# Mesozoic high-angle faults, east Hinnøy, North Norway

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Several NE-trending high-angle faults with NW-side down dip-slip have disrupted Caledonian structures on east Hinnøy. The faults are virtually vertical, and strictly brittle in style. These faults may be related to widespread Mesozoic faults in the continental shelf of Norway, which formed during Mesozoic rifting, prior to the opening of the Norwegian Sea in Cenozoic time.

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In the process of mapping the Caledonian basement/cover relationships on east Hinnøy, North Norway (68°45'N, 16°30'E), it became apparent that high-angle faults of post-Caledonian age were a much more important structural element of this part of Norway than had been previously recognzied. Several subvertical faults, trending 30° to 50°, cut the eastern part of Hinnøy and surrounding areas into NE-trending blocks. High-angle faults of probable early Cenozoic age were recognized by Vogt (1942) and discussed briefly by Gustavson (1972). Some of the faults are shown fragmentally on bedrock geologic maps by Gustavson (1974 a, b, c). However, the faults are more numerous, continuous, and consistent in orientation and sense of displacement than indicated by Gustavson.

Many of the high-angle fault juxtapositions have been previously explained by folds or thrusts. For example, the Straumsbotn Nappe hypothesized by Gustavson (1972) was largely based on the interpretation of the Langvann fault as a thrust, an interpretation untenable on the basis of present knowledge (see below). Although the actual faults are only occasionally exposed, contacts, folds, and fabrics are abruptly truncated along the traces inferred on the map (Fig. 1). The major faults in this area (Langvann, Storvann, Astafjord and Fjelldal faults) are also topographically expressed as linear valleys or fault-line scarps.

## General characteristics

The outcrop pattern of the high-angle faults is shown on a simplified geologic map in Fig. 1. Details of the Caledonian geology are in Bartley (1980) and in papers in preparation.

Faults, or secondary shear surfaces closely associated with them, are exposed in four localities (Fig. 1): (1) the long but minor fault north of Langvann is exposed 1 km NNW of Langvann; (2) subsidiary faults along the Langvann fault are exposed 0.5 km west of Langvann, where the fault places Storvann Group quartzite against Precambrian granite; (3) subsidiary shears in Salangen marbles along the Storvann fault are exposed at the northeast corner of Storvann; and (4) several areas of subsidiary shearing along the Fjelldal fault are exposed west of Fjelldal. Slickensides or other mesoscopic movement indicators have not been observed. Fig. 2 plots measurements of fault surfaces from these localities, emphasizing the steep attitude and consistent strike of the faults, aside from the minor E-W splays-off of the Storvann fault on the south side of Sørvikfjell.

The only entirely exposed fault is the minor fault north of Langvann. Where exposed, it cuts massive Precambrian granite, so that the magnitude of displacement on this fault is unknown, though it is probably small further east where it only slightly offsets the basement/cover contact (Fig. 1). Rocks along the fault have been intensely fractured (fracture spacing about 2 to 10 cm), in a vertical zone several meters wide. Local open space fillings of drusy quartz are present. No gouge or fault breccia were recognized. The very brittle style suggests movement occurred at low temperature and pressure, completely postdating Caledonian events.

Vertical subsidiary fault surfaces are exposed

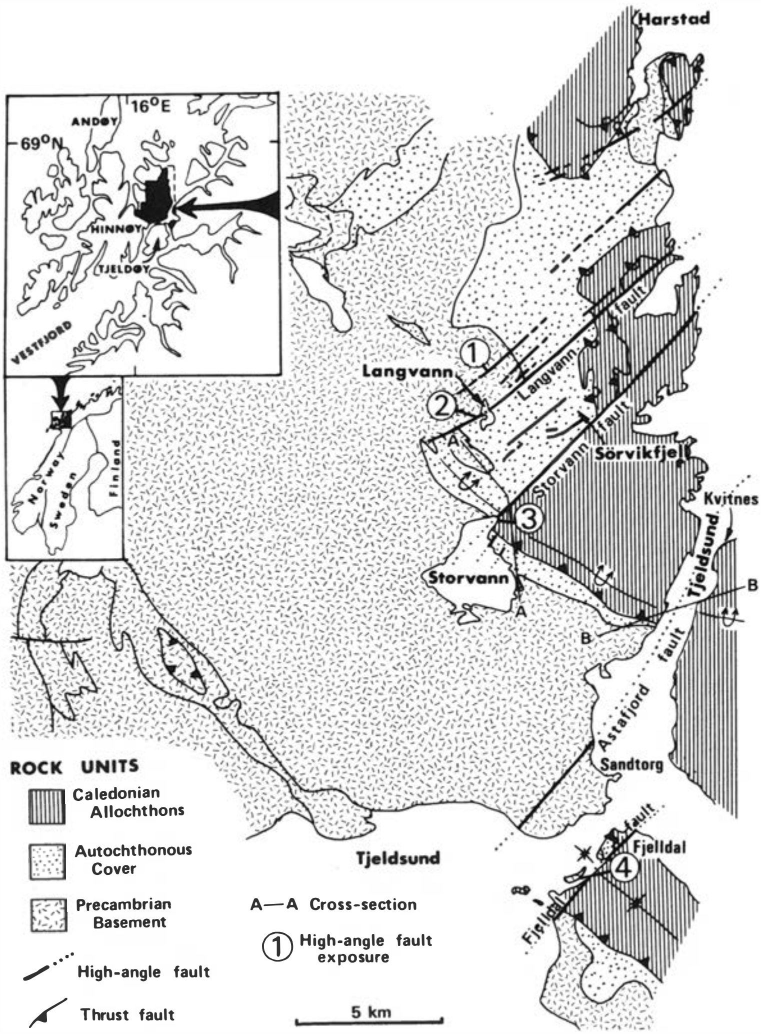


*Fig. 1.* Location and simplified tectonic map of east Hinnøy. Allochthons include rocks of the Narvik, Stangnes, and Salangen Groups (Gustavson 1966, Bartley 1980).

along the Langvann fault within the granite north of the main fault contact. Late Caledonian folds and all previous structures in the quartzite south of the fault are clearly truncated along the contact. From the ridge west of Langvann, the eastward trace of the fault is clearly recognizable, trending perfectly straight regardless of topography. Clearly, the steep dip of the subsidiary fault surface here (86°NW) reflects the attitude of the main fault as well.

At Storvann, the Salangen Group marbles immediately south of the concealed Storvann fault are broken by abundant minor subvertical shears striking 35° and about 1–2 cm apart. The fractures are in part healed by secondary calcite fillings. Southwest-dipping compositional banding is consistently offset right-laterally; where late Caledonian minor fold axes can be matched across shear surfaces, they are offset by north-side down dip-slip. Attitudes of penetrative fabrics in the sheared zone are not significantly different from those south of the zone, indicating that no significant bending or rotation was associated with faulting.

The exposures along the Fjelldal fault are similar to the others described above: intense vertical fracturing with local open-space fillings of vein quartz. Fault breccia is locally present here. One minor fault exposed in the granite gneiss directly north of the main fault trace separates a vertical quartz vein one meter in a left-lateral sense. Hence, at least some minor strike-slip movement occurred in this area.

## Map pattern and sense of movement

The major difference in the pattern of high-angle faults shown in Fig. 1 from the interpretations of previous workers is the arrangement of faults around Tjeldsund. Vogt (1942) identified the Astafjord fault as a NE-trending dip-slip fault truncated to the southwest by the NNE-trending Tjeldsund fault. Both of these faults as shown by Vogt (1942) were entirely concealed by water. The Tjeldsund fault was mapped as following Tjeldsund, curving at its south end and then terminating, because no evidence of the fault could be found on land along its projected trace. Vogt estimated right-lateral strike-slip of 3.5 km on the Tjeldsund fault while Gustavson (1972), adopting Vogt's overall interpretation, estimated 10 km of net slip.

There are several objections to these interpretations. Only planar features offset by the fault were considered by Vogt and Gustavson. Determination of net slip thus requires knowledge of the net slip direction. No independent data exist regarding the direction of slip. The surfaces being matched have been very complexly folded, so that small dip-slip displacements can produce large surface separations of units. Finally, it is geometrically difficult to terminate without a trace a strike-slip fault with 10 km of movement over a distance of a few kilometers.

The present study indicates that all the faults trend NE, consistently have NW-side down dip-slip movement, and that no strike-slip fault is present in Tjeldsund.

Three kilometers of right-lateral separation of the basement/cover contact occurs along the Langvann fault north of Finnslettheia. Only 3 km along the strike, vertically-dipping Caledonian cover units are scarcely separated across the fault. Consideration of the geometry of folds on the south side of the Langvann fault suggests the basement/cover contact was probably only a few hundred meters above the topographic surface at Sørvikfjell opposite opposite this contact north of the fault (Bartley 1981). Hence, northwest-side down dip-slip best explains the relationships along this fault.

The major late-Caledonian overturned antiform which crosses the Storvann fault is scarcely

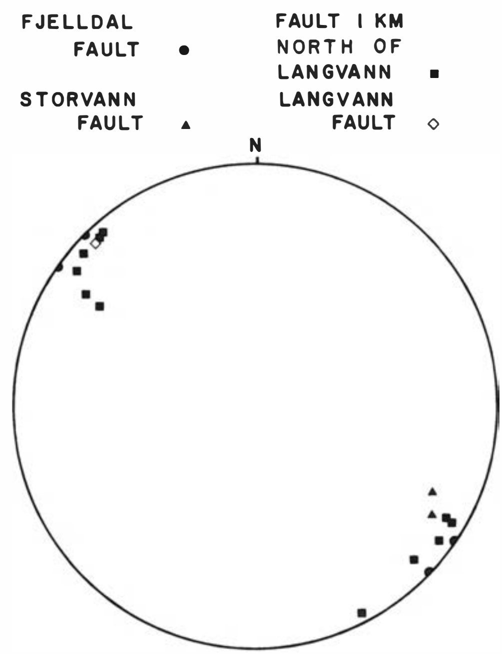


*Fig. 2.* Poles to surface of Mesozoic faults.

offset by it, although different rocks and structural units are juxtaposed (Fig. 1). Tracing of the Storvann Group rocks around the antiform south of the fault indicates they would intersect the fault a kilometer or more above the present topographic surface (depending on fold geometry), indicating northwest-side down movement (Fig. 3A).

On the north side of the Fjelldal fault, Precambrian granite, its autochthonous cover, and the structurally underlying Austerfjord Group, structurally overlie the Salangen Group marbles in the core of an open synform. South of the fault these units are absent above the marbles in the same synform. This relationship again indicates northwest-side down dip-slip movement.

Northwest-side down dip-slip movement along a simple extension of the Astafjord fault also best explains the relationships across Tjeldsund (Fig. 3B). The extensive area of allochthonous cover south of the Storvann fault lies in the inverted limb of a major Caledonian recumbent anticline (Bartley 1980, 1981b). The quartzite and schist at Kvitnes on the east side of Tjeldsund are in the core of the underlying recumbent syncline. The rocks of the inverted limb on Hinnøy would thus project above the rocks at Kvitnes. Hence, a slight southward bend of the

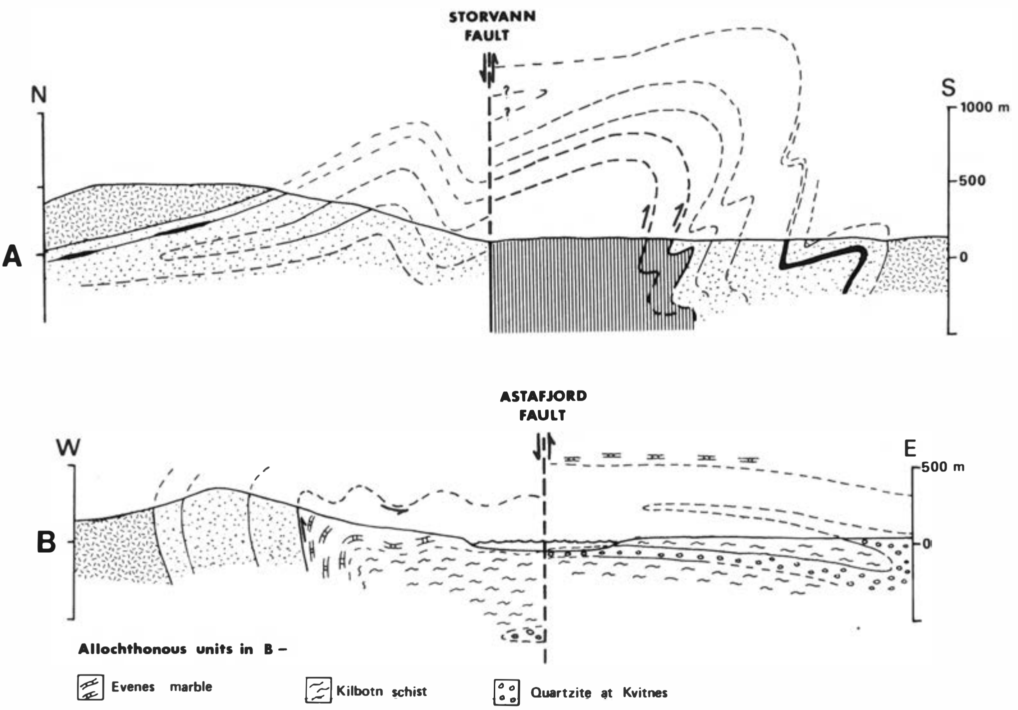


*Fig. 3.* Cross-sections showing approximate magnitude of dip-slip on two of the larger high-angle faults. Symbols as in Fig. 1 except for as indicated. See Fig. 1 for locations.

Astafjord fault to run through Tjeldsund, with NW-side down dip-slip, would satisfy these relationships without requiring the existence and abrupt disappearance of a separate strike-slip fault in Tjeldsund.

The proposed southward continuation of the Astafjord fault through the valley west of Sandtorg is suggested for three reasons: (1) this is a prominent NE-trending valley discordant to surrounding bedrock structure; may other similar valleys in this area follow high-angle faults; (2) the Caledonian major fold axial traces do not readily match across the valley. Considering that these folds are complex and overturned on the north side and open and apparrently simple on the south side, a one-for-one matching of the fold axes cannot readily be made; and (3) continuation of the Astafjord fault through this valley allows minimal deviation from the overall regional fault pattern.

While some of the faults have been shown to terminate westward, Tjeldøy to the south of the study area has not been mapped in comparable detail, so that it is uncertain whether the Astafjord and Fjelldal faults extend beyond the western limits shown here.

More NE-trending high-angle faults may be present further west in Lofoten-Vesterålen (Fig. 4). For example, Raftsund, between Austvågøy and Hinnøy, and the combination of Oksfjord and Gullesfjord which nearly divide Hinnøy in two, are prominent linear topographic features with similar trend to the high-angle faults described in this study. Since the high-angle faults described here are all expressed as topographic lows, these lineaments may well represent more as yet unrecognized high-angle faults.

## Timing and regional tectonics

Local control on the timing of movement of these faults is very poor. Their brittle style and total disregard for older structures indicate that these faults post-date Caledonian uplift and cooling, dated at 360 Ma by Rb/Sr biotite/whole rock studies (Bartley 1981b). The only materials unaffected by the faults are Quaternary sedi-

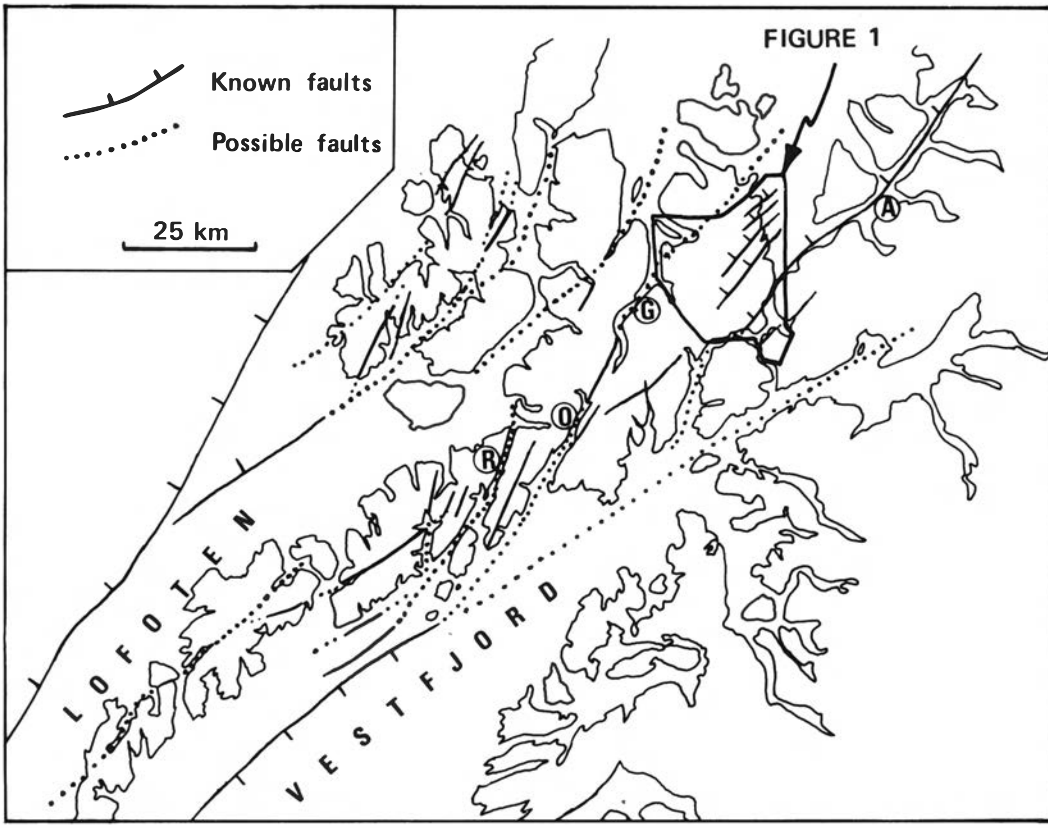


*Fig. 4.* Sketch map of Lofoten-Vesterålen, showing proposed distribution of high-angle faults. Known faults are taken from author's observations, Tveten (1978), Gustavson (1974c), and Jørgensen and Navrestad (1981).
R – Raftsund, O – Oksfjord, G – Gullesfjord, A – Astafjord.

ments. However, the timing of the faults can be reasonably inferred to be Mesozoic on the basis of regional relationships.

On Andøy (Fig. 1), a fault-bounded graben filled with Upper Jurassic-Lower Cretaceous clastic sedimentary rocks has long been known (Vogt 1905, Ørvig 1960). Detailed work by Dalland (1975, in press) has confirmed that the NNE-trending faults which dominate the graben cut rocks as young as Aptian. There is limited stratigraphic evidence of growth on the faults, suggesting some pre-Aptian history (Dalland in press), but the most important displacements must be post-Aptian. Sturt et al. (1979) suggested a late Cretaceous age for the Andøy faults, on the basis of K/Ar whole-rock ages on material from the sub-basin paleo-weathering horizon, where the weathering products (kaolinite and quartz) are affected by the faults. However, alternative interpretations of this K/Ar data cannot be eliminated (Sturt et al. 1979, p. 536–7), since the behavior of Ar in kaolinite is poorly known.

A rough correlation of the faults on Hinnøy with those on Andøy is reasonable, on the basis of their similar orientation and brittle style (cf. Sturt et al. 1979, p. 529). However, N- to NE-trending high-angle faults ranging from late Paleozoic to Cretaceous age occur throughout the Norwegian continental shelf (Rønnevik & Navrestad 1976, Rønnevik 1981, Jørgensen & Navrestad 1981). The most intense deformation appears to be pre-Late Cretaceous (Rønnevik 1981, fig. 4, Jørgensen & Navrestad 1981, figs. 2–8). The Hinnøy high-angle faults thus could be related to somewhat earlier movements, but probably are not post-Mesozoic.

Lofoten-Vesterålen is presently a horst projecting into a broad Mesozoic rift system from its eastern margin (Jørgensen & Navrestad 1981, fig. 1). This rift system encompasses the high-angle faults and related basins of the Norwegian continental shelf, and time-correlative faults and basins on- and off-shore in East Greenland (Surlyk 1977, 1978). This rifting is an expression of Mesozoic initiation of lithospheric extension prior to opening of the Norwegian sea by Cenozoic sea-floor spreading (Talwani & Eldholm 1977). Lithospheric extension following Caledonian orogenesis controlled the paleogeography of the North Atlantic region from the late Paleozoic to the present, and is fundamental to understanding development of petroliferous Mesozoic sedimentary basins (Ziegler 1978, 1981). The faults described here suggest that disruption of pre-Mesozoic rocks by this rifting may be more extensive within the Lofoten-Vesterålen horst than has been previously recognized.

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