Neotectonics in the Ranafjorden area, northern Norway

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Introduction

New data on Late Quaternary faults (Fig. 1), land uplift and earthquake distribution show that the bedrock of Fennoscandia is less stable than earlier anticipated. Opinions differ on the age of formation of individual postglacial faults; from formation immediately after deglaciation in northern Sweden (Lagerbäck 1992) to present active faulting in southwestern and northern Norway (Anundsen 1989, Olesen et al. 1992). There are numerous sharp lineaments representing potential postglacial faults along the coast of Norway. It is, however, very time consuming to map these lineaments to check if they represent young faults. In the search for postglacial faults it is therefore necessary to limit the area of investigation. Studies of the postglacial Stuoragurra Fault in the Precambrian of Finnmark showed that postglacial faulting is likely to occur in areas of increased seismicity, regional zones of weakness and anomalous land uplift (Olesen 1988, Olesen et al. 1992). When studying regional data-sets on seismicity (Bungum et al. 1991), land uplift (Bakkelid 1990, 1992, Olesen et al. 1994) and Landsat lineament analysis (Gabrielsen & Ramberg 1979a), the Ranafjorden area should be of particular interest when searching for postglacial faults in northern Norway. In the following we describe one such effort.

Fig. 1. Reported Late Quaternary faults in northern Fennoscandia (Olesen et al. 1994). The present study area is shown by the frame.

Land uplift

There is ample evidence for recent movements in the Ranafjorden area (Fig. 2):

1) A total of 0.89 m uplift of a bladder wrack mark from 1894 to 1990 (Bakkelid 1990) in Hemnesberget. This observation represents an annual average uplift of 9.2 mm (Fig. 2), which is similar to the present maximum uplift of Fennoscandia in the Bay of Bothnia due to glacial rebound.

2) Three measurements of uplift of bladder wrack marks on the islands of Hugla and Tomma (Fig. 2) in the outer Ranafjorden area show anomalous low land uplift (Fig. 2) from 1894 to 1990 (0.0-0.07m) compared with the uplift recorded (0.23-0.30m) in regions to the north and to the south (Bakkelid 1990, 1992, Olesen et al. 1994).

3) An uplift of approximately 1 metre of a farmhouse in the 1870's at Båsmoen (Grønlie 1923). The observation is made relative to the two neighbouring mountains Snøfjellet and Høgtuva. In the Båsmoen area, 6 out of a total of 7 breaks of water supply pipes during 1993 occurred within a circle of 250 m radius around this farmhouse (A. Hauknes, pers. comm. 1994). The cause of these breaks is not known. The densely built-up area of Båsmoen covers a region of 2 x 1 km.

4) Associated with the 1819 magnitude 5.8-6.2 earthquake (Muir Wood 1989) in the Ranafjorden area, Heltzen (1834) reported an uplift of the shallow sea floor above sea-level during an aftershock in the bay of Utskarpen (Fig. 2). During the main earthquake a major landslide occurred at the same location.

5) A boat-house is also reported to have been uplifted c. 0.5 m during the last 50 years in the Straumbotn area (P. Straumfors, pers. comm. 1994). This location is situated between Utskarpen and Båsmoen (Fig. 2).

In addition, these observations may be related to movements on faults along Ranafjorden but originally some of them were attributed to other causes: 1) Changing marine conditions in Ranafjorden (Bakkelid 1990); 3) Uplift of the

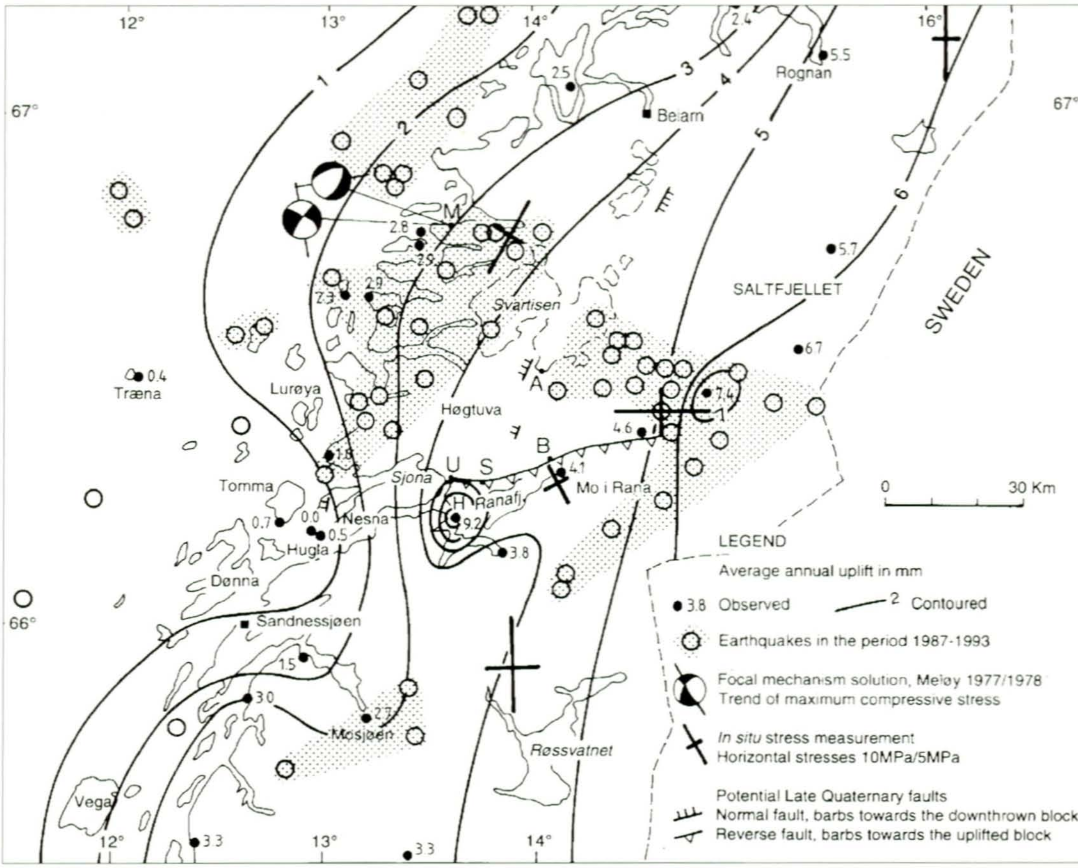

Fig. 2. Late Quaternary faults (Grønlie 1939) and potential Late Quaternary faults (Olesen et al. 1994), earthquake epicentres 1987-1993 (Byrkjeland in prep.), focal mechanism solutions (Bungum et al. 1979, Vaage 1980, Bungum et al. 1991), *in situ stress* measurements (Myrvang 1993) and land uplift data (Bakkelid 1990,1992) in the Ranafjorden-Svartisen area. A - Austerdalsvatnet, B - Båsmoen, F - Fagervika, H - Hemnesberget, M - Meløy, S-Straumbotn, U - Utskarpen. The Late Quaternary fault (Grønlie 1939) to the NE of the Svartisen glacier is classified as one of the most reliable claims of neotectonic surface fault rupture in Scandinavia (Muir Wood 1993).

mountain Høgtuva (Grønlie 1923); 4) Piling up of material behind a rotational slump in the marine clay (Muir Wood 1989).

Seismicity

Norway and nearby offshore areas have a low to moderate seismicity (Bungum et al. 1991), comparable with that in other intraplate regions. The coastal zone of Nordland (Fig. 2) is a seismically active area in northern Norway. The 1819 earthquake (see previous chapter) in the Ranafjorden area is the largest North European near-shore earthquake of the past centuries (Muir Wood 1989). The effects of the earthquake were quite dramatic and it was followed by an extensive aftershock sequence. The event caused widespread damage to foundation walls and chimneys of wooden buildings as well as very extensive rock-falls, liquefaction phenomena and a variety of disturbances in fjords and in the sea (Heltzen 1834, Muir Wood 1989). The spectacular Meløy (Bungum et al. 1979, Vaage 1980) earthquake swarm (Fig. 2) is also located within the seismicity zone of the Nordland coast. It occurred in 1977/1978 and contained more than 10,000 recorded events with magnitudes up to 3.2, but no main shock was recorded. Such swarms may be interpreted to be related to the formation of new zones of weakness in relatively competent bedrock (R. Muir Wood, pers. comm. 1993).

The strike trend of the main active faults within the Meløy swarm (Fig. 2) was N20 -35°E and the dip was 60°E (Bungum et al. 1979, Gabrielsen & Ramberg 1979b, Vaage 1980). The faulting had a large component of normal motion and a minor component of right-lateral strike-slip motion (Fig. 2). Significant deviations (Fig. 2) from this fault orientation occurred (Vaage 1980).

In situ stress measurements

Principal stress directions show an overall tendency to trend N-S or E-W in northern Norway and NE-SW or NW-SE in southern Norway (Myrvang 1993). Fig. 2 shows that the *in situ* stress measurements made by Myrvang (1993) reveal deviations from these general N-S and E-W trends and that this phenomenon is most likely due to local topography and geology. The horizontal stress magnitude is higher than expected from the effect of the overburden. The Nordland and Vestlandet areas display the largest horizontal stresses in Norway and are also characterised by increased seismicity (Bungum et al. 1991). The maximum horizontal stress in the Ranafjorden area is higher than 20 MPa at moderate depths of 200-800 m and causes exfoliation in natural and man-made cuttings and spalling in tunnels (Myrvang 1993, A. Myrvang, pers. comm. 1994). The orientations of maximum compressive stress direction as derived from focal mechanisms (Vaage 1980, Bungum et al. 1991) of the 1977/1978 earthquake swarm on Meløy reveals general N-S and E-W trends (Fig. 2).

Late Quaternary faults

Deep clefts on the Kvasshågen mountain ridge between the valleys of Beiardal and Grottådal to the north of the Svartisen glacier were described by Grønlie (1939). The clefts are up to 4 m wide and 10 m deep and trend NNE-SSW. The eastern side is downfaulted (Fig. 2). The structures are interpreted to be of postglacial age and could be the result of a WNW-ESE oriented extension. The faults are classified as some of the most reliable claims of neotectonic surface fault rupture in Scandinavia (Muir Wood 1993).

The Båsmoen Fault, BF, lies within the regional Ranafjorden lineament and is a potential postglacial fault. It consists of SSE-dipping (40-70°) segments of reverse faults and can be traced for 50 km from the head of Sjona in the west, continuing eastwards along Ranafjorden and further into the valley of Dunderlandsdalen. The ENE-WSW trending fault zone is locally composed of 2-3 parallel escarpments within a 2 km wide belt. The strike of the individual segments varies between N60°E and N110°E. The heights of the escarpments are 1 - 80 metres. A significant portion of these escarpments was formed before the last deglaciation since ice striation is observed locally in the escarpments. Study of the postglacial overburden in the Ranafjorden area shows that deformations like faulting and slumping occur apparently more frequently there than in the surrounding area (Olesen et al. 1994).

Some 1 - 5-cm thick layers of fault gouge and steeply dipping fractures were identified along the fault escarpments (Fig. 3A). The Båsmoen Mine collapsed along the BF in 1913 and the deeper sections of the mine were abandoned, due to the mud and water pouring into the mine along the rock-slide continuing all the way to the surface (Olesen et al. 1994).

The appearance of the BF is similar to that of the postglacial faults reported from the Lapland area in northern Fennoscandia (Lagerbäck 1992, Olesen et al. 1992). We have not yet found any conclusive evidence for postglacial movements along the BF, but there are several indications of abnormal recent land uplift along the fault. The locations Utskarpen, Straumbotn and Båsmoen on the northern shore of Ranafjorden are situated along the fault (Fig. 2). Hemnesberget is

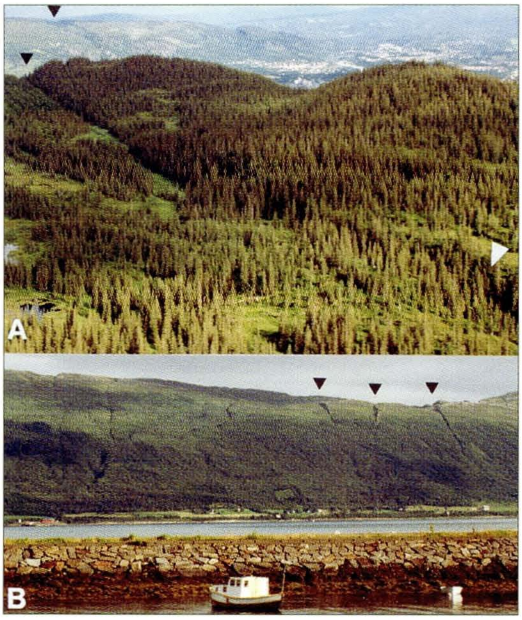

Fig. 3. (a) Oblique aerial photograph of the Båsmoen Fault looking east, approximately 4 km to the west of the centre of Mo i Rana in the background of the picture. The fault is shown by the arrows. The fault is trending ENE-WSW and cuts the strike of the bedding at an angle of approximately 20°. The southern block seems to be uplifted. (b) Several vertical normal faults on Handnesøya. The western blocks are downfaulted. Looking north from the quay in Nesna.

situated in the hanging-wall block 7 km to the south of the escarpment. An extension of the BF may continue in the sound immediately to the north or to the south of the Hugla and Tomma islands. All the above mentioned six locations show anomalous land uplift.

Two swarms of N-S trending normal faults (Fig. 3B) have been observed in the Nesna and Austerdalsvatn areas and may be Riedel-shears to the reverse fault.

Discussion and conclusions

Based on comparisons between observed seismicity and geodetic levelling, Slunga (1991) claimed that almost all present deformation in the Baltic Shield is episodic aseismic sliding along crustal faults, and that earthquakes occur when this slip is locked in small segments which then suddenly break. This type of aseismic creep can explain why relatively large-scale deformation in the Ranafjorden area may occur without large magnitude earthquakes. Geodetic and seismological studies in Finland and Sweden have also shown that horizontal movements can be even greater than, or of the same order of magnitude as the vertical block movements (Slunga 1991, Saari 1992).

There are indications of neotectonic deformation in the Ranafjorden area and the adjacent region. It is, however, difficult to find conclusive evidence for both postglacial and present-day movements along specific faults. We have therefore established a GPS network designed to measure the active geological strain in the Ranafjorden area (Olesen et al. 1994). Three 15-20 km long profiles are located across outer, central and inner Ranafjorden. The network is expected to give an accuracy of 5-10 mm in the horizontal plane and 15-20 mm in height. If there is any active deformation in the area, as indicated by previously published land uplift observations, this should be recorded by GPS in less than a decade.

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