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CRUISE REPORT

JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

R/V YOKOSUKA YK13-08 CRUISE

A SHINKAI 6500 STUDY ON THE SERPENTINITE-HOSTED ECOSYSTEM IN THE SOUTHERN MARIANA FOREARC

AND

TECTONIC RECONSTRUCTION OF INITIAL STAGES OF PHILIPPINE SEA PLATE FORMATION

AUGUST 27, 2013 TO SEPTEMBER 15, 2013

(YOKOSUKA, JAPAN TO GUAM, USA)

Table of Contents

List of cruise personnel ……………………………………………………….. ii
Note on using ………………………………………………………………... iii
Acknowledgements …………………………………………………………. iii

1. **General cruise information …………………………………………….. 1**
2. **Introduction ……………………………………………………………... 1**
3. **Background and objectives of the cruise …………………………….... 3**
4. **Survey items …………………………………………………………….... 7**
5. **Running cruise narrative ……………………………………………….. 7**
6. **Summary of the cruise results ………………………………………….. 9**
7. **References ……………………………………………………………….. 13**

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Notice on using

This cruise report is a preliminary documentation as of the end of the cruise. It may not be corrected event if changes on content are found after publication. It may also be changed without notice. Data on the cruise report may be raw or not processed. Please ask the Chief Scientist for the latest information before using the report and/or data.

Users of data and/or results on this cruise report are requested to submit their results to the Data Management Group of JAMSTEC.

Acknowledgements

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1. General cruise information

Cruise ID and ship name: YK13-08, R/V Yokosuka

Title of the cruise (this cruise consisted of the following two proposals):

1. A Shinkai 6500 study on the serpentinite-hosted ecosystem in the Southern Mariana Forearc
2. Tectonic reconstruction of initial stages of Philippine Sea Plate formation

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Investigation area (Fig. 1): Palau Basin and Kyushu-Palau Ridge, and Mariana Trench

Cruise period and port calls: August 27 to September 15, 2013 (Yokosuka to Guam)

Shinaki 6500 dive list:
6K-1358: Osamu Ishizuka (Mindanao Fracture Zone)
6K-1359: Yuki Kusano (Mindanao Fracture Zone)
6K-1360: Yumiko Harigane (Kyushu-Palau Ridge)
6K-1361: Osamu Ishizuka (Kyushu-Palau Ridge)
6K-1362: Hiromi Watanabe (Shinkai Seep Field)
6K-1363: Yasuhiko Ohara (Shinkai Seep Field)
6K-1364: Teruaki Ishii (Shinkai Seep Field)
6K-1365: Uta Konno (Shinkai Seep Field)
6K-1366: Sherman H. Bloomer (Shinkai Seep Field)

2. Introduction

In YK13-08 cruise, we successfully conducted an extensive DSV Shinkai diving and geophysical mapping program, which was consisted of two individual scientific projects. In more detail, one was led by Yasuhiko Ohara as PI to study the Shinkai Seep Field, whereas the other was led by Osamu Ishizuka as PI to study the Mindanao Fracture Zone and southern Kyushu-Palau Ridge (KPR) area (Fig. 1). Although these two scientific projects were independent each other, the scientists from each group aboard YK13-08 cruise helped each other. Because of the cruise logistical reasons, the Ishizuka Leg was done as the first part of the cruise (4 dives; 6K-1358 to 6K-1361), followed by the Ohara Leg as the second part (5 dives; 6K-1362 to 6K-1366). The background and objectives of each project are described in the following section.

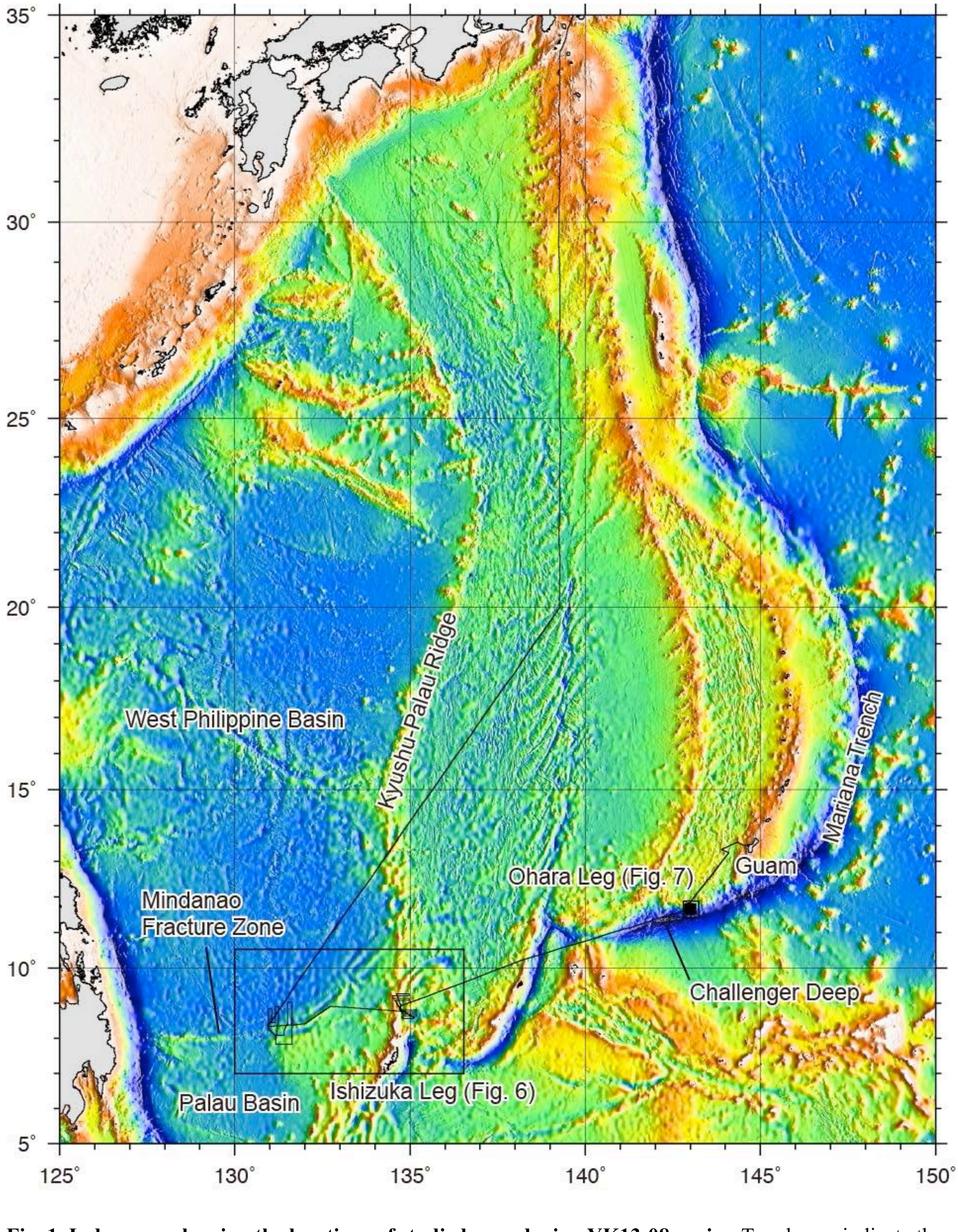

Fig. 1. Index map showing the locations of studied area during YK13-08 cruise. Two boxes indicate the locations of Ishizuka and Ohara Legs (Figs. 6 and 7). Cruise track lines are also shown.

3. Background and objectives of the cruise

3-1. Ishizuka Leg

Recent research in the Izu-Bonin-Mariana (IBM) forearc revealed volcanic section representing the earliest record of IBM arc magmatism (e.g., Ishizuka et al., 2006, 2011a; Reagan et al., 2010). The observed stratigraphy, combined with petrological, geochemical and geochronological studies led us to propose a model for subduction initiation along this arc (Fig. 2; Ishizuka et al., 2006, 2011a). This model assumes spontaneous subduction of an old and cold, thus higher density, plate that begins to sink beneath younger and hotter plate with lower density (Stern, 2004). This model for subduction initiation, however, has not been tested from a tectonic point of view. To do this, it is necessary to reconstruct the tectonic environment of Philippine Sea region before ~50 Ma.

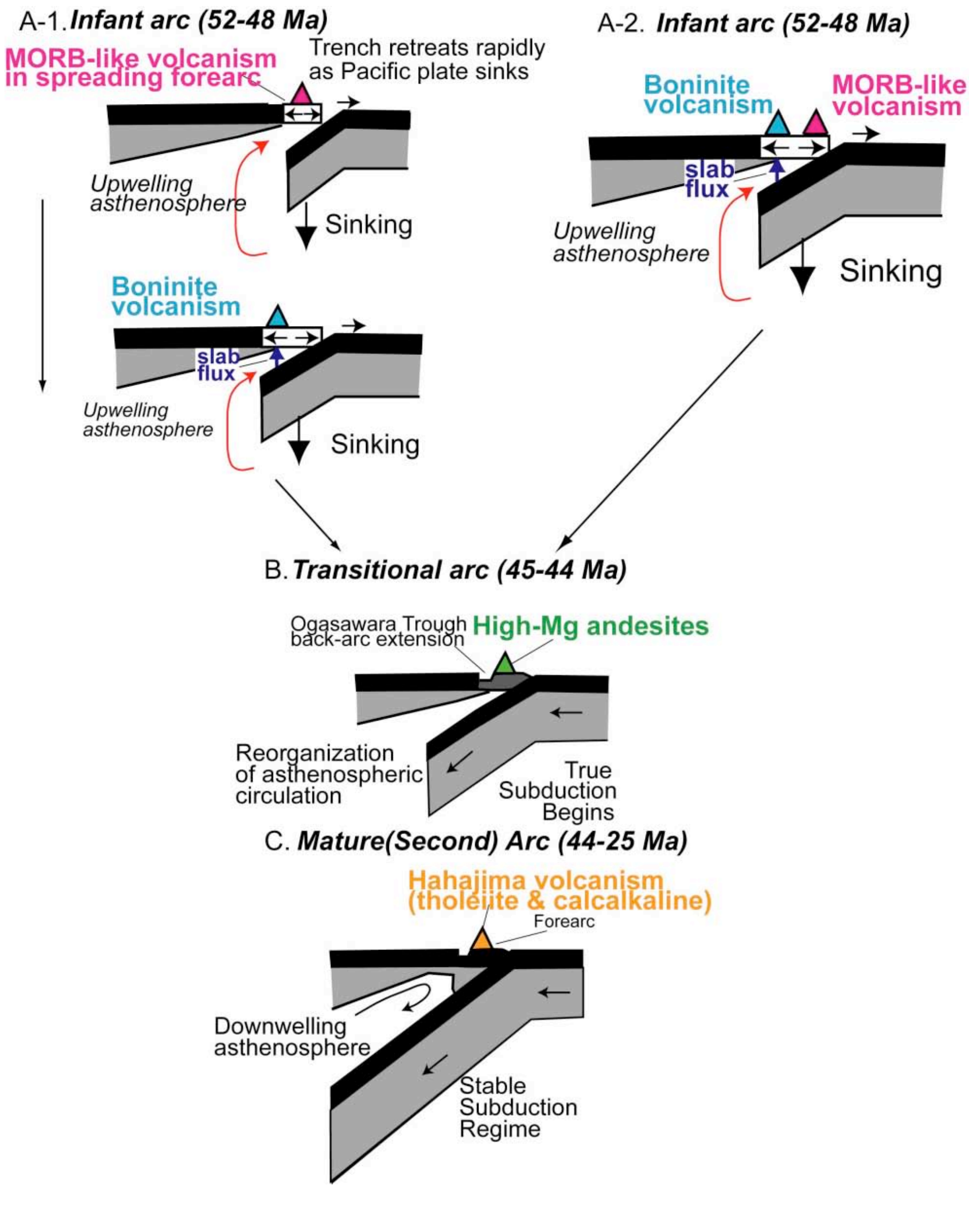

Fig. 2. Model of subduction initiation and evolution of infant arc (modified after Ishizuka et al., 2006).

The West Philippine Basin (WPB) and Palau Basin are supposed to have been the oldest oceanic basins in the Philippine Sea Plate (Fig. 1). Accordingly, their origin and growth history can be a critical constraint on the tectonic reconstruction of the Philippine Sea Plate. These basins could have existed prior to the IBM arc, or formed as a consequence of subduction initiation along the IBM arc (e.g., backarc basins of the IBM arc). However, due to the paucity of geological and geophysical data from these basins, their origin and history are yet unclear. Another constraint on tectonic reconstruction is expected to be obtained from the arc basement beneath KPR, where Cretaceous plutonic rocks have been reported (Malyarenko and Lelikov, 1995). There are locations where Mesozoic crust, which could be basement of the IBM arc, has been reported in the Philippine Sea area (Fig. 3). Such examples include Daito Ridge Group (Ishizuka et al., 2011b) and Izu-Bonin forearc (Ishizuka et al., 2011a). Understanding origin and history of these crusts could help to reconstruct tectonic environment prior to subduction initiation at the IBM arc.

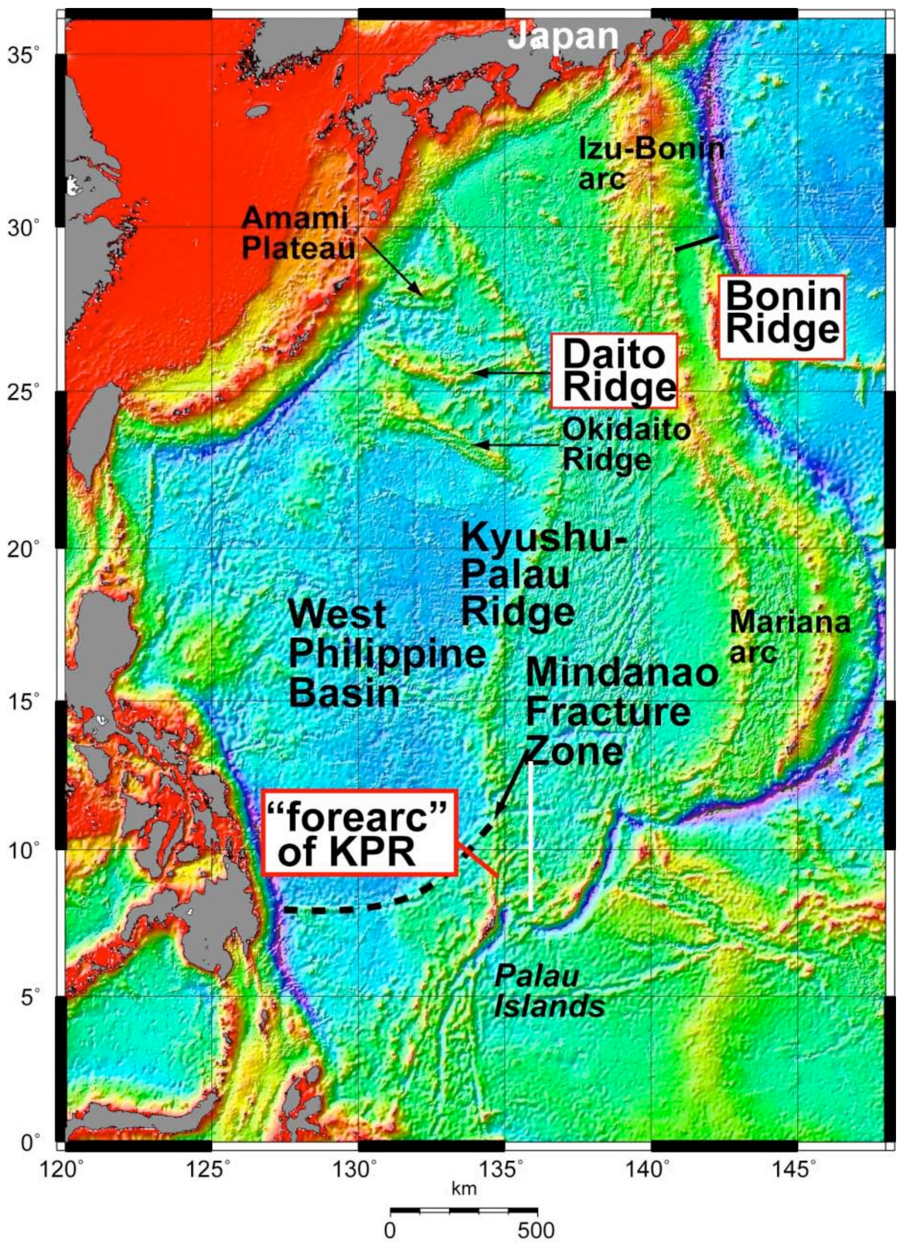

Fig. 3. Locations of possible Mesozoic arc basement.

Major objectives of the Ishizuka Leg were:
(1) To conduct geological observation and sampling of the ocean crust of Palau Basin to determine its formation age, mode of spreading and characteristics of magmatism.
(2) To conduct geophysical observation in the southernmost part of the WPB and Palau Basin (along the Mindanao Fracture Zone) to reveal mode of spreading (spreading rate, direction etc.) of these basins.
(3) To characterize the non-oceanic arc basement at the southern end of the KPR.

3-2. Ohara Leg

Most hydrothermal vents along mid-ocean spreading ridges are high-temperature, sulfide-rich, and low pH (acidic environments). In contrast, the Lost City hydrothermal field on the Mid-Atlantic Ridge is a low-temperature, alkaline-rich, high pH system (Kelley et al., 2001, 2005). It is hosted by serpentinized peridotite (olivine-rich rock, the major constituent of Earth's mantle). The discovery of the Lost City hydrothermal field has therefore stimulated interest in the role of serpentinization of peridotite in generating H_2- and CH_4-rich fluids and associated carbonate chimneys, as well as in the biological communities adapted to highly reduced, alkaline environments.

A new serpentinite-hosted ecosystem, the Shinkai Seep Field (SSF), was discovered by DSV Shinkai 6500 dive 1234 in the inner trench slope of the southern Mariana Trench, near the Challenger Deep, during YK10-12 cruise of R/V Yokosuka (PI = Yasuhiko Ohara) in September 2010 (Fig. 4).

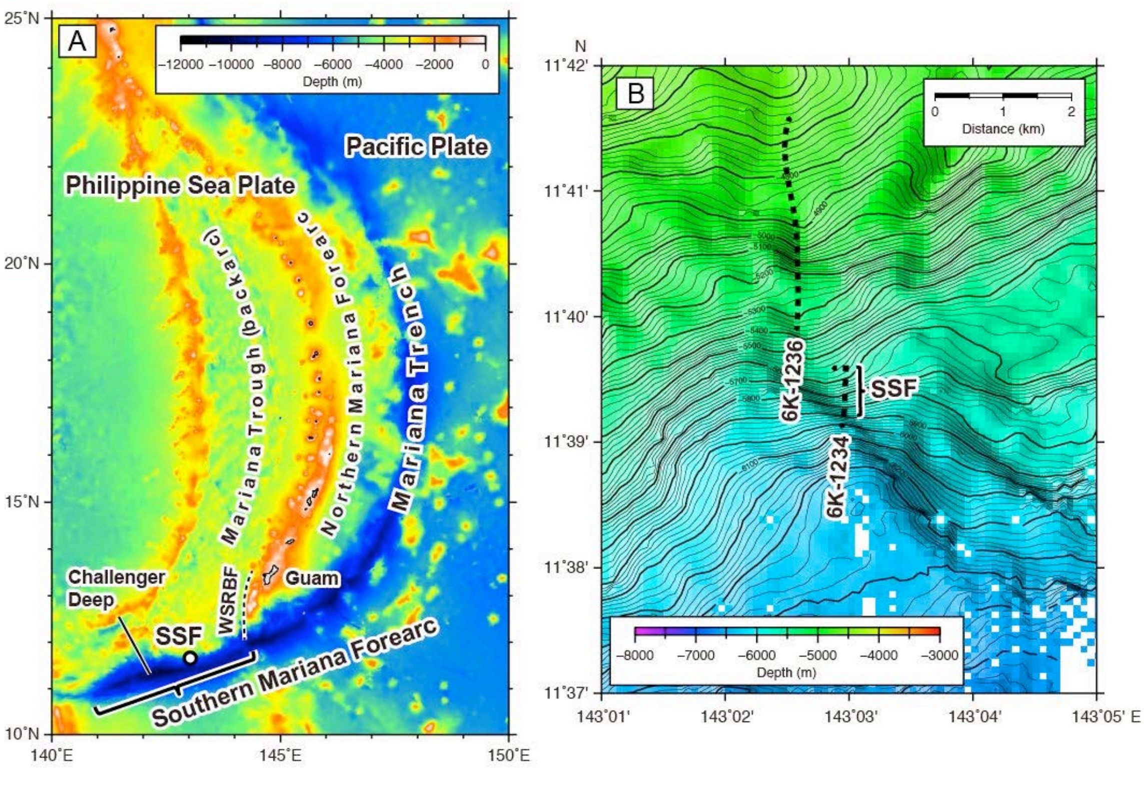

Fig. 4. Location of the Shinkai Seep Field (SSF) (after Ohara et al., 2012).
(A) Bathymetry of the Mariana Trench and location of the SSF. The West Santa Rosa Bank Fault (WSRBF) divides the Mariana forearc into the southern and northern parts (marked by a dotted line).
(B) Detailed bathymetry of the SSF area obtained during the YK10-12 cruise. Contours in 20 m intervals. The tracks of dives 1234 and 1236 are shown by black dotted lines. Approximate location of the SSF is

indicated. Dive 1236 recovered Eocene to Miocene subduction-related volcanics, not peridotites. The bathymetry in this area shows the absence of conical hills typical of serpentinite mud volcanoes common in the northern Mariana forearc.

Abundant chemosynthetic biological communities, principally consisting of vesicomyid clams are associated with serpentinized peridotite in the SSF (Fig. 5; Ohara et al., 2012). Although dive 1234 collected more than 30 live vesicomyid clams, along with peridotite, subordinate gabbro and a fragment of vent chimney, no water and sediment samples to be used for chemical and microbiological studies were collected, because Shinkai 6500 was not prepared to do this.

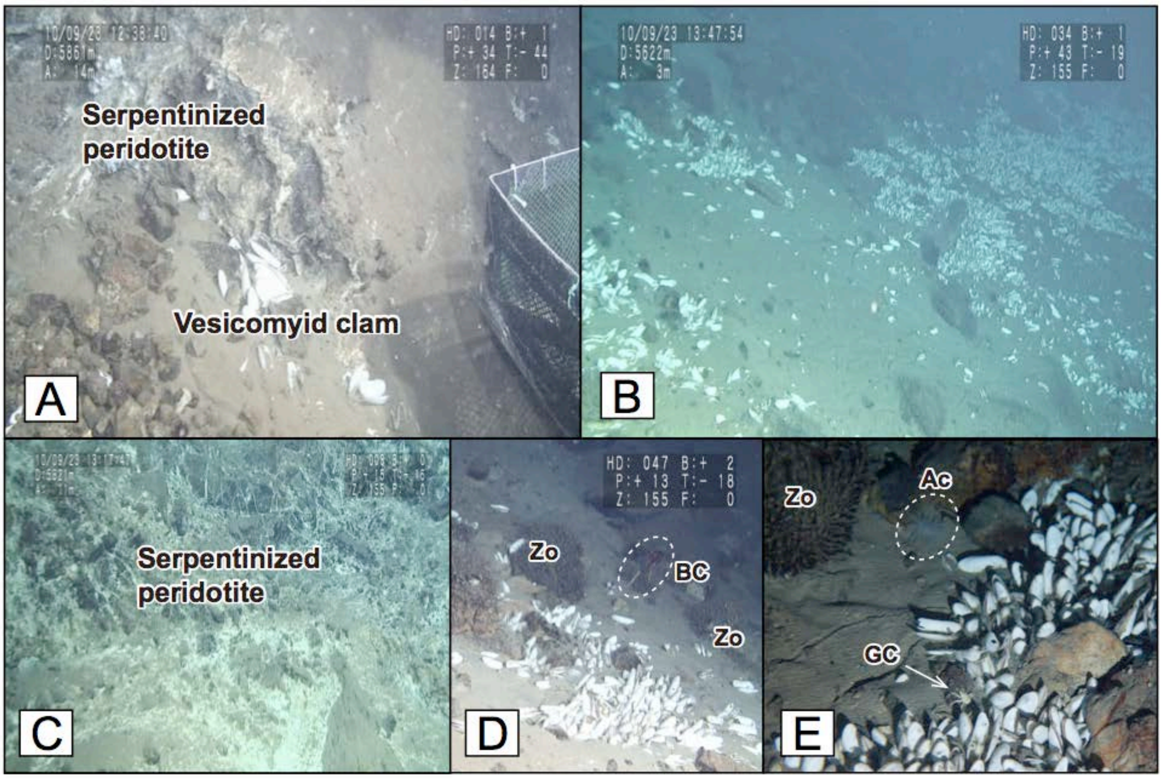

Fig. 5. Field photographs taken during the DSV Shinkai 6500 dive 1234 (after Ohara et al., 2012).
(A) Live vesicomyid clams on fractured and cemented serpentinized peridotite.
(B) Extensive vesicomyid clam community at 5622 m depth.
(C) An outcrop of fractured serpentinized peridotite filled with aragonite.
(D) Close-up view of the vesicomyid clam community at 5622 m depth, showing close association with zoanthids (Zo) and a *Beroe* comb jelly (BC; enclosed by a white dotted circle) with illuminated spots.
(E) Close-up view of the vesicomyid clam community at 5622 m depth, showing close associatiaon with zoanthids (Zo), an actiniarian (Ac; enclosed by a white dotted circle) and a galatheid crab (GC; pointed to by a white arrow).

Major objectives of the Ohara Leg were:

(1) Finding and locating active fluid venting in the SSF. If successful, sampling the vent fluid and associated sediment for chemical and microbiological study.
(2) Finding seep fields other than the SSF in the southern Mariana forearc. If another seep field is discovered along the southern Mariana forearc, we can safely conclude that serpentinite-hosted vents may be more widespread on the ocean floor than presently known.
(3) Comprehensive understanding of the geology of the SSF. It is important to understand the geological background of the SSF including tectonic development of the southern

Mariana forearc.

4. Survey items

During YK13-08 cruise, we have conducted nine Shinkai dives (Figs. 6 and 7). Geophysical mapping were done on the areas that were left uncovered by the previous surveys.

5. Running cruise narrative

Local time (Approximate)	Notes
27-Aug-13	**The Yokosuka YK13-08 cruise began. The Yokosuka was underway to the Palau Basin area.**
9:00	Scientists arrived at the Yokosuka moored in the Sumitomo Heavy Industies wharf.
14:00	YK13-08 cruise began.
28-Aug-13	**The Yokosuka was underway to the Palau Basin area.**
29-Aug-13	**The Yokosuka was underway to the Palau Basin area.**
30-Aug-13	**The Yokosuka was underway to the Palau Basin area.**
31-Aug-13	**The Yokosuka was underway to the Palau Basin area.**
1-Sep-13	**The Yokosuka was underway to the Palau Basin area.**
6:00-6:30	The Yokosuka arrived at 13°N, deployning XBT and proton magnetometer, and making figure-8 maneuvering.
2-Sep-13	**The Yokosuka arrived at the Palau Basin area in the morning. Site survey for the dive sites was conducted in the afternoon.**
10:30-11:00	The Yokosuka arrived at 8°23'N, near the first dive site, retreving the proton magnetometer, and deploying XBT.
11:00	The Yokosuka conducted site surveys for 6K-1358 and 6K-1359, and geophysical mapping.
3-Sep-13	**6K-1358 was conducted at Mindanao Fracture Zone in the Palau Basin. The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1358 site, retreving the proton magnetometer.
9:05	The Shinkai 6500 opened vent, start of 6K-1358 dive. Osamu Ishizuka as the observer.
17:09	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer.
4-Sep-13	**6K-1359 was conducted at Mindanao Fracture Zone in the Palau Basin. The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1359 site, retreving the proton magnetometer.
9:05	The Shinkai 6500 opened vent, start of 6K-1359 dive. Yuki Kusano as the observer.
17:18	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer, and making figure-8 maneuvering.

5-Sep-13	**The Yokosuka was underway to the Kyushu-Palau Ridge site. Geophysical mapping continued.**
6-Sep-13	**6K-1360 was conducted at the Southern Kyushu-Palau Ridge. The Yokosuka conducted geophysical mapping in the night.**
6:30	The Yokosuka arrived at the 6K-1360 site, retreving the proton magnetometer.
10:01	The Shinkai 6500 opened vent, start of 6K-1360 dive. Yumiko Harigane as the observer.
17:25	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer.
7-Sep-13	**6K-1361 was conducted at the Southern Kyushu-Palau Ridge. The Yokosuka conducted geophysical mapping in the night.**
6:40	The Yokosuka arrived at the 6K-1361 site, retreving the proton magnetometer.
10:00	The Shinkai 6500 opened vent, start of 6K-1361 dive. Osamu Ishizuka as the observer.
16:25	The Shinkai on deck.
17:00	The Yokosuka was underway to the Shinkai Seep Field area.
8-Sep-13	**The Yokosuka was underway to the Shinkai Seep Field area. No geophysical data were obtained during the transit.**
0:00	The ship time was adjusted to that of Guam, one hour ahead of Japan Standard Time. The Yokosuka was underway to the SSF site.
9-Sep-13	**6K-1362 was conducted at the Shinkai Seep Field. The Yokosuka conducted geophysical mapping in the night.**
5:30	The Yokosuka arrived at the 6K-1362 site at the Shinkai Seep Field, deployning XBT and making the site survey.
8:59	The Shinkai 6500 opened vent, start of 6K-1362 dive. Hiromi Watanabe as the observer.
16:21	The Shinkai on deck.
17:00	The Yokosuka started geophysical mapping, deploying proton magnetometer, and making figure-8 maneuvering.
10-Sep-13	**6K-1363 was conducted along the slope ~4 miles west of the Shinkai Seep Field.The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1363 site to the west of the Shinkai Seep Field, making the site survey.
8:58	The Shinkai 6500 opened vent, start of 6K-1363 dive. Yasuhiko Ohara as the observer.
17:38	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer.
11-Sep-13	**6K-1364 was conducted along the upper slope of the 6K-1363 site. The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1364 site, located just the upper slope of the 6K-1363 site.
10:15	The Shinkai 6500 opened vent, start of 6K-1364 dive. Teruaki Ishii as the observer.
17:31	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer.
12-Sep-13	**6K-1365 was conducted at the Shinkai Seep Field. The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1365 site at the Shinkai Seep Field.

9:02	The Shinkai 6500 opened vent, start of 6K-1365 dive. Uta Konno as the observer.
17:39	The Shinkai on deck.
18:00	The Yokosuka started geophysical mapping, deploying proton magnetometer.
13-Sep-13	**6K-1366 was conducted at the Shinkai Seep Field. The Yokosuka conducted geophysical mapping in the night.**
6:00	The Yokosuka arrived at the 6K-1366 site at the Shinkai Seep Field.
9:17	The Shinkai 6500 opened vent, start of 6K-1366 dive. Sherman Bloomer as the observer.
17:46	The Shinkai on deck.
18:22	The Yokosuka started geophysical mapping, deploying proton magnetometer.
14-Sep-13	**The Yokosuka finished geophysical mapping in the morning, then was underway to Guam.**
7:00	The Yokosuka finished geophysical mapping, retreving the proton magnetometer.
15-Sep-13	**The Yokosuka arrived in Guam in the morning. End of the cruise.**
6:00	The Yokosuka arrived in Guam in the morning. End of the cruise.
12:30	YK13-08 scientists disembarked.

6. Summary of the cruise results

6-1. Ishizuka Leg

- **6K-1358** surveyed a part of the northern margin of the Palau Basin, where the Mindanao Fracture Zone transects NE-SW trending abyssal hill of the Palau Basin. The dive observed north-facing steep slope between 5258 and 4497 m depth. There were abundant outcrops during the entire course of the dive. There are several locations where subparallel joints were observed, implying presence of dyke swarms (sheeted dykes). At 4719 m, jointed outcrop was directly sampled, and these jointed outcrops were found to be dolerite. This strongly implies that the outcrops with subparallel joints are dykes, possibly sheeted dykes. Since this type of jointed outcrop occur in wide depth range, the observed slope could be dominantly composed of sheeted dykes. Besides dolerite, basaltic lava clasts (aphyric or olivine, plagioclase-phyric) were collected at 6 localities. There are a couple of localities where apparent pillow lava tubes occur, but none of the basalt lava was recovered directly from outcrop. In summary, even though the stratigraphic relation between dolerite (dykes) and basalt lava flows could not be observed, it is clear that this dive observed a relatively lower part of upper crust of the Palau Basin ocean crust.

- **6K-1359** observed between 5985 and 4833 m depth in the Mindanao Fracture Zone. Several dikes striking N40°E were exposed on the seafloor at 5699 m and they were covered with a debris flow. Vertical cliffs showing columnar joints are a topographic character between 5620 and 4833 m. Their domed surfaces and columnar joints perpendicular to the surface imply that they are sections of lava flows. Rock samples of this dive are mainly aphyric basalt with some siltstone and one dolerite. Four basalt samples preserve glassy rims. Based on the evidence of geological observation and petrographyical features, this area corresponds to the uppermost part of dike complex and lower part of extrusive units in the Eocene oceanic crust.

- **6K-1360** surveyed an eastern steep slope at the southern Kyushu-Palau Ridge between 4030 and 2575 m depth. This dive collected 31 samples from talus and outcrop. Although plutonic rocks were not recovered from this slope, many metamorphic rocks were sampled. The slope between ~3700 and ~3600 m has continuous exposures of green schist as well as amphibole-epidote schist. There are some good exposures of green rock, green schist, amphibole schist, amphibole-epidote schist and amphibole-epidote mylonite at seven stops in the slope. Furthermore, we often observed talus during 6K-1360. The sampled rocks from talus represent the green rock, amphibole schist, amphibole-epidote schist and amphibole-epidote mylonite. In this dive, we observed two kinds of outcrops, i.e., schistose and blocky outcrops. The difference of these outcrops is the thickness of Mn-coating. The Mn-coating on the schistose outcrop is thin (film to ~4 mm), whereas on the blocky outcrop is thick, up to ~30 mm. It may be that schistose outcrop collapses often and so it is difficult to grow a thick Mn-coating. The collected rocks have mineral assemblage characteristic of epidote-greenschist facies, suggesting that the epidote-greenschist facies metamorphism was pervasive. However, the degree of deformation is different in each sample. Therefore, it implies that the recovered rocks could be affected by different deformation process after greenschist facies metamorphism. Furthermore, several mylonites were collected from this slope which infers the possibility of faulting.

- **6K-1361** surveyed a part of the eastern slope of the southern Kyushu-Palau Ridge, where the Kyushu-Palau Ridge is separated into two ridges by a N-S trending basin. This dive observed east-facing steep slope between 3377 and 2474 m depth. The outcrops observed during the dive can be divided into two types: one is massive looking, but with foliation, and the other type has clear schistosity. The samples collected from the former indicate that this type of outcrop is composed of mylonite. The latter type is dominantly composed of amphibole schist. These two types of rock appear to frequently intercalate with each other. Mylonite seems to correspond to the sections where strong deformation took place in the amphibolite schist. In the lowermost part of the dive track, there are blocks of felsic igneous rocks. These rocks will provide critical information about the age of the formation of this section (i.e., igneous activity), while amphibole schist could provide age for the metamorphism responsible for the formation of the schist. In summary, combined with the previous dive result (6K-1360), almost the entire length of the eastern ridge of the Kyushu-Palau Ridge here seems to be composed of thick sections of green schist to amphibolite facies metamorphic rocks. We have collected a good set of samples and geologic information from this ridge, and those will enable us to elucidate the origin of this ridge and its tectonic significance, including its relation to the early history of the Izu-Bonin-Mariana arc.

- **Geophysical survey** including on-board bathymetry, magnetic and gravity anomalies have been conducted during the YK13-08 cruise in the Mindanao Fracture Zone (MFZ) and Kyushu Palau Ridge. In addition to onboard measurement, deep-sea three-component magnetometer "*Shinkai-Minico*" was deployed with Shinkai 6500. Preliminary synthesis of bathymetric data indicates that topographic fabric associated with the seafloor spreading can be recognized in the southern part of the West Philippine Basin, and the strike of abyssal hills is nearly NW-SE. The strikes of the topographic fabric and MFZ make high angles in the east of 130°E, although there are complexities in the topographic fabric near the MFZ. The MFZ branches out into two or three scarps to the east of 130°E. Within the MFZ, *en echelon* lineaments between the major fractures were clearly mapped, implying lateral shear along the fractures. Bathymetric survey in the southernmost part of the KPR revealed that there are two bathymetric highs between the main KPR and Yap-Palau trench, and they are divided by N-S trending troughs from each other. 6K-1360 and 6K-1361 were conducted on the eastern slope of the ridge, just east of the main KPR.

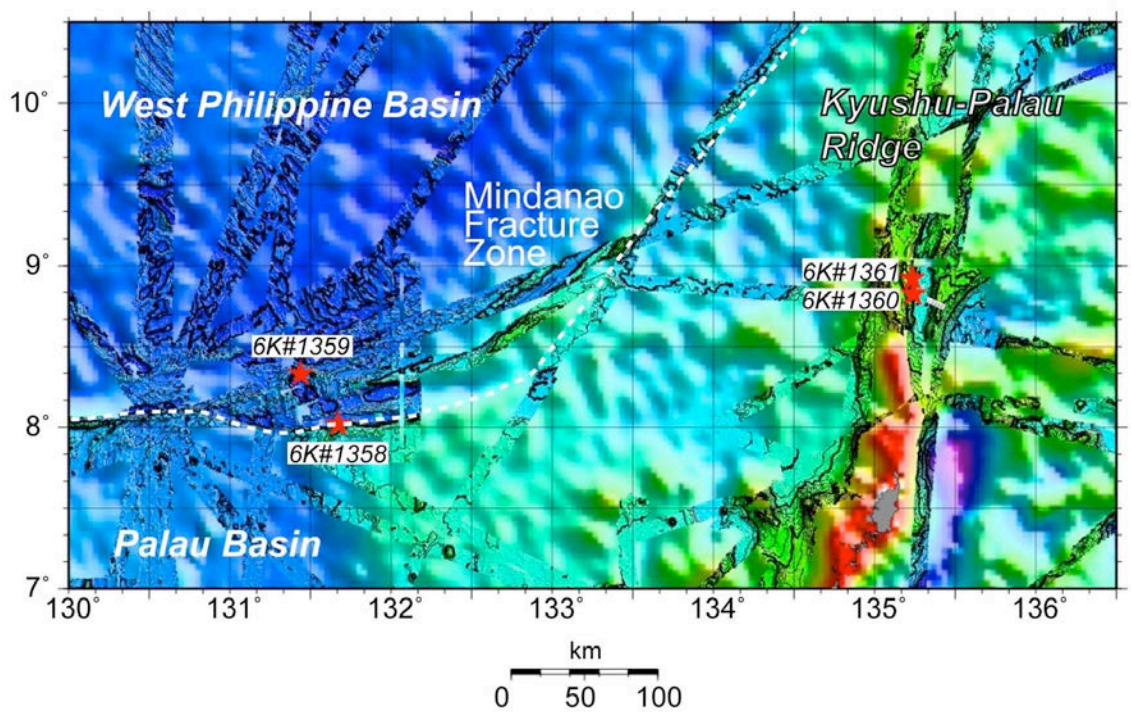

Fig. 6. Locations of the dives during the Ishizuka Leg.

6-2. Ohara Leg

- **6K-1362**: this dive successfully revisited the *Calyptogena* colonies found in 6K-1234 during YK10-12 cruise, obtaining core samples for investigation of faunal composition (Fig. 8A), microbial and geochemical analyses in sediments, Niskin and pressure-tight water samples for geochemical analyses, and DO and temperature measurements to characterize the environments.

- **6K-1363 and 6K-1364**: these two dives investigated the landward slope of the southern Mariana Trench ~4 miles west of the Shinkai Seep Field. 6K-1363 investigated the slope between 6093 m to 5585 m, whereas 6K-1364 investigated the same slope between 5608 m and 5197 m. Recovered rocks from both dives were mostly serpentinized harzburgites (Fig. 8B, C, D). Unfortunately, there were no indication of biological colonies. The fact that peridotites were still recovered from the shallower dive (6K-1364) indicates that the Moho is located further upslope there.

- **6K-1365**: initially, this dive was planned to make further samplings in the same site as 6K-1362. However, this dive serendipitously discovered a carbonate chimney site near the 6K-1362 site, successfully collecting the chimney. At this site, the dive also obtained core samples for investigation of faunal composition, microbial and geochemical analyses in sediments, Niskin and pressure-tight water samples for geochemical analyses, and DO and temperature measurements to characterize the environments.

- **6K-1366**: this dive was planned to find another seep site, and thus the dive started at a point ~1 mile west of the Shinkai Seep Field. This dive also discovered a carbonate chimney site near the 6K-1365 site. At this site, the dive also obtained Niskin and pressure-tight water samples for geochemical analyses, and DO and temperature measurements to characterize the environments.

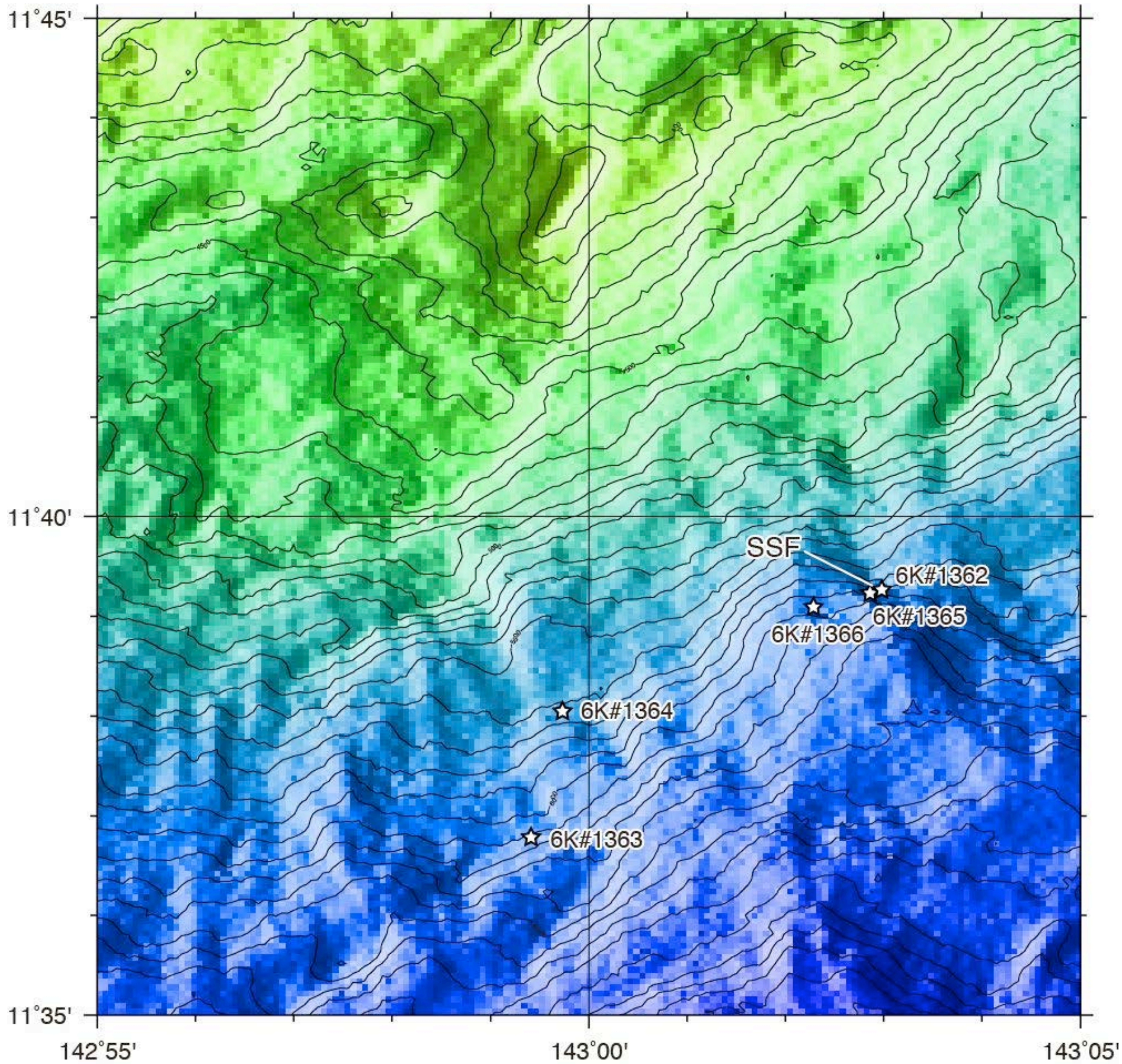

Fig. 7. Locations of the dives during the Ohara Leg. Contours in 100 m. SSF = Shinkai Seep Field.

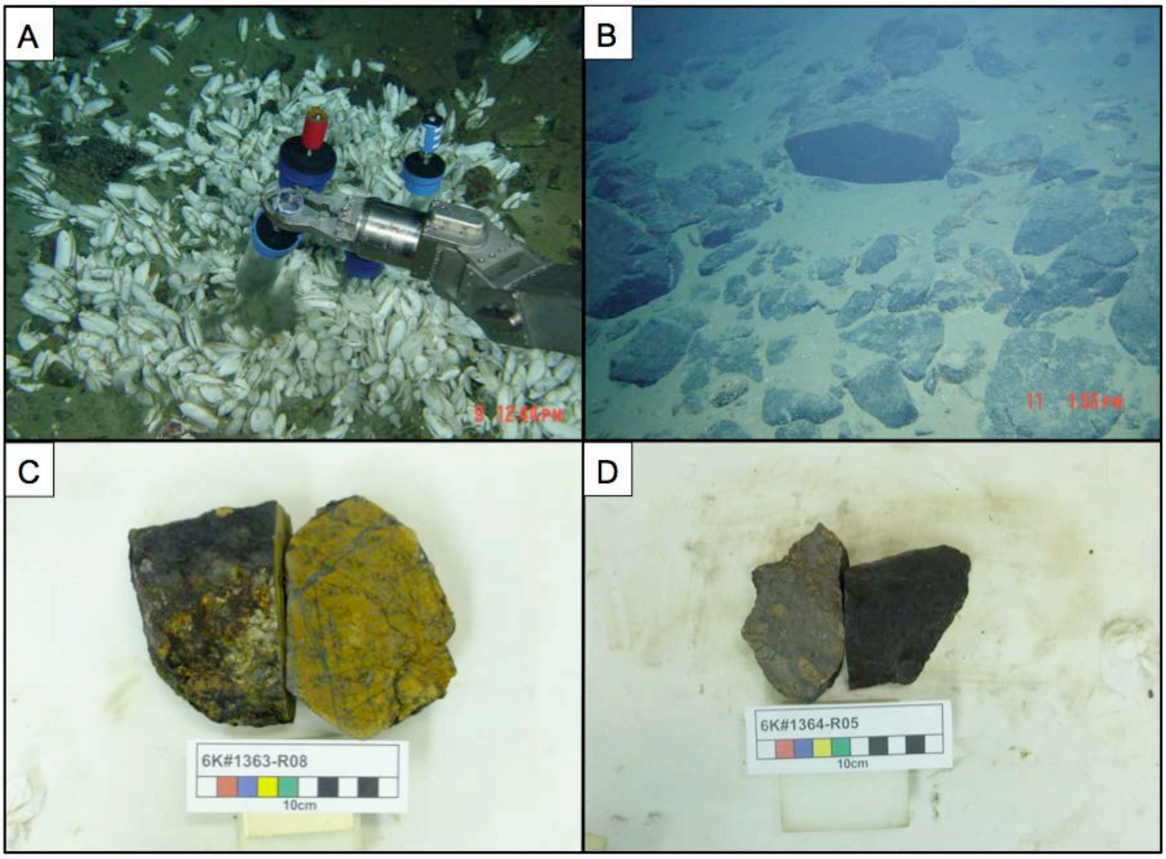

Fig. 8. Field observations and samples of the Ohara Leg.
(A) Coring attempt at the Shinkai Seep Field during 6K-1362.
(B) Slope covered by talus of serpentinized peridotite observed during 6K-1363.
(C) Serpentinized harzburgite collected during 6K-1363.
(D) Serpentinized harzburgite collected during 6K-1364.

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