tromsø map area. It is therefore assumed that there has been an important component of post-Caledonian movement along the faults in the Nordreisa area .

3.1.4 Caledonian and Post-Caledonian structures in the Tromsø and Helgøy map areas.

In the Tromsø and Helgøy map areas there is a prominent set of high-angle semi-ductile to cataclastic faults which Andresen (in prep.) called the the Vestfjord-Vanna Fault Zone.

In the southwestern part of the Tromsø map area the high-angle, normal, Solbergfjord Fault (SBF) schows a vertical displacement of 1000 m or more down to the south. Along the Stonglandeid Fault (Andresen pers. comm. 1990, Zwaan 1992), a westward branch running along the Senja shore, the country rock is cataclastically deformed and cemented by calcite and silica. Strike-slip movement along this fault is indicated by the dome like structure of the Stongland
Peninsula.

The Stonglandeid/Solbergfjord Fault, and the Heggdal Fault (HF) in the middle of Senja, are ENE-WSW striking, first-order high-angle faults with an intervening widespread set of secondary high-angle faults trending NE-SW.

The Heggdal Fault is characterised by an up to 200 m-wide semi-ductile breccia with a strike-slip movement of 500m or more. Thin-sections of the fault rock show this to be a chlorite-epidote schist. To the east, in Lenvik, the faults are bounded by a 20-30 km wide subsidence zone (the Lenvik Zone; see Fig. 16), which is a northeastward continuation of the Solbergfjord Fault. This indicates an extensional regime for the above-described system of first- and second-order faults. The NE-SW trend of the secondary faults (possible Riedel faults) then indicate a sinistral movement for the system.

The Lenvik Zone displays a system of curvilinear faults with a convex bending to the west for the eastern faults and concave for the western faults. There is no major high-angle normal fault within the zone and as a consequence the original basal Caledonian thrust zone is preserved. It is therefore possible that there was an upward movement of the crust towards the west. On the inland side of this limit of upward movement the crust was extended, forming a graben along steep-dipping listric faults. This zone is situated above the Precambrian Bothnian-Senja Shear Zone (Henkel 1991, the Senja Belt; se above, and the geophysical interpretation map (Olesen et al. 1993) which was "probably reactivated in connection with the opening of the Atlantic and the development of the Atlantic-Arctic shift of the rift zone" (Henkel 1991).

The reactivation of the Bothnian-Senja Shear Zone should be later than the Vestfjord-Vanna fault system (Henkel 1991). Thin-sections of rocks from the Astridal Shear Zone, which is part of the Senja Belt, display the usual high-T ductile mylonites, whereas mylonites from the western boundary of the shear zone are of semi-ductile character and retrograded to chlorite-epidote schists. The Lenvik Zone therefore represents an area with a complicated deformation history, where several fault sets have been interactive at different times. This zone of subsidence contrasts with the situation along the eastern sides of the islands of Kvaløya, Ringvassøya and Vanna. Here, the contact with the Caledonian rocks is represented by a continuous set of high-angle normal faults, called the Straumsbukta-Vanna Fault (SKF), with a down-to-the-east displacement of 2 to 3 km as noted by Forslund (1988) and Andresen(in prep.). The fault system has a characteristic step-like course with few, and then only weakly developed, secondary faults.

On Kvaløy, the fault is locally curved, and also concave to the east, suggesting a dip to the east. On the island of Vanna the presence of an antiform suggests a possible component of strike-slip movement. We therefore conclude that the upward movement of the Precambrian basement was mainly vertical in this area and that the graben or belt of subsidence to the east (as at Lenvik) is missing or only weakly developed. The eastern boundary of the Vestfjord-Vanna Fault System is coincident with the Ullsfjord-Fugløysund Normal Fault (UFF). Only a small vertical displacement can be inferred for this fault which runs through Målselv into the Skoelvdal Fault (SF). In the Målselv area it is developed as a swarm of parallel, minor, normal faults.

3.1.5 Conclusions for the Senja-Loppa Province.

A continuation of the Mesozoic Vestfjord Basin into the Tromsø area, as proposed by Andresen (in prep.), does not appear to hold. The occurrence of the Precambrian basement and Caledonian rocks leaves little place for such a basin.

Henkel (1991, p.73) has proposed a "200 to 300 km dextral movement of the Vestfjord Fault with reference to the Protogine Belt structures. The movement happened just prior to the Atlantic opening". On geophysical and geological grounds the Solbergfjord-Vanna Fault, a northeastward continuation of the Vestfjord Fault, shows little reactivation of the

Bothnian-Senja Shear Zone of Henkel (1991). Quite possibly the main part of the large dextral movement runs along Andfjorden, via N-S orientated faults, between Andøya and Senja, off the Senja-Vanna coast, leaving the inland side of the islands little disturbed.

The displacements forming the Lenvik Zone can also be interpreted as Mesozoic N-S movements, where the Bothnian-Senja Shear Zone is considered as a continuation of the Senja dextral fracture zone (Henkel 1991, p. 73). The Lenvik subsidence zone could then be interpreted as a small pull-apart basin, and the lensoid aeromagnetic anomaly in the underlying basement rocks as an extensional dextral duplex system (Woodcock & Fischer 1986, p. 731).

3.2 The Lofoten-Vesterålen Province.

In the section below, a group of faults, possible faults and fault related features, are described. Their respective localities are shown on the map (map sheet 2). Lineaments have tentatively been grouped together both on petrographic criteria and on strike direction; however, there is no obvious correlation between the two groups. Therefore, in the following, the order of descriptions is random .

3.2.1 The Eastern Andøy Fault Sets.

A possible fault runs along the west side of the Jura-Cretaceous sediments (P in map sheet 2). The justification for the interpretation of this stucture as a regional structure, is an abrupt change in lithology together with a sharp topographic signature on a locality some 15 km south of the Mesozoic sediments. Otherwise this hypothetical structure is completely covered with Quaternary deposits. The movement on the fault is assumed to be coupled with another set of shorter, E-W striking faults (see below), and it is thought to be of Tertiary age. (Sturt,Dalland and Mitchell 1979 pp.529). A further extension of the structure towards the south is possibly indicated by a sub-sea gully in the fjord south of Risøyhamn.

The mean direction of the lineament is N30E, which is parallell to the most prominent magnetic lineament off Langøy (Olesen, this report).

The second fault-set in Eastern Andøy, is described by Dalland (Dalland A.1975). It conducts movements coupled with the fault set decribed above, or alternatively; it is clearly younger than this.

3.2.2 The Vikeid Fault Zone on Langøy.

From locality "H" (map sheet 2), a 1 km wide, flat strip of land extends across to the west side of Langøy at Eidsfjorden. This is remarkable, since most of the island has a high relief with alpine type peaks, and the rocks are similar with respect to petrography. However, it appears from scattered observations in the largely covered strip of lowland, that 3 types of brittle deformation at least, have influenced the bedrocks:

a) Cemented breccia formation
b) Crush breccia formation
c) Black chlorite breccia formation

The last two types will easily shatter during glaciation, leaving a valley with flat bottom, of a size comparable with the fault-dissected area. This indicates that most of the land strip between Vikeid and Eidsfjord is intersected by several sets of faults, together forming a 1 km wide fault zone. Induvidual small scale faults observed, strike 280 -290 *.

a) Cemented breccia is found at one small locality in the mouth of the stream at Vikeid. Its fragments are altered gneissic rocks, probably metamangerite. See Fig. 3. for further description. The matrix contains prehnite.

b) Crush breccia is closely jointed, altered gneissic rocks. Fragments are usually cubic, a few cm large. Little or no movement is evident.

c) Black chlorite breccia is vertical zones, often several tens of metres wide. Fragments are lenses of totally unaltered granulite facies rocks, surounded by a black film, mainly consisting of chlorite and biotite (XRD). Well developed slide mirrors indicates significant movement across the zone (see Fig. 4). This type of fault zones is observed at four localities in the granulite facies terrain of Vesterålen(localities E,F,G,H, map sheet 2). At the locality at Myre, it is also followed by the same type of "plain-forming" topographic signature. In a few places, these structures are observed to be older than both pseudotachylites and narrow faults with gouge rock, zeolites and calcite.

3.2.3 The Trihyrna-Selvåg Fault on Langøy.

F.Priesemann describes a fault system in the Eidet-Hovden gabbro body (Priesemann 1982)(L on map sheet 2). He concludes that the main fault is of Precambrian age, and that the fault rock is mylonitic. However, according to photos in his dissertation and other information, some gouge rock is present, and it is reasonable to assume that the structure has been reactivated in Caledonian or post-Caledonian Times. Priesemann gives a reverse fault movement towards SE on the NW dipping fault plane.

3.2.4 The faults and lineaments along Eidsfjorden on Langøy.

A very conspicuous lineament runs along Eidsfjord out in the sea for more than 30 km, as shown on the aeromagnetic map, and "Q" on map sheet 2. The direction is about 50 *, which is parallel to the main Vestfjord lineament. The lineament is not traceable to the NE, but at the SW end it could join the main listric fault on the southern side of the Havbåen sub-basin. Close to the northern shore of inner Eidsfjord, a sub-surface gully indicates the probable trace of the fault.

3.2.5 The "Heier Zone".

Heier pointed to a structure south of Eidsfjorden (Fig. 5), which he interpreted as a thrust (Heier 1960), see "B" in map sheet 2). Anorthosite and other proterozoic and Archaean rocks rest upon a mylonite which grades downwards into augen gneiss and mangerites. Simple shear indicators beneath the mylonite show normal movement. Cognate(?) mylonites are observed on Hinnøy (see section A-A` in map sheet 2), where the same situation with anorthosite above augen gneiss, above mangerite, is exposed a few km. south of the profile line. The absolute age of the structure is unknown, but pseudotachylites and zeolite-filled small-scale faults, cut the mylonittic foliation.

Thin-sections from the mylonite show a fairly low-grade rock, with obvious post-tectonic amphibole and syn-tectonic sphene, see Fig. 6. It is a matter of discussion if these minerals are possible canditates for radiometric age determination. According to W. Hames of M.I.T. , who has seen the thin-sections, an Ar/Ar date would give a valid result.(W.Hames, personal comm.).

The fault may be a Caledonian structure, closely followed by a steeper and younger fault along Eidsfjord, or(and) it may be a surface of repeated movement.

At locality "C" in map sheet 2, a ductile shear zone,at least 60 m thick, has an almost horizontal attitude (Fig. 7). It is cut by 20-50 cm thick breccia-zones (Fig. 8) striking parallel with the Sortlandssundet lineament. The shear-zone has chlorite, recrystallised red K-feldspar and epidote, and is believed to be a SE continuation of "Heier`s Zone". Downfaulted fragments of the same structure (?) is found 25 km SE of the locality on Langøy, see the section at map sheet 2..

3.2.6 The Fault along Sortlandssundet.

A sub-surface groove in the middle of the sound between Langøy and Hinnøy indicates a fault. In the section A-A` (map sheet 2), this fault is assumed to take up a major part of the down-throw of the SE part of the sound. As the Eidsjord Fault (above) , it terminates in an "invisible" lineament from the head of Eidsfjord to Lødingen.

This structure, together with the faults along Eidsfjorden and Øksfjorden, seem to delimit fault-blocks in between. The terminations of these blocks towards theNE and SW, are apparently either the E-W or the NW-SE lineaments.

The N-S direction is possibly coupled to the other faults in the Sortlandssundet area. However, the fault rock is a pure breccia without movement indicators (Fig. 15 and "S" in map sheet 2).

3.2.7 Prominent lineaments in Lofoten.

On the Lofoten Islands, from Øksfjord towards SW. no field-work has been done for this project. However, some information may be extracted from maps and field-notes from earlier NGU-projects in the area.

Raftsundet, Øksfjorden and Øyhellsundet are very conspicuous lineaments because they follow sounds and fjords. It has not been successful to obtain samples of fault-rocks, and we do not know if any of the consulting companies posess drill-cores of interest.

The lineament along Øksfjorden seems not to be linked directly to the exposed fault labelled "I" (map sheet 2) in Gullesfjorden . Again we see that the zone from Eidsfjord to Lødingen acts as a NW-SE barrier for single-fault propagation.

North of Svolvær, W.Griffin mapped a fault which separated slightly retrograded acid mangerite in the north from the Hopen mangerite in the southern part of Austvågøy. No additional information on the fault is given (Griffin, 1969). Little areomagnetic and no gravitational signature are seen for this fault, and it is therefore interpreted as related to small movements.

Through Gimsøysundet, a lineament is thought to represent an important fault systen on the eastern side of the huge gravity anomaly beneath the outer Lofoten islands. According to the crustal model presented by .Svela, the down-throw should be on the eastern side (P.T.Svela 1971). From a distance, altered, zeolite-veined(?) fault-rocks can be observed on a small skerry off the eastern shore of Gimsøy.

The Vestfjord fault is a lineament on all surveys; magnetic, gravimetric and bathymetric. The joint pattern around Lødingen could possibly tell something about movement and stress-pattern. None of the directional groups of lineaments seem to cut more frequently than the others. The strike-slip component is assumed to be relatively small in this area, since no evident strike-slip duplex structures are developed.

3.2.8 The Pseudotachylites of Vesterålen.

East Langøy, Skogsøya and Hinnøy east of Sortlandssundet are the main localities for these conspicuous mesoscopic structures(Tveten, in prep.).

Pseudotachylite is a friction melt produced by brittle faulting. It is generally accepted that it represents a fossil remnant of a paleoseismic event (Allen 1979, Sibson 1975). A wealth of new knowledge about these structure has emerged during the last years (see Magloughlin and Spry 1991), but for the pseudotachylites of Vesterålen, further and more thorough investigation is necessary to take full advantage of this.

The pseudotachylites (P.T.), are found in numerous localities in the areas mentioned above. They are usually only a few mm thick, black and aphanitic. Often the observed P.T. are clean-cut dykes without any signs of abrasive activity or fragmentation. In these cases the P.T. may follow the margin of a pegmatite dyke, make a sharp, angular shift in direction, or otherwise show the characteristics of a true intrusive dyke. However, most of the cases are braided, complex zones of angular fragmentation of the host rock (Fig. 9 -10) . Sometimes the sence of shear along the faults may be deduced from the observed deformation structures. In the following, only the P.T. injected along assumed active melt-producing structures are included in the stereographic plots.

In less than ten cases, P.T. is observed to offset other P.T. or other features which are easy to correlate across the fault. In all these cases except one, the appearent offset is between 30 cm and 1 m. In the one case, a 5 cm thick P.T. running for at least 600 m as a completely planar structure (Fig. 9), offsets markers in the host rock apparently for more than 2.5 m .

Most P.T. dip between moderate angles and horizontal, therefore the stereographic net (lower hemisphere), is chosen to show their statistic relationships (see Fig. 12a). In North Langøy Fig. 12b, a distribution around an E-W horisontal axis is evident. Less evident is a second group distributed around an axis with a NE-SW direction, also horizontal (?). The second group is parallel to both regional and mesoscopic fault structures, while the first group is parallel to a more restricted fault direction(see Fig. 12e).

Fig. 12c from the southern side of Eidsfjorden shows mostly horizontal dips for the pseudotachylites, while Fig. 12d from the area southeast of Sortlandssundet, shows a distribution about a dipping axis. This may be interpreted as a late, oblique elevation of the area around the head of Øksfjorden, where the tallest mountains on Hinnøy are situated. (The tallest is Møysalen; 1266 m.). This area forms the northern limit of the huge Raftsund Mangerite Pluton. If the distribtion axis was originally horizontal, this elevation may have been about 30 *, measured in a vertical section slightly east of north..

10 observations of pseudotachylites of different relative ages show that the youngest structures are the steepest, but the small number of data points make the observation suspect. No other relation between age and direction is observed.

Simon Kelley at Open University has demonstrated successful age determinations of pseudotachylites by the Ar/Ar laser methode(Kelley , personal com.). T.Torsvik (this report) has tentatively calculated paleomag. pole for the pseudotachylites. The reult, however, was not very conclusive since it hit the P.W.P. at a Caledonian position, as did the host rock.

Microscopic studies and micro-probe analysis af P.T. show that the material is a very fine-grained matrix with numerous wall-rock fragments of all sizes, fluxion structures, decussate plagioclase microlites and inclusions of earlier generations of slightly different P.T. See Fig. 10-11 and Fig 13. Small grains of iron-oxide are evenly distributed in the matrix.

Tabell 1. Chemical composition is shown in the table below. Content of TiO2 is estimated to 0.5 - 1.5 %. 1 - 5 are all points in the same sample, 6 is the average composition.

	1.	2.	3.	4.	5.	6.
Na2O	3.40	3.13	2.83	3.49	2.58	3.09
MgO	6.12	6.09	6.41	4.92	5.54	5.82
Al2O	17.54	17.63	16.67	17.83	16.16	7.17
SiO2	53.86	54.93	51.53	55.40	53.46	53.84
K2O	1.03	2.02	2.33	1.45	2.60	1.87
CaO	7.20	7.95	8.69	7.56	7.78	7.84
MnO	0.20	0.14	0.17	0.16	0.07	0.15
FeO	8.58	7.54	9.13	8.27	9.45	8.60
Sum	97.95	99.47	97.80	99.12	97.67	98.38

This compares well with the most basic components of the migmatites, except for a slightly lower potassium content than those. However, it is considerably more mafic than the local wall rock, which is a quatz-diorittic, coarse-grained granulite facies gneiss with orthopyroxene and some red biotite. Few grains of OPX and biotite is observed as fragments in the P.T., whereas quartz and feldspar are over-represented.

The composition does not reflect any "minimum melt" process, but rather a mineralogically selective melting of mafic minerals, leaving quartz and feldspar as inclusions. The details of this process may be formation of melt, followed by rapid assimilation of grinded biotite and OPX. See Fig. 11 and Fig.13. These observations are in agreement with other publications on the same subject, for example R.H.Maddock 1992.

3.2.9 Faults NE of the Eidsjord-Lødingen line.

The Gullesfjorden fault (Fig. 14.) is exposed at locality "I", map sheet 2. Fault rocks are polygenic, mostly cemented breccias. They are light in colour and partly cemented with calcite. Marble fragments are also found. Some ductil deformed (phyllonittic) rocks are found as lining to the breccia. It has not been possible to follow the structure across to Øksfjorden, and again we have to note that a single fault-structure ends in the lineament Eidsfjord-Lødingen.

The N-S lineament with label "R" in map sheet 2, is justified by the fact that it runs along the eastern side of a gravitational anomaly over Northern Langøy. It has the same direction as the lineament "N" east of Harstad, but does not cut out Lofoten province rocks, which occupy the southern part of Andøya.

The NNE-SSW lineament in the southern part of Andfjorden is a possible fault between the Mesozoic sediments and the granittic and gabbroic rocks found on small islands in the middle of Andfjorden.

At "J" in map sheet 2, an almost horisontal ductile shear-zone on Taraldsviktind is faulted down on the SE side about 500 m.,but no exposures of fault rock are to be found.

East and south of Harstad, M. Gustavson indicates a system of faults; two of them displace the Caledonian rocks in the area apparently for more than a kilometer (Gustavson.M. 1967). The dip of the Caledonian front in this area is not accurately known, but conforms with downward movement of the SE block if the true movement is vertical (On Locality "M" south of Harstad, map sheet 2).

On the island of Anda, the outermost exposure of the Lofoten -Vesterålen Rocks towars north, a very regular set of joints are clearly seen on the air-photos. The island is built of homogenous Mangerite, and the joints are interpreted as "pinnate" , or extensional joints caused by a component of local sinistral strike-slip on the more prominent NE - SW lineaments off the island.

.2.10 Conclusions for the Lofoten - Vesterålen Province.

The rocks of this province are mainly high-grade metamorphic supracrustals and orthogneisses, partly in granulite facies (Griffin et. al. 1976). The age of the oldest gneisses are 2.7 GA, while the large plutons of almost undeformed intrusive rocks are 1.8 G.A.

Some authors has proposed that granulites have a brittle behavior even at lower crustal depths (Weber 1986). This opens up the possibility that late extensional faulting might have been strongly influenced by very old crustal structures.

Recognized faults in the province are distributed in five distinct orientations:

NNE - SSW
NE -SW
E - W
NW - SE
N - S

This conforms with lineaments in the Senja Province. The NE - SW and the NW - SE groups are also found in the Western Gneiss Region in Møre and Trøndelag (Forslund, 1988, Grønlie & Roberts 1989), and in Northern Scotland (Laubach & Marshak 1987). Mesoscopic faults and joints are also consistent with this pattern.

The first faulting clearly younger than the high grade texture, is along low-angle ductile shear-zones, accompanied by retrogression . The age of this episode is unknown on Langøy, but possible equivalents have a caledonian age on Vestvågøy (Hames,personal comm.).

Few indications for regional and local strike-slip movement are found.
One exception may be the island of Anda, where "pinnate joints" indicate local sinistral movement on NE - SW lineaments which pass the island. In the area south of Harstad, clear indications exsist for a several hundred meter downfaulting to the SE

The same sense of displacement is demonstrated across the Sortlandsundet. However, in this place the displacement is far more complicated to quantify.

Following the formation of ductile and semiductile shear-zones, the rocks must have been through a period of seismic activity. Pseudotacylites was formed in a crustal depth where microlites could grow, probably more than 6 km (M.T.Swanson 1992).

Analysis of mesostructures indicates that pseudotachylites are segments of faults, mostly of low-angle NW or N striking orientations. Obsevations of pseudotacylites on small listric faults of a few hundred meters , indicates that they are related to the formation of the extensional allochton in the province. The distribution parallel to a horizontal axis further strengthen this assumtion. It is tempting to speculate that the smaller, pseudotachylite- faults are secondary synthetic and antithetic faults in the hanging wall block of early, major listric normal faults.

The province must have been elevated in the following period. Since most pseudotacylite axis still are horizontal, the elevation must have been without rotation. An exception is the area NW Øksfjord, which may have been tilted towards N about 30 *.

A zone across Hinnøy, from Lødingen , to Langøy and the head of Eidsfjord, acts as a stopper for propagation of singel regional faults. This is also a rock-boundary with granulite facies rocks in SW. It is co-directional with the Caledonian (reactivated Precambrian) zones of Senja and Vestvågøy. The significance of the zone is uncertain. Irregular fault directions offshore Northern Langøy may indicate that the mecanism is resembling the "accommodation zones" of Boswoth (Bosworth, 1985).

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Fig. 3. Breccia from the stream-bed at Bruland, Vikeid. Red fragments are strongly altered feldspar and quartz. White cement is mainly prehnite. Note dark coloured fragment (pseudotachylite), containing smaller fragments. Tics at the edge are mm.

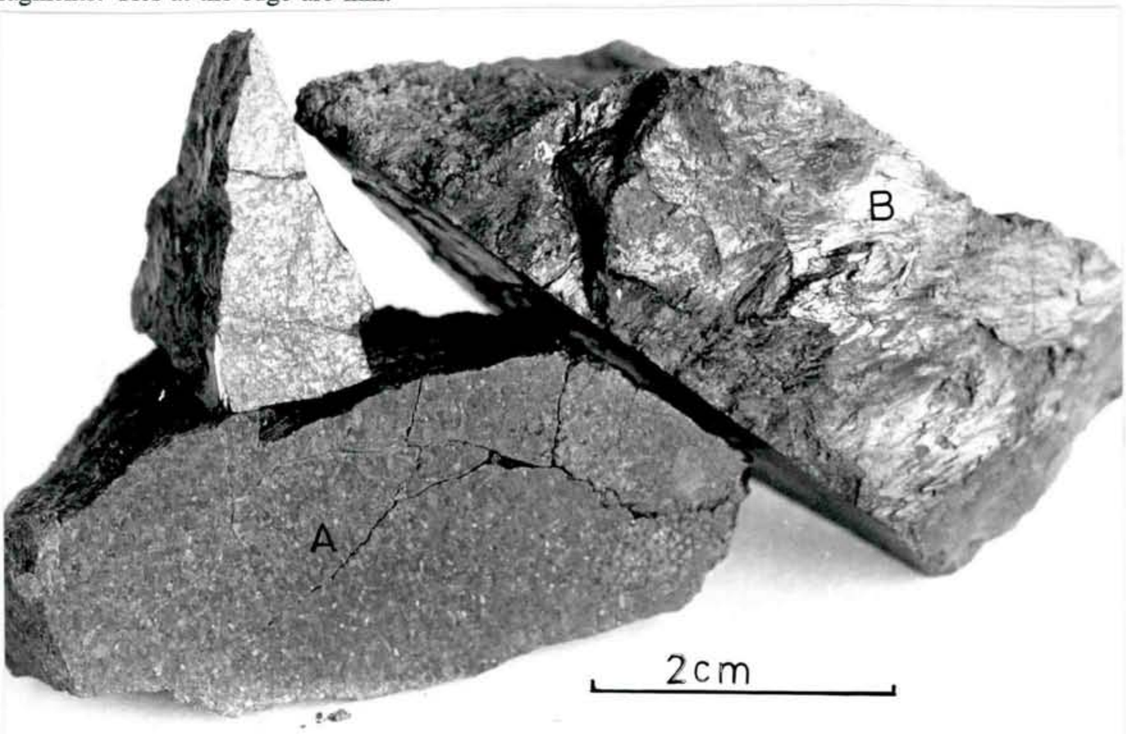


Fig. 4. Fragments of the "black fault" at lokality "G" on map sheet 2. The fragments form a phacoid-shaped network. The surfaces of some lozenges are linked to form faults with cm-thick , black glide-mirror, see "B" on the photo. Note that the interior of the lozenges is totally un-affected by retrogression and alteration, see "A" on the photo. Minerals in both the glide-mirrors and in the thin veins without movement are chlorite and biotite.

Fig. 5. Looking eastwards across Langvatn, south of Eidsfjorden. Anorthosite rest upon a mylonite zone, 4 - 5 meter thick. An augengneiss follows beneath about 100 meter, grading into mangerite.

Fig. 6. Photomicrograph of amphibolittic mylonite. Matrix in the lower part, is finegrained feldspar and white mica. Shear-band in upper half of the photo contains chlorite, hornblende, iron-ore, sphene (S), and post-tectonically grown hornblende.

Fig. 7. Ductile and brittle deformation in a quarry at locality "C" on the southern shore of Sortlandssundet. Banding and alteration is probably the result of a ductile deformation. Narrow breccias represent the brittle deformation, see fig. 8. Relative ages are not evident from the photo, but the breccias are younger than the banding.

Fig. 8. Breccia from locality "C" on the southern shore of Sortlandsundet. Note the alteration of the feldspar. Tics at the edge are millimeters.

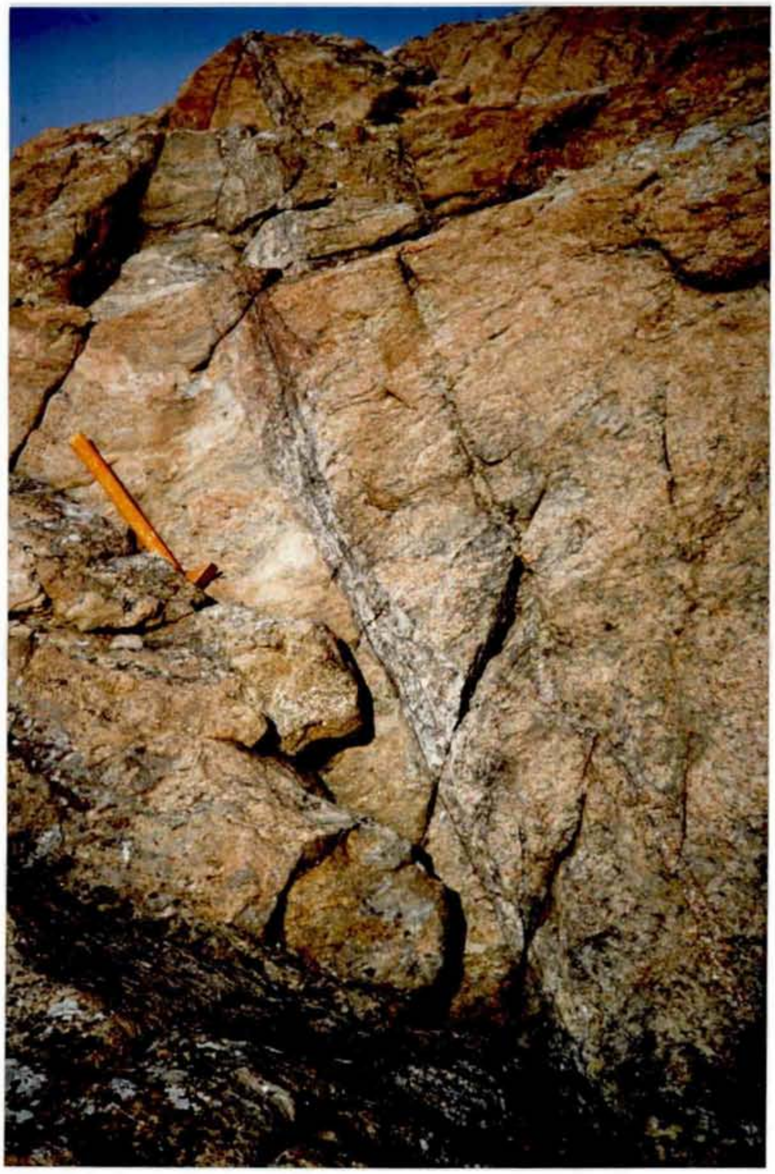


Fig. 9. West-dipping pseudotachylite cutting banded, granulite gneiss at Nyksund, Northern Langøy.

Fig. 10. More than 5 cm thick pseudotachylite from locality "D", central Langøy. The vein at the left is an "injection-vein", while the right (dark) half is a "fault-vein". The movement on the fault - vein has caused formation of "rip-outs" from the wall-rock, and these have been moved after formation of the injection-vein.

Fig. 11. Photomicrograph of pseudotachylite matrix. Rock-chip (with scale bar) is a fine-grained mylonite. Brown matrix at upper right and lower left is first generation of melt. Note the fluxion-structures ! Dark, red material is second generation of melt, darker colour for the late melt is common. Microlites are feldspar and quartz.

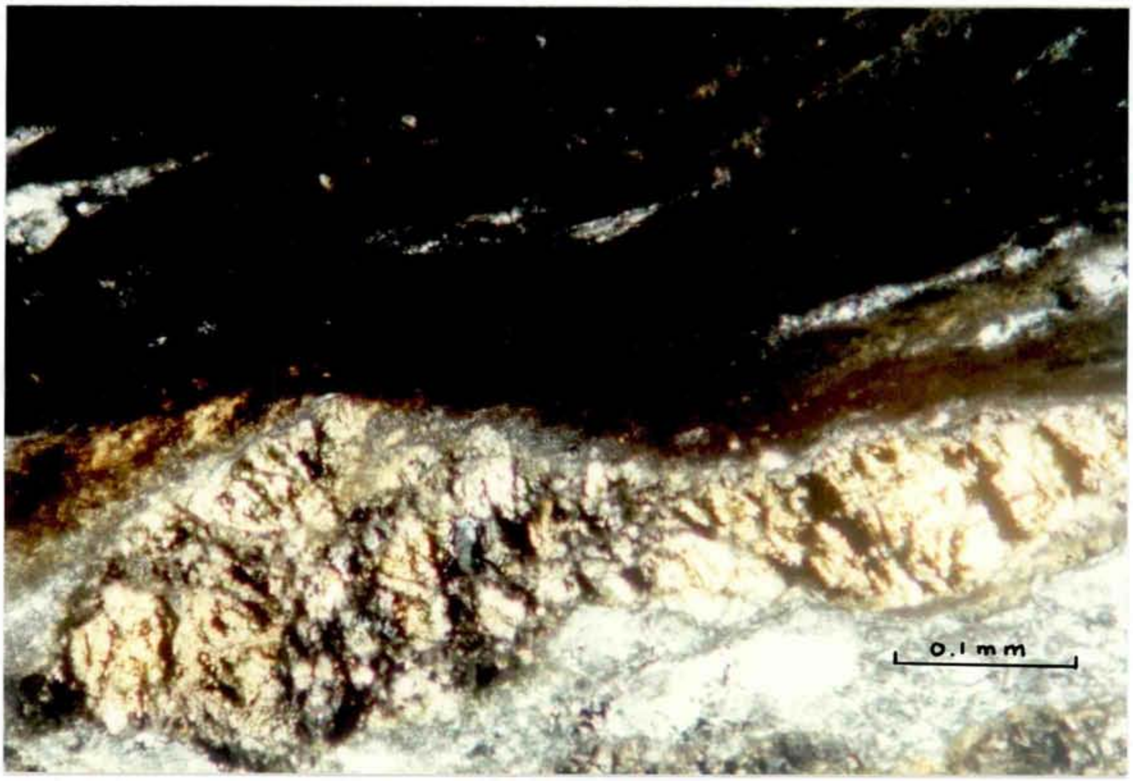


Fig. 13. Fluxion-structures at the margin of a pseudotachylite. The banding seems to be more developed when the mafic minerals are in contact with melt, in this case the mineral is orthopyroxene. This kind of contact make an accurate determination of shear-direction possible, provided a method for 3-dimentional viewing has been developed.

Fig. 14. Fault-canyon at Gullesfjorden, locality "I", looking towards NE.

Fig. 15. Breccia from Locality "S" west of Sortland. Fragments are retrograded mangerite. Matrix contains epidote and chlorite. Tics at the edge are mm.

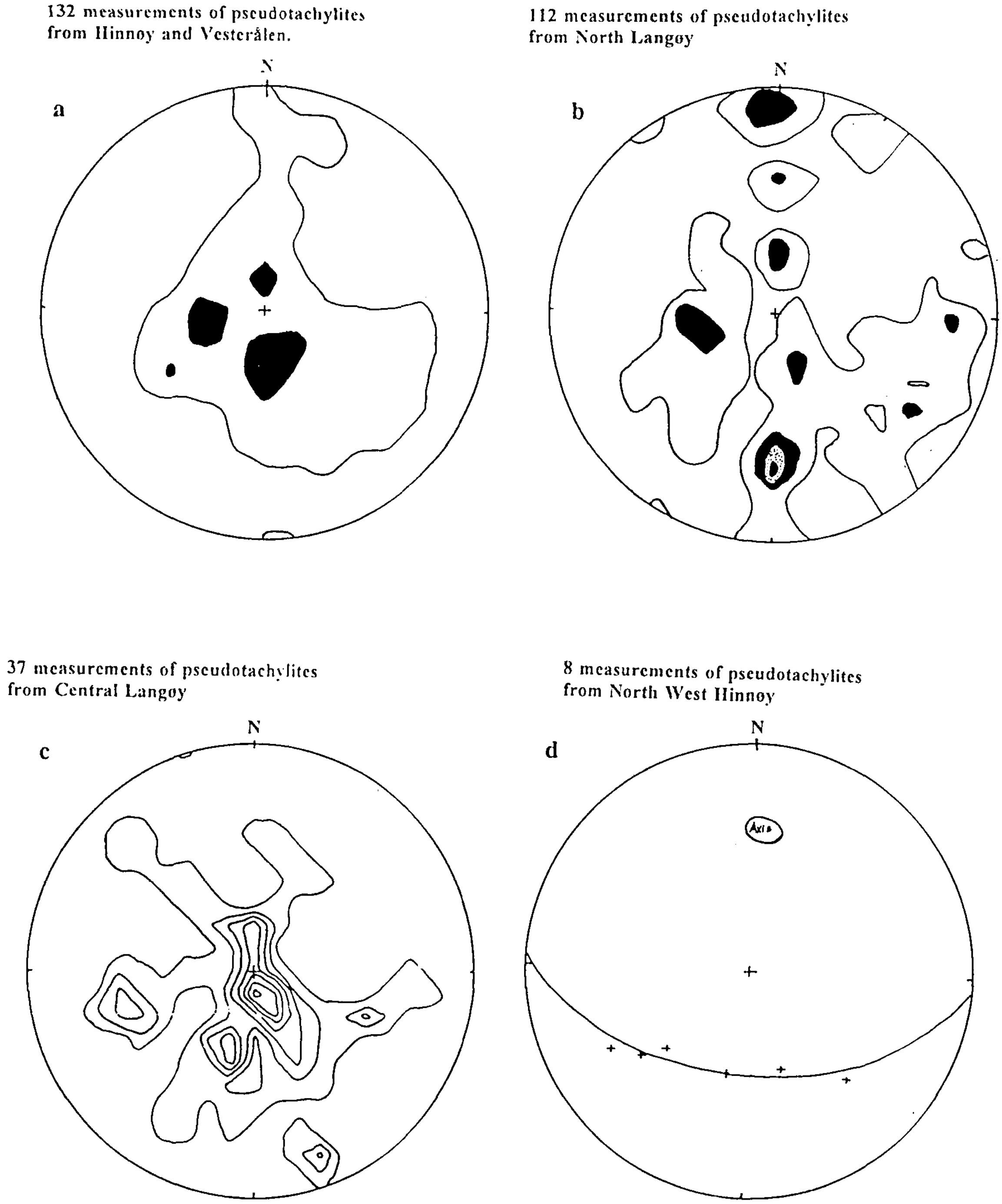
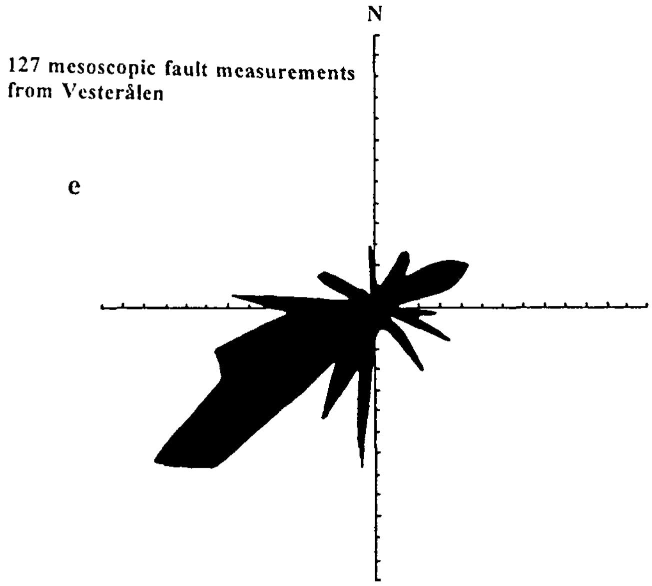
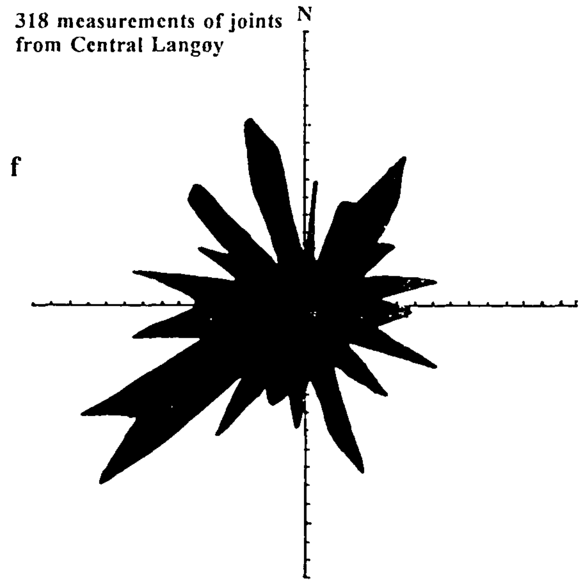


Fig. 12 a - d, Stereographic projections, lower hemisphere, of selected structural elements.





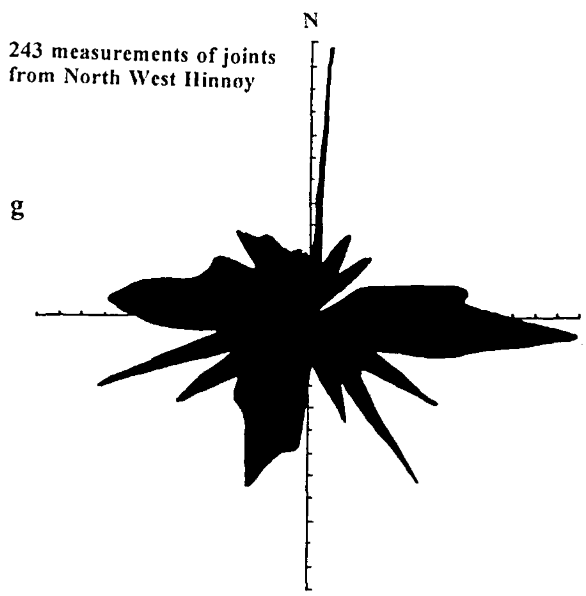
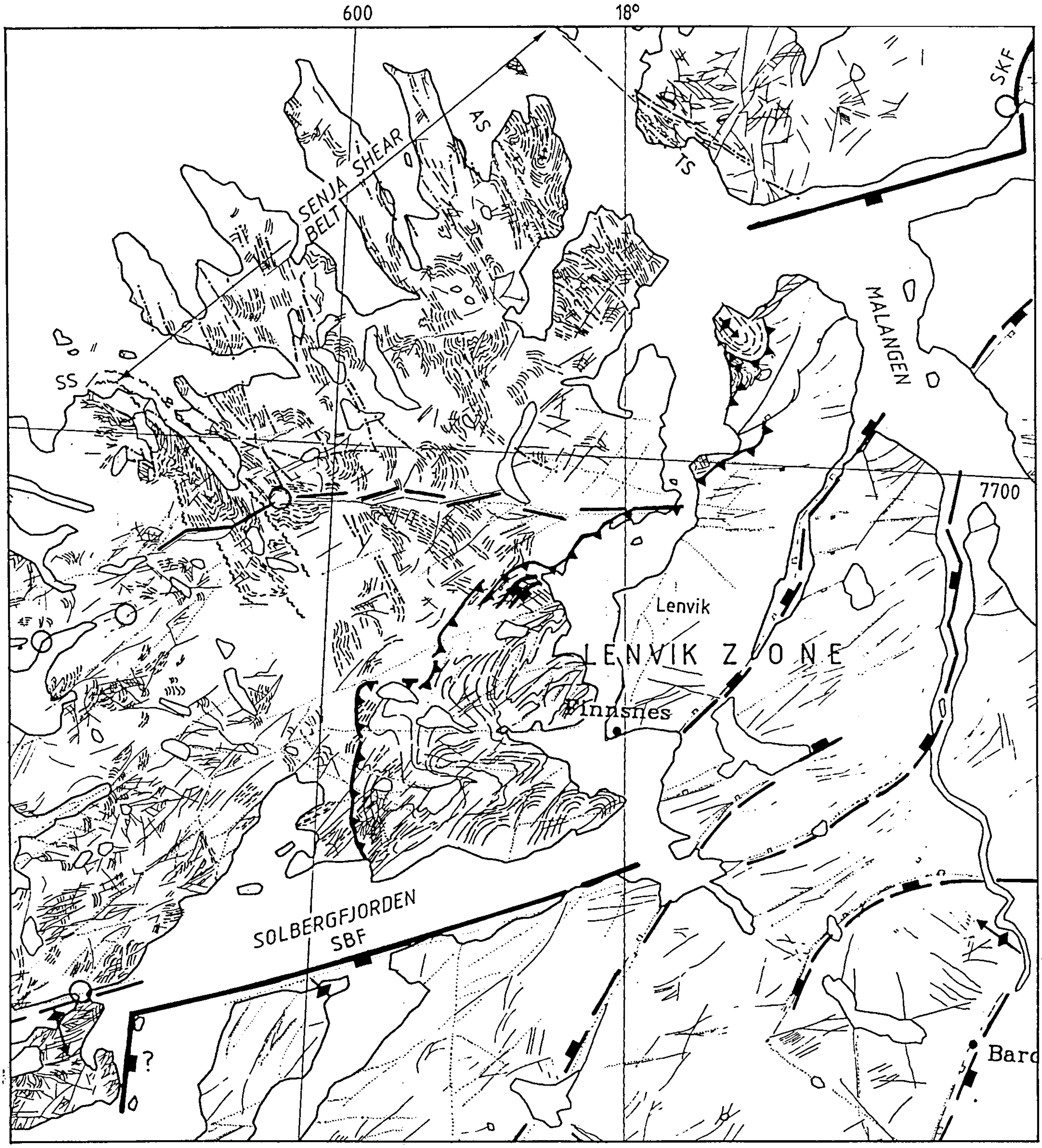
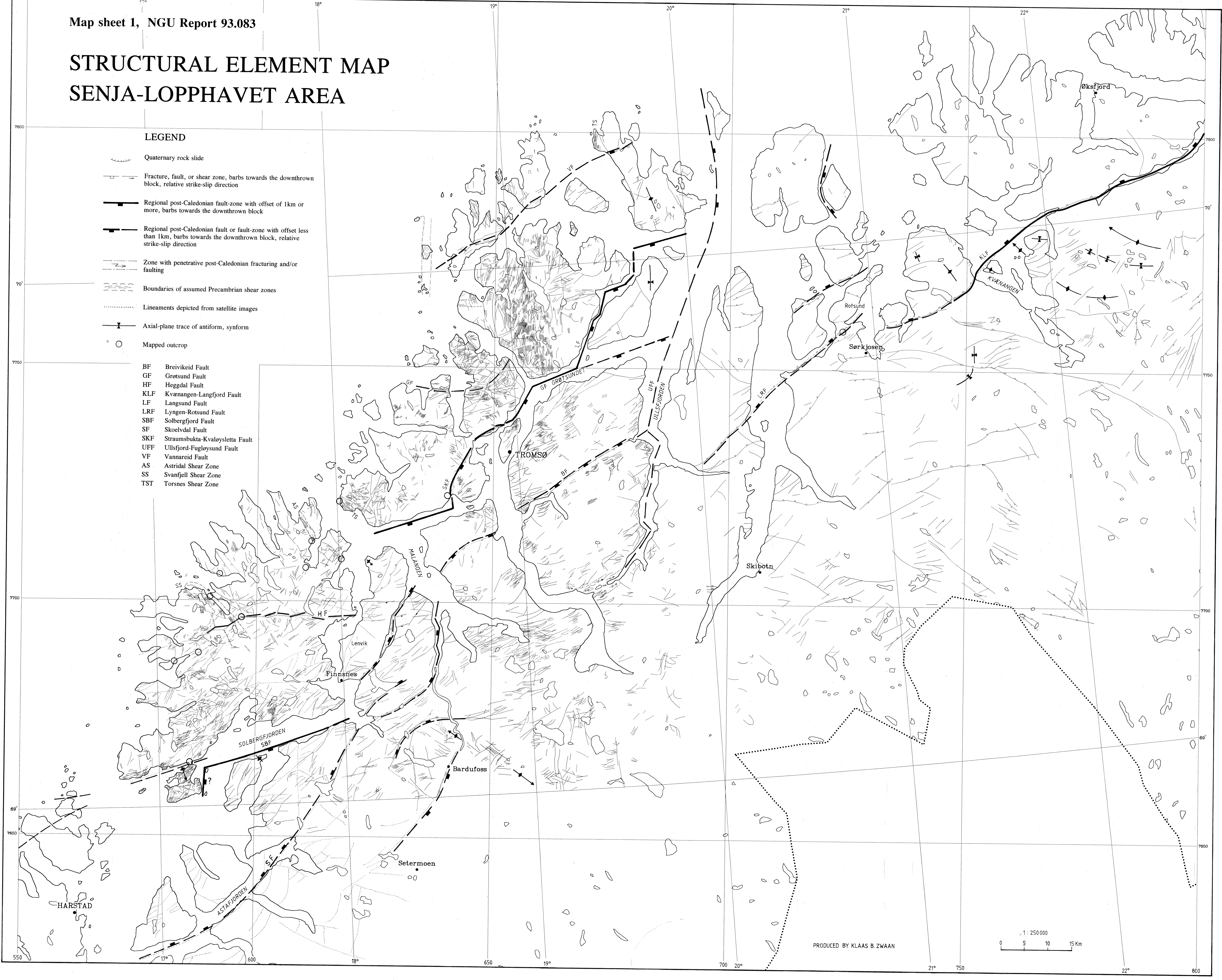


Fig. 12 e - g, Near vertical mesoscopic faults and joints from selected areas. Dip is to the right for the strike direction.



Caledonian thrust zone
Foliation trend interpreted from aerial photos
Precambrian fault or shear zone
Other fracture, fault, or shear zone
For other symbols, see legend to the structural map, Senja-Lopphavet area in scale 1:250,000.

Fig. 16


Map sheet 1, NGU Report 93.083
STRUCTURAL ELEMENT MAP
SENJA-LOPPHAVET AREA
LEGEND
Quaternary rock slide
Fracture, fault, or shear zone, barbs towards the downthrown block, relative strike-slip direction
Regional post-Caledonian fault-zone with offset of 1km or more, barbs towards the downthrown block
Regional post-Caledonian fault or fault-zone with offset less than 1km, barbs towards the downthrown block, relative strike-slip direction
Zone with penetrative post-Caledonian fracturing and/or faulting
Boundaries of assumed Precambrian shear zones
Lineaments depicted from satellite images
Axial-plane trace of antiform, synform
Mapped outcrop
BF Breivikeid Fault
GF Grøtsund Fault
HF Heggdal Fault
KLF Kvænangen-Langfjord Fault
LF Langsund Fault
LRF Lyngen-Rotsund Fault
SBF Solbergfjord Fault
SF Skoelvdal Fault
SKF Straumsbukta-Kvaløysletta Fault
UFF Ullsfjord-Fugløysund Fault
VF Vannareid Fault
AS Astridal Shear Zone
SS Svanfjell Shear Zone
TST Torsnes Shear Zone
Øksfjord
Rotsund
Sørkjosen
TROMSØ
Skibotn
Lenvik
Finnsnes
Bardufoss
Setermoen
HARSTAD
GRØTSUNDET
ULLSFJORDEN
MALANGEN
KVÆNANGEN
SOLBERGFJORDEN
ASTAFJORDEN
PRODUCED BY KLAAS B. ZWAAN
1 : 250 000
0 5 10 15 Km

Map sheet 2, NGU Report 93.083
STRUCTURAL ELEMENT MAP
LOFOTEN-VESTERÅLEN AREA
LEGEND
Location of structural feature referred to in the text
Line of geological cross section
Low-angle, NW-dipping fault
LINEAMENTS
NNE-SSW, local/regional
NE-SW, N-S, - " -
E-W, - " -
NW-SE, - " -
Apparent sense of displacement along fault
Geological cross section showing fault blocks between Eidsfjord and Øksfjord. Stippled line indicates mylonite serving as a structural marker level. (Exaggerated vertical scale)
EIDSFJORD
HINNØY
ANDA FYR
Andenes
Sortland
HARSTAD
Lødingen
Svolvær
Ballangen
NARVIK
Kjøpsvik
EIDSFJORD
SORTLANDSUNDET
ØKSFJORD
STRUCTURAL ELEMENTS
LOFOTEN – VESTÅLEN
AREA
version 93.1
Produced by E. Tveten
M 1 : 250000
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