Intensive Thermal Upwelling at a Seamount in the South Mariana Trough Observed by Ocean Bottom Seismic Instruments Using “Shinkai 6500” Submersible

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An MOOBS (Magneto Optical Ocean Bottom Seismometer) was deployed at just 1 m beside of a hot thermal vent whose temperature was 207°C on the summit region of the seamount located in 18km east of the south Mariana Trough axis. Although the seismicity just beneath the seamount was very weak, numerous pressure events were observed by hydrophone channel showing sudden pressure decrease. The characteristic period of the pressure pulses is from 30 seconds to 1 min. Submersible “Sinkai 6500” relocated MOOBS at 30m south of the vent and the seismic records show a drastic change of

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number and amplitude of pressure events. This suggests that pressure events might be generated by the hot water upwelling from the thermal vent, where an *alviniconcha* colony was found. There are two set of topographic lineaments, the one for axis region of the southern Mariana Trough, and the other located eastward of the axis. The eastward lineament, which forms echelon arrangements, cuts the summit of seamount where thermal vent chain were found along the lineament. The existence of thermal activity implies some extent of rifting process occurring in the 18 km east of the topographic ridge which is supposed to be the previous Trough axis.

Key words: Hot thermal vent, Pressure pulse, Ocean bottom seismometer, the Mariana Trough, Submersible

1. Introduction

Oceanic spreading and rifting are thought to be major sources of global climate changes because heat flux generated by submarine volcanic activities seems one hundred times of land volcanoes. Oceanic ridges and troughs are major constituents for such submarine volcanoes. Although there are extensive researches on volcanic activity of oceanic ridges and troughs done by portable instruments, none of surveys have been done continuously and in real time.

Mariana Trough is a good example of spreading center or rifting center of backarc regions (Fig. 1). In the north of Mariana Trough, several researches were made using deep-tow camera and rock drags (Hawkins, et al., 1990), submersible dives (Craig et al., 1987) and multi-narrow-beam (e.g., Kasahara et al., 1993). Thermal vents were found on the summit of ridge located at axis region of the Mariana Trough at 18° N by submersible *Alvin* dive (Craig et al., 1987). Temperature was measured as 287°C at one of these vents. Similar hydrothermal chimneys and biological colonies were confirmed by submersible "Shinkai 6500" dives at the same location, where the temperature was 280°C (Gamo et al., 1993). The topographic survey of Mariana Trough shows close resemblance to the Mid-Atlantic Ridge, which is a typical slow spreading center (Hawkins et al., 1990; Kong et al., 1993). Magnetic survey also supports that the Mariana Trough is a type of very slow spreading (Seama and Fujiwara, 1993). Intense seismicity was found at the Mariana Trough around 18° N (Hussong and Sinton, 1982; Kasahara et al., 1993). Crustal structure near the Pagan fracture zone at the 17°30′N shows a typical oceanic crust, suggesting young oceanic crust formation at this location (Bibee et al., 1980). Although there are extensive researches on volcanic activity of oceanic ridges and troughs done by portable instruments, none of surveys have been done continuously and in real-time. To monitor submarine volcanic activity in the Mariana Trough region, the authors are proposing to install an integrated geophysical station at one of the most active thermal vent as a part of Geo-TOC (Geophysical and Oceanographical Trans Ocean Cable) project (Kasahara et al., 1994).

In the southern part of the Mariana Trough, active thermal-vents, active chimneys and vent biological colonies were also found on a summit of seamount (143°55′E, 13°24′N, 1,470m) located at the eastern side of the trough axis by a "Shinkai 6500" #161 dive (Gamo et al., 1993). The temperature was found as 202°C at one of the most active thermal vent. Although a number of researches revealed strong evidences of backarc spreading or rifting in the northern part of Mariana Trough, southern half of the trough remains as unsolved problem in stage of backarc tectonics. Finding of hydrothermal vents in the 18 km east of the southern Mariana Trough axis might be an evidence of active spreading and detailed survey of these thermal vents will give solution for this question. It has been proposed that spreading of Mariana Trough occurred at the south and has migrated toward north (Karig, 1971). Ac-
According to this hypothesis, the southern part of Mariana Trough already stopped the spreading. It is interesting to examine whether this is correct or not.

In August 8, 1993, a large earthquake, whose magnitude is reported as M 8.2, occurred at forearc side of Mariana Islands and made some damages on buildings. During aftershocks sequence, some events occurred in the south Mariana Trough area (Fig. 2). Focal plane solutions of main shock and two large aftershocks were estimated as thrust having vertical and horizontal fault plane (PDE) although principal axes show different directions in the horizontal plane among them. Sugi (1993) concluded that the horizontal plane was rupture plane because aftershocks formed nearly horizontal distribution.

As this experiment was carried out in two months after the main shock (October 17 and 25), it was expected to detect some aftershock activities of the M 8.2 main shock occurring in the south Mariana Trough area. In this experiment, one digital OBS with a hydrophone was deployed on the summit of seamount, where active thermal vents were previously found by “Shinkai” dive, located eastern side of the southern Mariana Trough (Photo 1). It was planned to observe OBS and to replace it near an active thermal vent by submersible “Shinkai 6500”. The purpose of this experiment is to monitor nature of thermal vent activity just at neighbor of vent by seismic tools and measure the potential of backarc-rifting process of the south Mariana Trough. Identifying earthquakes beneath the seamount could be a good measure for tectonic activity if it exists. By use of submersible, it is realized to set OBS at a previously known thermal vent. Hydrophone is expected to detect any volcanic T-phase signals if volcanic activity can generate. Although a hydrophone detects earthquakes, it can also sense pressure variation because a hydrophone responds to water pressure change. It is also expected to detect volcanic tremors if the seamount is close to the stage of volcanic eruption.

2. Field Experiments
A digital ocean bottom seismometer called MOOBS
Fig. 2 Main (Solid diamond) and its aftershocks (solid circles) in August 6, 1993 obtained by PDE (USGS), at Mariana forearc and Mariana backarc. Bathymetry obtained by “Yokosuka” multi-narrow-beams during the present study. Contours are each 200m.

(Magneto Optical Ocean Bottom Seismometer) (Kasahara et al., 1992) was used. MOOBS has three-component 2 Hz seismometer (L-22E) and one hydrophone as seismic sensors, and an MO disk drive for data storage device. After digitizing seismic signals by 16-bit A/D converter, seismic data are stored in 256Kbyte temporary memory. MOOBS has two recording modes, event picking and continuous modes. In this experiment the continuous recording mode was selected for data-save except of noisy period due to shaking by MO disk drive. The sensitivities are 1.67 V/(cm/sec) and -87 dB/(V/µbar) (or -187 dB/(V/µPa)) for seismometer and hydrophone, respectively. Amplification factor for all channels is 40dB and sampling rate is selected as 50Hz. Response of amplifier is flat from DC to 30Hz. Instead of using glass sphere for pressure housing of OBS, an aluminum one was used in the viewpoint of safety in order to avoid a sudden implosive collapse of sphere, when “Shinkai 6500” carries an OBS.

Approximate deployment site was chosen by referencing the previous dive (“Shinkai 6500” Dive #181), where is the former active chimney location on the seamount at 143°55’E, 13°23’N and depth of 1,500m. Before the deployment, the exact observation site was carefully selected using multi-narrow-beam bathymetric map. Summit area (named “SNAIL Haven”) was chosen as the target site rather than slope side because seamount slope is very steep for OBS deployment. Although the summit appears as flat on multi-narrow-beam map within measurement resolution, which is approximately 20m in depth, the horizontal size is extremely small, nearly 30m square at depth of 1,500m. Later, a number of “Shinkai 6500” dives revealed that the summit area is very rough in the viewpoint of OBS deployment, although we expect the flat top with a sediment cover. The deployment of OBS was performed by R/V “Yokosuka”, which is a support vessel of “Shinkai 6500”.

After the deployment of OBS, Kasahara, one of authors, dove on the “SNAIL Haven” in order to move the OBS ("Shinkai 6500" Dive, #183), but the OBS was not found during his dive. It happened that the OBS was found by a later dive (#185, by R. Vrijenhoeh), just 1m beside of an active thermal vent. Temperature of the thermal vent was measured as 207°C. An Alviniconcha colony was found at this vent (seen as white in Photo 1). Alviniconcha is a kind of snail family and first found in the north
Mariana thermal vent by Alvin. Because sitting pose of OBS seemed too unstable to fulfill function as seismometer, it was decided better to move OBS to more stable place. Although a location, where should be wide and stable enough to reset the OBS, was sought around the vent by "Shinkai", there were so few. Finally, OBS was fixed at one location at the 30m south of the previous site by dive #185. Seeing the video tapes taken by #185 dive, the sitting shape at the first site is better than the second one. OBS records, however, showed that two horizontal seismometers are almost dead at the first site, and one horizontal seismometer is extremely unstable at the second site, showing low-frequency (ca. 0.3Hz) oscillation with large amplitude.

The 7 days record was obtained from 18:31 (local =GMT+ 8 hours) of October 17 to 11:05 (local) of October 25, 1993. The OBS was located at 143°55.241’ E, 13°23.615’ N and depth of 1,470m.

During the diving study, the multi-narrow-beam bathymetric survey was carried out by R/V "Yokosuaka".

3. Results

Data, however, have some losses at saving due to malfunction of MO disk drive. Amount of data obtained is nearly one third of the total periods during one week. By visual examination of video tapes obtained by "Shinkai 6500", basement of the summit region is extremely rough in the viewpoint of OBS landing point. The bottom surface of seamount is covered by mass of pillow lava, specially at the summit region and along seamount slope. There were only a few locations covered with thin sediments nearby the summit. There are no thermal vents at this flat region. OBS was found at the location just 1m beside of an active thermal vent (called "Geo-phonic vent" site, Photo 1) by "Shinkai 6500" Dive (#185, by R. Vrijenhoeh) in the narrow summit region with 30m square. Pillows are approximately 50cm to 1 m in diameter and form 1-2 m up and down topographic change. A biological colony of Alviniconcha was seen at the "Geo-phonic" thermal vent. Smearing of water was also observed at the vent during dive #185. By several dives, it was observed that the vents are forming a lineament and distributed along nearly N-S strike near the western wall side of summit.

One hundred and thirty seismic events were observed during 8 days period. Fig. 3 shows S-P time distribution of events. Most of S-P times are distributed between 10 and 50 seconds. None of events, which occurred inside of this seamount, were found. The S-P time for the nearest event is ca. 3-4 seconds. The P and S readings of events were compared to the list prepared by USGS Guam station (P. Hattori, personal communication), where is located at approximately 90km east of the OBS, and the results indicate very few events having earlier arrivals than in Guam. Examples of earthquake records are shown in Fig. 4.

During the current observation, numerous pulse shape events are recorded only on hydrophone trace, hereafter, these are called "pressure event(s)", because these are picked by pressure sensor (hydrophone), and none of pressure pulses were identified on seismometer traces even for the largest pulses. Fig. 5 shows three examples of pressure events. The characteristic period of pressure pulses is 30 seconds to 1 minute. The MEM spectrum also shows the same characteristics as visual inspection (Fig. 6). It is also confirmed that hydrophone worked correctly seeing natural earthquake records.
Fig. 4 Example of natural earthquakes. Channel 1 (top trace): vertical; channel 2: horizontal #1, channel 3 horizontal #2 and channel 4 (bottom trace): hydrophone. Vertical relative scales are shown far below after channel number. Tick on vertical scale corresponds to 5.36mV voltage scale. Two horizontals are nearly dead due to inclined OBS settlement at site 1. (a) Nearest earthquake with 655 seconds for full length and (b) with 40 seconds for full length at site 1, (c) further distant earthquake with 655 seconds at site 2 and (d) low frequency noise observed at site 2 with 40 seconds for full length. Vertical scales are 4, 1024, 4 and 16 from top to bottom. Extremely large noise on horizontal #1 is due to unstable OBS settlement.

At the second site, number of pressure pulses and specially amplitude of them quickly decreased. Pressure pulses tend to show negative first breaks. The above results strongly suggest that pressure pulses were generated by episodic and rapid upwelling of hot water generated by the “Geo-phonic vent”, not by smooth and continuous smearing. Negative first break might indicate local pressure decrease by this upwelling. Fig. 7 shows the time sequence of pressure pulses. Although the record is not completely continuous, only we can say it does not show an clear periodic nature except there is a possibility.
of 1 day or 12 hours periodicity.

4. Discussions

It, however, is necessary to examine whether pressure pulses can be observed by seismometer or not. Typical amplitude ratio between vertical seismometer and hydrophone at 2-8 Hz is approximately 2.5 : 1 as seen in Fig. 4. During low frequency oscillation period seen in Fig. 4 (d), the ratio of vertical seismometer and hydrophone decreased to 1 : 4 at 3.5 seconds. This amplitude decrease can be explained by low frequency response of 2 Hz seismometer because sensitivity of 2 Hz seismometer at 4 seconds is 1/8 of that at 2 Hz. The observed ratio is nearly this level. Considering this effect, the sensitivity at 32 seconds is approximately 1/64 of 2Hz. The observed amplitude of pressure pulse is 1.2V seen in Fig. 5. This corresponds to 0.02V at vertical seismometer channel. Because this is five times greater than noise level (4 mV) on vertical channel, pressure

Fig. 5 Examples of pressure events. Note on vertical scale difference between channels 1 and 4:8 and 128, respectively. Polarity for hydrophone is negative for up.
pulse should be seen if these are seismic nature. Pressure pulses with much larger amplitude are also not identified on vertical channel. Horizontal #2 channel has much larger amplitude than of vertical channel when it is active as seen in Fig. 4. This also supports no evidence of pressure events on horizontal #2 channel. If pressure pulses are generated by pressure change of surrounding water due to local upwelling of hot (or warm) water from the vent, the above observation can be explained. It is also supported by the evidence that change of OBS's location shows drastic decrease of number and amplitude of events. The nature that most of pressure pulses have negative first breaks seems difficult to happen for acoustic signals. If pressure pulses are shaking noise caused by unistable sitting pose, these should be observed simultaneously by seismometers. All of observations suggest that pressure pulses are not acoustic signals, but are generated by upwelling of hot water from the thermal vent intermittently and the circulation of water generates negative pressure change at the location of OBS. It is not likely that seismic oscillation such as in Fig. 4 (d) is volcanic tremors generated by volcanism. The most possible cause for such oscillation is bottom water currents.

Using multi-narrow-beam bathymetry data (unpublished data) taken by the current "Yokosuka" cruise combined with the results of cruise in 1993 (Gamo et al., 1993), the detailed topographic maps (Figs. 8 and 9) were generated for south of Mariana Trough and Mariana forearc region, respectively. In Fig. 8 (a), there are two different kinds of topographic lineaments, the one with NNE-SSW strike located in the westward and the other with echelon like lineaments crossing seamounts with N-S strike located in the eastward. Westward lineament corresponds to the axis of Mariana Trough. The other group of lineaments exactly corresponds to the thermal vent chain found by a series of the current dives (e.g. #185) just on the summit of "SNAIL Haven" seamount. The eastside lineament is a little wider width between 13°25' and 13°40'. N-S trend is also noticed just on the seamount at 13°10' ("Usagiyama" seamount). At this seamount, one of "Shinkai 6500" dive (#191, Ms. Masuda) found hydrothermal yellowish deposits along one of very steep walls, which cut the seamount by N-S strike. The yellowish deposits are clear evidence of hydrothermal activity (Masuda, personal communication). The Usagiyama seamount is cut by an an-
Fig. 8 Bathymetry map of Mariana Trough. (a) 50m contours and (b) color map with 200m contours. N-S faults cut submarine volcanos in the middle of mapping seen in (a). Mariana Trough axis runs with NNE-SSW strike in the left side of the map. E-W lineations across a seamount (Usagiyama) in 13°10'.
other lineament with the strike of E–W around 13°10'. This seems a conjugate fault set of N–S lineaments. In the south of 13°10', the Mariana trough axis changes the strike westward. The N–S strike of eastward lineament is slightly different from the one of westward lineament which has been thought as spreading axis. The N–S strike lineament is similar to the main strike of the middle and north Mariana Trough.

OBS at so called "SNAIL Haven" seamount recorded numerous pressure pulses, which are estimated as evidence of pressure decrease due to hydrothermal upwelling. The seamount is located 18km eastward of the south Mariana Trough and it is cut by N–S trend fault found in the bathymetric map. The observation of pressure pulses matches with the observation of high temperature (207°C) at "Geo- phonic vent", at 1 m distance from OBS. Any earthquakes beneath the seamount, however, were not observed during 7 days period, suggesting rather low intensity volcanism occurring on this seamount caused by the faulting activity. This might suggest that the eastward lineament is a kind of presently active rifting zone. The rifting stage of the east lineament seems very juvenile or extinction stage.

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References


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(Notice) Photos are given on the following page.
Photo 1  OBS beside of thermal vent ("Geo-phonie site") surrounded by pillow lava. Alviniconcha colonies seen as white.  (a) Far view and (b) near view.