

「しんかい2000」を用いた海底地震観測によってわかった沖縄トラフ・伊平屋海嶺の熱水活動の周期性の証拠

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沖縄トラフの伊平屋海嶺における熱水割れ目（通称「シロウリガイ地点」）近傍において海底地震計・ハイドロフォン観測を実施した。海底地震計のハイドロフォンセンサーに大振幅の圧力変動が観測された。このような変動は地震計には検知されなかった。割れ目の目視観察と、潜水艇での温度観測値、ハイドロフォンの波形の間には高い相関があることがわかった。白い物質が熱水割れ目から噴出する間、潜水艇で計測された温度値は上昇を示した。この間ハイドロフォンは大振幅の長周期的変動を記録し、これらのことはハイドロフォンによって観測された圧力変動が熱水割れ目からの熱水の上昇運動を示していることになる。

大振幅の圧力変動は明瞭な120時間周期と非周期性の変動の両方を示した。熱水上昇運動の周期性は潮汐との相関を示唆している。海洋潮汐による海面変動と地球潮汐による面積歪みと圧力変動とを比較した結果、これらの間の良い相関がわかった。圧力変動は負の歪みに現れ、このことは熱水の上昇運動が太陽-月系による圧縮力場によって加速されるか、トリガーされることを示している。この観測はマリアナ背弧海盆での観測と類似であり、典型的な海洋底拡大の場所である大西洋中央海嶺（TAG 地域）の中央谷における観測と逆である。これらは背弧海盆型のリフティングと海洋底拡大型における流体の循環システムの違いを示している可能性がある。

観測期間中地震活動は低かった。これは以前の沖縄トラフにおける観測結果と対照的である。特に、観測を行った熱水ベント近傍の地震は観測されなかった。また地震計にも火山性脈動は観測されなかった。これは「シロウリガイ地点」では、少なくとも観測期間中は、海底火山噴火の状態にはなかったことを示している。

キーワード：熱水ベント、熱水活動の周期性、地球潮汐、伊平屋海丘、海底地震計

Evidence for Periodic Hydrothermal Activity at the Hydrothermal Vent in the Iheya Knolls, in the Okinawa Trough, Japan, Measured by an OBS/H with the Assistance of the Submersible "Shinkai 2000"

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An OBS/H experiment carried out near to a hydrothermal fissure vent in the Iheya Knolls (so-called "Clam site"), in the middle Okinawa Trough, Japan, showed a pressure variation with a large amplitude observed by a hydrophone, but could not be identified using seismometers. A good correlation was found among a visual observation of the "Fissure Vent", temperature measurements by the submersible and a pressure variation observed by the hydrophone. White fragments exploding from the "Fissure Vent" were visually observed during a temperature increase measured by the submersible, while the hydrophone showed very large low-frequency signals, suggesting that the pressure variation detected by the hydrophone indicates hydrothermal up-welling from a fissure vent.

The large-amplitude pressure variation shows a clear periodic appearance of approximately 12 hours with some non-periodic activity. The periodicity of hydrothermal up-welling suggests a relation to the tide. A comparison of the pressure variation with two types of tides, areal strain by the earth tide and a sea-level change due to the ocean tide, indicates a better correlation with the areal strain than with the sea-level. The pressure variation appeared during negative strain, caused by a compressional force, suggesting that hydrothermal up-welling is accelerated or triggered by a compressional stress field, caused by the solar-moon system. This is similar to an observation of the Mariana backarc basin, but opposite to the case of the TAG site, in the rift valley of the Mid-Atlantic Ridge, which is a typical oceanic spreading center. There is a possibility that this might indicate a difference in the fluid-circulation systems between backarc type-rifting and oceanic type-spreading.

The seismic activity was low during the present experiment, in contrast to the previous OBS experiments in the middle Okinawa Trough. Especially, no nearby earthquakes were observed. Also, no volcanic tremors were observed based on seismometer records, which might imply that the Iheya "Clam site" is not ready for any submarine eruptions, at least during the current observation.

Key words : Hydrothermal vent, Periodic hydrothermal activity, Earth tide, Iheya Knolls, OBS/H

1. Geophysical setting of the Okinawa Trough and objectives of the experiment

The Okinawa Trough is a backarc basin corresponding to the Ryukyu Trench-the Okinawa forearc (Ryukyu island chain) system, and is an active back-arc basin similar to the Mariana Trough and the Lau Basin (Fig. 1(a)). The total length of the Okinawa Trough is more than 1,200km. The character of the Okinawa Trough has been summarized by Oshima et al. (1988). The depth for the axial zone of the Okinawa Trough is 2,000-2,200m in the south, 1,000-2,000m in the middle and 600-1,000m in the north. The Okinawa Trough shows a graben (depression)

structure covered by thick sediments, especially in the southern part. The wall of the graben shows step-like normal faultings. There are some igneous intrusive bodies in the axial zone of the depression. In the middle, a chain of small knolls forms a ridge. The Iheya Knoll is one example. A series of axes of the Okinawa Trough shows an echelon-shape structure from the western part of central Kyushu to the north-eastern coast of Taiwan. The Okinawa Trough is cut perpendicularly by two major channels (called Tokara and Kerama). The stress field in the Okinawa Trough is tensional; it is thought that graben structures were created by the N-S tensional stress

field. Studies of the crustal structure of the Okinawa Trough show crustal thinning in the south (Lee et al., 1980; Hirata et al., 1991) and an intermediate thickness of the crust in the middle (Nagumo et al., 1986), indicating that crustal thinning was caused by an extensional force occurred in the south, and is an ongoing process in the middle. Heat-flow measurements have shown high heat-flow values ($\sim 1\text{W/m}^2$) at the axis of the middle Okinawa Trough (Yamano et al., 1989). Sibuet et al. (1987) have suggested that the backarc rifting of the Okinawa Trough with submarine volcanism was initiated 2m. y. ago at the Plio-Plistocene boundary in the southern part, and has subsequently propagated to the north.

The hydrothermal activity was surveyed in the middle Okinawa Trough using "Shinkai 2000"; hydrothermal vents, chimneys and submarine "Giant Clams" and "Galathea" were found at the so-called "Clam site" in the Iheya Knolls of Iheya depression area at ($27^{\circ}30'35''$; $126^{\circ}55'127''10'$) (Kimura et al., 1987; Tanaka et al., 1989). The temperature of one of fissure in the "Clam site" was 220°C . At the so-called "Jade site" in the Izena hole, which is located 30km south of the Iheya depression, hydrothermal vents and chimneys were also found (Tanaka et al., 1990).

A seismic observation using ocean-bottom seismometers in 1984 (Kasahara et al., 1988) and in 1992 (Sato et al., 1994) also showed the existence of intensive seismic activities resembling to an earthquake swarm. Hypocenters in 1992 were located along the wall of the graben and ridges in the Iheya depression. The results of seismic observations also support an ongoing rifting process in the middle Okinawa Trough and submarine volcanism associated with backarc rifting. However, the detailed pattern of hypocenter distribution in 1992 showed low seismicity at a high heat-flow zone, suggesting the complementary nature of seismicity associated with the brittle fracture and ductile state by thermal heating.

In 1993, a digital ocean bottom seismometer with a hydrophone was deployed just 1m bedside a high-temperature (208°C) hydrothermal vent, located in the southern Mariana Trough, with the assistance of

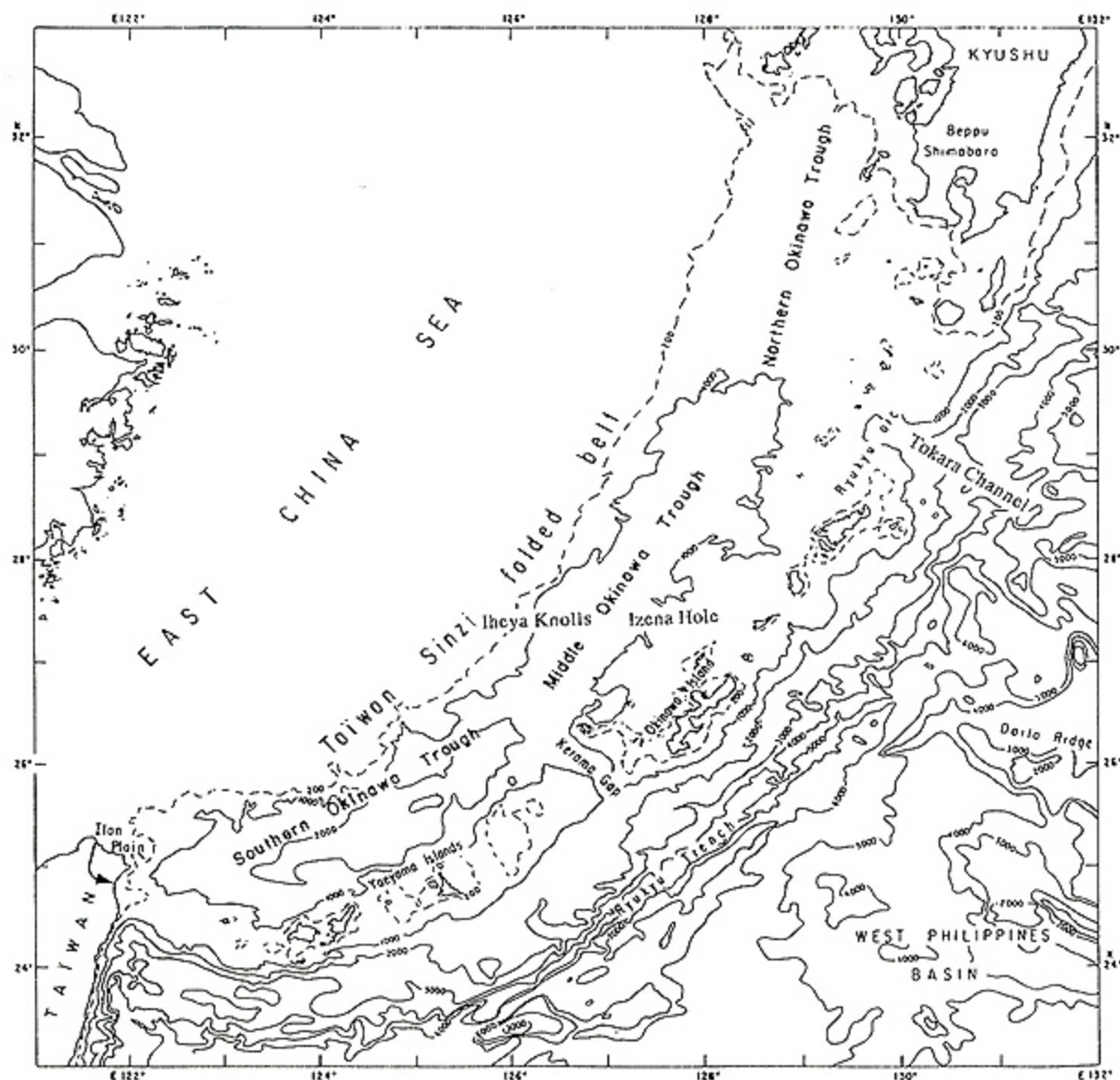
"Shinkai 6500". The result shows high-amplitude, low-frequency (c.a. 0.017Hz .) pulses, which appeared on hydrophone traces, but not on seismometer traces (Kasahara et al., 1994; Sato et al., 1995). Since the many low-frequency pulses observed only by the hydrophone appeared to be isolated from each other, these are called "pressure pulses". Kasahara et al. (1994) have proposed that hydrothermal up-welling is the cause of frequency pressure pulses. The relation between the sea-level change v.s. the number of pressure pulses shows a strong correlation between the two (Sato et al., 1995). The hydrothermal vents are located on the lineation of the rift zone along the eastern wall of the south Mariana Trough; hydrothermal venting along the rift zone suggests that a new rifting process is occurring in the eastern edge of the south Mariana Trough axial zone (Kasahara et al., 1994).

Although volcanic tremors associated with submarine volcanism were not observed in the Mariana Trough during the 1993 experiment (Kasahara et al., 1994), it would be interesting to examine whether it exists or not in the middle Okinawa Trough. Since very high-level micro-seismicities were observed during past OBS observations in the middle Okinawa Trough, it would be interesting to study the relation between the seismic activity and the hydrothermal activity of vents.

It is important to study the behavior of pressure pulses for different types of backarc hydrothermal vents, and to compare the nature of the pressure pulses of each, if observed. For the above-mentioned objectives, an OBS/H observation using "Shinkai 2000" was carried out at the "Clam site" of the Iheya Knolls region of the Iheya depression in October, 1994.

2. OBS/H field experiment and visual observation of the "Clam site"

A digital ocean-bottom seismometer with hydrophone, called MOOBS/H (Kasahara et al., 1995), was used. The MOOBS/H was operated in a buffer mode, which means continuous recording while a 256kB memory buffer is full. One MOOBS/H file corre-

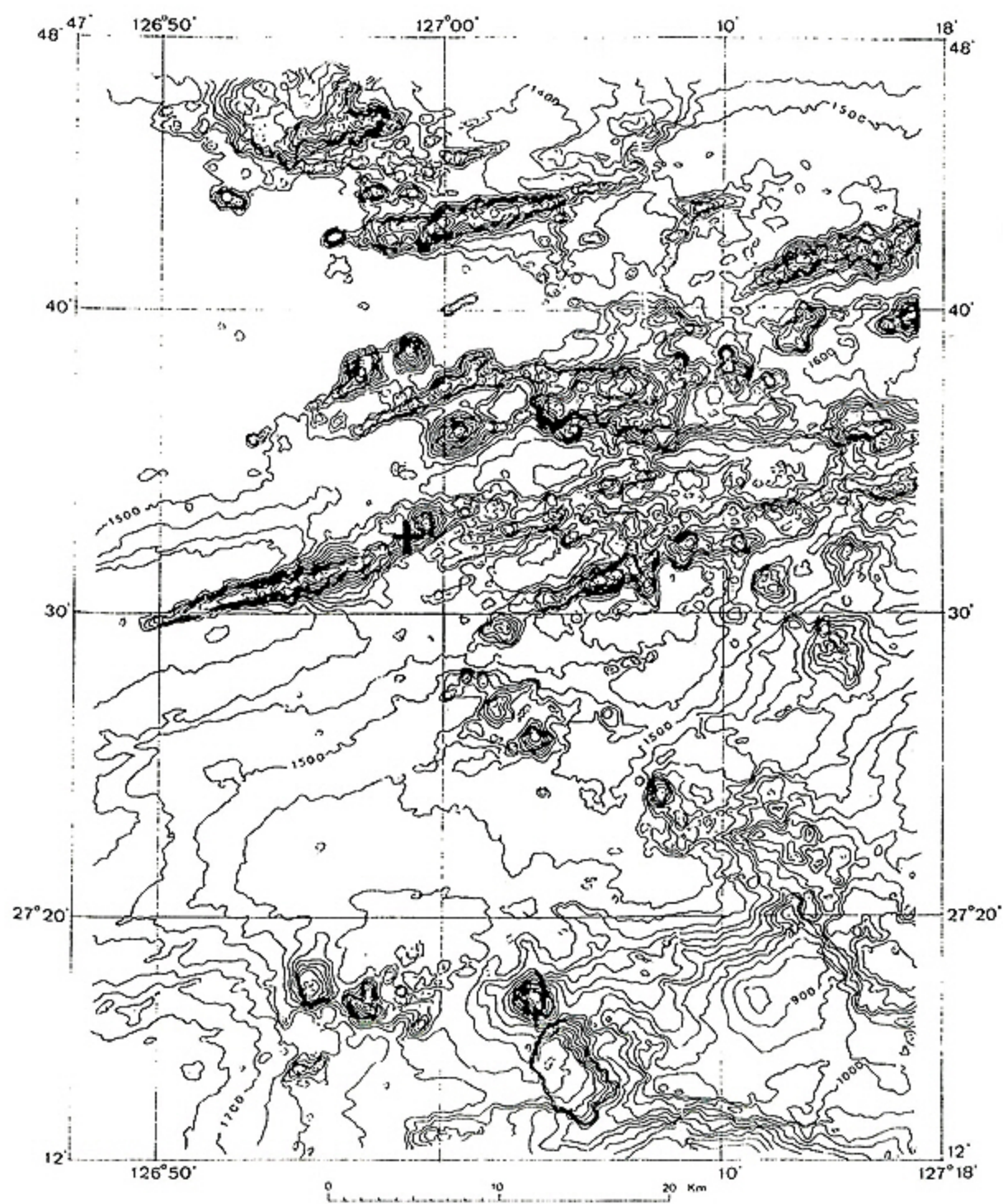


(a)

Fig. 1 (a) The Okinawa Trough and the Ryukyu island chain (modified after Sibuet et al., 1987). (b) Detailed bathymetric map of the middle Okinawa Trough (after Oshima et al., 1988). The diving and OBS/H position are shown by the cross hair. (c) Location of dive #677 and OBS/H with detailed bathymetric contours.

sponds to 7 min and 16 seconds. The total size of one MO disk is 320 Mb. Six channels of the MOOBS/H were assigned to low-gain and high-gain vertical seismometer channels, two high-gain horizontal seismometers perpendicular each other, and low-gain and high-gain hydrophone channels. Low-gain and

high-gain mean 20dB and 40dB amplification with a frequency spectrum of DC-30Hz flat, respectively. The sensitivity of the seismometers and hydrophone are 1.69V/(cm/sec) and -187dB/(μ V/Pa), respectively. A MOOBS/H has a 16bit A/D converter; the LSB of the 16bit converter corresponds to 0.76 μ V if 40dB



(b)

Fig. 1 (continued)

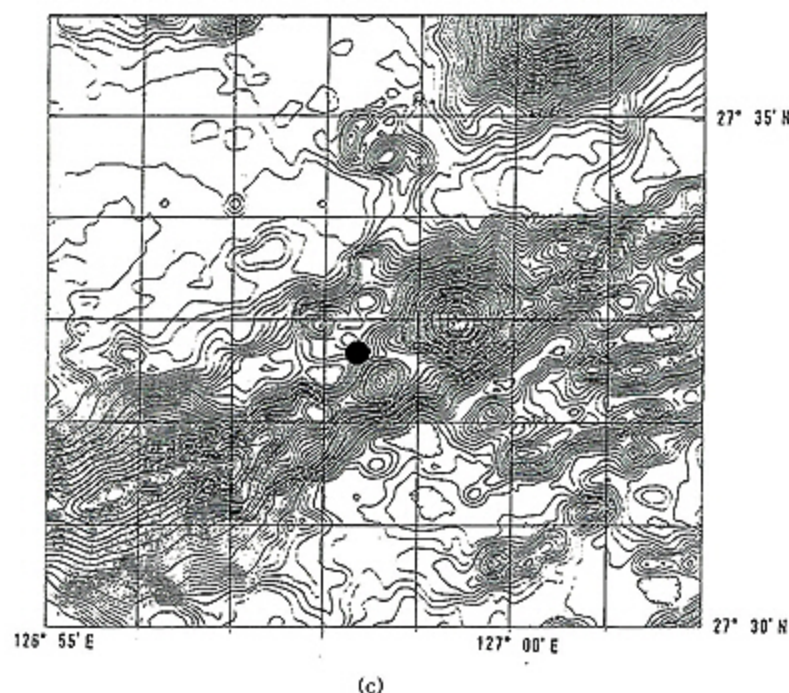


Fig. 1 (continued)

amplification is used (this equals 0.45μ (cm/sec)). However, the real instrumental noise level was estimated as to be approximately 2μ (cm/sec). A hydrophone was tied tightly to the external frame, and seismometers were mounted inside of an aluminum sphere pressure case of 60cm diameter. The MOOBS/H was deployed by a free-fall mode and retrieved by a pop-up mode using an acoustic release system.

At 06:21 AM, in October 16, 1994, we deployed a MOOBS/H (hereafter, OBS/H) from M/S "Natsushima" near to the vent field of the Iheya depression, which was repeatedly surveyed by "Shinkai 2000" (Fig. 1(b) and (c)). Kasahara (one of the authors) dove to the Iheya Knolls region using "Shinkai 2000" submersible (Dive #766) to find the OBS/H, and moved it to the "Clam site". Table 1 shows the log of the #766 dive operation of "Shinkai 2000". The submersible track of dive #766 is shown in Fig. 2. Kasahara visually identified the OBS/H from the submersible at 11:32, which was deployed from M/S Natsushima. The OBS/H was sandwiched by two rocks at a depth of 1,380m (Photo 1) in a flat plain covered

by thin sediments. Photo 1 also shows an external view of OBS/H used in this experiment. The OBS/H was lifted up the trapped OBS/H by a manipulator of the submersible, and was carried to the "Clam site" of the Iheya Knolls region. The vent field was located at approximately 400m in the southwest direction of the landing site of OBS/H. Between the landing site and the target "Clam site", there is a tiny ridge with a relative height of 30m. We arrived at the "Clam site" 1.5 hours later after leaving the first OBS/H position.

In the "Clam site", there are several hydrothermal vents called "Pyramid Chimney", "Fissure Vent", "Baby Chimney", "Yellow Ball" and "Kiko Chimney". All of these hydrothermal vents are located within a 50m-diameter circle (see Gamo et al., 1991). One small chimney was sampled during the present dive (described as below). Among these hydrothermal vents, the fissure vent is the hottest one, whose temperature was reported to be 220°C in 1988 dive (Tanaka et al., 1989). The fissure has a length of approximately 3m, and the opening of the fissure is

Table 1 Diving log of #677 on October 16, 1994. Observer was J. Kasahara. Numbers correspond to ones in Fig. 2.

- #1: 11:05 : Submersible arrived at bottom; D=1,387m.
 #2: 11:20 : D=1,383m.
 #3: 11:28 : D=1,381m.
 #4: 11:32 : D=1,382m; Visually Identified OBS/H.
 #5: 11:43 : Lift up OBS/H.
 #6: 11:51 : D=1,376m; A=9m.
 #7: 11:59 : D=1,353m; A=14m.
 #8: 12:06 : D=1,365m; A=4m.
 #9: 12:13 : D=1,354m; A=8m.
 #10: 12:17
 #11: 12:25 : D=1,385m; A=6m.
 #12: 12:32 : D=1,387m; A=8m.
 #13: 12:37 : D=1,388m; A=6m.
 #14: 12:56 : D=1,388m; A=6m.
 #15: 13:06 : D=1,388m; A=6m; Visually Identified "Pyramid Chimney".
 #16: 13:14 : D=1,389m; A=4m; OBS/H set-up started.
 #17: 13:25 : D=1,394m; OBS/H set-up finished. Sampled four rock specimens.
 #18: 14:27 : Sampled one rock specimen.
 #19: 14:34 : D=1,388m.
 #20: 14:53 : D=1,388m; Sampled one chimney sample of "Pyramid Chimney".
 #21: 14:57 : Visually Identified test buoy for bottom current.
 #22: 15:11 : D=1,353m; Visually observed a large colony of "Giant Clam".
 #23: 15:14 : D=13:52; Visually observed a large biological colony.
 #24: 15:16 : D=1,346m; At top of crest. Visually observed a colony of "Giant Clam".
 #25: 15:22 : D=1,346m; Visually identified finishing buoys.
 #26: 15:27 : D=1,346m; Submersible left bottom.

Note: D: Depth from surface; A: Depth to bottom.

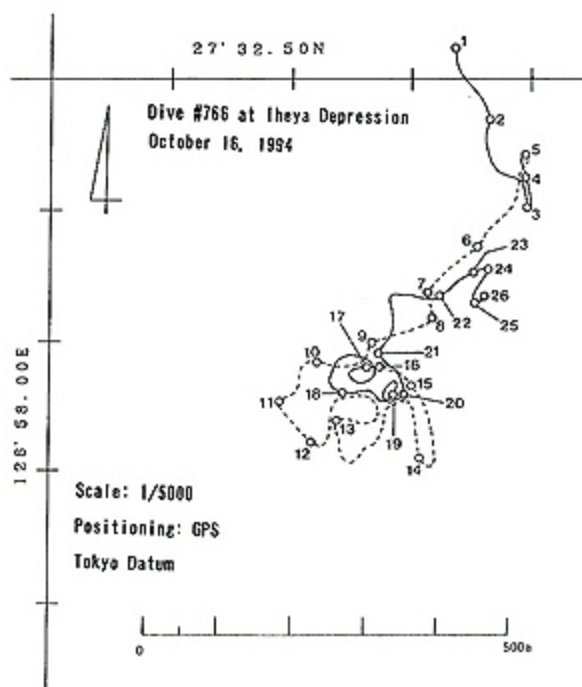


Fig. 2 Route map during "Shinkai 2000" dive #677. Numbers correspond to ones in Table 1. No. 1. Landing point of "Shinkai 2000" at 11:05; No. 4. visual identification of OBS/H at 11:32; No. 5. the first OBS/H landing position at 11:43; No. 17. the second OBS/H position beside of the "Fissure Vent" at 13:25; and No. 20. a chimney collected at the "Pyramid Chimney" at 14:53.

several cm maximum, which is covered by yellowish-white materials. Smearing water was observed during the present survey. Although other hydrothermal vents, such as "Baby Chimney" and "Pyramid Chimney", also showed smearing water, the smearing for the fissure was the most active. There were many linear fractures on the ground with sheet-flooding-like smoothness. Most of the fractures on the ground seemed to be roughly east-west strike. The linear fractures could be traced by the filling of white deposits.

The OBS/H was set at 13:25 beside the Fissure Vent with a distance of approximately 1m. The location of OBS/H was 27°32.772'N, 126°58.267'E, at 1,394m deep (Photo 2). During this operation, the temperature of the fissure was not measured, due to a limitation on the payload.

After observing the characteristics of the fissure, other vents and the tectonic structure of the "Clam site", the submersible left the sea-bottom at 15:27. One chimney having a grayish-white color was observed at the foot of the "Pyramid Chimney" (a corn-like chimney seen in Photos 3 and 4), which has not been reported. The "Pyramid Chimney" is 2-3m high and has the shape of a tiny pyramid. The height of the chimney was approximately 30cm and the diameter of its root (Photo 5) was approximately 6cm, indicating that this size of the chimney can be formed during a relatively short period, say, roughly a few years, if this has grown up recently. This chimney was sampled after a visual observation from the submersible. The chemical components will be analyzed by other scientists.

Colonies of "Galathea", a kind of prawn, were identified at the "Fissure Vent", "Pyramid Chimney", "Baby Chimney" and "Yellow Ball". A "Blind Shrimp" colony was seen at "Baby Chimney". Many white "Giant Clam" colonies were observed on the crest of the northern tiny-ridge north of the vent field. It was observed that some were dead, but some were alive.

We retrieved the OBS/H at 09:05 on October 20, 1994 by an acoustic release. A five-day seismic record (in total) was obtained.

The OBS/H records were pre-viewed by a NEC-PC and data on the MO disk were transferred to a workstation by the ftp utility. Waveform records were displayed by "X-wave6" and drum-style display software developed by the present authors (Kasahara et al., 1995).

3. Seismic results

Fig. 3 shows hydrophone and vertical seismometer records made during observations. Fig. 3(a) shows the record from landing to relocation to the vent field on October 16, 1994. One trace corresponds to 30 min. Before 11:40, OBS/H was located at 400m distance from the "Clam site". After 13:25, the OBS/H was moved to the Fissure Vent. It can be seen that although the record on the hydrophone channel is very quiet before 11:40, the OBS/H records after 13:25 show a low-frequency movement with an extremely large amplitude on the hydrophone trace, but not on the vertical seismometer trace. The figure at the top left of each hydrophone record in Figs. 3 (a) through 3 (e) shows an estimation of the ocean tide and the areal strain at the OBS/H location. A comparison of the pressure variation and the sea-surface change shows that most parts of the large pressure variation tend to appear at the ocean tide during a transient stage from high to low, or low to high, at the negative areal strain. In any case, a 12-hour period is clearly identified, though some other pressure-change activity appeared between two periodic activations.

More than 15 earthquakes were observed by the OBS/H (Fig. 3). These earthquakes were not only recorded by seismometers, but were also recorded by a hydrophone, especially by hydrophone traces after high-pass filtering. Fig. 4 shows an enlargement of a portion for two earthquakes. In the no-filter traces shown in (a) and (c), hydrophone channels (chs. 5 and 6) show high-frequency seismic waves superposed on low-frequency signals. After using a high-pass filter (>5Hz), earthquakes are clearly identified in (b) and (d). The apparent amplitude of the earthquakes on the hydrophone (ch. 6) is nearly 1/5 that of the vertical seismometer (ch. 2), con

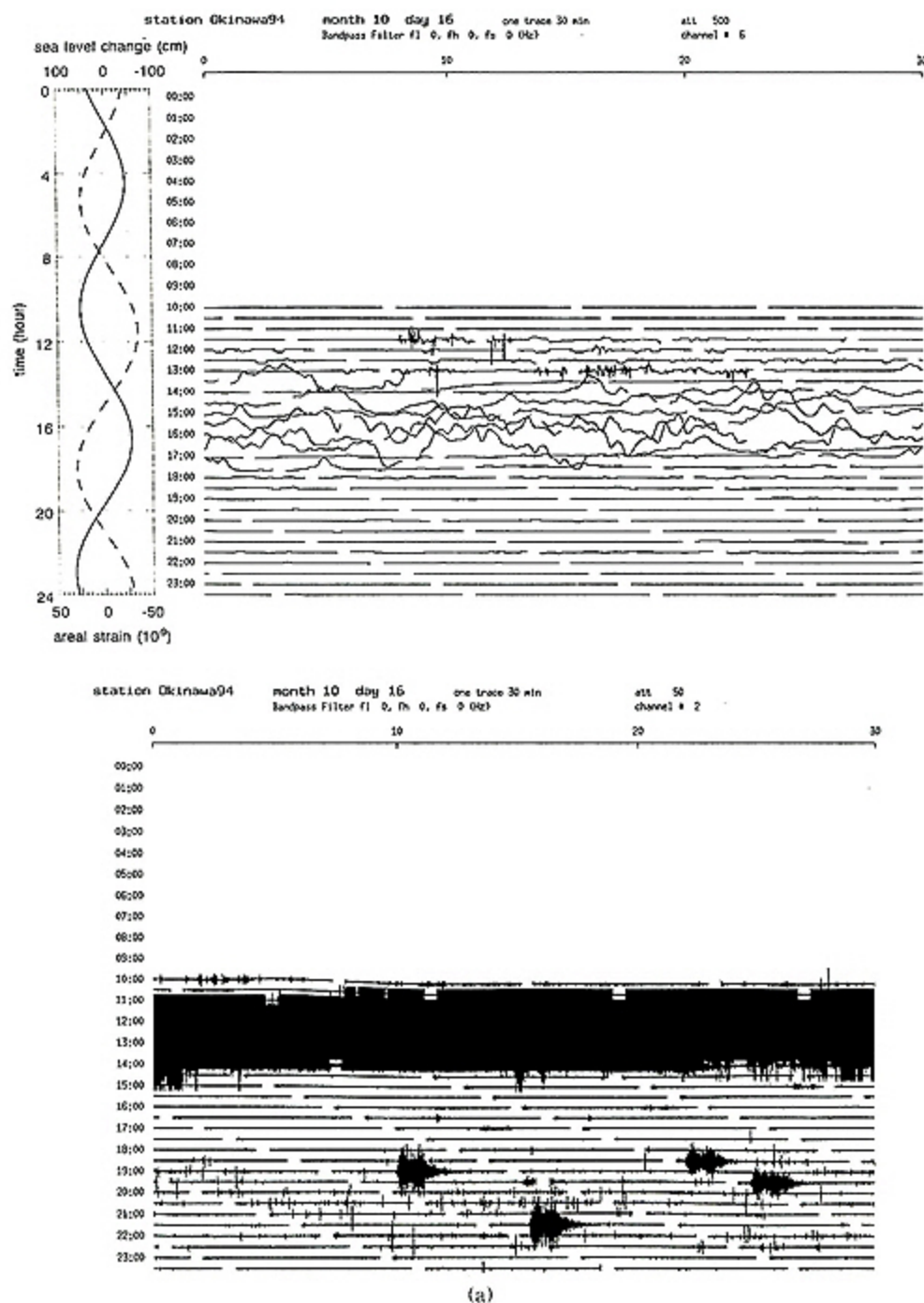
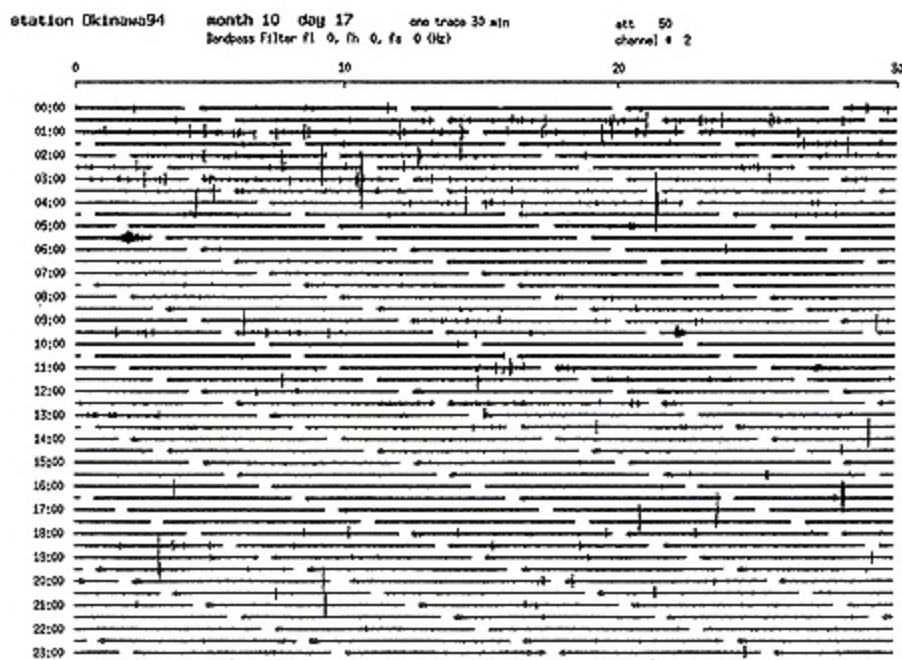
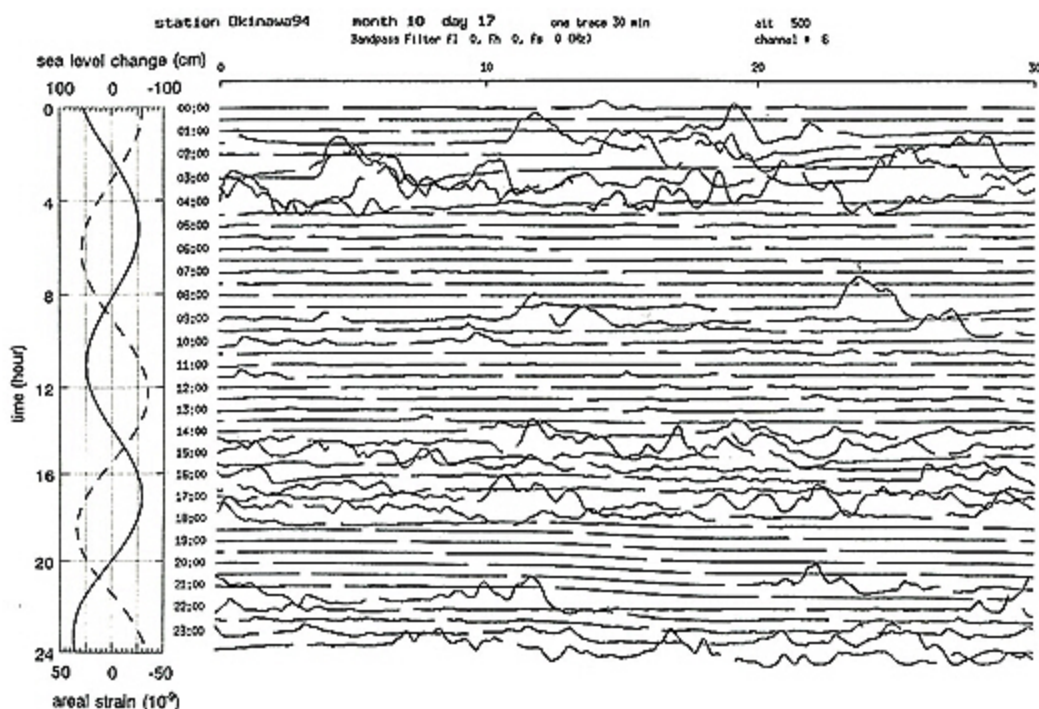
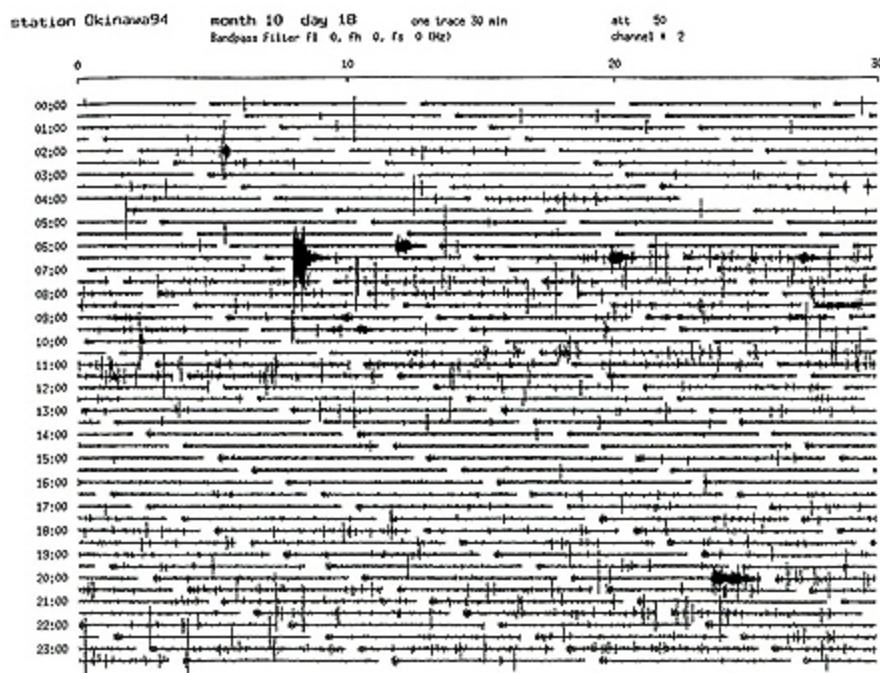
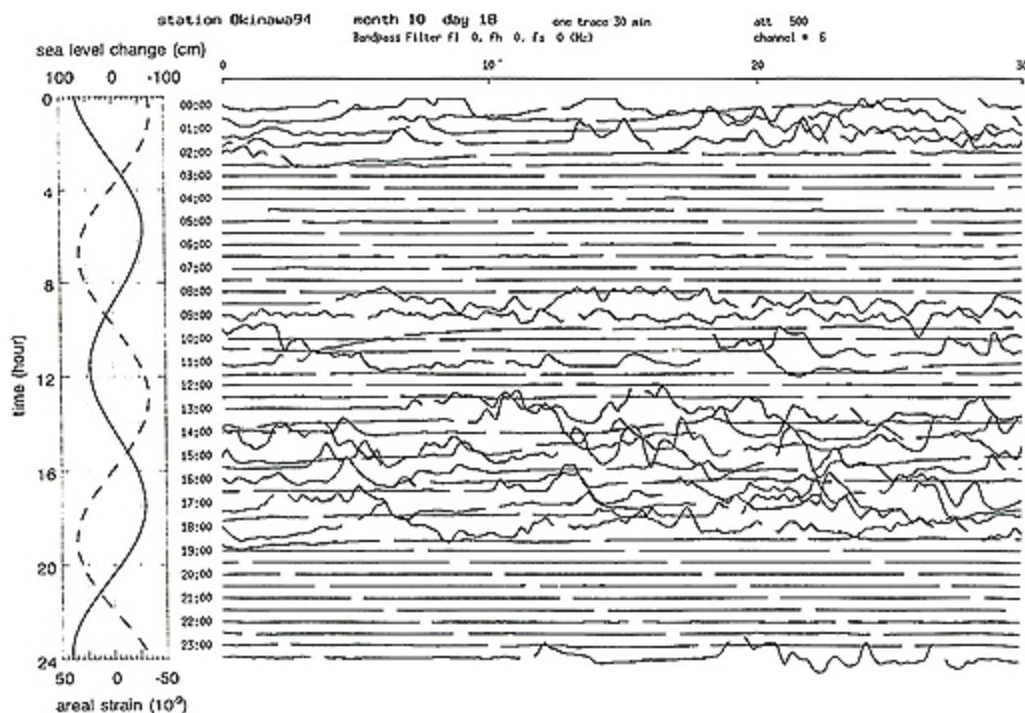


Fig. 3 One-day record observed by a low-gain hydrophone and a low-gain vertical seismometer. One trace is 30 min. (a) October 16, 1994. The upper figure is the hydrophone and the lower figure is the vertical seismometer. (b) October 17; (c) October 18; (d) October 19; and (e) October 20. Notice that the high amplitude of low-frequency signals appear every 12 hours. In (a), the OBS/H was at the first site before 10:40, and was at the second site after 13:25. Between two locations, the OBS/H was carried by the submersible. The top-left of each hydrophone record shows the sea-level estimation (dotted line) and the areal strain (solid line). Good agreement between low-frequency signals on the hydrophone and areal strain can be seen. The apparent display scale of the hydrophone is 50-times larger than that of the seismometers.



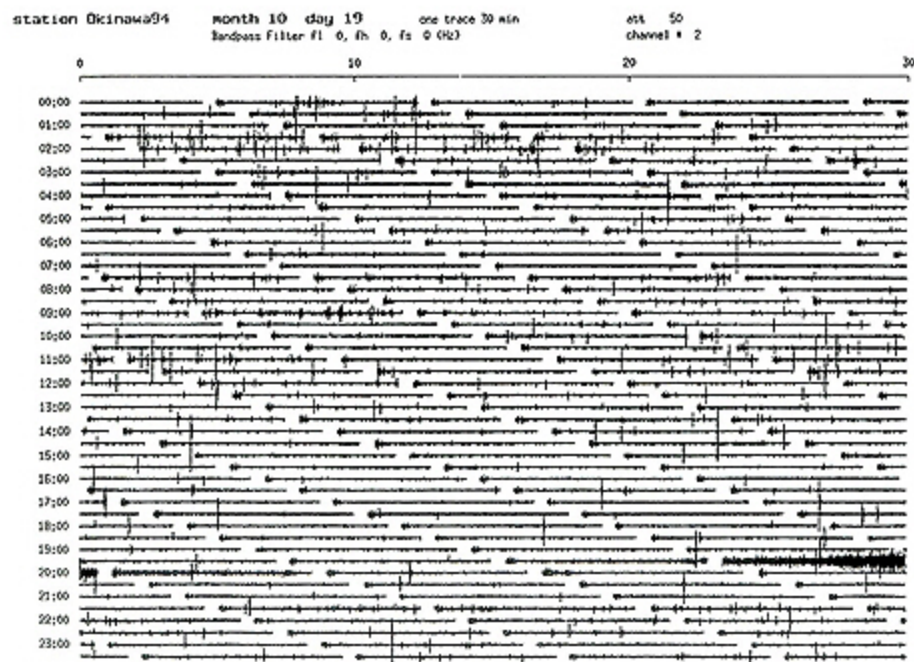
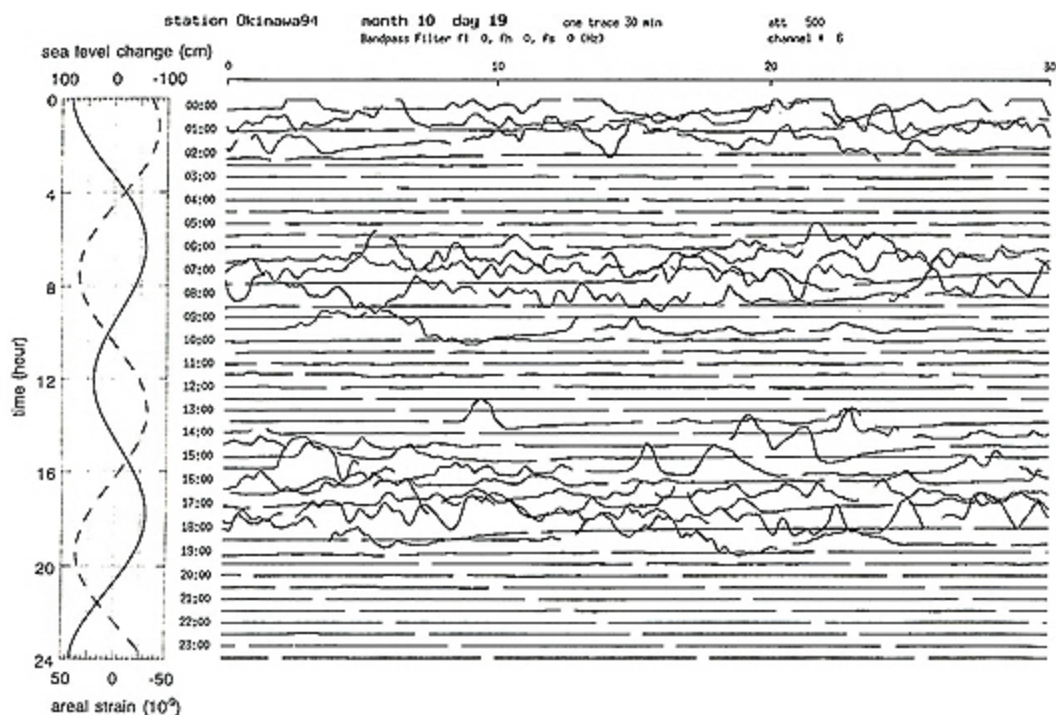
(b)

Fig. 3 (Continued)



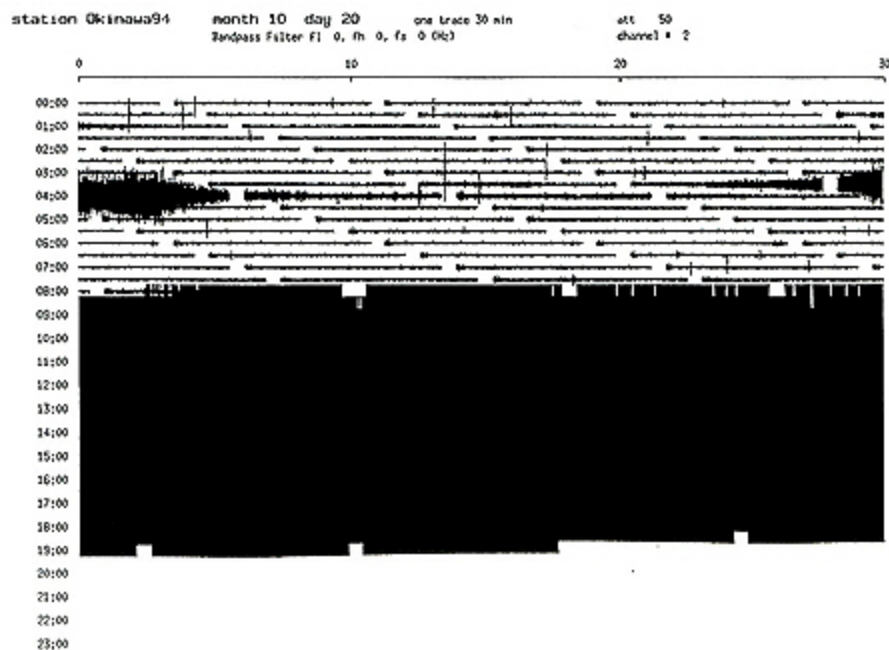
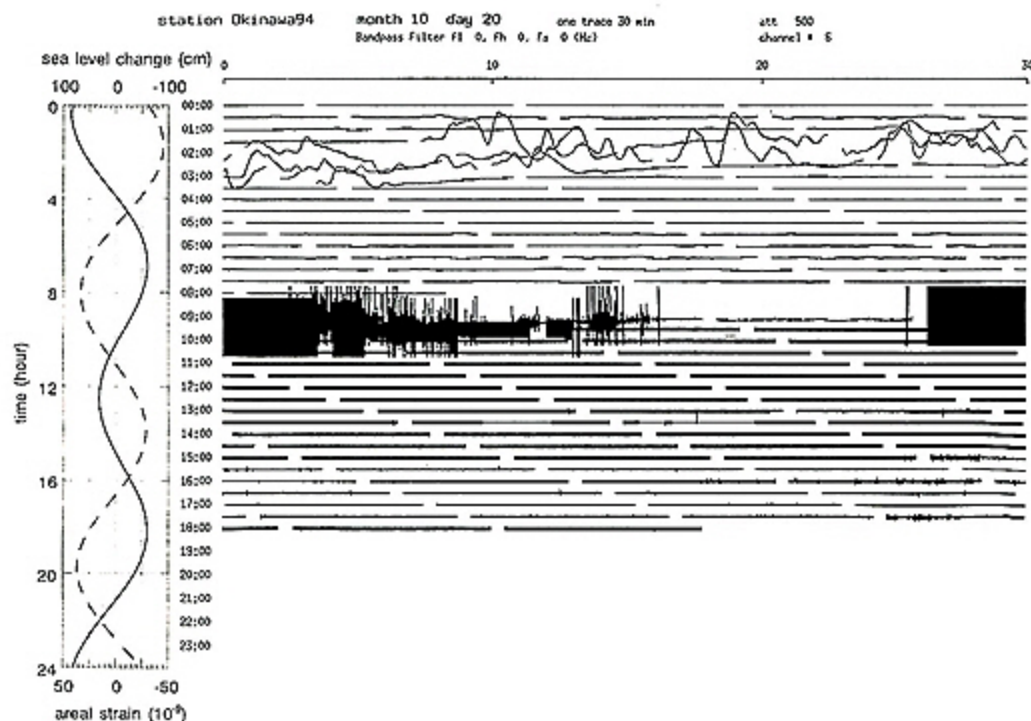
(c)

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(d)

Fig. 3 (Continued)



(e)

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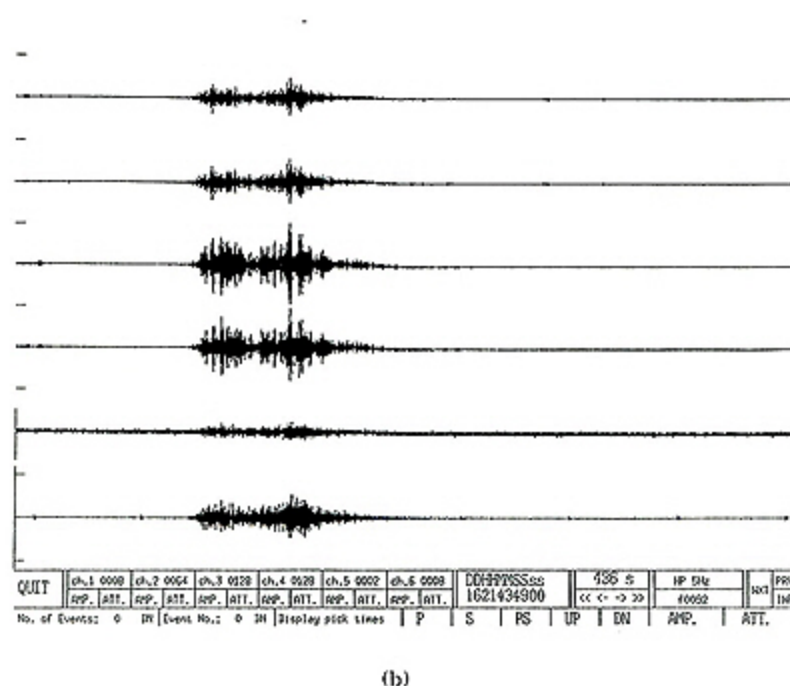
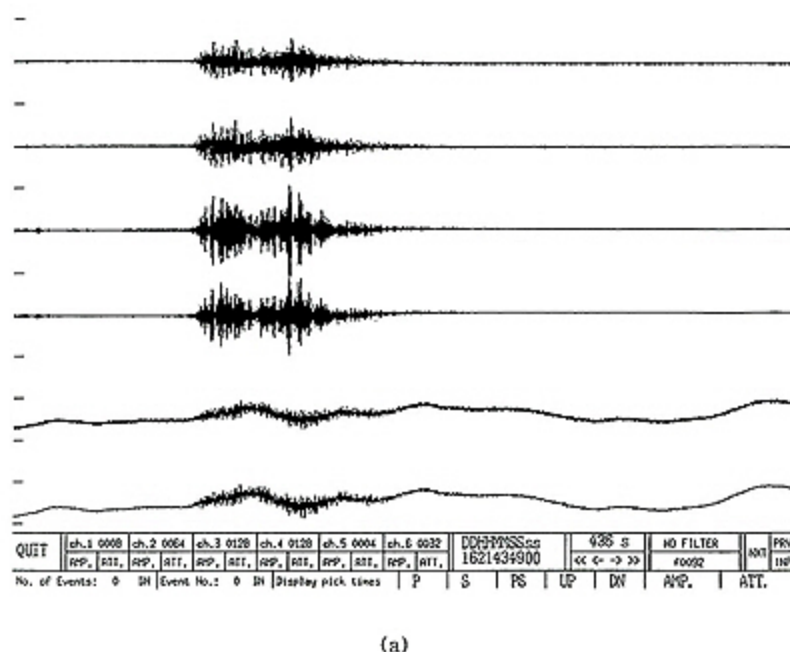
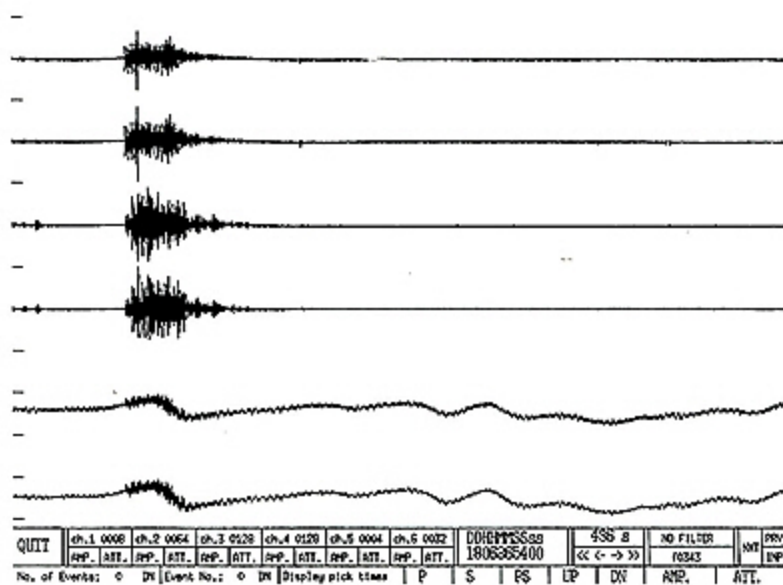
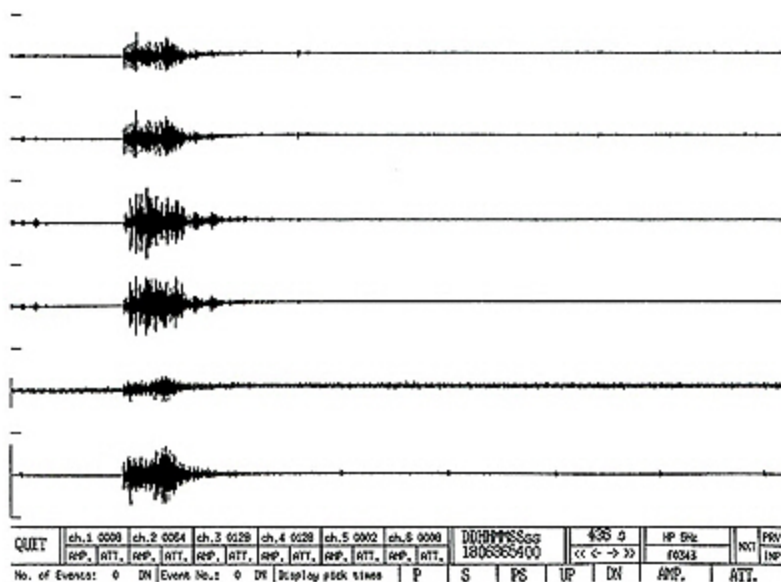


Fig. 4 Two examples of natural earthquakes. (a) and (c), No filter; (b) and (d), 5 Hz high-pass filter. The total length is 436 seconds. (a) and (b), begin at 21:43:49 of October 16, 1994; (c) and (d), begin at 06:36:54 of October 18, 1994. From the top trace to the bottom trace for each figure: ch. 1, vertical low-gain; ch. 2, vertical high-gain; ch. 3, horizontal-1 high-gain; ch. 4, horizontal-2 high-gain; ch. 5, hydrophone low-gain; ch. 6, hydrophone high-gain. High gain 40 dB and low-gain 20 dB. The vertical units from chs. 1 through 6 between two ticks are: in (a) (4.25, 3.4, 6.8, 6.8, 2.15, 1.7) mV; (b) (4.25, 3.4, 6.8, 6.8, 1.06, 0.425) mV; (c) the same as (a) and (d) the same as (b). The actual ground motion and pressure were obtained by dividing each sensitivity.



(c)



(d)

Fig. 4 (Continued)

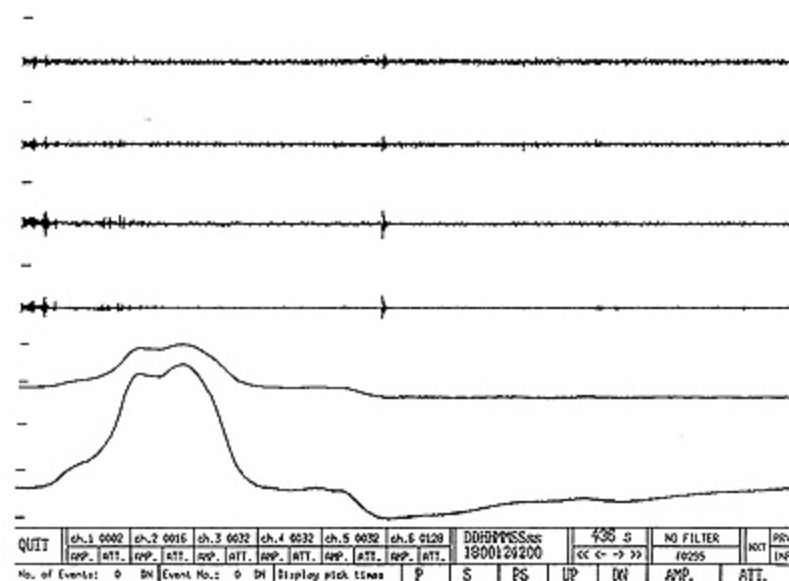


Fig. 5 Enlargement of Fig. 3(c), pressure variation seen on hydrophone trace. The captions are the same as in Fig. 4, except for the vertical scale. The vertical units from chs. 1 through 6 between two ticks are: (1.06, 0.85, 1.7, 1.7, 17.0, 6.8) mV. Note that the vertical scales for chs. 5 and 6 are large compared to chs. 1-4.

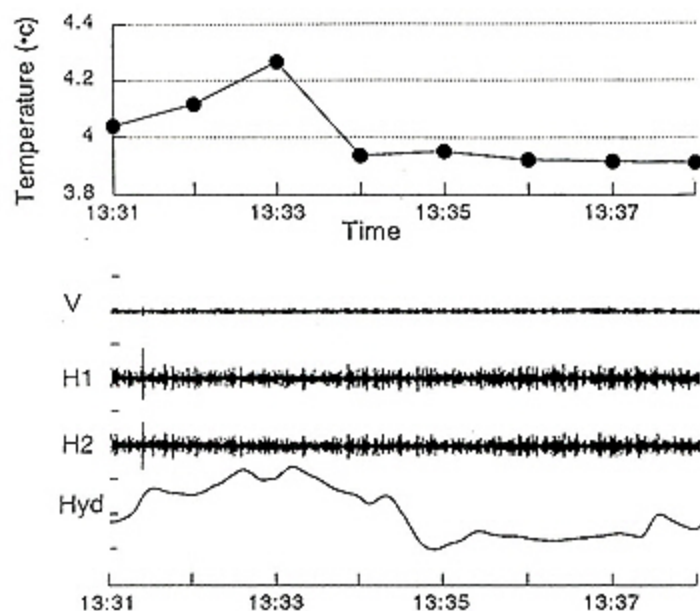


Fig. 6 Comparisons of the pressure variation on the hydrophone, seismometer outputs and temperature measurement (a) Temperature measurement by the submersible when the submersible is at 4 m distance from the fissure. (b) Pressure variation and seismometer outputs corresponding to (a). During the maximum of pressure, the temperature also shows the highest value.

sidering amplification, if we discard the sensitivity difference of the seismometers and a hydrophone, and between the physical quantities, that is, particle velocity for the seismometer and pressure for the hydrophone. The waveforms on the hydrophone are slightly different from those on the seismometer channels, because a hydrophone responds to acoustic waves in water (so-called "T-phase") and does not respond to shear waves. An earthquake-observation by a hydrophone is evidence for normal functioning of the hydrophone.

Fig. 5 shows an enlargement of a portion of Fig. 3(a). In this figure the relative vertical scale of ch. 2 is 8-times smaller than that of ch. 6. The other two horizontal (chs. 3 and 4) are 4-times smaller than ch. 6. Even though the seismometer channels are 8- to 6-times amplified on the display, and ordinary earthquakes show a 5-times greater amplitude than does the hydrophone channel, none of these seismometer channels show any evidence of low-frequency (~ 1 min period) signals, while the hydrophone shows a "pressure variation" with a very large amplitude.

The submersible submerged for approximately 50 min near to the "Fissure Vent" after the setting of OBS/H near to the fissure vent, while Kasahara observed the activity of the fissure and characteristics of the "Clam site". By his visual observation and the use of video-camera monitors of the submersible, white fragments extruding from the fissure were observed at between 13:28 and 13:35. The movement of the white fragments gives an image of boiling water at the fissure. The photos show both extinction (Photos 6 and 7) and distinction (Photo 8) of upwelling activity of the fissure, respectively. The temperature during the diving operation was measured by STD sensor equipped by the submersible. A good agreement between the pressure variation having a large amplitude and temperature measurements was obtained during a visual observation to identify the white fragments exploding from the fissure vent (Fig. 6). The STD temperature remained between 3.8 and 3.9°C during most of the dive, except at around 13:33. The temperature showed the maximum as 4.267°C at 13:33 among the whole temperature

records during this dive. The whole hydrophone records are shown in Fig. 3. This corresponds to the low-frequency variation on the hydrophone channel, strongly suggesting active hydrothermal venting at around this time. This is strong support for the relation between the pressure variation observed by a hydrophone and the thermal circulation of the venting water.

No volcanic tremors were observed by the seismometers, because volcanic tremors usually show seismic motions on seismometers at around 1 Hz, and these were not identified by the present experiment. This might imply that the vent-field was not under a condition for a submarine eruption, at least during the observation. Earthquake activity during the present observation was low compared to the previous two OBS observations. There were no nearby earthquakes during a period of 5 days.

4. Discussions

When the OBS/H was 400 m apart from the "Clam site" in the Iheya Knolls region of the Iheya depression, the hydrophone records were very quiet. When it was moved near to the "Fissure Vent" in the "Clam site", low-frequency signals were observed by the hydrophone. These, however, were not observed by seismometers, even if the amplification of seismometers was high and even if we consider the correction to the frequency characteristics of the instruments and signals (as discussed in the another paper (Sato et al., 1995)). Although ordinary natural earthquakes were also observed by both seismometers and the hydrophone, the apparent amplitude of the seismometer for earthquakes is 5-times larger than for the hydrophone. The present observation of the pressure variation with large amplitude was exactly the same as in the south Mariana Trough. Recently, the same instrument was deployed in the TAG (Trans Atlantic Geotraverse) area in the Mid-Atlantic Ridge. The OBS/H was set above a hydrothermal mound in the rift valley. Although the same kind of a pressure variation was observed by hydrophone traces, it was not observed by seismometer traces (Nishizawa et al., 1995). Three independent observations support

the hypothesis that the low-frequency signals observed by the hydrophone is an indication of hydrothermal up-welling from hydrothermal vents or mounds (Kasahara et al., 1994). In the Mariana Trough, although the pressure signals (called "pressure pulses") are of isolated nature, in both the present area and the TAG area, the pressure signals show a rather continuous change over a period of a few hours. The above-mentioned differences suggest that some differences in hydrothermal venting occur: impulsive venting at the hydrothermal vent in the Mariana Trough and continuous venting at two other places.

As can be seen in Fig. 3, a pressure variation appears with a 12-hour period with some exceptions. Fig. 7 shows comparisons among the activity of the pressure variation, areal strain of the earth tide, and the ocean tide. The comparison shows a strong correlation to both estimations. However, if the ocean tide is the cause, or a major factor, related to hydrothermal activity, strong hydrothermal activity corresponds to the transient stage from low tide to high tide, or vice versa. On the other hand, the strong

hydrothermal activity fits to the negative areal strain caused by compressional forces. This fitting is more reasonable for the cause of hydrothermal venting than the fitting at the transient stage of the ocean tide level. This observation is similar to the pressure pulses observed in the south Mariana Trough. However, the pressure variation observed by the same instrument in the TAG of the Mid Atlantic Ridge, has an opposite correlation; that is, a pressure variation appears at low-tide-level, which is caused by a tensional stress field due to the solar-moon system (unpublished data). This might indicate the difference for types of fluid circulation at rifting regions, such as backarc basins and spreading regions, such as oceanic ridges.

5. Conclusions

An OBS/H observation beside the hydrothermal "Fissure Vent" in the Iheya Knolls region of the middle Okinawa Trough showed a pressure variation with a large amplitude seen on a hydrophone channel, but not identified on seismometer channels. A good

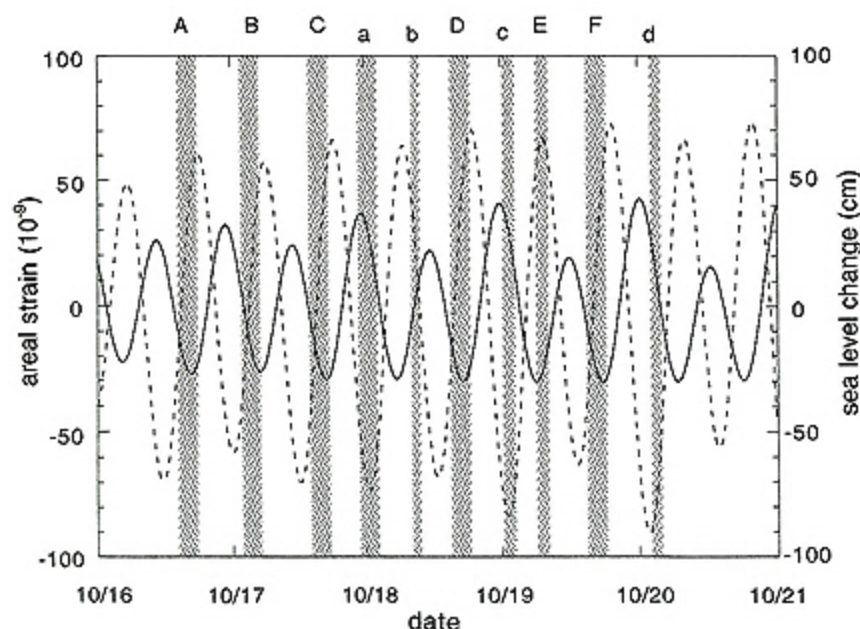


Fig. 7 Comparison of the pressure activity with a larger amplitude (shaded zone) and tides (areal strain of earth tide shown by solid line and sea-level by ocean tide). Note that the pressure variation has a large amplitude during negative areal strain. A-G correspond to 12-hours period and a-d are non-periodical activities.

correlation was found among the pressure variations on the hydrophone records, the visual observation at the "Fissure Vent", and the temperature measured by the STD sensor of the submersible. White fragments exploding from the "Fissure Vent" were observed during the temperature increase measured by the submersible. The above-mentioned observations suggest that the pressure variation detected by the hydrophone might indicate hydrothermal up-welling from the "Fissure Vent".

The pressure variation with a large amplitude shows a clear periodicity with an approximately 12-hour period with other non-periodic activities. This 12-hour periodicity implies a relation between the pressure variation and the tide. Two types of tides, the arterial strain of the earth tide and the sea-level change of the ocean tide were estimated. A comparison of these estimations with the pressure variation indicated a good correlation between the pressure and the areal strain. The pressure variation appears during a negative strain, caused by a compressional force generated by the solar-moon system. This is similar to the observation in the Mariana backarc basin, but is opposite to the case in the TAG, in the rift valley of the Mid-Atlantic Ridge, which is a typical oceanic spreading center. This might indicate a difference in the fluid circulation system of backarc-type rifting and oceanic-type spreading, although we can not deny the possibility of local differences to explain the above-mentioned results.

The seismic activity was low during the present observation, in contrast to the previous OBS observations in the middle Okinawa Trough. Especially, no nearby earthquakes were observed. Also no volcanic tremors were identified based on seismometer records. This might imply that the Iheya vent field is not ready for any submarine eruption, at least during the current observation.

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(Notice) Photos are given on the following page.



Photo 1 OBS/H deployed by the free-fall mode found at the first site. It was sandwiched by two rock slabs. The white ones are a kind of sponge.



Photo 4 Close up of the "Pyramid Chimney". The chimney grew very rapidly, during a period of roughly one year. The new chimney can be seen at the lower right. A colony of "Galathea" covers on the "Pyramid Chimney".

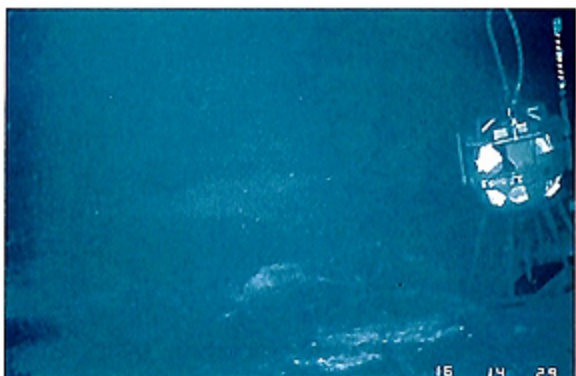


Photo 2 Landscape near the OBS/H. A small test buoy to the right of OBS/H can be seen. A white area in the far back is the "Baby Chimney" and another test buoy is seen there.



Photo 5 The chimney sampled at "Pyramid Chimney" which can be seen in Photos 3 and 4.



Photo 3 A grayish-white chimney with a cone-like shape (lower right) was found at the base of the "Pyramid Chimney".

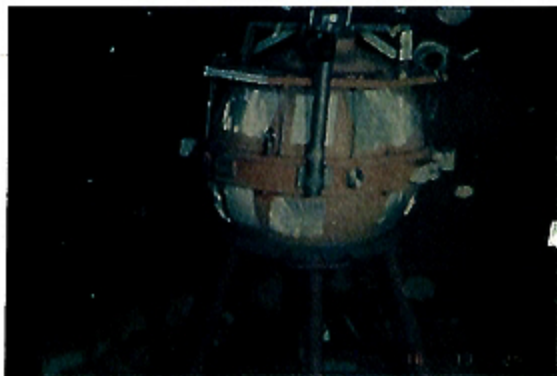


Photo 6 OBS/H after relocation beside the "Fissure Vent" (white small crevasse) at 13:28. Note the white fragments exploding from the Fissure Vent.



Photo 7 White fragments are exploding from the fissure into the water at 13:29.

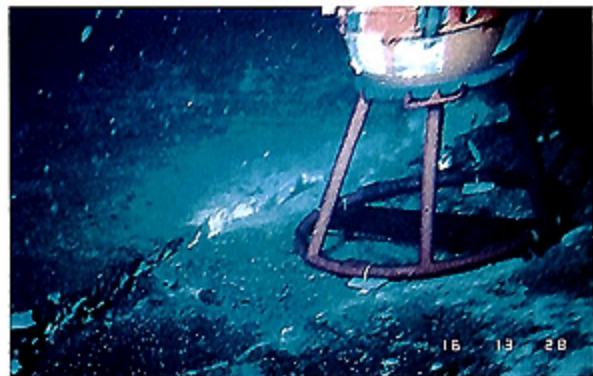


Photo 8 OBS/H at 13:43. Now the water is clean due to low hydrothermal activity.