SURFACE FAULTING AND FUMEROLIC ACTIVITY SINCE THE 1970 BEERENBERG ERUPTION, JAN MAYEN

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Post-eruption minor fault scarps, conjugate shear fracture, and at least one explosion crater formed in tephra around Skrukkelia crater between field studies in August 1972 and August 1973. They probably formed during a local earthquake swarm in January 1973. Steam and H_2S gas were rising from some of the new vents and thicker lava flows, and from Sentralkrateret and Eggøya.

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The 1970 flank eruption of Beerenberg volcano was the first well-documented historic eruption on Jan Mayen (Gjelsvik 1970, Siggerud 1971, 1972), although previous activity probably occurred in 1732 (Anderson 1746) and in 1818 (Scoresby 1820). The remoteness of Jan Mayen, its typically poor weather, and the difficulty of access have precluded detailed studies of the recent eruption area until August 1972, when Norsk Polarinstitutt mapped the area (Siggerud pers. comm. 1972). This note describes ephemeral tectonic and volcanic features which formed and have been active since August 1972. The observations were made on 16 August 1973 during a brief visit to a limited part of the eruption area.

The 1970 eruption is thought to have been triggered very early in the morning of 18 September 1970 by a magnitude 5 earthquake near the north end of Jan Mayen at a depth of about 28 km (Siggerud 1972, Zobin 1972, International Seismic Centre, Scotland). The first observers arrived two days later and saw lava and tephra erupting from a series of NE-trending fractures and related new craters on the east flank of Beerenberg volcano (Fig. 1). The eruption might be considered a typical one for Jan Mayen, because since the formation of Sentralkrateret, approximately 6000–7000 yrs. B.P., eruptive activity has occurred chiefly from numerous similarly oriented rifts and related adventive cones, both northeast and southwest of Sentralkrateret (Fitch 1964, Fitch et al. 1965, Roberts & Hawkins 1965).

Lava fountains built up large irregular tephra cones around Sigurdbreen and Skrukkelia craters and deposited a smooth-surfaced blanket of tephra over the surrounding area, much of which covered glaciers during the eruption. The blanket of tephra was smooth and unfractured when studied by the

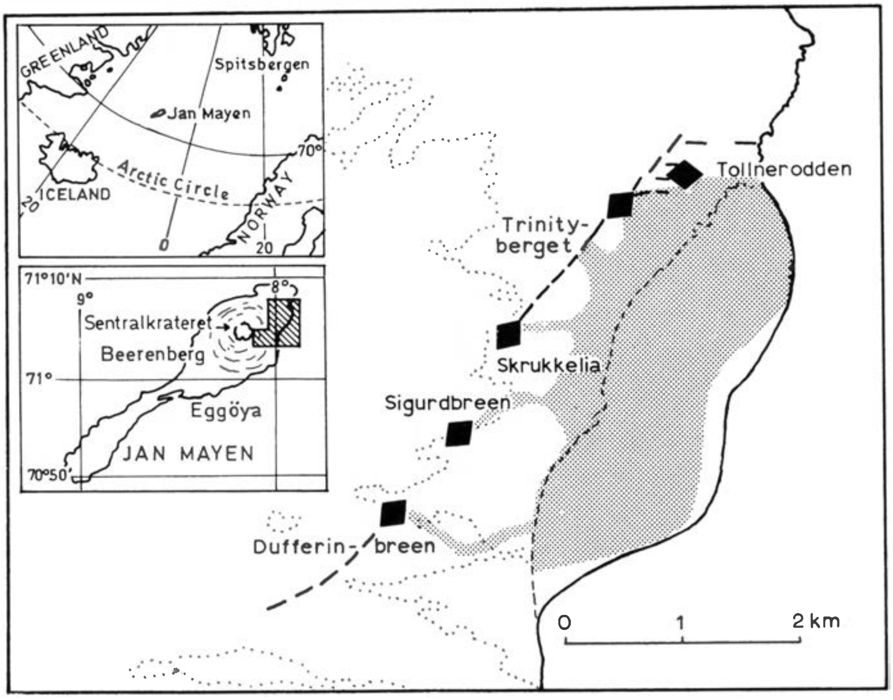

Fig. 1. Generalized map of part of north Jan Mayen showing new craters (diamonds) and rifts (bold dashes) active during the 1970–71 eruption (after Siggerud 1972, with modifications). The dotted line represents the limit of glacial ice, the dotted pattern represents the area covered by 1970–71 lava.

Norsk Polarinstitutt geologists in August 1972 (T. Siggerud pers. comm. 1973), and thus constitutes a reference surface against which subsequent activity can be measured.

The traverse to the eruption area on 16 August 1973 passed over Skrukkelia crater and near the two northern craters (Fig. 1). Sigurdbreen crater was seen from one kilometre; Dufferinbreen crater is in a valley and was hidden from our view by Sigurdbreen crater.

Faults, fissures and fractures

The surfaces of Skrukkelia cone and the surrounding blanket of tephra are broken by fault scarps, fractures and fissures (Fig. 2). Moderate fumerole activity was occurring in both Skrukkelia and Sigurdbreen craters on 16 August (Fig. 2).

The main fault feature is a northeast-trending graben, about 50 m long, 3 m wide and 1 m deep, which cuts the tephra blanket on the northwest slope of Skrukkelia crater. The graben is parallel to the rift zone along which the

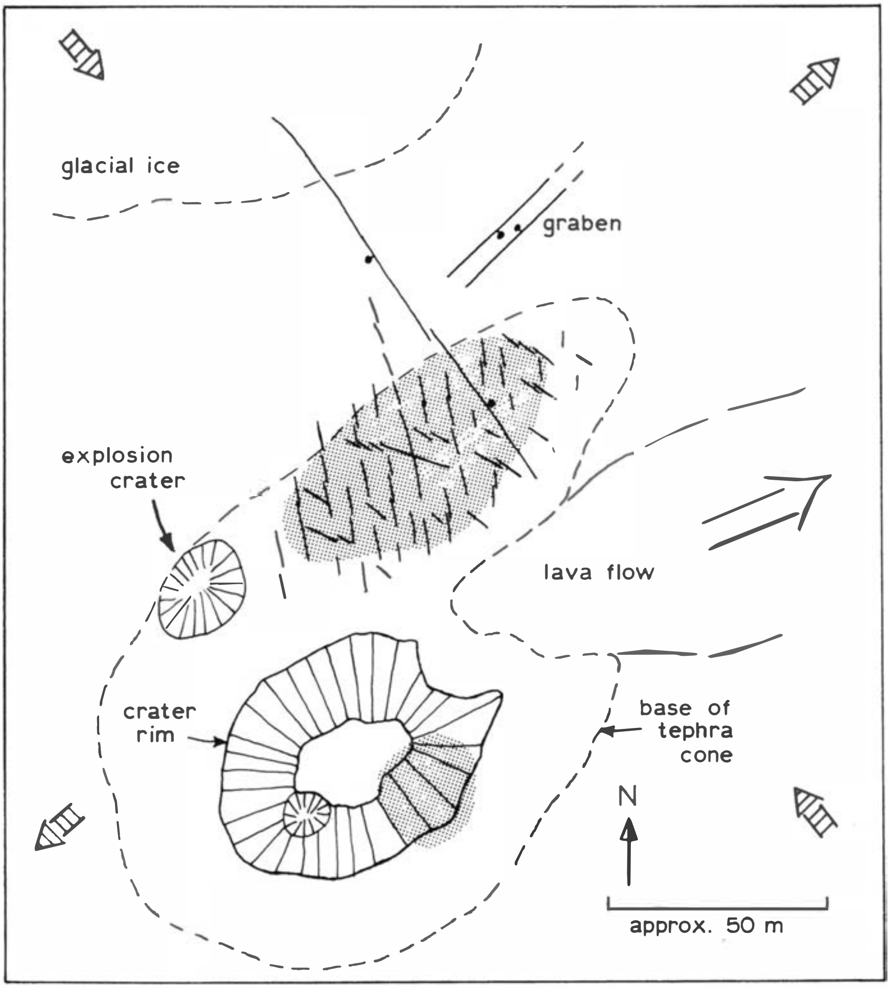

Fig. 2. Sketch map of Skrukkelia crater showing faults (ball on relatively down-dropped block), fractures and fumerolic areas (shaded). Arrows in corners of sketch indicate strain inferred from fractures.

eruption commenced, to the main cliff which may be fault controlled (Roberts & Hawkins 1965), and to an older sidehill graben within and nearly parallel to the main cliff. That the graben scarps are quite recent is suggested by their sharp edges and steep planar sides in the loose, unconsolidated tephra. If they were relatively old, one would expect the edges to be rounded and the sides slumped, resulting in a more irregular, subdued morphology.

The northwest flank of Skrukkelia tephra cone is cut by a series of northwest-trending faults, fractures and fissures with three main orientations as shown schematically in Fig. 2. Of particular interest is a fault which vertically offsets the surface of the northeast end of the cone about 1 m

(Fig. 3), and along which hydrothermally altered and partially indurated ash has slumped into fissures along the fault. The fault trends northwest from the top of the cone to its base. From there, an *en echelon* fault with the opposite sense of uplift continues across the tephra blanket (Fig. 4) and into a glacier as a 30 cm wide crevasse almost 30 m long. The edges of the crevasse were sharp, and there was no snow or tephra within the crevasse. The vertical separation of the cone surface, fissuring along part of the length of the fault, and the lack of strike-slip separation indicate that these are normal faults formed by NE–SW extension and NW–SE shortening.

A conjugate set of shear fractures, trending about NNW and WNW (Fig. 2), is bisected by the extension faults and related parallel fractures. They are

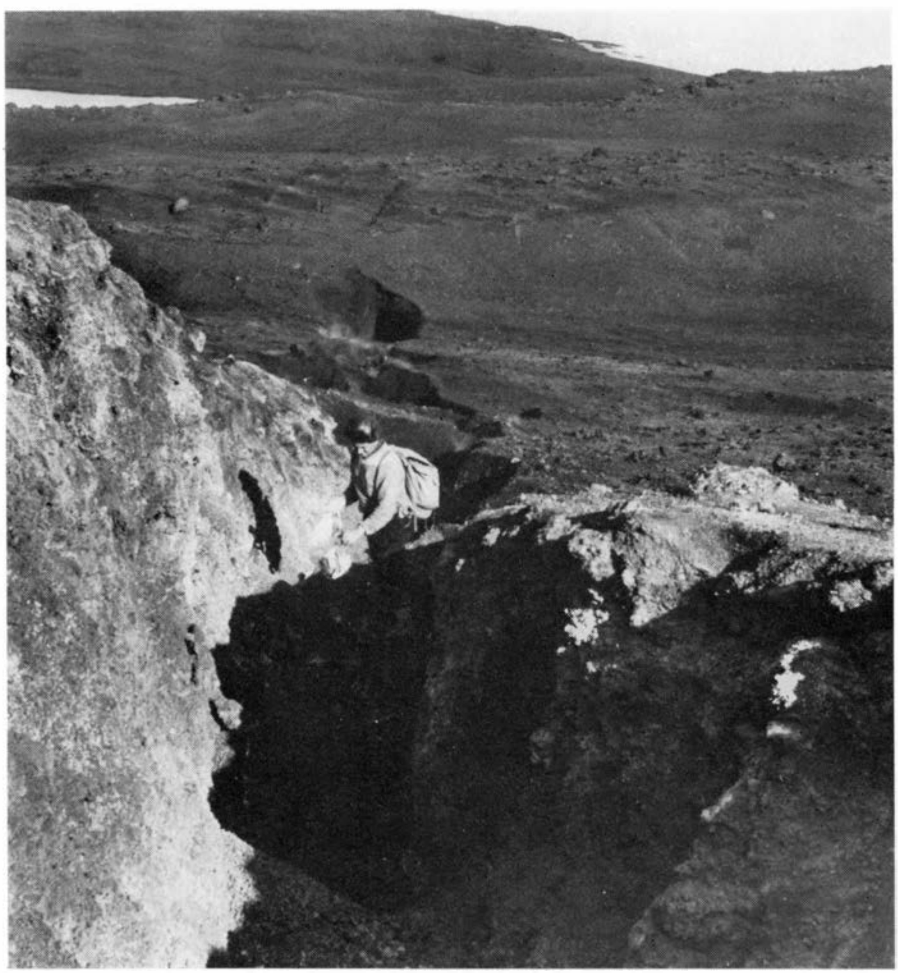

Fig. 3. Fissures along fault in hydrothermally altered tephra, Skrukkelia crater. Vertical separation across the fissure is about 1 m.

Fig. 4. View northwest parallel to the trace of a 10 cm high fault scarp in tephra of Skrukkelia crater. Fault continues into glacier in background. Hammer is 36 cm long.

sharply defined and frequently are composed in detail of numerous, short *en echelon* segments (Fig. 5). Vertical and horizontal separations are minimal. The geometry of the extension faults and the conjugate fractures suggests a strain pattern of NW–SE shortening and NE–SW extension.

The age of the fractures and faults clearly postdate the cessation of tephra production which may have been as early as 28 September 1970 (Birkenmajer 1972), but was certainly by spring 1971 (Siggerud pers. comm. 1972). The most likely time of their formation was probably during the first 15 days of January 1973 when an earthquake swarm occurred near the north end of Jan Mayen (Fig. 6), because it is the most significant seismic event to have occurred near Jan Mayen since 1971 (Navrestad & Sørnes 1974). More than 300 earthquakes were recorded, up to 90 earthquakes were recorded in one day, and 10 earthquakes of the swarm had body wave magnitudes ranging from 4.1 to 5.1 (NOAA PDE cards 2, 4, 5, 6–73). Although precision of location of individual events is low, the swarm certainly constitutes

Fig. 5. Northwest-trending *en echelon* fractures in tephra on Skrukkelia crater. Hammer is 36 cm long.

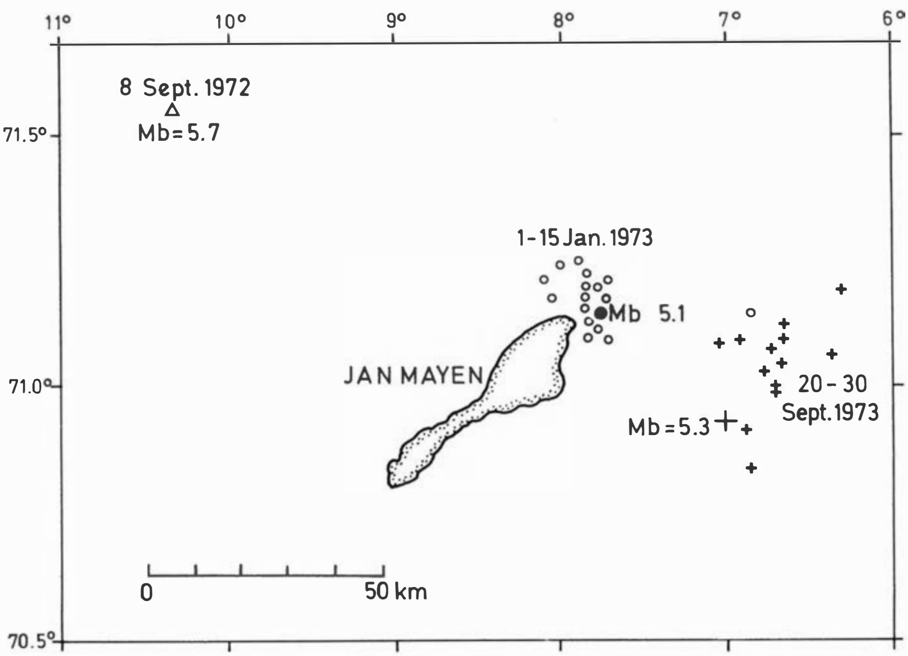

Fig. 6. Provisional epicentres of larger earthquakes ($M_b > 3.5$) registered near Jan Mayen, August 1972–August 1973 (T. Navrestad, pers. comm. 1973). Crosses represent epicentres for the earthquake swarm of 25–30 October 1972. Circles represent epicentres for swarms of 1–15 January 1973. Magnitudes for the three main earthquakes are taken from NOAA PDE cards.

a source of seismic energy strong enough and near enough to the eruption area to cause primary surface rupturing or secondary shaking or lurching features. The relatively sharp and fresh appearance of the fractures and fault scarps suggests they have formed even more recently, recently enough to have survived damage or obliteration by strong rain showers. Snow cover, however, could have provided protection until mid-summer for cracks that formed in winter.

The question arises to what extent these new features are related to surficial processes dominated by gravitational forces, and to what extent they reflect deeper regional tectonic processes. If the faults and fractures are related to the earthquake swarm, their origin may be owing to one or a combination of the following:

(1) The graben represents:

(a) A primary rupture formed in response to the same deformation processes responsible for the formation of the original pre-eruption rifts, or

(b) a secondary extension fault structure formed by the downslope gravitational sliding of the entire Skrukkelia cone, similar to the extension frac-

Fig. 7. Fumerolic activity in Skrukkelia crater on 16 August 1973 as seen from the northwest edge of the crater. The sea is in the background.

ture at the head of a landslide. The downslope sliding may have been triggered by shaking during the earthquake swarm.

(2) The normal faults and related conjugate shear fractures formed in response to:

(a) NE–SW stretching of the cone which would explain fractures at the northeasternmost end of the cone where steep slopes dip NE below the base of the cone, but which would not be consistent with the straight projection of the normal fault into the glacier, because it slopes to the southwest, or

(b) a downhill, SW-directed push by the glacier, triggered abruptly, perhaps, by shaking during the earthquake swarm.

It seems clear that the fractures and faults must have formed relatively quickly, as during an earthquake, otherwise the unconsolidated tephra should have adjusted by intergranular slip to such slow strain resulting from gravitational stress of a glacier. A more comprehensive and systematic study would be required, however, to choose confidently among the various mechanisms suggested above.

Fumerolic activity

Steam clouds were rising from Sigurdbreen and Skrukkelia craters, from part of the rift zone between Skrukkelia and Trinityberget craters, and from the aa flows on the plain below Skrukkelia, Sigurdbreen and Dufferinbreen craters (Fig. 1). A very small fumerole was encountered approximately 100 m northwest of the main rift between Trinityberget and Skrukkelia craters, suggesting that minor fumerolic activity may be more widespread than just in the craters and the main rift zone.

At Skrukkelia crater, steam with a faint odor of H_2S was rising through fissures and fractures on the northwest flank of the tephra cone (Figs. 2 and 4) and from a 25 m^2 area within the east side of the main crater (Fig. 7). The tephra around the steaming fissures and fractures was hot to the touch. Much of the black tephra is oxidized to reddish brown, and fissures and irregular areas of the cone surface are coated with a thin film of yellow sulphur.

Elsewhere on north Jan Mayen, steam was rising rather continuously from a 50–70 m^2 area within the north side of Sentralkrateret, and discontinuously from the crater at Eggøya (Fig. 1). Steam activity has been occurring intermittently in Sentralkrateret at least since summer 1972, and from Eggøya for more than 40 years (Siggerud, pers. comm. 1973).

An explosion crater on the southwest slope of Skrukkelia crater was not present in summer 1972 (Siggerud, pers. comm. 1973), indicating continuance of minor explosive activity more than a year after the eruption presumably ceased.

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