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CRUISE REPORT
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
R/V Yokosuka
Cruise YK09-06

Magmatic processes at the initiation of Izu-Bonin oceanic island arc
&
A role of forearc tectonics on the formation of Mariana arc-trench system with special reference to serpentinite seamounts

May 23 to June 10, 2009
(Chichijima to JAMSTEC)

TABLE OF CONTENTS:

LIST OF CRUISE PERSONNEL:

SCIENTIFIC PERSONNEL:

BONIN RIDGE GROUP

Osamu Ishizuka

Institute of Geology and Geoinformation, Geological Survey of Japan/AIST

Makoto Yuasa

Institute of Geology and Geoinformation, Geological Survey of Japan/AIST

Kenichiro Tani

IFREE, JAMSTEC

Susumu Umino

Graduate School of Natural Science and Technology

Kanazawa University

Kyoko Kanayama

Graduate School of Natural Science and Technology

Kanazawa University

Yumiko Harigane

Frontier Science Organization

Kanazawa University

Mark K. Reagan

Department of Geosciences, University of Iowa

Yuki Miyajima

School of Marine Science and Technology,

Tokai University

Mariana Serpentinite Seamount Group

Hirokazu Maekawa

Graduate School of Science

Osaka Prefecture University

Hisayoshi Yokose

Graduate School of Science and Technology

Kumamoto University

Shogo Yoshida

Graduate School of Science

Osaka Prefecture University

Hisanori Iwamoto

Marine Technician

Nippon Marine Enterprises, LTD.

SHINKAI 6500 OPERATION TEAM:

Toshiaki Sakurai, Operation Manager

Satoshi Ogura, Assistant Operation Manager

Kazuhiro Chiba, Assistant Operation Manager

Tsuyoshi Yoshiume, 1st Submersible Staff

Keita Matsumoto, 1st Submersible Staff

Masanobu Yanagitani, 1st Submersible Staff

Yosuke Chida, 2nd Submersible Staff

Keigo Suzuki, 2nd Submersible Staff

Hirofumi Ueki, 2nd Submersible Staff

Fumitake Saito, 2nd Submersible Staff

Takuma Onishi, 3rd Submersible Staff

Hitomi Ikeda, 3rd Submersible Staff

Masaya, Katagiri, 3rd Submersible Staff

CREW:

Eiko Ukekura, Captain

Shinichi Kusaka, Chief Officer

Shintaro Hashimoto, 2nd Officer
Makoto Okubo, 3rd Officer
Syunsuke Fujii, Junior 3rd Officer
Toshihiro Kimura, Chief Engineer
Takashi Ota, 1st Engineer
Saburo, Sakaemura, 2nd Engineer
Ichiro, Deguchi, 3rd Engineer
Satoshi, Watase, Chief Radio Operator
Katsutoshi Kitamura, 2nd Radio Operator
Yuka, Moriwaki, 3rd Radio Operator
Kingo Nakamura, Boat Swain
Shuji Takuno, Able Seaman
Osamu Tokunaga, Able Seaman
Hideo Isobe, Able Seaman
Nobuyuki Ichikawa, Able Seaman
Kaito Murata, Able Seaman
Shinsuke Uzuki, Able Seaman
Kiyoshi Yahata, No.1 Oiler
Hiroyuki Oishi, Oiler
Tomoyuki Hashimoto, Oiler
Shota Watanabe, Oiler
Chihaya Sano, Oiler
Tomihisa Morita, Chief Steward
Isao Matsumoto, Steward
Kiyotaka Kosuji, Steward
Takahiro Abe, Steward
Hiroki Fukuda, Steward
Takeshi Watanabe, Trainee
Mizuki Nakano, Trainee

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CRUISE NARRATIVE AND SCHEDULE OF OPERATIONS

2009/5/23

Weather: overcast/ Wind direction: SW/ Wind force: 2/ Wave: 1 m/ Swell: 1 m/ Visibility: 8 nautical mile (12:00 JST)

14:00-16:00	Onboard the R/V YOKOSUKA by boat
18:00-18:25	Briefing about ship's life and safety
18:30-19:45	Scientists meeting

2009/5/24

Weather: overcast/ Wind direction: SW/ Wind force: 4/ Wave: 2 m/ Swell: 2 m/ Visibility: 7 nautical mile (12:00 JST)

11:00	mooring off and transit to Ogasawara ridge
15:57	XBT
17:34-20:13	MBES

2009/5/25

Weather: overcast/ Wind direction: West/ Wind force: 3/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

09:06	Launching SHINKAI 6500 (6K#1149 dive)
11:41	6K landing (6499m)
14:51	6K leave the bottom (6024m)
17:31	6K on deck
18:24-	MBES
19:30-20:00	Scientists meeting

2009/5/26

Weather: fine but cloudy/ Wind direction: ENE/ Wind force: 3/ Wave: 2 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

-05:29	MBES
09:53	Launching SHINKAI 6500 (6K#1150 dive)
11:51	6K landing (4429m)
15:45	6K leave the bottom (3663m)
17:30	6K on deck
18:14-	MBES
19:30-20:05	Scientists meeting

2009/5/27

Weather: overcast/ Wind direction: ESE/ Wind force: 6/ Wave: 4 m/ Swell: 4 m/ Visibility: 8 nautical mile (12:00 JST)

09:40 Launching SHINKAI 6500 (6K#1151 dive)
11:52 6K landing (4765m)
15:40 6K leave the bottom (3927m)
17:32 6K on deck
18:41- MBES
19:30-19:45 Scientists meeting

2009/5/28

Weather: rain/ Wind direction: SSW/ Wind force: 5/ Wave: 3 m/ Swell: 3 m/ Visibility: 5 nautical mile (12:00 JST)

Dive was postponed, evacuation from wind off Anijima island.
19:30-19:50 Scientists meeting

2009/5/29

Weather: overcast/ Wind direction: SSE/ Wind force: 4/ Wave: 3 m/ Swell: 4 m/ Visibility: 7 nautical mile (12:00 JST)

09:01 Launching SHINKAI 6500 (6K#1152 dive)
11:33 6K landing (5986m)
15:13 6K leave the bottom (5570m)
17:39 6K on deck
18:52- MBES and Magnetic survey
19:30-19:50 Scientists meeting

2009/5/30

Weather: cloudy/ Wind direction: South/ Wind force: 5/ Wave: 4 m/ Swell: 4 m/ Visibility: 8 nautical mile (12:00 JST)

09:03 Launching SHINKAI 6500 (6K#1153 dive)
11:49 6K landing (6115m)
15:02 6K leave the bottom (5715m)
17:42 6K on deck
18:52- MBES and Magnetic survey
19:30-19:45 Scientists meeting

2009/5/31

Weather: fine but cloudy/ Wind direction: SSW/ Wind force: 4/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

-04:58 MBES and Magnetic survey
08:52 Launching SHINKAI 6500 (6K#1154 dive)
11:21 6K landing (5720m)

15:11 6K leave the bottom (5189m)
17:30 6K on deck
19:28- MBES and Magnetic survey
20:00-20:55 Scientists meeting

2009/6/1
Weather: fine but cloudy/ Wind direction: West/ Wind force: 3/ Wave: 2 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

Surface survey and transit to north Mariana fore-arc
15:24-15:34 Eight figure turn
17:30-18:05 Scientists meeting

2009/6/2
Weather: fine but cloudy/ Wind direction: NE/ Wind force: 3/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

09:56 XBT

2009/6/3
Weather: fine but cloudy/ Wind direction: East/ Wind force: 3/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

-05:50 MBES and Magnetic survey
09:52 Launching SHINKAI 6500 (6K#1155 dive)
11:31 6K landing (3601m)
15:57 6K leave the bottom (3259m)
17:30 6K on deck
19:28 MBES and Magnetic survey
19:30-20:00 Scientists meeting

2009/6/4
Weather: fine but cloudy/ Wind direction: ESE/ Wind force: 3/ Wave: 2 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

-04:48 MBES and Magnetic survey
08:51 Launching SHINKAI 6500 (6K#1156 dive)
10:44 6K landing (4313m)
14:38 6K leave the bottom (4097m)
16:34 6K on deck

2009/6/5
Weather: cloudy/ Wind direction: South/ Wind force: 5/ Wave: 3 m/ Swell: 4 m/

Visibility: 8 nautical mile (12:00 JST)

08:53	Launching SHINKAI 6500 (6K#1157 dive)
10:29	6K landing (3516m)
14:47	6K leave the bottom (3282m)
16:28	6K on deck
16:59-	MBES and Magnetic survey

2009/6/6

Weather: fine but cloudy/ Wind direction: South/ Wind force: 5/ Wave: 4 m/ Swell: 4 m/ Visibility: 8 nautical mile (12:00 JST)

18:00-19:00	Scientists meeting and seminar

2009/6/7

Weather: fine but cloudy/ Wind direction: SSW/ Wind force: 4/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

2009/6/8

Weather: cloudy/ Wind direction: NNE/ Wind force: 3/ Wave: 2 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

09:00-10:00	Onboard seminar
-15:41	Magnetic survey

2009/6/9

Weather: fine but cloudy/ Wind direction: ENE/ Wind force: 3/ Wave: 3 m/ Swell: 2 m/ Visibility: 8 nautical mile (12:00 JST)

02:40	Transit to JAMSTEC, Yokosuka
18:30-19:30	Scientists meeting

2009/6/10

07:30	Arrival at JAMSTEC, Yokosuka
10:00	Get off the R/V YOKOSUKA

Wind force criteria

0 = 0 - 0.2 m/sec.

1 = 0.3 - 1.5

2 = 1.6 - 3.3

3 = 3.4 - 5.4

4 = 5.5 - 7.9

5 = 8.0 - 10.7

6 = 10.8 - 13.8

7 = 13.9 - 17.1

8 = 17.2 - 20.7

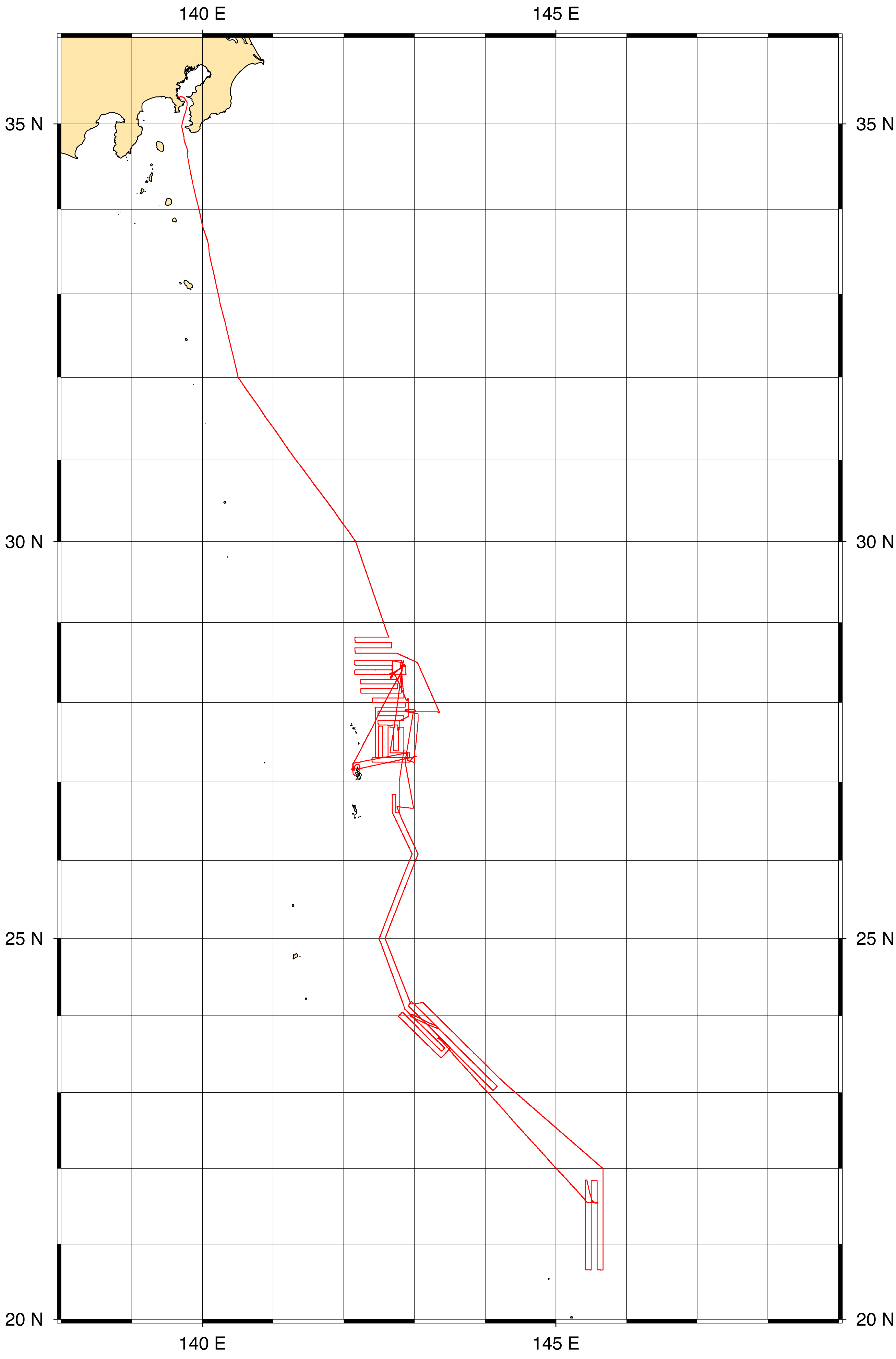
9 = 20.8 - 24.4

10 = 24.5 - 28.4

11 = 28.5 - 32.6

12 = 32.7 -

YK09-06 Ship Track



2009 Jun 10 09:52:10 **R/V YOKOSUKA, Mercator Projection,Data_source=SOJ**

Chapter 1: Magmatic processes at the initiation of Izu-Bonin oceanic island arc

1. Cruise objectives

Recent advances in understanding crustal structure and composition of oceanic arcs demonstrate that such arcs could represent the building blocks of continental crust (Suyehiro et al., 1996; Takahashi et al., 1998). In order to understand the formation of arc and continental crust, it is necessary to estimate growth rates of arc crust coupled with petrological and chemical evolution. Oceanic arcs, where thickened arc crust has formed on oceanic lithosphere, provide a unique opportunity to investigate this problem. The Izu-Bonin-Mariana (IBM) arc is an outstanding example of such an arc system.

Fore-arcs with thin sediment cover are particularly valuable for understanding how subduction zones begin. For example, Stern and Bloomer (1992) and Bloomer et al. (1995) recognized that the fore-arc basement of the IBM system formed in the initial phases of arc volcanism nearly synchronously over a zone up to 300km wide and thousands of kilometers long, at igneous production rates much higher than those of current arcs.

The Bonin Ridge is an unusually prominent fore-arc massif in the IBM arc that exposes early arc volcanic rocks on islands of Chichijima, Hahajima, and smaller islands (e.g., Kuroda et al., 1975; Taylor et al., 1994; Umino, 1985; Umino and Nakano, 2007). Submarine parts of the ridge, which could complement the record of volcanism preserved on the islands, only have been preliminarily investigated by ocean drilling (e.g. DSDP leg 60; Hussong, Uyeda et al., 1981; ODP leg 125 Fryer, Pearce, Stokking et al., 1992), dredging (Bloomer, 1983; recent cruises), and manned and unmanned submersible diving (e.g. cruises YK04-05; YK 06-12; YK08-08).

During the YK 04-05 expedition in May 2004, we carried out the first manned submersible (SHINKAI 6500) diving survey of the western escarpment of the Bonin Ridge (Ishizuka et al., 2006). This effort, along with new $^{40}Ar/^{39}Ar$ ages for Bonin island samples, provided new information about the duration of infant arc volcanism and how this progressively reorganized into a typical magmatic arc by Early Oligocene time (Fig. 1).

Dive cruises YK 06-12 and YK08-08 explored the Mariana fore-arc to the southeast of Guam. Eight of the 12 Shinkai 6500 dives in this area investigated the volcanic stratigraphy of the fore-arc between depths of 2000 to 6500 meters. One of the principal findings of this diving was the recognition that MORB-like basalts and related intrusive rocks crop out over large areas of the fore-arc trench-ward of boninites and younger arc rocks. This outcrop pattern, as well as the volcanic stratigraphy drilled at DSDP site 458 indicates that the MORB-like lavas underlie, and are therefore older than the boninites.

Geochemical analyses of these rocks have shown that they have some characteristics similar to those of MORB, but have some trace element ratios (e.g. Ti/V ratios) that are more similar to those of volcanic arcs. This has led us to postulate that these are the first subduction-zone lavas to erupt after subduction initiation (Reagan et al., 2008; Reagan et al., in prep). The similar outcrop pattern observed by dredging and ROV diving in the Bonin Ridge fore-arc suggests that this pattern of volcanism is also present in this area (e.g., Ishizuka et al., 2008). Preliminary U-Pb dating of gabbroic samples related to these MORB-like basalts collected from the Bonin fore-arc indicate that these MORB-like lavas have ages that stretch back as far as 52 Ma (K. Tani, unpublished data).

The major objectives of the YK09-06 cruise are:

1) To more clearly define the nature of "pre-boninite" volcanism in the Izu-Bonin arc and to test our hypotheses for how mantle convection and magma generation changes during the initiation and maturation of an oceanic island arc.

2) To establish the spatial distribution of all igneous rocks along the Bonin Ridge forearc,

3) To precisely determine the chronology of events after initiation of subduction in the Bonin Ridge region,

4) To better understand the constitution of the of arc crust including that produced during the earliest stages of subduction, and

5) To use this better understanding the lithologic make-up of the Bonin Ridge fore-arc to understand the gravity anomaly associated with the Bonin Ridge, which is the Earth's largest.

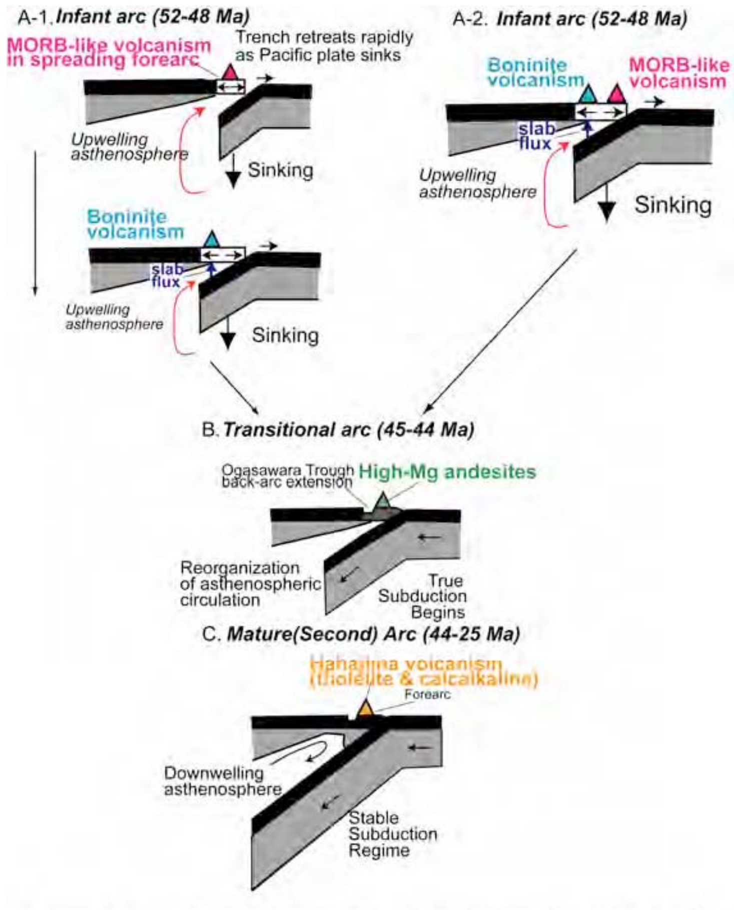


Fig. 1 Model of subduction initiation and evolution of infant arc (modified from Ishizuka et al. 2006)

2. Previous studies in the Bonin Ridge area

In 2007 we sampled along the entire length of the Bonin Ridge between the Bonin Islands and Izu-Bonin Trench to establish the nature and timing of the earliest stages of Izu-Bonin arc and to attempt to recover material from the deepest sections of the arc crust. We accomplished dredge sampling at 19 stations along the entire length of Bonin Ridge (Fig. 2) during 4 days of ship time (September 25-29, 2007).

Dredge stations on the deeper part of the landward slope (as deep as 6420m) of the Izu-Bonin Trench recovered pillow basalts as well as gabbroic rocks and peridotite.

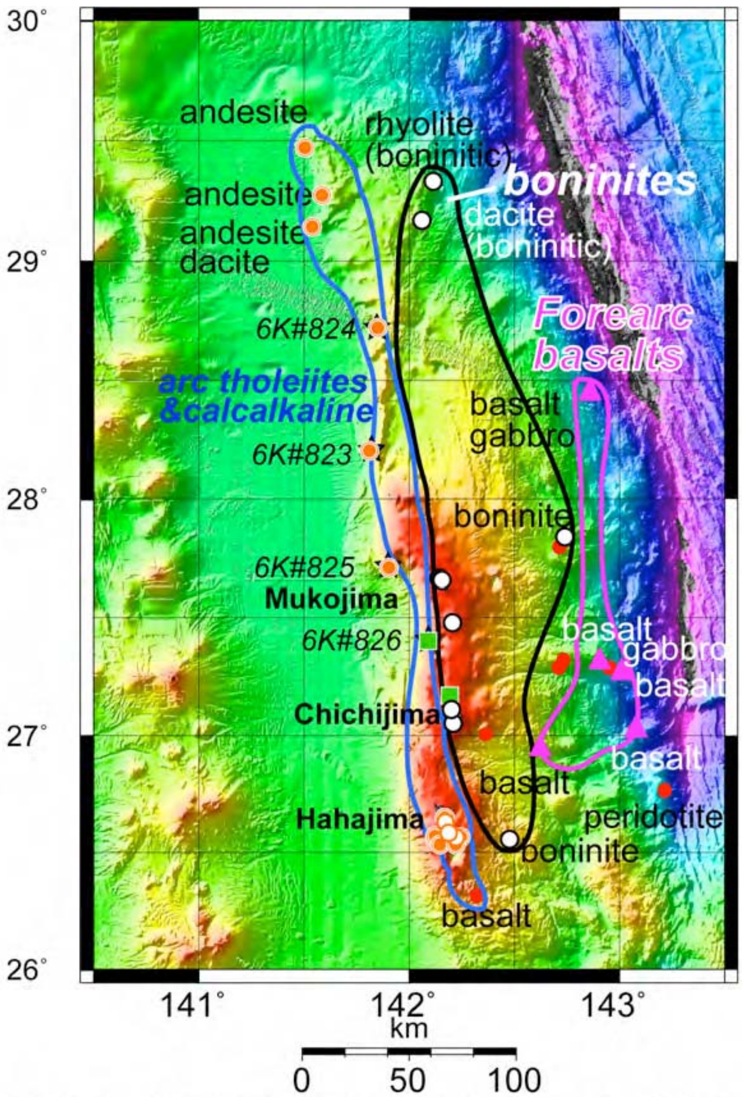


Fig. 2 Summary of dredging results and possible zoing of rock type distribution.

This is the first recovery of these types of rocks (i.e., upper mantle and lower crust) from the Izu-Bonin fore-arc other than at serpentine seamounts. Preliminary data imply that these basalts are MORB-like (i.e., with no slab signature). These lavas have lower Ti/V (14-16), which distinguishes them from subducting Pacific MORB (26-32) and Philippine Sea MORB (17-25), and thus, they are the potential basement components of the arc. Pb isotopes of the fore-arc MORB show that like other Izu-Bonin arc magmas they are derived from a mantle source with Indian Ocean characteristics. Chemically and petrographically they have similar characteristics to tholeiites from the Mariana fore-arc that are considered to be related to subduction but predate boninitic volcanism in that region (Reagan et al., in prep). This strongly implies that MORB-like tholeiitic magmatism was associated with fore-arc spreading along the length of the Izu-Bonin-Mariana arc. Like the adjacent boninitic magmatism, the likely source of these MORB-like basalts can be linked to an Indian Ocean-type source. Low concentrations of incompatible elements and low trace element ratios such as Nb/Yb imply that these lavas were from depleted mantle and/or were larger degree mantle melts compared to typical Philippine Sea MORB.

Dredge sampling at small bathymetric highs east of the Bonin Islands mainly recovered aphyric or ol-cpx basalt lava, which have not been recognized on the Bonin Islands nearby. This result implies that these fore-arc highs are remnant volcanic edifices. These basalts show weak slab signatures and could represent the arc prior to boninitic volcanism and immediately after MORB-like basalts.

Boninite from the Bonin Islands are characterized by high Δ7/4Pb and low $^{143}Nd/^{144}Nd$ relative to local MORB sources and the MORB-like basalt recovered in the fore-arc. The Bonin Islands are also distinct from the 44 Ma volcanics from the Hahajima Islands and the Bonin Ridge escarpment (Ishizuka et al., 2006). So potentially, the geochemical and isotopic characteristics of the arc may have evolved by 1) an initial decompression melting without significant slab flux producing MORB-like basalt at the onset of fore-arc spreading, 2) melting of subducted pelagic sediment and extremely depleted mantle followed during a limited period (48-45 Ma), 3) subsequent melting with more extensive hydrous fluid input generated the tholeiitic and calcalkaline magma after 44 Ma (Ishizuka et al., in prep).

3. Operations and data processing information

Shinkai 6500 usually dove with payloads that included 2 rock sampling baskets, with two push cores and one scoop sampler.

Data and samples from the dives were archived as customary. Half of all samples will be archived at JAMSTEC. Standard data products were provided to the shipboard scientific party.

4. Dive results

Summaries of the results of each dive are included in the sections below. All dive locations are shown in Fig. 4-1.

YK09-06 Bonin Ridge Dive index

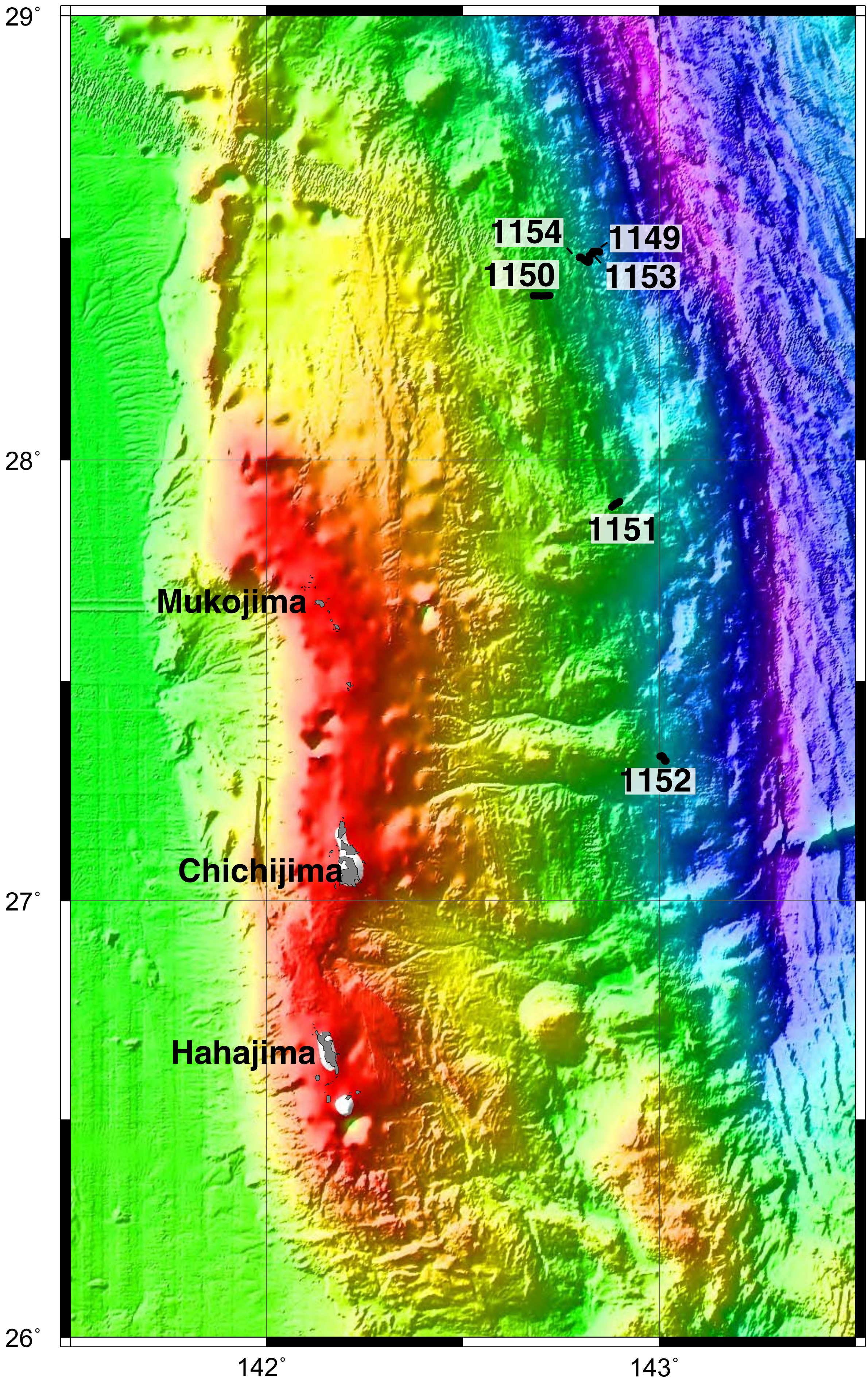


Fig.4-1 Dive locations in Bonin Ridge area during YK09-06.

Dive 1149 Report

Observer: Kenichiro Tani

Technical information:

Location: Northern Ogasawara Ridge
Objective: Geological observation and rock sampling in the deeper section of the landward side of Izu-Bonin trench slope.

Dive 667	On bottom:	Off bottom:
Time (local)	11:41	14:51
Latitude:	28°28.1592′ N	28°28.1884′ N
Longitude:	142°50.9459′ E	142°49.8737′ E
Depth (m):	6449	6024

Samples returned: 19 rocks

Scientific summary

The objective of this dive was geological observation and rock sampling in the deeper part of the landward side of Izu-Bonin Trench slope at the northern Ogasawara Ridge (Site A-1 in the cruise proposal). During the KH07-02 Leg4 cruise in 2007, clasts of basalt and gabbro were dredged at the nearby site (D42). The dive route was planned to find the outcrops of these rocks, as well as to find the boundary between the gabbro and basalt. The survey started from 6499 mbsl and then headed west to climb up the slope. The lower part of the slope (6499-6300 mbsl) was entirely covered with pale gray mud, with rare sub-rounded boulders. Samples R01 to R04 were two of these boulders, which were tuffaceous sandstone (R01) and mudstones (R02-R04).

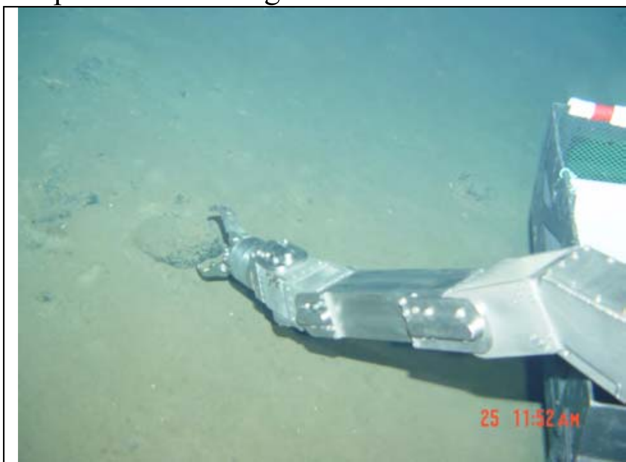
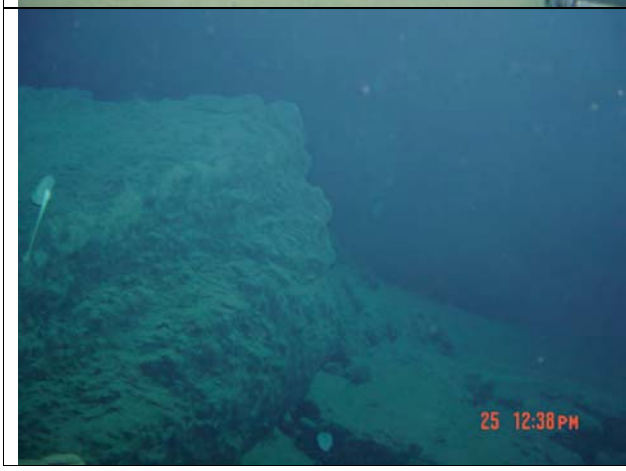
We observed the first outcrop at 6348 mbsl, which was a ~10 m-high steep wall of rough-surfaced blocky breccia. The sample collected from the outcrop (R05) was a sub-angular fine-grained gabbro. After the depth of ~6300 mbsl, we began to frequently observe talus deposits which consist of angular blocks ranges in size from ~10 cm up to ~several meters. Samples R06 to R09 were collected from these talus deposits, and they were all sub-angular to angular gabbros. Sample R09 was similar to the rocks observed at R05 site. It was a gabbroic breccia made up of angular to sub-rounded monolithologic fine-grained gabbro clasts ~3 to 10 cm in diameter. The talus deposits observed here might have been derived from outcrops of gabbroic breccia at a higher level. At a depth of 6179 mbsl, we encountered an outcrop of blocky breccia. Although the detailed observation was obscured by the sediment cover, the surface of the outcrop was similar to that of R05 site. Two samples (R10&R11) were collected from the blocks scattered at the foot of the outcrop, and they were sub-angular blocks of gabbros.

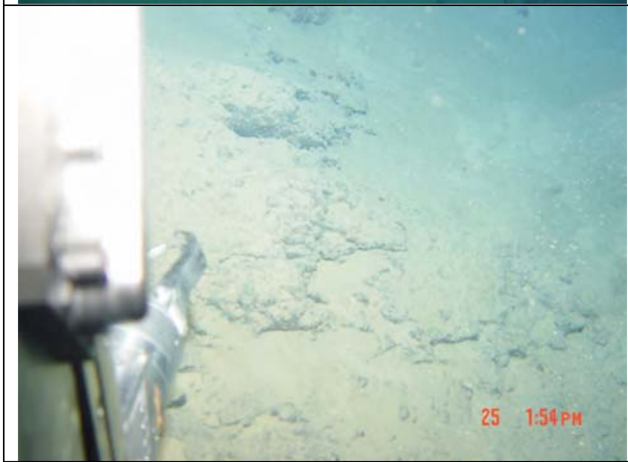
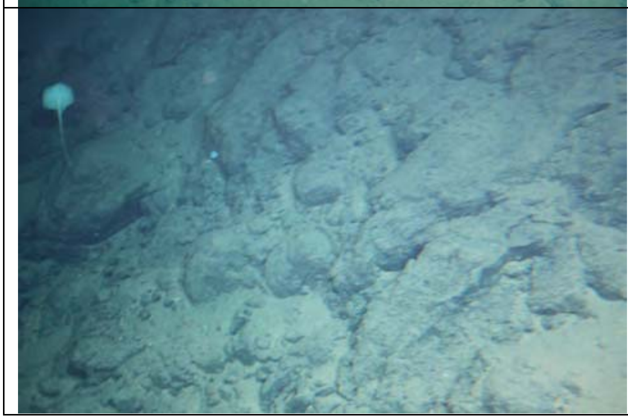
Above the R10&R11 site, the floor was covered again with thick white mud. At a depth of 6106 m, we found a small outcrop of breccia which was mostly buried in mud. The blocks in the breccia were angular to sub-angular in shape, and <20 cm in diameter, smaller than those observed in the lower levels. The sample collected from the outcrop (R12) was a small block of highly altered basalt. Another sample collected from this site (R13) was a gabbro, which was a floated rock scattered on the mud.

At a depth of 6088 mbsl, we encountered an outcrop which was composed of large fan-shaped and rounded blocks, probably derived from dismantled pillow lava. Some of the fan-shaped blocks show radial internal joints. A basaltic clast (R14) was collected from the outcrop. From a depth of 6069 mbsl, we began to see continuous outcrop of pillow lava and associated lava tubes. Pillow lavas were commonly disagregated to form angular talus deposits beneath the outcrop. Outcrops of pillow breccia were observed in between the pillow lavas. However, distinguishing these pillow breccias from the talus deposits was often very difficult. Samples R15 to R19 were collected from these talus deposits, and they were all highly to moderately altered basalt except for R16 (gabbro) and R18 (mudstone). The dive ended at a depth of 6024 mbsl.

In general, the lower (6500-6100 mbsl) part of the surveyed route was composed of gabbroic breccia, whereas in the upper (>6100 mbsl) part, basaltic pillow lavas and associated breccia and talus deposits were dominant. However, we were not successful in locating the boundary between the gabbroic rocks and the basaltic rocks. Gabbroic rocks were collected from the upper part as well (R13&R16), which indicate that outcrops of gabbroic rocks are still present at a higher level.

Representative images:

	Depth: 6499 mbsl, Time: 11:52 Collecting floated block (R02) on a mud covered slope. Still Camera: DSC05462.jpg
	Depth: 6348 mbsl, Time: 12:38 Blocky outcrop of gabbroic breccia. Still Camera: DSC05542.jpg

	Depth: 6287 mbsl, Time: 12:58 Angular talus deposits on a muddy slope. Gabbroic samples (R06&R07) were collected from this site. Still Camera: DSC05576.jpg
	Depth: 6106 mbsl, Time: 13:54 Collecting sample R12 from a breccia outcrop. This was the first basaltic sample collected from this dive. Still Camera: DSC05672.jpg
	Depth: 6054 mbsl, Time: 14:37 An outcrop of pillow lava and pillow breccia. Just above the sampling site for R15&R16. Still Camera: DSC05745.jpg
	Depth: 6053 mbsl, Time: 14:38 Continuous outcrop of pillow lava and lava tubes. Onboard Camera (#1): IMG_0073.jpg

Dive 1150 Report

Observer: Mark Reagan

Technical information:

Location: Northern Ogasawara Ridge
Objective: Geological observation and rock sampling of the trench-ward side of the Bonin Ridge.

	On bottom:	Off bottom:
Time (local)	11:51	15:45
Latitude:	28°22.3181′ N	28°22.2603′ N
Longitude:	142°43.3068′ E	142°40.7960′ E
Depth (m):	4429	3663

11 samples collected

Purpose:
The main purpose of this dive was to observe and sample rocks from the sea floor in the Bonin fore-arc that erupted during the transition from basaltic to boninitic volcanism. This site was chosen because basalt and gabbro were found at dive site 1149 and in a dredge haul to the east-northeast of this dive site, and boninites were found to the west on seamounts and islands of the Ogasawara Ridge. This site was labeled A-3 in the original proposal.

Observations:
The dive began (Stop 1) at 11:50 and 4429 m on a relatively flat surface covered by mud and a few isolated subrounded to subangular clasts, which probably are fragments mudstone and volcanic breccia/conglomerate found farther up-slope.

Stop 2 (4420 m, 12:00) was just upslope in a cluster of subrounded cobbles and boulders. These rocks probably were derived from outcrops and talus just up-slope. Three relatively large samples were collected. Sample R1 (28x15x7 cm) was a mudstone with a heavy Mn crust; R2 (30x20x5) also was a mudstone; and R3 was a matrix-supported conglomerate with basaltic to boninitic clasts. Upslope from this location the bottom was mud with isolated outcrops and talus of subangular to rounded cobbles and boulders. Some of the outcrops had a slabby appearance (Figure 1). After examination of the rocks after the dive, it became apparent that these slabby outcrops probably are massive, half-meter scale beds of volcanic conglomerate whose orientation is approximately a dip-slope.

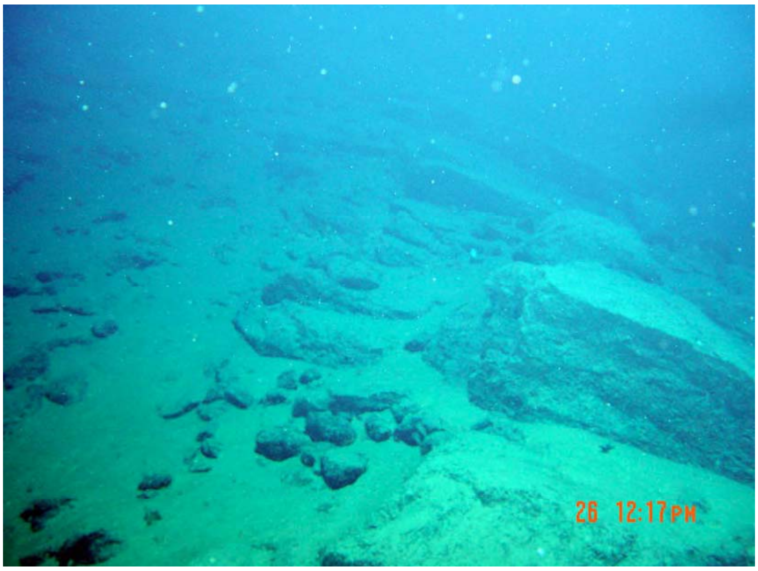


Figure 1 – Slabby outcrop of volcanic conglomerate near stop 2.

Stop 3 (4378 m; 12:20) was on another rubbly area of outcrop and talus. The samples collected here were from talus. Sample R4 (23x22x16 cm) was a large, subrounded fragment of volcanic conglomerate with basaltic clasts. Sample R5 (31x20x15 cm) also was a volcanic conglomerate with a range of basaltic to andesitic clasts.

This pattern of surface lithologies (mud with clusters of larger subangular to angular rocks and rare outcrop) continued through the next stop.

Stop 4 (4292 m; 12:44) was at a deposit of talus consisting of cobbles boulders as large as about a meter across and perhaps sub-outcrop of massive rock (Figure 2). Two large subrounded to subangular clasts were collected here. R6 (18x17x9 cm) was a subangular clast of plagioclase-phyric basalt with a thin coating of sandy to muddy matrix suggesting that it was a clast from a volcanic breccia or conglomerate. R7 (19x17x9 cm) was a clast-supported monolithologic volcanic breccia with angular to subangular andestic clasts.

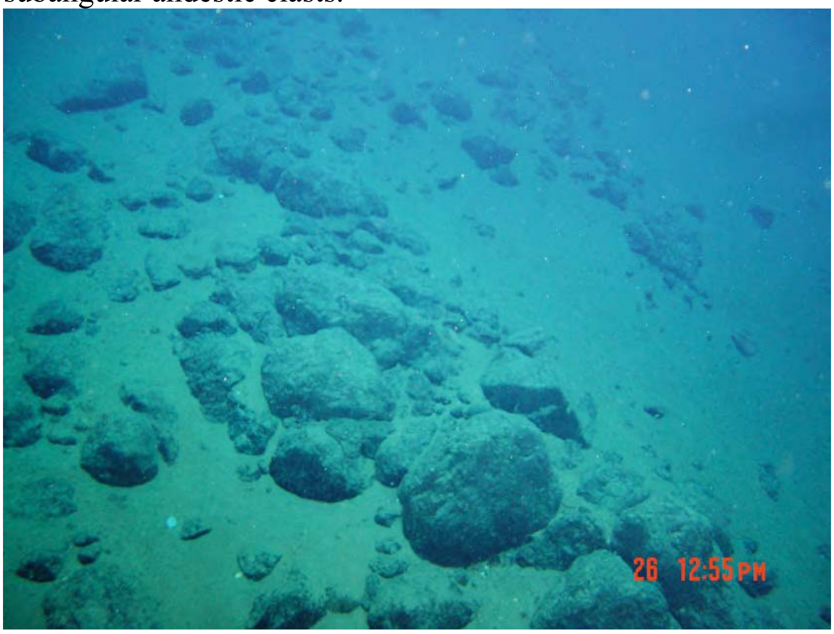


Figure 2 - Talus and sub-outcrop (?) of volcanic conglomerates and breccias.

Up slope from here to about 4200 m, the surface was similar to that at stop 4 with patches of talus/sub-outcrop separated by mud. The frequency of talus patches and surface rocks altogether decreased above this depth.

Sample collection was attempted at two sites: Stop 5 at 4180 m (~13:15) and Stop 6 at 4145 m (~13:30). The surface in both areas was largely covered with mud, with rare patches of scattered subangular to subrounded cobbles and boulders. These rocks deformed and fragmented when they were grasped by the pincers of the robotic arm. Thus, they were probably weakly lithified mudstones. Some slabby sub-outcrops of what was probably mudstone poked through the unconsolidated mud. The orientation of these slabs suggested the mudstones form a dip slope here. Sample collection was abandoned in this area, and we moved off to the next stop by "flying" about 1800 m to the west.

The landing site was in a "sea" of mud at about 3850 m depth (~14:20). We moved on until we found patches of cobble- to boulder-sized clasts. Sampling was a severe problem in this area due to the upslope current, which would billow mud and organic debris around the Shinkai 6500 each time we stopped, as well as the lack of outcrop. Sampling was attempted at Stop 7 (3813 m; 14:36). Two rocks were successfully grasped by the robotic arm, but each was a mudstone that quickly fragmented. We moved to 3770 m depth (Stop 8; 14:55) and attempted to sample the scattered rock fragments again. This time the Shinkai 6500 was enveloped with turbidity, such that visibility went to zero and sampling became impossible. Finally, at a depth of 3679 (15:22) sample 8 (17x15x12 cm) was collected as a catcher would catch a very slow baseball by the pincers grasping the sample as the Shinkai continued to move forward (Figure 3). This rock turned out to be a mudstone.

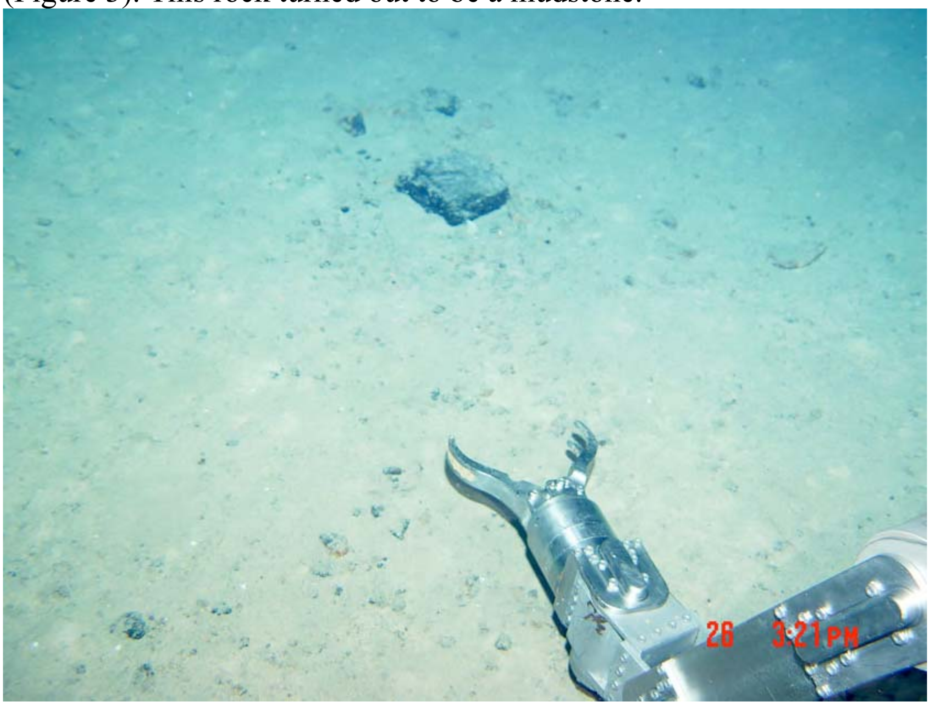


Figure 3 – Collecting sample 8 while the Shinkai 6500 moved forward to avoid being enveloped with suspended sediment.

Moving on, the bottom continued largely to be mud-covered with widely spaced rocks or clusters of rocks. Outcrop emerged from the mud in a couple of locations, but these appeared to mudstones, as each time we tried to grasp a piece of this material, it crumbled into mud and tan-colored fragments. When bedding was apparent, it largely formed a dip-slope.

Three samples were collected in the last several minutes of the dive at a depth of 3662 m. Each was an isolated subangular boulder or cobble surrounded by mud. All three samples (R9, 12x9x9 cm; R10, 11x8x4 cm; R11, 14x13x7 cm) all mudstones. The dive ended at about 15:50.

Summary:

The scattered outcrops in lower section of the dive site consisted volcaniclastic conglomerates and breccias with dips similar to the sea-floor slope. The clasts in these rocks were basalts, boninites, and andesites that are similar to those in the encountered on the Bonin Islands and on seamounts along the Ogasawara ridge. These sediments probably armor the surface, rendering this area as unsuitable for collecting the original target rocks: transitional basalt to boninite. The upper section of the dive site was covered by unconsolidated and consolidated muds.

Dive 1151 Report

Observer: Makoto Yuasa

Technical information:

Location: Northern Ogasawara Ridge
Objective: Geological observation and rock sampling in the deeper part of the inner trench slope of the Ogasawara Ridge.

	On bottom:	Off bottom:
Time (local)	11:51	15:40
Latitude:	27°54.4119′ N	27°53.6007′ N
Longitude:	142°53.9886′ E	142°52.7278′ E
Depth (m):	4765	3927

10 samples collected

Dive summary

Purpose

The main purpose of this dive was to observe and sample rocks from the middle section of the crust of inner trench slope of the Izu-Ogasawara Trench area at the northern Ogasawara Ridge (Site B-2 in the cruise proposal). Before this diving cruise, boninitic rocks were sampled from a knoll on the uppermost part of the target slope during the KH07-02 Leg4 cruise in 2007 (at site D39). The target slope was planned to find outcrops of underlying lithologies, especially basalt and gabbro, and to detect the boundaries between boninite and basalt layers, and basalt and gabbro layers.

Topography

The dive site was located on the trench inner slope from 4800 to 4000 m depth (Fig. 1). The upper and lower portions of the dive had slopes of 21 and 24 degrees with a gently inclined narrow shelf of about 14 degrees between them from 4200 to 4120 m depth.

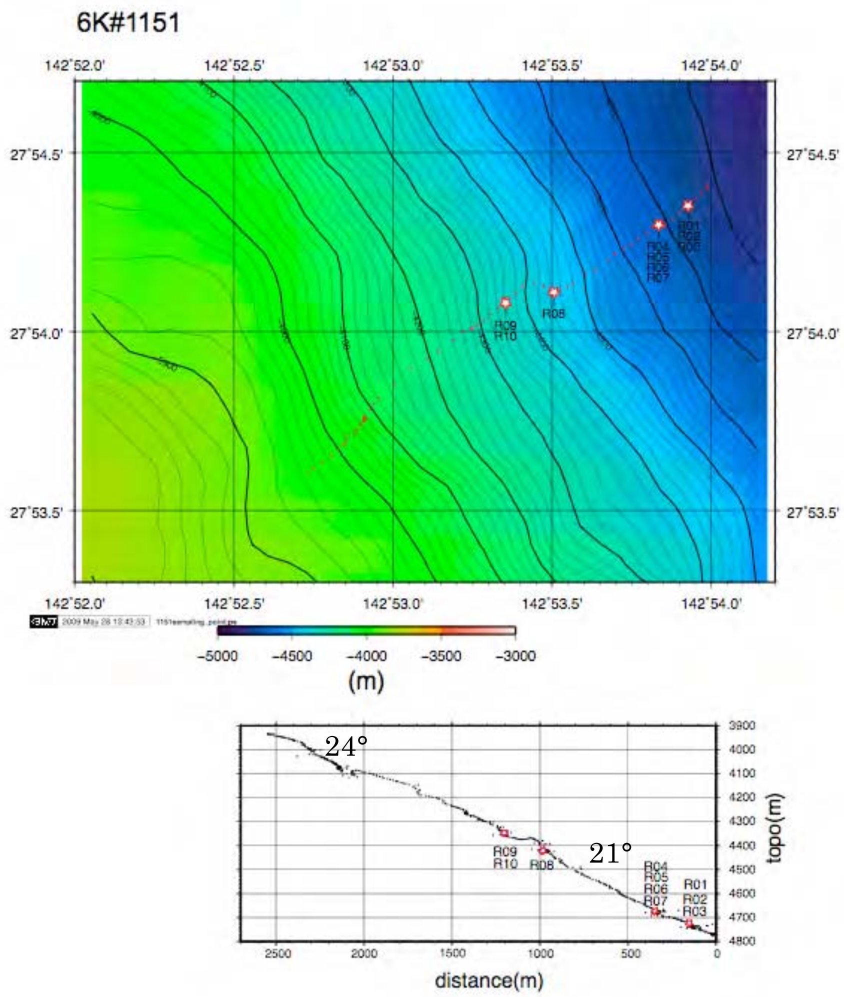


Figure 1 Topographic map and sub track (upper) and topographic section based on depth data of the sub (lower). Average inclination of the slope is shown on the lower figure.

Geological observation

The lower slope was covered by muddy sediment (Fig. 2). Cobble and boulder size rock blocks were scattered on the surface and often in clusters (Fig. 3). As the rocks in this area were blocky sometimes with cubic and columnar shapes and possibly joint-originated planes, I thought they might be gabbro boulders. After examination of the rocks on ship, they were found to be volcanic breccias with clasts of boninite.

Figure 2 Muddy floor near the landing point.

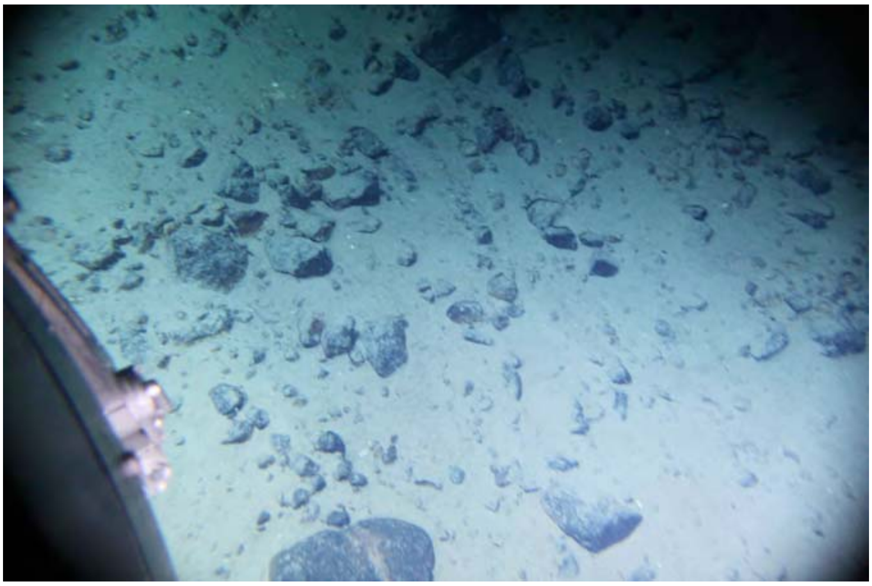


Figure 3 Cluster of cobbles and boulders of volcanic breccia on the lower slope.

A huge block, which was originally thought to be outcrop, was encountered at 4340 m on upper part of the lower slope (Fig. 4). I first described it as an outcrop on the video data. However, when the sub arrived at its top, I saw it was surrounded by sedimented sea-floor and concluded that it could be a large talus block. The sampled fragments from the block are volcanic breccia.

Figure 4 The “outcrop” of volcanic breccia near upper part of the lower slope. Samples #9 and #10 were caught from light-colored part of the “outcrop.”

Near at the uppermost part of the lower slope 4258 m depth, overlying sediment became very thin cover and sedimentary rock outcrop was observed sometimes under the thin sediment cover.

As the inclination of the slope became gentle near 4200 m depth, the sub “flew” over to the upper slope at 15-20 m height above the seafloor. The sub landed again on the basal area of the upper slope at 4090 m. Light brownish-colored sedimentary rock blocks were scattered on the seafloor at this location. The sedimentary rock was found to be a young mudstone because it was too soft to be caught by the sub’s manipulator. The mudstone cropped out through the thin surface sediment in some locations (Fig. 5), and I concluded that the floor of the upper slope was constructed of mudstone.

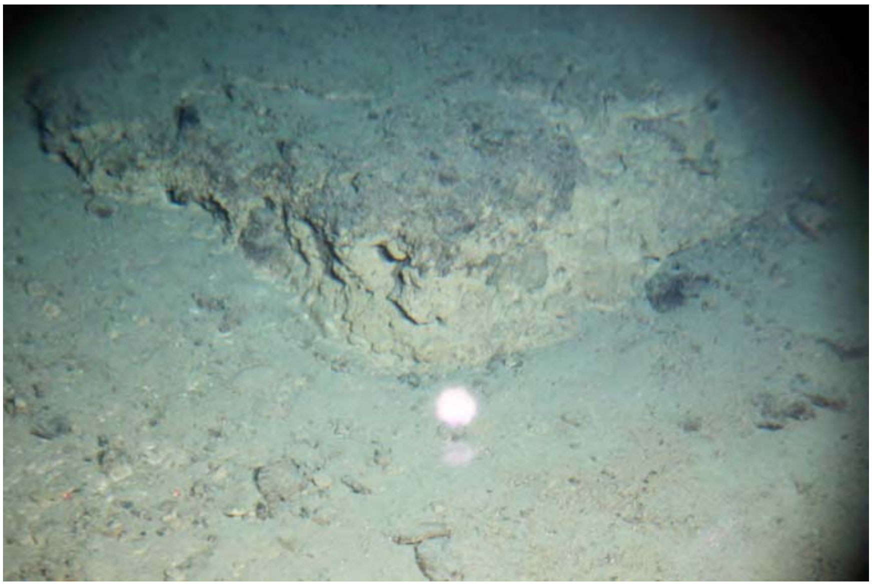


Figure 5 An outcrop of mudstone on the upper slope.

The sub ascended the upper slope and encountered an area with a gentle slope at about 3950 m depth. Light brownish-colored mudstone with platy cleavage cropped out there. The mudstone was partly stratified, with an orientation that approximated a dip-slope.

Explanation of landing and sampling sites

Stop 1 On bottom (4765 m, 11:51)

The landing was on a muddy flat area that is thinly covered by coarse sediment. Boulders and cobbles are dispersed on the seafloor. The large blocks show slightly rounded shape.

Stop 2 Sampling site (4731 m, 12:15)

Upslope from the landing point to this stop 2, rock frequency increases. Rock blocks with possibly joint planes were often found as clusters of boulders. I collected three samples:

#1 volcanic breccia (boninite clasts)

#2 volcanic breccia (boninite clasts)

#3 pillow breccia (basaltic pillow fragments and boninite?).

Stop 3 Sampling site (4669 m, 12:58)

A huge rock block larger than 2 m across was surrounded by (?) a clustered mound of boulders. Although we tried to collect rocks with different shapes to increase rock variety, every rock sampled was volcanic breccia with boninite or basalt.

The samples collected here are:

#4 boninite breccia

#5 volcanic breccia (boninite and basalt clasts)

#6 basalt (one big basalt clast from conglomerate)

#7 volcanic breccia (basalt clast)

Stop 4 Sampling site (4418 m, 13:40)

No outcrops were found in spite of the steeper slope. Boulders from 1m across to cobble size rocks were embedded in sediment on the slope. The shapes of rocks were cubic, columnar and so on. A rugby ball sized block with joint planes was sampled here.

#8 boninite breccia

Stop 5 Sampling site (4347 m, 14:08)

A huge rock wall several meters high appeared on left side of the sub. Its fresh surface was grayish white with light brownish patches. We thought it an outcrop and tried to obtain a sample directly from the wall by the sub's manipulator. The rock sampled turned out to be a volcanic breccia with a coarse matrix. After sampling, the sub went beyond the "outcrop" and discovered that it was a huge rock block surrounded by sedimented seafloor. However, it is likely that the block was derived from a nearby outcrop of volcanic breccia layer.

The samples collected here are:

#9 boninite breccia (fine-grained groundmass) pale gray-colored

#10 boninite breccia (fine-grained groundmass) pale gray-colored.

Dive 1152 Report

Observer: Yumiko Harigane

Technical information:

Location: Eastern Ogasawara Ridge.
Objective: Geological observation and rock sampling in the deeper section of the landward side of Izu-Bonin trench slope.

	On bottom:	Off bottom:
Time(local)	11:33	15:13
Latitude:	27°19.0856′ N	27°19.7451′ N
Longitude:	143°1.0873′ E	143°0.1164′ E
Depth (m):	5980	5570

Samples returned: 7 rocks

Summary of dive observations

The objective of this dive was geological observation and rock sampling in the deeper part of the landward side of Izu-Bonin Trench slope at the Eastern Ogasawara Ridge (Site C-2 in the cruise proposal).

The Shinkai 6500 landed on the seafloor at 5980 m at 11:33. The landing point had a mud buttom with scattered Mn-coated boulders that were partially covered by mud (Stop 2; Fig. 1). We began observing and tried to sample at the landing point, but the rocks were mudstone that fragmented when grasped by the robotic pincers. We headed west (heading 250º-310º) to climb the slope. This slope was covered by yellow mud with a few subrounded or subangular boulders and cobbles. These scattered rocks looked like small islands in mud and their orientations were parallel to the dip of the slope. We examined and tried to collect the rocks in several locations. The goal was to obtain basaltic-gabbroic rocks or volcaniclastic sediments. Unfortunately, the rocks all appeared to be mudstone (Fig. 2). Samples R01 at 5921m (Stop 3) and R02 at 5842m (Stop 4) were two of the subrounded and subangular boulders atop the mud in this slope. These samples turned out to be Mn-coated mudstones (R01, R02).

The heading of the Shinkai 6500 changed from W (heading 280º) to NW (heading 340º) as specified by the dive schedule. At this heading, the Shinkai 6500 moved along the 5820 m contour. Like before, this slope had scattered Mn-coated cobbles and boulders in yellow mud (Fig. 3). We continued to try to examine and sample boulders in the slope from 5809 m to 5793 m, but again these rocks all turned out to be soft mudstone. At 5793 m depth, 2 samples (Stop 5; Fig. 4; R03, R04) were collected from some boulders on mud. These samples were sub-angular Mn-coated mudstones. We observed that an east dipping muddy angular or subangular boulders and cobbles talus covered the slope in this area (Fig. 5). Moving upward about 30m from Stop 5, we observed talus. The talus consisted of monolithologic sub-angular blocks covered with very little mud (Stop 6; Fig. 6). The samples collected here (R05, R06 and R07) were all aphyric basalts with thin Mn-coatings (Fig. 6a).

The heading of the Shinkai 6500 changed from NW (heading 310º) to W (heading 270º) in line with the dive schedule. The slope was covered by yellow mud with few sub-rounded or sub-angular boulders (Fig. 7). Although we tried to get some samples in the slope, we were unsuccessful in sampling because these boulders were all mudstone (5577m-5725m).

Finally, we also observed an talus that was subangular boulders and cobbles with mud and examined boulders until the Shinkai 6500 made its ascent to the surface at 5570 m (15:11).

Summary of sample observations

Seven samples were collected from three stops in this dive. The lithology of the seafloor along the dive course was mostly yellowish mud with scattered debris of sub-angular mudstone crusts of various sizes, ranging small size cobbles to large-sized boulders. One talus deposit of aphyric basalt was observed and collected.

Hand specimen observations indicate that the rocks collected during the dive are 4 mudstones and 3 aphyric basalts with thin Mn-coatings. The total weight of the samples in this dive was 47.5 kg. Many of the mudstones that were collected include some small black chips that may be fragments of basalt. The aphyric basalt samples probably were the interiors of pillow lavas. These basalts had a variolitic texture and a fine-grained groundmass, quite unlike any other samples collected on this dive cruise.

Representative images:

	Fig. 1. Depth: 5980 m, Time: 11:37 The landing point was mud with a few cobbles partially covered by mud.
	Fig. 2. Depth: 5980 m, Time: 11:41 We tried unsuccessfully to sample rocks at the landing point, because they consisted of soft mudstone.

Fig. 3. Depth: 5819m, Time: 13:50

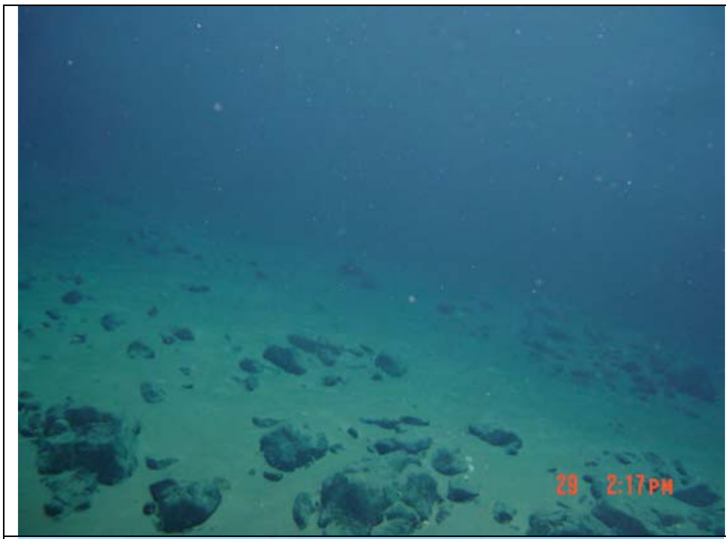
Shinkai 6500 moved to the NW along the 5820m contour. The slope mainly consisted of yellow mud and mudstone, with scattered Mn-coated cobbles and boulders.

Fig. 4. Depth: 5793m, Time: 13:58

At 5793 m of depth, 2 samples (R03, R04) were collected from some boulders on mud. They were sub-angular Mn-coated mudstones. We continued to try to examine some boulders at this location, but all were mudstone.

Fig. 5. Depth: 5819m-5793m, Time: 13:54

The slope was covered with an east-dipping talus.

	Fig. 6. Depth: 5766m, Time: 14:17 3 samples (R05, R06, R07) were collected from the talus with monolithologic sub-angular blocks with very little mud covering.
	Fig. 6a. R05 R05 is an aphyric basalt.
	Fig. 7. Depth: 5577m, Time: 15:05 The slope was covered by yellow mud with a few sub-rounded or sub-angular boulders.

Dive 1153 Report

Observer: Susumu Umino

Technical information:
Location: Northern Ogasawara (Bonin) Ridge
Objective: Geological observation and rock sampling of the trench-ward side of the Ogasawara Ridge.

	On bottom:	Off bottom:
Time (local)	11:46	15:02
Latitude:	28.46475°N	28.45082°N
Longitude:	142.83250°E	142.82174°E
Depth (m):	6112	5715

9 samples collected

Purpose:
The main purpose of this dive was to observe and sample rocks from the sea floor in the Bonin fore-arc that predates boninite volcanism. This site was chosen because pre-boninite basalt and gabbro were found at dive site 1149 and in a dredge haul to the east-southeast of this dive site, and volcanic breccias consisting of boninite clasts were found at dive site 1150 to the south on the northeastern slope of the Ogasawara Ridge.

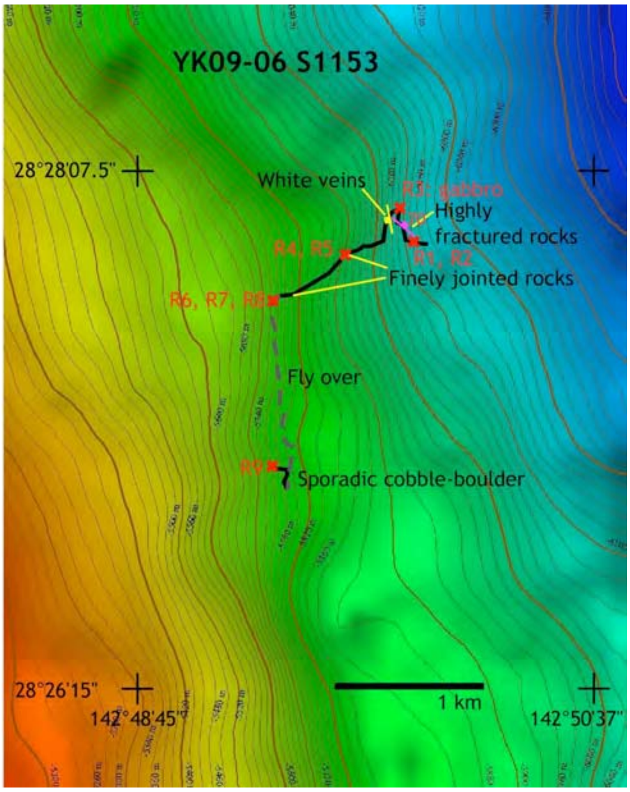


Figure 1. Dive track and sample locations. Observed dike and vein trends are shown.

Observations:

The dive began (Landing point) at 11:46 and 6112 m on a relatively flat surface covered by mud and a few isolated subrounded to subangular clasts, which probably are fragments basalt and dolerite found at Stop2 to the north (Figure 1).

We then moved upward. White veins dipping 250° are exposed on the sediment, suggesting very thin sedimentary cover on the probable dolerite-basalt basement because these white veins are observed cutting jointed and fractured rocks further upslope.

Stop 1 (6066 m, 12:00) was just 50 m upslope of the landing point in a cluster of subrounded cobbles and boulders on steep (>40°) slope. These rocks probably were derived from outcrops nearby. Two samples (R1, R2) of dolerite were collected.

We then turned northward to the last outcrop of dive number S1149, where basalt pillows are exposed. We passed outcrops of white veins cutting highly fractured and columnar jointed rocks, most likely sheeted dikes. Two dikes with columnar joints strike 270°-310°, dipping 90°-70°N (Figure 2).

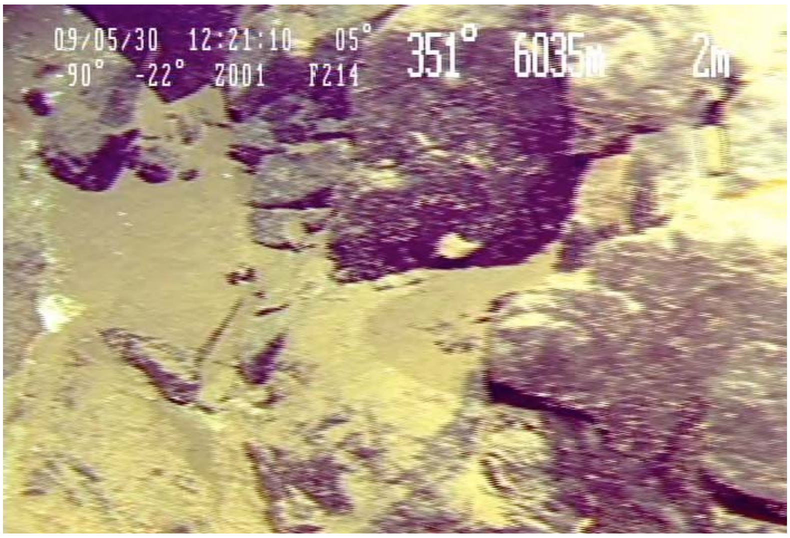


Figure 2. Columnar jointed dikes exposed before Stop 2. Subhorizontal columnar joints indicate subvertical dikes.

Stop 2 (6033 m; 12:25) is on rectangular roughly jointed outcrop. Angular blocks filling galleys form talus deposits between outcrops. White veins are attached to the surfaces of blocks. The sample R3 collected here is coarse-grained isotropic gabbro.

We moved to the south and passed white veins striking 170° and dipping 260° into roughly jointed rocks with smooth curved surfaces, most likely of gabbro (Figure 3). Yellow stains are also observed on the rock surfaces. After passing through steep talus exposing some finely jointed rocks for about 150 m, we went into sedimented gentle slope and then turned to the west. Went up steep slope of fractured outcrops with some columnar massive lava (dikes?), which strike 180° and dip steeply E, onto a sedimented gentle slope (Figure 4).

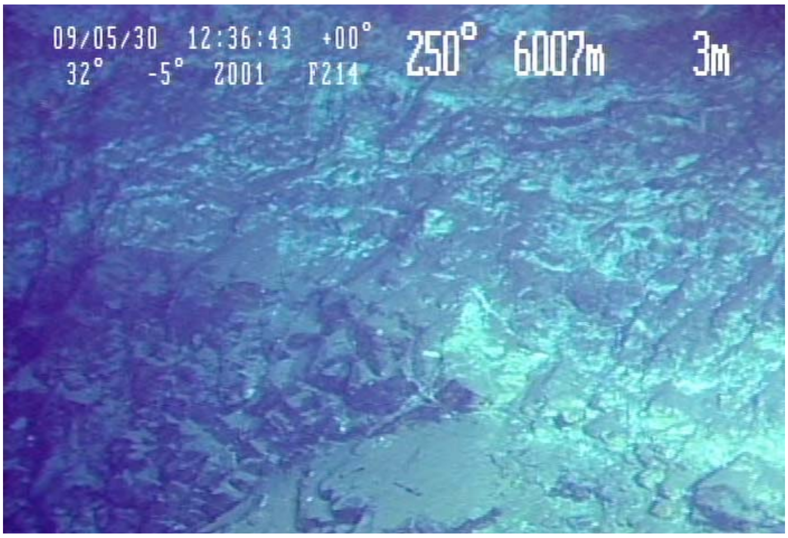


Figure 3. White veins in columnar jointed rock with smooth surfaces (gabbro?).

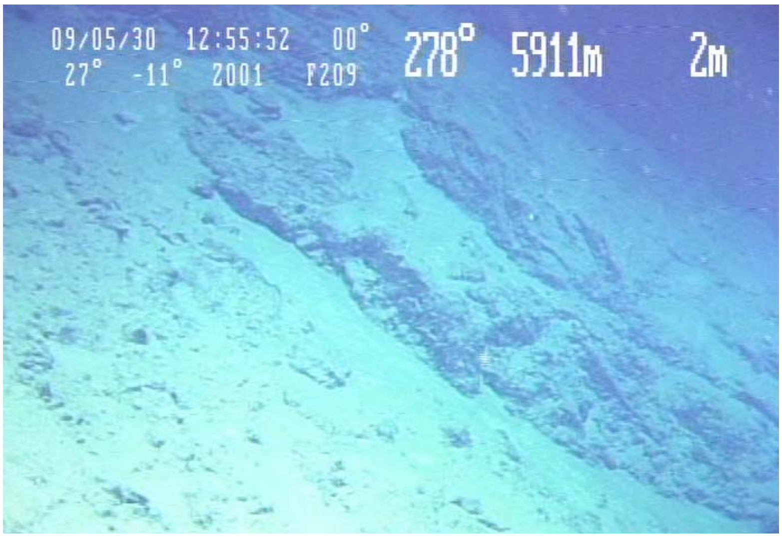


Figure 4. Columnar jointed sheet (dike) embedded in finely fractured rock.

Stop 3 (5827 m; 13:11) is highly fractured outcrop of coarse dolerite on the edge of sedimented slope facing a valley to the south. Two samples (R4, R5) were taken from fractured outcrop.

Passing through a sedimented slope for 300 m, we went into rocky slope covered with talus. There are sporadic exposures of fractured and jointed rocks.

Stop 4 (5697 m; 13:45) is almost the end of the fractured rock exposures. We collected three samples of dolerite, and then flew over to the south.

We landed on sedimented gentle slope 1 km to the south of Stop 4. We moved back northward to search for an outcrop, but we could found only patches of cobble- to boulder-sized clasts. The last sample R9 is a block of basalt hyaloclastite with fresh glass.

We took off 15:01:40 at 5715 m.

Summary:

Northernmost outcrops close to the last sample site of dive number S1149 are most likely of hydrothermally veined gabbros. The rest of the northern is probably underlain by highly fractured sheeted dikes which experienced severe tectonic disturbances. However, these dikes have consistent trends of NNW to N and steep northward dips. There was no outcrop in the southern area. Cobbles and boulders of hyaloclastite on sediments indicate the presence of the extrusive carapace overlying the dikes further upslope.

Dive 1154 Report

Observer: Osamu Ishizuka

Technical information:

Location: Northern Ogasawara Ridge. Upper slope of Dive 1153.
Objective: Geological observation and rock sampling of the trench-ward side of the Bonin Ridge.

	On bottom:	Off bottom:
Time (local)	11:21	15:11
Latitude:	28°26.8217′ N	28°27.4296′ N
Longitude:	142°49.3403′ E	142°47.7895′ E
Depth (m):	5720	5189

24 samples collected (1 lost)

Purpose:

The main purpose of this dive was to observe and sample rocks from the sea floor in the Bonin fore-arc that erupted during the transition from basaltic to boninitic volcanism. This dive was a continuation of the up-slope transect at proposal site A-1, which was begun with dive 1149 and was continued with dive 1153. Basalt and gabbro were found at dive site 1149, dolerite and basalt lava were recovered at dive site 1153, Dive 1150 was conducted at proposal site A-3 up-slope from the A-1 site between 4429 and 3663m, and recovered conglomerate and volcanic breccia consist of boninitic and basaltic clasts. These results implied that the transition between basaltic to boninitic transition crops out between 5700 and 4429m in this area. The site for dive 1154 was chosen because it was the most likely location to encounter this transition.

Observations:

The dive began (Stop 1) at 11:21 and 5720 m on a relatively steep muddy seafloor with abundant cobbles and boulders (float blocks). These blocks were sampled (R01, R02) and found to be diabase (dolerite) composed of olivine, plagioclase and pyroxene. Their angularity, implied that outcrop likely exists up-slope from this location.

The slope between Stop 1 and Stop 2 (5651 m, 11:45) has small steps with probable offsets of 1-2m. Angular blocks tend to accumulate on these steps.

Two angular floating blocks (R03, R04) were samples at Stop 2 (Fig. 1) where the slope became steeper and number of blocks significantly increased. The collected samples are vesiculated (10-20%) and highly fractured aphyric basalt.

At 11:50 (5631 m), very large blocks (>1m) started to emerge on left-hand side slope.

Stop 3 (5584 m, 11:57) was at the foot of the coming very steep slope. Three samples (R05-07) were collected from an area with large, jointed blocks lying on a muddy surface. All three samples are dolerite mainly composed of plagioclase and pyroxene showing ophytic texture.

At 12:07 (5563 m) the slope became even steeper and jointed outcrop appeared. Joints are nearly vertical and along the course of the submersible (270-300^{o}). At 12:08

(Stop 4) 5555 m) we reached a scarp where heavily jointed outcrop was observed (Fig. 2). Near the surface, the rocks were so finely-jointed and fractured, it was very difficult to obtain samples with the manipulator. Sample R08 was eventually collected (Fig. 3). It is fine-grained diabase. We moved a short distance to the upper slope and conducted sampling again from fractured outcrop. Sample R09 is a large jointed block of diabase taken from coarsely jointed part of the outcrop. Sample R10 was collected from surface area, and turned out to be bedded sandstone.

Figure 1 – Angular floating blocks of basalt on muddy seafloor near stop 2 (DSC07088.JPG).

At 12:38 finely and irregularly-fractured outcrop emerged. It appeared to the observer that jointed dike outcrop continuously extends from the lower slope to this point (Fig. 4). The finely-fractured outcrop at this location could be basaltic lava intruded by dikes. The jointed outcrop continued to Stop 5 at 5522 m. Possible lava outcrop also was seen at 12:43.

The block (R11) collected at 12:53, a block with possible radial joint (broken along the joint when grabbed by manipulator) was aphyric basalt. Then submersible shifted to left where coarsely jointed dyke outcrop was observed. R13 and R14 were collected from this outcrop. These are diabase.

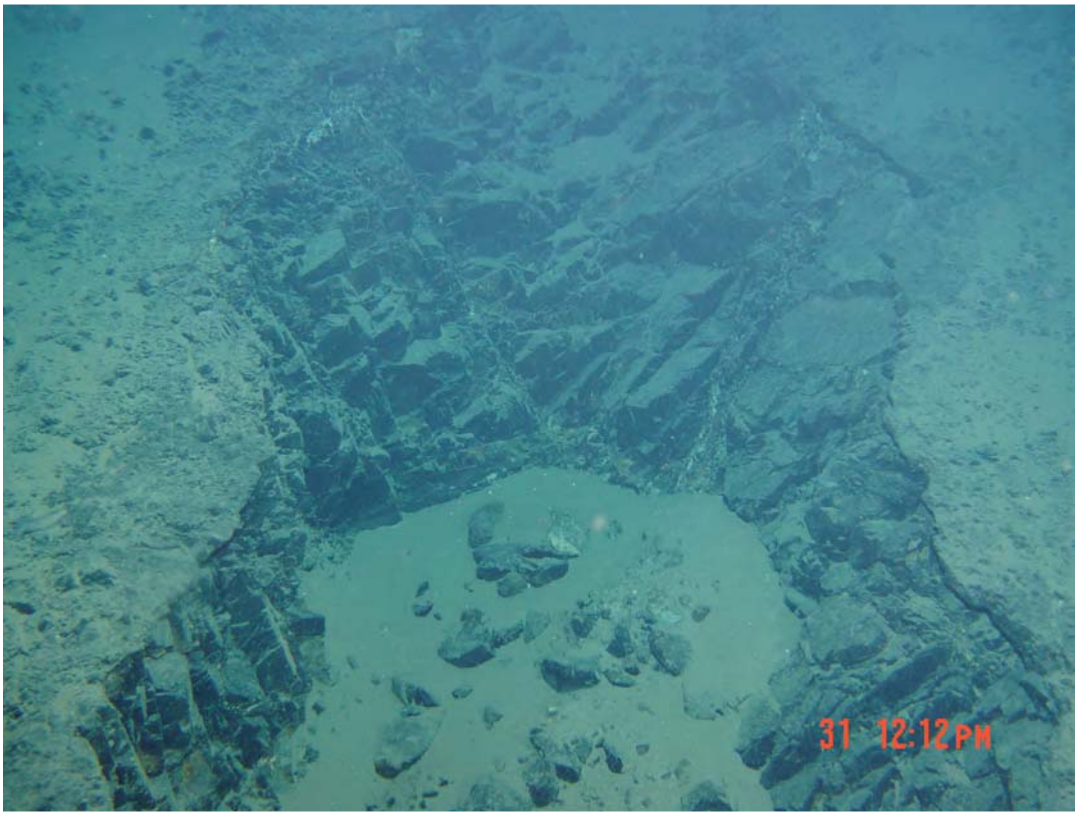


Figure 2 – Jointed outcrop of diabase at stop 4 (DSC07141.JPG).


Figure 3 – Sampling of R08 (diabase) at stop 4 (#2 IMG_0024.JPG).

Figure 4 – Dyke margin(?) at 12:38, 5540 m (#1 IMG_0030.JPG)

Figure 5 – Dyke observed at 13:03, 5498 m (No.2 camera)

Figure 6 – Outcrop of fractured basaltic lava observed at 13:13, 5438 m (No.2 camera)

At 5503 m (13:02-13:03), possible pillow lava outcrop appeared again. Then again at 5499 m coarsely-jointed dike emerged (Fig. 5). At 5490 m (13:04:50) a nearly vertical dike with strike of around 300^{o} was recognized.

At 5438m (Stop 6: 13:11), irregularly-jointed outcrop emerged after passing muddy area with gentle slope. Five samples were collected from this area showing mixed lithology. However, the lithology of the outcrop appears to be represented by R15, R18 and R19, which are fractured basalt with white-colored fracture fillings (Fig. 6). R17 has a glass rind.

Shinkai flew to the next steep slope for about 1800 m and reached seafloor at 5278 m (Stop 7). This area has a lot of mudstone (?) blocks shed from higher up the slope. These blocks are covered with relatively thick white-colored sediment. A sample collected in this area (R20) is a platy calcareous breccia, that may be the surface lithology under the unconsolidated white sediment.

Stop 8 is a slope with scattered massive outcrops as well as large boulders and slabs sitting on a muddy slope. The sample collected here (R21) is a chert-like siliceous stone coated with thin mudstone veneer.

Stop 9 at 5207 m is also covered with large boulders, possibly of mudstone or other types of sedimentary rocks (Fig. 7). We tried collecting many blocks, but all were mudstone. Eventually, a massive volcanic sandstone was collected at this stop (R22, Fig. 8).

The final stop area at around 5190 m has scattered cobles and boulders thinly covered with white sediment. Two samples were collected in this area. R23 is subangular basaltic lava block with plagioclase and olivine phenocrysts, and R24 is volcanic sandstone. This basaltic lava is petrographically distinct from those recovered at lower slope.

The dive ended at about 15:10, 5189 m bsf.

Figure 7 – Outcrop at the upper slope covered with Mn-oxides at 5208m (DSC07323.jpg)

Figure 8 – Sample R22 collected from floating block-rich seafloor at 14:46, 5207 m (No.2 camera)

Summary:

Dive #1154 surveyed 2 steep slopes between water depth of 5700 and 5200m, and completed the series of dives at proposal site A-1, whose tasks were to obtain samples from a crustal transect in NE of Mukojima Island.

The lower slope between 5700 and 5400 m has good exposures of diabase as well as basaltic lava. The diabase is petrographically similar to those observed in Dive#1153 and composed of plagioclase, pyroxene ± olivine. The strike of the dikes are generally NW. Basalt lava occurs in the shallower part of the lower slope. These observations imply that we observed the relatively upper section of crust formed at the initial stage of subduction (possibly sheeted dikes and lavas) during this dive.

The upper slope (5278-5189 m) is mainly composed of sedimentary rocks such as volcanic sandstone, chert-like siliceous rock, and indurated mudstone. Volcanic sandstone and chert-like rock seem to have been deposited after falling from an upper slope. These lithologies also might form outcrop only rarely present on this slope. One basalt block was recovered and this basalt is petrographically distinct from those collected at deeper sites by having abundant plagioclase (and olivine) phenocrysts. This basalt block could have been either nearly in situ or a fragment of float from farther up-slope. In any case, this basalt probably erupted after the to basaltic magmatism observed on the lower slope.

5. Bathymetric and Geophysical Survey

During the YK09-06 cruise, bathymetric data were collected using the SeaBeam 2112 system deployed on M/V Yokosuka, which has frequency of 12 kHz beams and a swath width of 150°. The SeaBeam system uses sound velocity data from XBT data not only for calculating the depth and position of each beam during the ray tracing process, but also for the beam forming process. The sound velocity of the surface layer is very important for this step, so the system measures and uses these surface velocities in real time. Except for the surface layer, data from a CTD installed in the Shinkai 6500 were used for calculating sound velocities. The survey was conducted mainly in nighttime during 5/24/2009 and 6/1/2009. Mean ship's speed during the survey was 12 kt. The quality of the obtained bathymetry depends mostly on the sea state, which had been very good during the cruise.

Proton magnetometer was deployed during bathymetric survey.

Three-component magnetometer data (Hx, Hy, Hz) was collected during our survey lines using an SFG-1214 magnetometer (Terra Tecnica Inc.). A figure eight track to calibrate the effect of the ship's magnetization was carried out on June 1st.

Gravity data was collected, though it was not processed on board.

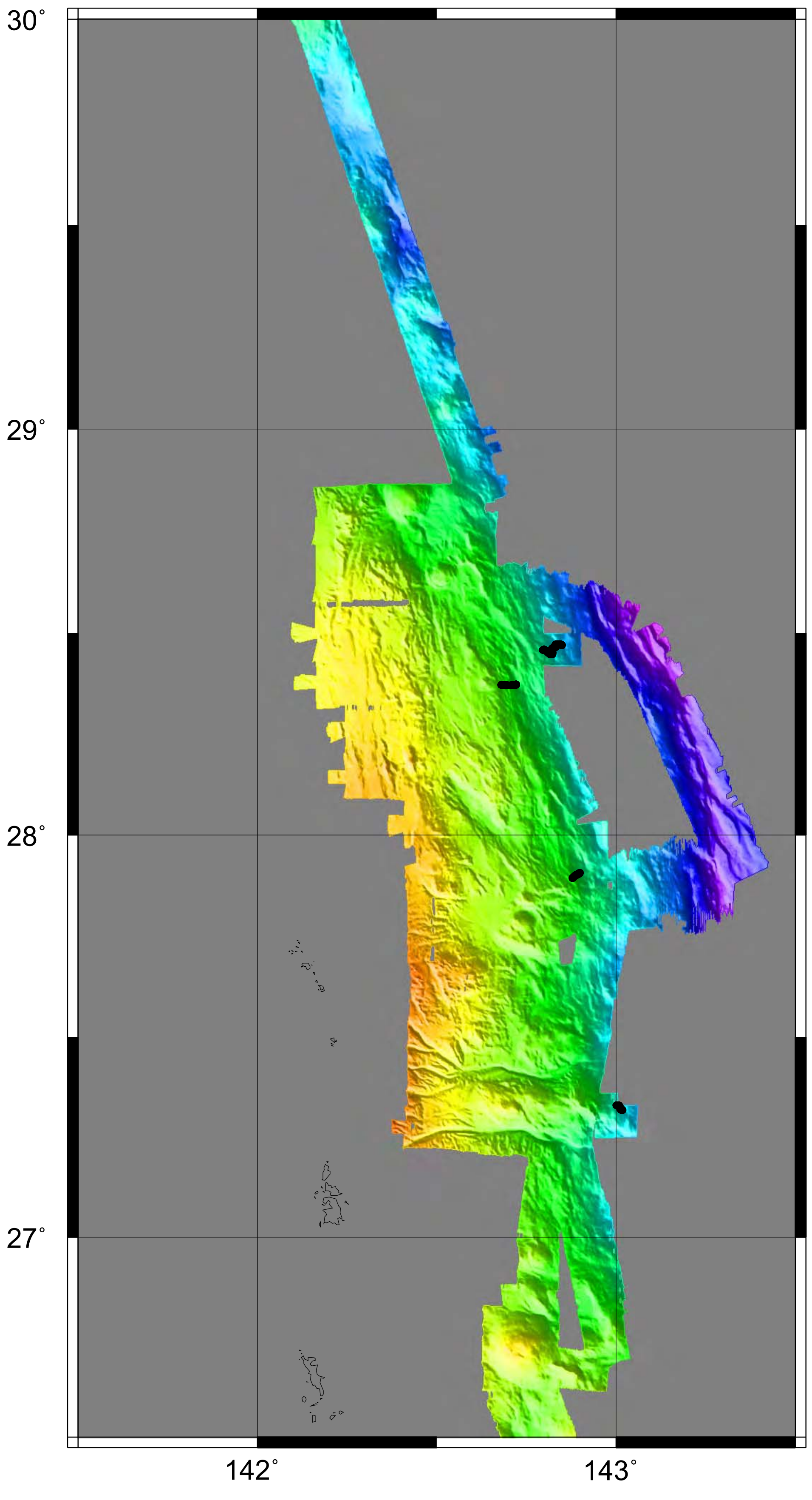


Fig. 5-1 Shaded relief image (lighting from 225o) of eastern slope of Bonin Ridge after YK0906.

6. Shore-based studies

A comprehensive work plan for the rock samples was developed by the shipboard scientific party. This work will include major element analyses, trace element analyses, geochronology studies, mineral analyses, petrographic characterization, and radiogenic isotope characterization. The work will be completed at the Geological Survey of Japan/AIST, JAMSTEC, Kanazawa University, University of Iowa, Tokai University and other possible collaborators. Analytical responsibilities include:

•Whole rock chemical composition (XRF, ICP-MS): GSJ
•Mineral chemistry (major elements: EPMA, trace elements: LA-ICP-MS): Kanazawa, GSJ
•Ar/Ar dating and some radiogenic isotopes (Sr, Nd, Pb): GSJ
•U-Pb dating (JAMSTEC)
•Structural petrology of gabbro (Kanazawa Univ.)
•Petrology of gabbro (Tokai Univ.)
•Hf isotopes (Iowa)
•Hf isotopes of zircon (JAMSTEC)
•Water content analysis by FTIR and/or SIMS (Iowa)

Other shore-based studies include:
•Bathymetric and magnetic data will be merged with existing data and synthesized at GSJ.
•Volcanic and geologic synthesis will be done at GSJ, JAMSTEC, Kanazawa University, etc..
•Links between arc crustal structure and characteristics of magma will be extensively investigated with shore-based collaborators.

7. Summary

We investigated 3 areas of the Bonin Ridge. In the northernmost survey area (Area A) near 28°25'N, we used 4 dives (Dive 1149, 1150, 1153, 1154) to look at the lower to upper crustal section formed in the earliest stage of oceanic island arc formation. The deepest dive of Dive 1149 observed both gabbro and basalt/dolerite, and appears to have passed over the boundary between the two. Lower slope is composed of fractured gabbro, whereas pillow lava was observed in the uppermost part of this dive track. Dives 1153 and 1154 surveyed up-slope of D1149. These two dives found outcrop of numerous doleritic basalt dykes and fractured basaltic lava cut by dykes between water depth of 6000 and 5500m. The shallowest dive of Dive1150 recovered volcanic breccia and conglomerate with boninitic and basaltic clasts.

Area B near 27°54'N, down slope of small knoll (probably a remnant edifice of boninite) was surveyed by Dive 1151 with a goal of observing the transitional section between the lower basaltic section and the upper boninitic section. Dive 1151 surveyed between water depths of 4760 and 4300m. This slope was covered with blocks of volcanic breccia containing boninitic and basaltic clast. The expected transition of basaltic and boninitic magmatism might exist somewhere between 5500 and 4760m, or it simply may be covered with the observed volcaniclastics.

Area C at around 27°19'N was surveyed by Dive1152 because of the uniqueness of its stratigraphic sequence inferred from dredging results. Beneath the upper basaltic and gabbroic sequences, pillow lava blocks were recovered during the dredging and this basaltic lava was dated to be >130Ma. The Dive 1152 surveyed a slope between water depths of 6000 and 5600 m. Outcrops of mudstone were frequently observed during the course of this dive. Sub-angular basaltic blocks were found only at 5766m as talus deposit. These were basaltic pillow lavas with partially preserved glassy rinds.

In summary, the first six dives of this cruise established stratigraphy of lower to upper crust formed at the initial stage of Izu-Bonin arc. Collected samples will provide information about the evolution of magmatic system in association with subduction initiation and subsequent arc maturation.

8. References

S.H. Bloomer, Distribution and origin of igneous rocks from the landward slopes of the Mariana Trench: Implications for its structure and evolution, J. Geophys. Res. 88(1983) 7411-7428.

S.H. Bloomer, B. Taylor, C.J. MacLeod, R.J. Stern, P. Fryer, J.W. Hawkins, L. Johnson, Early Arc volcanism and the Ophiolite problem: A perspective from drilling in the Western Pacific, in: B. Taylor, J. Natland, (Eds), Active Margins and Marginal Basins of the Western Pacific, American Geophysical Union, Washington D.C., 1995, pp. 67-96.

P. Fryer, J.A. Pearce, L.B. Stokking, e. al., (Eds), Proceedings of the Ocean Drilling Program, Scientific Results 125, College Station, TX, 1992.

D.M. Hussong, S. Uyeda, Tectonic processes and the history of the Mariana Arc, A synthesis of the results of Deep Sea Drilling leg 60, in: D.M. Hussong, S. Uyeda, e. al., (Eds), Initial Reports of the Deep Sea Drilling Project, Leg 60 60, U.S. Government Printing Office, Washington D.C., 1982, pp. 909-929.

O. Ishizuka, J.I. Kimura, Y.-B. Li, R.J. Stern, M.K. Reagan, R.N. Taylor, Y. Ohara, S.H. Bloomer, T. Ishii, U.S. Hargrove III, S. Haraguchi, Early stages in the volcanism: new age, chemical and isotopic constraints, Earth and Planetary Science Letters, 250, (2006) 385-401.

O. Ishizuka, M. Yuasa, I. Sakamoto, K. Kanayama, R.N. Taylor, S. Umino, K. Tani, Y. Ohara, Earliest Izu-Bonin arc volcanism found on the submarine Bonin Ridge, (2008) AGU fall meeting abstract.

N. Kuroda, K. Shiraki, Boninite and related rocks of the Chichi-jima, Bonin Islands, Japan, Rep. Fac. Sci. Shizuoka Univ. 10(1975) 145-155.

M.K. Reagan, B.B. Hanan, M.T. Heizler, B.S. Hartman, R. Hickey-Vargas, Petrogenesis of Volcanic Rocks from Saipan and Rota, Mariana Islands, and Implications for the Evolution of Nascent Island Arcs. J. Petrol. 49 (2008) 441-464.

R.J. Stern, S.H. Bloomer, Subduction zone infancy : Examples from the Eocene Izu-Bonin-Mariana and Jurassic California, Geol. Soc. Am. Bull. 104(1992) 1621-1636.

K. Suyehiro, N. Takahashi, Y. Ariie, Y. Yokoi, R. Hino, M. Shinohara, T. Kanazawa, N. Hirata, H. Tokuyama, A. Taira, Continental crust, crustal underplating, and low-q upper mantle beneath an oceanic island arc, Science 272(1996) 390-392.

N. Takahashi, K. Suyehiro, M. Shinohara, Implications from the seismic crustal structure of the northern Izu-Bonin arc, The Island Arc 7(1998) 383-394.

R.N. Taylor, R.W. Nesbitt, P. Vidal, R.S. Harmon, B. Auvray, I.W. Croudace, Mineralogy, chemistry, and genesis of the Boninite Series Volcanics, Chichijima, Bonin Islands, Japan, J. Petrol. 35(1994) 577-617.

S. Umino, Volcanic geology of Chichijima, the Bonin Islands (Ogasawara Islands), J. Geol. Soc., Jap. 91(1985) 505-523.

S. Umino, Magma mixing in boninite sequence of Chichijima, Bonin Islands, Journal of Volcanology and Geothermal Research 29(1986) 125-157.

S. Umino and S. Nakano, Geology of the Chichijima Islands, Quadrangle Series, 1:50000, Geological Survey of Japan, AIST, 2007, 63p (in Japanese with English abstract).

Chapter 2: A role of forearc tectonics on the formation of Mariana arc-trench system with special reference to serpentinite seamounts

1. Cruise objectives

It is well accepted that the recycling of subducted materials within active convergent plate margins is important for global mass balance studies. The cycling of lithospheric components from the subducted plate into the mantle of the overriding plate is important for understanding the distribution of the components within the shallow part of the subduction zone, and for their eventual availability as contributions to deeper arc and backarc magma genesis. We have learned a great deal about the potential for escape of slab-derived fluids and both slab and mantle wedge materials through the study of forearc serpentinite diapirism in the southern Mariana region (Fig. 1) (Fryer and Fryer, 1987; Fryer et al., 1990; Fryer 1992; 1996; Fryer and Mottl, 1992; Maekawa et al., 1992; 1995; Savov et al., 2002; 2005; Mottl et al., 2004; Wheat et al., 2008). However, the northern forearc, where tectonic processes are very different, remains unexplored.

The plate convergence direction (i.e., from the southeast) is nearly orthogonal at S. Chamorro Seamount (at 13°45'N) and remains at a high angle at Conical Seamount at 19°32'N. However, northward along the trench, especially beginning at ~21°N, the convergence direction changes, so that it quickly becomes close to parallel to the trench axis. This is reflected in what appears to be a profound change in strain partitioning and the nature of fault distribution along the forearc (Stern et al., 2003). South of ~21°N, deformation in the forearc has developed a well-defined set of conjugate faults with a dominant NE trend and a subdominant NW trend (Fryer and Pearce, 1992). North of ~21°N the faulting in the outer half of the forearc, where serpentinite mud volcanoes most commonly form, is dominantly trench-parallel (Stern et al., 2003). There are several unsampled forearc seamounts north of 21°N that lie along some of these trench-parallel fault traces. Despite the fact that we have no samples from these seamounts, their positions, adjacent to fault scarps, and the monogenetic, conical morphology of the edifices are identical to that of sampled serpentinite mud volcanoes south of 20°N. Because the fault traces along which the seamounts lay are roughly trench-parallel, the seamounts occur within a narrower distance-range from the trench than those of the southern forearc. By coincidence, they lie within the 70 to 85 km distance from the trench from which we have not previously been able to sample. From such a point of view, we conducted YK08-08 cruise to survey serpentinite diaper seamounts in the northern Marina forearc, and we successfully found two seamounts and one small mound in the area further north to Conical Seamount (Maekawa et al., 2008). During YK08-08 cruise, we recognize the possibility that some serpentinite diapir seamounts are distributed in the northern end of Mariana forearc where we don't have detail morphological information. The second half of the YK09-06 cruise was planned to conduct bathymetry surveys, search serpentinite diapir seamounts in the northern end of Mariana forearc, and clarify the distribution of seamounts in the whole Mariana foreac.

The study would help to constrain estimates of degree of serpentinization of forearc mantle and thus increase our understanding both of how volatiles behave within the shallower portions of subduction zones and how much of them and where they are supplied to the deeper sub-arc and sub-backarc regions of magma genesis.

2. Perological background of the serpentinite diaper seamounts in the Mariana forearc

Dredging and drilling in the circum-Pacific regions have revealed that the serpentinized peridotites are often exposed in the forearc regions (e.g. Fisher and Engel, 1969; Hawkins et al., 1972; Bloomer and Fisher, 1987; Ogawa et al., 1985a; Ogawa et al., 1985b; Honza and Kagami, 1977; IGCP Working Group, 1977; Fryer et al., 1985; Ishii, 1985; Fryer, 1996, Fryer and Fryer, 1987). In the Izu-Bonin (=Ogasawara) and Mariana forearcs, enormous amounts of serpentinized peridotite have been raised from the mantle wedge to the seafloor to form a zone of seamounts (Fryer et al., 1985) (Figure 2-1). Fryer et al. (1990) described the fluids seeping from the chimneys at the summit of one of the seamounts (Conical Seamount), and indicated that the fluids were derived from the dehydration process of descending slab.

Ultramafic rocks obtained from the serpentinite seamounts are mainly harzburgite with subordinate dunite, which are more depleted than the abyssal peridotites from the mid-oceanic ridge (Ishii et al., 1992). They were often highly tectonized. Common occurrences of kink band in olivine and pyroxene crystals provide evidence of penetrative deformation. All of them are serpentinized to some degree. Serpentine minerals are antigorite, chrysotile and lizardite (Saboda et al., 1992; D'Antonio and Kristensen, 2004). In addition to these minerals, serpentinized peridotites often contain brucite, and rarely contains minor amounts of acicular diopside and tremolite. Two types of serpentine mineral association are recognized in serpentinized peridotites; one is antigorite bearing and one is antigorite free. In the rocks with the former association, chrysotile and/or lizardite also occur in vein or matrix as later-stage secondary serpentine minerals. Antigorite is stable to higher temperatures than chrysotile (Iishi and Saito, 1973; Evans et al., 1976), and stable association of antigorite and brucite gave stability range of 300˚C~450˚C (Evans et al., 1976). Lizardite favours low temperature condition of less than 300˚C, and is considered to have the same P-T stability field as chrysotile (Peacock, 1987). The high-temperature antigorite-bearing assemblages are only found in the serpentinites from Conical, Big Blue, Celestial, and South Chamorro Seamounts. Antigorite-bearing peridotites always contain secondary iron-rich olivine and metamorphic clinopyroxene, and antigorite seems to coexist stably with them. Iron-rich secondary olivine (Fo86–90) occurs as overgrowth on the rim or along the cleavage traces of primary olivine (Fo90–92). The assemblage shows high-temperature conditions of serpentinization at ~450–550 °C, whereas chrysotile- and/or lizardite-bearing assemblages occur at ~200–300 °C. In antigorite-bearing samples, chrysotile and/or lizardite veins both predating and postdating antigorite formation are recognized. This may refl ect a complex process of tectonic cycling of shallow mantle
wedge serpentinized peridotites to depth and then back again to the surface. One of our aims of this cruise is to examine mineral assemblages of serpentinites from the many seamounts as much as possible, to establish the distributions of above two serpentine mineral assemblages in the forearc area, and to clarify the origin and process of serpentinization in the subduction zone. We believe that the results obtained this

study could be important to proceed the scismological study around the subduction zone.

During Ocean Drilling Program Leg 125, small clasts of high-pressure/low-temperature blueschist facies metabasites were recovered from Conical seamount. It suggests the blueschist facies metamorphism beneath the forearc (Maekawa et al., 1992 and 1993). Recent discoveries of blueschist-facies rocks and sediments including fragments of blueschist-facies minerals from other seamounts suggests that the blueschist-facies rocks must be common in the Izu-Bonin and Mariana forearc seamounts (Maekawa, 1995; Maekawa et al., 2004). To understand the behavior of slabderived fluids during serpentinization and metamorphism is important because the fluids must be one of the main controlling factors of physical properties of subduction zone materials, which could affect the modes of material transport and earthquakes within the subduction zone. Metamorphic rock clasts recovered from Hole 778A and 779B at Conical Seamount provide essential information on interaction between forearc materials and water. Geochemical study of the 778A metabasites indicates that the rocks have chemical affinity with mid-ocean ridge basalts, some of which have zigzag REE patterns due to intense interaction with seawater. These MORB-type rocks probably have originated from trapped oceanic crust in the Mariana forearc when the subduction of the Pacific plate started. The trapped oceanic crust has been tectonically eroded by the subducting slab, contaminated with seawater, and dragged into depth, where blueschist facies metamorphism has prevailed. The Hole 778A metabasites commonly contain quartz veins, which have been produced prior to or during blueschist facies metamorphism because high-pressure minerals, lawsonite, pumpellyite, and aragonite were often crystallized in the vein. When the trapped oceanic crust has been eroded by the subducting slab, the fragmented oceanic crust had encountered the pelagic sediments at the top of the subducting slab. The Si-rich fluids having permeated the Hole 778A rocks were probably derived from pelagic sediments on top of the subducting slab. A metasomatic rock clast rich in phengite and chlorite was obtained from Hole 779B (125-799B-01R-06, 19-22) at Conical Seamount (Maekawa et al., 2001), and abundant tremolite-chlorite schists were reported from South Chamorro Seamount during ODP 195 (Shipboard Scientific Party, 2002). Rocks with similar mineral associations and similar geochemical characteristics are often found in metasomatic reaction zone developed at the boundary between serpentinite and pelitic schist in the high-pressure Sanbagawa metamorphic belt, Japan. The clast may have been formed at the boundary between hanging-wall peridotite and subducting oceanic crust where the hydrothermal metasomatic reactions have pervasively occurred (Maekawa et al., 2001 and 2004). We wish to establish the general ideas of metamorphism and metasomatism along and above the subduction boundary by examining these rocks obtained during this cruise. Furthermore, we will make effort to clarify the modes of occurrence (= morphological features) of the forearc seamounts, petrological and geochemical characteristics of serpentinized peridotite, metamorphic rocks, and metasomatic rocks occupying the seamounts, and consider the phisico-chemical conditions below the forearc and the behavior of water squeezed from the subducting slab in the formation of serpentinite seamounts.

References:

Bloomer, S. and Fisher, R. L., 1987, Petrology and geochemistry of igneous rocks from the Tonga Trench – a non-accreting plate boundary. Jour. Geology, 95, 469-495.

D'Antonio, M., and Kristensen, M.B., 2004, Serpentine and brucite of ultramafi c clasts from the South Chamorro Seamount (Ocean Drilling Program Leg 195, Site 1200): Inferences for the serpentinization of the Mariana forearc mantle: Mineralogical Magazine, v. 68, p. 887–904

Evans, B. W., Johannes, W., Oterdam, H. and Trommsdorff, V., 1976, Stability of chrysotile and antigorite in the serpentinite multisystem. Schweiz Mineral Petrogr Mitt, 56, 79-93.

Fisher, R. L. and Engel, C. G., 1969, Ultramafic and basaltic rocks dredged from the nearshore flank of the Tonga Trench. Geol. Soc. Am. Bull., 80, 1373-1378.

Fryer P., 1996, Tectonic evolution of the Mariana convergent margin. Reviews of Geophysics, 34, 89-125.

Fryer, P., Ambos, E. L. and Hussong, D. M., 1985, Origin and emplacement of Mariana forearc seamounts, Geology, 13, 774-777.

Fryer, P. and Fryer, G. J., 1987, Origins of nonvolcanic seamounts in a forearc environment. In: B. Keating et al. (eds), Seamounts, Islands, and Atolls, AGU Geophys. Monogr. Ser., 43, 61-69.

Fryer, P., Mottl, M., Johnson, L., Haggerty, J., Phipps, S. and Maekawa, H., 1995, Serpentine bodies in the forearcs of Western Pacific convergent margins: origin and associated fluids. In: B. Taylor and J. Natland (eds.), Active Margins and Marginal Basins of the Western Pacific, AGU Geophysical Monograph 88, 259-280.

Fryer, P., Saboda, K. L., Johnson, L. E., Mackay, M. E., Moore, G. F. and Stoffers, P. 1990, Conical seamount: Sea MARC II, Alvin submersible, and seismic-reflection studies. In Fryer, P., Pearce, J. A., Stokking, L. B., et al., Proc. ODP, Init. Repts., 125: College Station, TX (Ocean Drilling Program), 69-80.

Fryer, P., 1992, A synthesis of Leg 125 drilling of serpentine seamounts on the Mariana and Izu-Bonin forearcs, Ocean Drilling Program Leg 125, Scientific Results Leg 125, 593-614.

Fryer, P. and Pearce J. A., 1992, Introduction to the scientific results of Leg 125, Ocean Drilling Program Leg 125, Scientific Results Leg 125, 3-11.

Fryer, P. and M. Mottl, 1992, Lithology, mineralogy and origin of Serpentine muds drilled at Conical Seamount and Torishima Forearc Seamount, Ocean Drilling Program Leg 125, Scientific Results Leg 125, 343-362.

Fryer, P., Wheat, C. G. and Mottl, M. J., 1999, Mariana blueschist mud volcanism: Implications for conditions within the subduction zone. Geology, 27, 103-106.

Fryer, P., 1996, An actively venting serpentine seamount on the southeastern Mariana forearc: Shinkai 6500 dives 280 and 281, JAMSTEC Journal of Deep Sea Research, 12, 247-256.

Hawkins, J., Fisher, R. L. and Engel, C. G., 1972, Ultramafic and mafic rock suites exposed on the deep flank of the Tonga Trench. Geol. Soc. America Abs. with Prog., 4, 167-168.

Honza, E. and Kagami, H., 1977, A possible accretion accompanied by ophiolite in the Mariana Trench. Jour. Geography, Tokyo, 86, 80-91.

IGCP Working Group, 1977, 'Ophiolites'. Initial report of the geological study of oceanic crust of the Philippine Sea floor. Ofioliti, 2, 137-168.

Iishi, I. and Saito, M., 1973, Synthesis of antigorite. Am Mineral., 58, 915-919.

Ishii, T., 1985, Dredged samples from the Ogasawara fore-arc seamount or "Ogasawara paleoland" - "fore-arc ophiolite". In N. Nasu et al. (eds.), Formation of Active Ocean Margins, 307-342. Terra Sci. Pub. Company, Tokyo.

Ishii, T., Maekawa, H., Ozawa, H., Ashi, J., Matsuoka, H., Konishi, K. and Kobayashi, K., 1989, Description of dredged samples from ophiolitic seamount (in Tori-Shima fore-arc), Uyeda Ridge and Ogasawara Plateau, during the first leg (Tokyo to Guam) of KH 87-3 cruise. Preliminary Report of the Hakuho Maru Cruise KH-87-3, Ocean Res. Inst., Univ. of Tokyo, 92-99.

Ishii, T., Robinson, P. T., Maekawa, H. and Fiske, R., 1992, Petrological studies of peridotites from diapiric serpentinite seamounts in the Izu-Ogasawara-Mariana forearc. Proc. ODP, Sci. Results, 125: College Station, TX (Ocean Drilling Program), 445-486.

Johnson, L. E., 1992, Mafic clasts in serpentine seamounts: petrology and geochemistry of a diverse crustal suite from the outer mariana forearc. Proc. ODP, Sci. Results, 125: College Station, TX (Ocean Drilling Program), 401-413.

Maekawa, H., Shozui, M, Ishii, T., Saboda, K. and Ogawa, Y., 1992, Metamorphic rocks from the serpentinite seamounts in the Mariana and Izu-Ogasawara forearcs. Proc. ODP, Sci. Results, 125: College Station, TX (Ocean Drilling Program), 415-430.

Maekawa, H., Shozui, M., Ishii, T., Fryer, P. and Pearce, J. A., 1993. Blueschist metamorphism in an active subduction zone. Nature, 364, 520-523.

Maekawa, H., Fryer, P. and Ozaki, A., 1995, Incipient blueschist-facies metamorphism in the active subduction zone beneath the Mariana forearc. In: B. Taylor and J. Natland (eds.), Active Margins and Marginal Basins of the Western Pacific, AGU Geophysical Monograph 88: 281-289.

Maekawa, H., 1995, Metamorphic rocks from serpentinite seamounts in the Mariana and Izu-Bonin forearcs, In: H. Tokuyama et al. (eds.), Geology and Geophysics of the Philippine Sea, Japanese-Russian-Chinese Monograph, 357-369, Terra Scientific Publishing Company, Tokyo.

Maekawa, H., 2000, Comparison of genesis and tectonic setting of Jurassic and Cretaceous high-pressure metamorphic belts in the circum-Pacific regions. In H. Okada and N. J. Mateer (eds.): Cretaceous Environments of Asia , Elsevier Science B. V., 169-180.

Maekawa, H., Yamamoto, K., Ishii, T., Ueno, T., Osada, Y., 2001, Serpentinite seamounts and hydrated mantle wedge in the Izu-Bonin and Mariana forearc regions. Bulletin of the Earthquake Research Institute University of Tokyo, 76, 355-366.

Maekawa, H., Yamamoto, K., Ueno, T., Osada, Y., Nogami, N., 2004, Significance of serpentinites and related rocks in the high-pressure metamorphic terranes, circum-Pacific regions. International Geology Review 46, 426-444, 2004, and In Ernst, W. G. ed., "Serpenmtine and Serpentinites: Mineralogy, Petrology, Geochemistry, Ecology, Geophysics, and Tectonics". Geological Soiciety of America, 167-185.

Mottl, M. J., 1992, Pore waters from serpentinite seamounts in the Mariana and Izu-Bonin forearcs, Leg 125: evidence for volatiles from the subducting slab. Proc. ODP, Sci. Results, 125: College Station, TX (Ocean Drilling Program), 373-385.

Mottl, M. J., C. G. Wheat, P. Fryer, J. Gharib, and J. B. Martin, 2004, Chemistry of springs across the Mariana forearc shows progressive devolatilization of the subducting plate, Geochimica et Cosmochimica Acta, 68(23), 4915–4933.

Ogawa, Y., Fujioka, K., Nishiyama, T., Uehara, S. and Nakagawa, M., 1985a, Ophiolitic rocks of the Middle America Trench landward slope off Guatemala: Deformational characteristics and tectonic significance. Init. Repts. DSDP, 84, 791-809.

Ogawa, Y., Naka, J. and Taniguchi, H., 1985b, Ophiolite-based forearcs: a particular type of plate boundary. In N. Nasu et al. (eds.), Formation of Active Ocean Margins, 719-746.

Peacock, S. M., 1987, Serpentinization and infiltration metasomatism in the Trinity peridotite, Klamath province, northern California: implications for subduction zones. Contrib. Mineral Petrol., 95, 55-70.

Saboda, K. L., Fryer, P., and Maekawa, H., 1992, Metamorphism of ultramafic clasts from Conical

Seamount: Site 778, 779, and 780. Proceedings of the Ocean Drilling Program, Scientific Results, 125: College Station, TX (Ocean Drilling Program), p. 431-443.Shipboard Scientifi c Party, 2002, Leg 195 summary, in Salisbury, M.H., et al., Proceedings of Ocean Drilling Program, Initial reports, Volume 195: College Station, Texas, Ocean Drilling Program, p. 1–63 [CD-ROM].

Savov, I.P., J.G. Ryan, L. Chan, M. D,Antonio, M. Mottl, P. Fryer, and ODP Leg 195 Scientific Party (2002) Geochemistry of serpentinites from the S. Chamorro seamount, ODP Leg 195, Site 1200, Mariana forearc–implications for recycling at subduction zones. Geochim. Cosmochim. Acta 66:A670.

Savov, I. P., Guggino, S., J. G. Ryan, Fryer, P., and Mottl, M. J., 2005, Geochemistry of serpentinite muds and metamorphic rocks from the Mariana Forearc, ODP Sites 1200 and 778 -779, S.Chamorro and Conical Seamounts, Proceeding of the Ocean Drilling Program Scientific Results Volume 195, on line at http://www-odp.tamu.edu/publications/195_SR/103/103.htm

Stern, R.J., Fouch, M. J., Klemperer, S. L., 2003, An Overview of the Izu-Bonin-Mariana Subduction Factory, in J. Eiler and M. Hirschmann (eds.) Inside the Subduction Factory, Geophysical Monograph 138, American Geophysical Union, 175-222.

Wheat, C. G., P. Fryer, A. T. Fisher, S. Hulme, H. Jannasch, M. J. Mottl, E. Davis, and K. Becker, Fluid Flow from an Active Serpentine Seamount: ODP Hole 1200C South Chamorro Seamount, EPSL, 267 (2008) 401-409.

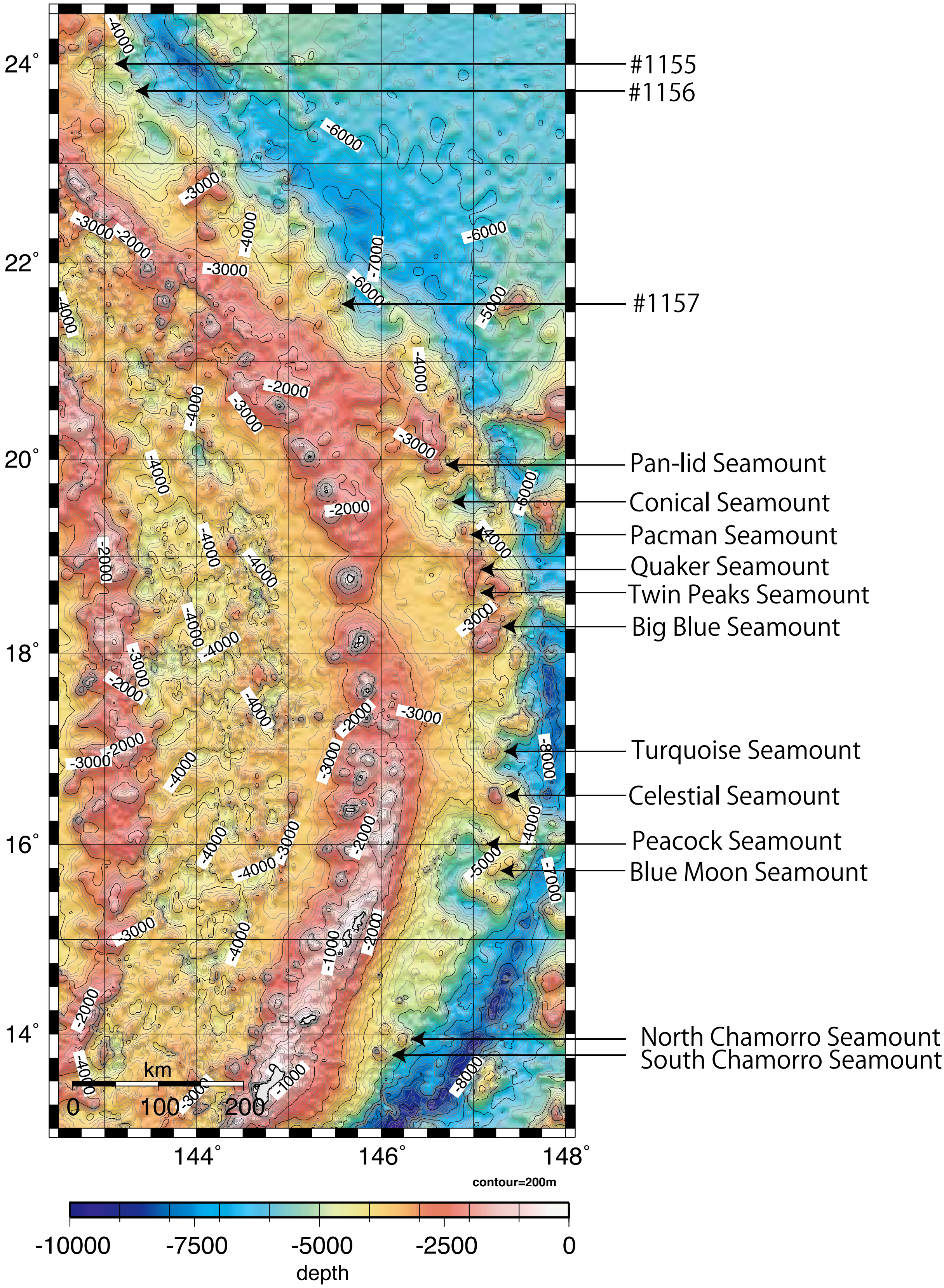


Figure 2-1. Serpentinite seamounts in the Mariana forearc. The sites #1155, #1156, and #1157 are targets of this cruise.

3. Operations and data processing information

Shinkai 6500 usually dove with payloads that included 2 rock sampling baskets, with two to four push cores and one scoop sampler.

Data and samples from the dives were archived as customary. Half of all samples will be archived at JAMSTEC. Standard data products were provided to the shipboard scientific party.

4. Dive results

Summaries of the results of each dive are included in this sections. All dive locations are shown below.

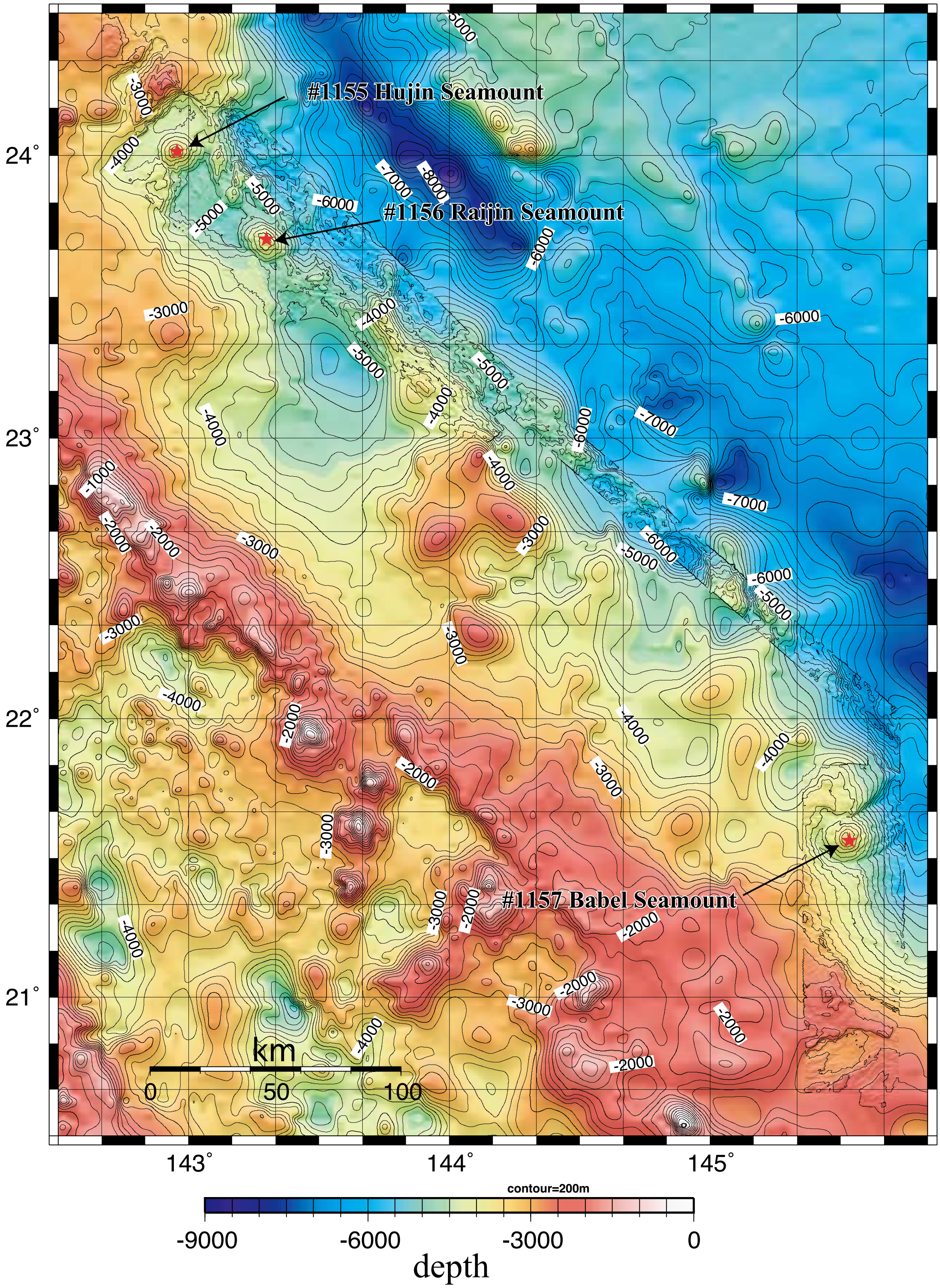


Fig.4-1 Dive locations in norther Mariana forearc region during YK09-06.

Dive Report: SHINKAI 6500 Dive #1155
Date: 3 June, 2009
Site name: Hujin Seamount, north Mariana forearc region
Landing: 11:31; 23_59.5466'N, 142_56.9882'E, 3601 m
Off bottom: 15:57; 24_0.7494'N, 142_57.6792'E, 3259 m
Observer: Hisayoshi Yokose (Graduate School of Sci & Tech, Kumamoto University)
Pilot: Y. Chida, Co-Pilot: F. Saito

Hujin Seamout is a plausible candidate for serpentinite seamount on the northern end of the Mariana forearc region and it remains unexplored. It is expected to be a critical element for discussion on the along arc variation. The object of this dive are (1) to confirm distribution of serpentinite seamounts along the Mariana forearc region; (2) to describe characteristics of serpentinite dome indicated in the bathymetric map; and (3) to collect samples for petrographic investigations.

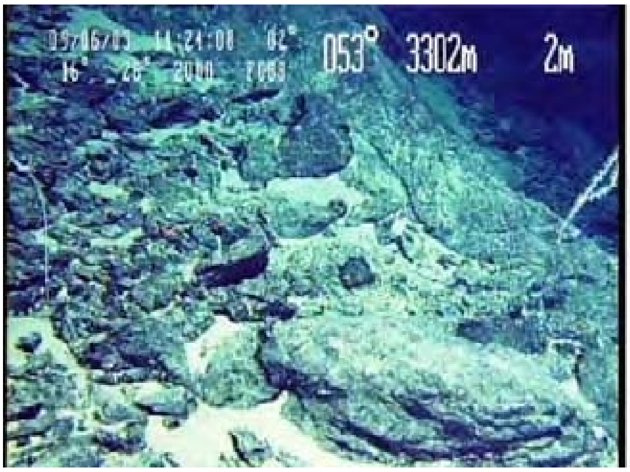
The first detailed bathymetric study on Hujin Seamount carried out during this cruise. The summit region of the seamount has flat-topped dome shape, 4 km in diameter and ~ 400 m in altitude. Topographic boundary of the dome is delineated by the slope break at around 3600 m in depth. The summit region consists of three peaks, ~ 500 m in diameter. There is a small crater like depression in the center of the summit region. The southern part of the dome has steep slopes which are greater than 15 degree of average slope angle. In addition the southern and northeastern flanks of the dome indicate acoustically high reflection areas in the back scatter image. Based on the topographic analysis, the dive course was planed that started from the southern flank of the dome at 3600m in depth, through the central depression area, to the eastern peak (3260 m in depth) where is the shallowest point of the seamount, and then leave the bottom.

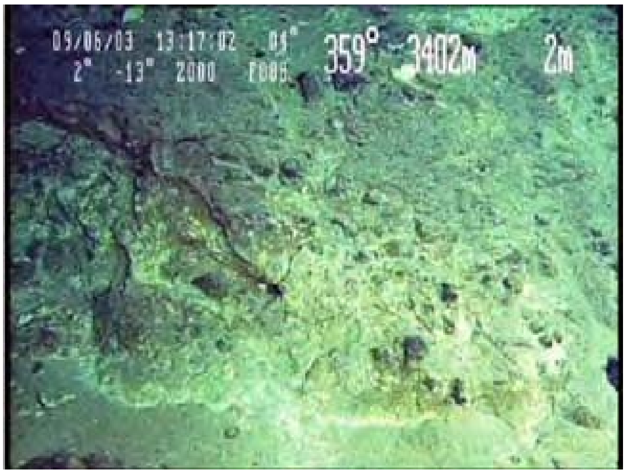
The geological units are classified into four categories: unconsolidated mud with peridotite breccias, layered mudstone, loosely packed breccia, and serpentinite flow breccia. The unconsolidated mud was observed widely on this course. The size of breccias on the mud varies from gravel to boulder. Layered mudstones are slightly consolidated and were often observed on the lower flanks of the dome. The thickness of the mudstone is approximately 50 cm. Surface of the mudstones are often coated with iron-manganese oxide crust. The mudstones were changed into tabular rocky floats by translational slips on the slope. Four outcrops of the serpentinite dome were observed on the upper part of the steep slope and top of the seamount. Although the appearance of the outcrops are different depending on the degree of alteration and shear state, they are basically breccias with small amount of matrix. Loosely packed breccias consist of equant blocks with minor serpentinite mud. As the central depression was thickly covered with recent soft sediment, we could not find any vent and chimney.

We obtained 12 rock samples and 1 mudstone during the dive. The rock samples are dominated in highly serpentinized peridotite. Some samples indicate mylonite texture.

Pepresentative outcrops of Dive #1155

A: Serpentinite flow breccia

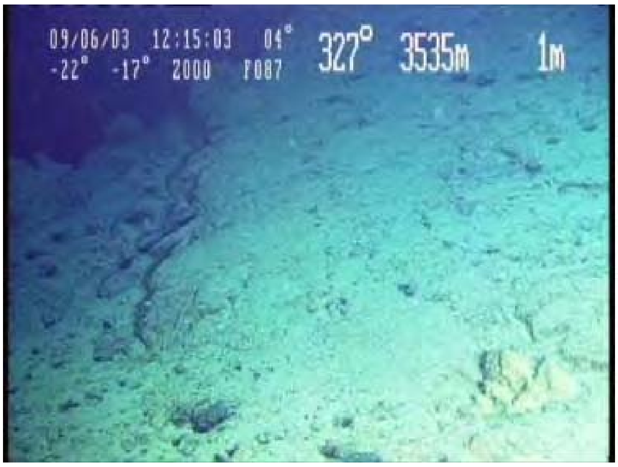




Appearance of the outcrops are different depending on the degree of alteration and shear state. Serpentinite flow brecias are commonly matrix poor.

14:24 Outcrop of metamorphic block
12:59 Small mound type outcrop
13:17 Outcrop on a large fault scarp

B: Layered mudstone



The layered sediment is a block free mudstone. The gravels are float and probably derived from recent erosion processes.

Dive Report: SHINKAI 6500 Dive #1156

Date: 4 June, 2009

Site Name: Raijin Seamount, northern Mariana forearc region.

Landing: 10:44; 23° 42.0743'N, 143° 20.5422'E, 4313 m

Leaving: 14:38; 23° 42.3857'N, 143° 19.6247' E, 4097 m

Observer: Hirokazu Maekawa (Graduate School of Science, Osaka Prefecture University)

Pilot: K. Matsumoto, Co-Pilot: H. Ueki

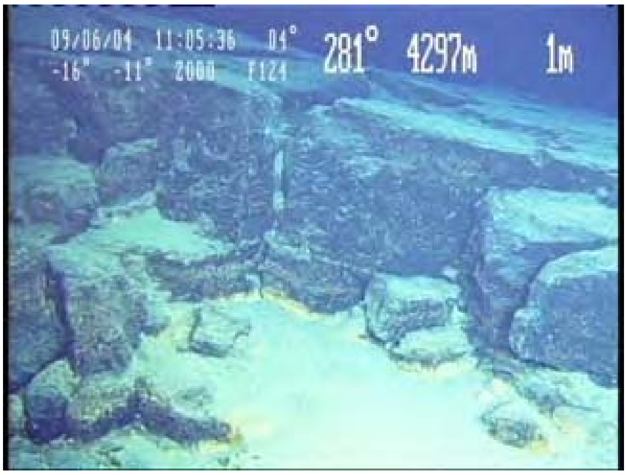
Two dome-shaped seamounts are recognized at the northern end of the Mariana forearc. They are Hujin Seamount in the north and Raijin Seamount in the south. Dive #1156 targetted Raijin Seamount, and aimed to investigate modes of occurrence of rocks and sediments on the hillside of the seamount, take rock samples to know constituent materials inside the seamount and confirm whether Rijin Seamount is diapiric serpentinite seamount.

Dive #1156 was carried out on the eastern hillside of Raijin Seamount from 4313 m, to 4097 m. We landed Most part of the flank are covered by bedded mudstone of tens centimeter to more than fifty centimeter thick. Characteristic joints are commonly deveoloped in the mudstone in the direction normal to bedding surfaces, and the mudstone are often fragmented to box-like blocks and peridotite blocks probably of underlying serpentinite flow are exposed. During this dive, 17 serpentinized peridotites and 6 mudstones were recovered. Some serpentinized peridotites well retain primary olivine, spinel, and pyroxenes.

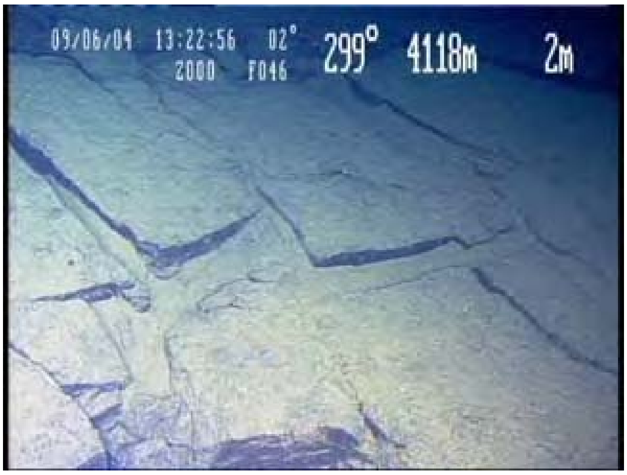
We landed 200 m east of the proposed landing point on the eastern hillside of Raijin Seamount at a depth of 4313 m. The landing point was widely covered with muddy sediments. Muddy sediments are commonly composed of altered and clayey serpentine mud materials. Pebble- to cobble-sized rock fragments commonly scatter on the seafloor. We started on eastwesterly course up the slope to observe the modes of occurrence of rocks and sediments. Most part of the flank are covered by brown-colored bedded mudstone of tens centimeter to more than fifty centimeter thick (Figure 1). Characteristic joints are commonly deveoloped in the mudstone in the direction normal to bedding surfaces, and the mudstone are often highly fragmented to box-like blocks. Peridotite blocks in underlying serpentinite flow with block-in-matrix fabrics are often exposed (Figure 2). Figure 3 shows common view of the boundary between thick bedded mudstone and underlying serpentinite flow. During this dive we collected 23 rocks, 415 and 110 still photos of the external and inner camera, respectively, and No. 1 video and 2 video records. The 23 obtained rocks consist of 17 serpentinized peridotites and 6 mudstones. Some serpentinized peridotites well retain primary olivine, spinel, and pyroxenes.

Pepresentative outcrops of Dive #1156

A: Serpentinite boulders

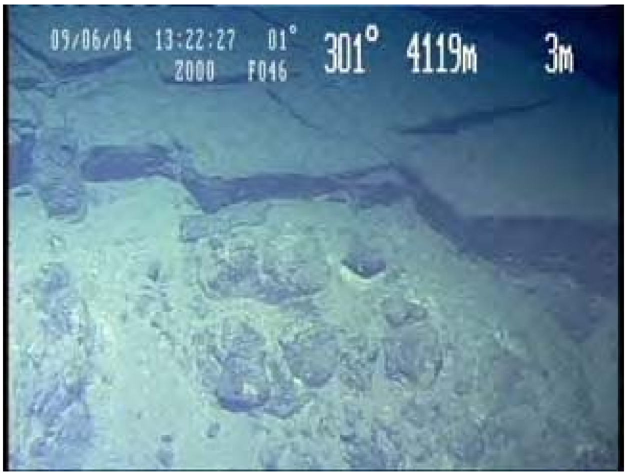


B: Thick mudstone layers. The layers cover underlying serpentinite flow. Yellow colored basal part is serpentinite flow.



C: Pecular joint developing in mudstone layers.

D: Fragmented mudstone.



E: Serpentinite flow and overlying thick mudstone layers.

Dive Report: SHINKAI 6500 Dive #1157
Date: 5 June, 2009
Site name: Babel Seamount, north Mariana forearc region
Landing: 11:29; 21_33.3490'N, 145_32.2987'E, 3516 m
Off bottom: 14:37; 21_34.2855'N, 145_30.7878'E, 3282 m
Observer: Hisayoshi Yokose (Graduate School of Sci & Tech, Kumamoto University)
Pilot: T. Yoshiume, Co-Pilot: F. Saito

Babel Seamout is a plausibly serpentinite seamount as proposed by Stern and Smoot (1998) and is located in the middle of the northern and central group of serpentinite seamounts. The nature of serpentinite seamount could be important clue for continuous variation along the arc. The object of this dive are (1) to confirm geology of the highly acoustic reflection area on Babel Seamount; (2) to describe the nature of a huge flow lobe with large-scale undulation; and (3) to collect rock samples for petrographic investigations.

Detailed bathymetric survey on Babel Seamount has never been carried out before this cruise. The altitude of Babel Seamount is ~1800 m. A remarkable flow lobe, 20 km long, can be traced from the summit to the eastern flank of the seamount. Surface of the flow lobe has large-scale undulation, ~2 km in wavelength and ~0.2 km in wave height. The central part corresponds to acoustically high reflection area on the back scatter image. This suggests that the flow is not covered by thick soft sediments.

The dive survey was started from southeastern submarine flank at depth of 3516 m to the top of the seamount at depth of 3282 m. Many gravel size peridotite breccias are scattered on the seafloor. The submarine flanks on the dive course have small-scale undulation. The undulation is 50 m ~ 200 m in wavelength and 2 m ~ 40 m in wave height. Outcrops of serpentinite breccias or loosely packed breccias with equant blocks were observed whenever we met ridges and mounds. When the height of ridge exceeded 4 m, outcrops of massive serepentinite breccias were occurred. On the other hand, the valleys of the undulation were filled with soft sediments. serpentinite flow is covered directly by a mudstone layer ~ 80 cm in thickness at the depth of 3430 m.

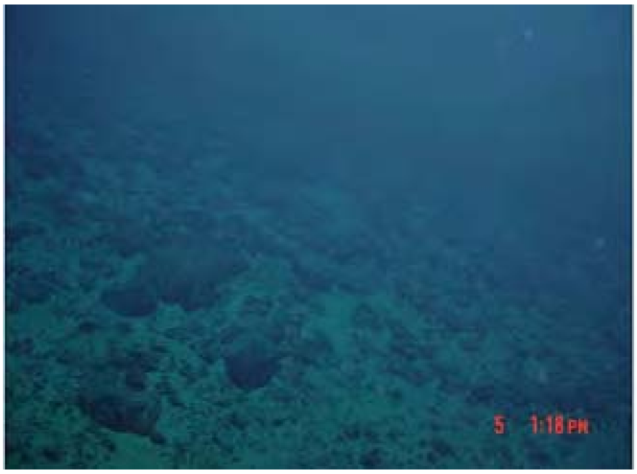
Large scale fault scarp with 6 m depression was observed around the summit region. Based on the sonar image of the submersible, the fault scarp is assumed to be a part of crater wall that is approximately 200 m in diameter.

We collected 22 samples including 5 soft sediments and two push cores. Rock samples include some metamorphic rocks other than peridotite and serpentinite. Metamorphic rocks were recovered mainly from the talus breccias around the foot of very large boulder blocks (> 2m). Iron–manganese oxide crust both on the outcrops and rock samples are very thin. The mudstone layer contains abundant foraminiferal fossils. Because Globorotalia truncatulinoides is observed in the mudstone, the serpentinite flow underling the mudstone probably erupted during Quaternary period.

Pepresentative outcrops of Dive #1157

A: Serpentinite flow breccia

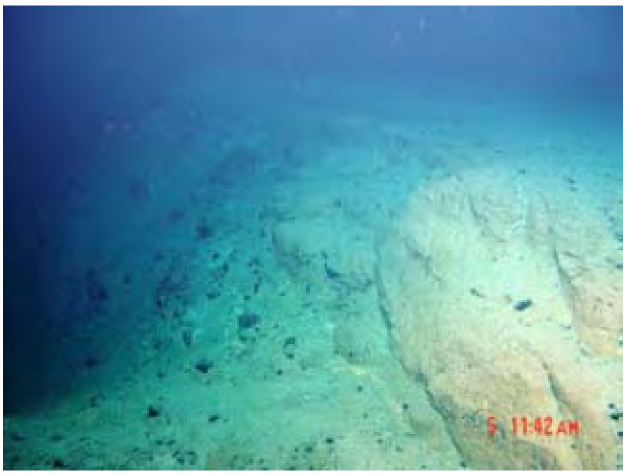
B: Loosely packed serpentinite breccias (reworked serpentinite flow breccia?)



Ridge type

Mound type

C: Highly sheared serpentinite flow brecdias underlying layered mantle bedded mudstone.



D: Soft sediment. Many gravel size peridotite breccias are scattered on the seafloor.