The volcanic eruption on Jan Mayen 1970

BY

THOR SIGGERUD

Contents

Abstract

A major eruption took place on Jan Mayen in September–October 1970. The lava flows were first observed 20 September but evidence is discussed which indicates that the first opening of the fissures occurred two days earlier. Five crater groups were formed along a 6 km long fissure zone on the NE slope of Beerenberg, from about 1,000 m a.s.l. down to sea level. Lava from the craters built out approximately 4 km^2 new land into the sea, and the volume of the effusives is at least 0.5 km^3, probably much more. The lavas are composed of a potassium-rich basalt. In late October the lava eruption ceased but tephra and gases were emitted sporadically up to the last observations in 1971.

Introduction

Preliminary information on the 1970 eruption on Jan Mayen has been given by GJELSVIK (1970) and by the Smithsonian Institution, Center for Short-lived Phenomena.

Jan Mayen is a remote island of 380 km^2 in the Norwegian Sea (Fig. 1). The volcanic origin of Jan Mayen has long been recognized from the many and typical crater mounds occurring on the island. The crater summit of the large strato-volcano, Beerenberg, reaches 2,277 m a.s.l., and this volcano is considered to be one of the most conspicuous volcanoes in the world (Fig. 2).

Although the central crater of Beerenberg has not erupted in historical time,

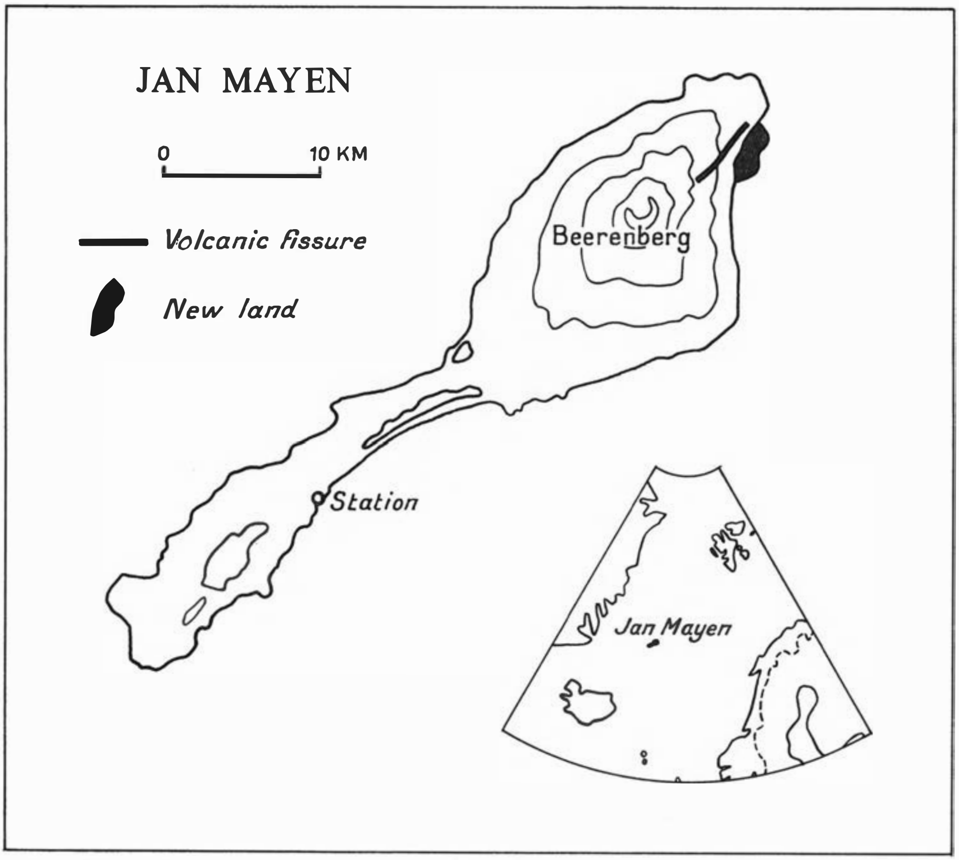

Fig. 1. *The locality of the new volcanic area on Jan Mayen and the geographical position of the island.*

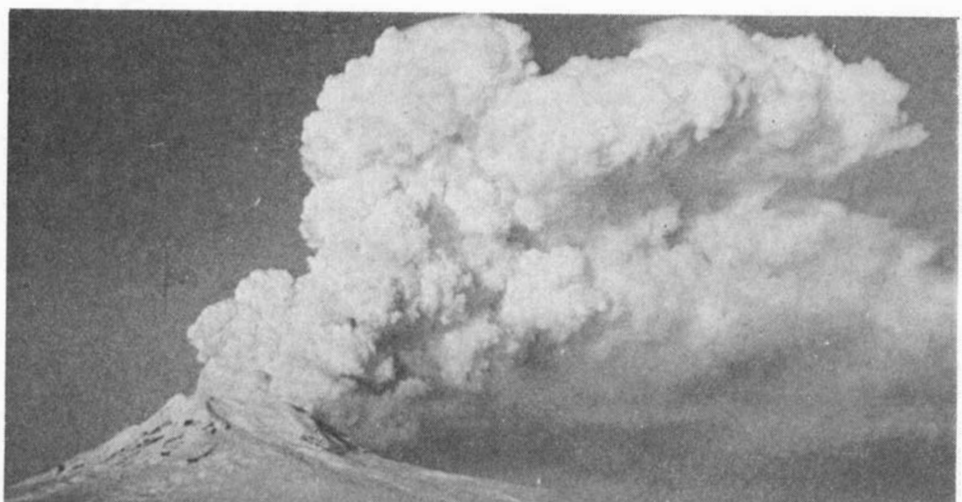

Fig. 2. *Beerenberg with steam cloud, September 20, 1970.*

written accounts about parasitic volcanic activity (ANDERSON 1746, SCORESBY 1820) confirm its volcanic origin.

Members of the Austrian expedition (1882–83) were the first to bring back geological material for a closer study, and gave a short description of it (BOLDVA 1886). This was the only geological record until the results of the "1921 Cambridge Expedition" were published (WORDIE 1922, 1926, TYRRELL 1926).

In the years 1947–1961 a number of British geological expeditions worked especially on the northern part of Jan Mayen, and their results have been published i.a. by NICHOLLS (1955), FITCH (1964), and ROBERTS & HAWKINS (1965). Samples collected during these expeditions have also been used for paleomagnetic studies (FITCH et al. 1965b) and for radiometric age determinations (FITCH et al. 1965a).

In 1959 a Norwegian geologist worked on the southern part of Jan Mayen (CARSTENS 1961, 1962). Nothing has yet been published from the central part of the island.

The petrography of the Mid-Atlantic islands in relation to their position relative to a Mid-oceanic ridge system has caused much interest (HEEZEN, THARP and EWING 1959). Today Jan Mayen's connection to the Mid-Atlantic Ridge is well known, and the island's special situation in this regard has been described by JOHNSON & HEEZEN (1967), JOHNSON (1968).

Earthquakes occur frequently in this part of the Norwegian Sea. HEEZEN & EWING (1961) point out that earthquake epicenters in the North-Atlantic Ocean (as plotted by GUTENBERG & RICHTER (1954)) tend to concentrate in a region along the central rift of the Mid-Atlantic Ridge. (It is interesting that KOLDERUP & KVALE (1938), in a paper on the earthquakes on Jan Mayen in 1936, called attention to the concentration of epicenters along a line in the middle of the Norwegian Sea.)

Similar observations were made by SYKES (1965) on the basis of more accurate determinations of epicenters in the Norwegian Sea, i.e. from central Iceland (neovolcanic zone) to Jan Mayen and northwards.

There is an obvious relationship between seismic activity, volcanic activity, and the Mid-Atlantic Ridge system, of which Jan Mayen is the northernmost island.

The beginning of the eruption

The first certain observation of the last eruption on Jan Mayen was made by the crew of a Japanese airplane at c. 0300 MET, September 20, 1970.

Later in the morning smoke columns protruding up to 10,000 m and fire were observed from Italian and German commercial planes.

In the preceding days a low pressure zone (995 millibars) had approached Jan Mayen from the south-west and this passed the island on September 20. This caused the formation of heavy clouds in the area and made earlier observations from the air impossible. On the night of September 20, a blizzard from the south-west made observations from the ground equally impossible, even if one had known what was going on.

The meteorological and LORAN station on Jan Mayen is situated about 30 km from the place where the eruptions occurred, with the towering Beerenberg between. At 0308 MET on September 18 an earthquake shook the Jan Mayen area and, in spite of the time of the day, was noticed by almost all of the crew of the station. This earthquake was recorded by most seismic stations and in Strasbourgh the position of the epicenter was calculated to be 71.2°N and 7.7°W, i.e. northeast of Jan Mayen. The actual locality where the eruption occurred is however well within the accuracy range of this location of the epicenter area. Smaller earthquakes were noticed later, particularly one at about 2300 MET on September 19.

As mentioned above, earthquakes are not uncommon in these waters and need not be connected with an eruption. However, a few other events focus our attention on the night between September 17 and 18. A Norwegian plane circling Beerenberg on the afternoon of September 17 did not notice anything extraordinary (B. WESTERN, pers. comm.). The plane stopped overnight on Jan Mayen and left the following morning at about 1000 MET; when breaking through the stratiform clouds that covered the area, the crew noticed the presence of a huge cumulus cloud in the vicinity of Beerenberg. The center of the above mentioned low pressure system was at that time situated near Jan Mayen. The same plane with the same crew made a new flight to Jan Mayen on October 2, and, when seeing the steam cloud above the eruption that day, were convinced that the cumulus cloud observed on September 18 was formed as a result of an eruption. This was the more likely as the cumulus cloud observed on September 18 was the only one to be seen above the stratus clouds for a long distance.

It is not unlikely that there was a connection between the low pressure passing Jan Mayen in this period and the beginning of the eruptions (Table 1). Low pressures have often been suggested to serve as the final trigger mechanism in releasing eruptions.

ESSA 8 satellite pictures as well as NIMBUS images have been studied and show the extent of the volcanic dust and gases. A NIMBUS picture from September 21, 1217 MET, displays a plume at least 400 km long, extending from Jan Mayen towards Norway (Fig. 3).

Table 1
Some observations from
the Jan Mayen meteorological station, September 1970

Date	Time GMT	Wind in knots			Pressure in millibars
		at sea level	3,000 m	5,000 m	
17	1200	0 —	ESE 10	S 20	
18	0000	ENE 10	ESE 25	ESE 30	1002.7
	1200	N 25	NE 35	NE 50	990.1
19	0000	W 5	S 10	NW 15	991.9
	1200	WNW 10	NW 25	WNW 120?	995.3
20	0000	WNW 10	NW 40	NW 45	1002.2
	1200	W 20	NW 35	NW 25	1010.0
21	0000	NW 20	No observations because of the volcanic eruption		
	1200	W 20			

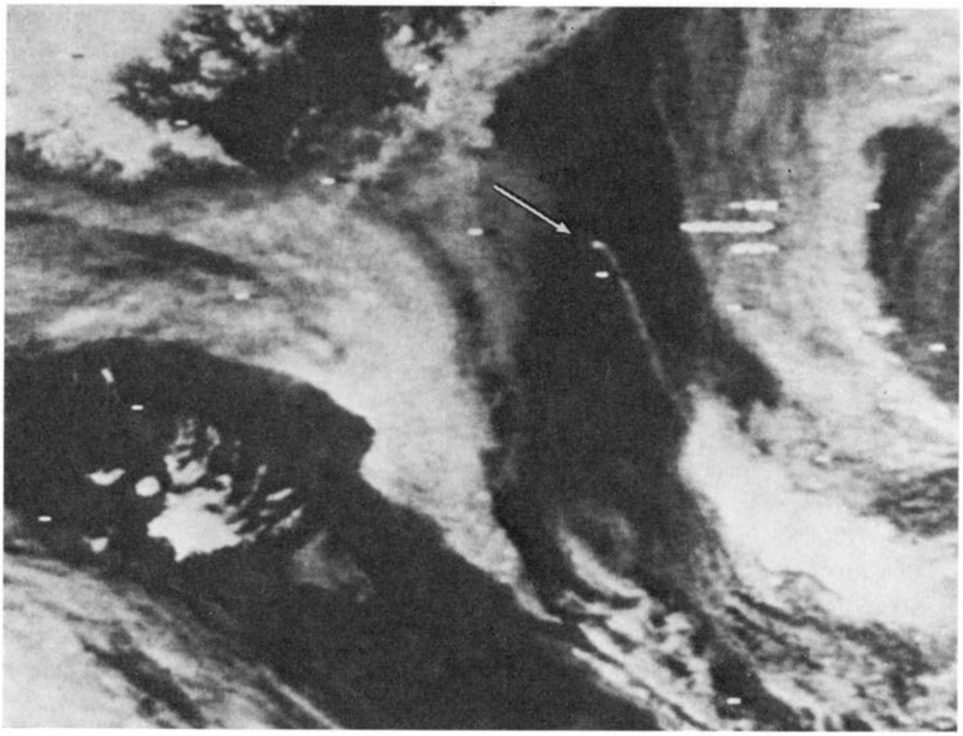

Fig. 3. *Jan Mayen with the plume of dust and steam, September 21, 1970.*
(NIMBUS IV 1217.02 MET, 1,100 km high.)

According to Y. GOTAAS (pers. comm.), dust from Jan Mayen came in over northern Norway on September 21 and lowered the visibility considerably. Volcanic dust sunset colors and prolonged twilight were noticed in southern parts of England on some of these days.

When comparing the position of the cloud on satellite photographs with wind speeds and wind directions on September 20 and 21 (Table 1), there are strong indications that the volcanic dust must have been brought into the atmosphere before the first certain observations of the eruption on September 20 (H. H. LAMB, pers. comm.).

It is concluded that dust was injected into the stratosphere in the initial phase of the volcanism, and that this must have taken place earlier than September 20 (SMITHSONIAN CARD, 1078–79).

All these different indications seem to give strong evidence for assuming that the eruption actually began during the night between September 17 and 18 and that the recorded earthquake was connected with the final penetration of the magma.

It is interesting at this point to speculate on how long it would have taken to become aware of the eruption had there been no flights by airplanes in the area, and if the unusually fine weather had not occurred on September 21 and 22, when the steam cloud was still high above Beerenberg. It seems likely to the author that as little as 20 years ago, when the weather-station was situated at the south-western foot of Beerenberg, this eruption would not have been recorded.

This should be kept in mind when discussing the frequency of eruptions on Jan Mayen, or of any remote, unpopulated volcanic island.

The observations of the eruption

After the volcanic activity had been reported on September 20, planes from Royal Norwegian Airforce were directed to the area, and from then on air-photographs were available. Especially during this early stage of the eruption the area was obliterated by smoke and tephra clouds originating from the vents or the steam formed when the lava entered the sea. The prevailing winds in these waters are easterly, and this resulted in the whole of the active area often being completely covered. However, this also happened at rather frequent intervals later during the eruption.

The crew of the station was evacuated to Norway by plane on the evening of September 20, but the next afternoon a plane returned to Jan Mayen with some of the crew and three geologists: BOYE FLOOD and THOR SIGGERUD from Norsk Polarinstitutt and Prof. CHRISTOFFER OFTEDAHL from the University of Trondheim. SIGGERUD returned with the same plane, to organize more regular observation flights with a plane from Iceland.

To get from the meteorological station to the northern side of Beerenberg over land is impossible. The area of eruption is therefore inaccessible without a ship, but landings are difficult and often dangerous, with the swell breaking at the nearly vertical old lava cliffs or on the new beach of pyroclastics.

On September 22 the Norwegian naval vessel, KNM «Heimdal», arrived at Jan Mayen and stayed in these waters, mainly outside the eruption area, until September 29. FLOOD and OFTEDAHL made three successful landings from this vessel, on September 22 to the southern lava stream, and the following day to the northernmost crater field. On the same evening the Icelandic geologist, Dr. G. SIGVALDASON, came to Jan Mayen with a plane from Iceland bringing along equipment for temperature measurements and gas sampling. Because of heavy swell, only one more landing was possible. The group went on shore at the north side of Koksslettta and walked towards the eruption site (Fig. 4). However, a strong wind from the east carried tephra and volcanic gases towards the group, and it was not even possible to try to sample gases and measure temperatures. Sampling of solidified lava was carried out during all these landings.

At the same time, SIGGERUD observed the area from the air on September 21, 25, and 28, and October 1 and 8. From October 1 he stayed on at Jan Mayen onboard M/S «Polarbjørn». On October 3 he was able to go on shore from this vessel near the southernmost lava stream, and, although this was a rather wet and dramatic trip, a substantial amount of new lava samples were brought back.

Tourist flights to Jan Mayen on October 9 and 11, with geologists as guides onboard, reported steam and ash columns up to at least 500 m above the summit

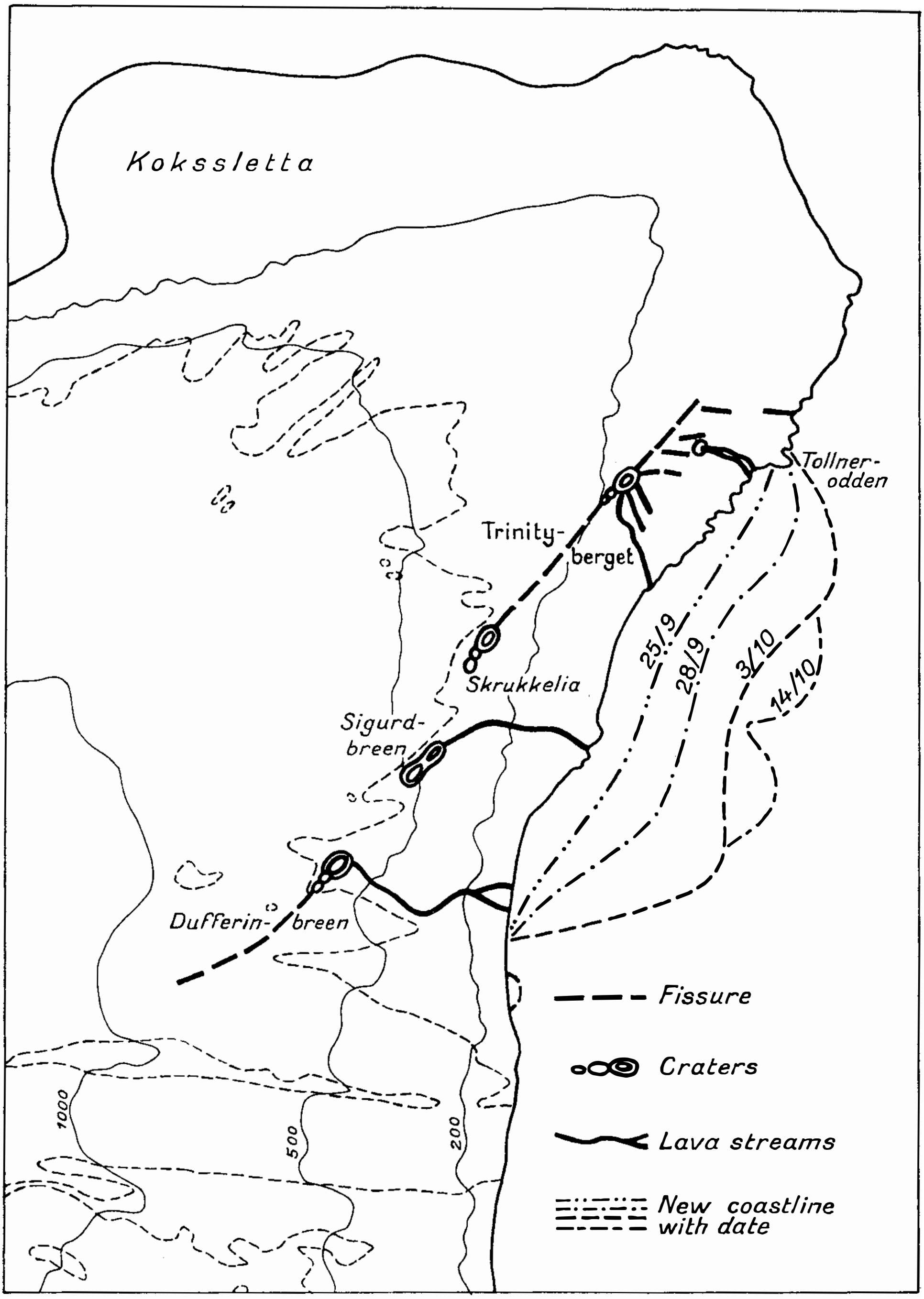

Fig. 4. *Map of the new volcanic area, north-east Jan Mayen.*

of Beerenberg. The actual craters could not, however, be seen because of clouds. After unloading provisions to the station, M/S «Polarbjørn» again patrolled outside the active area on October 14. This time no geologist was onboard and low clouds covered the craters. However, the extension of the lava front into the sea on that date (as shown by the radar screen) was plotted on the chart.

Later, only occasional clear days, as October 20 and 26 and November 5 and 17, made it possible to see the northern part of Jan Mayen with Beerenberg from the station. Columns of smoke and steam rising up behind Beerenberg made it clear that the activity had not ceased. The seismic event counter confirmed these observations. When OFTEDAHL revisited Jan Mayen on November 26, lava production had ceased.

In March 1971 new clouds were observed, but not until April 26 was SIGGERUD able to come to Jan Mayen and observe the previous eruption area from the air. At that time two craters were emitting smoke columns.

Observations on the volcanic activity

The activity was located along a fissure extending SW–NE for about 6 km along the north-eastern slopes of Beerenberg.

The fissure runs from Frielebreen about 1,000 m a.s.l. to Tollnerodden about 40 m a.s.l., and contains the following crater fields from south-west to north-east (Fig. 4): the Dufferinbreen crater about 600 m a.s.l., where lava production probably ceased on September 28; the Sigurdbreen crater about 500 m a.s.l., and the Skrukkelia crater about 450 m a.s.l., both producing lava in the beginning of October but with little activity in the middle of November; the Trinityberget crater about 50 m a.s.l., with probably still some lava activity on October 11; the Tollnerodden crater about 40 m a.s.l., where lava activity probably ceased as early as September 21.

During the first days the eruption was, as mentioned, rather explosive. The pilots on the first plane reaching Jan Mayen on the morning of September 20 reported seeing an 11,000 m high cloud, and stones that were hurled up to 5,000 m. The production of steam and gases showed large variations. After the first days came a period when the formation of steam clouds over the craters was rather limited, but it increased again and in the beginning of October the cumulus cloud was often much higher than the summit of Beerenberg. In the first week the production of tephra was also the greatest. In the neighbourhood of the volcano it was mostly as pumic lapilli in sizes up to 5 cm. These coarse-grained lapilli were formed by the gas-filled lava being thrown out in the lava fountains (see frontispiece).

The activity of the lava fountains pulsed and more local ash-falls around the craters were not uncommon. A vessel 5 km from the Sigurdbreen crater on the morning of October 2 was covered in a short time by a 1–2 cm thick layer of tephra with grain size up to 1 cm.

During most of the eruption the smell of sulphur was very pronounced as was occasionally also the smell of manure. On several occasions the small observation plane got into "gas clouds" that neither could be seen nor had any particular smell but that caused a severe irritation of the mucous membrane resulting in flood of tears.

The activity during the first week or so was not confined to craters. Steam was emitted at many places along the main fissure, and also from smaller more E–W directed fissures cutting the main one. On the other hand, some open fissures that were visited were cold.

Particularly during the first week the three southern craters were characterised by lava fountains. They all were pulsing with greater or less activity. However, lava fountains several hundred m high, and once probably up to 600 m, could go on for hours (see frontispiece). There were often two, three or even four jets of lava in each crater. Lava fountains were never very active in the Trinityberget crater. Here the lavas mostly poured out in streams, filling depressions and flowing out towards the sea.

The following description of the Sigurdbreen crater on October 2 can be taken as a very good example of the volcanic activity during this eruption: Around the Sigurdbreen crater a cone, at least 50 m high on the inner side towards Beerenberg, had been accumulated. The lavas were flowing rather quietly out of a large opening on the north-eastern side of the cone. Suddenly a series of small explosions took place on the south-western side of the cone, and a pulsing lava fountain was quickly developed. Glowing lava was spurted up to 200 m, falling down as plastic cakes and sliding down the cone and the mountain sides. Some of the blocks must have been at least 100 m^3. The more fine-grained material was blown much higher, taking the form of a tephra column. During this sequence the base of the lava fountain increased and became between 50 and 100 m in diameter. Meanwhile grey smoke began to form on the north-east side of the cone and developed into a gigantic ash column. Clouds of glowing ashes were occasionally thrown up inside the ash column. The glowing increased as the "cloud" expanded and could clearly be seen in the afternoon light. At other times similar completely dark "clouds" were emitted. After the eruption had gone on for about one hour, the amount of white steam clouds increased and covered the whole eruption area. However, judging from the noises, the eruption still continued for about three hours before it probably quietened down although the lava fountain was seen again in this crater both on October 9 and 11.

During the events described, lava production increased tremendously and consequently the lava streams rapidly increased in size, forming several branches as they ran down the mountain side. The temperature was determined with pyrometer to be between 1010 and 1030°C.

The lava streams soon acquired the very characteristic form with a darker crust in the middle of the stream and a sharper glow along the sides, caused by the frictional turbulence bringing new lava to the surface.

The lava streams were difficult to observe at the foot of the mountain, and the lava probably mostly ran in tunnels. As far as could be seen, the lavas approached and ran into the sea in two ways. Either the whole lava mass was pro-

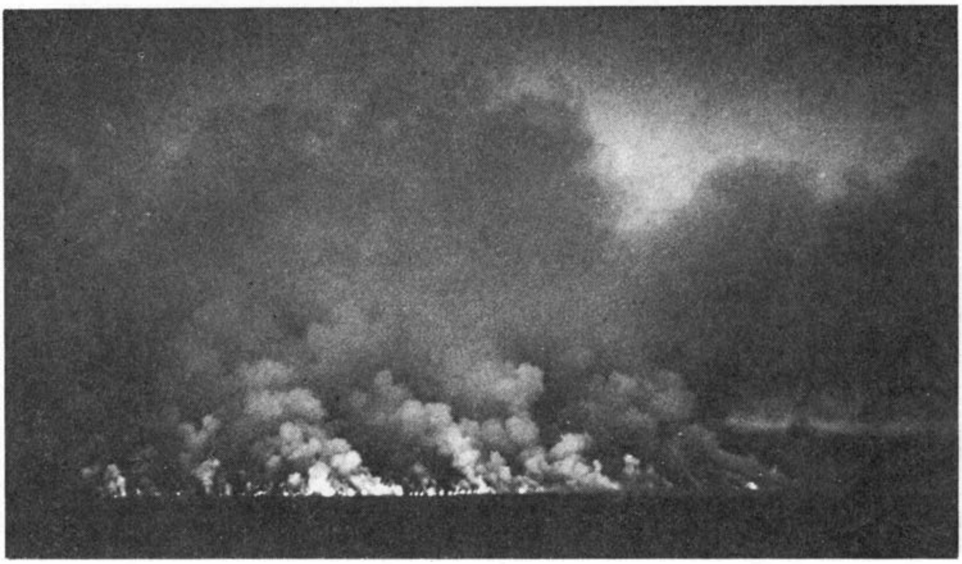

Fig. 5. *A nearly 1 km wide lava front advancing into the sea by breaking through the cooler lava surface.*

truded forward behind a cooler skin of lava, or, at places this skin ruptured and the molten glowing lavas poured directly into the sea (Fig. 5). In some of these cases the temperature was measured to 960–975°C.

The sea boiled and produced great amounts of steam along the lava front. Since the advance of the lava was irregular, there were places where the lava apparently had been cooled down before reaching the sea and thus caused no steam.

The question of how the lava moved along the sea bottom cannot yet be solved. However, there were indications of lava streams moving along the bottom 1,500 m in front of the newly formed lava coast at a water depth of c. 500 m. This assumption is naturally based on echo soundings and depth recordings, but upwelling areas of hot water well in advance of the lava coast is also taken as an indication.

On land the lava flowed rapidly over the vertical cliffs on the mountain side, but gave impression of being fairly viscous. The surface of the flows had the character of an a-a lava type. Usually the top of the lava was covered by blocks mostly 10–50 cm but up to 2 m in diameter. When ruptured, these blocks usually had a porous crust and a more massive, olivine porphyritic core. The blocks thrown out as bombs either exploded when hitting the ground, or deformed plastically, shaping themselves to the ground where they landed.

Seismic events

The earthquakes that initiated the eruption have been mentioned above.

On September 29, a seismic event counter was installed in the middle of the island, about 25 km from the nearest crater and one km from the shore. The instrument was set at a background of waves from a full storm and counted separate shocks 70% above background. Average counting level until October 12 was 600–800 per 24 hours, with variations up to 1450 and down to 200. Unfortunately the instrument broke down during a blizzard in the beginning of November, the last readings indicating 476 shocks per 24 hours.

One is inclined to assume that the shock waves are related to explosions in the upper part of the craters which were seen and heard from the observation boat. At times the explosions were very loud. On the morning of October 2, everyone sleeping onboard M/S «Polarbjørn» were woken by the loud noises even though the ship was more than 5 km north-east of the northernmost crater.

The volume of the effusives

During the whole eruption period the volume of effusives emitted per day, i.e. both pyroclastical material and lavas, showed great variation. For example, the volume of lavas increased in late September/early October; this is well demonstrated in Fig. 4, if one takes into consideration the increasing depth of the sea into which the lavas protruded. As no terrestrial measurements or new bathymetrical maps have been made, it is difficult to give even a rough estimate of the total volume of the effusives, as we have very little information on the gradient of the lava flows in the sea.

By October 14 the lavas and pyroclastics had built up a new land area of more than 4 km² outside the old coast line. The new coast line was mostly at a depth of between 50 and 100 m on the hydrographical map, but in one area it extended out to the 300 m line in the map. An estimate of the volume of the effusives (under the assumption that the gradient of the lava in the sea is c. 45°) gives a figure of the order of 0.5 km³, nearly all made up of lavas. This new land area was apparently at its maximum in the middle of October before erosion began along the new coast line. No continuous tephra cover of any great thickness was observed, except when concentrated by wind and water. However, in the initial explosive phase (probably intensified as the water from the melting glaciers poured into the opening craters) fine material was even injected into the stratosphere and carried for hundreds of kilometers.

Later in the eruption period, when the lava fountains started to puls, a new active phase was usually initiated by explosions forming ash columns and local falls of pumic lapilli. On landing in the sea, these ash falls floated initially, but became slowly soaked with water and started to sink. Tephra clouds, which were slowly settling in the sea in this way, could often be seen on echograms. On land the area covered by tephra was never very large, at most 10 × 10 km. This was probably because of the violent draught of cold air down the snow-covered slopes of Beerenberg and the prevalent westerly winds. Even in the first days of eruption, the areas covered by floating tephra in the ocean east of Jan Mayen were small compared to the volume of the later lava production. At best one can only arrive at a reasoned guess for the amount of pyroclastics deposited outside the lava

Table 2
Analyses of Beerenberg basalts of 1970

	Sample 1	Sample 2
	early, The Dufferin-breen crater	October 3, The Sigurd-breen crater
SiO_2	48.40	45.79
TiO_2	3.20	3.19
Al_2O_3	17.10	16.21
Fe_2O_3	4.33	2.22
FeO	7.89	8.59
MnO	0.23	0.23
MgO	4.99	5.89
CaO	9.10	10.57
Na_2O	3.07	3.66
K_2O	2.69	2.68
H_2O		0.38
CO_2		0.22
P_2O_5		0.26
Total	101.00	99.89

covered area; on the basis of all available information, I would suggest that the volume is only equivalent to 0.025^3 km of lavas, i.e. it constitutes 5% of the suggested total volume of extrusives.

The lavas

According to a preliminary examination, lavas sampled both from the northernmost and the southernmost craters seem to be of the same lithology as those earlier described as Beerenberg basalts. Darker pyroxene and lighter olivine phenocrysts occur together with some intermediate plagioclase in a fine-grained basalt matrix. The new lavas are also very similar to the older ones in thin section. It is evident that there are two or three generations of crystallisation with more and more anorthitic plagioclases. Earlier fissure eruptions on north-east Jan Mayen (ROBERTS and HAWKINS 1971) were characterized by potash-rich basalts with pyroclastic material and viscous lava flows in the early phase of the eruption. This was followed by hotter and more ordinary basalts until eruption ceased. Two typical chemical analyses are given in Table 2. Sample 1 is from a lava stream from the Dufferinbreen crater one of the first days, and sample 2 is pyroclastic material from the eruption of the Sigurdbreen crater in the morning of October 3.

A more detailed description of the mineralogy and petrography of the lavas is given by WEIGAND (1971, this vol., pp. 42–52).

Later events and observations

During the winter no observations of the area of eruption were made.

The crew of the Jan Mayen station reported in March 1971 that clouds and ash columns had again appeared above Beerenberg. Unfortunately it was impossible at that time to make any direct observations of the eruption area. A little later a passing ship reported heavy steam clouds 1–1.5 km south of the Dufferinbreen crater.

The author did not get the opportunity to observe the area from the air before April 28. There was still some activity in the Skrukkelia and Sigurdbreen craters, with bluish-grey columns of dust-laden volcanic gases. White vapour clouds were seen everywhere, but no lavas or glowing gases were visible in the bright daylight. The area around the Dufferinbreen crater and farther south was obscured by clouds. When returning the next day, it was more cloudy but a well developed fissure in the glacier south of Dufferinbreen could be seen through a break in the cloud; it could also be seen that warm water had cut its way down Frielebreen.

A new visit on June 10 gave the information that gases were still being emitted from the Dufferinbreen crater and the two other craters but these were more quiet than in April.

There were reports from the station of a smoke column on June 8, which lasted for more than an hour and was higher than Beerenberg. Smaller columns were not uncommon. Another new development was that, since an earthquake in March, clouds could occasionally be seen on Eggøya, the old crater at the southern foot of Beerenberg. Tephra from this eruption had been collected and, as they are completely ungraded, the possibility of long transport from the northern eruption area seems small. More probably there may have been secondary eruptions of tephra, caused by gases blowing out through old ash layers in the strato-volcanic cone of Eggøya. Hot gases, with a temperature of 62°C, escaped from 5–10 cm wide fissures in the top of Eggøya.

(In 1935–36 it was quite common for the crew that wintered near Eggøya to see irregular outbursts of steam from this island, usually about 50 m high (WESTERN, pers. comm.). During the same period earthquakes were frequent and some damage was done to the meteorological station.)

The most recent information from Jan Mayen concerns movements of the ground, although these are not properly confirmed by reference to bench-marks. On the other hand, such movements would be expected to occur in a volcanic area.

Acknowledgements

The field work on Jan Mayen was also conducted by geologist BOYE FLOOD from September 21 to 29. Before he left for Tasmania in the early winter, we discussed this paper and he placed all his information and notes at my disposal, and for this he is most heartfully thanked. For stimulating conversations with Prof. CHR. OFTEDAHL I am very thankful.

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Literature

ANDERSON, J., 1746: *Nachrichten von Island, Grönland und der Strasse Davis.* Hamburg.

BOLDVA, A. B. VON, 1886: Österreich. Polarexpedition Jan Mayen 1882–83. *Beobachtungs-Ergebnisse.* **1.** Wien.

CARSTENS, H., 1961: Cristobalite-trachytes of Jan Mayen. *Norsk Polarinst. Skr.* Nr. 121. Oslo.

— 1962: Lavas of the southern part of Jan Mayen. *Norsk Polarinst. Årbok* 1961, 69–82. Oslo.

FITCH, F. J., 1964: The development of the Beerenberg volcano, Jan Mayen. *Proc. Geol. Ass.* **75.** 133–165. Colchester.

FITCH, F. J., D. L. GRASTY and J. A. MILLER, 1965a: Potassium-argon ages of rocks from Jan Mayen and an outline of its volcanic history. *Nature.* **207,** 1349–1351. London.

FITCH, F. J., A.E.M. NAIRN and C. J. TALBOT, 1965b: Palaeomagnetic studies on rocks from North Jan Mayen. *Norsk Polarinst. Årbok* 1963. Oslo.

GJELSVIK, T., 1970: Volcano on Jan Mayen alive again. *Nature.* **228.** London.

GUTENBERG, B., and C. F. RICHTER, 1954: Seismicity of the Earth. *Princeton University Press.*

HEEZEN, B. C., and M. EWING, 1961: The Mid-Oceanic Ridge and its extension through the Arctic Basin. In: *The geology of the Arctic.* **I,** 622–642. Toronto.

HEEZEN, B. C., M. THARP and M. EWING, 1959: The floors of the oceans. 1. The North Atlantic. *Geol. Soc. Amer. Special Paper.* **65,** 1–122. New York.

JOHNSON, G. L., 1968: Marine geology in the environs of Jan Mayen. *Norsk Polarinst. Årbok* 1966. 105–111. Oslo.

JOHNSON, G. L., and B. C. HEEZEN, 1967: Morphology and evolution of the Norwegian and Greenland Sea. *Deep-sea Res.* **14,** 755–771.

KOLDERUP, N.-H. og A. KVALE, 1938: Jordskjelvet på Jan Mayen 26. oktober 1936 og seismikken i Norskehavet og Nordsjøen. *Bergens Mus. Årbok* 1938. Nat.rekke nr. 3. Bergen.

NICHOLLS, G. D., 1955: The Geology of North-east Jan Mayen. *Geol. Mag.* 69, 186–200. London.

NORSK POLARINSTITUTT, 1959: *Map of Jan Mayen,* 1: 50,000. Oslo.

ORVIN, A. K., 1960: The place-names of Jan Mayen. *Norsk Polarinst. Skr.* Nr. 120. Oslo.

ROBERTS, B. and T. R. W. HAWKINS, 1965: The geology of the area around Nordkapp, Jan Mayen. *Norsk Polarinst. Årbok* 1963. 25–48. Oslo.

— 1971: The petrology of the volcanic and intrusive rocks of Nord-Jan, Jan Mayen. *Norsk Polarinst. Årbok* 1970 (this vol.). Oslo.

SCORESBY, W., 1820: *An Account of the Arctic Regions.* **1.** 154–169. Edinburgh.

SYKES, L. R., 1965: The seismicity of the Arctic. *Bull. Seism. Soc. Am.* **55,** 501–518.

TYRELL, G. W., 1926: The petrography of Jan Mayen. *Trans. Roy. Soc. Edinb.* **54,** 747–756. Edinburgh.

WEIGAND, P. W., 19xx: Bulk-rock and mineral chemistry of Recent Jan Mayen basalts. *Norsk Polarinst. Årbok* 1970 (this vol.). Oslo.

WORDIE, J. M., 1922: Jan Mayen Island. *Geographical Journ.* London.

— 1926: The geology of Jan Mayen. *Trans. Roy. Soc. Edinb.* **54,** 741–745. Edinburgh.