Focal Mechanism of Volcanic Earthquakes *

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Abstract

The focal mechanism solutions for Type A volcanic earthquakes connected with eruptions of the Miake-sima, Tori-shima (Japan) and Beerenberg (Jan Mayen Island) volcanoes are presented. All the considered volcanic earthquakes show focal mechanism of the strike-slip type of faulting. Stresses acting in the volcanic earthquake foci can well be attributed to the regional stress systems.

Introduction

Earthquakes are called volcanic if they are associated regionally and genetically with volcanic eruptions, and with generation and movement of magma. There are several types of volcanic earthquakes (MINAKAMI, 1960; TOKAREV, 1966). In this paper it will be considered the focal mechanism of volcanic earthquakes of Type A according to Minakami's classification, which includes earthquakes generating near the volcano at depths from 0 to 10 km. These earthquakes usually anticipate eruptions but sometimes also occur during the initial eruptive phase.

Research on the shift mechanism at the foci of volcanic earthquakes is an interesting but poorly studied problem of seismology and volcanology. So far, works on this subject have been rare and mainly of qualitative nature.

A number of volcanological and seismological reports on the eruptions of different volcanoes (MINAKAMI, 1964; WADA and SUDO,

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TABLE 1 - Focal Mechanism Parameters of Volcanic Earthquakes.

No.	Date	Time	Focal Depth km	M	Compressive Stress Az°	Compressive Stress e°	Tension Stress Az°	Tension Stress e°	Intermediate Stress Az°	Intermediate Stress e°	Nodal Surface I Az°	Nodal Surface I e°	Nodal Surface I α°	Nodal Surface II Az°	Nodal Surface II e°	Nodal Surface II α°
								Miake-sima Volcano								
1.	May 5, 1962	11h11′	0	5.8	310	10	40	5	130	80	355	85W	85	265	85N	275
	—	—	33	—	295	5	25	5	160	85	340	90	90	250	85NNW	270
2.	Aug. 26, 1962	06h48′	0	5.9	295	15	30	15	160	70	345	90	90	255	70NNW	270
	—	—	33	—	295	25	30	20	160	60	345	85WSW	85	255	60NNW	275
3.	Aug. 26, 1962	22h35′	0	5.2	120	5	25	20	215	70	345	75ENE	275	70	80NNW	85
	—	—	33	—	300	20	35	10	145	65	350	80WSW	85	260	65NNW	275
4.	Aug. 29, 1962	20h20′	0	5.2	120	5	30	20	215	75	345	75ENE	275	75	80NNW	85
	—	—	33	—	135	5	45	20	230	70	5	80E	270	90	80N	90
5.	Aug. 29, 1962	22h36′	0	5.8	155	10	65	5	310	80	200	80ESE	90	110	85SSW	270
	—	—	33	—	155	15	65	5	305	75	195	75ESE	90	110	85SSW	270
								Tori-shima Volcano								
6.	Nov. 12, 1965	17h52′	0	6.2	280	20	190	5	100	70	240	75NW	270	320	75SW	90
								Beerenberg Volcano								
7.	Sept. 18, 1970	02h06′	33	5.0	115	10	200	15	360	75	335	85WSW	90	245	75SSE	270

Az° = azimuth; e° = angle with the horizontal surface; α° = angle between the movement direction on the rupture plane and the direction of the incidence plane.

1967; ADAMS and DIBBLE, 1967; TOKAREV *et al.*, 1968; etc.) include analyses of distribution of the P-wave first motions from volcanic earthquakes. However, since most of the volcanic earthquakes only reach magnitude 4 and have, as a rule, a focus close to the surface, the records taken by a small number of seismic stations show rather indistinct arrivals. Therefore the data obtained do not often give the possibility to evaluate the focal mechanism in a simple way. In those cases when some conclusions are drawn they are often based on insufficient ground.

This paper presents the results of the focal mechanism determination of volcanic earthquakes connected with the formation of subordinate vents in the Miake-sima volcano in 1962, with the submarine eruption of the Tori-shima volcano in 1965, and with the preparatory phase of the Beerenberg volcano eruption on Jan Mayen Island in 1970. Focal mechanism solutions were obtained following the Vvedenskaya's method (VVEDENSKAYA, 1969). The author used data on P-wave first motions recorded at the seismic stations of Kamchatka and at other Soviet and foreign stations as reported in several bulletins (1). For each earthquake the following parameters have been determined: 1) the axis of compressive stress, *i*; 2) the axis of tension stress, *k*; 3) possible rupture surfaces, I and II, in the earthquake foci.

Each individual case will be examined.

Analysis of Focal Mechanisms of Various Volcanic Earthquakes

Miake-sima Volcano

Miake-sima volcano (Japan) is located in one of the islands of the Izu arc. The Miake-sima eruption took place on August 24, 1962 at 22h20′ GMT. As a result of the eruption a chain of craters formed along a radiating crack on the northeastern slope of the central crater (Fig. 1). The eruption ended by August 26, small hours, *i.e.* it lasted less than 48 hours.

(1) *Operative Bulletin of the Institute of Physics of the Earth*, USSR Academy of Sciences; *Earthquake Data Reports*, U. S. Coast and Geodetic Survey; *B.I.S.C. Issues*, Edinburgh; *Seismological Bulletin of the Japan Meteorological Agency*.

Two swarms of volcanic earthquakes connected with this eruption were observed. The first swarm occurred in May-July, 1962, a few months before the eruption; the second swarm started about 5 hours after the beginning of the eruption. These volcanic earthquakes were rather strong and some of them reached magnitude 5.5-5.9 (J.M.A.) (MINAKAMI, 1964).

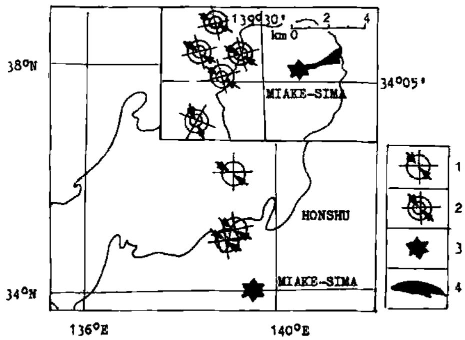
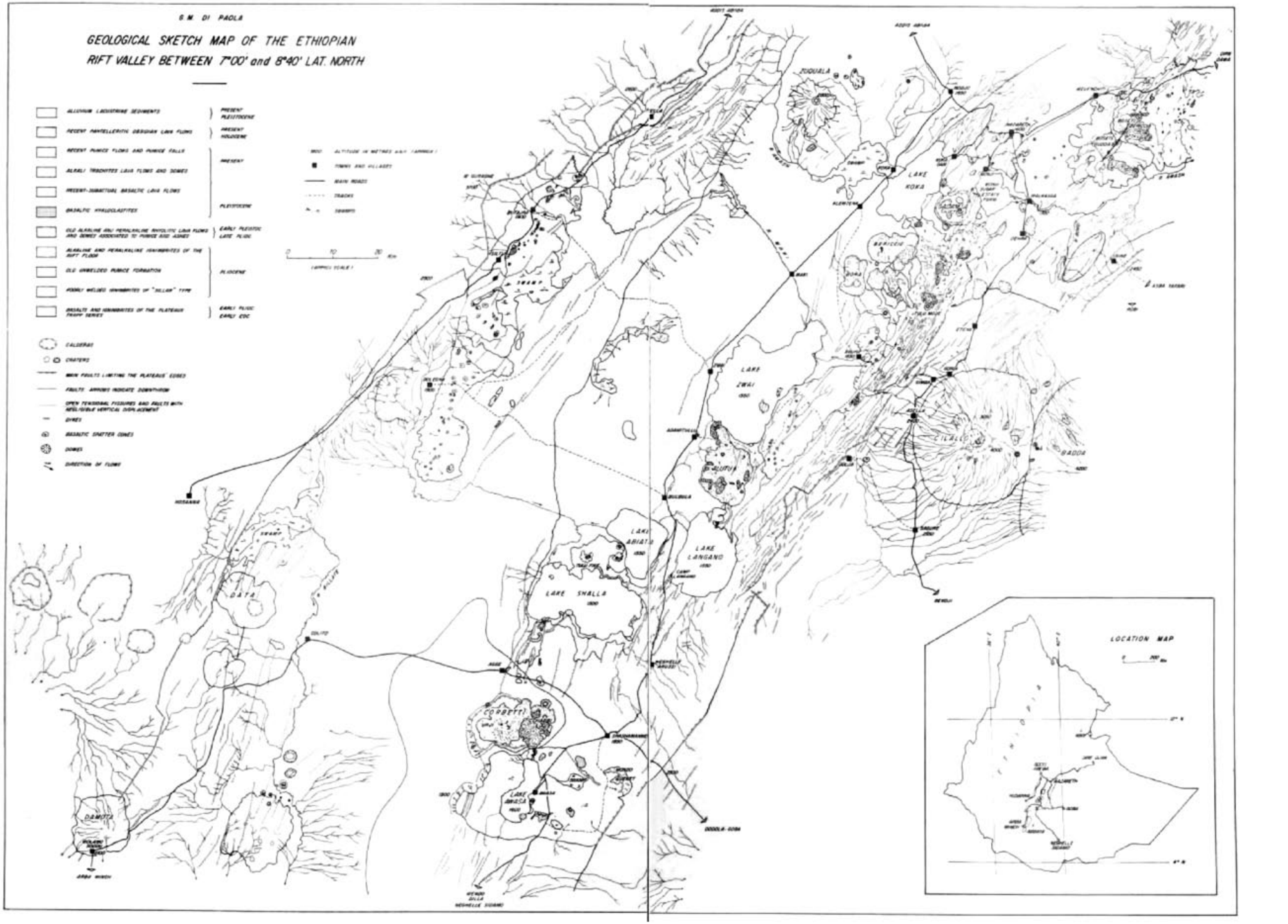


FIG. 1 - Epicenters of volcanic earthquakes at Miake-sima volcano.
1 - Compressive stresses in the foci of tectonic earthquakes (after HONDA *et al.*, 1952); 2 - Compressive stresses in the foci of volcanic earthquakes; 3 - Volcanic cone; 4 - Chain of volcanic craters.

For an earthquake of the May, 1962 swarm and for four earthquakes of the August, 1962 swarm nodal surfaces have been constructed. The constructions on the Wulff net were made for depths 0 and 33 km (Fig. 2). The main data and the focal mechanism parameters of these earthquakes are given in Table 1.

All five earthquakes have a similar focal mechanism close to a strike-slip type of faulting. Axes of compressive and tension stresses are nearly horizontal. The possible rupture surfaces are oriented nearly E-W and N-S. One of the two possible rupture surfaces coincides in azimuth with the orientation of the chain of craters.

It must be pointed out that our results differ from those of MINAKAMI (1964), who suggested a different mechanism for the May and August swarms. Minakami believes that the focal mechanism of most of the earthquakes of the August swarm may be interpreted as a special mechanism consisting of a single negative source and an ordinary mechanism (quadrant type or cone type). However, this conclusion is evidently erroneous, in any case, for strong earthquakes. In fact, Minakami used for the analysis only the data from seismic


G.M. DI PAOLA
GEOLOGICAL SKETCH MAP OF THE ETHIOPIAN
RIFT VALLEY BETWEEN 7°00' and 8°40' LAT. NORTH
ALLUVIUM LACUSTRINE SEDIMENTS
PRESENT PLEISTOCENE
RECENT PANTELLERITIC OBSIDIAN LAVA FLOWS
PRESENT HOLOCENE
RECENT PUMICE FLOWS AND PUMICE FALLS
PRESENT
ALKALI TRACHYTES LAVA FLOWS AND DOMES
BASALTIC HYALOCLASTITES
PLEISTOCENE
EARLY PLEISTOC
LATE PLIOC
OLD UNWELDED PUMICE FORMATION
PLIOCENE
EARLY PLIOC
EARLY EOC
CALDERAS
CRATERS
MAIN FAULTS LIMITING THE PLATEAUS' EDGES
FAULTS: ARROWS INDICATE DOWNTHROW
OPEN TENSIONAL FISSURES AND FAULTS WITH NEGLIGIBLE VERTICAL DISPLACEMENT
DYKES
BASALTIC SPATTER CONES
DOMES
DIRECTION OF FLOWS
TOWNS AND VILLAGES
MAIN ROADS
TRACKS
SWAMPS
ZUQUALA
LAKE KOKA
LAKE ZWAI
LAKE LANGANO
LAKE ABIATA
LAKE SHALLA
LAKE AWASA
CORBETTI
CILALO
BADDA
DAMOTA
HOSANNA
LOCATION MAP

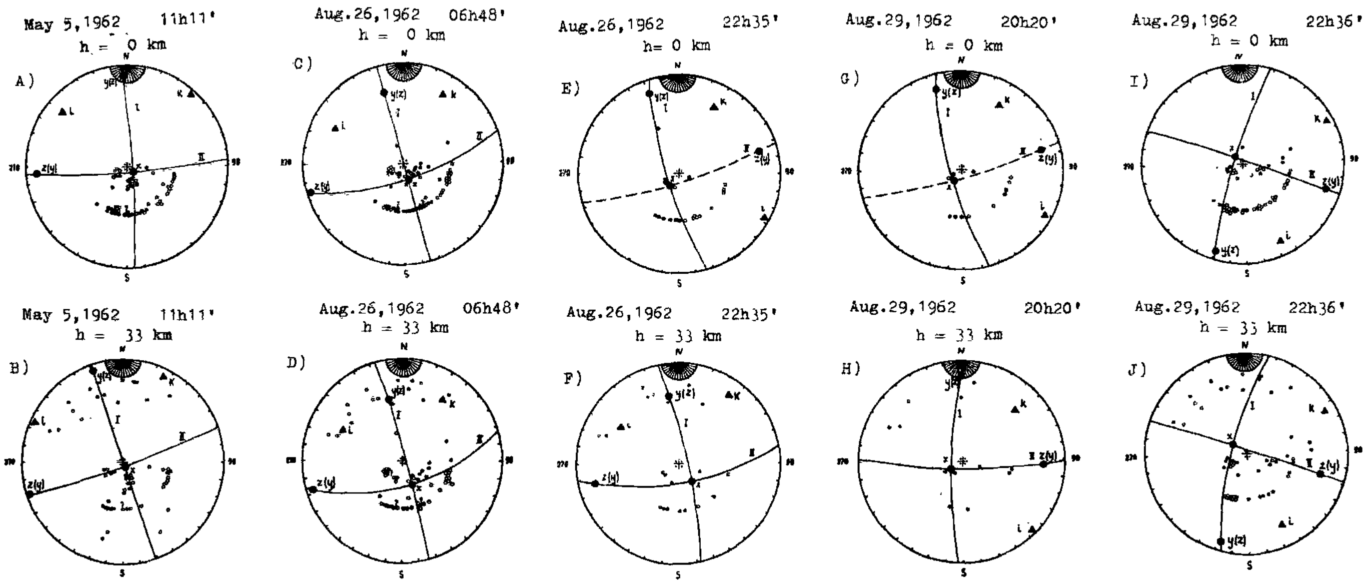


FIG. 2 - Focal mechanism solutions for the volcanic earthquakes of Miake-sima volcano.
Solid circles = Compressions; Open circles = Tensions; i = axis of compressive stress; k = axis of tension stress; I-II = possible rupture surfaces.

stations in Japan, which, for the considered swarm, are within one quadrant including only rarefaction waves.

ICHIKAWA (1970) considered in detail the focal mechanism of the tectonic earthquakes of the Izu peninsula-Izu islands, and reported the regions where orientation of stresses was stable for the period 1926-1966. The Miake-sima island is just in one of these regions.

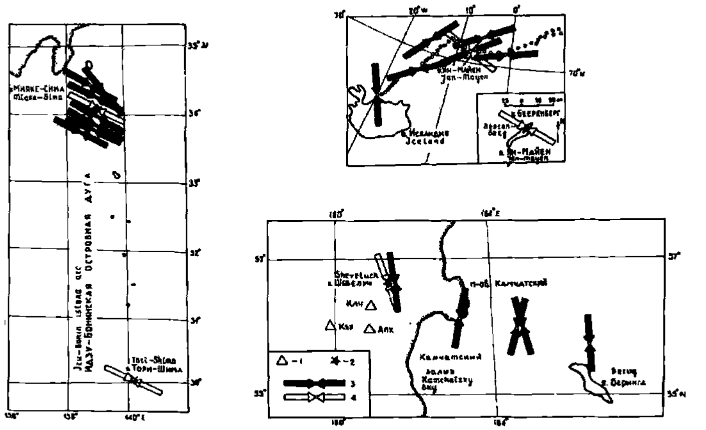


FIG. 3 - Compressive stresses in the foci of volcanic and tectonic earthquakes in volcanic regions.
1 - Seismostations; 2 - Volcanic cones; 3 - Compressive stress in the foci of tectonic earthquakes; 4 - Compressive stress in the foci of volcanic earthquakes.

On the basis of data on 30 earthquakes we can consider $321^\circ \pm 5.5^\circ$ to be the mean orientation of the axis of compressive stress for this region. This value is close to our determinations for volcanic earthquakes.

Figure 3 shows that compressive stresses in volcanic earthquake foci can well be attributed to the regional stress system. Thus, the focal mechanism of volcanic and tectonic earthquakes is similar.

Tori-shima Volcano

Tori-shima volcano (Japan) is located on the homonymous island at the southern end of the Izu-Bonin island arc.

On November 12, 1965 a submarine volcanic eruption took place preceded and accompanied by an intensive earthquake swarm (NORRIS and JOHNSON, 1969). This eruption occurred 1.5 km SW of the island (Fig. 4).

We have studied the mechanism of the strongest earthquake of this swarm, observed on November 12 at 17h52′ ($M = 6.2$).

Seventy-six stations reported the data on the first motions of P-waves and made it possible to construct two nodal surfaces for depths 0 and 33 km (Fig. 5). The focal mechanism parameters (Table 1) show that the compressive and tension stresses were nearly hori-

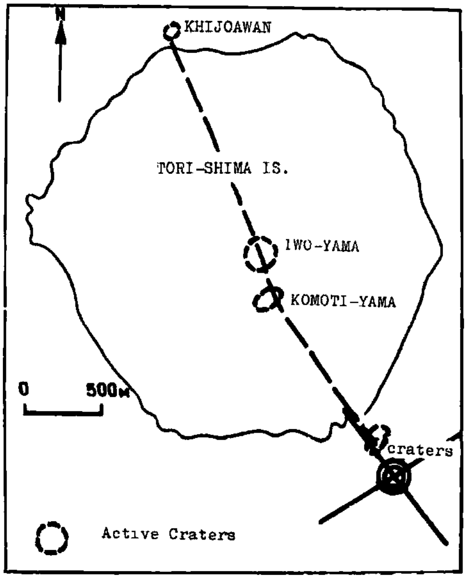


FIG. 4 - Active craters of Tori-shima volcano and the possible rupture surfaces (cross cutting the double open circle) in the focus of volcanic earthquakes.

zontal and were typical of this focus. The focal mechanism can be modelled by a strike-slip type of faulting.

It must be emphasized that one of the two possible rupture surfaces at the focus of the volcanic earthquakes coincided in strike with the line of active craters of the volcano (see Fig. 4). This fact learly indicates the presence of a volcanogenous fault just where the active craters are located.

According to ICHIKAWA (1970) the focal mechanism of the volcanic earthquakes of the Tori-shima volcano is similar to that of the tectonic earthquakes of the Izu arc region and has the characteristics of the regional tectonics (Fig. 3). Also KATSUMATA and SYKES (1969) have studied the focal mechanism of this earthquake swarm. However, they used only the data given by the WWSSN long-period seismograms, and their results differ from ours (Fig. 5).

Beerenberg Volcano

Beerenberg volcano (Jan Mayen Island) is located in the rift arctic zone.

According to the Smithsonian Institution Center for Short-lived Phenomena, the first displays of activity were observed on Sept. 19,

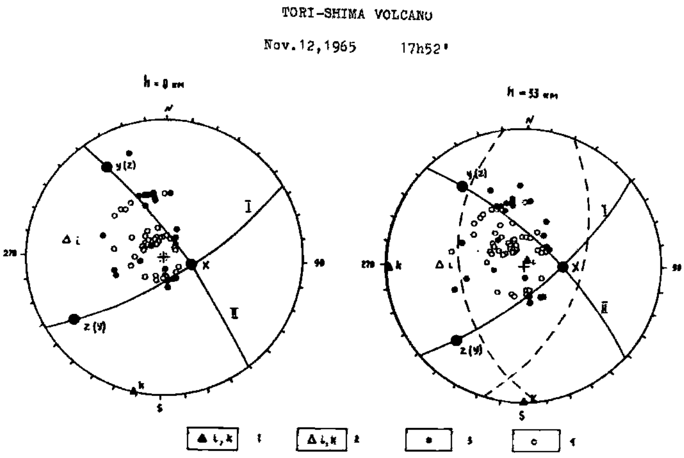


FIG. 5 - Focal mechanism solutions for the volcanic earthquakes of Tori-shima volcano. 1 - stress axes after KATSUMATA and SYKES (1969); 2 - stress axes according to the present author; 3 - compressions; 4 - tensions; dashed lines = focal mechanism solutions after KATSUMATA and SYKES (1969).

1970 at 10h00′ along the 6 km long fault at the northeastern slope of the volcano in the NE-SW direction. There are 6 craters on the fault from which lava emission occurred. By October 4th, 3 km² of lava were emitted. Besides lava, a certain amount of pumice and ash was also ejected.

High seismic activity was observed before and during the eruption. By October 12, 1970, 600-800 shocks in 24 hours occurred on average.

The strongest earthquake of the swarm was associated with the beginning of the eruption. Its intensity was III-IV on Jan Mayen island, and its magnitude was 5.0 (average value between the U.S.A. and the U.S.S.R. data). Construction of nodal surfaces was made using the data from 20 stations (Fig. 6). The main data on this earthquake and the focal mechanism parameters are given in Table 1. Judging by these data the axes of compressive and tension stresses are nearly horizontal. Possible rupture surfaces are nearly vertical and directed along NE-SW and NW-SE, respectively. The focal mechanism is close to a strike-slip type of faulting.

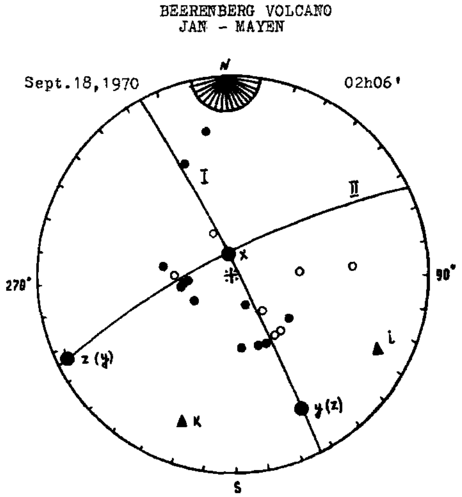


FIG. 6 - Focal mechanism solution for the volcanic earthquake of Beerenberg volcano, Jan Mayen island.
Solid circles = compression; Open circles = tension; i = axis of compressive stress; k = axis of tension stress; I-II = possible rupture surfaces.

It must be emphasized that the chain of six craters from which lava erupted, corresponds to the NE-SW fault on the northeastern flank of the volcano. One of the two possible rupture surfaces coincides with the fault plane at the focus of the volcanic earthquakes.

The focal mechanism of the tectonic earthquakes of the arctic region was analyzed by MISHARINA (1967), who concluded that the regional foci are characterized by the nearly horizontal orientation of the axes of compressive and tension stresses. The focal mechanism of these tectonic earthquakes is close to a horizontal shifting. Compressive stress axes are oriented along the strike of the epicenters line.

One can see that the focal mechanism of the volcanic earthquake is similar to that of the tectonic earthquakes. The compressive stress axis lies along the strike of the epicenters line, constructed according to SYKES (1965), and reflects very closely the regional stress system (Fig. 3).

Sheveluch Volcano

The eruption of Sheveluch volcano (Kamchatka) occurred in November, 1964. The focal mechanism of the Sheveluch strong volcanic earthquakes was discussed in a previous paper by the present author (ZOBIN, 1971). This mechanism was a strike-slip type of faulting.

Comparing the obtained system of stresses at the foci of the volcanic earthquakes with the system of stresses of the Kamchatsky Cape peninsula typical of this region of Kamchatka, it is found that compressive stresses at the foci of the volcanic earthquakes follow closely the regional stress system (Fig. 3).

Conclusions

The above data make it possible to draw the following conclusions on the focal mechanism of volcanic earthquakes and its correlation with the regional systems of tectonic stresses.

1. All the considered volcanic earthquakes (Type A) with magnitude 5-6.2 show a focal mechanism of the strike-slip type of faulting.

2. The focal mechanism of strong volcanic earthquakes is similar to that of tectonic earthquakes in the region, and is evidently related to the regional stress system.

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