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3. *Ocean Bottom Seismometer Study on the Seismic Activity in the Mariana Island Arc Region.*

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Abstract

Using OBS's (ocean bottom seismometers) and island based stations, microearthquake observations were conducted in the Mariana island arc region during July and August, 1973 and again during January and February, 1976. Although microearthquake activity was very high along the Mariana island arc, no local earthquakes were detected within the Mariana basin. A few local earthquakes from the Caroline Islands region were recorded. Seismic activity was particularly high around the island of Guam towards the southwestern Mariana area, whereas very few earthquakes occurred around the island of Saipan. Hypocenters were determined for 40 events, only two of which were reported by the Earthquake Data Report (EDR). An analysis of earthquake hypocenters in the Mariana region determined from this study delineates distinct active seismic elements of this area. These are, (a) shallow earthquakes ($h<70$ km) under the trench slope break along the trench axis, (b) intermediate earthquakes ($70 \leqq h<210$ km) under the Mariana ridge axis, (c) shallow earthquakes ($h<70$ km) around the terminus of the Mariana ridge, extending from southeast to southwest off Guam Island. A close correlation exists between the hypocenter distribution and bathymetric features such as the ridge axis and the trench slope break, implying that these tectonic elements are active. Long term data from ISC regional catalogue show that they are associated with several major tectonical elements of this island arc system. High sensitivity microearthquake observations also revealed that earthquake activity occurred at several places in a wide region along the Mariana island arc, and included two swarms and intermediate earthquakes. The temporal pattern of these observations suggests that a broad region was tectonically activated as a whole almost simultaneously, a process that we have called "regional activation".

Introduction

The Mariana island arc-trench system is a typical active mid-ocean island arc-trench system (KARIG, 1971a, b), and is situated in the middle of the west Pacific Ocean. Because it lies more than two thousand km from the nearest continental margin, it is considered to be free from the complicating influence of the continent. Thus the Mariana region may be regarded as an especially suitable place to study the dynamics of the island arc-trench system.

To delineate the presently active seismotectonic elements, microearthquake observations were conducted twice in the Mariana region during July and August, 1973 and January and February, 1976, along with the OBS (ocean bottom seismometer) long range experiments in the Mariana basin (ASADA and SHIMAMURA, 1976 ; NAGUMO et al., 1981). In addition to the OBS array deployed upon the Mariana basin, island-based stations were placed on the islands of Guam, Saipan and Marcus. Since the observation periods were of limited duration, data from the Bulletin of the International Seismological Centre (ISC) (January, 1964-June, 1974) and the Earthquake Data Report (EDR) of U. S. Geological Survey (USGS) (August, 1975-July, 1976) were used for studying long term features of the seismicity.

This paper reports several interesing features of the microearthquake activity in the Mariana island arc-trench system. It was found that the microearthquake activity was very high and that the distribution of the earthquakes seems to be divided into several groups which seem to be correlated to the tectonic elements.

Previously, the seismicity in this region has been studied by using data of the U. S. Coast and Geodetic Survey (USCGS) and the Japan Meteorological Agency (JMA) (KATSUMATA and SYKES, 1969 ; SANTO, 1969 ; BRACEY and OGDEN, 1972). A preliminary report on the microearthquake observations discussed here has been reported by NAGUMO and KASAHARA (1976). As regards the usage of geological terminology, we followed KARIG's papers (1971a, b ; 1975).

Field Operation

During the first observation in 1973, one OBS station (St-5) was deployed in the middle of the Mariana basin, and the other station was placed at the Santa Rosa WWSSN station on Guam Island (Fig. 1 and Table 1). During the second observation in 1976, 5 OBS stations were

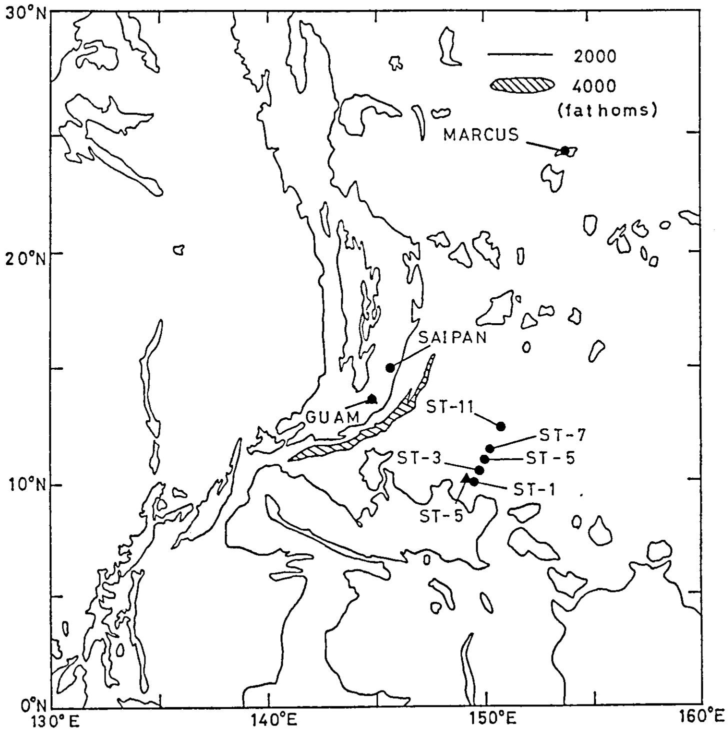

Fig. 1. Bathymetric map of the Mariana region showing locations of ocean bottom seismographs (solid triangles; experiment in July—August, 1973, and solid circles; experiment in January—February, 1976) and island based stations. In 1973, an island based station was placed only on the island of Gaum.

Table 1. Locations and observation periods of the OBS stations in the Mariana basin and island based stations on Guam, Saipan and Marcus.

Station	Location		Altitude	Observation Period	
	Lat. (N)	Long. (E)	(m)	from	to
1973					
St-5	10°11′7	149°16′7	−5585	July 18 10: 30~	Aug. 2 09: 30
Guam Is.	13°32′3	144°54′7	230	July 13 14: 00~	Aug. 5 13: 30
1976					
St-1	10°00′3	149°29′6	−5550	Jan. 22 17: 20~	Jan. 25 12: 00
St-3	10°28′2	149°44′2	−5750	Jan. 22 13: 50~	Jan. 31 09: 00
St-5	10°58′5	149°59′4	−5810	Jan. 21 17: 50~	Jan. 30 09: 10
St-7	11°25′3	150°13′1	−5865	Jan. 22 13: 50~	Jan. 27 10: 20
St-11	12°24′3	150°45′4	−5930	Jan. 20 13: 30~	Jan. 28 10: 40
Guam Is.	13°32′3	144°54′7	230	Jan. 8 16: 40~	Feb. 4 09: 40
Saipan Is.	15°04′8	145°46′4	60	Jan. 9 15: 00~	Feb. 3 14: 40
Marcus Is.	24°17′	153°58′	2	Jan. 8 22: 00~	Feb. 4 15: 20

deployed in the Mariana basin and 3 island-based stations were placed on Guam, Saipan and Marcus Islands (Fig. 1 and Table 1).

An anchored buoy system was used for mooring the OBS's (NAGUMO and KASAHARA, 1976) except at St-1 in 1976 where a free fall pop-up type OBS was used. The recording units of the OBS's and the island-based stations were composed of vertical and horizontal component geophones, amplifiers, 4 channel recorder and a crystal clock. Geophones with natural frequency of 1 Hz were used at St-5 in 1973 and at St-3 in 1976. At other stations, geophones with natural frequency of 4.5 Hz were used for both vertical and horizontal components. Open reel type direct recording (DR) tape recorders (NAGUMO et al., 1970) which allowed 1000 hours of recording were used for OBS at St-5 in 1973, and for the island-based stations, and for St-3 in 1976. Cassette type DR tape recorders allowing 300 hours of recording were used at the other stations. The overall frequency characteristics of these instruments are shown in Fig. 2.

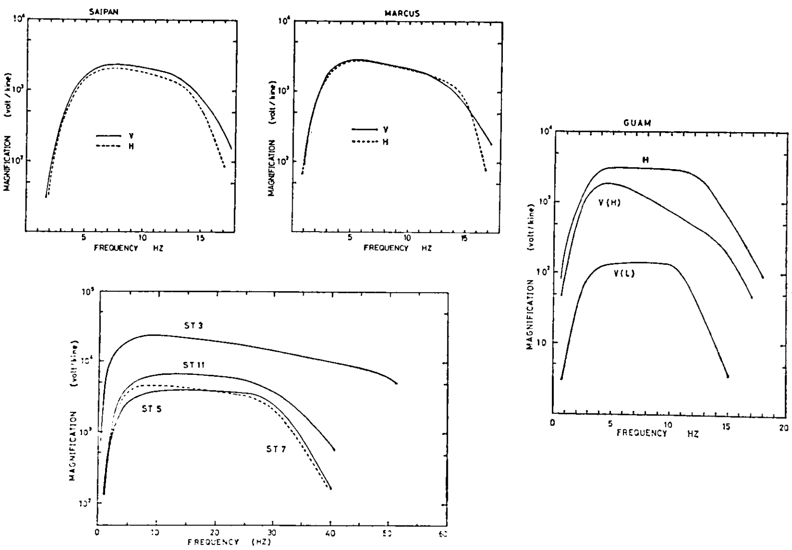

Fig. 2. Frequency characteristics of the OBS's and the island based stations (1976).

Seismicity in the Mariana Region

[A] Mariana Basin (St-5 in 1973 and St-3 in 1976)

During 15 days of OBS observation at St-5, in the middle of the Mariana basin about 600 km southeast of Guam, we recorded 78 events or about 5.2 events/day. At station St-3, we recorded 205 events during a 9 day period in 1976, or about 23.3 events/day. This includes all events with velocity amplitude of 20 μ cm/sec or higher. Histograms of numbers of events recorded with various S-P times (Fig. 3) indicate that earthquakes with S-P times between 50 and 70 seconds are the most common. Apparently these events occur along the Mariana arc-trench region. The level of the seismicity is very high, as high as in the Sanriku region, around the Japan trench, northeast of Japan (NAGUMO et al., 1976). No earthquakes were detected within a S-P time range 10 seconds, and this suggests that no earthquakes occurred in the Mariana basin. Since the background noise levels were as low as 4-7 μ cm/sec at about 1 Hz in the basin, it is quite certain that no local earthquakes of magnitude above about 1 occurred within about 100 km of the OBS stations in the Mariana basin. The earthquakes whose S-P times were between 10 and 40 seconds probably occurred in the Caroline Islands region.

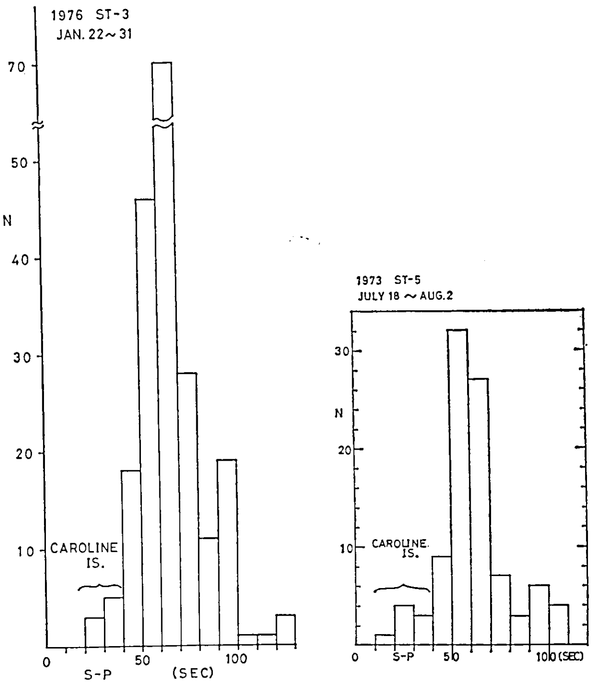

Fig. 3. S-P histograms of earthquakes recorded at OBS St-3 (1976) and OBS St-5 (1973).

[B] Guam Island

At Guam, a total of 336 shocks or 22.4 events/day were registered during 15 days observation in the summer of 1973 and a total of 473 shocks or 17.3 events/day during 27 days in the winter of 1976 (Fig. 4). The detection levels were 20 μ cm/sec minimum velocity amplitude in 1973

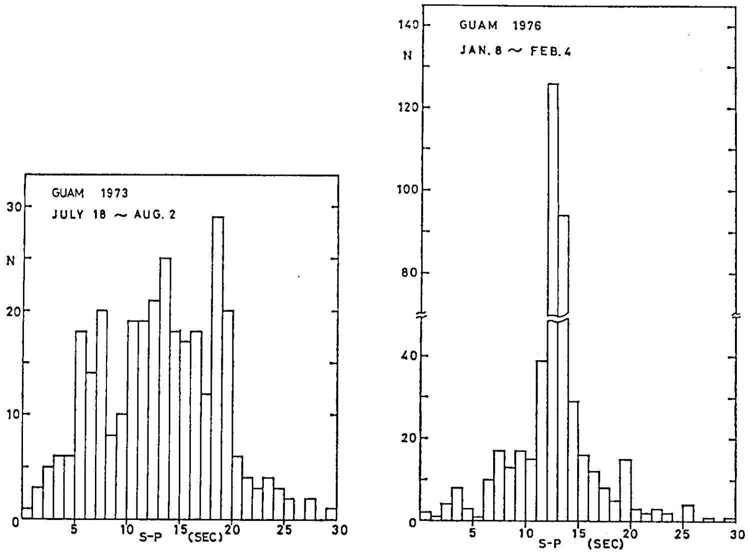

Fig. 4. S-P histograms of microearthquakes registered at Guam seimograph station. Left, July 18 to August 2, 1973; right, January 8 to February 4, 1976.

and 30 μ cm/sec in 1976. The level of the microearthquake activity was very high. The broad distribution of S-P times (5 to 20 seconds) suggests that the microearthquakes were occurring in a wide region around Guam. The predominant peak (12-14 seconds) in the S-P distribution in 1976 is caused by the swarm activity which occurred to the southwest of Guam and which will be discussed in a later section. Most of the earthquakes with S-P times in the range from 10 to 20 seconds may have occurred along the Mariana volcanic ridge and the marginal escarpment of the Mariana trench. A number of events occurred with S-P times smaller than 5 seconds. These earthquakes must have occured just below and/or very close to Guam.

[C] Saipan Island

A total of 64 shocks or 2.6 events/day was detected during 24 days of observation at Saipan from January 9 to February 3, 1976 (Fig. 5). During this time, the background noise was relatively high, or about 20 μ cm/sec. The S-P time distribution has no sharp peak between about 10 and 40 seconds, suggesting that the activity was not localized. No earthquakes were detected with S-P times smaller than 9 seconds during the 24-day observation period, suggesting that the rate of microearthquake activity in the immediate vicinity of Saipan is very low.

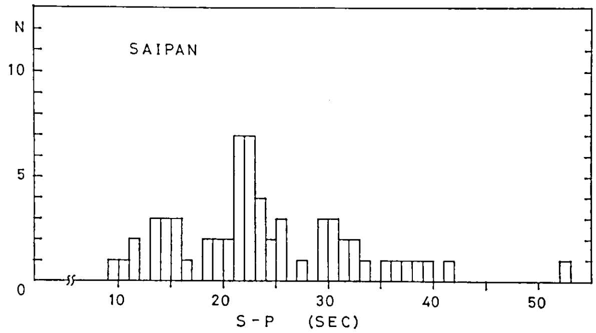

Fig. 5. S-P histogram of microearthquakes observed at Saipan Island during the period from January 9 to February 3, 1976.

The appearance of the earthquakes recorded at Saipan is quite different from those recorded at Guam, even though these two islands are situated on the same ridge axis and have nearly identical geophysical situations. In addition, the events recorded at Saipan were characterized by low predominant frequencies (5-6 Hz) and S phases which are highly attenuated (Fig. 6). However, microearthquakes recorded at Guam contained much higher frequency components, sometimes higher than 10 Hz (Fig. 7).

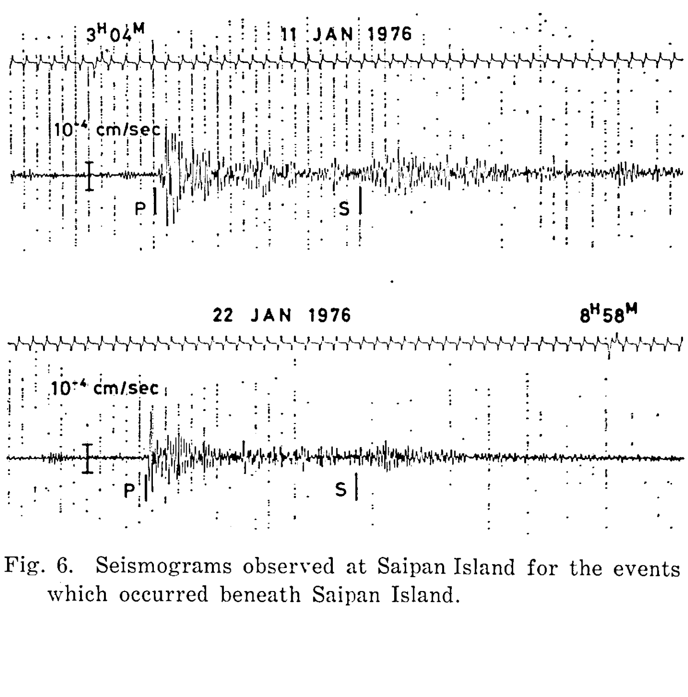

Fig. 6. Seismograms observed at Saipan Island for the events which occurred beneath Saipan Island.

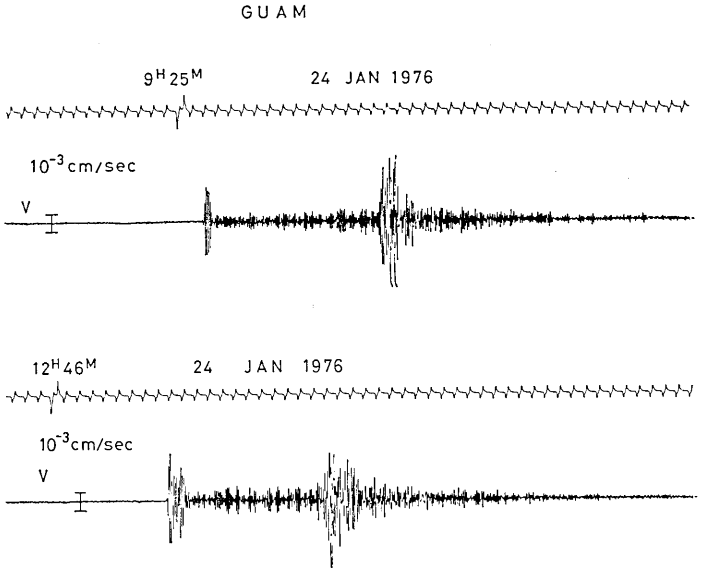

Fig. 7. Seismograms observed at Guam Island for the microearthquakes which occurred under Guam Island (group A).

[D] Marcus Island

The backqround noise at Marcus Island was very high, as high as 100 μ cm/sec for the vertical component, and hence the detection capability for earthquakes was poor. Only several earthquakes were detected during the 27 days observation from January 8 to February 4, 1976. One was at 21 : 38 on January 12 JST (Japan Standard Time) (23.3°N, 142.8°E ; h=113 km ; Mb=5.2). Others were T phases from the Kuril earthquakes [main shock M=6.5, 19 : 06 January 21, 1976 (JST), (JMA)]. They were clearly recorded at Marcus Island, more than 2000 km from the epicenters (Fig. 8). Apparently the transmission of T phases in the northwestern Pacific is very efficient. Neither P nor S phases from these events were detected. Although the detection capability was poor, there seemed to be no notable microearthquake activity in the vicinity of Marcus Island during this obsarvation period.

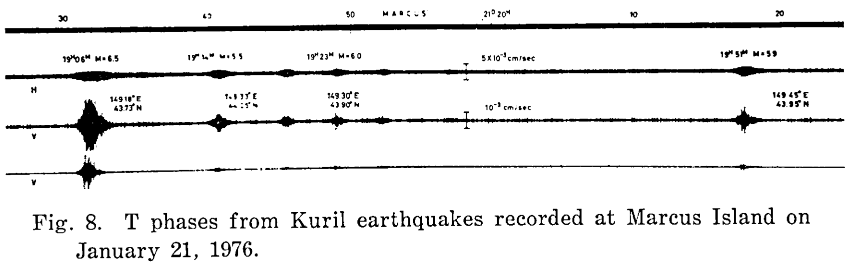

Fig. 8. T phases from Kuril earthquakes recorded at Marcus Island on January 21, 1976.

Hypocenter Distribution of Microearthquakes

(1) Method of Hypocenter Determination

We attempted to locate all the earthquakes which were recorded at 3 stations or more from 21 to 30 January in 1976, using both P and S arrival times. Since the observation network included both oceanic and island areas, it was necessary to use a different velocity model for each region. The hypocenter computation program by KAYANO (1973) was modified so as to use different velocity models for different stations. The average P velocity Vp=8.2 km/sec was assumed for the oceanic region and Vp=6.5 km/sec (for S-P times less than 20 seconds) or Vp=7.0 km/sec (for S-P times larger than 20 seconds) were assumed for the island arc region. The values Vp=8.1−8.2 km/sec in the Mariana basin were observed for the upper-most mantle by the long range explosion experiments which were conducted during the same cruises (ASADA and SHIMAMURA, 1976; NAGUMO et al., 1981). Similar Vp values of 8.0–8.4 km/sec have been also obtained in the area offside the Japan trench by microearthquake studies (NAGUMO et al., 1970; KASAHARA and HARVEY, 1976). As for S velocity in the Mariana region, we assumed Vp/Vs=1.76 which was obtained for the oceanic lithosphere offside the Japan trench (NAGUMO et al., 1970).

Because of the uncertainty as to which velocity model was most appropriate, we calculated hypocenters for several different velocity models.

Table 2. Earthquakes in the Mariana region from January to February 6 in 1976 reported in EDR (USGS).

	M	D	H	M	S	Lat. (N)	Long. (E)	Depth	M
1976	1	12	21	38	29.60	23.31	142.78	113.0	5.2
	1	19	0	41	7.10	16.86	147.23	76.9	4.7
	1	19	1	23	14.60	21.68	143.15	328.9	5.0
	1	19	7	6	11.50	12.86	144.32	33.0	4.5
	1	19	12	59	46.80	16.96	147.20	33.0	4.8
	1	20	13	8	45.90	17.05	147.25	38.0	5.2
	1	22	4	5	52.30	16.13	146.20	148.3	
	1	24	1	57	10.10	17.06	147.26	33.0	4.4
	1	24	12	32	36.80	17.03	147.15	50.7	4.4
	1	31	13	6	3.10	18.82	145.39	241.4	4.4
	2	1	21	43	27.70	18.50	145.26	406.3	5.0
	2	3	15	24	48.90	17.82	147.25	33.0	4.5
	2	6	7	9	48.00	12.99	143.56	126.6	4.7

For different models, the locations of the computed hypocenters differed as much as 20-30 km. Since the hypocenter distribution determined using a velocity model with Vp=8.2 km/sec and Vp/Vs=1.76 showed the best correlation with the bathymetric features, we concluded that this hypocentral distribution was the most reliable.

For the earthquakes occurring near the trench slope break at about 17°N, the source depth was fixed at 30 km. Because the earthquakes in this region were so distant from our network, the hypocentral depths could not be determined reliably by our data. Fortunately, however, two earthquakes were registered by USGS during our observation period and the source depths were reported at about 30 km (Table 2).

The magnitudes of microearthquakes recorded at St-3 in 1976 were determined to be in the range of 3.0-5.5 by using WATANABE's formula (1971). However, these magnitudes may be somewhat high because of the especially efficient transmission of high frequency seismic waves in oceanic regions (OUCHI, 1978).

(2) Features of Hypocenter Distribution

A total of 40 earthquakes were located during the period from 21 to 30 January in 1976 (Fig. 9 and Fig. 10). Among these events, only two earthquakes were reported by EDR (USGS). The distribution of hypo-

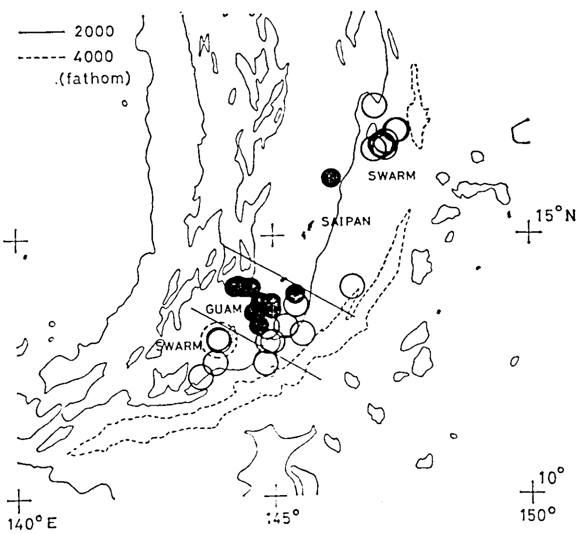

Fig. 9. Epicenter distribution of microearthquakes in the Mariana island arc region during the period from January 21 to 30, 1976. Hypocenters were determined by P and S wave arrival times at stations of Guam, Saipan, St-3, St-7 and St-11.

centers shows that there is intense seismic activity in the vicinity of Guam Island and around the marginal escarpment or trench slope break at about 17°N. However, there is no earthquake activity near Saipan Island. These features of the hypocenter distribution are consistent with those found in S-P time distributions of microearthquakes at both stations.

It is possible to divide these earthquakes into four tectonic groups.

Group A: Intermediate depth ($70 \leqq h < 210$ km) earthquakes occurring near Guam Island (solid circles in Fig. 9).

Group B: Shallow ($h < 70$ km) earthquakes occurring to the southwest of Guam Island (open circles in Fig. 9).

Group C: Shallow ($h < 70$ km) earthquakes occurring to the southeast of Guam Island (open circles in Fig. 9).

Group D: Shallow ($h < 70$ km) events under the trench slope break (open circles in Fig. 9).

NAGUMO and KASAHARA (1976) used almost the same grouping in a preliminary study of these events, and also labeled these groups as group A, B, C and D. These groups will be used in the later section for describing the temporal variation in the microearthquake activity.

For events in group A, the depth cross section (Fig. 10) of microearthquake distribution around Guam shows deep seismic zone, about 20-30

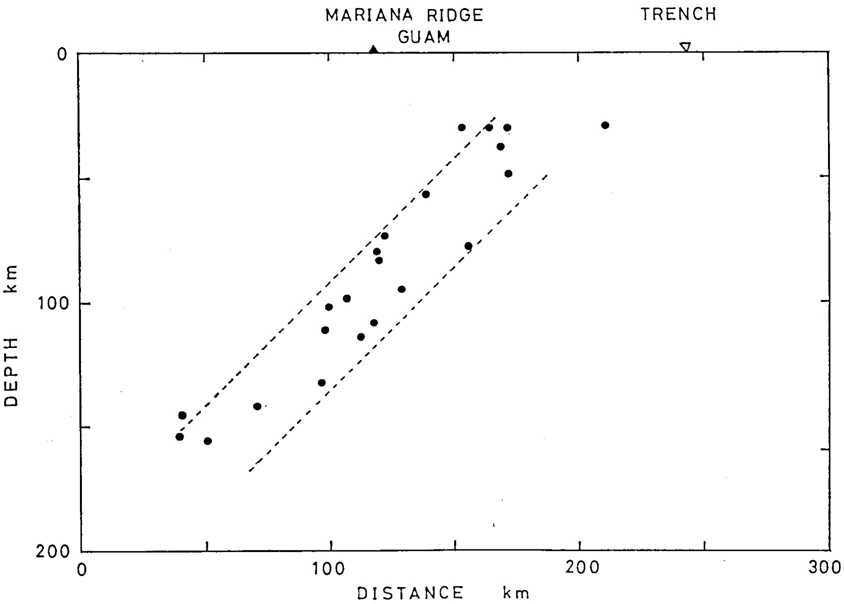

Fig. 10. Side projection of earthquakes between the solid lines shown in Fig. 9. Dashed lines denote the estimated deep seismic zone.

km thick, dipping about 45° from the trench axis to a depth of about 150 km. Although the existence of this deep seismic zone has been known from studies of teleseismic data (KATSUMATA and SYKES, 1969; SANTO, 1969; BRACEY and OGDEN, 1972), it is very interesting that we could observe it so clearly in such a short observation period. The wave forms of intermediate events are quite distinctive, with impulsive P and S phases and with a predominant frequency as high as about 10 Hz at the station on Guam (Fig. 7).

The activity in group B is characterized by the presence of two swarms, dotted circles in Fig. 9, which occurred southwest of Guam on January 19 and 24, 1976. The occurrence of earthquakes in group B was characterized also by chain breaks (Fig. 11). The b values of these earthquake swarms determined by the maximum likelihood method (AKI, 1965; UTSU, 1965) were b=1.2 for the swarm on January 19, and b=1.1 for the swarm on January 24 (Fig. 12). The events in group C occurred eastward of Guam between the continental slope of Guam to the trench slope axis.

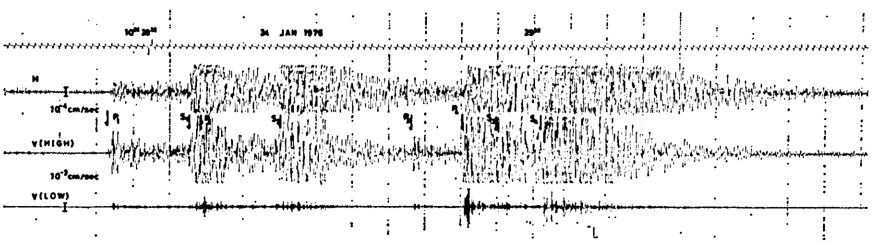

Fig. 11. Record example at Gaum for the earthquakes occurred southwest of Guam Island (group B). Events are characterized by typical "chain break" appearance.

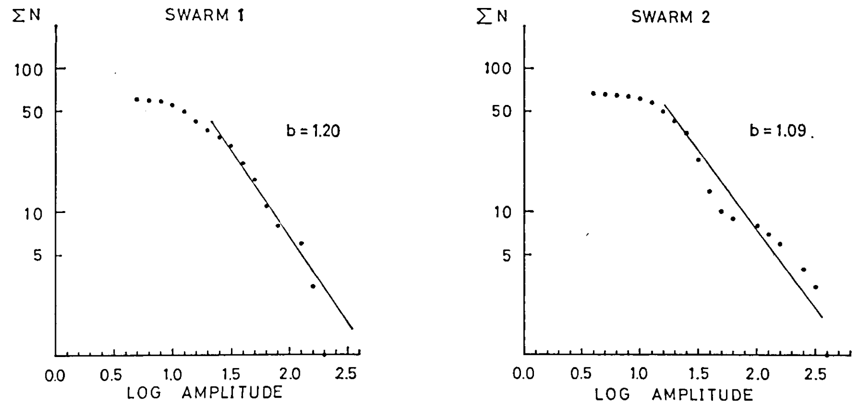

Fig. 12. Cumulative plots of microearthquakes and estimated b values for the activities at the southwestern part of Guam (group B). Left; swarm 1 on January 19, 1976 and right; swarm 2 on January 24, 1976.

The activity in group D included earthquake swarms which were recorded on January 24–25, 1976. From an anlysis of teleseismic data (see next section), this swarm activity at about 17°N began on January 19, 1976 just prior to the deployment of our OBS's in the Mariana basin, and lasted for several months until June, 1976.

ISC Data

In order to compare the hypocenter distribution of microearthquakes obtained during our short term observation to the distribution of earthquakes occurring over a long time period, we looked at events reported in the regional catalogue of the ISC. We can identify several important features of earthquakes (Mb≧5) which occurred during the period from January 1964 to June 1974 (Fig. 13a).

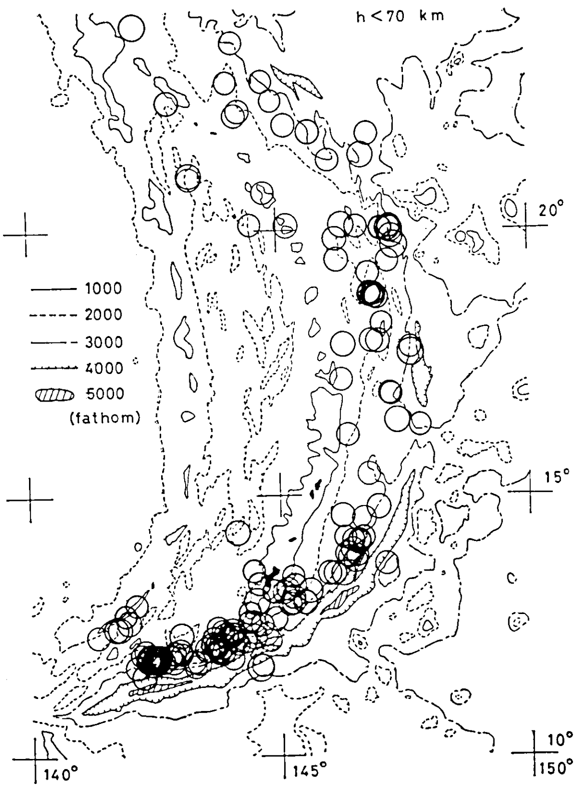

Fig. 13a. Epicenters of shallow focus earthquakes (h<70 km, Mb≧5). Open circles are those from ISC catalogue in the period from January 1964 to June 1974. Bathymetric contour: from Bathymetric Atlas of the North Pacific Ocean, 1973.

(i) Shallow Earthquakes

The epicenter distribution of shallow (h<70 km) shocks shows a remarkable correlation with bathymetric features. Most earthquakes occur under the "trench slope break" and around the terminus of the Mariana ridge. The shallow earthquakes are particulary prominent around the trench slope break between 17°N and 20°N and around the southern terminus of the Mariana ridge between 12°N and 15°N.

(ii) Intermediate Earthquakes

The epicenter distribution of intermediate (70≦h<210 km) earthquakes is concentrated in a narrow zone under the Mariana ridge (Fig. 13b) as noted by KATSUMATA and SYKES (1969). Activity also extends from the ridge axis towards southwest into the deep sea area. There are also two seismically quiet zones along the ridge axis, one between 19°N and 21°N, and the other between 14°N and 16°N near Saipan Island.

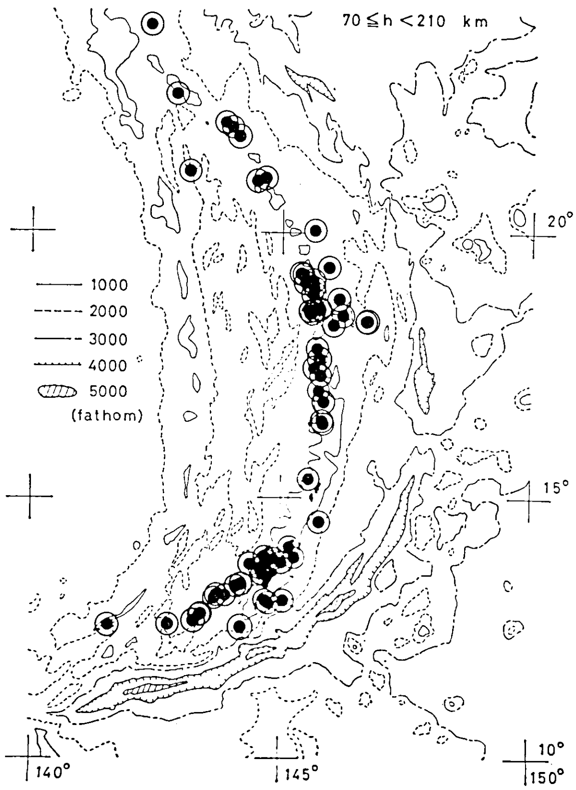

Fig. 13b. Epicenters of intermediate depth earthquakes (70≦h<210 km, Mb≧5).

(iii) Deep Seismic Zone

The epicenter distribution of deep earthquakes (h≧210 km) is concentrated in a narrow zone near the central part (16°N–19°N) of the Mariana ridge and in an area around 22°N (Fig. 13c). No deep activity exists in the south Mariana area.

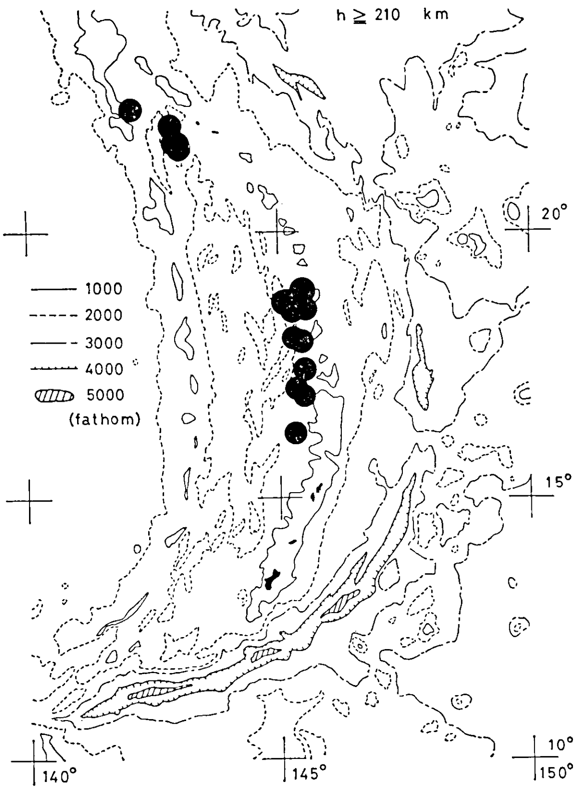

Fig. 13c. Epicenters of deep earthquakes (h≧210 km, Mb≧5).

(iv) b Value

The b value for this seismic activity is b=1.3 for the shallow earthquakes (h<70 km) and b=1.8 for the intermediate (70≦h<210 km) earthquakes (Fig. 14). Both of these b values are relatively higher than the common values

(v) Grouping

To investigate the relationship of the epicentral distribution of the ISC data and that of the microearthquakes in the present study, we divided the epicenters into several groups. The intermediate depth earth-

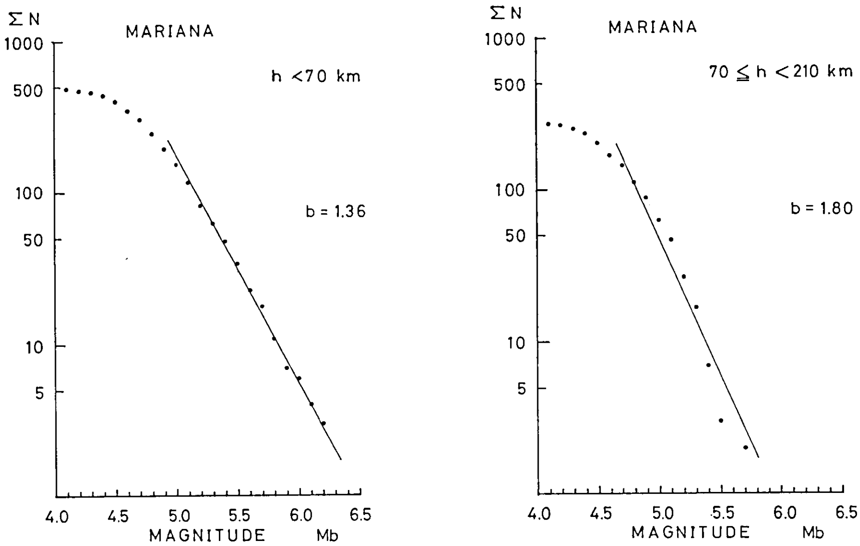

Fig. 14. Cumulative plots of shallow (left; h<70 km) and intermediate (right; 70≦h<210 km) earthquakes from the Mariana island arc area for the period from January 1964 to June 1974 (from ISC regional catalogue).

quakes in Fig. 13b might be divided into the three distinct groups of A_1, A_2 rnd A_3 (Fig. 15). The shallow shocks under the trench slope break (Fig. 13a) might be also divided into the three groups of D_1, D_2 and D_3 and the shallow earthquakes in the south Mariana might be divided into the three groups of B, C and E.

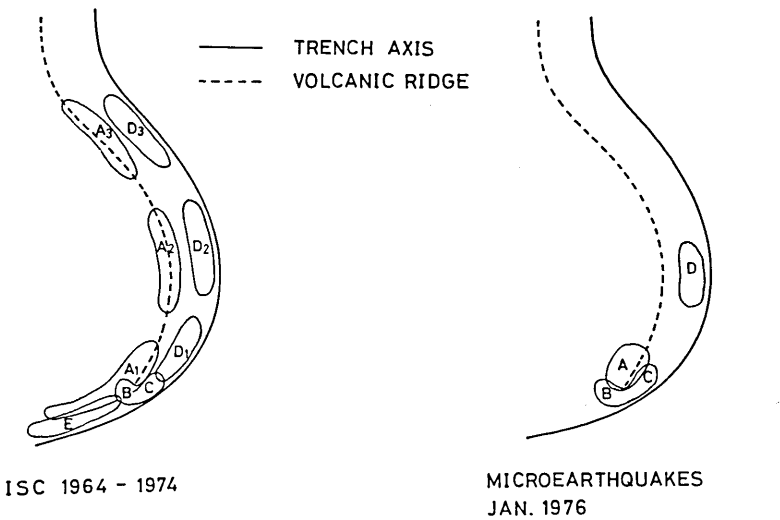

Fig. 15. Schematic seismicity map of the Mariana island arc region. Areas A_1, A_2, A_3, B, C, D_1, D_2, D_3, E (left) and A, B, C, D (right) show the active areas. Left; ISC, January 1964 to June 1974. Right; microearthquake study, January 21 to 30, 1976.

Temporal Variations of the Microearthquake Activity

In 1976, we recorded a high rate of microearthquake activity including two swarms which lasted for several days and which occurred almost at the same time, but about 500 km apart (Figs. 16 and 17). In fact, this activity occurred in several places, namely in group B near Guam Island, in group D under the trench slope break near 17°N and in group A, the intermediate shocks near Guam.

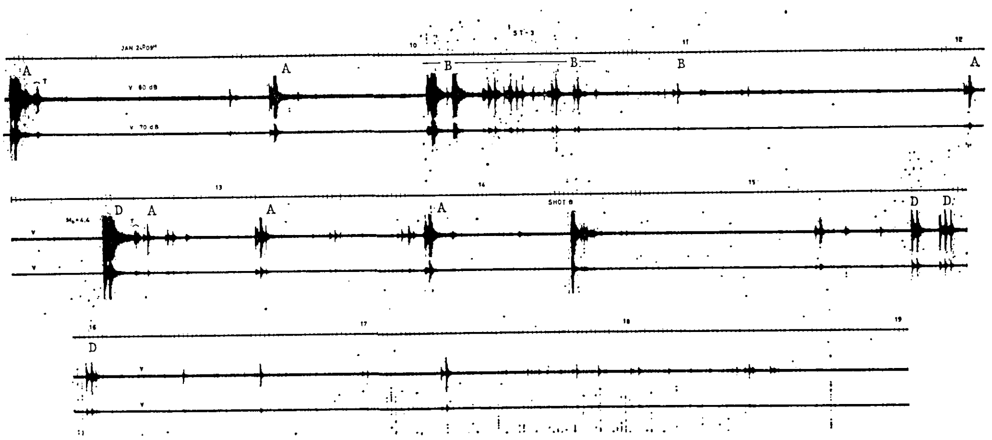

Fig. 16. Play out record of the swarm activity of January 24, 1976, observed at the OBS station St-3. The letters "A", "B" and "D" denote the earthquakes of group A, B and D respectively. At first, shocks in group A occurred at 8: 27 and 9: 24 January 24. They were followed by the shocks in the region B. At 12: 32 January 24, the largest shock in the swarm (Mb=4.4, EDR) occurred in the region D accompanying the intermediate earthquakes.

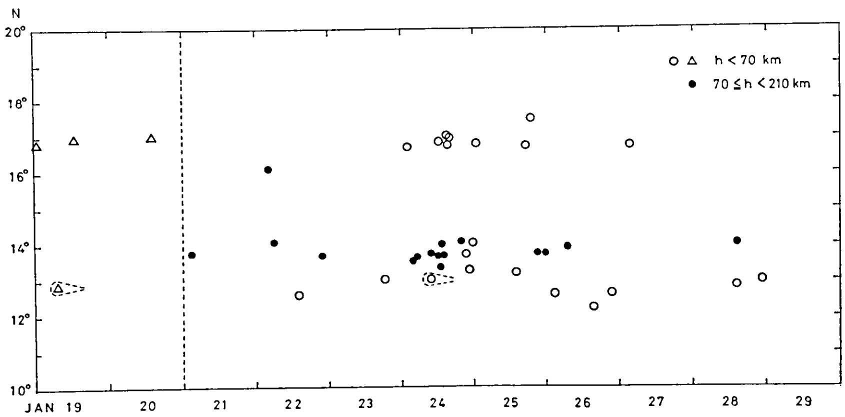

Fig. 17. Time space plot of micorearthquakes of the Mariana arc region for the period from January 19 to 30, 1976. Data from January 19 to 20 are from EDR (USGS). Dashed lines denote the swarms. Note the successive occurrence of microearthquakes.

The first swarm occurred in the group B, southwest of Guam on January 19, 1976 (Fig. 17), and was followed by intermediate depth earthquakes which occurred between January 21 and 23. The second swarm in group B began at 10: 02 January 24, 1976. About two hours later, at 12: 32, another swarm began in group D about 500 km distant from group B. Proceeding this swarm activity, intermediate depth earthquakes in group A began to occur and continued intermittently throughout the period of swarm activity (Fig. 16). The shallow earthquakes in the group C, southeast of Guam were also accompanied by this swarm activity (Fig. 17).

The existence of this increased activity can be also identified by the large number of microearthquakes registered at nearby stations (see Figs. 3, 4 and 5). The temporal variation in the rate of activity at the station Guam directly reflects the swarm activity occurring in group B both on January 19 and 24. From the variation of the activity rate at St-3

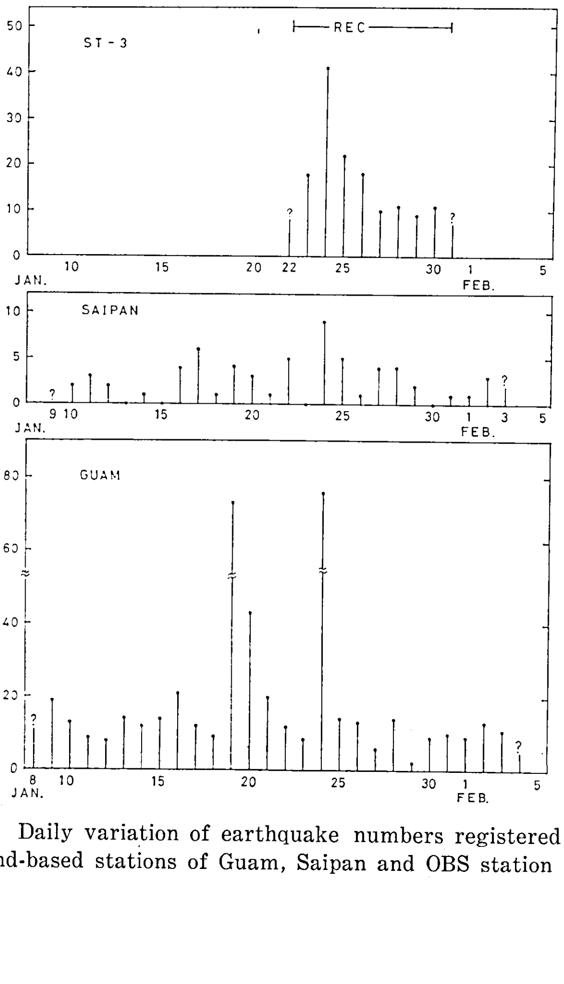

Fig. 18. Daily variation of earthquake numbers registered at the island-based stations of Guam, Saipan and OBS station St-3.

in the Mariana basin, it is clear that the swarm activity in group D, which began on January 24, continued for several days (Fig. 18).

In order to investigate the seismic activity in this region before and after our short observation period, we plotted the epicenter distribution reported by EDR for two periods, the one from August 1975 to January 20, 1976 and the other from February to July 1976 (Fig. 19). Prior to our observation, intermediate depth earthquakes occurred around the middle of the Mariana ridge which may be related to the occurrence of shallow activity in group D under the trench slope break at 17°N. The activity in group D continued for several months after our observation period. It should be noted that a felt earthquake (Mb=6.1) occurred near Guam Island, about 113 km deep, on November 1, 1975. Felt earthquakes are quite uncommon in this region.

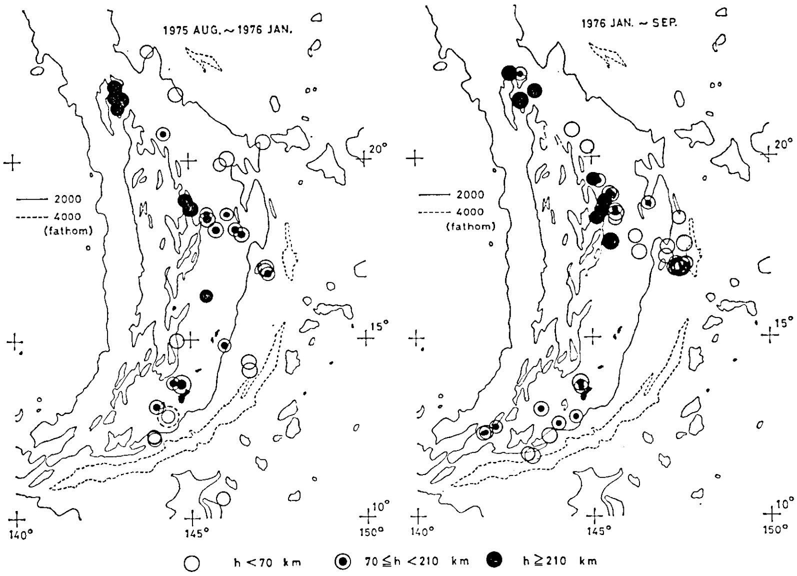

Fig. 19. Epicenter distributions of the Mariana island arc region before and after the observation period (from EDR, USGS). Left, August 1, 1975 to January 20, 1976; right, January 31 to July, 1976.

Discussion and Conclusion

Microearthquake study in the Mariana island arc area revealed several distinct earthquake groups which are closely related to the bathymetric features of this area. Long term data from ISC regional catalogue also support the same seismic features in this area. We have divided the earthquakes in the Mariana island arc-trench region into several groups which correspond to bathymetric features. They are group A (intermediate depth earthquakes under the Mariana ridge), groups B, C, E (shallow earthquakes around the terminus of the Mariana ridge), and group D (shallow earthquakes under the trench slope break). Groups A and D have been previously identified by KATSUMATA and SYKES (1969), which suggests that today the same tectonic elements are active as before. The configuration of groups B, C and E is rather complicated, apparently because of the complex bathymetric pattern in the southern Mariana.

It is interesting that intermediate earthquake activity is very high under the volcanic ridge, possibly suggesting that there is active igneous activity under the volcanic ridge, especially near Guam Island. The high b value of 1.8 for intermediate earthquakes supports this speculation. It is also notable that the swarm activity near Guam included intermediate events. Because intermediate depth earthquakes probably occur along the dipping slab under the volcanic ridge and probably they are closely related with the magma generation, such a process as phase transition may play a very important role under the volcanic ridge near Guam. However, swarms which occurred in the southwestern part of Guam Island seem to be tectonical in nature, since b values of them are 1.1 and 1.2 respectively, somewhat high but within the normal values for tectonic earthquakes.

Both the microearthquake observations reported in this study and the epicenters obtained from the ISC regional catalogue show that there is an aseismic region around Saipan Island along the Mariana ridge. This feature is associated with highly attenuated S phases at Saipan, possibly suggesting that there may be some differences in the physical state of the crust.

The seismicity in the south Mariana region is rather complicated. The prominent bathymetric high of the Mariana ridge axis terminates at the Santa Rosa Reef, southwest of Guam. The extension of the ridge axis towards the southwest is obscure between the Santa Rosa Reef and the junction at 140°E, 11.5°N. In spite of the existence of the Mariana trench following a nearly E-W direction at about 11.5°N latitude, the bathymetric highs on the island arc side are fragmented from several deep troughs. Since the "continental slope" is not well defined there, the trench slope break and the mid-slope basement high cannot be identified in this region.

The hypocenter distribution of shallow earthquakes in this region suggests the existence of several tectonically active elements. NAGUMO and KASAHARA (1976) studied the microearthquake activity in groups B and C and speculated that these events might be related to the termination of the uplifting motion of the ridge axis. BRACEY and OGDEN (1972) suggested the existence of the fracture zones in this area from a study of magnetic anomalies. In either case, high activity of microearthquakes including swarms from Guam towards the southwestern Mariana area reflects the active tectonic movement in this area. However, the problem of the seismotectonics in this region is still controversial and further study is necessary to delineate any definite tectonics.

The high rate of activity observed in January 1976 in a very wide area of the Mariana island arc-trench region is quite unique, and this phenomenon might be called "regional activation" indicating that the microearthquake activity occurred almost simultaneously at several places over a wide area. Since the occurrence of earthquakes is an indication of active tectonic movement, the above phenomenon implies that a wide area in the Mariana island arc-trench system was subjected to tectionic activation.

When earthquakes occur, it is not always clear whether this represents a localized tectonic deformation or a regional tectonic deformation. However, in the present case the seismic activity seems to be related clearly to the tectonic deformation over a broad region. In addition, the fact that intermediate depth earthquakes were included in this phenomenon implies also that igneous activity was involved.

Other examples of "regional activation" has been reported previously. Examples of this are the successive occurrence of large earthquakes (MATSUZAWA, 1976), the activation of microearthquakes at a distant place after a large earthquake (see SEKIYA, 1973), such as the earthquake swarm at Tokachi-dake immediately after the 1968 Tokachi-oki earthquake (Ms=7.9). The huge source area extending more than 1000 km in length in the 1957 Andreanof, 1960 Chile, and 1964 Alaska earthquakes (MOGI, 1968) would also be typical representation of "regional activation".

It is quite possible that regional activation in island arc region occurs quite frequently, but usually goes undetected. We were able to detect this phenomenon in the Mariana region only because of the efficient transmission of high frequency body waves in oceanic regions (OUCHI, 1978). By operating high sensitivity OBS networks in island arc-trench systems, we shall be able to detect the occurrence of regional activation more frequently. Such observations would be especially useful for understanding the dynamics of island arc-trench systems.

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References

AKI, K., Maximum likelihood estimate of b in the formula $\log N = a - bM$ and its confidence limits, *Bull. Earthq. Res. Inst.*, 43, 237-239, 1965.

ASADA, T. and H. SHIMAMURA, Observation of earthquakes and explosions at the bottom of the Western Pacific: Structure of oceanic lithosphere revealed by longshot experiments: *Am. Geophys. Union Geophys. Monogr.*, 19, 135-153, 1976.

BRACEY, D.R. and T.A. OGDEN, Southern Mariana arc: Geophysical observations and hypothesis of evolution, *Geol. Soc. Am. Bull.*, 83, 1509-1522, 1972.

KARIG, D.E., Structural history of the Mariana island arc system, *Geol. Soc. Am. Bull.*, 82, 323-344, 1971a.

KARIG, D.E., Origin and development of marginal basins in the western Pacific, *J. Geophys. Res.*, 76, 2542-2561, 1971b.

KARIG, D.E. and G.F. SHARMAN, Subduction and accretion in trenches, *Geol. Soc. Am. Bull.*, 86, 377-389, 1975.

KASAHARA, J. and R.R. HARVEY, Seismological evidence for the high velocity zone in the Kuril trench area from ocean bottom seismometer observations, *J. Geophys. Res.*, 82, 3805-3814, 1977.

KATSUMATA, M. and L.R. SYKES, Seismicity and tectonics of the western Pacific; Izu-Mariana-Caroline and Ryukyu-Taiwan regions, *J. Geophys. Res.*, 74, 5923-5948, 1969.

KAYANO, I., On some problems in epicenter determination of local earthquakes (in Japanese), *Special Bull. Earthq. Res. Inst.*, 12, 83-98, 1973.

MATSUZAWA, T., Theory of earthquakes and its applications (in Japanese), Tokyo Univ. Press, 1976.

MOGI, K., Development of aftershock area of great earthquakes, *Bull. Earthq. Res. Inst.*, 46, 175-203, 1968.

NAGUMO, S., S. HASEGAWA, S. KORESAWA and H. KOBAYASHI, Ocean-bottom seismographic observation at the offside of Japan trench near the Erimo seamount, seismic activity of the oceanic lithosphere and velocity structure around the geophysical "ocean-continent boundary", *Bull. Earthq. Res. Inst.*, 48, 769-792, 1970.

NAGUMO, S. and J. KASAHARA, Ocean bottom seismograph study of the western margin of the Pacific, *Am. Geophys. Union. Geophy. Monogr.*, 19, 155-167, 1976.

NAGUMO, S., J. KASAHARA and S. KORESAWA, Structure of microearthquake activity around Japan trench, off Sanriku, obtained by ocean-bottom seismographic network observation, *J. Phys. Earth*, 24, 215-225, 1976.

NAGUMO, S., T. OUCHI, J. KASAHARA, S. KORESAWA, Y. TOMODA, K. KOBAYASHI, A. FURUMOTO, M. ODEGARD and G. SUTTON, Sub-moho seismic profile in the Mariana basin by OBS long rang explosion, *Earth Planet. Sci. Lett.*, **53**, 93-102, 1981.

OUCHI, T., Spectral structure of high frequency *P* and *S* phases observed by OBS in the Mariana basin (submitted to *J. Phys. Earth*), 1978.

SANTO, T., Regional study on the characteristic seismicity of the world. Part V, Bonin-Mariana Island Region.—Comparative study on the reliability of USGS seismic data since 1963—, *Bull. Earthq. Res. Inst.*, 48, 363-379, 1969.

SEKIYA, H., Earthquake swarm and earthquake prediction, Symposium on earthquake prediction (in Japanese), (Seismol. Soc. Japan), 67-75, 1972.

UTSU, T., A method for determining the value of b in a formula $\log N=a-bM$ showing the magnitude frequency relation for earthquakes (in Japanese), *Geophys. Bull. Hokkaido Univ.*, **13**, 99-103, 1965.

WATANABE, H., Determination of earthquake magnitude at regional distance in and near Japan (in Japanese), *Zisin* II, 24, 189-200, 1971.

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3. 海底地震計を用いたマリアナ島弧における地震活動の研究

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マリアナ海盆上の海底地震計と Guam, Saipan 及び Marcus における島上の臨時観測点を用いて，マリアナ地域における微小地震観測を行った．観測期間は1973年7月～8月及び1976年1月～2月の2度．観測期間中マリアナ島弧に沿って群発地震を含むきわめて活発な微小地震活動が観測された．カロリン地域の地震も観測されたが海底地震計近傍のマリアナ海盆には地震は起っていないように思われる．微小地震は Guam 島付近から南マリアナにかけて特に活発であるが，同じマリアナ海嶺上にある Saipan 島近傍にはほとんど地震が起っていない．計40個の地震の震源が求められた．これらの震源は大別して (a) 海溝軸に沿った「trench slope break」下の浅い (h≦70 km) 地震，(b) マリアナ海嶺下の稍深発 (h>70 km) 地震，(c) Guam 島付近のマリアナ海嶺末端から南西にかけた浅い (h≦70 km) 地震に分けられる．地震活動と海底地形との対応は非常に明瞭であり，これらの造構要素が活動していることを示している．ISC のデータの示す長期間 (1964年1月～1974年6月) の震源分布は，これらの微小地震活動がマリアナ島弧における主要な造構運動を反映したものであることを示している．

高感度の微小地震観測により，マリアナ島弧に沿って，きわめて広範囲にわたっていっせいに地震活動が活発になる現象が見出された．数百 km に及ぶいくつかの地域に広がっており群発地震や稍深発地震も含んでいる．このことは広域にわたって造構運動が一時期いっせいに活発になったことを示しており，この現象は「regional activation」というべき現象と思われる．