– Report –

A submersible study of the Mariana Trough back-arc spreading center at 17°N

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During the JAMSTEC R/V *Yokosuka* YK08-08 Leg-1 cruise, the submersible *Shinkai 6500* survey of the central Mariana Trough at 17°N was carried out to study a formation process of oceanic lithosphere in the active back-arc spreading center. Three dives were devoted to the median valley in the 17°N segment center. Visual observation of geology, lava flow morphology, and fault structure provides ground references for the backscattering imagery obtained from the deep-towed side-scan sonar survey conducted in 2003 to discuss volcanotectonic features. Smooth surfaces of side-scan imagery with high backscattering intensities are found to be jumbled-wrinkled, folded sheet, or lobate lava flows. The visual observation proves that the 17°N segment is covered with sheet lava flows of high effusion rates. Quantifiable degrees of sedimentation superposed on the lavas suggest relative age differences of formation. Sheet lava flows in the axial portion of the median valley are considered to be the youngest among the three dive observations. Sedimentation more or less gradually increases toward the western margin of the median valley. The observed eastern margin of the median valley is covered with sedimentary layers of ~0.5-2 m thickness, thus the area is regarded as the oldest in our dive observations. North-south trending tectonic structures (i.e. faults, fissures), oblique to the median valley direction, could be younger than valley-parallel NNW-SSE trending structures because they show relatively little accumulation of sediment, and they cut the other structures in some places. Basaltic rock samples were collected at a total of 22 stations where several types of lava flow morphology are shown. Spatial variations in the rock faces, suggesting variations of chemical characteristics and rock ages, were found (phyric/aphyric, manganese coating, vesiculation). Hemipelagic sediment samples including nanofossils were also collected at 6 stations.

Keywords : Mariana Trough, back-arc spreading, lava flow, lobate sheet, pillow, Shinkai 6500.

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1. Introduction

As a prologue to our study, in 2003 we conducted a deep-towed side-scan sonar (~100 kHz) survey in the central Mariana Trough back-arc spreading centers (R/V *Kairei* KR03-12 cruise). We surveyed a segment at 17°N which is characterized by a dome-shaped topography shoaling at the segment center (Figure 1). The morphology is supposed to be a consequence of enhanced magma supply.

As a result of our survey, we discovered that smooth surfaces of sidescan sonar imagery with high backscattering intensities are dominant in the median valley of the segment center (Figure 2). On the other hand, small ridges around the axial portion of the median valley and areas toward the segment end are associated with sidescan imagery of bumpy surfaces (Deschamps et al., 2004; Deschamps et al., 2005; Asada et al., 2007). The bumpy sidescan images suggest pillow mounds and ridges, and the smooth surfaces suggest sheet-like lava flows or lobate flows. The different flow morphologies primarily reflect the rate at which the lava erupted. The presence of sheet flow morphology suggests a high rate of eruption, pillow flow morphology suggests a low rate of eruption, and lobate flow morphology indicates an intermediate eruption rate (e.g. Gregg and Fink, 1995). The smooth surfaces occupy half of the survey area. Such a broad area of smooth surfaces is an unusual characteristic among slow spreading centers (the central part of Mariana Trough has a full spreading rate ~30 km/myr).

As corroborative observational evidence, the mantle Bouguer gravity anomaly in the 17°N segment shows a bull's-eye low with large amplitude (Kitada et al., 2006). Consistently, seismic velocity structure shows that the thickness of the crust in the spreading axis at 17°N is ~2 km thicker than in the off-axis (Takahashi et al., 2007; 2008) (Figure 3). These observational results indicate that enhanced magma supply yielded lava flows of the high effusion rate and produced the thick crust. As a result of the crustal structure, the abnormal crustal thickness extends off-axis to ~30 km distance. It may indicate that duration of the enhanced magma supply is ~1 myr (30 km ÷ 30 km/myr). Moreover, the morphology of lava flows has spatial variation within the median valley. The spatial variation may indicate recent temporal variation of the magma supply.

Why has such a large amount of magma been provided to the 17°N segment? The contribution of water and/or volatiles to decrease the melting temperature is a possible explanation; or mantle temperature temporally increased. The previous petrological study did not suggest a distinguished influence of water at 17°N (Gribble et al., 1996). However, there was only one dredge point in this segment. The sample may not represent the geochemical character of the segment. Therefore, to investigate chemistry of magma in this segment, we need to collect more rock samples at sites carefully selected by utilizing visual observations.

If the chemistry of the rock samples is an ordinary one of back-arc basin basalt, it does not prove into fact the enhanced magma supply; the tectonics of the back-arc spreading thus may be considered. The bow-shaped Mariana back-arc spreading may introduce reorganization of spreading geometry and a local high spreading rate, then decompression melting enhances. Detailed tectonic evolution will be a key to understanding this. However, the details of magnetic stripe patterns are still not clear (Iwamoto et al., 2002; Deschamps et al., 2005); because the trough is situated in low latitudes and the survey line interval is sparse. Therefore, acquisition of additional magnetic data is significant.

Are the structural changes of crustal thickness and/or the lava morphology a consequence of temporal variation of the magma supply? To investigate this issue, we need to examine spatial variation of the rock chemistry and age difference within the median valley and the off-axis. To deduce age difference, radiometric age of lava, sedimentary layers covering lava flows, and magnetization intensities of lava flows will be examined.

We proposed seven submersible dives for the study (a combination of dives across the spreading axis, along-axis, and off-axis). Three dives were finally approved. Although the cruise was initially assigned in 2007 and we suffered delays of the cruise, at last the YK08-08 Leg-1 cruise was on schedule in June-July 2008. We revisited the Mariana Trough with the *Shinkai 6500*. Objectives of the submersible survey were (1) geological observation of lava flow morphology, faults, and fissures and their spatial variation, (2) collection of rock and sediment samples for chemical and age analysis, and (3) geophysical observation using a deep-sea magnetometer and a sub-bottom profiler to investigate magnetization of the lava flow and thickness of sedimentary layers that cover the lavas. In this paper, we focus on our visual geological observations.

(a)

(b)

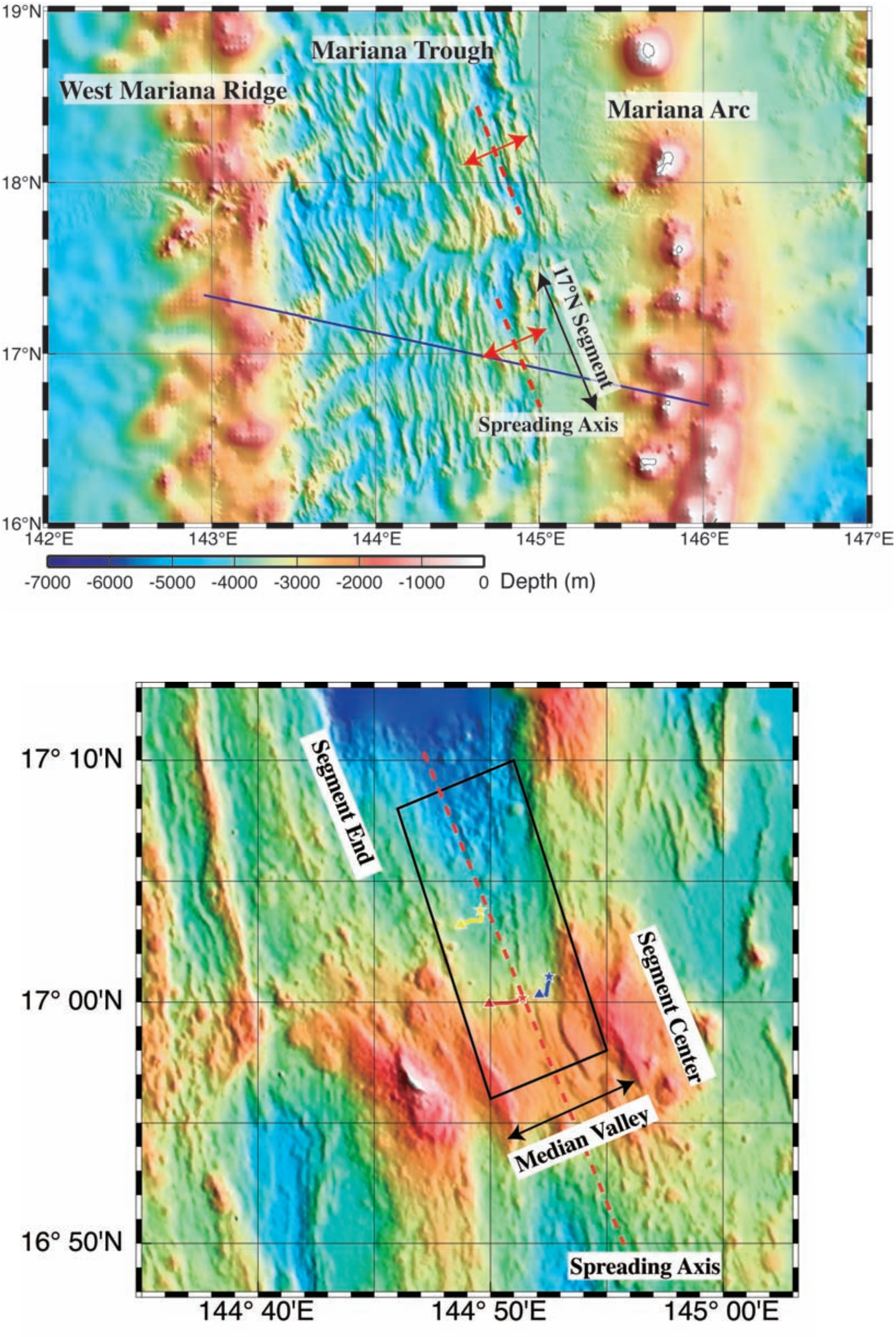

Fig. 1 (a) Bathymetry of the central Mariana Trough showing the location of the study area. The blue line indicates the position of the seismic profile shown in Figure 3.

(b) Bathymetry of the Mariana Trough 17°N segment. The strike of spreading axis trends in the direction of NNW-SSE (~N20°W). The black box shows the KR03-12 sidescan sonar survey area in 2003. Red, blue and yellow lines show the dive tracks of dives #1088, #1089, and #1090 respectively.

2. YK08-08 Leg-1 Cruise

The YK08-08 Leg-1 cruise took place from 25 June to 6 July 2008 from Yokosuka, Japan, to Guam using the JAMSTEC R/V *Yokosuka* and the submersible *Shinkai 6500*. The *Shinkai 6500* dives focused on two specific sites. The first area encompassed the Mariana fore-arc region, where serpentine seamounts evolved. Three submersible dives in this area were led by Prof. Hirokazu Maekawa of Osaka Prefectural University, and will be discussed separately elsewhere. The second area encompassed the Mariana back-arc spreading center at 17°N. Three dives were devoted to the median valley in the segment center (Figure 1(b) and Table 1).

Dive #1088 traversed a small ridge situated in the center of the median valley and took a route on the western flank of the median valley of ~3420 m depth. The small ridge corresponds to bumpy side-scan sonar images, and the western flank to smooth surfaces with high backscatter intensity (Figures 2 and 4). Dive #1089 climbed a small volcano complex on the eastern side of the valley. The side-scan sonar imagery shows a small volcano complex that consists of bumpy aggregates of dome-like structures along the foot of the eastern valley wall, which continues to superposed fan-shaped terraces (Figures 2 and 4). Dive #1090 traversed the western side of the valley to three miles north of dive #1088. The dive took a route across linear structures trending in the NNW-SSE (sub-parallel to the strike of the median valley) and the N-S (oblique to the median valley) and in smooth surfaces which are recognized in the side-scan sonar image.

The submersible carried a magnetometer and a sub-bottom profiler to investigate magnetization of the lava flows and thickness of sedimentary layers that cover the lavas. The magnetometer was built by the Ocean Research Institute of the University of Tokyo to collect vector field data (e.g. Sato, 2005). The sub-bottom profiler system was originally developed by the Geological Survey of Japan (e.g. Kisimoto et al., 2004; Umino, 2004), and the installed sub-bottom profiler was built by JAMSTEC IFREE (e.g. Kumagai, 2005). These geophysical instruments were operated continuously during all six dives in addition to visual

Table 1. Shinkai 6500 dives in the Mariana Trough 17°N. Described is Guam local time (UT+10 hrs).

#1088

Date: 2 July 2008

Landing: 11:32; 17°00.1711'N, 144°51.3784'E, 3408 m

Leaving: 15:46; 16°59.9297'N, 144°49.9328'E, 3425 m

Observer: Toshiya Fujiwara (IFREE, JAMSTEC)

Pilot: Keita Matsumoto, **Co-Pilot:** Fumitaka Saito

#1089

Date: 3 July 2008

Landing: 11:34; 17°01.0559'N, 144°52.525157'E, 3505 m

Leaving: 15:46; 17°00.3066'N, 144°52.1021'E, 3351 m

Observer: Susumu Umino (Kanazawa Univ.)

Pilot: Tetsuya Komuku, **Co-Pilot:** Kazuhiro Chiba

#1090

Date: 4 July 2008

Landing: 11:41; 17°03.8'N, 144°49.6'E, 3820 m

Leaving: 15:41; 17°03.2'N, 144°48.7'E, 3611 m

Observer: Miho Asada (HADEEP, ORI, Univ. of Tokyo)

Pilot: Yoshitaka Sasaki, **Co-Pilot:** Hirofumi Ueki

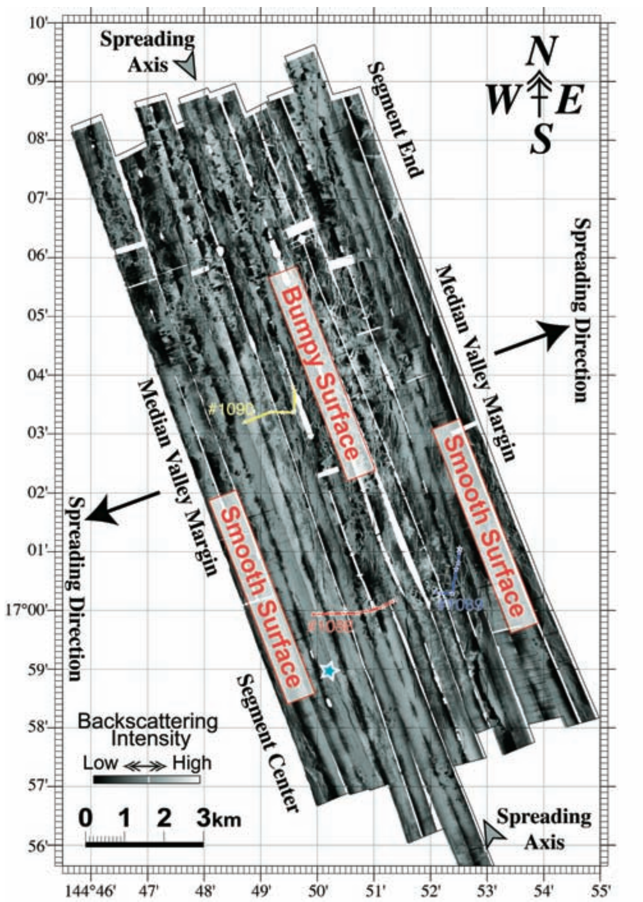

Fig. 2 Sidescan backscattering image of the median valley in the spreading center at 17°N (modified from Asada et al., 2007). Light color shows high backscattering intensity. Red, blue and yellow lines show the dive tracks of dives #1088, #1089, and #1090 respectively. Stars and triangles on the dive tracks point out landing and leaving points, respectively. The blue star points out a rock sampling site of Gribble et al. (1996).

geological observation. Preliminary results of the sub-bottom profiler observations are discussed separately (Koike et al., 2008, this volume).

During the cruise, a surface-ship geophysical survey including swath bathymetry was conducted at night and an additional day. The survey area extends into the central part of the trough between the Mariana Arc and the West Mariana Ridge (Figure 1(a)). Survey lines on YK08-08 were designed to be parallel to and in between the survey lines previously obtained to increase the spatial density of magnetic and gravity data, and the ship tracks were laid out in the WSW-ENE direction, which is the general direction of the seafloor spreading of the Mariana Trough. Bathymetric surveys for dive-site inspections provided high-resolution data of which measurement points are densely distributed because the ship ran at a slow speed of 8 knots. The high-resolution swath bathymetry can be correlated with the sidescan sonar images and the submersible observations for discussion of the volcano-tectonics in the vicinity of dive sites (Figure 4(b)). Thanks to good weather conditions, a high quality of data was acquired.

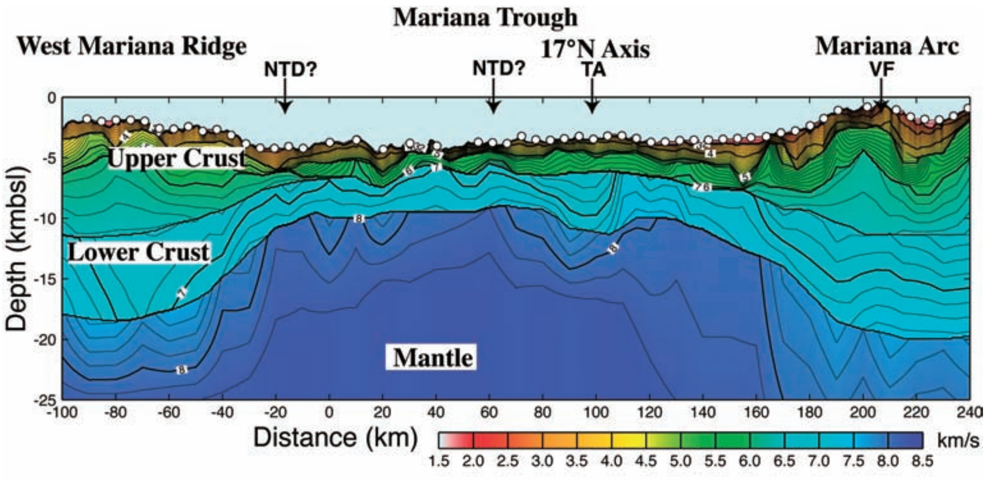

Fig. 3 P-wave velocity structure across the Mariana Trough. The spreading axis at 17°N is located at ~100 km in the horizontal axis (Velocity data from Takahashi et al., 2007; 2008).

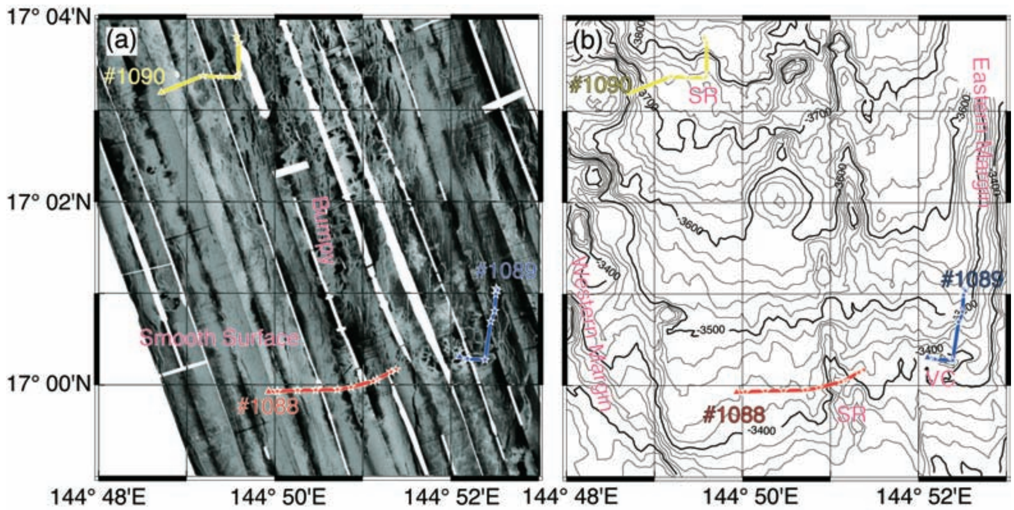

Fig. 4 (a) Sidescan sonar backscattering image of the median valley in the 17°N segment center (Data from Asada et al., 2007). Light color shows high backscattering intensity.
(b) Bathymetric map with 20 m contours. The red, blue, and yellow lines superposed on the sidescan image and the swath bathymetry show the *Shinkai 6500* dive tracks of dives #1088, #1089, and #1090 respectively. Symbols on the dive tracks point out sampling sites. SR: Small Ridge; VC: Volcano Complex.

3. Submersible Dive Observations

3.1. Dive #1088

The landing point is an axial portion of the median valley and an eastern foot of the small ridge of ~150m relative height elongating NNW-SSE (~N20°W) subparallel to the median valley direction (Table 2, Figure 4). Morphology at the landing point is jumbled-wrinkled lavas (Photo 1(a)). The lava morphology suggests sheet and turbulent flow at high eruption rates. The lava flows could be very young, because they show no or little accumulation of sediment. It seems to be the freshest lava flows observed among the three dives (#1088-#1090).

The dive traversed the ridge. The ridge mainly consists of pillow and pahoehoe lavas covered with thin sediment. Pillows are ~2 m in length and ~1m in diameter (Photo 1(b)). The top of the small ridge is covered with thin sediment. In the western half of the dive route, we took the route on the western flank of the median valley beyond the small ridge, where there are various types of lava morphology. It shows a mixture of pahoehoe, folded sheet, lobate sheet, and jumbled flows produced by sheet flows with a high effusion rate (Photos 1(c)-(f)). Topography is a series of ridges and troughs. The relative height is ~5-10 m. The topography may have originated from tectonic structures such as faults, or volcanic structures such as fissures or lava channels. Strikes of the ridges and troughs are in the NNW-SSE or N-S direction. It is difficult to distinguish this small angle difference from the submersible visual observations because their topographic edges are not sharp. According to tectonic interpretation of the side-scan sonar images (Asada et al., 2007), the submersible passes across an area of N-S lineated structures, and then across an area of NNW-SSE lineated structures. Sediment coating in the area of N-S structures tends to be thinner than that in the area of NNW-SSE structures. It may suggest that the N-S structure is newer than that of NNW-SSE inferred from the sediment accumulation.

Sediment cover more or less gradually increases toward the margin of the median valley in accordance with the distance from the axial portion although the spatial variation in detail is not monotonic. Onboard records of the sub-bottom profiler indicate very thin sediment cover through the dive route, although it is difficult to obtain a clear reflection image from the sediment/lava boundary due to wave scattering and diffraction caused by rough seafloor relief (Koike et al., 2008, this volume).

3.2. Dive #1089

The plain near the eastern margin of the median valley where we landed is underlain by lobate sheets covered with thin sediments (Table 2 and Photo 2(a)). Spherical to bulbous pillows are exposed on the sedimentary cover. The submersible landed on a tumulus several meters in height and ~10 m in diameter with a wrinkled surface and wide and deep inflation cracks. Swollen and fractured pillows and irregular pillow lobes are present on the sedimentary plain. The lobate sheet with pillowy knobs continues 400 m farther before entering into a field of pillow mounds.

Table 2. Event list of the Shinkai 6500 dives.

#1088 Event List

Time	Latitude	Longitude	Depth	Event
11:32	17° 00.1711' N	144° 51.3784' E	3408 m	Landing
11:37	17° 00.1711' N	144° 51.3784' E	3408 m	Sampling R01
12:01	17° 00.1440' N	144° 51.3232' E	3372 m	Sampling R02
12:26	17° 00.0591' N	144° 51.1631' E	3253 m	Sampling S01
12:40	17° 00.0414' N	144° 51.1192' E	3349 m	Sampling R03
13:25	16° 59.9788' N	144° 50.8656' E	3420 m	Sampling R04
13:53	16° 59.9521' N	144° 50.7131' E	3427 m	Sampling R05
14:24	16° 59.9477' N	144° 50.4666' E	3415 m	Sampling R06 & S02
15:00	16° 59.9427' N	144° 50.2611' E	3415 m	Sampling R07
15:27	16° 59.9340' N	144° 50.0297' E	3417 m	Sampling R08
15:44	16° 59.9297' N	144° 49.9328' E	3425 m	Sampling R09 & S03
15:46	16° 59.9297' N	144° 49.9328' E	3425 m	Leaving

#1089 Event List

Time	Latitude	Longitude	Depth	Event
11:34	17° 01.0559' N	144° 52.5157' E	3505 m	Landing
11:46	17° 01.0375' N	144° 52.5311' E	3508 m	Sampling R01
12:10	17° 00.9916' N	144° 52.5150' E	3501 m	Sampling R02
12:43	17° 00.8083' N	144° 52.5003' E	3481 m	Sampling R03
13:38	17° 00.6977' N	144° 52.4560' E	3441 m	Sampling R04
13:41	17° 00.6977' N	144° 52.4560' E	3441 m	Sampling S01
14:51	17° 00.2777' N	144° 52.3906' E	3361 m	Sampling R05
15:23	17° 00.2907' N	144° 52.1900' E	3354 m	Sampling R06
15:46	17° 00.3066' N	144° 52.1021' E	3351 m	Leaving

#1090 Event List

Time	Latitude	Longitude	Depth	Event
11:39	17° 03.8051' N	144° 49.5683' E	3795 m	Landing
11:46	17° 03.8051' N	144° 49.5683' E	3795 m	Sampling R01
12:10	17° 03.7415' N	144° 49.5920' E	3798 m	Sampling R02
13:10	17° 03.3862' N	144° 49.5912' E	3743 m	Sampling R03 & S01
13:23	17° 03.3645' N	144° 49.5792' E	3740 m	Sampling R04
14:12	17° 03.3641' N	144° 49.3841' E	3724 m	Sampling R05
14:36	17° 03.3779' N	144° 49.1880' E	3732 m	Sampling R06
15:39	17° 03.1950' N	144° 48.7122' E	3616 m	Sampling R07 & S02
15:39	17° 03.1950' N	144° 48.7122' E	3616 m	Leaving

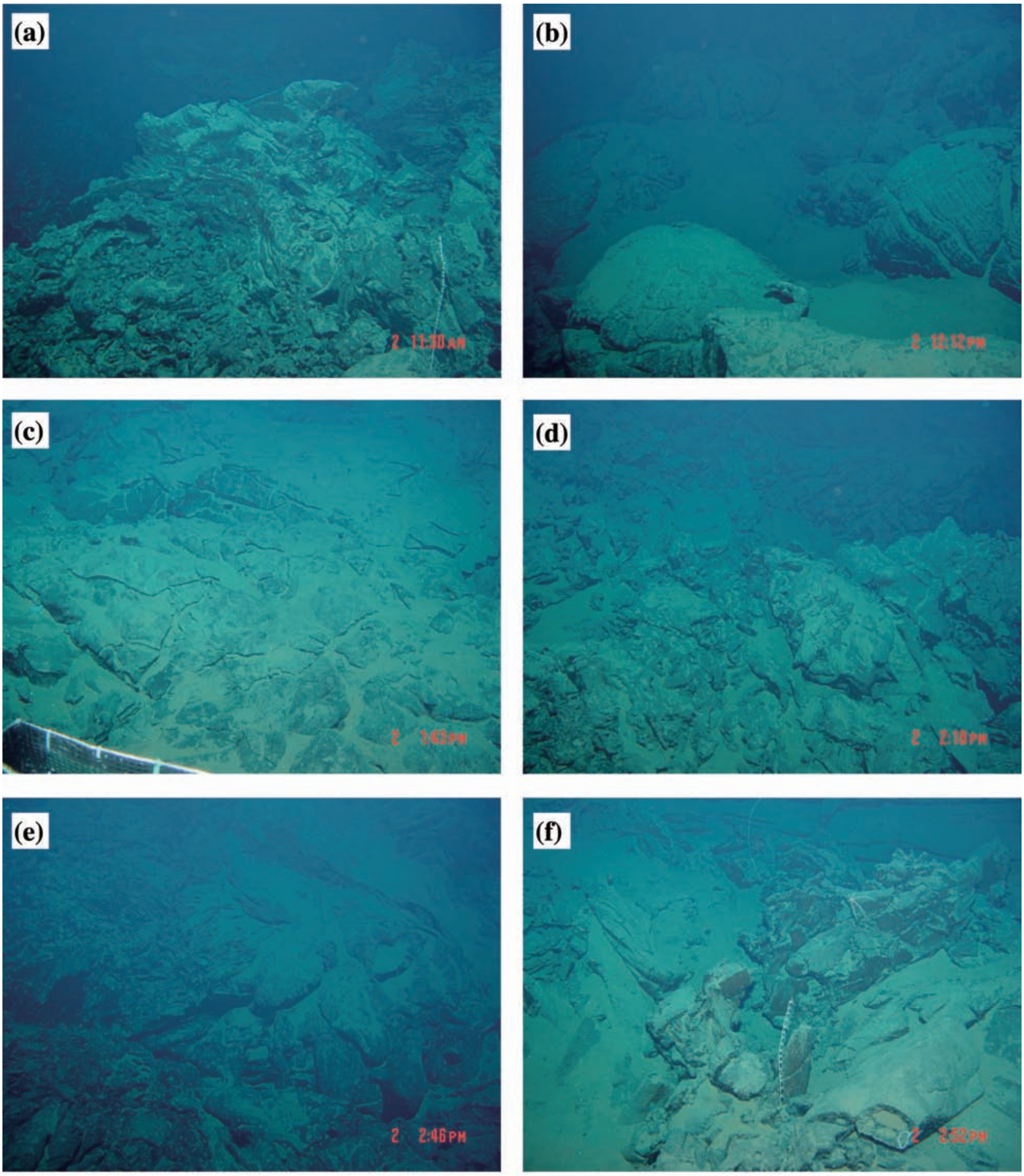

Photo 1. Photos of dive #1088 taken by the Shinkai 6500 digital camera. Time indicated in the lower right is Guam local time (UT+10 hrs). (a) Jumbled lava flows near the landing point (17° 00.17'N, 144° 51.38'E, 3408 m). (b) Pillow lavas on the small ridge (17° 00.07'N, 144° 51.24'E, 3380 m). (c) Pahoehoe-like lavas on the western flank of median valley (16° 59.96'N, 144° 50.74'E, 3426 m). (d) Jumbled lava flows on the western flank of median valley (16° 59.96'N, 144° 50.50'E, 3415 m). (e) Lobate lavas on the western flank of median valley (16° 59.95'N, 144° 50.32'E, 3418 m). (f) Folded sheet lavas on the western flank of median valley (16° 59.94'N, 144° 50.26'E, 3415 m).

The submersible moved southward into the bumpy area, a field of pillow mounds several to a few tens of meters high, and swam along the curved steep slopes of elongate pillows directing downslope (Photo 2(b)). Passing through the pillow mounds, the submersible went into the terrain of terraces underlain by thick sedimentary plains with sporadically exposed big pillows. The flat plain is covered with thick sediments with sporadic holes and knobs of bulbous-round pillows. The thickness of the sedimentary layer is estimated to be ~0.5-2 m (Koike et al., 2008, this volume). Interiors of hollow lobes can be seen from the holes on the sedimentary plain, suggesting the presence of lobate sheets beneath the sediments. The submersible traversed the edges of fan-shaped terraces fringed with elongate pillows (Photo 2(c)). The submersible then turned its head southwest and passed through a sedimentary terrace to the foot of the hummocky ridge with an apron of elongate pillows.

The submersible went up a very steep slope of 60-70° of elongate and knobby pillows directing downslope with a thin sedimentary carapace in the small volcano complex consisting of a bunch of large domes 100-300 m across that form a broad ridge 1 km east-west, 700 m north-south and 30-40 m in height. The summit of the hummocky ridge is cut by faults running NNE and NNW, which expose truncated pillow lobes (Photo 2(d)). Swimming over a few pillow mounds, the submersible went down slopes of elongate pillows.

3.3. Dive #1090

The submersible landed on a small ridge (Table 2 and Figure 4). On the ridge, large pillows and lava tubes of ~1.5 m diameter are found under thick sediment (Photo

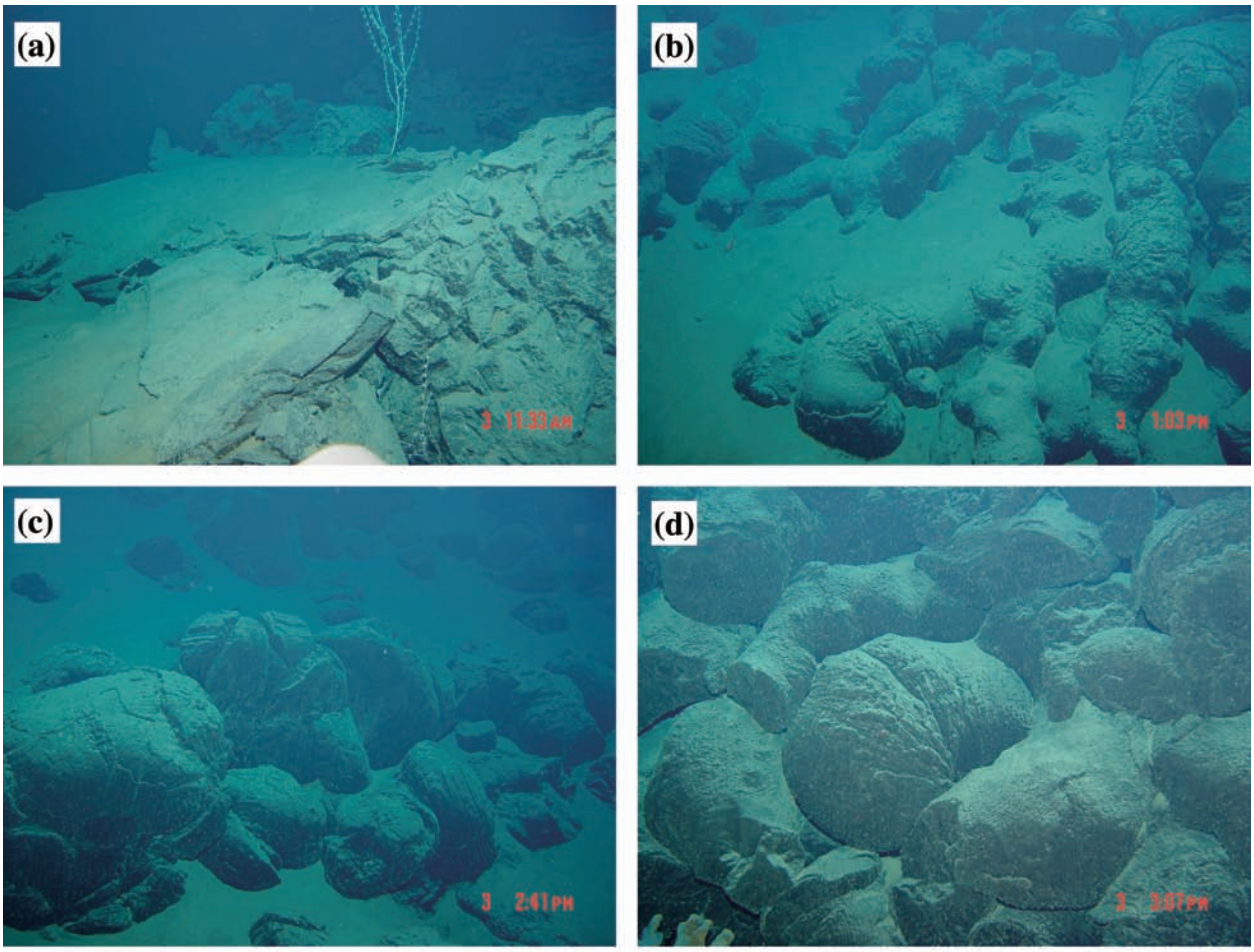

Photo 2. Photos of dive #1089. (a) Lobate sheet lavas on the eastern flank of the median valley near the landing point (17° 01.06'N, 144° 52.52'E, 3508 m). (b) Elongate pillow lavas on a slope (17° 00.76'N, 144° 52.44'E, 3440 m). (c) Elongate pillow lavas on a fan-shaped terrace (17° 00.29'N, 144° 52.40'E, 3386 m). (d) Pillow lavas on the pillow mound (17° 00.28'N, 144° 52.25'E, 3325 m).

3(a)), and nearly N-S trending fissures that have very fresh crack surfaces are developed. We found a large depression along the ridge. The depression may have formed when the basement collapsed or subsided due to tectonic movement. The floor of the depression is also covered with thick sediments.

The submersible passed the ridge and traversed the western lava flow plain. The lava plain is supposed to be slightly older because it is associated with a thick sediment blanket consistent with low backscattering intensity of the sidescan sonar image. The area has a series of ridges and valleys with undulations several meters high. The direction of these ridges and valleys is NNW-SSE. Some fissures are trending N-S. The width is ~5 m and the depth is greater than 10 m. They look fresh because cut sections of pillows and lava tubes are exposed on the sharp fissure walls (Photo 3(b)). The fissures cut the NNW-SSE trending structures; therefore the fissures trending N-S are considered to be newer than the NNW-SSE trending structures. The lava plain is distributed broader than 500 m in width.

The morphology in the portion between the lava plain and the western margin is thinly sedimented sheet flows, and the boundary is unclear bathymetrically. The lava flow morphology is similar to that found in dive #1088 (Photo 3(c)). At the western end of the dive near the western wall of the median valley, the seafloor is composed of heavily sedimented pillows and lava tubes (Photo 3(d)). In visual observation, heavy sedimentation is obvious compared to the seafloor in dive #1088. As a result of the sub-bottom profiler observations, the thickness of the sedimentary layers is estimated to be less than several tens of centimeters (Koike et al., 2008, this volume). Therefore, the sedimentation of western margins of the median valley is thinner than that of the eastern margin.

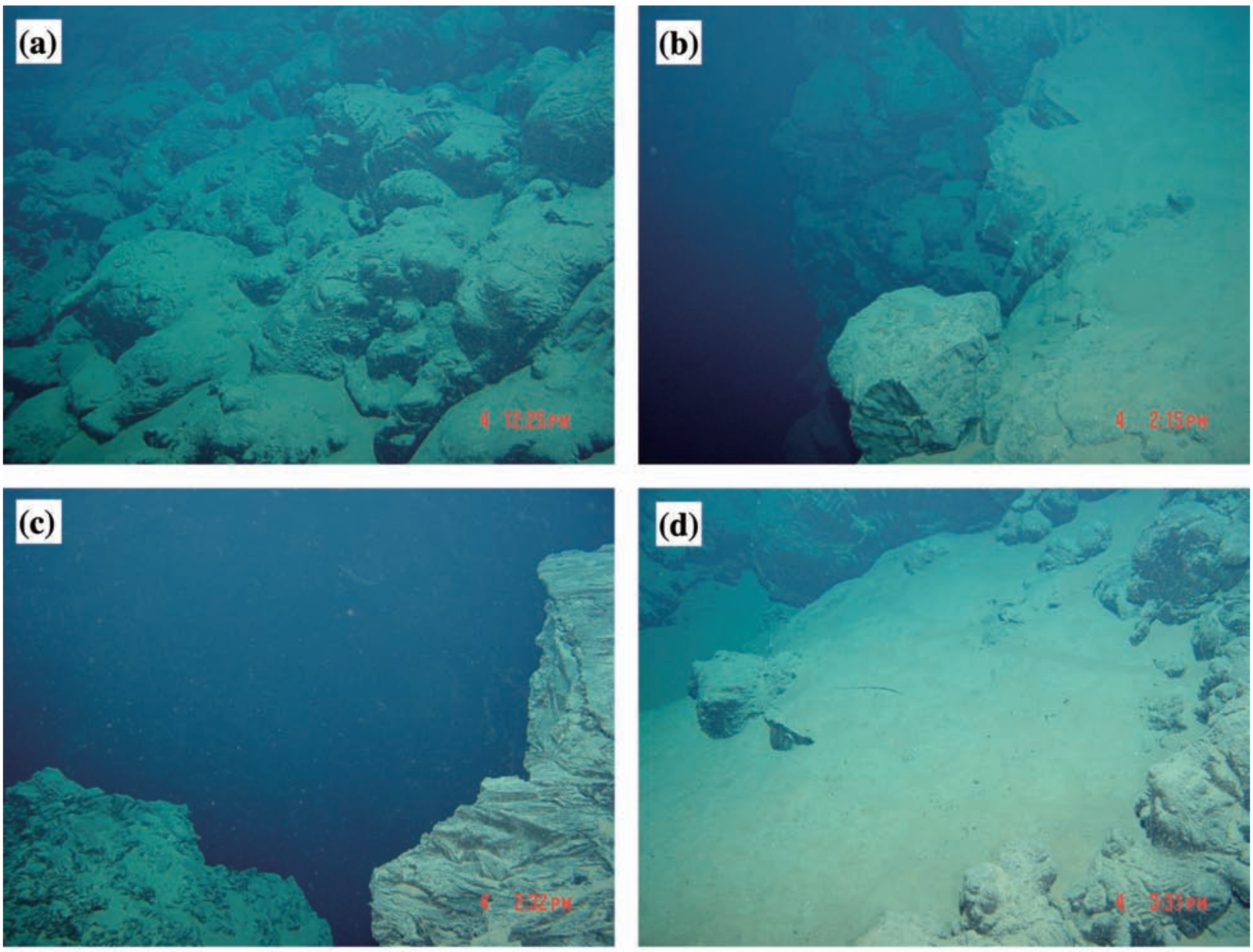

Photo 3. Photos of dive #1090. (a) Pillow lavas near the landing point (17° 03.63'N, 144° 49.58'E, 3770 m). (b) Pillow lavas exposed on a fissure (17° 03.36'N, 144° 49.35'E, 3724 m). (c) Fragmented sheet lavas on the western flank of the median valley (17° 03.38'N, 144° 49.21'E, 3731 m). (d) Pillow lavas covered with sediment near the western margin of median valley (17° 03.19'N, 144° 48.73'E, 3616 m).

4. Sample Descriptions

4.1. Rocks samples

Basaltic rock samples were collected at a total of 22 stations on the three dives (Table 3, Symbols on the dive tracks shown in Figure 4). The samples are folded crust of sheet flows or pillow lava fragments. Samples obtained from dive #1088, particularly sampled at the axial portion of the median valley, have glass rinds and almost no manganese coating (<1 mm), indicating very fresh lavas. Basaltic lavas taken from sheet lava in dive #1088 are highly vesicular (e.g. 6K#1088R-01, Photo 4(a)). Compared to the samples of dive #1088, samples collected in dive #1089 and dive #1090 look slightly older because of manganese coating and/or on-site sediment accumulation.

All samples collected in dive #1088, dive #1090, and samples collected at the northern plain of dive #1089 are aphyric basalts. On the other hand, plagioclase-rich samples were collected from the pillows on the terraces and the hummocky ridge of the small volcano complex in dive #1089. Samples collected from pillow lavas (6K#1089R-04 and R-06) have abundant plagioclase and rare olivine phenocrysts and tiny hypersthene microphenocrysts (Photo 4(b)). However, hypersthene was identified only based on optical characteristics using a hand lens; it needs to be tested by polarized microscope and electron microanalysis. The sample 6K#1089R-05 is abundantly plagioclase-phyric. The sample lacks olivine and hypersthene.

It is remarkable that there are variations between western and eastern flanks or between lava plains and volcano complexes. The variations may suggest differences in degrees of differentiation, temperature, or magma sources.

4.2. Sediment samples

Sediment samples that coated lava flows were collected at 6 stations in all using push corers (Table 4). These samples are hemipelagic olive brown colored clay or silty sand that include volcanic glass, oxides of iron or manganese, radiolarian, foraminifer, and nanofossils (coccoliths) (Photo 4(c)). On optical inspection these samples do not show any material difference from each other. Therefore no significant difference of sedimentation rate can be assumed, and a degree of sediment accumulation on in-situ lava flows could indicate age differences.

Although specific age within a narrow range is not determined, fossils may give information on the age of underlying lava flows. Species of the fossils of planctonic foraminifer are identified as shown in Table 4. Fossils of foraminifer are partly dissolved in the samples of dive #1088 and dive #1089. In the samples obtained on dive #1090 at ~200-500 m deeper than the other dives, the population of foraminifer or nanofossils is small, and only fragments of foraminifer are found; their species cannot be thereby identified. This may be caused by the water depth where the samples were taken. The depth may be as deep as carbonate compensation depth (CCD).

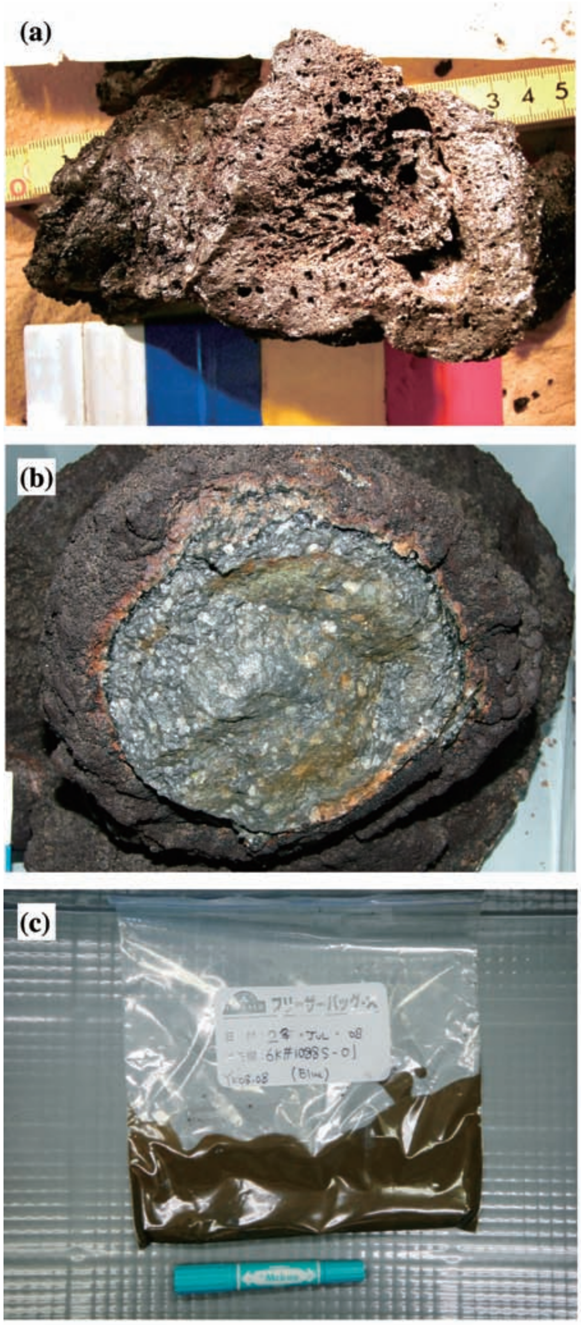

Photo 4. (a) Sample photo of 6K#1088R-01. (b) Sample photo of 6K#1088R-04. (c) Sample photo of 6K#1088S-01.

Table 3. Rock sample descriptions.

Dive#	Sample I.D.*	Size [cm]	Mn coating [mm]**	Palagonite [mm]	Vesicularity	Rock name	Phenocrysts	Note
1088	6K#1088R-01A	30x27x14	none	0.1	3%, 0.5 mm (max 2.0 mm)	Grey aphyric basalt	none	Folded crust of sheet flow. Core is highly vesicular. Slightly altered surface glass.
1088	6K#1088R-01B	14x12x8	none	-				
1088	6K#1088R-01C	14x9x6	none	-				
1088	6K#1088R-02A	34x21x18	Fr <1.0	0.6	<<0.1%, 0.1 mm (max 5.0 mm)	Grey aphyric basalt	Pl <0.1%, <4.0 mm	
1088	6K#1088R-02B	8x6.5x6.5	Fr 1.0	0.2				
1088	6K#1088R-02C	8x7x5	Fr 0.1	0.2				
1088	6K#1088R-02D	5x4.5x3	Fr 0.5	0.1				
1088	6K#1088R-03A	21x12x8	Fr 0.1	1.0				
1088	6K#1088R-03B	17x12x12	Fr 0.1	-	<0.1%, 0.2 mm (max 5.0 mm)	Grey aphyric basalt	Pl <0.5%, <4.0 mm	Stain along fractures
1088	6K#1088R-04A	18x14x9	Fr <<0.1	0.2	-	Aphyric basalt glass	none	Black lustered glass with a slightly hydrated surface
1088	6K#1088R-04B	13x9x7	-	-				
1088	6K#1088R-04C	6x4x2	-	-				
1088	6K#1088R-05A	21x15x12	none	-				
1088	6K#1088R-05B	17x12x8	none	0.05				
1088	6K#1088R-05C	14x11x9	none	-				
1088	6K#1088R-05D	8x8x7.5	none	-	8%, 0.8 mm (max 3.0 mm)	Grey vesicular aphyric basalt	none	Crust of lobate sheet with surface glass and lava curtains and stalactites on the back. Elongate and pipe vesicles 17x6 mm. Stain along fractures.
1088	6K#1088R-05E	<2	0.3	0.1				
1088	6K#1088R-06A	33x23x22	Fr 3.0	0.3				
1088	6K#1088R-06B	19x12x12	Fr 0.8	0.5				
1088	6K#1088R-06C	11x9x8	Fr 0.1	0.5	1%, 0.2 mm (max 4.0 mm)	Grey aphyric basalt	none	Folded crust of wrinkled sheet flow with glassy surface.
1088	6K#1088R-06D	<8	Fr 3.0	0.1				
1088	6K#1088R-07A	26x14x12	Fr 5.0	1.0	3%, 0.8 mm (max 5.0 mm)	Dark grey aphyric basalt	none	Folded crust of wrinkled sheet flow. Vesicular core
1088	6K#1088R-07B	18x14x7	Fr 1.5	0.8				
1088	6K#1088R-07C	18x15x6	Fr 2.0	2.0				
1088	6K#1088R-07D	<9	Fr 0.3	0.3				
1088	6K#1088R-08A	12x9x8	Fr 0.7	0.6	<1%, 0.2 mm (max 2 mm)	Grey aphyric basalt	none	Folded crust of wrinkled sheet flow that are coalesced together.
1088	6K#1088R-08B	12x9x7	0.3	0.1				
1088	6K#1088R-08C	<5	0.1	0.5				
1088	6K#1088R-09A	17x14x10	Fr 0.3	0.2	10%, 1.0 mm (max 4.0 mm)	Grey aphyric basalt	none	Radially jointed pillow fragment. Stain along fractures.
1088	6K#1088R-09B	18x15x14	Fr .0.7	0.6				
1088	6K#1088R-09C	17x15x8	Fr 0.5	0.1				
1089	6K#1089R-01	<18x15x10.5	Fr 0.3	0.3	3%, 0.5 mm (max 6x3 mm)	Dark grey aphyric basalt	none	Folded crust with glassy surface of a tumulus.
1089	6K#1089R-02	24x24x14	Fr 1.0	0.8	0.5%, 0.8 mm (max 4.0 mm)	Grey aphyric basalt	none	Radially jointed pillow fragment. Stain along fractures.
1089	6K#1089R-03	21.5x14x2.5	Fr 1.0	0.5	5%, 0.5 mm (max 5x3 mm)	Dark grey aphyric basalt	none	Slabby crust of sheet lava with glassy surface and inner roof with lava curtains and stalactites. Linear streaks on the glass surface.
1089	6K#1089R-04	38x34x42	Cr 2.0	1.0	none	Dark grey hyp-ol-bg. pl-phyric basalt	Pl 30%, 5.0 mm (max 10x5 mm); ol rare, 1.0 mm; hyp tiny grains	Big pillow lobe with abundant plagioclase.
1089	6K#1089R-05A	12.5x6.5x6	Fr 2.0	0.2	none	Dark grey pl-phyric basalt	Pl 15%, 3.0 mm (max 6.0 mm)	
1089	6K#1089R-05B	3.3x2.8x2.8	none	0.5	10-15%, 0.2 mm (max 1.5x0.6 mm)	Dark grey aphyric basalt	none	Contaminated from other sample?
1089	6K#1089R-06	36x31x24	Fr 0.7	0.6	none	Dark grey hyp-ol-bg. pl-phyric basalt	Pl 35%, 5.0 mm (max 7.0 mm); ol rare, 3.0 mm; hyp rare tiny grains	Big pillow lobe with abundant plagioclase.
1090	6K#1090R-01	12x13x8	Fr 0.5	0.5	Very poor, tiny vesicles	Grey aphyric basalt	none	Magician's cap shaped protrusion. Slightly altered with stain along cracks; chunks in a bag
1090	6K#1090R-02	18x14x13	Fr 0.5	0.5	0.1%, max 0.5 mm	Grey aphyric basalt	none	Radial jointed pillow clast. Stain along cracks
1090	6K#1090R-03	19.5x18x12	Fr 0.5	0.6	0.3%, 0.2 mm (max 1.0 mm)	Dark grey apyric basalt	rare ol	Small finger-like protrusion
1090	6K#1090R-04	14x11x8	Fr 2.0	2.0	<0.1%, tiny vesicles	Grey aphyric basalt	rare ol	Hemi-cylindrical lobe. Stain along cracks
1090	6K#1090R-05	20x18x17	Fr 1.0	0.4	Very poorly vesiculated, < 0.5 mm	Grey aphyric basalt	none	Cylindrical pillow lobe. Vesicles filled by secondary mineral (limonite?). Stains along cracks
1090	6K#1090R-06	31x17x16	Fr 0.1	-	15%, max 0.1x3.0 mm pipe vesicles	Dark grey aphyric basalt	none	Jumbled glassy crust of a sheet flow. Stains along cracks. Chunks denoted as R-06B
1090	6K#1090R-07	25x17x16	Fr 1.0	0.7	none	Dark grey aphyric aug-hyp-ol-bg. pl basalt	pl 0.5%, 1x5 mm; ol 0.1%, <3 mm; hyp 0.1%, <1 mm; aug rare, <1 mm	Clyndrical pillow lobe. Stain along cracks

* Alphabets postfixing sample numbers from dive #1088 are either pieces taken from the same rock bodies or samples broken into pieces after recovery..
** Fr: franvoidal, Cr: crust
Chunks are fragments collected from sample boxes; could be contaminated with other samples

Table 4. Sediment sample descriptions.

Name	Latitude	Longitude	Depth	Description
6K#1088S-01	17° 00.0591' N	144° 51.1631' E	3253 m	Olive brown clay including volcanic glass & foraminifer
				Globigerinoides ruber (Early Miocene-recent)
				Globigerinoides tenellus (Late Pliocene-recent)
6K#1088S-02	16° 59.9477' N	144° 50.4666' E	3415 m	Olive brown clay including volcanic glass & foraminifer
				Sphaeroidinella dehiscens (Early Pliocene-recent)
6K#1088S-03	16° 59.9297' N	144° 49.9328' E	3425 m	Olive brown clay including volcanic glass & foraminifer
				Beella digitata (Pleistcene-recent)
6K#1089S-01	17° 00.6977' N	144° 52.4560' E	3441 m	Olive brown silty sand including volcanic glass & foraminifer
				Globorotalia truncatulinoides (Late Pliocene-recent)
6K#1090S-01	17° 03.3862' N	144° 49.5912' E	3743 m	Olive brown clay including volcanic glass & foraminifer
6K#1090S-02	17° 03.1950' N	144° 48.7122' E	3616 m	Olive brown clay including volcanic glass & foraminifer

5. Conclusions

Three dives of the submersible *Shinkai 6500* in the back-arc spreading center of the Mariana Trough at 17°N were conducted during the R/V *Yokosuka* YK08-08 Leg-1 cruise. Our visual geological observation yielded the following results.

1. Ground references for the sidescan sonar survey to discuss volcanotectonic features were obtained. Bumpy surfaces of the sidescan images were pillow mounds or ridges. Smooth surfaces of sidescan imagery with high backscattering intensities were found to be jumbled-wrinkled, folded sheet, or lobate lava flows. The visual observation proved that the seafloor at the 17°N segment was covered with sheet lava flows of high effusion rates.
2. Sheet lava flows in the axial portion of the median valley were considered to be the youngest among the three dive observations because the sediment cover was thinnest. Sedimentation more or less gradually increased toward the western margin of the median valley in accordance with the distance from the axial portion. The observed eastern margin of the median valley was covered with sedimentary layers of ~0.5-2 m thickness, and thus the area was regarded as the oldest in the dive observations. The sedimentation of western margins of the median valley was in between the axial portion and the eastern margin.
3. N-S trending tectonic structures (i.e. faults, fissures) could be younger constructions than NNW-SSE trending structures because they showed relatively little accumulation of sediment, and they cut the other structures in some places.
4. Basaltic rock samples were collected at a total of 22 stations where several types of lava flow morphology were shown in order to further discussion on the spatial and temporal variation of magma generation. Spatial variations in the rock faces, suggesting variations of chemical characters and rock ages, were found (phyric/aphyric, manganese coating, vesiculation), roughly between western and eastern flanks or between lava plains and volcano complexes.
5. Hemipelagic sediment samples were collected at 6 stations to strengthen the discussion regarding age differences of the lava flows.

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