CRUISE REPORT

JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

R/V YOKOSUKA YK06-12 CRUISE

COMPOSITION AND STRATIGRAPHY OF THE MARIANA ARC CRUST AND IMPLICATIONS FOR ARC MASS BALANCE AND THE ORIGIN OF CONTINENTAL CRUST: A SUBMERSIBLE STUDY OF THE SOUTHERN MARIANA ARC

AUGUST 27, 2006 TO SEPTEMBER 5, 2006

(REPUBLIC OF PALAU TO GUAM, USA)

Table of Contents

List of cruise personnel

Science

Dr. Yasuhiko Ohara, co-chief
Hydrographic and Oceanographic Department of Japan
(also at IFREE-JAMSTEC)
5-3-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan
Tel: 81-3-3541-4387
Fax: 81-3541-3870
E-mail: ohara@jodc.go.jp

Dr. Mark K. Reagan, co-chief
Department of Geosciences, University of Iowa
10 Glendale Court, Iowa City, IA 52242, USA
Tel: 1-319-335-1802
Fax: 1-319-335-1821
E-mail: mark-reagan@uiowa.edu

Dr. Teruaki Ishii
Ocean Research Institute, University of Tokyo
1-15-1 Minamidai, Nakano-ku, Tokyo 164-8639, Japan
Tel: 81-3-5351-6447
Fax: 81-3-5351-4645
E-mail: ishii@ori.u-tokyo.ac.jp

Dr. Jun-Ichi Kimura
Department of Geological Sciences, Shimane University
1060 Matsue, Shimane 090-8504, Japan
Tel: 81-852-32-6462
Fax: 81-852-32-6469
E-mail: jkimura@shimane-u.ac.jp

Dr. Osamu Ishizuka
Geological Survey of Japan, AIST (also at IFREE-JAMSTEC)
Central 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan
Tel: 81-29-861-3828
Fax: 81-29-856-8725
E-mail: o-ishizuka@aist.go.jp

Dr. Katsuyoshi Michibayashi
Institute of Geosciences, Shizuoka University
Ohya 836, Suruga-ku, Shizuoka, 422-8529, JAPAN
Tel: 81-54-238-4788
Fax: 81-54-238-0491
E-mail: sekmich@ipc.shizuoka.ac.jp

Dr. James W. Hawkins
Scripps Institution of Oceanography, Geological Resources Division MC0220, University of California, San Diego
9500 Gilman Drive, La Jolla, CA 92093, USA
Tel: 1-858-534-2161
Fax: 1-858-534-0784
E-mail: Jhawkins@ucsd.edu

Dr. Robert J. Stern
Geosciences Department, University of Texas at Dallas
Box 830688, 2601 N. Floyd Rd., Richardson, TX 75083, USA
Tel: 1-972-883-2442
Fax: 1-972-883-2537
E-mail: rjstern@utdallas.edu

Dr. Sherman H. Bloomer
Geosciences Department, Oregon State University
128 Kidder Hall, Corvallis, OR 97331, USA
Tel: 1-541-737-3877
Fax: 1-541-731-1009
E-mail: Sherman.bloomer@oregonstate.edu

Dr. Patricia Fryer
School of Earth Sciences and Technology, University of Hawaii
1680 East-West Rd, POST Bldg #504, Honolulu, HI 96822 USA
Tel: 1-808-956-3146
Fax: 1-808-956-6322
E-mail: pfryer@hawaii.edu

Dr. Katherine A. Kelley
Graduate School of Oceanography, University of Rhode Island
Narragansett Bay Campus, Narragansett, RI 02882, USA
Tel: 1-401-874-6838
Fax: 1-401-874-6811
E-mail: Kelley@gso.uri.edu

Ms. Brittney Blake
Geosciences Department, University of Texas at Dallas
Box 830688, 2601 N. Floyd Rd., Richardson, TX 75083, USA
Tel: 1-972-342-7667
Fax: 1-972-883-2537
E-mail: blb031000@utdallas.edu

Mr. Satoshi Okada, onboard marine technician
Nippon Marine Enterprises, Ltd.
2-15 Natsushima, Yokosuka, Kanagawa 237-0061, Japan
Tel: 81-46-865-6803
Fax: 81-46-865-6503
E-mail: okada@nme.co.jp

Ship Crew

Mr. Fusao Saito, Captain

Mr. Takafumi Aoki, Chief Officer
Mr. Isao Maeda, Second Officer
Mr. Jun Takao, Third Officer

Mr. Kiyonori Kajinishi, Chief Engineer
Mr. Masahiro Kajihara, First Engineer
Mr. Yoshinobu Hiratsuka, Second Engineer
Mr. Yutaka Hashimoto, Third Engineer

Mr. Satoshi Watase, Chief Electronics Operator
Mr. Katsutoshi Kitamura, Second Electronics Operator

Mr. Kingo Nakamura, Boatswain
Mr. Kozo Yatogo, Able Seaman
Mr. Kuniharu Kagoguchi, Able Seaman
Mr. Shuichi Yamamoto, Able Seaman
Mr. Masanori Ohata, Able Seaman
Mr. Yuki Yoshino, Able Seaman
Mr. Hideki Takahashi, Sailor

Mr. Kiyoshi Yahata, No. 1 Oiler
Mr. Kozo Miura, Oiler
Mr. Hiroyuki Oishi, Oiler
Mr. Sakoh Tanaka, Assistant Oiler
Mr. Masaki Tanaka, Assistant Oiler

Mr. Takeshi Miyauchi, Chief Steward
Mr. Shinsuke Tanaka, Steward
Mr. Tadayuki Takatsu, Steward
Mr. Takahiro Abe, Porter
Mr. Satoshi Tomiuka, Porter

Shinkai operation team

Mr. Yoshiji Imai, Operation Manager

Mr. Toshiaki Sakurai, Assistant Operation Manager
Mr. Yoshitaka Sasaki, First Submersible Staff
Mr. Tetsuji Maki, First Submersible Staff
Mr. Yoshinari Ono, First Submersible Staff

Mr. Tetsuya Komuku, Second Submersible Staff
Mr. Keita Matsumoto, Second Submersible Staff

Mr. Hirofumi Ueki, Third Submersible Staff
Mr. Fumitaka Saito, Third Submersible Staff
Mr. Takuma Onishi, Third Submersible Staff

Acknowledgements

We are grateful to captain Fusao Saito, the Shinkai operation team manager Yoshiji Imai, the crew of R/V Yokosuka , and the Shinkai team for their outstanding efforts to make this scientific program successful. We also thank JAMSTEC for their support of this project. The U.S. science group acknowledges the support of a National Science Foundation grant to the University of Texas at Dallas. Most of the expendable supplies used in the cruise were provided from the Hydrographic and Oceanographic Department of Japan.

Summary

The forearc of the Izu-Bonin-Mariana Trench comprises crust formed in the earliest stages of arc volcanism, during the initiation of subduction. Recent studies on Guam, Saipan, the Bonin Islands, the Ogasawara escarpment and Palau; along with work on DSDP and ODP drill cores, have provided constraints on the timing, composition, sources, and subsequent vertical tectonic history of the volcanic portion of this earliest arc crust. Constraints on the lower crustal structure of the nascent arc crust are much more limited. Several dredges from the Mariana Trench to the south and southeast of Guam identified exposures of relatively fresh ultramafic, gabbroic, tonalitic, and diabasic rocks, along with subduction-related volcanics. Therefore, the scientific party for YK06-12 postulated that forearc south and east of Guam potentially contains the entire suite of rocks associated with what could be termed a "supra-subduction zone ophiolite" that formed during subduction initiation, and dive sites for YK06-12 were chosen to sample and observe the geology and geography of this region. The five dives of this cruise (973-977) spanned a 215 km distance beginning at 12°14'N, 144°7'E and ending at 13°15'N, 145°57'E. Dive sites were along what appear to be major left-lateral strike-slip and normal dip-slip fault scarps that cut the forearc region. SeaBeam mapping and sidescan imagery were collected around and between each of the dive sites. The Pacific plate entering the trench between the dive sites also was mapped using these methods. This mapping expanded the previous high-resolution bathymetry collected by HMR-1 and compiled by Patricia Fryer onto the downgoing plate.

Dive 973 was along a scarp created by a N-S strike slip fault south of Guam. It recovered partially serpentinized dunites and harzburgites from 6500 to 5900 m. Most of the samples had prominent high-temperature deformation fabrics, including possible proto-mylonitic/mylonitic fabrics. Dives 974, 975 and 976 formed a discontinuous N-S transect of the forearc slope near 145°20'E from 6500 m to 3000 m. Basalt or boninite, hornblende andesite, medium-grained gabbro, and abundant diabase (in some cases intruded into gabbro) were collected at the two deepest dive sites (974 and 976), which were in two different structural blocks between 6500 m and 5800 m. Dive 975 recovered diabasic textured shallow intrusive rocks overlain by volcaniclastic sedimentary rocks with some coralline debris on its transect between 3800 and 3000 m to the top of a small seamount. Dive 977 at the far eastern end of the dive area found mostly diabase with basaltic or boninitic compositions that may have been in the form of dikes at 6500 m to 5600 m depth. These were directly overlain by a Mn-coated foram-bearing clay near the top of a small seamount.

Taken together, the dive results document a sequential but disjointed crustal section floored by CPX-poor ultramafic rocks. The crustal section appears to consist of a relatively thin gabbroic layer, then a comparatively thick zone of diabasic-textured rocks ranging in composition from basaltic to dacitic, and a volcanic and sedimentary section that may correlate with the middle Eocene to lower Oligocene sections on Guam and DSDP site 458. The Moho appears to deepen to the east and the gabbroic section is consistently thinner than is typical of most ophiolites. Two dives ended near the summits of seamounts in shallow intrusive rocks capped by sediments, which is consistent with subaerial erosion before downdropping to their present 3-6 km depth.

Upcoming laboratory work by the scientific team will investigate the geochemical, petrologic, and age characteristics of the collected samples to investigate the origin and evolution of the nascent IBM arc crust. In addition, the bathymetry and sidescan imagery collected on this voyage will be used to study deformation in the Pacific plate shortly before it subducts.

1. Introduction

Subduction of oceanic lithosphere is the primary contributor to the global mass and chemical flux between the lithosphere and the deeper mantle and provides the source of a significant proportion of the world's volcanism (Stern, Fouch et al. 2003). Thus, gaining a better understanding of how subduction starts, how magmatic arcs develop with time after subduction begins, how mass cycles through subduction zones, and the role that arc crust plays in the formation of continental crust would broadly impact the geoscientific community. Investigations into these processes are best carried out on juvenile "intra-oceanic" arcs, such as the Izu-Bonin-Mariana arc system (Leat and Larter 2003).

Our understanding of mass transfer from the subducting slab and melting processes has improved through investigations of volcanic outputs at intraoceanic arcs, but our understanding of how arcs form and the structure and composition of deep arc crust and upper mantle is not as far advanced. The need to understand the origin and architecture of arc crust has been recognized by most international geoscientific research programs concerned with crust formation and evolution. The IODP (2001) Initial Science Plan states (p. 67): " *The creation and growth of continental crust remains one of the fundamental, unsolved problems in Earth science. Arc magmatism is thought to be a principal process in continental creation. Bulk continental crust is andesitic in composition, but the primary melt extracted from the upper mantle in subduction zones is basaltic. We still do not understand what causes this compositional change. IODP will drill into juvenile oceanic arcs, ideal sites for addressing this question, because extensive dredging and seismic surveys suggest that a major part of the middle arc crust is composed of rocks with andesitic compositions. ... Probing the possible new "continental root" beneath juvenile oceanic arcs by IODP will be a tremendous step towards understanding the origin of andesitic continental crust*." JAMSTEC's science plan for 2005-2010, the US-NSF-MARGINS Science Plan, and the International Continental Scientific Drilling Project (ICDP) white paper all identify understanding crust formation and element recycling at convergent plate boundaries as a top priority. The importance of this research also is reflected in the recommendations of the 2002 joint JAMSTEC-NSF MARGINS workshop on the IBM system, which strongly encouraged the study of early arc volcanism and the characterization of the lower crustal composition of the forearc through field studies, studies of existing dredged samples, and drilling

One of the objectives for YK06-12 was to help identify candidate sites for IODP drilling. On a more fundamental level, the scientific party for this cruise collected samples and observed sea-floor geology and geography with a goal of improving our understanding of the architecture and composition of the forearc crust. This research is a continuation of research begun in 2004 with diving west of the Bonin Ridge. Four dives (YK04-05, dives 823-826) were intended to study the lower crust and upper mantle exposed on the eastern escarpment of the Ogasawara Ridge north and west of the Ogasawara Islands. We found that these scarps were mantled with andesitic lavas that erupted 4-6 million years after subduction began in the IBM system (Ishizuka, Kimura et al. 2006). This project fostered co-operation between Japanese and US geoscientists and generated results that are important for our understanding for the early evolution of the IBM arc. However, we did not find what we were looking for – exposures of lower arc crust and upper mantle. YK06-12 continued this effort during August 27 to September 5, 2006, at another promising location, at the southern end of the Izu-Bonin-Mariana (IBM) arc system near Guam (Fig. 1).

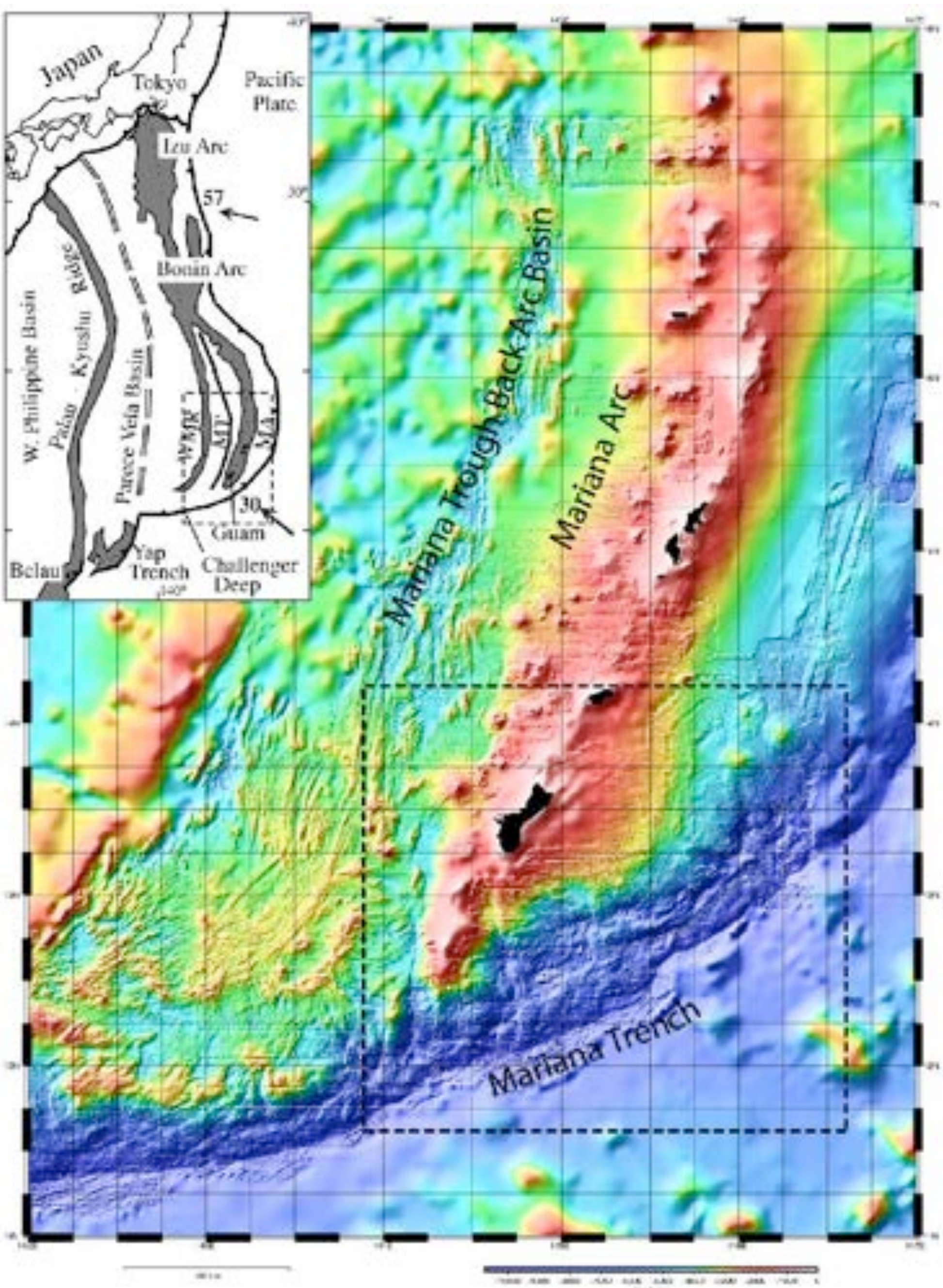


Fig. 1. Regional bathymetry of the southern Mariana area.

2. Geodynamic Background

Recent studies of the IBM forearc have produced a number of important new observations about the evolution of intraoceanic arc systems. The first, and most striking, is the recognition that the forearc basement formed in the initial phases of volcanism in these subduction zones (middle to late Eocene) nearly synchronously over a zone up to 300 km wide and thousands of kilometers long. Igneous production rates were much higher than those of mature arcs and similar to those of slow-spreading ridges (Figure 1; Stern and Bloomer 1992; Bloomer, Taylor et al. 1995; Ishizuka et al. 2006). This rapidly generated crust also is one of the best known recent analogs for ophiolites. The chemical signature of most ophiolites indicate that they must have formed at a convergent plate margin and so are termed 'supra-subduction zone (SSZ) ophiolites'. Most scientists think that SSZ ophiolites originate in back-arc basins because this is the only modern geotectonic environment where the compositional and structural constraints can be satisfied. The duration of volcanism, volcanic and plutonic rock compositions, and structural setting of the IBM forearc are virtually identical to those of the best preserved ophiolites, and this observation leads us to conclude that SSZ ophiolites mostly form in forearc environments during the early stages of subduction (Bloomer et al., 1995).

Previous sampling of the Izu-Bonin-Mariana forearc system by dredging, drilling, and subaerial field work has yielded a wide range rock types, including those expected in a SSZ ophiolite. In the north, Chichijima and Mukojima of the Bonin Islands and ODP site 786 expose ca. 48 Ma boninite and related rocks. On the islands, the boninitic rocks are overlain by 45-44 Ma high-Mg andesite and dacite. Hahajima has 44 Ma high-Mg and low-Mg tholeiitic andesites and basalts, but boninite is not reported (Suzuki 1885; Kikuchi 1890; Yoshiwara 1902; Hanzawa 1947; Kaneoka, Isshiki et al. 1970; Kuroda and Shiraki 1975; Shiraki, Kuroda et al. 1978; Komatsu 1980; Shiraki, Kuroda et al. 1980; Tsunakawa 1983; Kuroda 1984; Umino 1985; Vidal, Auvray et al. 1985; Dobson 1986; Umino 1986; Kuroda, Shiraki et al. 1988; Dobson and Tilton 1989; Taylor, Nesbitt et al. 1994; Yajima and Fujimaki 2001; Ishizuka et al., 2006). Dredges along the western escarpment of the Ogasawara Ridge (Ishii 1985; Haraguchi 1999) recovered large volumes of low- and high-Mg tholeiites, similar to the exposures in the Hahajima group, as well as some gabbroic pebbles. Previous diving by the YK06-12 scientific party along this escarpment recovered high-Mg andesites as well as tholeiitic to calcalkaline andesites that range in age from 41.8 to 43.9 Ma (Ishizuka et al. 2006). ODP Sites 782, 783, 784, 785, 786 and 787 in the Izu forearc collected boninitic to tholeiitic arc rocks and associated sediments (Fryer, Taylor et al. 1990; Arculus, Pearce et al. 1992; Fujioka, Matsuo et al. 1992; Hiscott and Gill 1992; Murton, Peate et al. 1992; Parkinson, Pearce et al. 1992; Pearce, Thirlwall et al. 1992; Pearce, van der Laan et al. 1992; Taylor 1992; Taylor, Lapierre et al. 1992; van der Laan, Arculus et al. 1992; Clift 1995; Pearce, Kempton et al. 1999).

Work in the Mariana portion of the forearc includes dredging from south of Guam to 22^{o}N (Bloomer 1983; Bloomer and Hawkins 1983; Stern, Morris et al. 1991, Ohara and Ishii 1998). Rocks sampled by this dredging includes peridotites, gabbroic rocks, tonalitic rocks, and some boninitic and tholeiitic volcanic rocks, suggesting that this rocks above and below the Mohorovic discontinuity at the time of forearc generation. crop out on the sea floor in this region. DSDP Sites 458 and 459 drilled into a sequence of 48 Ma (Cosca, Arculus et al. 1998) boninites and underlying tholeiitic basalts (Meijer 1980; Bougault, Maury et al. 1982; Hickey and Frey 1982; Hussong, Uyeda et al. 1982; Natland and Tarney 1983; Hickey-Vargas 1989), suggesting that the outer forearc has crust was generated at about the same time as for the Bonin islands area to the north. Outcrops on Guam, Rota, and Saipan expose volcanic rocks ranging in age from 45 Ma to the Miocene. The oldest sequences include high-Si rhyolites (Saipan) and boninitic pillow lavas with compositions that are somewhat transitional to those of later more typical volcanic arc magmas (Guam). The oldest of these typical arc lavas in this area are 41-42 Ma tholeiites on Guam (Meijer, Reagan et al. 1983; Reagan and Meijer 1984; Hickey-Vargas and Reagan 1987; Reagan, Mohler et al. 2003).

Diving, surveying, and dredging along the Mariana forearc have identified seamounts and smaller structures consisting of serpentine mud flows containing blocks of material from both plates. Many of these seamounts actively vent this mud along with fluids that largely originated in the subducting plate. These features appear to be associated with faults resulting from extension of the region between the trench and the volcanic front that created avenues for escape of slab-derived fluids. The rise of these fluids and the mobilization of fault gouge resulting from forearc faulting produces serpentinite mud volcanism on the outer 100 km of the forearc and forms serpentinite mounds along fault traces and larger edifices (up to 50 km in diameter and 2 km high) (Fryer and Fryer 1987; Fryer, Pearce et al. 1990; Fryer 1992; Wessel, Fryer et al. 1994; Fryer, Lockwood et al. 2000). This mud volcanism provides a means by which we may study the processes of fluid-rock interactions in materials derived from shallow to intermediate depths (10-30 km) along the decollement and in the overriding plate’s mantle (Fryer, Wheat et al. 1999; Mottl, Komor et al. 2002; Mottl, Wheat et al. 2004).

Recent studies of seismic anisotropy in the mantle beneath volcanic arcs have shown that fast S-wave directions in the mantle beneath volcanic arcs and forearcs often align with the trench, whereas fast S-wave directions commonly are orthogonal to the trench in the mantle beneath back-arcs (Fischer, Fouch et al. 1998; Nakajima and Hasegawa 2004). This may either result from a change in the direction of flow in the asthenospheric mantle from back-arc to forearc, or it may represent a change in olivine orientation due to hydration. A study of the seismic anisotropy in olivine as well as the deformation history of the lithospheric mantle and asthenospheric mantle in the vicinity of the southern Mariana Trench has recently been initiated (Michibayashi et al. submitted). The focus of these studies has been the relationship between microstructures and olivine fabrics (Michibayashi and Mainprice 2004; Michibayashi, Ina et al. 2006). Some of the peridotite samples measured in these studies have B-type olivine crystal-preferred orientations, suggesting that the asthenospheric mantle in the tip of the southern Mariana trench could be hydrated (e.g., Jung and Karato 2001).

Four main inferences from these earlier studies led us to propose the Shinkai 6500 dives whose results are reported here. These are: (1) forearc volcanism along the entire arc began at about 48Ma (Ishizuka et al., 2006). This volcanism may have been associated with forearc spreading caused by catastrophic collapse of the leading edge of the Pacific plate (Stern and Bloomer, 1992). This event may have been associated with thrusting of the

Philippine plate over the Pacific plate (Hall 1999). The stucture of this forearc crust could be ophiolitic, but with subduction influenced igneous rocks. (2) Mantle decompressed to build this "protoarc" (Pearce et al., 1999) crust of boninite and related rocks. The compositions of volcanics then switched to those more typical of volcanic arcs when the mantle to begin to couterflow. This switch apparently began between at different times and at different locations in the arc: ca 44 Ma in the Bonin-Islands, Ogasawara Ridge area; 45 Ma on Saipan; and 42 Ma on Guam. (3) The forearc southeast of Guam was built during the proto-arc stage of volcanism, and records this geodynamic transition. (4) This forearc region also has a record of recent tectonic activity and active fluid venting that could provide information about current subduction dynamics and the cycling of water through the arc.

3. Objectives of the Cruise

This cruise took advantage of the deep-diving ability of the Shinaki 6500 to sample exposures along steep escarpments of created by faulting of the forearc. Some of the primary questions addressed by this diving and the subsequent studies are the following.

- *Is the Mariana forearc floored exclusively by post-48 Ma arc crust and underlying mantle? Alternatively, is older MORB, back-arc, (DeBari, Taylor et al. 1999) or arc crust (Fryer et al., in prep) locally present in the forearc basement? If the former is true, then older crust either was never present because of forearc spreading (Stern and Bloomer, 1992) or was removed by subduction erosion.*
- *Are late Eocene or younger igneous rocks present? If so, were they tectonically transported to the forearc or do they represent forearc volcanism?*
- *What is the geology of the forearc crust, and what is its overall stratigraphy and structure? The rock types encountered will be studied to determine if they are consistent with an ophiolitic structure and if this structure is consistent with the forearc spreading hypothesis.*
- *What is the origin of tonalities in the Mariana forearc? Tonalities were dredged near one of the dive sites, and we hope to determine whether these were generated in the IBM protoarc, or if they represent older or yonger magma generation events. We also would like to determine whether they are generated by anatexis of amphibolites in the lower crust (Tamura and Tatsumi 2002), or by another mechanism.*
- *Does the sub-arc mantle in this region have a composition that is consistent with the hypothesis that it represents the residue left after melting to generate arc crust? Alternatively, is it mantle that was trapped in the forearc by the nucleation of subduction, or perhaps mantle that flowed into the region after subduction began due to trench rollback?*
- *Is the composition of Mariana arc crust a progenitor of continental crust if modern arc and early arc crustal compositions are balanced and crust thickens to the point that refractory lower arc crust can delaminate?*
- *Do fluids commonly vent along fault zones? Are these fluid vent areas associated with eruption of serpentine muds?*

- *Can deformation of peridotites in the presence of water lead to seismic anisotropy with fast values parallel to the trench as is commonly observed in arcs?*

Combined with the work on the islands and previous dredge sampling, our work is establishing the nature of the IBM forearc crust. If our petrological and geochemical studies find that MORB or back-arc material is entirely lacking, then we will have strong evidence that the early arc volcanism proceeded at a rate and in a style that made it possible to remove most of the pre-existing crust. The distribution and volumes of boninitic and tholeiitic lavas that we find in the area investigated will have important implications for the sources and melting processes of lavas associated with the earliest phases of subduction.

By addressing these questions, our work will test parts of the model of early arc volcanism as the progenitor of supra-subduction zone ophiolites. The validation of that model has ramifications for modern marine geology and for the interpretation of ophiolites in the geologic record. We also will gain a significantly greater understanding of the overall composition of the IBM arc system crust, which has significant geodynamic implications for determining how continental crust is manufactured on earth. Both would be a fundamental contribution to earth science and set the stage for deep scientific drilling.

4. Running cruise narrative and weather

Local time (approximate)	Notes
25-Aug-06	**The YK06-12 science party flew to Palau. It was rainy on the island.**
19:50	The science party arrived in the island.
20:30	The science party checked-in Airai Veiw Hotel.
26-Aug-06	**Palau field trip.**
8:15	The science party rent two mini-vans for geological excursion of the island.
18:00	Return to Airai Veiw Hotel; end of the excursion.
27-Aug-06	**The YK06-12 cruise began.**
10:30	The science party got in R/V Yokosuka at the east harbor of Malakal port of Palau.
11:40-12:00	Guidance for the ship's rule for scientists from the Chief Officer and the Chief Radio Officer.
15:00	Leave Palau for the 1st dive site; the ship steams to ~ 70 degrees.
16:40-17:00	Ceremony on bridge to begin cruise ("Konpira-san" ceremony).
18:00-18:30	Science meeting (Yasuhiko Ohara on logisticall issues).
28-Aug-06	**The Yokosuka was underway to the dive #973 site; scientists worked on organizing the Palau field trip samples.**
10:00	Guidance for the submersible operations for scientists from the 6K team.
13:00	Orientation for scientists participating in submersible observations

	from the 6k team.
18:15-20:00	Science meeting (Osamu Ishizua talked on YK04-05 Leg 4 results + recent Japanese continental shelf survey project result).
Mid-night	Time change to Guam standard time (UTC+9 hours).
29-Aug-06	**The Yokosuka was underway to the dive #973 site; scientists worked on sawing the Palau field trip samples. Site survey for dives # 973-#976 at night (WP1 to WP9).**
14:30	Arrived at the dive #973 site; XBT was deployed (at 12-12.9927'N, 143-59.6460'E).
14:57-15:42	Site survey for dive #973 (WP1 to WP2).
18:00-19:30	Science meeting (Patricia Fryer talked on the tectonics of the southern Mariana forearce and Katsuyoshi Michibayashi talked on lheological feature of the southern Mariana forearc peridotite (break for sunset seeing during 18:30-18:40).
20:52-21:35	Site survey for dive #974 (WP3 to WP4).
21:54-22:38	Site survey for dive #975 (WP5 to WP6).
23:49-25:32	Site survey for dive #976 (WP7 to WP8).
30-Aug-06	**Shinkai 6500 dive # 973 was conducted at the southern Mariana Trench landward slope; Teruaki Ishii as observer. Geophysical mapping at night (WP9 to WP13). Although a proton magnetometer was deployed, it was malfanctioned.**
8:59	Dive #973 started (the Shinkai opened vent).
11:45	The Shinkai on bottom (6469 m).
14:47	The Shinkai off bottom (5957 m); total 12 rocks and one push core were sampled at 5 locations.
17:08	The Shinkai on surface.
18:00-22:00	Scientists worked on rock description, video archiving.
19:20-20:00	Science meeting (Teruaki Ishii talked on the dive #973 results, and Katherine Kelley talked on the objectives of the dive #974).
31-Aug-06	**Shinkai 6500 dive # 974 was conducted at the southern Mariana Trench landward slope; Katherine Kelley as observer. Site survey for dive #977 (WP14 to WP15) and geophysical mapping (WP13 to WP22) at night. Proton magnetometer was not deployed.**
8:57	Dive #974 started (the Shinkai opened vent).
11:32	The Shinkai on bottom (6270 m).
14:48	The Shinkai off bottom (5757 m); total 13 rocks and two scoops, one push core were sampled at 9 locations.
16:53	The Shinkai on surface.
18:00-22:00	Scientists worked on rock description, video archiving.
19:20-20:00	Science meeting (Katherine Kelley talked on the dive #974 results, and Jun-Ichi Kimura talked on the objectives of the dive #975).
1-Sep-06	**Shinkai 6500 dive # 975 was conducted at the southern Mariana Trench landward slope; Jun-Ichi Kimura as observer. Geophysical mapping (WP22 to WP28) at night. Proton**

	magnetometer was not deployed.
8:55	Dive #975 started (the Shinkai opened vent).
11:38	The Shinkai on bottom (6489 m).
14:57	The Shinkai off bottom (5892 m); total 27 rocks, one scoop and one push core were sampled at 13 locations.
17:07	The Shinkai on surface.
18:00-22:00	Scientists worked on rock description, video archiving.
19:30-20:00	Science meeting (Jun-Ichi Kimura talked on the dive #975 results, and James Hawkins talked on the objectives of the dive #976).
2-Sep-06	**Shinkai 6500 dive # 976 was conducted at the southern Mariana Trench landward slope; James Hawkins as observer. Geophysical mapping (WP28 to WP32) at night. Proton magnetometer was not deployed.**
10:01	Dive #976 started (the Shinkai opened vent).
11:41	The Shinkai on bottom (3802 m).
15:52	The Shinkai off bottom (3079 m); total 20 rocks were sampled at 13 locations (one push core attempt was not successful).
17:02	The Shinkai on surface.
18:00-22:00	Scientists worked on rock description, video archiving.
19:00-19:30	Science meeting (James Hawkins talked on the dive #976 results, and Robert Stern talked on the objectives of the dive #977).
3-Sep-06	**Shinkai 6500 dive # 977 was conducted at the southern Mariana Trench landward slope; Robert Stern as observer. Geophysical mapping (WP32 to WP43) at night and at the daytime on Sep. 4. Proton magnetometer was not deployed.**
9:00	Dive #977 started (the Shinkai opened vent).
11:39	The Shinkai on bottom (6363 m).
15:03	The Shinkai off bottom (5483 m); total 26 rocks and one scoop were sampled at 11 locations.
17:13	The Shinkai on surface.
17:58-18:15	Figure-eight track for 3D magnetic data correction
18:00-22:00	Scientists worked on rock description, video archiving.
19:00-19:30	Science meeting (Robert Stern talked on the dive #977 results).
4-Sep-06	**Scientists worked on curating samples and video records. Geophysical mapping (WP32 to WP43) at the daytime on Sep. 4. Proton magnetometer was not deployed.**
13:30-14:45	Science presentations to crew by Yasuhiko Ohara and Teruaki Ishii.
14:50	Group photograph of scientific, ship, and Shinkai crew.
17:00-23:00	Reception in mess for ship's party.
21:20	Geophysical mapping completed.
5-Sep-06	**The YK06-12 cruise ended.**
7:00	The Yokosuka anchored in Guam.
12:30	The science party disemberked.
6-Sep-06	**Guam field trip.**

8:15	The science party rent two mini-vans for geological excursion of the island.
18:00	Return to Marriott Hotel; end of the excursion.

Table 1. Weather conditions during the YK06-12 cruise

Local time	Weather	Wind	Sea condition	Position
27-Aug-06	Fine	NW (light breeze)	N/A	Palau
28-Aug-06	Fine	ENE (Light air)	Rippled calm	10-02N, 138-05E
29-Aug-06	Fine	W (Gentle breeze)	Smooth	12-03N, 143-32E
30-Aug-06	Fine	No wind (Calm)	Rippled calm	12-14N, 144-08E
31-Aug-06	Fine	NNE (Light breeze)	Rippled calm	12-55N, 145-19E
1-Sep-06	Fine	SW (Light air)	Rippled calm	12-47N, 145-29E
2-Sep-06	Fine	NW (Light breeze)	Smooth	13-02N, 145-20E
3-Sep-06	Fine	NW (Light breeze)	Rippled calm	13-17N, 145-57E
4-Sep-06	Fine	-	-	-
5-Sep-06	Fine	-	-	Guam

5. Operations and data processing

Waypoints for the survey lines employed during the YK06-12 cruise are listed in Table 2. Figure 2 shows the survey lines and waypoints.

5-1. DSV Shinkai 6500

DSV Shinkai 6500 is one of the finest manned submersibles in the world. The operational characteristics of the submersible are described elsewhere.

5-2. Bathymetric data

Bathymetric data were collected using the SeaBeam 2112 system deployed on M/V Yokosuka. 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 (Tables 3). We used XBT data for calculating sound velocities on August 29, 2006. The quality of the obtained bathymetry depends mostly on the sea state, which had been very good during the cruise (Table 1). Survey lines and way point locations are shown in Figure 2.

5-3. Gravity data

Gravity data was collected during YK06-12, though it was not processed on board.

5-4. Magnetics data

Three-component magnetometer data (Hx, Hy, Hz) was collected during our survey lines using an SFG-1214 magnetometer (Terra Tecnica Inc.). To determine the effect of the ship's mangetication, we carried out figure eight track on 17:58-18:15 of September 3, 2006.

The proton magnetometer was not deployed during the cruise.

Table 2. List of way points during the YK06-12 cruise

Way Point	Lat (deg)	Lat (min)	Lon (deg)	Lon (min)	Time (Local)		Time (UTC)		Note
					yyyy/mm/dd	hh:min	yyyy/mm/dd	hh:min	
1	12	15	144	5	2006/08/29	14:57	2006/08/29	04:57	
2	12	15	144	11	2006/08/29	15:42	2006/08/29	05:42	
3	12	55.5	145	17	2006/08/29	20:52	2006/08/29	10:52	
4	12	55.5	145	23	2006/08/29	21:35	2006/08/29	11:35	
5	12	58	145	23	2006/08/29	21:54	2006/08/29	11:54	
6	12	58	145	17	2006/08/29	22:38	2006/08/29	12:38	
7	12	47	145	27	2006/08/29	23:49	2006/08/29	13:49	
8	12	47	145	33	2006/08/30	00:32	2006/08/29	14:32	
9	12	15	144	8	2006/08/30		2006/08/29		Dive#973
10	11	45	144	40	2006/08/30	21:23	2006/08/30	11:23	
11	12	20	145	40	2006/08/31	02:59	2006/08/30	16:59	
12	12	30	145	40	2006/08/31	03:50	2006/08/30	17:50	
13	12	55.5	145	20	2006/08/31		2006/08/30		Dive#974
14	13	13	145	50	2006/08/31	20:05	2006/08/31	10:05	
15	13	13	146	10	2006/08/31	22:28	2006/08/31	12:28	
16	13	16	146	10	2006/08/31	22:48	2006/08/31	12:48	
17	13	16	145	50	2006/09/01	00:48	2006/08/31	14:48	
18	13	3	145	23	2006/09/01	03:15	2006/08/31	17:15	
19	13	3	145	10	2006/09/01	04:19	2006/08/31	18:19	
20	13	0.5	145	10	2006/09/01	04:35	2006/08/31	18:35	
21	13	0.5	145	23	2006/09/01	05:48	2006/08/31	19:48	
22	12	46	145	27	2006/09/01		2006/08/31		Dive#975
23	12	30	145	45	2006/09/01	19:29	2006/09/01	09:29	
24	12	52.5	146	10	2006/09/01	22:06	2006/09/01	12:06	
25	12	50	146	17.5	2006/09/01	22:42	2006/09/01	12:42	
26	12	25	145	55	2006/09/02	01:15	2006/09/01	15:15	
27	12	8	145	35	2006/09/02	03:23	2006/09/01	17:23	
28	13	3	145	20	2006/09/02		2006/09/01		Dive#976
29	13	3	145	13	2006/09/02	18:14	2006/09/02	08:14	
30	11	52	145	30	2006/09/02	22:59	2006/09/02	12:59	
31	12	30	146	11	2006/09/03	03:13	2006/09/02	17:13	
32	13	16.5	145	56.5	2006/09/03		2006/09/02		Dive#977
33	13	0	146	24	2006/09/03	20:45	2006/09/03	10:45	
34	12	34.5	146	30	2006/09/03	22:42	2006/09/03	12:42	
35	11	15	145	7	2006/09/04	7:10	2006/09/03	21:10	
36	11	15	144	52	2006/09/04	8:15	2006/09/03	22:15	
37	11	44	145	21	2006/09/04	11:20	2006/09/04	1:20	
38	11	57	145	16.5	2006/09/04	12:21	2006/09/04	2:21	
39	11	22	144	42	2006/09/04	15:57	2006/09/04	5:57	
40	11	30	144	33	2006/09/04	16:50	2006/09/04	6:50	
41	11	47	144	47	2006/09/04	18:30	2006/09/04	8:30	
42	12	10	144	45	2006/09/04	20:01	2006/09/04	10:01	
43	12	0	144	30	2006/09/04	21:20	2006/09/04	11:20	

Table 3. List of sound velocity profiles used in narrow multibeam survey

Depth (m)	Velocity (m/s)
4.5	EXT
136	1537.0
230	1510.7
386	1493.0
500	1489.4
640	1486.3
1000	1485.8
1500	1487.0
2000	1491.1
2500	1498.0
4000	1523.0
6000	1559.4
8000	1596.3
11000	1653.8

Data based on an XBT shot at 12-12.9927'N, 143-59.6460'E on 04:30 Aug 29, 2006 (UTC).

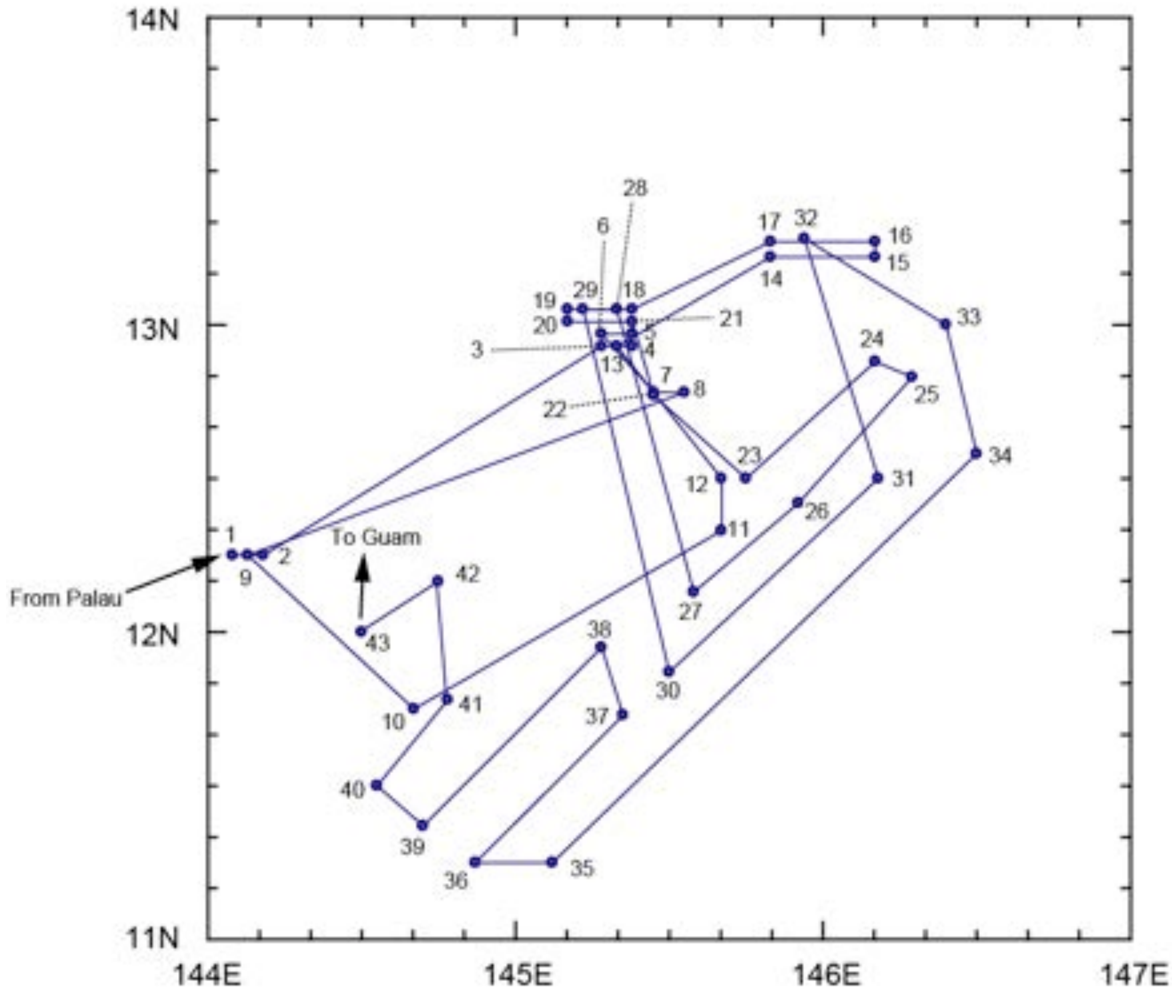


Fig. 2. Survey lines and way points (see Table 2) employed during YK06-12 cruise.

6. Scientific results

6-1. Bathymetry

The preliminary SeaBeam bathymetry map of the southern Mariana area is shown in Fig. 3. The mapped area covered both the landward and oceanward slope of the Mariana Trench. On the landward slope, parts of the Santa Rosa Bank, West Santa Rosa Bank Fault (WSRBF), and East Santa Rosa Bank Fault (ESRBF) are mapped (cf. Fryer et al., 2003). The bathymetry to the southwest of Guam shows approximate ENE-WSW trending lineation, suggesting WNW-ESE extensional regime in this parts of the Marina forearc. At the northeast end of the survey area, a possible serpentine diapir seamount was mapped. On the oceanward slope, bathymetric lineations paralleling to the trench axis are clearly mapped. Several seamounts erupted on the subducting plate are also mapped.

6-2. Sumbersible studies

We conducted five dives during the cruise (Table 4 and Fig. 4). A summary of the video records for those dives is included in Table 5 and video logs are listed in Appendix A. Appendix B includes plots of the dive tracks for each dive, in X-Y units.

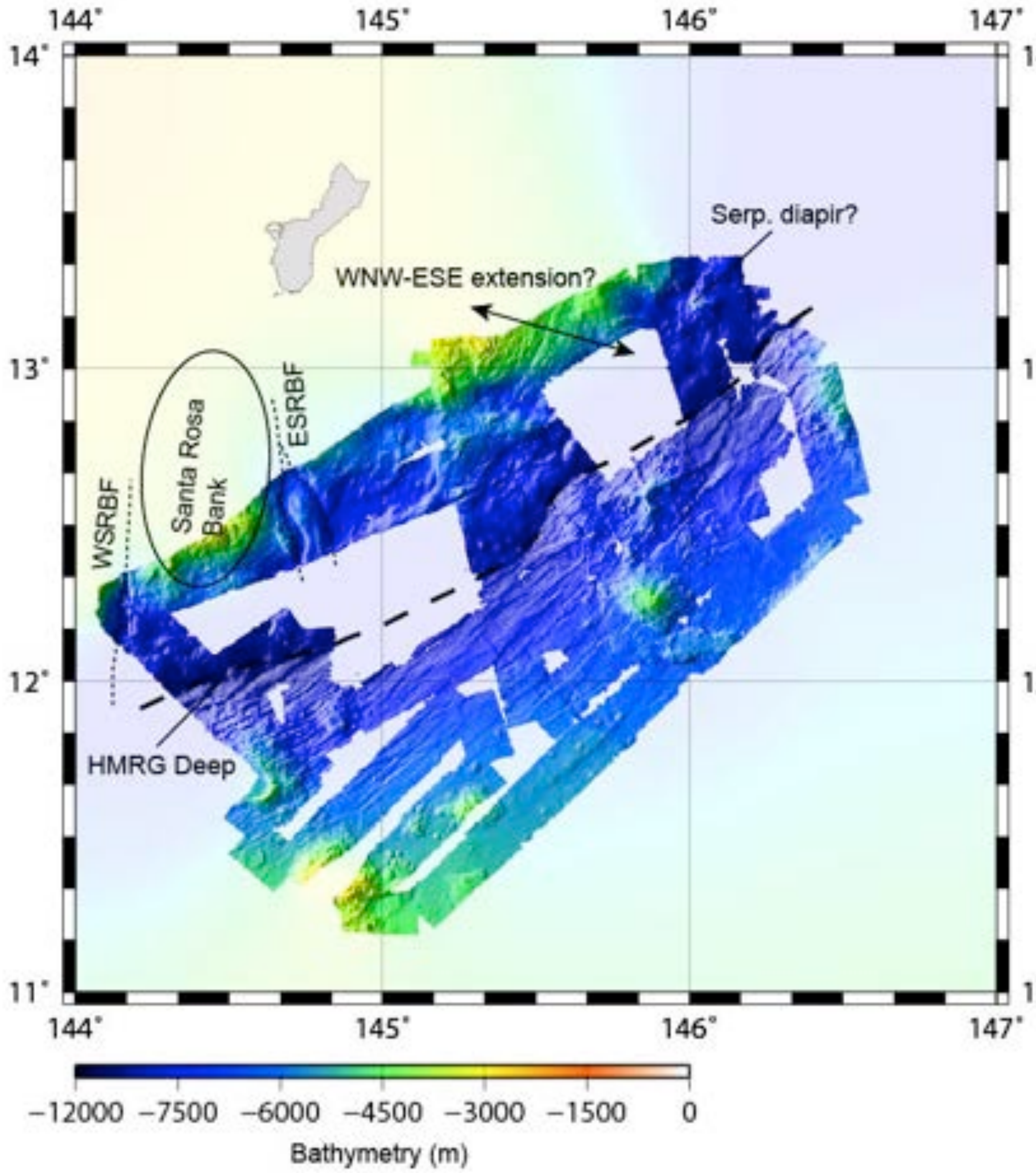


Fig. 3. Bathymetry obtained during YK06-12 cruise. Dashed line indicates the trench axis. WSRBF (West Santa Rosa Bank Fault), ESRBF (East Santa Rosa Bank Fault), HMRG Deep are after Fryer et al. (2003).

Table 4. List of Shinkai 6500 dives completed during the YK06-12 cruise

Dive #	Date	Observer	Pilot	Co-pilot	On bottom / Off bottom	Lat	Lon	Start depth / End depth	Samples	Location
973	30-Aug-06	Teruaki Ishii	Keita Matsumoto	Tetsuya Komuku	11:45	12-14.5516 N	144-07.8100 E	6469 m	12 rocks + 1 push core + 1 scoop	Eastern scarp of the NS linearment, (i.e., WSRBF) south of the Santa Rosa Bank
					14:47	12-14.9588 N	144-06.8095 E	5957 m		
974	31-Aug-06	Katherine Kelley	Yoshinari Ono	Hirobumi Ueki	11:32	12-55.2345 N	145-18.9270 E	6270 m	13 rocks + 1 push core + 2 scoops	Lower slope of the south dipping scarp southeast of Guam
					14:48	12-55.9862 N	145-18.7998 E	5757 m		
975	1-Sep-06	Jun-Ichi Kimura	Toshiaki Sakurai	Tetsuya Komuku	11:38	12-47.1764 N	145-28.9189 E	6489 m	27 rocks + 1 push core + 1 scoop	The south dipping slope of the outer ridge, south of the dive #974 site
					14:57	12-48.1224 N	145-28.7107 E	5892 m		
976	2-Sep-06	James Hawkins	Yoshitaka Sasaki	Yoshinari Ono	11:40	13-02.0952 N	145-20.5585 E	3802 m	22 rocks	Upper slope of the south dipping scarp of southeast of Guam
					15:52	13-03.7499 N	145-19.4416 E	3079 m		
977	3-Sep-06	Robert Stern	Keita Matsumoto	Toshiaki Sakurai	11:39	13-16.4609N	145-56.7032 E	6363 m	26 rocks + 1 scoop	Lower slope of the southeast dipping scarp southeast of Guam
					15:03	13-17.2571N	145-56.0253 E	5483 m		

Ship's navigation: D-GPS + WGS84

Submersible's navigation: SSBL

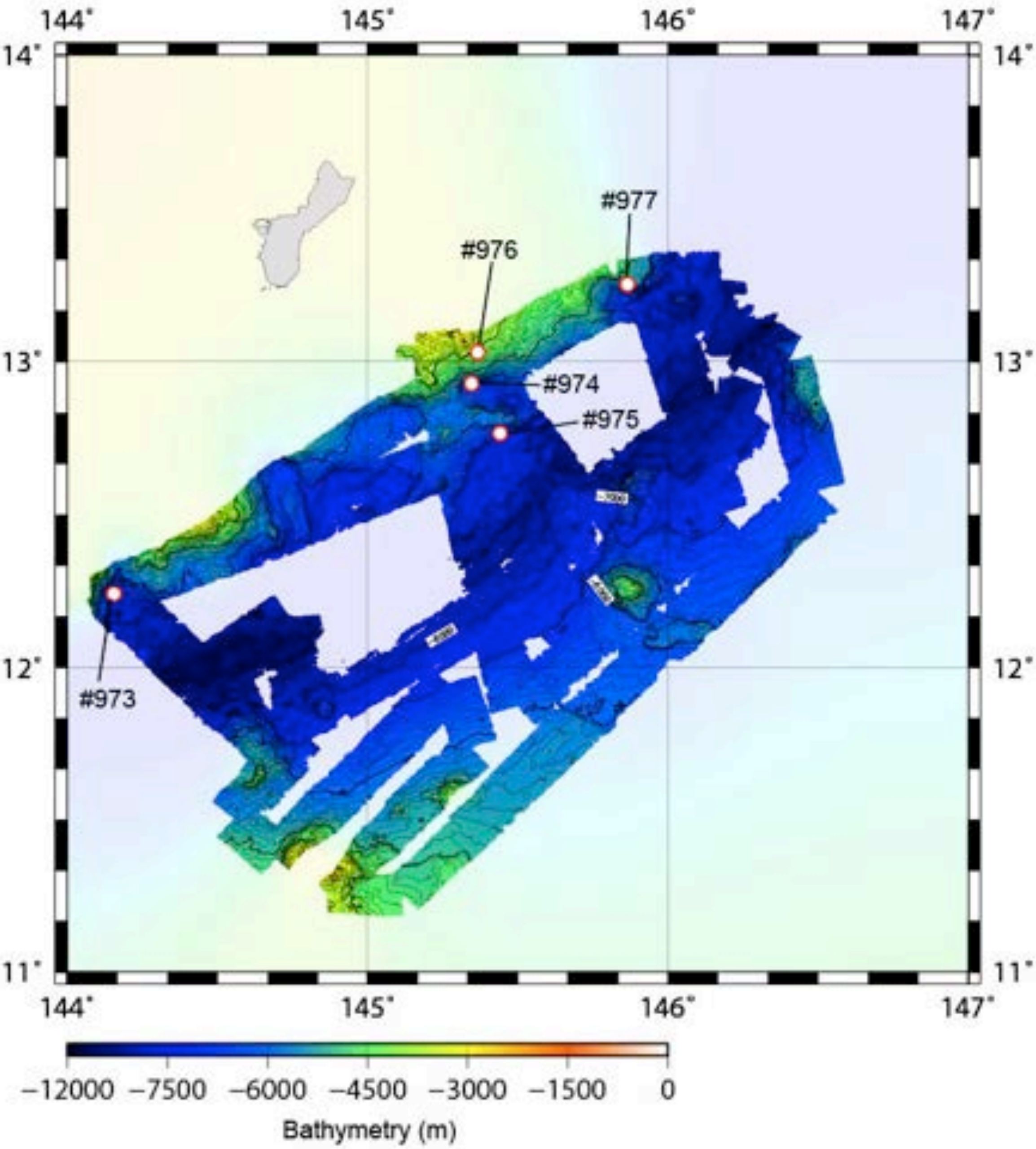


Fig. 4. Location of the dive sites during YK06-12 cruise. Contour interval is 100 m.

Table 5. List of the video and camera records obtained during the YK06-12 cruise

Dive #	Date	Obserever	Tape #	No.1 Camera (Recorded time)	No.2 Camera (Recorded time)	Handheld still photos	Shinkai-mount still photos
973	30-Aug-2006	Teruaki Ishii	1 of 4	11:37-14:38		276 stills	385 stills
			2 of 4	14:38-14:46			
			3 of 4		11:37-14:38		
			4 of 4		14:38-14:46		
974	31-Aug-2006	Katherine Kelley	1 of 4	11:25-14:17		44 stills	336 stills
			2 of 4	14:17-14:48			
			3 of 4		11:25-14:17		
			4 of 4		14:17-14:48		
975	1-Sep-2006	Jun-Ichi Kimura	1 of 4	11:32-14:34		96 stills	357 stills
			2 of 4	14:34-14:48			
			3 of 4		11:32-14:34		
			4 of 4		14:34-14:48		
976	2-Sep-2006	James Hawkins	1 of 4	11:33-14:33		20 stills	284 stills
			2 of 4	14:34-14:58			
			3 of 4		11:33-14:33		
			4 of 4		14:34-14:58		
977	3-Sep-2006	Rbert Stern	1 of 4	11:32-14:39		53 stills	355 stills
			2 of 4	14:40-15:04			
			3 of 4		11:32-14:39		
			4 of 4		14:40-15:04		

6-2-1. Report for Dive 973, 8/30/2006: T. Ishii

The initial goal for this dive was to examine an eastward-facing slope of one of two N-S striking left-lateral fault zones that have caused approximately 20 km of displacement along each (Fryer et al., 2003) in the Mariana fore-arc, from ~6500 m to ~5600 m depth. Anticipated rock types in this area were known to be harzburgite (Bloomer and Hawkins 1983) and we hoped this dive might go across the crust-mantle boundary ('Moho'). We expected to characterize the structure of the fault zone and to locate the position of the crustal-mantle boundary in this region within the fore-arc crustal structure and compare this result with the four following dives. As a result, the rocks recovered from this dive are only peridotites that are mostly harzburgite with a few dunitic rocks. It is noted that all peridotites are tectonites including a few mylonitic rocks, suggesting that they were derived from intensely deformed lithospheric mantle.

The Shinkai 6500 started diving at 9:00 and reached on the bottom of 6469 m deep at 11:45 (total time for down going: 2h45m). Scientific dive operations began immediately at 11:45 when Shinkai 6500 touched bottom. We maintained an approximately westward heading for the duration of the dive, covering ~1940m in total distance and 513 m in vertical relief, that is the average inclination of the surface was about 14.8 degree. The lithology of the seafloor along the dive course was mostly coarse debris made of angular rock clasts, dominantly ~10-50 cm but ranging to boulders of 1-3 m in size.

Photo 1. A view of 100% exposure of coarse debris with a few very large blocks. 6354 m at 12:43.

Near the point of touchdown, we attempted to sample sediment by a push core (blue) and subsequently collected one sample of a cobble, which was moderatedly deformed harzburgite (R1) with well developed foliation. Subsequently, we scooped the surface sediment, which consists of pebbles and loose coarse sands of peridotites, gabbros and some diorites etc. We then proceeded westward. At 12:17, we stopped to collect two pieces of the debris within sandy surface at 6385m; the first one (R2) is intensely deformed mylonite and the other (R3) is weakly or moderately deformed harzburgite but heavily altered. We then continued up the slope up to 6350 m, viewing a very smooth surface with a few tiny rocks. At 12:42, we started traversing at 100 % exposure of coarser debrics with various sizes and angular to subangular shapes (Photo 1), where we collected five samples (R4-8 at 6355 m). R4 is intensely deformed mylonite, which is similar to R2 but seems to have more inhomogeneous texture. The rest of samples (R5-8) are weakly or moderately deformed harzburgite and/or dunite, although they are somewhat altered, making it difficult to identify any structure. After continuous exposure of coarser debris, outcrop appeared from 6313m at 13:00 to 6298 m at 13:02 (Photo 2). It may be assumed that the debris (and some samples) at deeper levels could be derived from this outcrop.

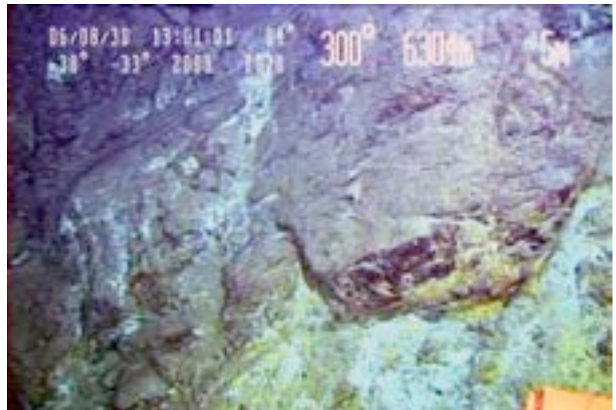


Photo 2. An outcrop at 6304 m.

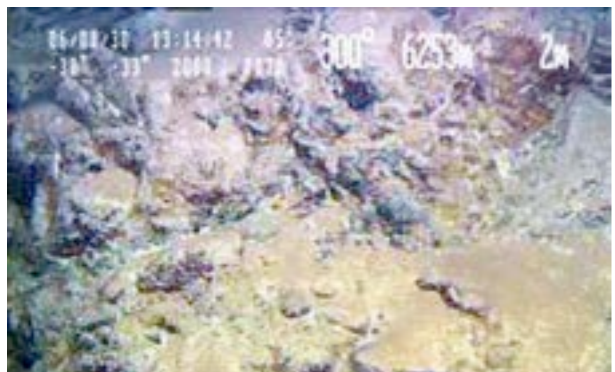


Photo 3. Serpentine breccia at 6253 m.

At 13:14, large blocks or outcrops with an appearance of serpentine breccia were encountered at 6253m (Fig. 3). Proceeding up the slope at 13:17, views from the port side showed another blocky deposit of 100% debris at 6241 m. This deposit consisted of dark grey or dark greenish angular to subangular medium (<1 m) to large (>1 m) boulders. Two samples of this coarse debris were taken at 6228m; R9 is a dunite possibly with very fine-grained olivine and R10 is moderately deformed and heavily altered harzburgite. The rocky exposure ended at 6185 m (13:34). The floor was mostly covered by pelagic sediments with some angular-shaped cobbles and locally a few boulders. Continuing onward, the slope was continuously covered by thick sediments of debris flow with many cobbles and boulders. No other outcrops were encountered to 5957m, where we stopped and collected two samples of the smaller debris (R11-12). These two samples are weakly deformed harzburgites, which might represent the deeper level of lithospheric or asthenospheric mantle. We put a marker on a boulder before beginning our ascent to the surface. Shinkai started to ascent at 14:47 and reached the sea surface at 17:09 (total time for going up: 2h22m).

Waypoints and sample stops for Dive #973 (30-Aug-2006)

Point Number	Sample Stop	Samples	Observer Record Time*	Pilot Record Time*	Latitude	Longitude	Depth (m)	X	Y
1	-	Landing Target		9:00	12° 14.5900' N	144° 07.8100' E	0	-387.1	1287.3
2	1	Landing, 1 rock, 1 scoop, 1 core	N/A	11:45	12° 14.5516' N	144° 07.7835' E	6469	-457.9	1239.2
3	2	2 rocks	N/A	12:17	12° 14.6058' N	144° 07.6795' E	6385	-358	1050.7
4	3	5 rocks	N/A	12:50	12° 14.7454' N	144° 07.4405' E	6355	-100.6	617.3
5	4	2 rocks	N/A	13:26	12° 14.8242' N	144° 07.3243' E	6228	44.6	406.6
6	5	2 rocks, #49	N/A	14:47	12° 14.9588' N	144° 06.8095' E	5957	292.7	-526.7

*Observer record is the starting time at a sampling stop; Pilot record is the time of departure from a sampling stop

6-2-2. Report for Dive 974, 8/31/2006: K. Kelley

Photo 1. View from the Shinkai 6500 port side window at ~13:15 (6014 m). This terrain is typical of the sea floor throughout the course of Dive #974.

The initial goal for this dive was to examine a southward-facing slope of the Mariana fore-arc, from ~6300 m to ~5600 m depth. Anticipated rock types in this area were unknown, since no other dives or dredges had previously been conducted in the immediate area. We expected to identify the position of this region within the fore-arc crustal structure and use this information as a guide for planning the three following dives. The rocks recovered from this dive, although not in place, sample a wide variety of lithologies from hornblende gabbro to diabase to mafic and felsic volcanic rocks. If these samples are representative, then these deposits sample rocks that are characteristic of the upper arc crust, which likely exists in place at bathymetrically higher levels. All times and depths noted here are from the observer's notes and do not necessarily coincide with the timing of Shinkai waypoint markers. Please refer to Table 1 for cross-referenced data for the dive waypoints.

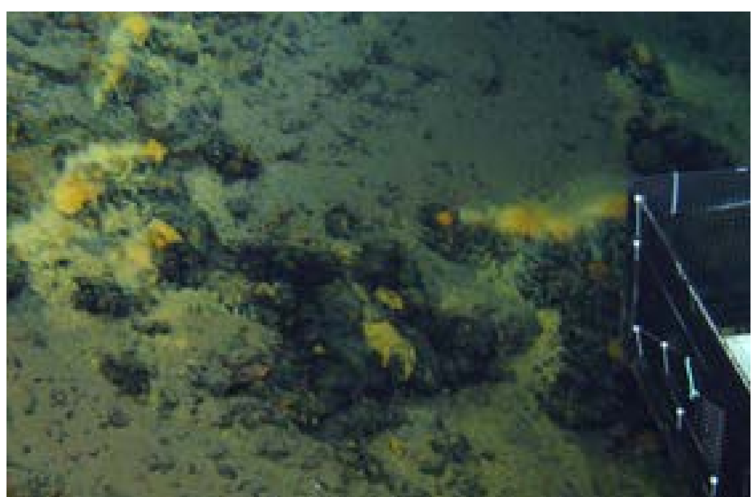


Photo 2. Possible hydrothermal seep area encountered at ~13:56 (5834 m). Pale yellow material is probably algae, bright orange deposits are Fe-oxide.

Scientific dive operations began at 11:32 when Shinkai 6500 touched bottom at a depth of 6270 m. We maintained an approximately northward heading for the duration of the dive, covering ~1 mile in total distance and 514 m in vertical relief. The lithology of the seafloor along the dive course was mostly coarse debris made of loosely consolidated angular and rounded rock clasts, dominantly ~5-10 cm but ranging to boulders of 1-2 m in size (Photo 1). The seafloor was uniformly covered with a thin veneer of

fine brown pelagic sediment. No in-place rock outcrop was encountered over the full course of the dive, so all samples were taken from periodic exposures of coarser debris. These deposits may be debris flows or some other product of large-scale submarine mass wasting. Surface deposits occasionally showed arrangement of clasts in small ridges, suggesting channelized flow of debris along the sloped surface. Most rocks had only very thin manganese coatings, suggesting that these deposits may be fairly young.
Near the point of touchdown, we collected two samples of coarse debris, which were a volcanic dacite (R1) and a light-colored, rounded cobble of hornblende gabbro (R2). We then proceeded northward up a shallow ~30° slope of medium-sized debris (5-10 cm) and sediment. At 12:06, we stopped to take a scoop sample, with the hope of recovering some pieces of the debris, but collected only fine brown sediment. Views from the port window showed a slightly steeper ridge to the port side, composed of similar debris deposits. We then continued up the slope, stopping periodically to collect samples of rock clasts whenever the debris became coarse. Clasts collected from stops in the first half of the dive were composed of carbonate- and fossil-bearing angular conglomerate (R3), mafic volcanic rock (R4), and diabase (R5-6).

Photo 3. Stratigraphy exposed in a debris slope at ~14:30 (5796 m). Sample R#11 and push core #1 are from the upper light colored deposit.

At ~13:05, the slope steepened to ~45-50°, and coarse debris was encountered again at 13:15. Two samples of this coarse debris are intermediate to felsic volcanic rocks (R7-8). At 13:40, the slope became shallower (~30°) and two samples of coarse debris recovered at this break in slope revealed a breccia of small, mafic pillow basalts (R9) and hyaloclastite (R10), both containing fresh glass. At ~13:50, the slope again steepened to ~45°, and at 13:56 the co-pilot noticed bright yellow/orange material off the starboard side. We stopped to investigate, and discovered what appeared to be a small hydrothermal seep (Photo 2). From a distance, we observed no shimmering water or smoky fluid emanating from the sea floor, and no obvious fluid flow was evident from the video footage, suggesting a low temperature fluid and/or a low fluid flux. The orange and yellow deposits jiggled when poked with the Shinkai basket and disseminated when we attempted to take a sample. Further scrutiny of video footage and still camera photos shows the deposits are probably a pale yellow algae colored in places with orange Fe-oxide. A scoop sample of this material recovered none of the algae, but the scooped rock clasts (basalt and diabase) are also are partly coated with bright orange Fe-oxides possibly of hydrothermal origin.

Proceeding up the slope, views from the port side revealed layered stratigraphy within the debris deposits. A sub-horizontal, dark layer of rubbly debris was clearly overlain by a light colored layer of rubbly debris (Photo 3). We stopped in the light colored deposit to collect a large clast of intermediate composition volcanic rock (R11) and to take a push core of the light colored matrix. We continued up the slope, and at 14:36 the slope shallowed to ~15° and we encountered a large (~2 m) rounded boulder with several smaller boulders lying to one side. No outcrop was visible ahead, so we stopped and collected two samples of the smaller debris alongside the boulder before beginning our ascent to the surface. These final two samples are two-pyroxene intermediate volcanics (R12-13).

Waypoints and sample stops for Dive #974 (31-Aug-2006)

Point Number	Sample Stop	Samples	Observer Record Time*	Pilot Record Time*	Latitude	Longitude	Depth (m)	X	Y
1	-	Landing Target	9:00	9:00	12° 55.2800' N	145° 19.0000' E	0	-958.6	0
2	-	Landing	11:32	11:32	12°55.2345' N	145° 18.9720' E	6270	-1042.5	-132
3	1	2 rocks (R#1-2)	11:42	11:53	12° 55.2442' N	145° 18.9215' E	6267	-1024.7	-141.9
4	2	1 scoop (#1)	12:06	12:19	12° 55.3824' N	145° 18.8912' E	6183	-769.9	-196.7
5	3	2 rocks (R#3-4)	12:32	12:42	12° 55.4550' N	145° 18.8474' E	6115	-636	-275.9
6	4	2 rocks (R#5-6)	12:54	13:00	12° 55.5241' N	145° 18.8533' E	6078	-508.6	-265.2
7	5	2 rocks (R#7-8)	13:18	13:21	12° 55.6496' N	145° 18.8721' E	6014	-277.2	-231.2
8	6	2 rocks (R#9-10)	13:43	13:47	12° 55.8506' N	145° 18.8610' E	5863	93.2	-251.3
9	7	1 scoop (#2)	13:56	14:00	12° 55.8683' N	145° 18.8536' E	5834	125.9	-264.7
10	8	1 rock (R#11), 1 core	14:09	14:22	12° 55.9027' N	145° 18.8430' E	5801	189.3	-283.9
11	9	2 rocks (R#12-13)	14:36	14:48	12° 55.9862' N	145° 18.7998' E	5757	343.2	-362

*Observer record is the starting time at a sampling stop; Pilot record is the time of departure from a sampling stop

6-2-3. Report for Dive 975, 9/01/2006: J-I. Kimura

Aim and scope of dive #975

The aim of this dive was to observe a section on the SSE-flanking slope of a ridge in the Mariana fore-arc. This ridge is located about 15 km southeast of dive #974. The dive track was intended to follow the steep slope with depth ranging from 6500 to 5800 mbsl. Anticipated rock types were serpentinized peridotites, gabbros, and tonalites based on the results of previous dredge sampling done on the down slope of this slope (>7000 mbsl.; D64 site of Fryer (2000), AGU Fall Meeting). We expected to see the MOHO transition through this dive and to collect samples to determine its lithologic structure (i.e., whether it is an ocean floor mantle section or mantle-crust section of the early arc system). The dive slope is classified into three topographic segments; (a) lower slope (7200-6100 mbsl.), (b) mid-slope bench with a tiny ridge (6100-6000 mbsl.), and (c) upper slope (6000-5800 mbsl.) with rounded ridge crest (5200 mbsl.). The dive track was initially set crossing the steepest slope SSE-NNW.

Observations

Hereafter, the description of the observation is made in the context of each topographic segment.

(a) Lower slope

The dive operation record began at 11:36 at a depth 6489 mbsl. when Shinkai 6K touched down on the bottom (Loc. #1). We set our heading almost north to 340 degrees. The seafloor was covered by talus deposits consisting of fine-grained gabbro. These deposits were blocky breccias of cobble to boulder size covered with mud at 6,489 mbsl. (Photo1: 11:40AM). Rocks were sampled from the talus breccias at depth 6489 mbsl (Loc. #2; R1-3: fine-grained gabbro to troctoritic gabbro with ±olivine, pyroxene and plagioclase). For the first 15 minutes, the blocky talus deposits were continuously exposed with various sizes of gabbro breccias and with various thickness of mud cover. We observed a gabbro outcrop with a blocky surface and randomly oriented joints at 6432 mbsl. (Photo2: 11:55AM). We collected two gabbro samples from this outcrop at 6240 mbsl. (Loc. #3; R4-5: fine-grained gabbro to diabase containing pyroxenes and plagioclase with/without olivine). This outcrop continued and was observed until 12:05AM at the depth of 6401 mbsl. Cobble to boulder size blocky talus deposits followed and sampling of two rock pieces from the talus deposits were made at a depth 6364 mbsl. (Loc. #4; R6-7: fine-grained gabbro and diabase containing plagioclase and pyroxenes with/without olivine; Photo3: 12:15PM). A gabbro outcrop possessing the same surface features as was observed for a few minutes at 6339 mbsl., followed by coarse talus deposits. The breccias in the talus deposits were blocky and continued to show the same features since the first observation. After this observation, we crossed a small valley which runs perpendicular to the slope at 12:24PM at depth 6300 mbsl. Blocky boulder size talus appeared again and a rock sample was collected from the site at 6297 mbsl. (Loc. #5; R8: troctolite to troctolitic gabbro containing olivine, pyroxenes, and plagioclas; Photo 4: 12:32PM).

At 12:35PM, the talus deposit changed from angular breccias to sub-rounded cobbles and boulders at 6288 mbsl. The color of the clasts collected from this location is reddish brown, which is different from the dark-gray color of the breccias on the lower slope. Sampling was anticipated and two altered basalt lava clasts were collected from the talus at 6236 mbsl. (Loc. #6; R9-10; extremely altered basalt to basaltic breccia containing pyroxenes and plagioclase, Photo 5: 12:41). Reddish boulder clasts were dominant in parts of this area, but breccias are dominant in other parts in the talus deposit. A gabbro outcrop with a blocky surface was sampled at 6212 mbsl. (Loc. #7; R11-13: troctolite to troctolitic gabbro containing pyroxene, olivine, and plagioclase; Photo 6: 12:50PM). The gabbro has white thin vein developed along a joint perhaps due to hydrothermal infiltration and deposition. This gabbro outcrop continued until 12:59PM at 6184 mbsl., and Shinkai flew over a valley running perpendicular to the slope.

(b) Mid-slope bench

At 13:03, we saw a basalt lava outcrop at 6152 mbsl. The surface was blocky but radial to platy joints were developed. Sampling was done from the outcrop and internal surface was light white in color suggesting highly altered feature (Loc. #8; R14-15: highly altered and veined basalt lava; Photo 7: 1:06PM). After this outcrop, the shape of talus breccias was blocky but not much angular compared with gabbro breccias on the lower slope. Two samples were collected from the talus breccias at 6103 mbsl., which were later identified as altered aphyric basalt lava (Loc. #9; R16-17: altered aphyric basalt; Photo 8: 1:20PM). An outcrop of the same basalt was observed at 13:45 at 6006 mbsl., and sampling was performed (Loc. #10; R18-19: aphyric basalt lava, Photo 9: 1:48PM). The sea bottom began to slope downward and the Shinkai followed the surface topography. One push core sample was taken from the bottom mud near the mid-slope of the valley at 6005 mbsl. (Loc. #11; Photo 10: push core (blue); Photo 10: 2:03PM). Further deepening of the valley occurred to a depth of -15m from 6003 mbsl.

(c) Upper slope

Platy slabs were found on the bottom at 6010 mbsl after the deep valley. We applied a strong manipulator grip to the slabs, which were soft and thought to be clay sediments (Photo 11: 2:14PM), and no samples were taken. At the base of the upper slope, a light colored pebbly talus deposit was observed at 5973 mbsl. A scoop sample was taken from this deposit, and its contents were found to be pebbly soft clay sediment mixed with volcanic pebble and cobbles (Loc. #12; Scoop sample: Photo 12: 2:29PM: 5973 mbsl).

A talus deposit with sub-rounded cobbles and boulders was observed. After climbing up the slope up to 5951 mbsl., three rock samples were collected from the talus deposit (Loc. #13; R20-22; one altered aphyric basalt and two volcanic conglomerate; no photo). We continued to ascend and took five additional samples at 5892 mbsl. (Loc. #14; R23-27; three aphylic basalt lavas and two volcanic conglomerate and a siltstone: Photo 13: 2:50PM). Samples collected from the upper slope were mostly altered aphyric basalt lavas with volcanic conglomerate and siltstone gravels.

Summary of dive observations

The most probable geology of the ridge is that it is a stratified Layer 2 (gabbro) and Layer 3 (basalt) of oceanic type crust. On the lower slope up to the shoulder of the mid-slope bench, fine grained gabbro outcrops were frequently observed. Based on the observation, the depth range between 6432 and 6184 mbsl is considered to be underlain by gabbro. The talus deposits in this area are blocky and coarse, supporting this assumption. No particular deformation textures were abserved, although joints that may have been produced by cooling were observed. Therefore, the thickness of the gabbro layer is more than 238 m. Aphyric basalt lavas in various states of alteration occur from 6152 mbsl. This layer continues up to 6006 mbsl where it was observed in outcrop. The depth range correlates almost exactly with the depth of the mid-slope bench. This basalt layer may continue up to the top of the ridge through upper slope, because four out of eight talus gravel clasts from the upper slope at 5951 and 5892 mbsl were aphyric basalt with or without alteration. If so, then the total thickness of the basalt lava layer is > 380 m. Judging from aphyric texture and blocky jointing, the basalt lavas may be sheet flows or shallow quenched dikes. Hydrothermal alteration assemblages are common and suggest that the lavas were emplaced underwater. All the features above strongly suggest that the Layer 2 – Layer 3 section of the oceanic crust is exposed along the dive #975 track.

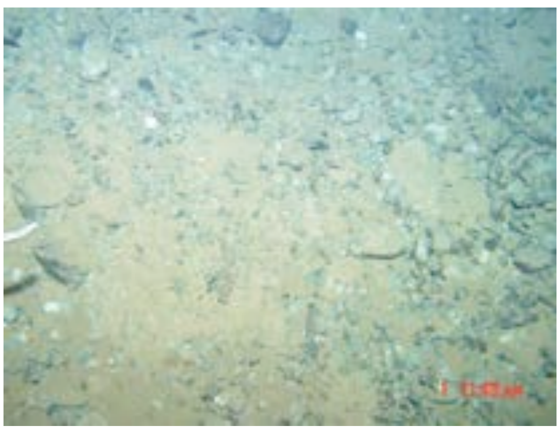


Photo 1. Talus deposit with blocky cobble to boulder breccias (R1-3 site: gabbros).

Photo 2. Gabbro outcrop with randomly oriented joints (R4-5 site: gabbros).

Photo 3. Blocky talus deposit (R6-7 site: gabbros).

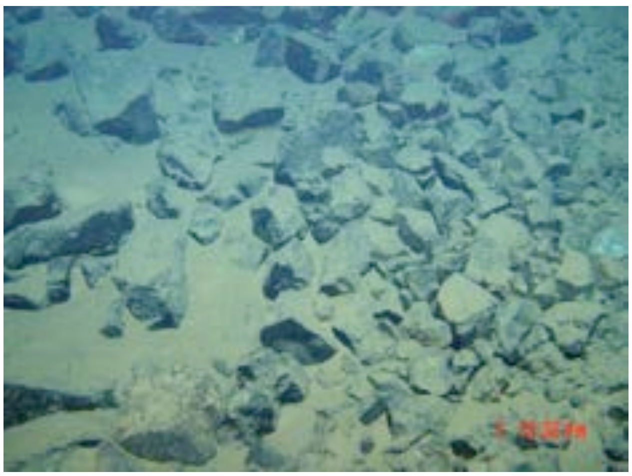


Photo 4. Blocky talus deposit (R8 site: gabbros).

Photo 5. Talus deposit with sub-rounded to angular blocks (R9-10 site: altered basalts).

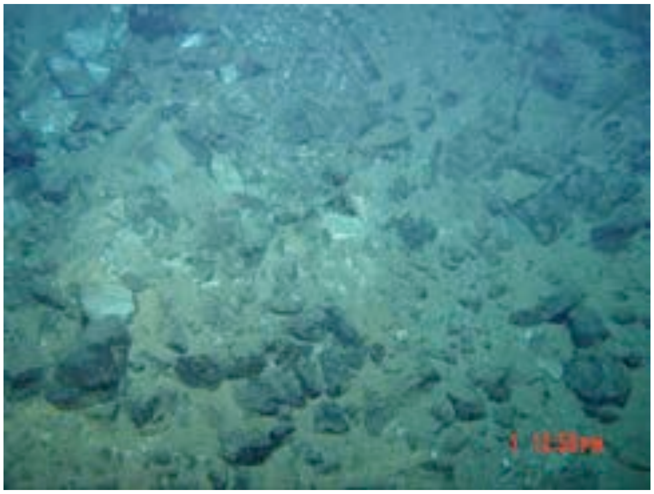


Photo 6. Outcrop with randomly oriented joints (R11-13 site: gabbro with thin vein).

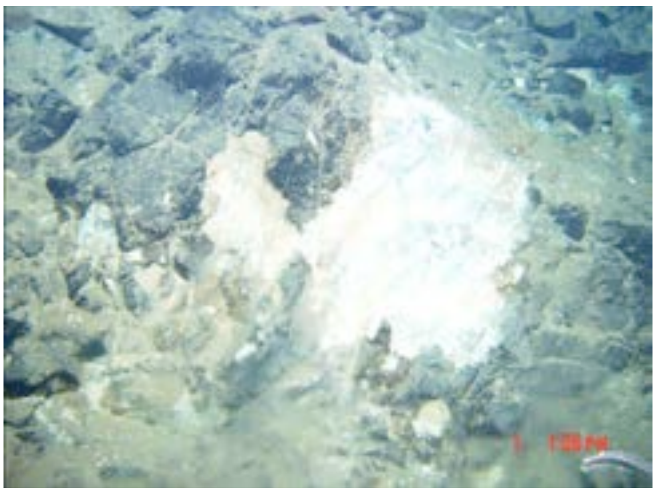


Photo 7. Outcrop with platy jointing (R14-15: highly altered basalts).

Photo 8. Talus deposit of altered basalt (R16-17: altered aphyric basalt).

Photo 9. Outcrop of altered aphyric basalt lava (R18-19: altered aphyric basalt).

Photo 10. Push core sampling near the bottom of a valley.

Photo 11. Platy clay sediment slab in talus deposit.

Photo 12. Pebbly talus containing rock fragments and clay pebbles.

Photo 13. Sub-rounded gravel in talus (R20-27: altered aphyric basalt, aphyric basalt, conglomerate, and siltstone).

Waypoints and sample stops for Dive #975 (1-Sep-2006)

Point Number	Sample Stop	Samples	Observer Record Time*	Pilot Record Time*	Latitude	Longitude	Depth (m)	X	Y
1		Landing Target		9:00:00	12° 47.1400' N	145°28.9500' E	0	-1032.4	452.3
2	1	3 rocks	N/A	11:38:00	12°47.1764' N	145°28.9189' E	6489	-965.3	396
3	2	2 rocks	N/A	12:03:00	12°47.2328' N	145°28.9071' E	6420	-861.3	374.7
4	3	2 rocks	N/A	12:16:00	12°47.3037' N	145°28.8993' E	6364	-730.6	360.5
5	4	1 rock	N/A	12:31:00	12°47.3738' N	145°28.8765' E	6297	-601.3	319.3
6	5	2 rocks	N/A	12:44:00	12°47.4237' N	145°28.8802' E	6236	-509.3	326
7	6	3 rocks	N/A	12:55:00	12°47.4505' N	145°28.8699' E	6212	-459.9	307.4
8	7	2 rocks	N/A	13:07:00	12°47.4910' N	145°28.8735' E	6153	-385.3	313.9
9	8	2 rocks	N/A	13:25:00	12°47.5597' N	145°28.8721' E	6103	-258.6	311.3
10	9	2 rocks	N/A	13:52:00	12°47.7673' N	145°28.7895' E	6005	124	161.9
11	10	1 core	N/A	14:04:00	12°47.8432' N	145°28.7674' E	6005	264	121.9
12	11	1 scoop	N/A	14:32:00	12°48.0529' N	145°28.7232' E	5973	650.6	41.9
13	12	3 rocks	N/A	14:39:00	12°48.0833' N	145°28.7181' E	5951	706.6	32.7
14	13	5 rocks	N/A	14:57:00	12°48.1224' N	145°28.7107' E	5892	778.7	19.3

*Observer record is the starting time at a sampling stop; Pilot record is the time of departure from a sampling stop

Video log for Dive 975 checked by J.-I. Kimura (see also for Appendix A).

Local time	Depth	Heading (deg.)	Note	Remarks
11:36:25	6489	6	On bottom, subangular breccia talus covered by mud	
11:42:22	6487	11	Rock sampling from blocky breccia in talus deposit (sp#1)	
11:45:35	6483	34	Rock sampling from blocky breccia in talus deposit (sp#2)	
11:48:12	6489	15	Rock sampling from blocky breccia in talus deposit (sp#3)	XY=-970,410
11:50:00	6474		Moving over talus (?) slope	
11:53:10	6455	340	Blocky talus deposit covered with mud	
11:55:22	6432	344	Outcrop jointed blocky rock surface	
11:59:52	6424	49	Rock sampling from outcrop (sp#4), cooling joint	
12:02:44	6420	11	Rock sampling from outcrop (sp#5), cooling joint	XY=-860, 370
12:07:35	6401	345	Outcrop blocky rock surface with randomly oriented cooling joint	
12:09:00	6379		Talus	
12:10:15	6373	346	Large blocky talus deposit covered with mud	
12:14:36	6366	23	Rock sampling from talus (sp#6)	
12:15:55	6364	23	Rock sampling from talus (sp#7)	XY=-731, 361
12:18:00	6360		Talus slope	
12:20:17	6339	345	Outcrop jointed blocky rock surface	
12:22:59	6319	345	Valley, 8m depth	
12:24:10	6300	346	Blocky talus deposit no mud cover	
12:30:10	6297	63	Rock sampling from talus deposit (sp#8)	XY=-601, 319
12:35:14	6288	359	Talus deposit with sub-rounded boulder to cobble covered with mud	
12:40:00	6236		Debris flow with matrix	
12:42:00	6236		Rock sampling from talus deposit with reddish sub-rounded gravels (sp#9)	
12:44:13	6236	327	Rock sampling from talus deposit with reddish sub-rounded gravels (sp#10)	XY=-509, 326
12:46:55	6221	352	Talus deposit with sub-angular to sub-rounded boulder to cobble covered with mud	
12:52:00	6212	11	Rock sampling from outcrop, blocky jointed (sp#11)	
12:53:00	6212	11	Rock sampling from outcrop, blocky jointed (sp#12)	
12:55:01	6212	11	Rock sampling from outcrop, blocky jointed (sp#13)	XY=-460, 307
12:57:00	6199		Moving over talus and outcrop	
12:57:27	6203	351	Blocky jointed outcrop	
12:59:01	6184	1	Blocky jointed outcrop	
13:01:53	6151	13	Valley	
13:03:39	6152	9	Outcrop with radial joint, internal surface color is white	
13:05:00	6153	4	Rock sampling from outcrop (sp#14)	
13:07:00	6153	4	Rock sampling from outcrop (sp#15)	XY=-385, 314
13:13:08	6137	359	Cobble-pebbly mud flat	
13:16:45	6111	0	Talus deposit with sub-rounded boulder to cobble covered with mud	
13:19:00	6103	308	Rock sampling from talus deposit (sp#16)	
13:25:00	6103	308	Rock sampling from talus deposit (sp#17)	XY=-259, 311

13:30:06	6079	340	Talus deposit with sub-rounded boulder to cobble covered with sandy mud	
13:33:59	6057	340	Valley	
13:34:38	6054	340	Valley	
13:35:00	6053		Almost 100% sediment; light color and slight undulations across slope	
13:36:00	6049		~50% pebbles to boulders	
13:37:00	6042		Large boulders scattered in ~70% sediment	
13:38:07	6036	340	Valley, mud flat	
13:40:16	6025	341	Slabby outcrop inclining toward downslope	
13:40:50	6024		Large outcrop of subangular blocks; lightly sedimented	
13:42:30	6021		Stopped to sample at field of boulders on steep slope (south of a prominent feature appears on the bathymetry)	
13:45:23	6006	311	Outcrop, reddish blocky surface	
13:46:00	6005	301	Rock sampling from outcrop (sp#18)	
13:52:00	6005	301	Rock sampling from outcrop (sp#19), muddy matrix?	XY=124, 162
13:54:18	5998	350	Outcrop? Slabs on surface	
13:57:07	5991	350	Pebble to cobble covered with mud	
13:57:41	5990	350	Big rock block, talus breccia?	
13:59:27	5992	348	Downslope	XY=210, 140
14:03:25	6005	432	Push core sampling (blue)	XY=262, 122
14:08:46	6003	350	Valley (15m deep)	
14:15:37	6010	351	Platy rounded slab blocks (younger sediment?)	
14:20:14	6006	310	Try grabbing platy slab and see soft, give up sampling	
14:32:00	5973	312	Scoop sampling of pebbles	XY=651, 42
14:36:00	5951	342	Rock sampling from talus gravel (sp#20)	
14:38:00	5951	342	Rock sampling from talus gravel (sp#21)	
14:39:00	5951	342	Rock sampling from talus gravel (sp#22)	XY=707, 33
14:45:57	5890	348	Land on talus grabel floor for sampling	
14:45:00	5892	348	Rock sampling from talus grabel (sp#23)	
14:48:00	5892	348	Rock sampling from talus grabel (sp#24)	
14:49:00	5892	348	Rock sampling from talus grabel (sp#25)	
14:50:00	5892	348	Rock sampling from talus grabel (sp#26)	
14:57:00	5892	348	Rock sampling from talus grabel (sp#27), ascend to surface	XY=779, 19

6-2-4. Report for dive 976, 09/02/06: J. W. Hawkins

Objectives and introduction for Dive 976

A major objective for Dive 976 was to continue the vertical sampling and surveying of the geology of the trench slope southeast of Guam from ~ 3850 to 3000 meters depth. The dive track followed the trend of three broadly conical, partly coalesced features roughly aligned on a NW – SE trend across the higher levels of the forearc. Dive operations began at 11:40:00 when Shinkai 6500 touched bottom at 13°2.0952'N, 145°20.5585'E in water depth of 3802 m. Here we took the first samples 976 R-1 and R-2. These are cobbles of microgabbro / diabase.

We set a northerly course that would take us to the top of the southernmost of the three conical features. At 11:57, depth of 3722 m, we traversed above a field of very large (up to ~ 3 meters) subrounded boulders interspersed with numerous smaller boulders and cobbles. These could not be sampled. At 12:05:00, depth 3699 m, we collected R-3, a polymict conglomerate, and R-4, a Mn-crusted block of layered sandstone and siltstone. Image 383 taken at 12:00 shows the nature of the bottom near here.

We continued up slope to 3687 m depth stopping at 12:16:00 to sample prominent layered rocks. These, R-5 and R-6, are Mn crusted alternating layers of sandstone and siltstone similar to R-4. Photo 1 below shows typical seafloor of this area.

Photo 1. Bottom near Site R-3, R-4 (Still photo #383).

Rocks R-7 and R-8, both are well sorted lithic - feldspathic sandstones with clasts of volcanic rock, were collected at 12:32:00 in depths of 3615 m. Rock R-9, collected at 12:52:00, depth 3501 m, is a polymict conglomerate with subrounded clasts of "diorite" and vesicular basalt. Here we changed course to run NW toward the top of the second conical feature. At 13:30:00, depth of 3466 m, we collected R-10 a mottled pink and tan claystone and R-11, a soft, mottled, soft, carbonate rock in which fossil remains (coral ?) are preserved.

We continued up slope to 3320 m depth where, at 13:55:00, we collected R-12, a purple gray andesite and R-13, a purple black andesite. Neither is porphyritic. Continuing on course, we sampled R-14 andesite at 14:07:00, depth 3278 m. Single push core attempt at that point was not successful. R-15, a fine grained, purplish, plagioclase -rich andesite was collected at14:19:00, depth of 3220 m. Another andesite R-16, collected at 3162 m depth, 14:33:00, is similar to R-15. Near the top of this conical feature, 3110 m depth, we collected R-17 and R-18 at 14:49:00. Both rocks are micro-gabbro / diabase. Rock R-19, a similar micro-gabbro / diabase, was collected in depth of 3086 m at 15:05:00. The platy surface near site R-19 is shown in Photo 2.

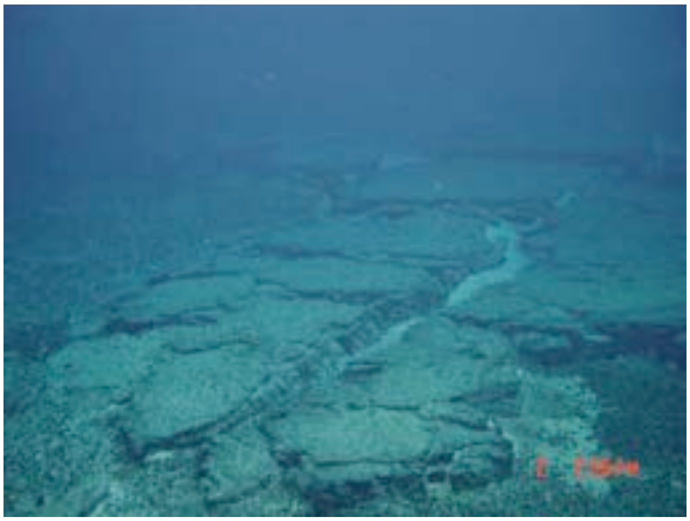


Photo 2. Bottom near site R-19 (Still photo #577 taken at 14:56).

The final set of samples, R-20, 21, 22, all are siltstones, were collected in depth of 3079 m. at about 15:50. Here the dive ended at 15:52:00 and Shinkai left bottom. Photo 3 shows the bottom here.

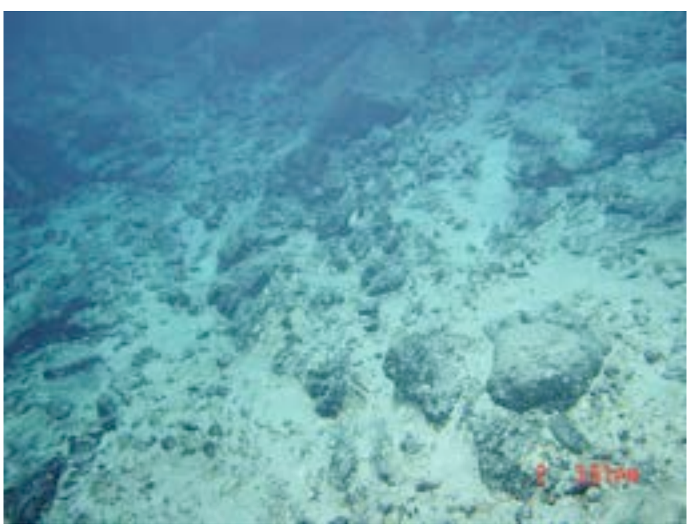


Photo 3. Bottom at end of dive traverse (Still photo #637 taken at 15:51).

A Summary of major observations

Igneous rocks recovered on the traverse comprise fine-grained, micro-gabbro and diabase as well as more evolved, broadly andesitic composition rocks. Volcaniclastic rocks with varied textures and grain size from conglomerate to claystone also were recovered. Mn oxide – hydroxide crusts are on all samples with thickest crusts (cm sized) being on the sediments

The slopes at Dive #976 are mainly covered by a sediment veneer having clasts ranging in size from gravel to sand to silt size. The gravel – covered slopes appear to be separated by barren areas in which boulders of varied size are dominant. Gravel "channels" may be separated by long "channels" of finer grained material. In many areas a fine covering of probable silt and clay sized material partly buries the coarser material. It seems likely that the surface sediment cover is a dynamic feature that changes sediment size distribution frequently.

Rounded to subrounded boulders, some of them several meters in size, are common and in some places the surface cover was nearly total with interstices between large boulders filled with smaller boulders and cobbles. These boulder fields gave way to finer sediments on all sides and seemed to form isolated domains.

An inference is that the original basement, some of which is igneous rocks and some of it Mn-crusted sedimentary rocks derived from volcanic material, is episodically blanketed by debris flows. These may remobilize and mix with older debris flows

The general appearance of the seafloor on the dive track is reminiscent of the surface of alluvial fans on the margins of fault bounded extensional basins of the southern California deserts. The seafloor at the dive site is veneered with a carpet of gravel, sand and fines silts analogous to those deposited and reworked by flash floods in desert areas

Rock types: petrologic summary

All of the igneous rocks are from cobbles. A few apparent outcrops suggested that they were igneous but we could not sample them. Those cobbles that we collected all are plagioclase-rich (PL), with lesser amounts of clinopyroxene (CPX). Some samples may have hornblende (HBL). Olivine replaced by iddingsite was found in only one sample. Quartz was not found but may be present in trace amounts.

The small grain size in igneous rocks, typically less than 2 mm - rarely 3mm, suggests rapid cooling of the melts. A lack of vesicles implies low volatile content. Although these lack apparent quench textures, the fine grain size, and lack of phenocrysts, suggests that the rocks probably represent liquid compositions and have a chemical composition close to the original parental melt even though not necessarily a true mantle – derived parent melt.

The assemblage of sedimentary rocks and their abundances along the dive track, suggests that there was relatively long-lived erosion of a volcanic arc in which quartz was not abundant or, indeed, absent. The source rocks were dominated by plagioclase rather than mafic minerals e.g., an intermediate composition or "andesitic arc. An alternative explanation could be that the general low abundance of mafic minerals is owing to extreme weathering of the source area

Hand sample petrographic descriptions

Igneous rocks

All of the igneous rocks are PL-rich, they lack vesicles or phenocrysts. All are generally fine to medium grained (1-3 mm). The least evolved (i.e., most mafic) sample probably is 976 R-17 collected at 3110 m depth atop the northwestern most of the three presumed conical volcanic edifices. It is holocrystalline (holoxlln) has very fine to fine grain size , ~ 1 – 2 mm grains, non-porphyritic, in which there is up to 10 – 15% iddinsgsite (derived from alteration of olivine). The rock is mainly PL with lesser amounts of CPX.

976 R-18, from the same site has similar texture but lacks the iddingsite.

976 R-19, depth 3079 m, is PL-rich with CPX and has fine grained texture.

All three of these "mineralogically least evolved" rocks are from near the summit of the NW-most of the line of three conical features presumed to represent volcanic centers.

More "evolved" rocks are broadly "andesitic". They are represented by PL-rich samples having relatively lesser amounts of mafic minerals than the first group. Generally they are slightly purple or gray in color.

976 R-1 and R-2, collected at the landing site, 3802 m depth, have fine grained texture ~ 1 - 2 mm, are holoxlln, non-porphyrytic, and comprise mainly PL and CPX PL > CPX. These may be found to be chemically similar to the summit samples.

976 R-14, 3220 m depth, is gray, holoxlln, PL-rich, fine grained, having about 10-15% CPX or HBL.

976 R-15, 3162 m depth, is gray, holoxlln, fine grained, PL-rich, mafic mineral may be HBL.

976 R 16, 3110 m depth, is similar to R-15. NOTE this sample is from the same location as 976 R-17.

976 R-13, 3278 m depth, fine grained purple – black, holoxlln, non porphyritic, PL-rich with HBL.

Sedimentary rocks

The sedimentary rocks range widely in clast size from coarse gravel (cm size) to claystone. The mineralogy and clast compositions indicate derivation from an arc provenance. Rocks are almost all volcaniclastics with rare carbonate material (rock 976 R-11). Nearly all of the sedimentary rocks have a rind of Mn oxide hydroxide on the order of a cm thick.

Mineralogically, the volcaniclastic rocks are mainly PL with much less (e.g., 5%) mafic minerals – (HBL or CPX). Quartz seems not to be present.

Some typical examples are:

976 R-8 depth 3500 m, medium grained feldspathic sandstone.

976 R-3 depth 3699 m, Polymict conglomerate with cm - sized clasts of angular to sub-rounded diorite or basalt. These are set in a matrix of well –sorted subangular medium grained PL and minor CPX or HBL.

976 R-6 depth 3615 m and R-5 depth 3687 m, are mainly buff tan to gray siltstones in which cm thick layers of silt are interbedded with fine to medium grained sandstone.

976 R-20 depth 3079 m, is a typical siltstone in which a crude layering also has mottled patches of gray and tan fine grained material (burrows ?)

976 R -19 depth 3079 m, has a gray – tan claystone layer interbedded with siltstone. The claystones are mainly found as parts of layered samples in which there are cm scale layers of interbedded sandstone, siltstone and claystone.

One unusual sample is 976 R-11 depth 3320 m, which appears to be a claystone or carbonate rock with fossil coralline material.

Waypoints and sample stops for Dive #975 (1-Sep-2006)

Point Number	Sample Stop	Samples	Observer Record Time*	Pilot Record Time*	Latitude	Longitude	Depth (m)	X	Y
1		Landing Target			13° 2.0900' N	145° 20.5200' E	0	-1309	759.1
2	1	2 rocks (R1-2)	11:40	11:40	13° 2.0952' N	145° 20.5585' E	3802	-1299.4	828.7
3	2	2 rocks (R3-4)	12:01	12:05	13° 2.2312' N	145° 20.5518' E	3699	-1048.6	816.6
4	3	2 rocks (R5-6)	12:14	12:16	13° 2.2435' N	145° 20.5393' E	3687	-1026	794
5	4	2 rocks (R7-8)	12:28	12:32	13° 2.3766' N	145° 20.5474' E	3615	-780.6	808.6
6	5	1 rock (R9)	12:46	12:52	13° 2.5465' N	145° 20.5503' E	3501	-467.3	813.9
7	6	2 rocks (R10-11)	13:26	13:30	13° 2.9833' N	145° 20.3541' E	3466	337.9	459.2
8	7	2 rocks (R12-13)	13:53	13:55	13° 3.0896' N	145° 20.1697' E	3320	533.9	125.9
9	8	1 rock (R14)	14:05	14:07	13° 3.1244' N	145° 20.1417' E	3278	598	75.3
10	9	1 rock (R15)	14:17	14:19	13° 3.1547' N	145° 20.1026' E	3220	653.9	4.6
11	10	1 rock (R16)	14:28	14:33	13° 3.1894' N	145° 20.0598' E	3162	717.9	-72.6
12	11	2 rocks (R17-18)	14:46	14:49	13° 3.2393' N	145° 19.9506' E	3110	809.9	-270
13	12	1 rock (R19)	14:57	15:05	13° 3.2712' N	145° 19.9506' E	3086	868.7	-351.3
14	13	3 rocks (R20-22)	15:44	15:52	13° 3.7499' N	145° 19.4416' E	3079	1751.3	-1190

*Observer record is the starting time at a sampling stop; Pilot record is the time of departure from a sampling stop

6-2-5. Report for dive 977, 9/3/2006: R. Stern

This was the easternmost of the five YK06-12 dives. The dive site was chosen to be just north of where the broad part of the Mariana forearc to the north is terminated by the major E-W structure dived on during dive 974 and 976. The dive site was also chosen to lie south of where debris from South Chamorro serpentine seamount covers the inner trench wall. There are no previous samplings in the vicinity that we are aware of, so we had no inkling of what lithologies to expect. Bathymetric and backscatter maps were consulted to identify a steep region where bare rock exposures were likely to be examined. A plan was developed to sample from 6400-6000 m, then fly west to sample 5900-5500 m, in the hopes of seeing as much of the crustal section as possible. Because of the excellent Shinkai pilot and co-pilot (Matsumoto-san and Sura-san), the plan was accomplished. We spent a total of 3.5 hours on the bottom and occupied 11 separate stations. Stations 1-5 were taken at approximately 100m steps on a 800 m-long N-S transect and stations 6-11 were similarly taken at approximately 100 m.

Most of the rocks were taken from talus-covered slopes, especially for the first 5 stations, but the observer's impression is that these did not travel far. Shipboard petrographic examination indicates that 19 of the 26 samples are diabase, 2 or 3 are basalt, 4 are clastic sediments, and one (the scoop sample) is pelagic calcareous sediment. The diabase is rich in plagioclase and only diabases collected from the first 3 stations (> 6200 m) contain much olivine; other diabases consist of plagioclase and pyroxene. The first transect sampled almost entirely diabase, with only one sample of weathered volcanic sandstone recovered at station 5 (5994 m), the shallowest station on this transect. Similar volcanic sandstone was recovered at station 7 (5901 m) and claystone at station 8 (5799 m), along with basalt; basalt was also recovered from station 10 (5600 m). Basalts are rich in plagioclase and pyroxene and poor in olivine. No systematic variation in grain size was seen in the diabases. All samples except for the scoop have thin (1mm or less) Mn encrustation. We suspect that the diabase-dominated section observed and sampled below 5525 m depth are Eocene in age. Typical talus-covered outcrops from the lower transect are shown in Photos 1 and 2 below.

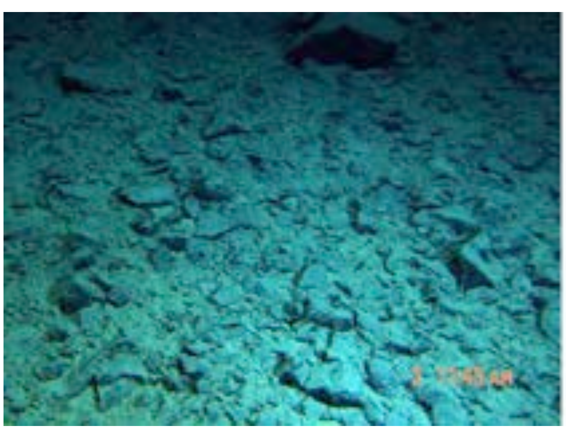
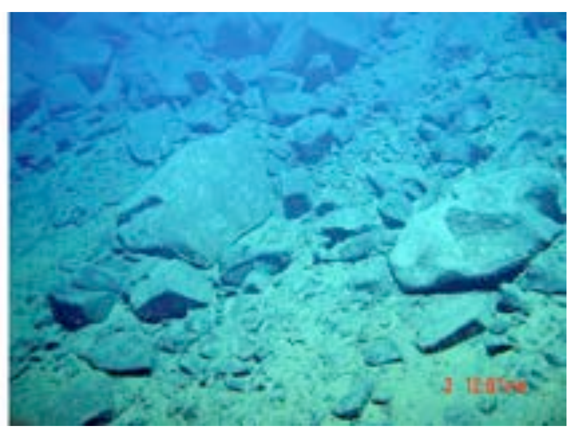
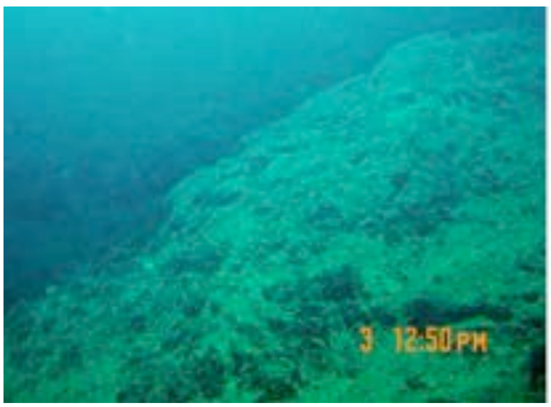



Photo 1 (left): Diabase talus near landing of Shinkai at 6363m depth and collection site of 977R1 and R2. Photo 2 (right): Talus slope of boulders-to-gravel sized diabasic talus at 6296m and collection site of 977R3 and R4.

The inner trench wall that was traversed is effectively at the angle of repose for coarse talus and broken outcrop. This angle is probably maintained by combined interaction of subduction erosion, which continuously removes material from the base of the inner trench slope, and earthquakes, which fracture outcrops and dislodge rocks. Clearly tectonic erosion is required to expose the ~900 m thick section of diabases sampled during this dive, although the upper volcanic section must also have been removed by erosion prior to deposition of the white sediments observed briefly to lie above 5525m. This interpretation is supported by the fact that samples collected had relatively thin Mn coating, implying relatively recent exposure to on the ocean bottom, although all samples show a significant degree of low-temperature seafloor "brownstone" weathering. The slopes traversed during this dive average ~30°, much greater than the ~3-8° average slopes for the inner trench walls of erosional margins inferred by Clift and Vannucchi (2004). Typical slope profiles are shown in Photos 3 and 4 below.



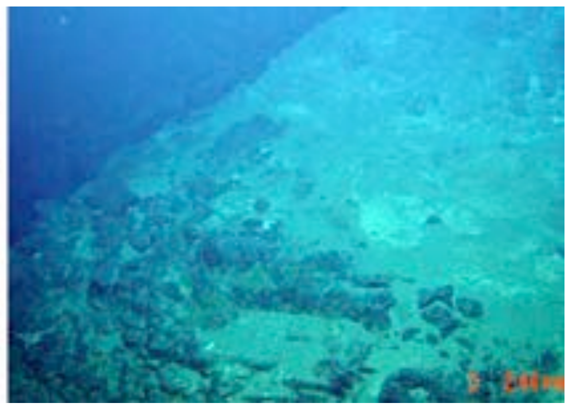


Photo 3 (left): Slope profile of exposed diabase at 6000 m depth, near sampling site for R977 9-12. Note ~30° slope. Photo 4 (right) Slope profile at 5525 m depth. This also shows the nearly horizontal contact between underlying diabases and overlying layered sediments. Scoop sample 1 was collected from the white sediments above this contact.

The second, shallower part of the transect revealed several exposures and steeply-dipping nearly vertical dikes were observed in a few places. This is consistent with petrographic observations that all but 3 of 23 hard rock samples collected with the Shinkai manipulator from 10 sampling sites are diabasic igneous rocks. The three remaining samples are volcaniclastic sediments (from sampling sites 7 and 8). Photos 5 and 6 below show typical exposures of dikes observed during the second, shallower transect.

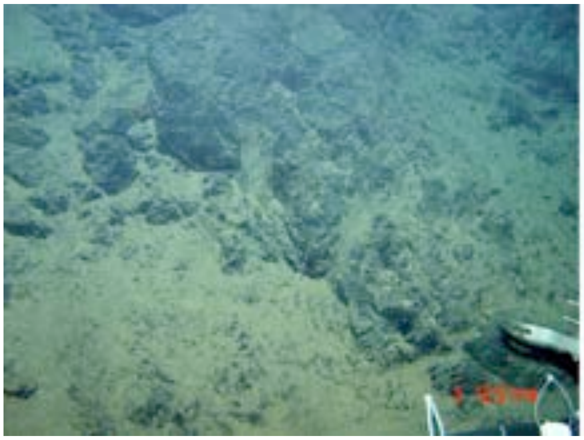
 

Photo 5 (left): Thin diabasic dikes (center) dipping steeply to right (~east) exposed at 6000 m depth, near where R977 9-12 were collected. Photo 6 (right): Fractured dikes, dipping steeply left (~west), exposed at 5844 m, just below where samples R977 18-20 were collected.

A distinctive, nearly horizontal contact was observed between the underlying diabasic section and overlying, poorly consolidated sediments (Photo 4). This was observed at the very end of the dive and we did not have adequate time to investigate the overlying sedimentary section before returning to the surface. We did have time to take a few photographs of this well-layered unit (Photo 7) and to take a scoop sample (Scoop sample 1; Photo 8). Preliminary examination indicates that this sediment is rich in foraminifera and this should give us a chance to determine its biostratigraphic age.

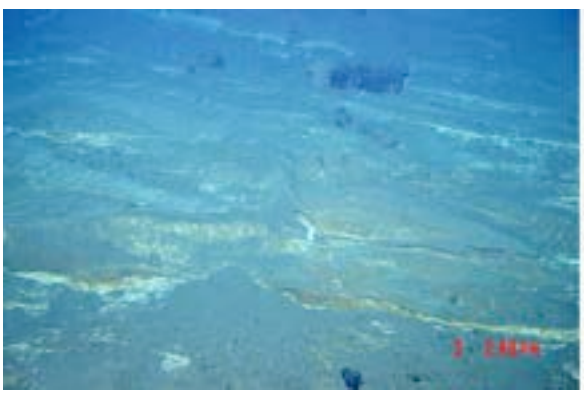
 

Photo 7 (left): Layered sediments at 5484 m depth. Note thicker buff-colored zones separated by thin white layers. Photo 8 (right): Layered sediments at 5482 m depth. Exposures produced by scoop sampler reveals that buff coloration is surficial and that the interior of the sediment is white.

In summary, Shinkai Dive 977 traversed a ~900 m thick section of fractured diabase outcrops with minor associated volcaniclastic sediments, and steep talus slopes composed of material shed from shallower outcrops. An important unconformity lies at ~5525 m, separating the diabases below from overlying, poorly consolidated sediments. This unconformity suggests uplift and erosion to remove overlying basalts, followed by subsidence to almost 5.5 km below sealevel, possibly as a result of tectonic erosion.

Waypoints and sample stops for Dive #977 (3-Sep-2006)

Point Number	Sample Stop	Samples	Observer Record Time*	Pilot Record Time*	Latitude	Longitude	Depth (m)	X	Y
1	-	Landing Target	9:00	9:00	13° 16.5500' N	145° 56.7200' E	0	-829.6	758.4
2	-	Landing	11:37	11:39	13°16.4609' N	145° 56.7032' E	6363	-993.9	728
3	1	2 rocks (R#1-2)	11:42	11:39	13° 16.4609' N	145° 56.7032' E	6363	-993.9	728
4	2	2 rocks (R#3-4)	12:04	12:06	13° 16.5918' N	145° 56.6943' E	6297	-752.5	712
5	3	2 rocks (R#5-6)	12:20	12:23	13° 16.6843' N	145° 56.6958' E	6206	-582	714.7
6	4	2 rocks (R#7-8)	12:35	12:37	13° 16.7892 N	145° 56.7076' E	6106	-388.6	736
7	5	4 rocks (R#9-12)	12:53	12:58	13° 16.8868’ N	145° 56.6825' E	5994	-208.7	690.7
8	6	2 rocks (R#13-14)	13:16	13:21	13° 16.9107' N	145° 56.3170' E	6005	-164.6	30.6
9	7	3 rocks (R#15-17)	13:35	13:41	13° 17.0163' N	145° 56.2823' E	5901	30	-31.9
10	8	3 rocks (R#18-20)	13:51	13:57	13° 17.1023' N	145° 56.2439' E	5799	188.6	-101.3
11	9	3 rocks (R#21-23)	14:17	14:19	13° 17.1833' N	145° 56.2099' E	5688	337.9	-162
12	10	3 rocks (R#24-26)	14:27	14:32	13°17.2462' N	145°56.1612' E	5600	453.9	-250
13	11	1 scoop (#1)	14:55	15:03	13°17.2571' N	145°56.0253' E	5483	474	-496

*Observer record is the starting time at a sampling stop; Pilot record is the time of departure from a sampling stopp

55

6-2-6. Synthesis of the dive results

As a tentative synthesis, based on the present dive results and the previous works, we just like to note that the depth of the Moho (herein lithologically defined as the top of mantle peridotite) in this part of the Mariana forearc declines to the east. See the schematic cartoon drawn by Robert Stern (Fig. 5).

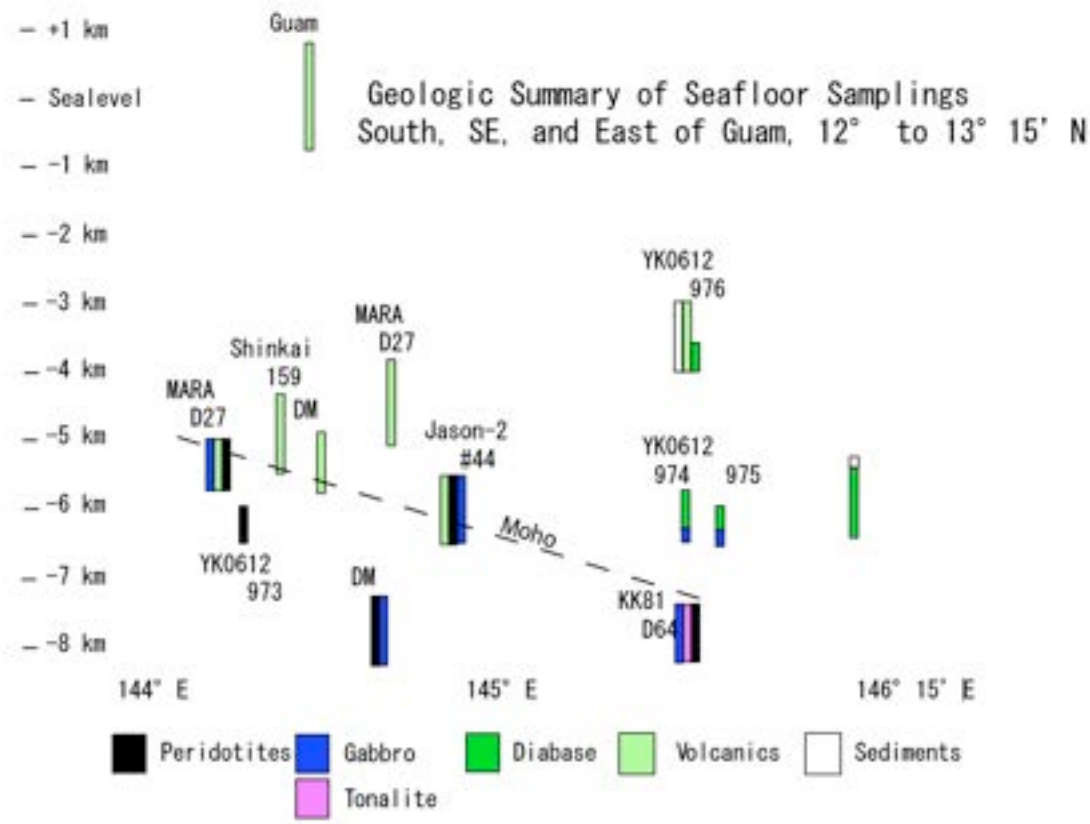


Fig. 5. Geologic summary of seafloor samplings in the southern Mariana forearc drawn by Robert Stern.

6-3. Sample descriptive notes

Every rock sample was described as hand sample onboard. These descriptions are presented as tables shown below.

Dive #973	Described by SHB, OI and KM	
Sample #	**Lithology**	**Descriptive Notes**
R1	Serpentinized harzburgite	Serpentinized harzburgite, moderately sheared, 5-15% OPX?, it's hard to ID. Probably 30-40% serpentine. Porphyroclasts of OPX in finer-grained matrix of serpentine and olivine; minor spinel.
R2	Serpentinized dunite	Serpentinized dunite, <5% PX, minor spinel. Grades from moderately sheared to proto-mylonitic on one end; thick serpentine veins on each side.
R3	Serpentinized harzburgite	Very large serpentinized harzburgite block, moderately or weakly sheared, 60% serpentinized. Large, elongate block with smooth black surface. Sandy crust on one corner suggests this is a block from a debris flow. Small round to elongate porphyroclasts of OPX in a sheared matrix of finer grained serpentinized OL. Likely minor spinel.
R4	Serpentinized dunite	Intensely sheared serpentinized dunite; probably mylonite; elongate porphyroclasts (aspect ratio: up to three), serpentine veins, minor pyroxene spinel. This sample is similar to R2, but more inhomogeneous.
R5	Serpentinized dunite	Moderately sheared serpentinized dunite or harzburgite; porphyroclastic minor spinel. PX porphyroclasts are pretty elongated and their aspect ratios are up to three. Some interstitial white spots, probably formerly gabbroic veins or interstitial melt, now altered to prehnite and other calcic assemblages.
R6	Serpentinized harzburgite	Serpentinized harzburgite, weakly sheared, 50-70% serpentinized. Angular block, smooth grey brown surfaces with some serpentine. Lenses of round to slightly elongate OPX in finer grained matrix of OL and serpentine. Foliation is not well defined. Maybe, it was cut obliquely with respect to its structure.
R7	Serpentinized harzburgite	Serpentinized harzburgite to dunite, highly or moderately deformed. Elongate lenses of OPX (aspect ratio: up to three) in finer grained OL-serpentine matrix. Foliation is well defined by alignments of elongated pyroxene grains. Minor spinel with no structure; anastamosing serpentine veining, 30% serpentine.
R8	Serpentinized dunite	Serpentinized dunite?; minor OPX, spinel. Moderately or weakly sheared. Extensive serpentine veining. OPX porphyroclasts (40%) show round to slightly elongate shapes in finer olivine matrix. 20-30% serpentine. Foliation is not
R9	Serpentinized dunite	Orange grey, serpentinized dunite. Very fine grained, possibly mylonitic. Appears to be recrystallized fine-grained olivine. The core is dark grey, probably fresh. Half the sample is orange hued, probably extensively serpentinized. Abundant spinel.
R10	Serpentinized harzburgite	Serpentinized harzburgite? Elongate to subrounded pophyroclasts in matrix of serpentine and finer-grained olivine. Thin (<1mm) irregular veins of prehnite (altered gabbroic material?) Moderately sheared. It was supposed to be cut parallel to a lineation, but foliation is not clearly defined.
R11	Serpentinized harzburgite	Serpentinized harzburgite, OPX porphyloclast in finer grained serpentine/olivine matrix. Spots of interstitial prehnite (altered gabbroic material?), some spinel.
R12	Serpentinized harzburgite	Serpentinized harzburgite with 2 cm wide zone of diffuze prehnite/gabbroic veining. Shearing not obvious in this cut. Maybe, this represents a structure in the deeper level. Most highly serpentinized sample.
Scoop 1	Various plutonic gravels	Scoop sample of gravel to coarse sand sized material. Most common type is ultramafic, but also gabbro, breccia, sediment, and perhaps altered volcanics. Maybe some small more leucocratic pieces.
Push Core 1	Sediment and water	

Dive #974	Described by SHB and OI	
Sample #	**Lithology**	**Descriptive Notes**
R1	Dacite	Finely phyric dacite; microphenocrysts of PL, HB, CPX, <2mm; 1 rounded xenocryst about 5 mm, possibly of altered OL; cut surface has a pink cast.
R2	HB gabbro	Medium-grained HB gabbro, possibly some OPX; equigranular, HB needles to 4 mm, no preferred fabric.
R3	Coarse sandstone to conglomerate	Poorly sorted lithic conglomerate to very coarse sandstone, coarse sand to pebble-sized pieces, many somewhat rounded. Some size layering with a thick (3 cm) layer of Mn-coated sand on one side. Clasts of silicic and mafic volcanics, silicic and mafic plutonics, carbonate fragments some with fossils (a few of these were picked out and bagged; most carbonate pieces are recrystallized). Matrix of Mn grains, altered PL., other materials.
R4	OL-PX phyric volcanic	OL-PX phyric basalt, could be boninitic. Black clayey clots seem in places to pseudomorph OL, no primary OL remains. 4 cm weathering rind on one side gives PX a whitish look, but there is probably not any PLAG. 15% phyric, quite mafic, fine grained ground mass.
R5	OL-PX phyric diabase	Densely phyric (15-20%) diabase; altered OL phenocrysts to 2-3mm, PX phenocrysts. Groundmass is microcrystalline needle-like intergrowths of PL and PX. No obvious PL phenocrysts. Similar to R4 but with coarser groundmass.
R6	OL-PX phyric diabase	very much like R5; densely phyric with diabasic groundmass of acicular, needle-like intergrowths; no PL phenocrysts.
R7	Andesite to dacite	Half-buried dense (non vesiculated) dacite block.
R8	Dacite to rhyolite	Half-buried, well-rounded dacite block
R9	Pillow breccia	Pillow breccia mainly composed of pillow basalt. Aphyric, non-vesiculated basalt to andesite.
R10	Pillow breccia	Pillow breccia mainly composed of basaltic or andesitic black glass fragment with subordinate amount of gray-colored, aphyric, non-vesiculated basalt. Similar to R9, but lack in cobble of lava.
R11	Dacite to andesite	Fresh, non-vesiculated angular block of dense dacitic block. No matrix attached.
R12	2PX andesite-dacite	Angular PL-phyric andesitic block in conglomerate. Sandy matrix attached to the rim.
R13	2PX andesite-dacite	Fresh, angular block of non-vesiculated andesitic lava similar to R12.
Scoop 1	Brown sediment	N/A
Scoop 2	Diabasic fragments	Angular fragments of fine-grained aphyric diabse/basalt. Many coated by orange-cemented sand, likely a low-T hydrothermal precipitate.

Push core 1	Sediment	N/A
Loose samples #1 from basket	Various volcanic and diabase	N/A
Loose samples #2 from basket	Various volcanic and diabase	N/A

Dive #975	Described by SHB and OI	
Sample #	**Lithology**	**Descriptive Notes**
R1	Fine-grained gabbro	Fine grained gabbro, dominantly PL-PX perhaps with some small OL. Noticeably altered, with slight greenish cast to pyroxenes.
R2	Troctolitic gabbro	Troctolitic gabbro with 2-3 mm subrounded OL with interstitial PL and lesser CPX. Mineral proportions are estimates of original amounts. OL is extensively altered to orange-brown iddingsitic assemblages, some PL is albitized. There is fresh OL. Some veining of sample.
R3	Fine-grained gabbro	1-3mm fine-grained gabbro, PX-PL subequal amounts, equigranular, somewhat altered. At least one outer edge has a coarser grained gabbro (to 5 mm). Looks like a gradational contact but it is hard to tell on this cut. May be some OPX in finer section. Some alteration of CPX and veining.
R4	Diabase to gabbro	Diabase to medium-grained gabbro cut by thin 1 mm white veins; mostly diabase. Contact is diffuse and irregular. Diabase appears intrusive with fragments of gabbro in diabase, rather than being variations in a heterogeneous textured gabbro.
R5	Olivine gabbro	Olivine gabbro, grades across sample from about 5% to 15% olivine; OL uniformly altered to dark reddish assemblages. OL generally coarser than PL and PX; PL and PX usually show roughly equiganular interlocking texture.
R6	Fine-grained gabbro	Fine grained gabbro, cut by < 1 mm white veins; PL, PX, minor oxides? Some amphibolitization of PX.
R7	Diabase to medium grained gabbro	Complex rock of diabase/microgabbro that appears to have included clots and pieces of coarser grained gabbro within it; it looks like the diabase has stoped pieces of the gabbro. The gabbro occurs in 3 mm to 3 cm clots and pieces of gabbro to OL-gabbro. OL gabbro pieces concentrated in one zone. 2-5 mm grains in the gabbroic clots, <1 - 1 mm grains in the microgabbro/diabase. Gabbro varies in grain size and OL content; diabase is about 50-60% PL. Needs a thin section, a very complex texture. Thin <1 - 1 mm white veins cut across sample.
R8	Troctolite to troctolitic gabbro	Troctolite to troctolitic gabbro. OL are generally rounded with intercumulus PL. 50-60% OL, 2-4 mm grains. PL 20-30% as intercumulus grains, looks like some interstitial CPX. OL is variously altered to serpentine or orange oxidative assemblages. Sample is cut by 3 large veins (1-2 mm) around which PL is albitized and OL is altered to a dark green-black assemblage.
R9	Altered basalt/basalt breccia?	On first appearance is brecciated with light and dark "clasts"; a closer look suggests the dark grey and the brown regions are both the same microcrystalline aphyric basalt. Intergrown, needlelike CPX and PL can be clearly seen in binocular scope. Sample is intensely altered leaving small patches of grey fresher material. While aphyric, there are white vug or cavity fillings that could be taken for PLAG phenocrysts. The brown patches are more extensively weathered, the grey less so. Cut by a network of fractures and veins, some as thick as 3-5 mm. Most veins are white, but there are some diffuse greenish hued veins and patches that may be chloritic.

R10	Altered diabase to basalt	An altered diabase or microcrystalline basalt; could be something like R9, but not quite as altered. Was sparsely phyric (2-5%) but all are now altered to dark greenish clots, likely a clay. Probably were PX phenocrysts, as they do not have OL morphologies and don't look like PL replacements. Microcrystalline groundmass of PL and CPX cut by a network of 1 mm white veins, with 1 reddish vein across one corner.
R11	Troctolite or troctolitic gabbro	Troctolitic gabbro to troctolite. Probably closest to troctolite of samples examined so far. Subrounded OL 1-3 mm. OL extensively altered to orange, oxidative assemblages. Some patches of albitized PL. PL has an intercumulus texture.
R12	Troctolite or troctolitic gabbro	Troctolite to troctolitic gabbro; 1-3 mm rounded, subrounded OL; OL around 3 margins is entirely altered to bright orange iddingsite-type assemblages in a rind (1-3 cm thick) around sample. Interior fresher, dark grey. Sample not extensively veined.
R13	Troctolite or troctolitic gabbro	Troctolite to troctolitic gabbro, much like others. May be some modal variation but it is hard to see through the alteration. OL is variously altered to orange assemblages in patches and lenses and there are a couple places where PLAG is albitized. Sample is veined with a subparallel network of 1-<1 mm green black veins, with alteration of OL around them to a dark, green black assemblage.
R14	Highly-altered and veined basalt	Dark green-colored altered basalt(?) with network of white veinlets (2mm width). Could be silica veinlet. No original igneous texture remains.
R15	Highly-altered and veined basalt	Green-colored rock with network of veins of possibly silica (1mm). Prismatic crystals grow in vug.
R16	Altered aphyric basalt	Completely altered brown colored basalt, partly bearing reddish color around vesicles.
R17	Altered aphyric basalt	Light gray to brown colored, highly altered, slightly vesiculated basalt block. Pervaisive alteration. Minor white-colored veinlet observed.
R18	Altered aphyric basalt	Highly-altered aphyric basalt with network of white to green colored veinlet and associated alteration. Altered parts bear reddish to greenish color. Veinlets are composed of silica(?), calcite(?) and epidote.
R19	Altered aphyric basalt	Highly-altered light gray-colored aphyric basalt. Network of white to green colored veinlets prevails, possibly composed of calcite,(silica) and epidote.
R20	Altered aphyric basalt	Dark gray-colored, non vesiculated basalt. Groundmass is dominated with acicular PL and PX(?). PL aggregates composed of fibrous PL widely distributed. Probably constituent of conglomerate.
R21	Conglomerate	Conglomerate containing rounded light-gray colored basalt fragment with 2-3 mm alteration rim. Matrix is dark-colored clayish material and volcanic sand. Semi-consolidated.
R22	Conglomerate	Conglomerate dominantly composed of black-colored glassy basaltic fragment and minor amount of light-gray colored aphyric basalt. Fragments are angular to subangular. Glassy fragments have ca. 1mm palagonitized rim. Matrix is black-colored relatively soft material probably originated from altered glass. White-colored veinlets(calcite?) are widely observed.

R23	Conglomerate	Conglomerate mainly composed of subrounded to subangular basaltic fragment similar to R25-R27. Lava fragments have 1-2mm palagonitized rim. In matrix glassy fragments are abundant.
R24	Siltstone	Light brown-colored siltstone with clear lamina. Lamina can be recognized by difference in color of each layer.Thickness of each laminae is 3-4mm. There is a dewatering texture. Uppermost layer contains 1-2mm sized siltstone fragments.
R25	Aphyric basalt	Light gray-colored dense aphyric basalt. In groundmass accicular PL is dominant. Variolitic texture observed in the marginal part. No PL aggregate present.
R26	Aphyric basalt	Light gray-colored dense aphyric basalt. Aggregate of PL dendrites are widely dispersed. Possible altered OL phenocrysts are observed. Block in debris(matrix attached).
R27	Aphyric basalt	Light gray-colored, non vesiculated, nearly aphyric basalt with variolitic texture composed of accicular PL and PX This is also block of debris.
Scoop 1	Not described	N/A
Push core 1	Not described	N/A

Dive #976	Described by SHB and OI	
Sample #	**Lithology**	**Descriptive Notes**
R1	Basalt, basaltic andesite?	Non-vesiculated basalt, maybe basaltic andesite, may be some ground mass amphibole. Mn stain, but a centimeter thick sediment crust on one side.
R2	Basalt	Diiabasic to microcrystalline basalt, aphyric except for trace altered OL pseudomorphs; white vein coating on one surface of sample.
R3	Coarse sandstone	Very coarse sandstone to conglomerate; poorly sorted, subrounded to angular clasts of gabbro, diabase, volcanics, perhaps other sandstones. Largely igneous derived grains.
R4	Siltstone, claystone	Sediment with two major layers, one siltstone, one claystone. Cut by filled burrows perpendicular to layering. Thick Mn crust, to 2 cm in places.
R5	Siltstone, sandstone	Siltstone-mudstone-claystone; angular piece, an 8 cm claystone layer, then a thin lithic/crystal sandstone layer, 4 cm claystone layer, then 1 cm sandstone layer.
R6	Layered sediment	Layered sediment; 2 cm lithic/crystal sandstone, 5 cm claystone, 0.5 cm sandstone, 10 cm siltstone, Mn stain and Mn crusts to 5 mm.
R7	Coarse volcanic sandstone	Very coarse lithic/crystal volcanic sandstone; mostly weathered PL and PX grains, some lithics of volcanics, daibase, and fine gabbro (?).
R8	Coarse volcanic sandstone	Very similar to R7.
R9	Breccia	Matrix supported breccia; angular clasts 2-20 mm of volcanics, diabase, fine grained gabbro in a coarse volcanic sand matrix, with a larger proportion of PL grains; thick Mn rim.
R10	Claystone	Burrowed claystone, very soft, white tan to green tan and spotted with Mn; 1 mm Mn coating.
R11	Coral	Subrounded coral fragment.
R12	Andesite	Rectangular piece of light grey (on cut surface) diabasic textured andesite with trace amount of hb phenocrysts similar to R1; some Mn stain.
R13	Diabase	Highly weathered diabase; PL-PX with significant porosity, that is probably from plucking of grains not from vesicles (note that the weathered surface is not vesicular).
R14	Andesite	Hornblende andesite; sparsely HB phyric, microcrystalline groundmass, brown grey on cut surface.
R15	Andesite	Angular block of andesite, microcrystalline, reddish grey brown on cut surface. May be some groundmass hornblende?
R16	Diabase	Very similar to R13. A little coarser and includes a 1 cm light grey diabasic clast or inclusion.
R17	OL basalt	Altered olivine basalt. Fine grained phyric OL really almost groundmass size, all altered to iddingsite assemblages. 2-3 cm lighter grey-brown weathering rind around most of sample.
R18	OL basalt	CPX-OL basalt; OL here really seems to be mostly part of the groundmass, not really phenocrysts.
R19	Siltstone, fine sandstone	Layered fine grained volcanic sandstone and siltstone with thick Mn crust.

R20	Sandstone, siltstone	Siltstone to sandstone; tan siltstone or fine sandstone with volcanic grains, maybe some forams, patches of coarser volcanic sand and some irregular dark brown clasts (2-10 mm in size) that might be highly altered volcanic fragments?
R21	Claystone	Burrowed claystone similar to R10.
R22	Sandstone, with two major layers	Sandstone with two layers. One is a white tan fine-grained sandstone (white from altered PL grains? Carbonate pieces?) possibly overlying (based on burrows) an orange-brown coarser volcanic sandstone (1-2 mm grains). The orange sandstone has burrows in it filled by the white-tan material.

Dive #977	Described by SHB and OI	
Sample #	**Lithology**	**Descriptive Notes**
R1	PL-PX-OL diabase	Altered fine-grained diabse. PL generally shows quenched texture (acicular). Mafic minerals are altered.
R2	PL-PX-OL diabase	Atered fine-grained diabase. Acicular habit of PL is absent. Apart from that, very similar to R1.
R3	PL-PX-OL diabase	Finer grained altered diabase. Interstitial phases are completely altered. No quenched texture observed.
R4	PL-PX-OL diabase	Highly altered diabase suffered pervasive chloritization and oxidation. No fresh part remained.
R5	PL-PX-OL diabase	Altered PL-PX-OL diabase. Mafics are mostly oxidized.
R6	PL-PX-OL diabase	Altered PL-PX-OL diabase. Slightly coarser than R5.
R7	Fine-grained diabase	Extensively altered diabase, fine grained, with abundant clay, judging from how it saws. Aphyric, equigranular matrix of PL and PX. PX appears quite altered. One irregular vein or clast that seems to be volcanic textured. Can't tell if it is a partially assimilated clast or a crack filled with volcanic sand grains
R8	Medium-grained diabase	Much like R9 and R11. PL needles with interstitial CPX in groundmass. One large fracture, a little veining.
R9	Diabase	Medium-grained diabase, coarser than 10 and 11
R10	Diabase	Angular diabase, moderately to highly weathered; interlocking PL and CPX with interstitial CPX. May be some very rare 1-2 mm altered OL phenocrysts. There is a finer grained zone, about 1-2 cm thick along one edge. This is certainly a sharp textural change with a finer grained texture. It may just be a difference accentuated by the weathering, but it looks to have very sharp boundaries with the larger diabase, and may be the intrusive margin of another diabase body.
R11	Diabase	Angular grey-green brown diabase with interlocking PL-PX grains. The CPX is interstitial to PL grains and needles, typically 1-2 mm. There are rare microphenocrysts of altered CPX up to 3 mm. The brown hue suggests extensive alteration of CPX and of any interstitial microcrystalline groundmass. Alteration % estimates here are a very rough guess; mineral proportions are estimates of primary amounts.
R12	Weathered volcanic sandstone	Small pebble of a coarse volcanic sandstone? Very irregular and highly weathered, grains to 4 mm.
R13	Diabase	Angular block of diabase, grey to brown on cut surface. An aphyric diabase, somewhat coarser than 9 and 11. Equigranular, intergrown CPX and PL (few PL needles as in 9 and 11). The core is grey, and appears fresher, but is also altered to a different kind of assemblage. The grey core is surrounded by a 3-6 cm weathering rind that is greenish brown. In places there are slightly higher concentrations of PL grains that create little "snowflake" like patches of white. These occur in the grey and brown portions. Some of the lighter spots in the brown rind are just spots altered in the same way as the core. minor small white veins < 1mm thick.

R14	Diabase	Angular block of diabase, a bit coarser than 9, 11, 14 (maybe 1-3 mm). 8 cm grey core that may be fresher, but at least is weathered differently than the brown rind. Texture in both has equigranular interlocking PL and CPX. There are 5-8% phenocrysts or micorphenocrysts (2-4 mm in size), now largely altered. In the grey part these are altered to dark black-green clay, in the brown part to soft, red-brown assemblages. The morphology of the pseudomorphs suggests they were OL. There are some interstitial oxides.
R15	Diabase	Diabase, highly altered with no grey core, aphyric (very rare microphenocrysts that are altered, could have been CPX or PL?). Most interesting are ovoid bands around the center that must mark weathering fronts, perhaps a precursor to creating spheroidal, weathered blocks? One irregular, 1 mm thick vein filled with dark red brown material.
R16	Sandy calcareous grainstone inside a brown claystone	A rounded core of sandy calcareous grainstone (maybe with partially crystallized forams?). Block is white tan with fine volcanic-derived sand grains. Piece is inside a 3-4 cm rind of brown claystone. The claystone is a mottled dark brown.
R17	Clayey fine-grained sandstone	Subrounded brown clayey sandstone; mostly fine sand < 1 mm but rare grains or clasts to 2 mm. Essentially sandstone with a large amount of intergranular brown clay. Cut by veins filled with sediment that is darker brown and more clay rich than the matrix.
R18	Basalt	Large block of aphyric microcrystalline basalt to very fine-grained diabase. There is an ovoid, grey, less weathered core surround by a 5-12 cm thick brown, weathered rind.
R19	Fine-grained diabase to basalt	Fine-grained diabase to microcrystalline basalt largely < 1 mm. Sparse PL microphenocrysts to 1 mm with a vuggy, porous surface. Some of that appears to be primary porosity, though some is clearly developed by weathering. Moderately weathered, less weathered than R7 or R8. No obvious oxides in groundmass.
R20	Brown-red claystone	Brown-red claystone, a few discontinuous black veins, look like fractures with some Mn oxy-hydroxide deposits.
R21	PL-PX diabase	Coarse-grained diabase similar to R22, but much more altered. Yellowish brown colored patches of secondary minerals are widely scattered.
R22	PL-PX diabase	Relatively coarse grained PL-PX-(OL) diabase. Almost can be called PL-phyric texture. One of the freshest sample. Accicular PX crystals are observed.There are some yellowish brown colored alteration minerals(clays) filling intertstitial space.
R23	PL-PX diabase	Relatively coarse grained altered PL-PX diabase. PL sometimes shows accicular habit.
R24	Basalt	Microphyric basalt ; 2-3% altered OL microphenocrysts (to 1 mm), 1-2% CPX phenocrysts. The groundmass PL-CPX is about 60:40, groundmass texture looks equigranular. Fractures and cracks in sample have Mn staining.
R25	Fine-grained diabase	Diabase, fine-grained, fairly mafic, looks like more abundant CPX than in some of the others. In places PL looks interstitial to CPX. A subtly different texture than previous diabase. Some orange hydrothermal coating on outside.

R26	Fine-grained diabase	Fine to medium-grained diabase, 1-3 mm. Coarser than R25 but otherwise similar in mineral proportions and textures.
Sccop 1	Calcareous sediment	White tan unconsolidated clayey sediment with sand and gravel-sized volcanic or diabasic grains in it. Probably has some forams in the sediment.

7. Analytical tasks

All samples will be archived in Ocean Research Institute, University of Tokyo.

Volcanics:
TI: petrography, microprobe, general characterization
JH: major elements and ICPMS traces
OI: isotopes and $^{40}Ar/^{39}Ar$ geochronology
JK: Li isotopes, Hf isotopes (?)
MR: FTIR glasses and Hf isotopes (?)
KK: LA-ICPMS, SIMS glasses, ICPMS traces (especially Li and U,Th,Pb)
PF: Raman, microprobe

Gabbros:
KM: mineral fabrics
TI: petrography, microprobe
TI, JH: bulk rock major and trace element
JK : LA-ICPMS; isotopes
OI : ages

Ultramafics:
KM: mineral fabrics
YO, TI: general characterization, mineral analyses, bulk rock major and trace elements
JK: LAICPMS, isotopes

Metamorphics:
PF

Tonalites:
PF, MR: sample characterization, microprobe, major elements, trace elements, zircons(?)
OI: $^{40}Ar/^{39}Ar$ ages and isotopes

Analyses of Palau volcanics:
TI: petrography, microprobe, general characterization
JH: major elements and ICPMS traces
OI: isotopes and $^{40}Ar/^{39}Ar$ geochronology
JK: Li isotopes, Hf isotopes (?)
MR: FTIR glasses and Hf isotopes (?)
KK: LA-ICPMS glasses, ICPMS traces (especially Li and U,Th,Pb)
PF: Raman, microprobe

Note: Yasuhiko Ohara (YO); Mark Reagan (MR); Teruaki Ishii (TI); Jun-Ichi Kimura (JK); Osamu Ishizuka (OI); Katsuyoshi Michibayashi (KM); James Hawkins (JH); Robert Stern (RS); Sherman Bloomer (SB); Patricia Fryer (PF); Katharine Kelley (KK)

8. References

Arculus, R. J., J. Pearce, et al. (1992). Igneous stratigraphy and major-element geochemistry of Holes 786A and 786B. Proceedings of the Ocean Drilling Program, Scientific Results. P. Fryer, J. Pearce and L. B. Stokking. 125: 143-169.

Bloomer, S. H. (1983). Distribution and origin of igneous rocks from the landward slopes of the Mariana Trench; implications for its structure and evolution. Journal of Geophysical Research. B 88(9): 7411-7428.

Bloomer, S. H. and J. W. Hawkins (1983). Gabbroic and ultramafic rocks from the Mariana Trench; an island arc ophiolite. The tectonic and geologic evolution of Southeast Asian seas and islands; Part 2. D. E. Hayes. 27: 294-317.

Bloomer, S. H., B. Taylor, et al. (1995). Early arc volcanism and the ophiolite problem: a perspective from drilling in the western Pacific. Active Margins and Marginal Basins: a Synthesis of Ocean Drilling in the Western Pacific. B. Taylor and J. H. Natland. Washington D.C, AGU Geophysical Monograph Series. 88: 1-30.

Bougault, H., R. C. Maury, et al. (1982). Tholeiites, basaltic andesites, and andesites from Leg 60 sites; geochemistry, mineralogy, and low partition coefficient elements. Leg 60 of the cruises of the drilling vessel Glomar Challenger; Apra, Guam to Apra, Guam; March-May 1978." Initial Reports of the Deep Sea Drilling Project 60: 657-677.

Clift, P. D. (1995). Volcaniclastic sedimentation and volcanism during the rifting of Western Pacific backarc basins. Active Margins and Marginal Basins: a Synthesis of Ocean Drilling in the Western Pacific. B. Taylor and J. H. Natland. Washington D.C., AGU. 88: 67-96.

Cosca, M., R. J. Arculus, et al. (1998). 40Ar/ 39Ar and K-Ar geochronological age constraints for the inception and early evolution of the Izu-Bonin-Mariana arc system. The Island Arc 7: 579-595.

DeBari, S. M., B. Taylor, et al. (1999). A trapped Philippine Sea plate origin for MORB from the inner slope of the Izu-Bonin trench. Earth and Planetary Science Letters 174(1-2): 183-197.

Dobson, P. F. (1986). The petrogenesis of boninite; a field, petrologic, and geochemical study of the volcanic rocks of Chichi-Jima, Bonin Islands, Japan, Stanford University: 178 pp.

Dobson, P. F. and G. Tilton (1989). Th, U and Pb systematics of boninite series volcanic rocks from Chichi-jima, Bonin Islands, Japan. Boninites and related rocks. A. J. Crawford. London, Unwin-Hyman: 396-415.

Fischer, K. M., M. J. Fouch, et al. (1998). Anisotropy and flow in Pacific subduction zone back-arcs. Pure and Applied Geophysics 151: 463-475.

Fryer, P. (1992). A synthesis of Leg 125 drilling of serpentine seamounts on the Mariana and Izu-Bonin forearcs. Proceedings of the Ocean Drilling Program, Scientific Results. L. H. Dearmont, E. K. Mazzullo, N. J. Stewart and W. R. Winkler. College Staton, TX, Ocean Drilling Program. 125: 593-614.

Fryer, P. and N. Becker, et al. (2003). Why is the Challenger Deep so deep? Earth and Planetary Science Letters 211: 259-269.

Fryer, P. and G. J. Fryer (1987). Origins of nonvolcanic seamounts in a forearc environment. Geophysical Monograph. B. Keating, P. Fryer, R. Batiza and G. W. Boehlert. Washington, DC, AGU. 43: 61-69.

Fryer, P., J. P. Lockwood, et al. (2000). Significance of serpentine mud volcanism in convergent margins. Special Paper - Geological Society of America. Y. Dilek, E. M. Moores, D. Elthon and A. Nicolas. Boulder, CO USA, Geological Society of America. 349: 35-51.

Fryer, P., J. A. Pearce, et al. (1990). Summary of results from Leg 125. Proceedings of the Ocean Drilling Program, Part A: Initial Reports. College Station, TX,, Ocean Drilling Program. 125: 367-380.

Fryer, P., B. Taylor, et al. (1990). Petrology and geochemistry of lavas from the Sumisu and Torishima backarc rifts. The Mariana Trough; special section." Earth and Planetary Science Letters 100(1-3): 161-178.

Fryer, P., C. G. Wheat, et al. (1999). Mariana blueschist mud volcanism; implications for conditions within the subduction zone. Geology (Boulder) 27: 103-106.

Fujioka, K., Y. Matsuo, et al. (1992). Tephras of the Izu-Bonin Forearc (Sites 787, 792, and 793). Proceedings of the Ocean Drilling Program, Scientific Results. B. Taylor, K. Fujioka and e. al. College Station, Texas, Ocean Drilling Program. 126: 47-74.

Hall, R. L. (1999). Late Bajocian and Bathonian (Middle Jurassic) ammonites from the Fernie formation, Canadian Rocky Mountains. Journal of Paleontology 62(4): 575.

Hanzawa, S. (1947). Eocene foraminifera from Hahajima. Journal of Paleontology 21: 254-259.

Haraguchi, S. (1999). Early arc and rifting volcanism in the paleo-Izu-Ogasawara-Mariana arc (Kyushu Palau Ridge and Izu-Ogasawara-Mariana forearc region). Ocean Research Institute, University of Tokyo: 429.

Hawkins, J. W. and P. R. Castillo (1998). The early history of the Izu-Bonin-Mariana arc system: Evidence from Belau and the Palau trench. The Island Arc 7: 559-578.

Hickey-Vargas, R. (1989). Boninites and tholeiites from DSDP Site 458, Mariana Forearc. Boninites and related rocks. A. J. Crawford. London, Unwin Hyman: 339-356.

Hickey-Vargas, R. and M. K. Reagan (1987). Temporal variation of isotope and rare earth element abundances in volcanic rocks from Guam; implications for the evolution of the Mariana Arc. Contributions to Mineralogy and Petrology 97(4): 497-508.

Hickey, R. L. and F. A. Frey (1982). Geochemical charactreristics of boninite series volcanics: Implications for their source. Geochimica et Cosmochimica Acta 46: 2099-2115.

Hiscott, R. N. and J. B. Gill (1992). Major and trace element geochemistry of Oligocene to Quaternary volcaniclastic sands and sandstones from the Izu-Bonin Arc. Ocean Drilling Program, Scientific Results. B. Taylor, K. Fujioka and e. al. College Station, Texas, Ocean Drilling Program. 126: 467-486.

Hussong, D. M., S. Uyeda, et al. (1982). Initial Reports of the Deep Sea Drilling Project. Washington, US Goverment Printing Office.

Ishii, T. (1985). Dredged samples from the Ogasawara forearc seamount of "Ogasawara Paleoland" - forearc ophiolite. Formation of Active Ocean Margins. N. Nasu. Tokyo, Terrapub.: 307-342.

Ishizuka, O., J.-I. Kimura, et al. (2006). Early stages in the Evolution of Izu-Bonin Arc volcanism: new age, chemical, and isotopic constraints. Earth and Planetary Science Letters in press.

Jung, H. and S.-i. Karato (2001). Effects of water on dynamically recrystallized grain-size of olivine. Journal of Structural Geology 23: 1337-1344.

Kaneoka, I., N. Isshiki, et al. (1970). K-Ar ages of the Izu-Bonin Islands. Geochemical Journal 4: 53-60.

Kikuchi, Y. (1890). On pyroxenic components in certain volcanic rocks from Bonin Island. Journal of the College of Science, Imperial University of Japan 3: 67-89.

Komatsu, M. (1980). Clinoenstatite in volcanic rocks from the Bonin Islands. Contributions to Mineralogy and Petrology 74: 329-338.

Kuroda, N. (1984). Magma mixing and quartz-bearing boninites from Chichijima and Ani-jima, Bonin Islands. Mem Geol. Soc. Japan. 24: 157-164.

Kuroda, N. and K. Shiraki (1975). Boninite and related rocks of Chichijima, Bonin Islands, Japan. Reports of the Faculty of Science, Shizuoka University 10: 145-155.

Kuroda, N., K. Shiraki, et al. (1988). Ferropigeonite quartz dacites from Chichijim, Bonin Islands: latest differentiates from boninite-forming magma. Contributions to Mineralogy and Petrology 110: 129-138.

Leat, P. T. and R. D. Larter (2003). Intra-oceanic subduction systems; Introduction. Geological Society Special Publications 219: 1-17.

Mason, A., G. Corwin, et al. (1956). Military geology of the Palau Islands, Caroline Islands, report. Washington, D.C., Intelligence Divivision Office Of the Engineer HQ, U.S. Army (rear).

Meijer, A. (1980). Primitive arc volcanism and a boninite series; example from western Pacific Island arcs. The tectonic and geologic evolution of Southeast Asian seas and islands. D. E. Hayes. Washington, DC, American Geophysical Union. 23: 269-282.

Meijer, A., M. Reagan, et al. (1983). Chronology of volcanic events in the eastern Philippine Sea. The tectonic and geologic evolution of Southeast Asian seas and islands; Part 2. D. E. Hayes. Washington, DC, American Geophysical Union. 27: 349-359.

Michibayashi, K., T. Ina, et al. (2006). The effect of dynamic recrystallization on olivine fabric and seismic anisotropy: Insight from a ductile shear zone, Oman ophiolite. Earth and Planetary Science Letters 244: 695-708.

Michibayashi, K. and D. Mainprice (2004). The role of pre-existing mechanical anisotropy on shear zone development within oceanic mantle lithosphere; an example from the Oman Ophiolite. Journal of Petrology 45: 405-414.

Mottl, M. J., S. C. Komor, et al. (2002). Deep fluids from the subducting Pacific Plate and associated extremophilic microbial activity on a Mariana forearc serpentine seamount, ODP Leg 195. 66: 528.

Mottl, M. J., C. G. Wheat, et al. (2004). Chemistry of springs across the Mariana forearc shows progressive devolatilization of the subducting plate. Geochimica et Cosmochimica Acta 68: 4915-4933.

Murton, B. J., D. W. Peate, et al. (1992). Trace-element geochemistry of volcanic rocks from Site 786; the Izu-Bonin forearc. Proceedings of the Ocean Drilling Program, Scientific Results. P. Fryer, J. A. Pearce and L. B. Stokking. 125: 211-235.

Nakajima, J. and A. Hasegawa (2004). Shear-wave polarization anisotropy and subduction-induced flow in the mantle wedge of northeastern Japan. Earth and Planetary Science Letters 225: 365-377.

Natland, J. H. and J. Tarney (1983). Petrologic evolution of the Mariana arc and back-arc basin system - A synthesis of drilling results in the southern Philippine Sea. Initial Reports of the Deep Sea Drilling Project. D. M. Hussong and S. Uyeda. 60: 877-908.

Ohara, Y. and T. Ishii (1998). Peridotites from the southern Mariana foreare: heterogeneous fluid supply in mantle wedge. Island Arc 7: 541-558.

Parkinson, I. J., J. Pearce, et al. (1992). Trace element geochemistry of peridotites from the Izu-Bonin-Mariana forearc, Leg 125. Proceedings of the Ocean Drilling Project, Scientific Results. P. Fryer, J. Pearce and L. B. Stokking. 125: 487-506.

Pearce, J. A., P. D. Kempton, et al. (1999). Hf-Nd element and isotope perspective on the nature and provenance of mantle and subduction components in Western Pacific arc-basin systems. Journal of Petrology 40: 1579-1611.

Pearce, J. A., M. F. Thirlwall, et al. (1992). Isotopic evidence for the origin of boninites and related rocks drilled in the Izu-Bonin (Ogasawara) forearc, Leg 125. Proceedings of the Ocean Drilling Program, Scientific Results. P. Fryer, J. A. Pearce, L. B. Stokking and e. al. College Station, TX USA, Ocean Drilling Program. 125: 237-261.

Pearce, J. A., S. R. van der Laan, et al. (1992). Boninite and harzburgite from Leg 125 (Bonin-Mariana forearc); a case study of magma genesis during the initial stages of subduction. Proceedings of the Ocean Drilling Program, Scientific Results. P. Fryer, J. A. Pearce, L. B. Stokking and e. al. 125: 623-659.

Reagan, M., D. Mohler, et al. (2003). Sources and melting processes for the proto-Mariana arc. Geophysical Research Abstracts 5: 14493.

Reagan, M. K. and A. Meijer (1984). Geology and geochemistry of early arc-volcanic rocks from Guam. Geological Society of America Bulletin 95(6): 701-713.

Shiraki, K., N. Kuroda, et al. (1978). Evolution of the Tertiary volcanic rocks from the Izu-Mariana arc. Bulletin Volcanologique 41: 548-562.

Shiraki, K., N. Kuroda, et al. (1980). Clinoenstatite in boninites from the Bonin Islands . Nature 285: 31-32.

Stern, R. J. and S. H. Bloomer (1992). Subduction zone infancy; examples from the Eocene Izu-Bonin-Mariana and Jurassic California arcs. Geological Society of America Bulletin 104: 1621-1636.

Stern, R. J., M. J. Fouch, et al. (2003). An overview of the Izu-Bonin-Mariana subduction factory. Inside the subduction factory. J. Eiler, American Geophysical Union. 138: 175-222.

Stern, R. J., J. D. Morris, et al. (1991). The source of the subduction component in convergent margin magmas; trace element and radiogenic isotope evidence from Eocene boninites, Mariana Forearc. Geochimica et Cosmochimica Acta 55(5): 1467-1481.

Suzuki, T., 1885. Volcanic rocks of the Chichi-jima group. Bull Geol. Soc.Japan, Pt. A. 1, 23-39. (1885). Volcanic rocks of the Chichi-jima group. Bulletin of the Geological Society of Japan, Pt. A 1: 23-39.

Tamura, Y. and Y. Tatsumi (2002). Remelting of an andesitic crust as a possible origin for rhyolitic magma in oceanic arcs: an example from the Izu-Bonin arc. Journal of Petrology 43: 1029-1047.

Taylor, B. (1992). Rifting and the volcanic-tectonic evolution of the Izu-Bonin-Mariana Arc. Proceedings of the Ocean Drilling Program, Scientific Results. B. Taylor, K. Fujioka, T. R. Janecek and e. al. 126: 627-651.

Taylor, R. N., H. Lapierre, et al. (1992). Igneous geochemistry and petrogenesis of the Izu-Bonin forearc basin. Proceedings of the Ocean Drilling Program, Scientific Results. B. Taylor, K. Fujioka and e. al. 126: 405-430.

Taylor, R. N., R. W. Nesbitt, et al. (1994). Mineralogy, chemistry, and genesis of the boninite series volcanics, Chichijima, Bonin Islands, Japan. Journal of Petrology 35: 577-617.

Tsunakawa, H. (1983). K-Ar dating on volcanic rocks in the Bonin Islands and its tectonic implication. Tectonophysics 95: 221-232.

Umino, S. (1985). Volcanic geology of Chichijima, the Bonin Islands (Ogasawara Islands). Journal of the Geological Society of Japan 91: 505-523.

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

van der Laan, S. R., R. J. Arculus, et al. (1992). Petrography, mineral chemistry, and phase relations of the basement boninite series of Site 786, Izu-Bonin forearc. Proceedings of the Ocean Drilling Program, Scientific Results. P. Fryer, J. A. Pearce and L. B. Stokking. 125: 171-201.

Vidal, P., B. Auvray, et al. (1985). Origin of boninites from Bonin Islands: Nd, Sr, and Pb isotopic constraints. Terra Cognita 5: 286.

Wessel, J. K., P. Fryer, et al. (1994). Extension in the northern Mariana inner forearc. Journal of Geophysical Research, B, Solid Earth and Planets 99: 15,181-15,203.

Yajima, K. and H. Fujimaki (2001). High-Ca and low-Ca boninites from Chichijima, Bonin (Ogasawara) archipelago. Japanese Magazine of Mineralogical and Petrological Sciences 30: 217-236.

Yoshiwara, S. (1902). Geological age of the Ogasawara Group (Bonin Islands) as indicated by the occurrence of Nummulites. Geological Magazine 9: 296-303.

Appendix A: Video logs

Dive 973 Date 8/30/06 Observer T. Ishii

Time	Depth (m)	Comments
11:42	6461	Bottom in sight
11:43	6465	On bottom; Large subangular, blocky rocks with sediment cover (90%)
11:44	6470	Scattered loose cobbles and boulders
11:45	6470	Officially on bottom
11:47	6469	Push core aft Attempt (blue) X=-457.9 Y=1239.2
11:52	6469	Claw appears and maybe attempt rock
11:53	6469	Rock #1 in #10 box (forward port side) *Location #1
11:54	6469	Picking up scoop
11:55	6469	Scooping sediments (seems indurated)
11:57	6469	Scoop sample in bio box # 1
11:58	6469	Returned scoop to box and close bio box
11:59	6469	2 large boulders - subangluar, blocky
12:00	6469	Start moving; blocks 10%
12:02	6466	Large block, subangular
12:03	6460	Patches of light sediment
12:05	6439	
12:06	6437	Lots of small rocks and light streaks
12:07	6417	Slightly seen small rocks
12:08	6413	Lots of small rocks in sandy surface
12:10	6408	
12:12	6395	Moving, tiny rocks in sandy surface
12:13	6390	A relatively big rock observed, still moving
12:15	6385	Smooth surface, a few rocks
12:16	6385	Sampling in 11 (R2) * X=-358.0 Y=1050.7
12:17	6385	Sampling in 12 (R3); it's a pretty big sample
12:19	6382	Moving, Very smooth surface with a few tiny rocks

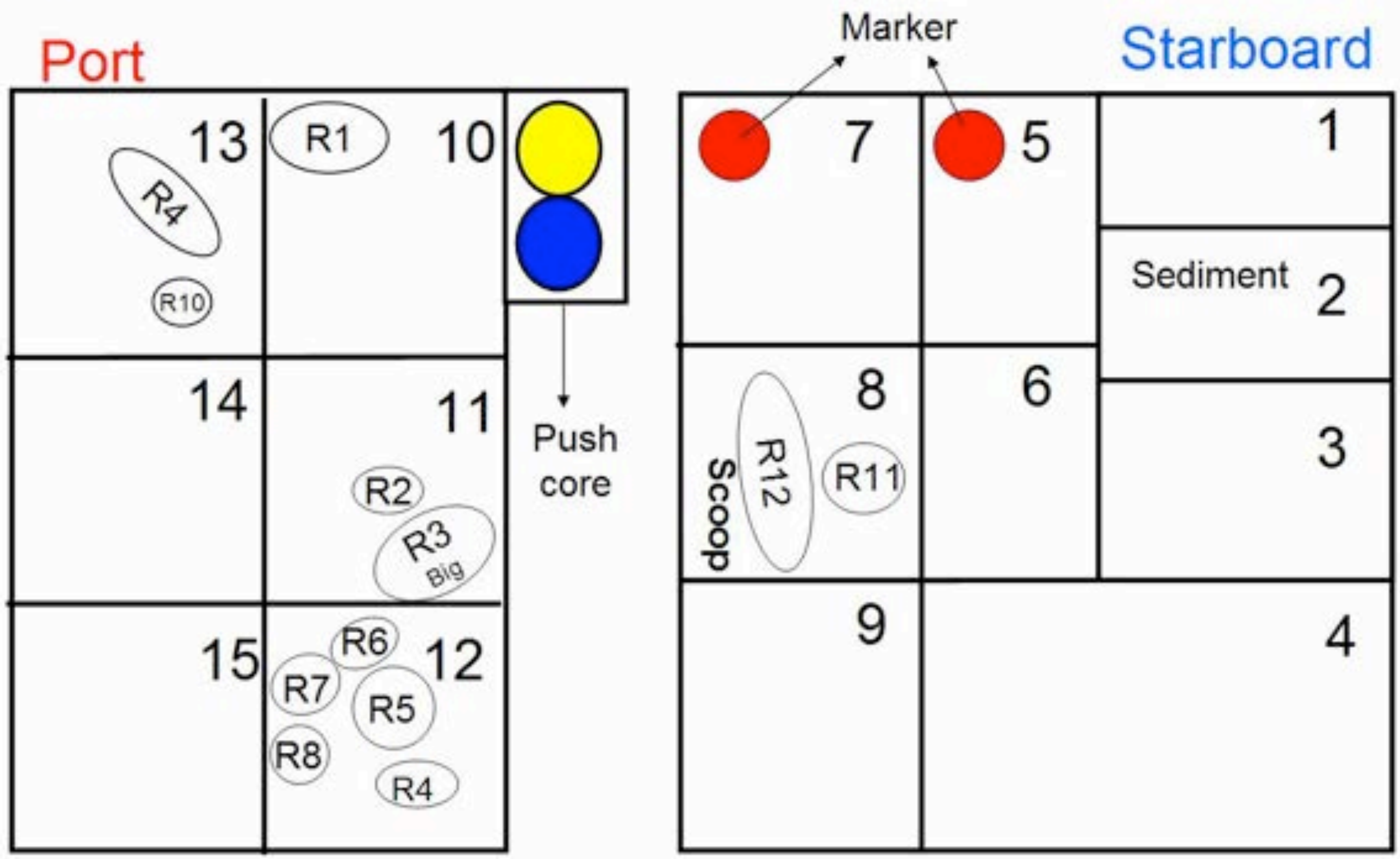
12:21	6377	Very smooth surface with a few tiny rocks
12:23	6371	A few big rocks on the right side
12:24	6366	Very smooth surface with a few very tiny rocks
12:28	6351	Rough rock
12:30	6341	
12:32	6338	Right side boulder angular
12:32:38	6336	Larger block; very angular
12:33:50	6334	
12:37	6341	
12:41	6356	
12:42	6354	100% talus slabs
12:44	6355	Sampling (plume of sediment)
12:46	6355	Sample R#4, R#5, R#6, R#7, R#8 * X=-100.6 Y=617.3
12:50	6355	End sampling cobbles; blocky and subangular
12:53:53	6349	100% cobbles, some very large blocks
12:54	6348	
12:54:14	6346	
12:55	6339	Lots of talus; various sizes angular-subangular and larger
12:58	6328	Small depression filled with sediment
1:00	6313	Outcrop! Large irregular with white streaks
1:01	6302	Outcrop close up
1:02	6298	End of outcrops with some sediment and white streaks
1:03	6290	
1:05	6283	Checking position for sample
1:07	6277	Angular to subangular blocks with some sediment cover
1:11	6265	Lots of angular boulders/cobbles
1:13	6261	Slabby talus; size is variable
1:13:50	6258	Very angular talus
1:15	6252	Serpentine Breccia

1:17	6241	Large to medium, angular to subangular boulders
1:19	6229	Still traversing talus (sizes variable)
1:21	6228	Light color, R#9 in Box #13 from talus patch* (near outcrop?) X=44.6 Y=406.6
1:24	6229	Light, small R#10 *
1:29	6217	Dark outcrop with light veins *
1:31	6206	Very irregular rough surface on boulders
1:36	6174	Large boulders (anemone)
1:39	6184	Went over a small stair step (fault?)
1:40	6185	More boulders
1:41	6185	Back to sediment (90%)
1:41:59	6188	Still going deeper
1:43	6183	Talus in sediment angular to subangular; various sizes
1:49	6129	Fine talus with "cementing" matrix and cobbles to boulders as sub goes up slope
1:51	6118	Very fine talus (100%)
1:54	6094 (4 m)	Going over a small step that drops off up slope (fault trace?)
1:55:30	6084 (2 m)	Lots of cobbles with sediment cover (50%)
1:57	6073	Large boulder (2m?); subangular
1:58	6070	Numerous very large blocks
2:00	6068	Getting ready to sample? (guess not…)
2:05	6067	Mostly sediment cover with a few large subangular blocks
2:09	6068 (6m)	Traveling toward steeper part of slope
2:13	6055	Sediment looks white
2:14:30	6039	Talus with steep slope and numerous subangular blocks
2:15	6027	Larger subangular talus blocks
2:23	6006	Blocky large boulder
2:24	5998	Shrimp
2:25	5989	Large angular block surrounded by sediment
2:30	5961	Scattered cobbles and boulders in sediment

2:32	5956	Scattered larger boulders in sediment
2:34	5953	More numerous
2:35	5955	Big block
2:37	5957	
2:39	5957	Sampling
2:41	5957	Rock #11 in Box #8 X=292.7 Y=-526.7
2:43	5957	Marker from box #5
2:44	5957	Rock #12 in Box #8; very large
2:46	5957	Hole rock came from
2:46:50		End dive

Sketch of the sample baskets

Dive# 973 Date: 30/8/2006 Observer: T. Ishii



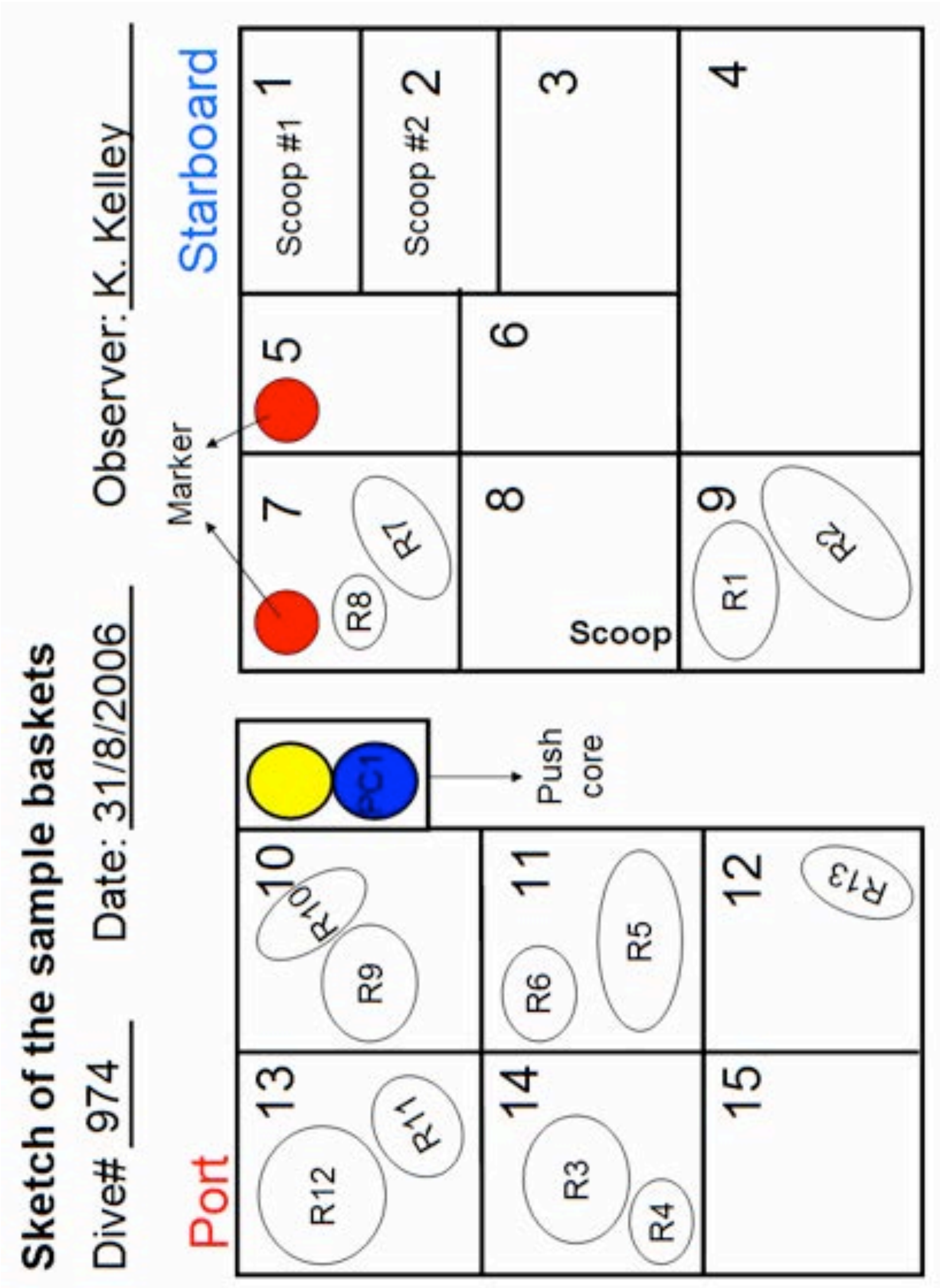
Dive 974 Date 8/31/06 Observer Katherine Kelley

Time	Depth (m)	Comments
11:28	6263 (10 m)	Bottom in sight; a few small boulders
11:31	6270	Large, angular blocks with sediment around them
11:35	6270 (1 m)	Claw of manipulator (sampling)
11:36	6270	Sampling big orange rock (R#1 in Box #9) *
11:40	6269	Spiral animal trace
11:42	6269	Boulder field (35%) in sediment
11:43	6265 (5 m)	Sediment with 1 or 2 boulders
11:44	6268	Sediment sloping down from right
11:45	6267	Big white rock near another spiral
11:46	6268	Seeing sediment tongues sloping down from right
11:47	6267	Sampling
11:52	6267	Sample (R#2) Light-colored, disc-shaped rock in box #9 *
11:54	6261	Sediment-covered, a few rocks
11:59	6246	Several blocky rocks
12:00	6245	Sediment; few rocks
12:06	6181	Sediment; few rocks
12:08	6183	Rocky surface
12:10	6183	Stopping to scoop sediment; Scoop #1 in Box #1
12:16	6183	Trying a second scoop samping; in Box #1
12:20	6176	Moving
12:22	6172	Sediment-covered rocks
12:23	6168	Gravel and cobbles
12:25	6164	Talus slope
12:27	6145	Fine talus chutes w/ some finer sediment tongues, some cobbles
12:30	6119	Some very light pebbles and cobbles scattered among
12:31	6116	More light rocks in a field of very variable lithologies
12:37	6116	Sampling R#3, big orange rock in #14 *
12:41	6115	Sample R#4 in box #14; orange *

12:44	6115	A lot of small, angular, white blocks
12:45	6111	Talus is much finer
12:45:45	6109	Tongue of slightly larger material
12:46	6102	Larger cobbles (polymict)
12:47	6100	Very wide lithology variation (pebbly)
12:48	6088 (6 m)	Bottom dropped a bit
12:49	6085	white debris around the bottom of some rocks
12:50	6079	Sediment with scattered cobbles and boulders; stopped to sample
12:52	6080	Small channel across slope upper right to lower left (saw 2 very round boulders)
12:54		Brittle star on round rock
12:55	6080	Rock #5 in box #11 *
12:56	6079	Very smooth sedimented bottom
12:57	6079	A few large boulders with sediment around them
12:58	6079	Sampling dark rock (crust crumbled off); recovered a rounded orange cobble
1:00	6079	Rock #6 in box #11 *
1:01	6078	Leaving sample site; there was a vertical ridge of sediment ~2-3 cm high
1:04	6073	~5% cobbles/boulders to ~20%; rest is sediment
1:06	6064	10% cobbles/90% sediment; white streaks and white on down-side of boulders
1:07	6057	Steep slope with fine pebbles
1:11:00	6034 (5 m)	Up in water column and moving toward steeper slope
1:14	6023	See bottom; mostly sediment with scattered pebbles and cobbles
1:15	6016	More cobbles (15%) grading into patches of cobbles with sediment between
1:18	6014	Settled on bottom to sample R#7; large orange cobble in box #7
1:20	6014	Sample #R8; small rounded cobble in box #7
1:24	6006	White streaks under cobbles
1:25	6001	Cobbles 5-10% (no streaks of white)
1:26:30	5989	Not many pebbles (mostly fine sediment with ~2-3% pebbles)
1:28	5977	Not many pebbles (mostly fine sediment with ~2-3% pebbles)

1:28:50	5974	10-15% pebbles
1:29:31	5968	1-3% pebbles
1:33	5940	3-5% pebbles (variable)
1:36	5912	3-5% pebbles (variable)
1:40	5869 (4 m)	~15% pebbles
1:42	5853	Some larger cobbles
1:43	5853	Spiral and some boulders (~15%) set down to sample
1:46	5853	R#9 large, red and black in #10 box; R#10 medium, irregular-shaped orange and black in #10 box **
1:48	5853	Finished sampling
1:49	5852	40% pebbles
1:50	5850	60% pebbles
1:51:20	5841	Slope up to right
1:52	5834	Rocky slope; ~70% pebbles
1:53	5834	Hydrothermal (vent or seep?); orange on black;
1:56	5834	Tried to sample with arm, but crumbled
1:57	5834	scoop #2 in box #2*
2:02	27	20-30% pebbles
2:04	5812	White streaks in sediment
2:05:30	5807	Scattered pebbles
2:07	5801	Very light colored layers of fine seiment
2:09	5801	Settling to sample
2:12	5801	Angular light color boulder R#11 in box #13 *
2:19	5800	Blue push core in brown sediment (failed)
2:22	5801	second try at push core got a good recovery
2:23	5800	Preparing to leave sample site
2:25	5795	Looks like light mud flows
2:29:50	5769	Light mud and lots of pebbles (30%)
2:30:19	5768	Mostly fine sediment (no-1% pebbles)
2:35:20	5757	Rocky slope ~ 40% cobbles and boulders; one very large (~2-3m) boulder (rounded); scattered subangular boulders around it; stopped to sample

2:40:00	5757	R#12; large brown rock with black coating in Box#13
2:45:00	5757	R#13; sort of small brown rock in box #12
2:48		End dive



Sketch of the sample baskets
Dive# 974
Date: 31/8/2006
Observer: K. Kelley
Port
Starboard
Marker
Push core
PC1
1
Scoop #1
2
Scoop #2
3
4
5
6
7
R8
R7
8
Scoop
9
R1
R2
10
R10
R9
11
R6
R5
12
R13
13
R12
R11
14
R3
R4
15

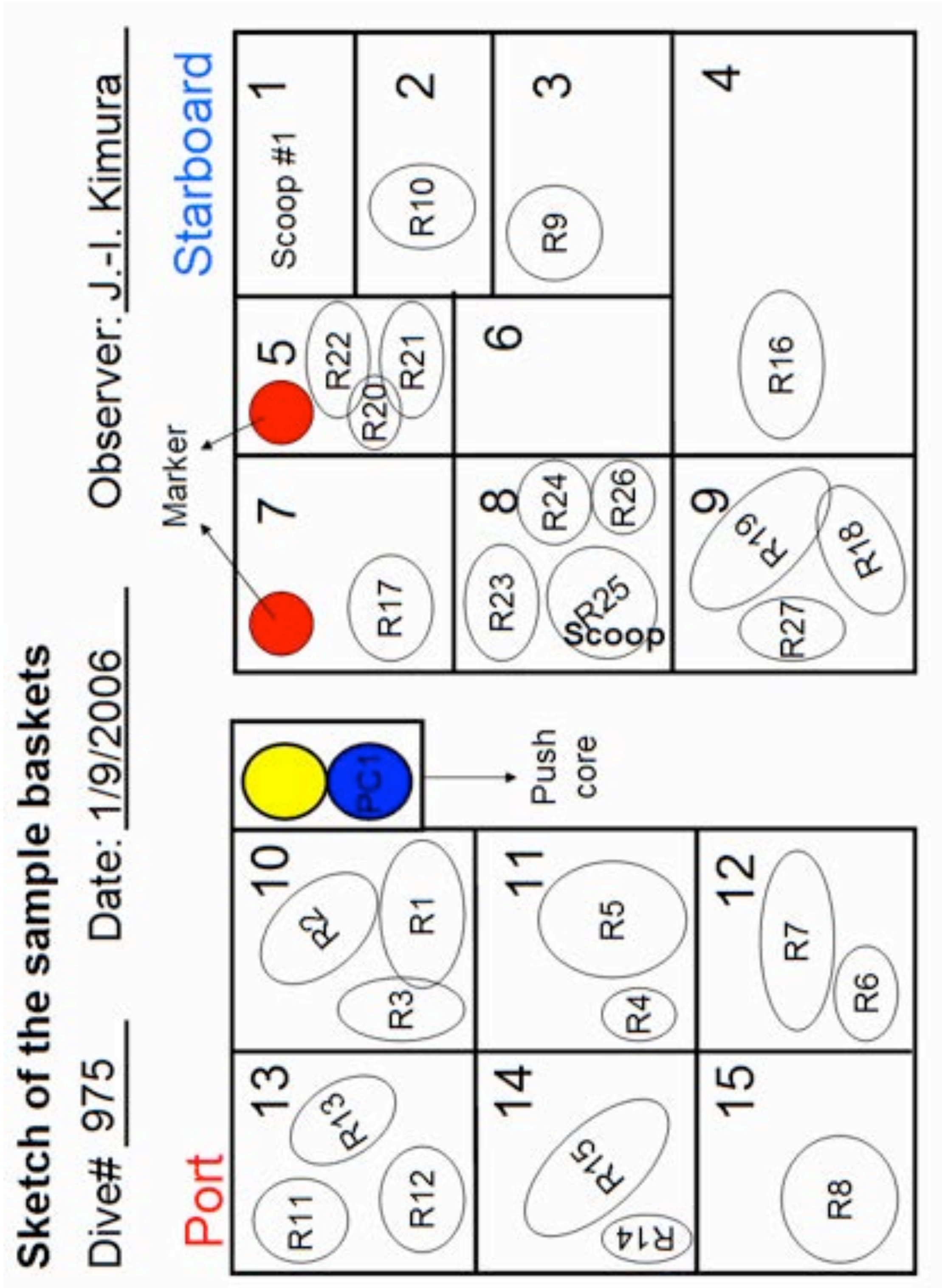
Dive 975 Date 9/1/06 Observer J.-I. Kimura

Time	Depth (m)	Comments
11:35	6482	Bottom in sight; pebbly sea floor with ~35% sediment; looks like lots of variety in lithology
11:41	6486	Preparing to sample in a field of cobbles (subangular) to boulders
11:42	6487	R#1 in Box#10 *
11:45	6482	R#2 in Box #10; elongate with brown mud on bottom 2/3 *
11:48	6481	R#3 in Box #3; very large *
11:50	6474	Moving over talus (?) slope
11:56	6427	Sampling blocky outcrop
11:59	6425	R#4 collected in #11 (I think) *
12:02	6425	R#5 collected in #11 (I think) *
12:05	6417	Moving over dark outcrops, foliated, possible peridotite
12:09	6379	Talus
12:11	6370	Dark, angular brick-size blocks
12:14	6365	R#6 in #12 *
12:16	6364	R#7 in #12 *
12:18	6360	Talus slope
12:21	6333	Talus slope
12:23	6315	Talus slope
12:27	6296	Sampling talus
12:30	6295	R#8 in #15
12:35	6293	Talus
12:37	6266	More white rocks in talus
12:40	6236	Debris flow with matrix
12:42	6326	R#9 from debris flow; place in bio box #3 *
12:44	6326	Rock #10 in Box #3 (??) *
12:46	6326	Debris flow outcrop
12:49	6315	Talus slope
12:51	6213	Outcrop of
12:52	6212	Rock #11 from outcrop in #13 *

12:53	6212	Rock #12 from outcrop in #13 *
12:55	6212	Rock #13 from outcrop in #13 *
12:57	6199	Moving over talus and outcrop
1:00	6170	Outcrop - this is sampled
1:05	6152	R#14 in Box #14 *
1:07	6152	R#15 in Box #14 *
1:10	6151	Steep slopes of debris flow
1:12	6138	Outcrop
1:13	6132	Talus and sediment
1:15	6126	Mostly sediments; few rocks and talus
1:19	6103	R#16 in #4 (talus) *
1:21	6103	R#17 in #7 *
1:26	6100	Moving over sediment, minor rocks
1:30	6091	Debris flow
1:31	6073	Sediments; few rocks
1:33	6064	Smooth surface with few rocks
1:33:55	6060	White streaks in sediment
1:35	6053	Almost 100% sediment; light color and slight undulations across slope
1:36	6049	~50% pebbles to boulders
1:37	6042	Large boulders scattered in ~70% sediment
1:38:30	6037	Smooth fine sediment with scattered pebbles (~95% sediment); some light patches (animal burrows)
1:40	6031	Some boulders
1:40:50	6024	Large outcrop of subangular blocks; lightly sedimented
1:42:30	6021	Stopped to sample at field of boulders on steep slope (south of a prominent feature appears on the bathymetry)
1:46	6005	Sample R#18 in Box #9 from outcrop of blocks (some with black coating in light matrix?) *
1:49	6005	R#19 in Box #9 *
1:52	6005	Preparing to scoop?; did not collect a sample
1:54	6000	Moving over slope with cobbles and sediment
1:56	5992	Mostly sediment with a few scattered cobbles
1:58	5989	Large subangular blocks

1:58:20	5989	Smooth sediments with few rocks
2:00	6000	Smooth sediments
2:01	6004	Sediments with burrows and edge of a few blocks
2:03	6005	Large blocks surrounded by brown sediment; taking blue (aft) push core at south tip of prominent contour *
2:05	6004	Boulder field
2:07	6006	Mostly sediment with a few large boulders
2:07:50	6007	50% boulders
2:08:25	6005	Mostly sediment
2:08:40	6003	Debris then drop off
2:10	6004 (11m)	Moving north fast
2:13:30	6019 (3 m)	Brown sediment with burrows and only an occasional rock
2:14:40	6017	Irregular to subangular boulders
2:15:16	6012	Sediment
2:16	6009	Sediment
2:17	6006	Grey animal
2:20	6006	Tried to sample (probably crumbled and fell apart)
2:22	6008	Seems to be changing position
2:25	5993	Some boulders scattered in heavily sedimented surface
2:27	5983	Occasional white rocks (subangular)
2:28	5977	Lots of small white pebbles and subangular black boulders
2:29	5975	Debris material of various colors; many light pebbles and cobbles with very little fine sediment (at base of slope on contour map)
2:31	5975	Scoop #1 in Box #1
2:34	5965	Debris chute with white streaks
2:35	5953	Mixed debris; some boulders but mostly pebbles to cobbles
2:36	5951	R#20 in Box #5 *
2:38	5951	R#21 (stuck?) *?
2:39	5951	R#21 in Box #5 *
2:41	5944	Mainly cobbles and pebbles with ~50% sediment; looks like debris
2:42:30	5930	Some larger boulders
2:43	5920	Some light sediment surfaces with small rocks

2:43:30	5912	White streaks
2:45	5885	Stopping to sample at a boulder field
2:48	5890	R#22 in Box #8
2:49	5890	R#23 in Box #9
2:50	5889	Field of boulders (most have black coating)
2:52	5889	R#24 (?) in #8
2:57		End Dive



Sketch of the sample baskets
Dive# 975
Date: 1/9/2006
Observer: J.-I. Kimura
Port
Starboard
Marker
Push core
PC1
Scoop #1
Scoop
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
R25
R26
R27

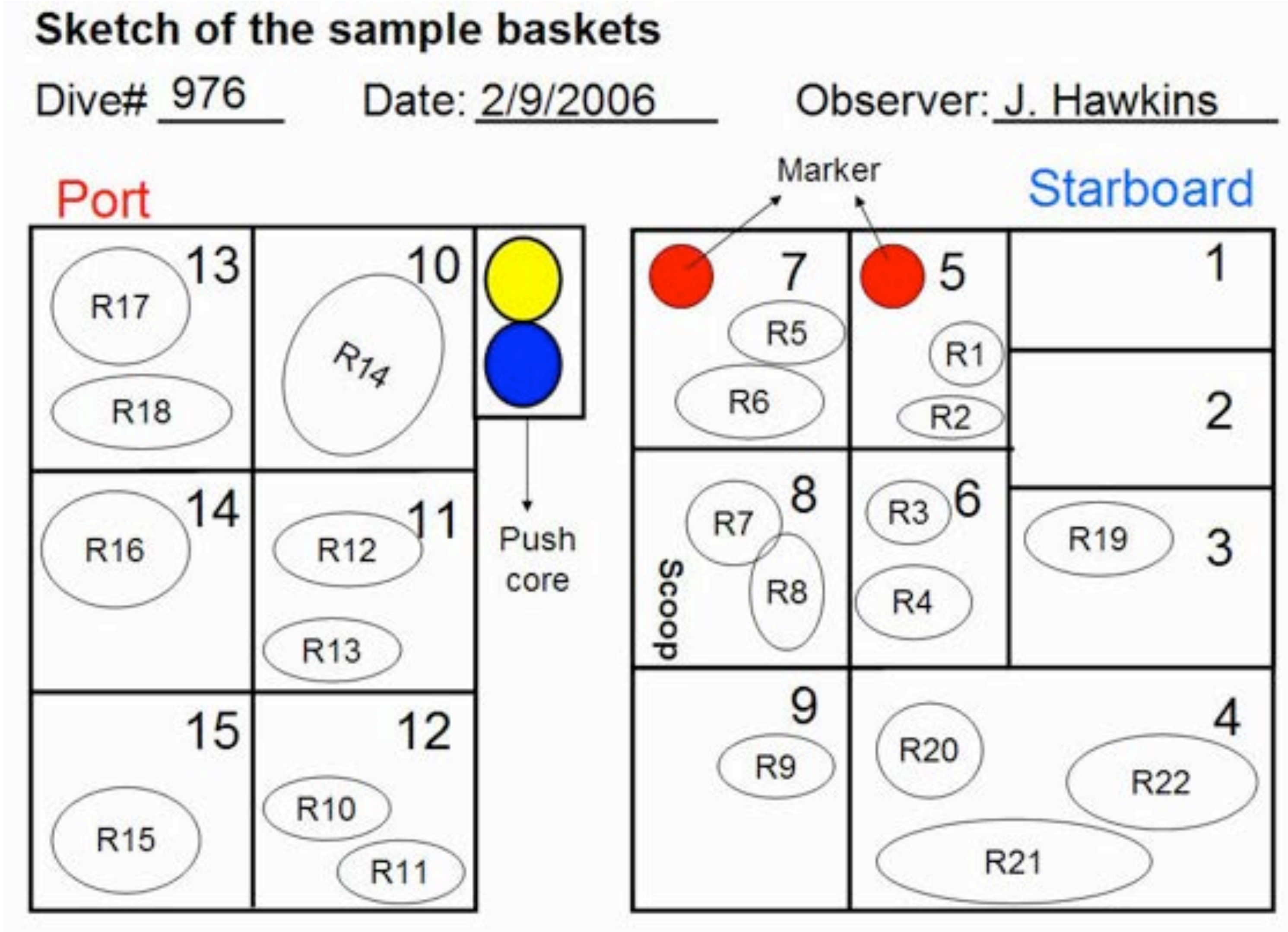
Dive 976 Date 9/2/06 Observer J. Hawkins

Time	Depth (m)	Comments
11:38	3795	Bottom in sight; boulders - cobbles ~50%; sediment ~50%; steep slope
11:43	3802	Sampling in Box #5 (Dropped it)
11:45	3802	Sampling R#1 in Box #5
11:48	3797	Still debris, but finer with few rocks
11:49	3792	Very much finer sediment with 3% cobbles
11:51	3798	Mostly finer sediment with occasional boulders
11:52:30	3767	Maybe outcrop on the slope with debris surrounding
11:55	3739	Slope with 3% cobbles and variable size pebbles and finer debris
11:56:30	3729	Much more rock looks like outcrop
11:58:30	3714	Rubbly with light and dark patches; some finer debris surrounding the rocks
12:04	3699	Outcrop of blocky rock; R#2 in Box #8
12:05	3699	Rock #3 (?) in Box #8
12:06	3696	Moving over sediment covered outcrop
12:08	3686	Gently sloping outcrop
12:09	3683	Rocky outcrops on coarse debris flow
12:12	3686	Rock and sediment; gentle slope
12:14	3687	Sampling R#4 in Box #7
12:15	3687	Sampling R#5 in Box #7
12:18	3686	Moving over rocky slope and outcrop
12:20	3665	Outcrop - maybe dikes?
12:22	3655	Sediment and outcrop (light-colored)
12:24	3634	Rocky outcrop
12:25	3628	E-dipping layers - outcrop
12:28	3615	Outcrop of slabby rocks
12:28	3615	Pillows?
12:30	3615	R#6 in Basket #8
12:32	3615	R#7 in Basket #8
12:33	3613	Traveling over slabby outcrop

12:35	3608	Large scale, rounded boulders
12:40	3579	Sediment covered slope with some rocks
12:43	3532	Large boulder (rounded) in debris
12:46	3511	Outcrop (brecciated?)
12:50	3503	R#8 in Basket #9
12:58	3477	Good basket image since sampling
12:59:30	3475	Blocky, rough outcrop (maybe hydrothermal alteration - white streaks)
1:00:45	3460	Rubbly surface, some outcrop with white streaks
1:02	3445	Rubble then smooth sedimented surface with a few rocks
1:03	3441 (4 m)	Smooth surface (sedimented); lifting off to move across the glat area at ~7m off bottom
1:11	3479	Turning to go up slope 330° heading; seafloor looks covered with sediment with burrows or small clumps of sediment
1:16	3481 (3 m)	Sediment with burrowing animal clumps and a trail (black) (occasional cobbles)
1:20	3473 (5 m)	Apparently bioturbated surface, sediment with small mounds
1:24:30	3466	Outcrop with sediment surrounding it; slabby surface with crevices between slabs filled with sediment
1:26	3465	More blocky/rubbly surface with some minor sediment
1:27:30	3465	Sampling? Long skinny R#9 in Box #12
1:30:10	3466	R#10; small, lighter rock in Box #12
1:34:50	3455 (7 m)	Moving over slabby rock with
1:35:35	3452	Outcrop with white streaks; very rough
1:36:20	3453 (3 m)	Smooth sedimented surface with small clumps from burrowing animals
1:37	3452	Large boulders scattered on rubbly to smooth sedimented debris
1:38:25	3448	Rubbly
1:39:30	3442	Bolder in rubble to smooth sediment
1:41:25	3429	Mostly boulders
1:42	3426	Mostly debris with a few boulders
1:43:30	3411	Smooth sediment with occasional boulders
1:46:40	3381	Debris
1:48:20	3365 (6 m)	Looks like fine debris with very rare cobbles from 6 or 7 m up
1:52	3323	Debris slope; mostly fine to medium material with some

1:53:30	3321	Settling down on very rough, rubbly surface to sample R#11 in Box #11; R#12 in Box #11
1:57	3318	Moving again; debris surface with some boulders and cobbles
1:59	3305	Debris flow (boulders with finer surrounding matrix)
2:00:15	3297	Fine mud/debris surface
2:02:40	3275	Fine mud/debris with many clasts
2:04:30	3278	Very rubbly with many clasts; sampling
2:05:00	3278	R#13 in Box #10
2:07	3278	Yellow push core attempt, failed
2:09	3275	Moving
2:12	3276	Rubbly outcrop
2:17	3220	R#14 (volcanic breccia?) into #15
2:21	3215	Moving over rubbly outcrops
2:22:22	3213	Debris with occasionally larger boulders
2:25:30	3288	Boulders and blocks with surrounding pale matrix (mud?)
2:27:45	3168	Outcrop breccia with light veins and alteration
2:29	3163	Sampling R#15 (light with black coating) in Box #14 from a steep face of rubble in a pale matrix
2:34:17	3159	Looking at steep slope with mainly light colored mud/matrix
2:39:15	3133	Some rounded boulders in mud
2:39:55	3128	Sponge
2:40:30	3127	Finer debris and sediment with bioturbation lumps
2:42	3124	Outcrop? Of rubbly surfaced rock (?)
2:43	3120	Smooth sedimented surface with many dark (MnO?) pebbles and debris
2:45:22	3114	Abundant pebbles and cobbles of debris
2:46	3111	Outcrop of solid rock with some loose blocky surfaces stopping to sample
2:47	3110	R#16; small, orange/red into Box #13 (has a black coating on one side)
2:50	3108	Solid rock face (close-up)
2:51	3105	Upslope from outcrop surface in groove with a little sediment in the bottom of the grooves
2:53:10	3094	Light blocky jointed outcrop
2:54	3086	Layered looking outcrop with angular joint pattern on upper
2:56	3085	Flat surface lightly sedimented with a few loose blocks or rubble

2:57	3086	Pavement with linear joint pattern sedimented between blocks
2:59:30	3086	Stopped to sample R#17
2:03	3087	Close up of sample R#17 in Box #1
3:06	3084	Moving
3:10	3071	Outcrop of rough rock in light matrix
3:10:20	3070	Smooth solid rock slope with fractures
3:11	3069	Smooth slope with some fissures; in some places it is slabby
3:14	3072 (6 m)	Slabby flat surface with cracks between slabs and sediment infilling
3:18:48	3071 (5 m)	Edge of darker pavement (edge is irregular scalloped)
3:27	3055 (3 m)	Smooth sedimented surface with trails and small bioturbation mounds
3:28:30	3051 (4 m)	A few boulders
3:31	3043 (7 m)	Faint image (some boulders?)
3:36	3084 (18 m)	At the north margin of the
3:37:17	3092 (8 m)	Seeing bottom sedimented and showing bioturbation and some small rocks
3:39:30	3085 (4 m)	More rubble with sediment
3:43	3080 (4 m)	Some rocks with current effects (down current to upper left)
3:43:45	3078 (4 m)	Lots of rocks
3:44:50	3078 (1 m)	Stopping to sample R#18 long; their rock with black coating on one side in Box #4 also R#19 (small rock)
3:52	3078	Leaving the bottom


Sketch of the sample baskets
Dive# 976
Date: 2/9/2006
Observer: J. Hawkins
Port
Starboard
Marker
Push core
Scoop
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22

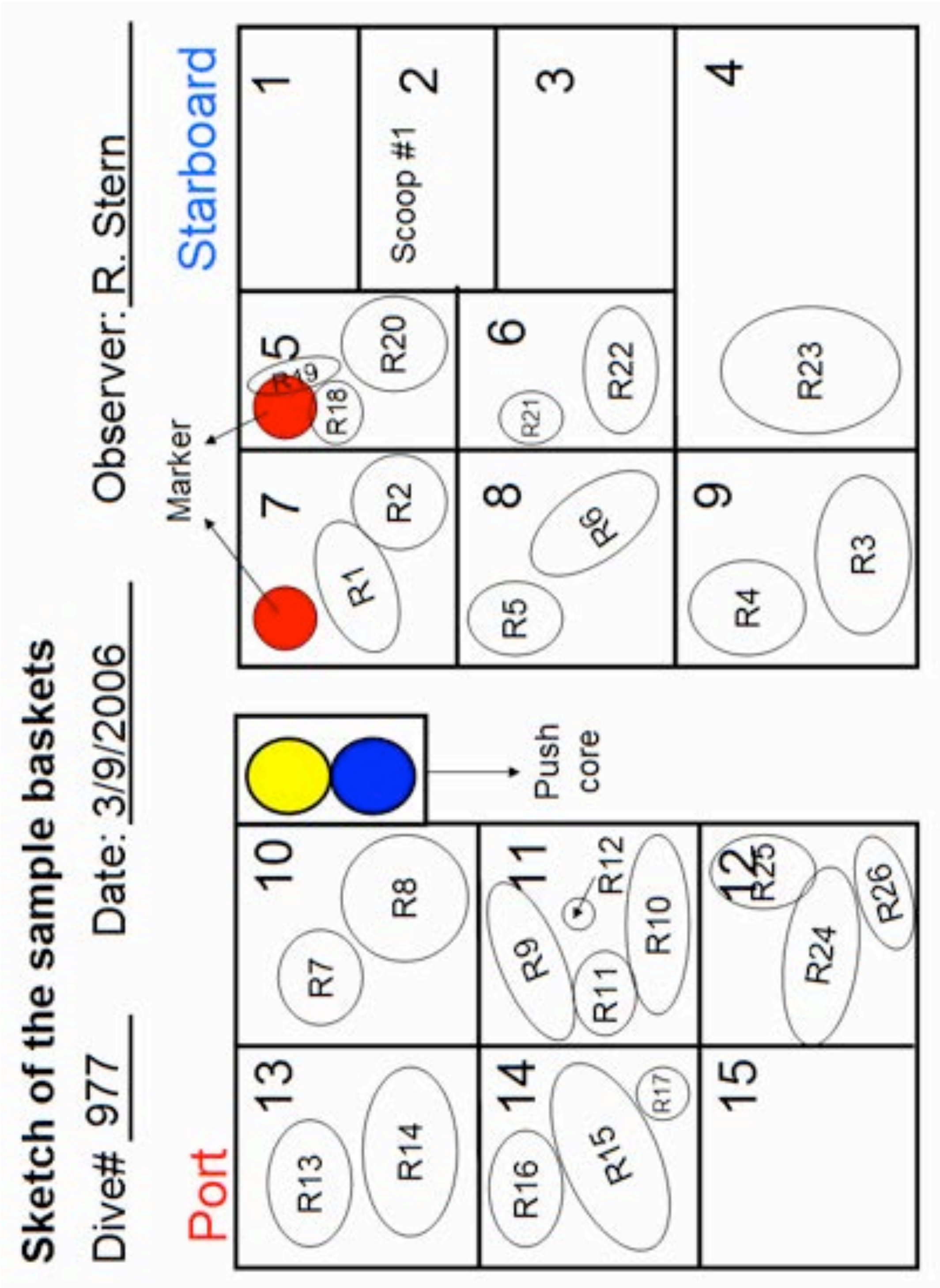
Dive **977** **Date** **9/3/06** **Observer** **R. Stern**

Time	Depth (m)	Comments
11:36	6358	Bottom in sight; debris
11:41	6363 (0)	On bottom; fairly steep talus-covered slope with ~50% sediment; Sampling R#1 and R#2 in Box #7 **
11:48	6357	Sedimented surface
11:53	6346	Sedimented surface with a few scattered boulders
11:54:42	6339	1 large boulder subrounded in sediment
11:55:17	6336 (2 m)	Field of large, subrounded to subangular boulders with sediment between
11:58	6311	Smoother surface with a few boulders
12:01	6299	Small cobbles 70%
12:04	6296	Small cobbles 70% with occasional boulder
12:06	6296	Sampling R#3 in Box #9 *
12:07	6296	Sampling R#4 in Box #9 *
12:07:50	6296	Large blocky, angular boulders and cobbles
12:09	6291	Cobbles ~80% with occasional boulder
12:10:40	6282	Smooth, large boulders (gabbro?)
12:12	6269 (4 m)	Cobbles 50%; boulders 20% (angular)
12:14:40	6251	Many boulders ~90%
12:16:30	6235	Cobbles ~90%; lots of small rocks; one very large, angular boulder
12:20:30	6205	Lots of small rocks with some boulders
12:21:14	6206	Sampling
12:22:09	6206	R#5 in Box #8 *
12:23	6206	R#6 in Box #8 *
12:24:20	6204	Lots of small rocks to cobbles ~95%
12:26:00	6194	Sedimented surface with small rock and occasional large boulder
12:28	6176	Cobbles ~90%; some larger
12:29:45	6157	Large, angular boulder surrounded by small rocks
12:34:20	6109	Lots of small boulders (angular)
12:35:50	6106	R#7 in Box #10; large and angular *
12:36:40	6106	R#8 in Box #10 *

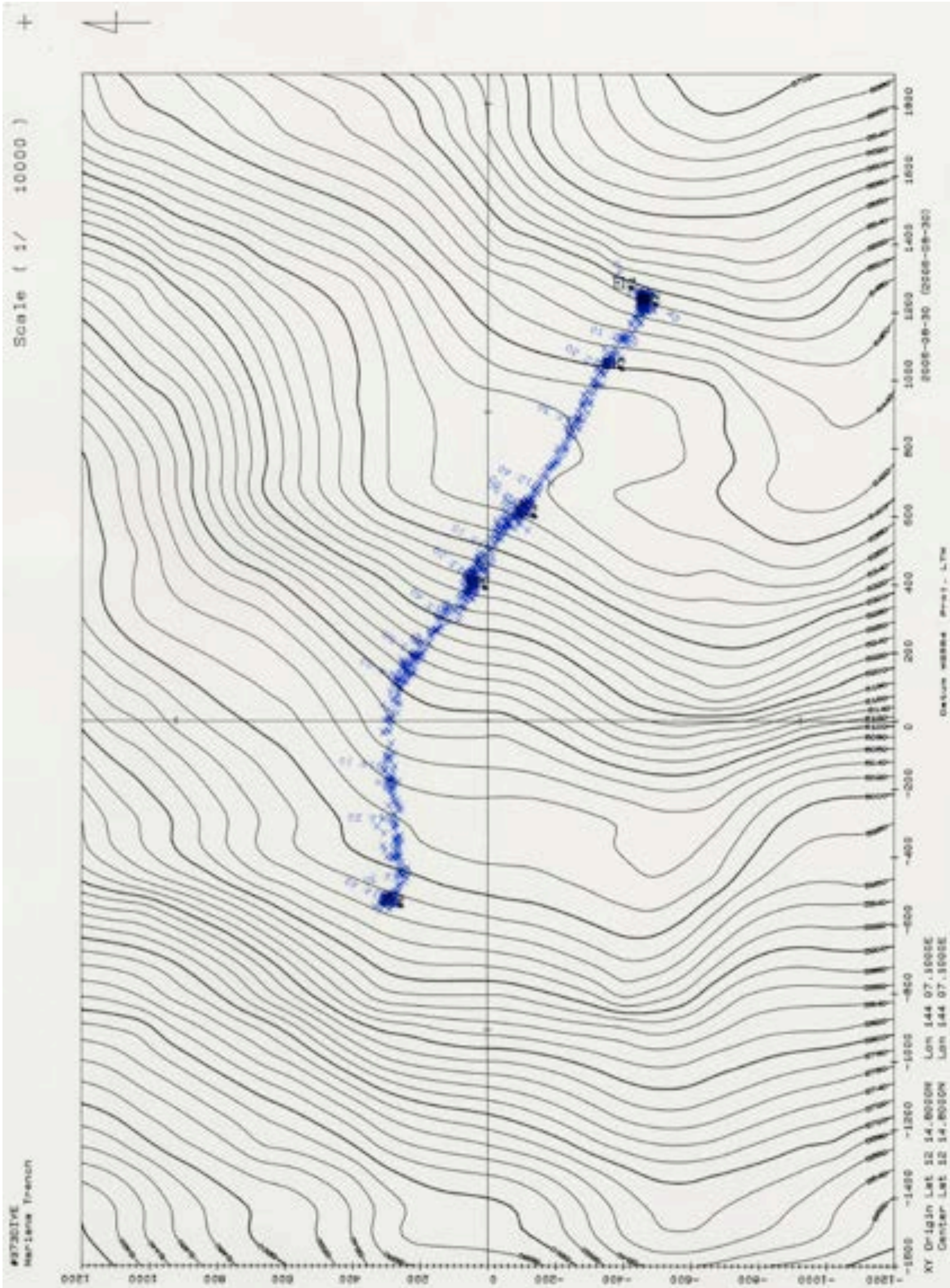
12:38:30	6103 (3 m)	Large, angular to subangular blocks with little sediment (between blocks)
12:40	6089	Large, angular to subangular blocks with little sediment (between blocks)
12:41	6074	Slope is covered with more sediment and finer pebbly debris surrounding boulders
12:45:30	6032	Continuing sediment with boulders
12:47	6020	Smoother sedimented slope
12:48	6008	Rough surface with ~50% sediment between and dusting rocks
12:50	5998	A steeper slope with tongues of finer debris surrounding rough textured boulders
12:51:30	5996	Possible outcrop with some loose boulders and sediment between
12:53	5998	R#9 (red) in Box #11 *
12:56:30	5994	R#10 (larger) in Box #11 *
12:57:30	5994	R#11 (even larger) in Box #11; R#12 (in Box 11?) (maybe in 10?) **
12:59	5994	Leaving sample locality
1:00:30	5994	Seafloor looks like it has layering and slopes up to the upper right
1:02		Turning course to 270° and lifting off bottom
1:13:43	6015 (13 m)	Steep slope up to right covered with rough rubble with a finer matrix or sediment between boulders
1:15:30	6005	Rubble with cobbles and boulders surrounded by finer debris
1:17:00	6005	Stopped to sample
1:18	6004	R#13 in Box #13 (and maybe a very small piece) *
1:20:30	6002	R#14 in Box #13
1:22:50	6001	Finer rubble covered slope
1:23:53	5996	~50% fine matrix overlain with ~50% larger cobbles to boulders
1:28:50	5956	Some large boulders with ~70% finer debris and sediment
1:30:50	5938	Back to ~50/50 sediment and angular to subangular blocks
1:33	5912	Numerous (70%) boulders; many are rounded and they are a variety of colors
1:33:40	5915	Fine sediment cover with a few angular blocks
1:34	5908	Debris with a few blocks (angular)
1:35	5902	Stopped to sample blocks (some black, some light, one huge orange one) sitting on a surface with finer debris between the rocks
1:38	5902	Picked up light (orange) R#15; broke apart when going into box #14 *

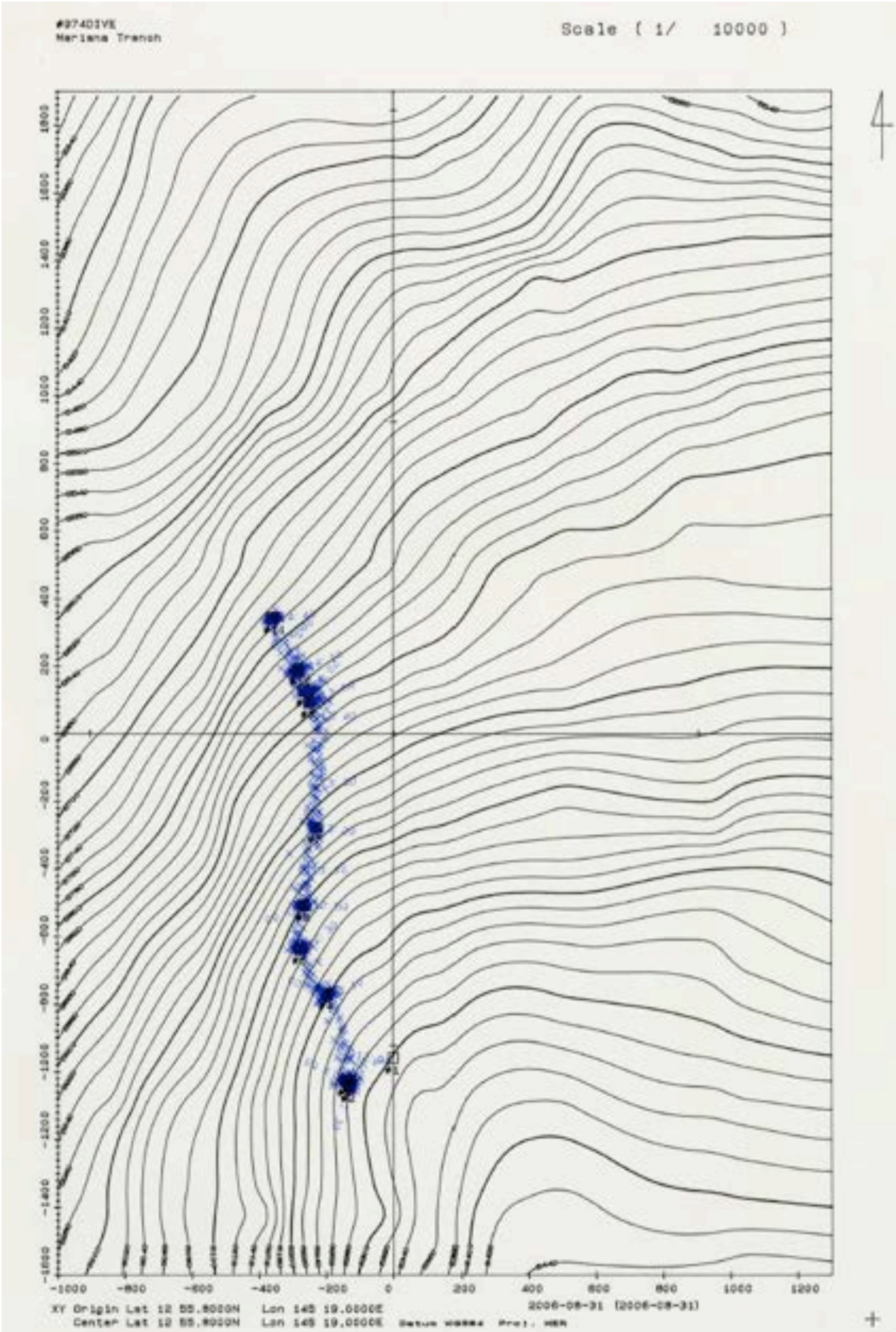
1:40:44	5901	R#16 in Box #14 *
1:43	5900	Looking at surface with both rounded light-colored cobbles/boulders and dark angular blocks
1:47	5866	More fine debris than boulders or blocks
1:47:50	5858	Fining up-slope
1:48	5854	More big dark angular blocks
1:49	5845	All angular blocks with sediment between and some light dusting of sediment
1:50:57	5823	Brittle star on boulder; all blocks angular, sediment between
1:52	5809	Big, light block
1:53	5801	Stopped to sample (most rocks are angular and dark sitting in brown sediment; some rocks look brown)
1:55:45	5795	Very square R#18 in Box #5; small brown R#19 in Box #5; maybe picked up R#20 first (box #5) ***
1:58:30	5795	Leaving sample locality (view of seafloor shows angular dark blocks in brown sediment/debris)
2:01:30	5774	Still seeing angular blocks surrounded by finer sediment
2:03	5758	Larger blocks slightly less angular; 2 brittle stars
2:03:30	5749	Many more blocks (little sediment)
2:05:45	5719	Rough surfaced rocks with sediment between
2:07	5703	Looks like outcrop with blocky surface; jointed; stopping to sample
2:08	5696	Starting to sample
2:12	5690	R#21 brown/orange rock with 1/2 black coating in Box #6 *
2:17	5687	R#22 probably in Box #6 *
2:18:20	5687	R#23 in Box#4
2:20:30	5687	End of sampling
2:21:20	5679	Boulders (dark angular) with brown sediment)
2:22:11	5670 (3 m)	Travelling over broken outcrop
2:23:10	5652	Larger blocks with more sediment
2:24:30	5636	Outcrop?

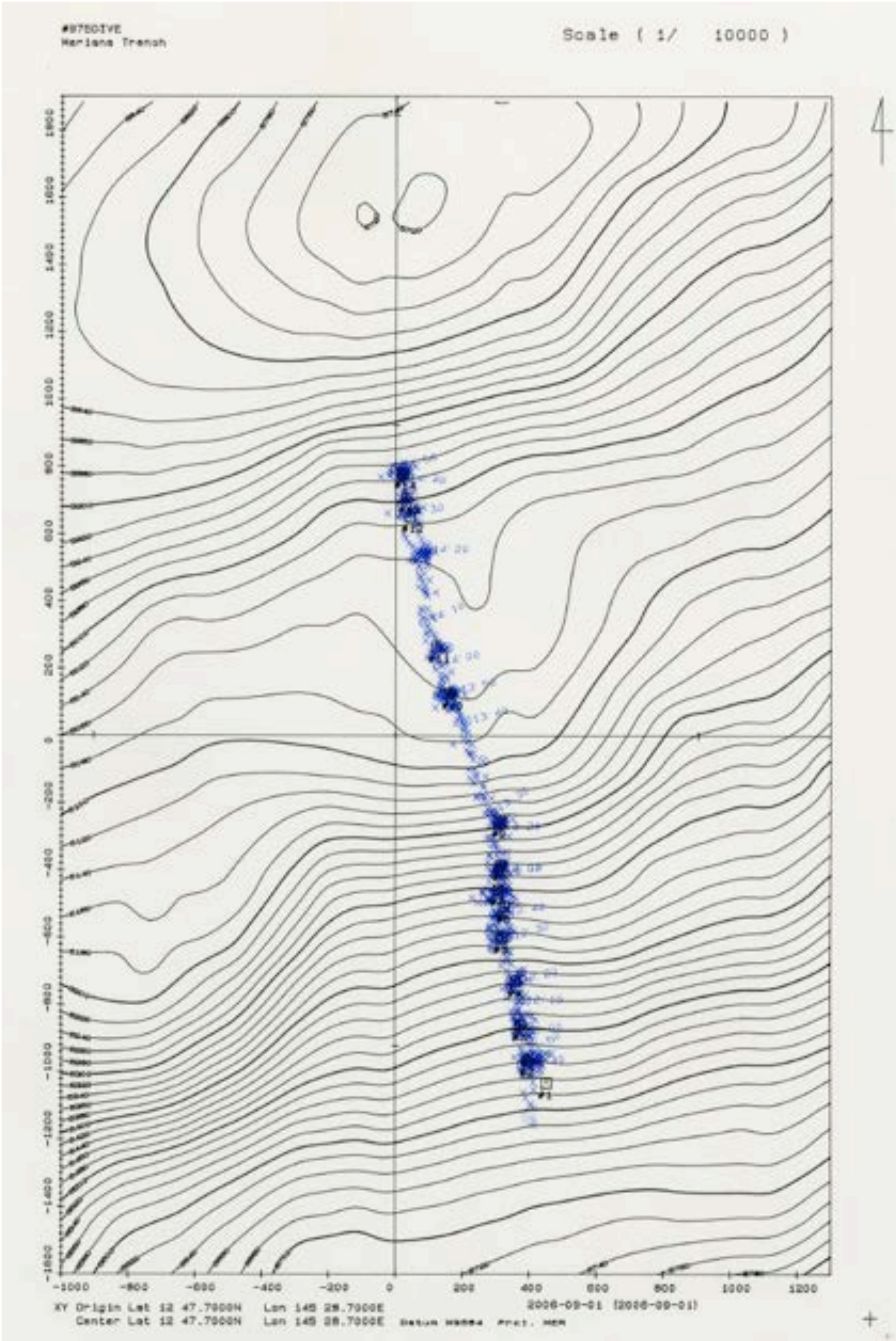
2:26:28	5613	Blocky boulders; little sediment
2:27:30	5603	Variable types of blocks
2:28:30	5600	Stopped to sample
2:30	5601	R#24 in Box #12 *
2:31	5601	R#25 in Box #12; very orange *
2:32:10	5601	R#26 in Box #12
2:32:50	5601	Leaving sample locality
2:35:40	5594 (4 m)	Looking down on rocky seafloor with some sediment
2:39	5584 (3 m)	Very blocky, angular boulders with sediment between
2:40:10	5575 (3 m)	A patch of lighter sediment than seen before
2:41:20	5560 (6 m)	Rubbly surface with numerous boulders; steep slope with small channels
2:43:15	5545	Sponge
2:44:13	5531	Steep slope with light sedimented shelves and channels
2:45:21	5518	Lots of light sediment
2:46	5509 (7 m)	Light sediment with some cracks showing light interiors
2:47:20	5499	Layered strata
2:49	5489	Layered sediment
2:49	5484	Red layers of sediment; stopping to sample
2:51:50	5483	Removing scoop
2:55	5482	Streaks of grey sediment covered with brown debris
2:56:25	5482	Picture of where scoop was taken; shows very light material
2:58:30	5483	Scooped up some of the light sediment layer; returning scoop
3:00	5483	To Box #1 and ended dive; the sediment surface shows some white patches

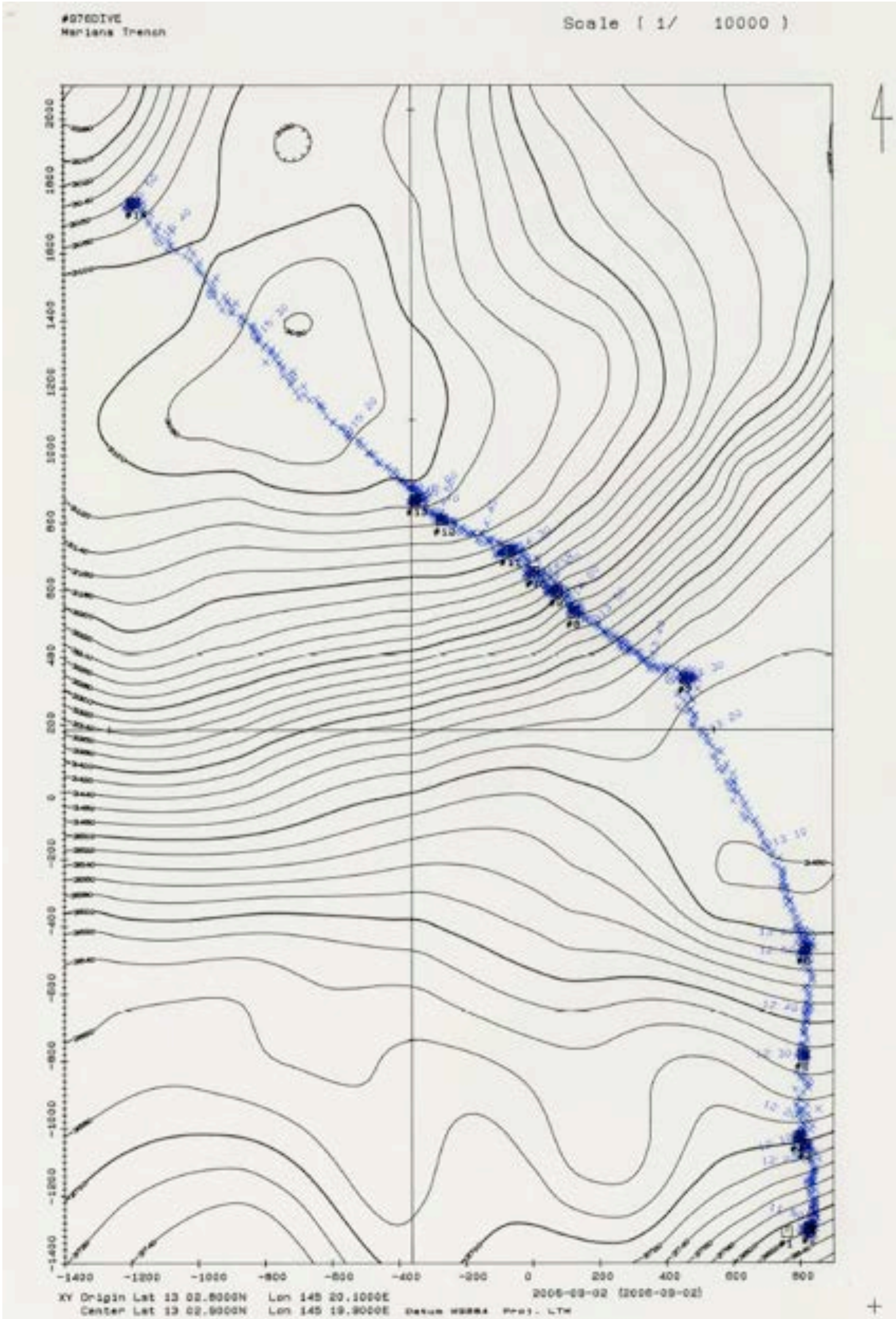

Sketch of the sample baskets
Dive# 977
Date: 3/9/2006
Observer: R. Stern
Port
Starboard
Marker
Push core
Scoop #1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
R25
R26

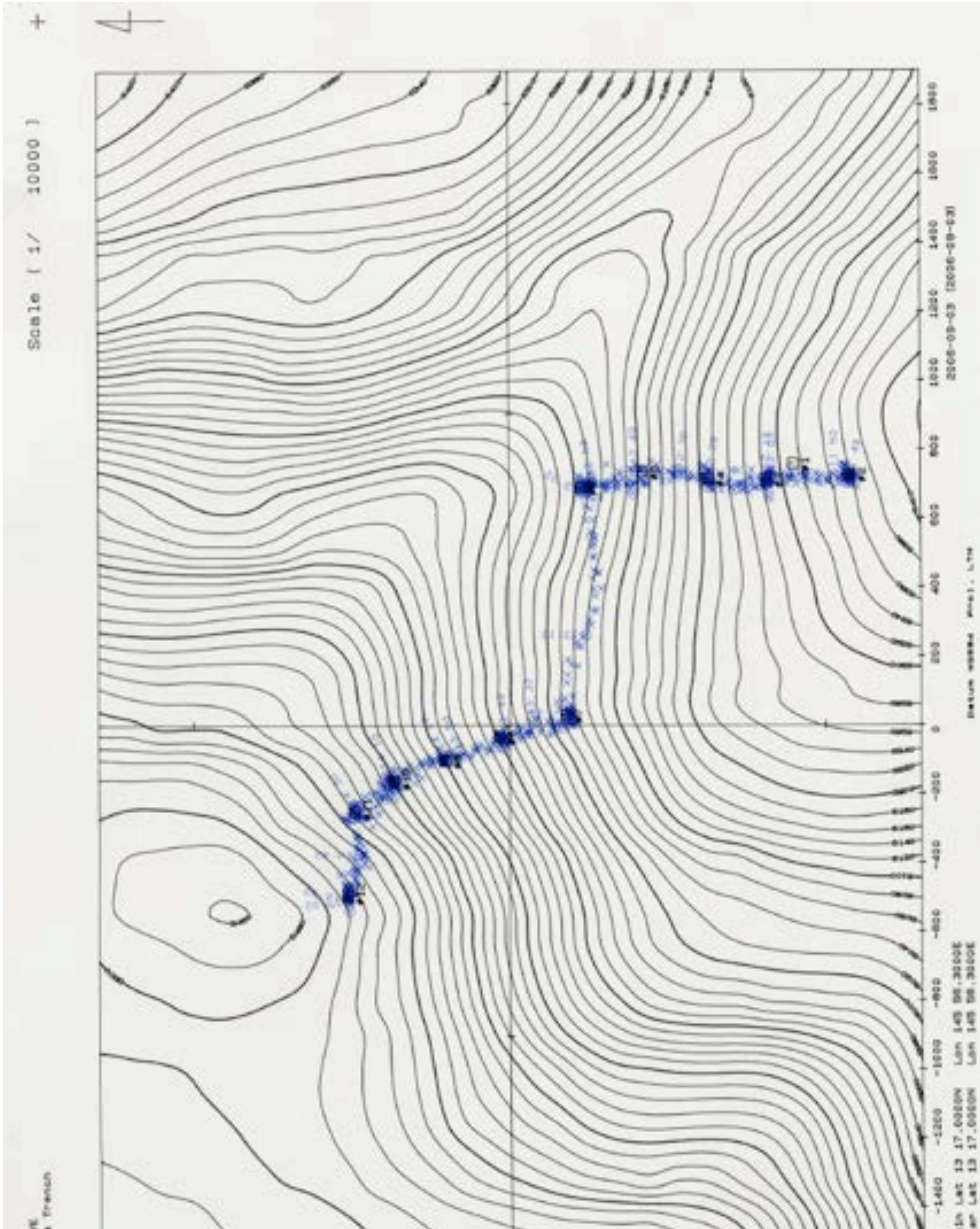
Appendix B: Dive tracks on X-Y coordinates


Scale (1/ 10000)


#974DIVE
Mariana Trench
Scale (1/ 10000)
4
-1000 -800 -600 -400 -200 0 200 400 600 800 1000 1200
XY Origin Lat 12 55.8000N Lon 145 19.0000E
Center Lat 12 55.8000N Lon 145 19.0000E
2006-08-31 (2006-08-31)

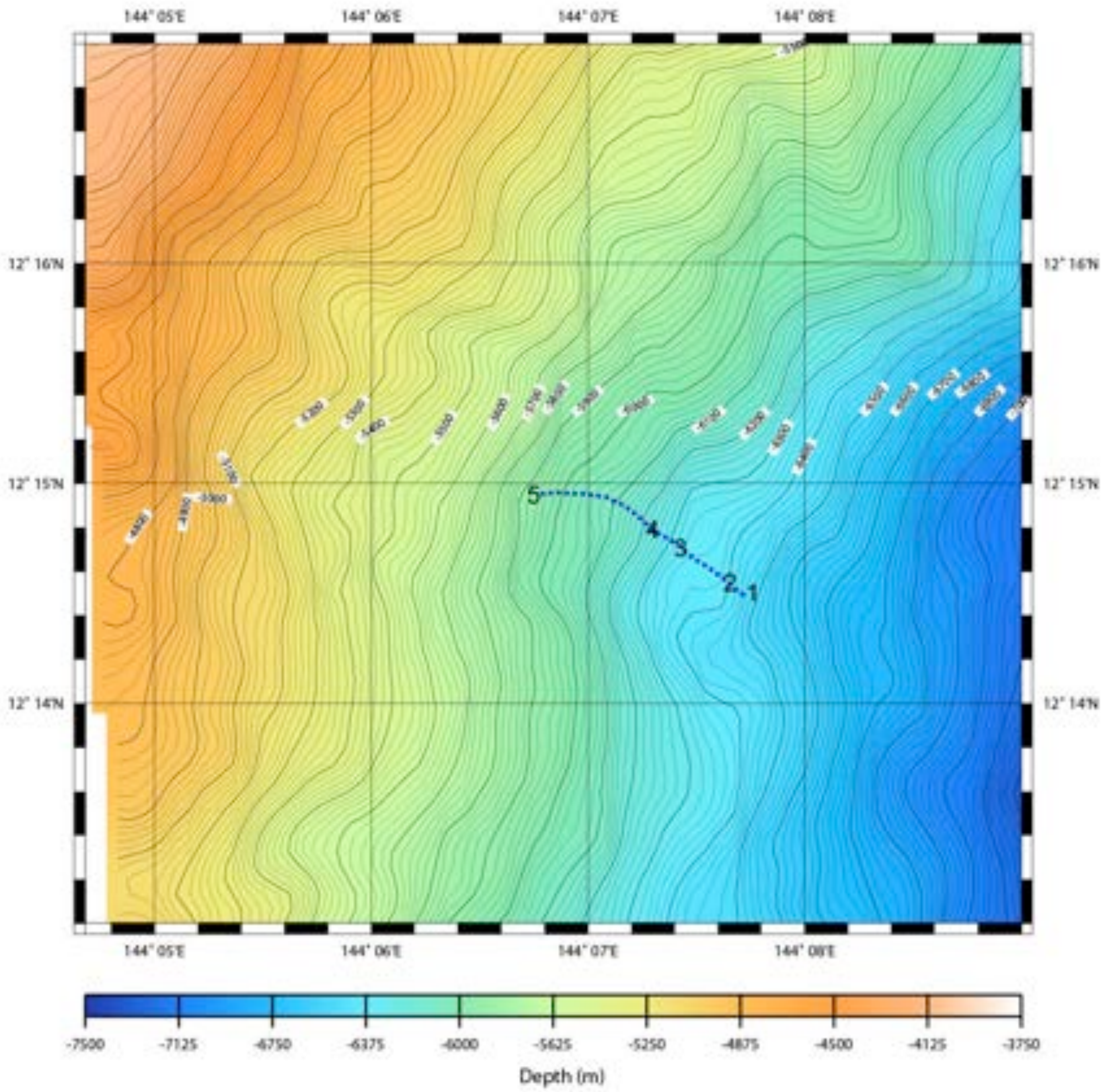

Mariana Trench
Scale (1/ 10000)
XY Origin Lat 12 47.7000N Lon 145 28.7000E
Center Lat 12 47.7000N Lon 145 28.7000E
2006-09-01 (2006-09-01)
4


#976DIVE
Mariana Trench
Scale (1/ 10000)
4
XY Origin Lat 13 02.8000N Lon 145 20.1000E
Center Lat 13 02.9000N Lon 145 19.9000E
2006-09-02 (2006-09-02)

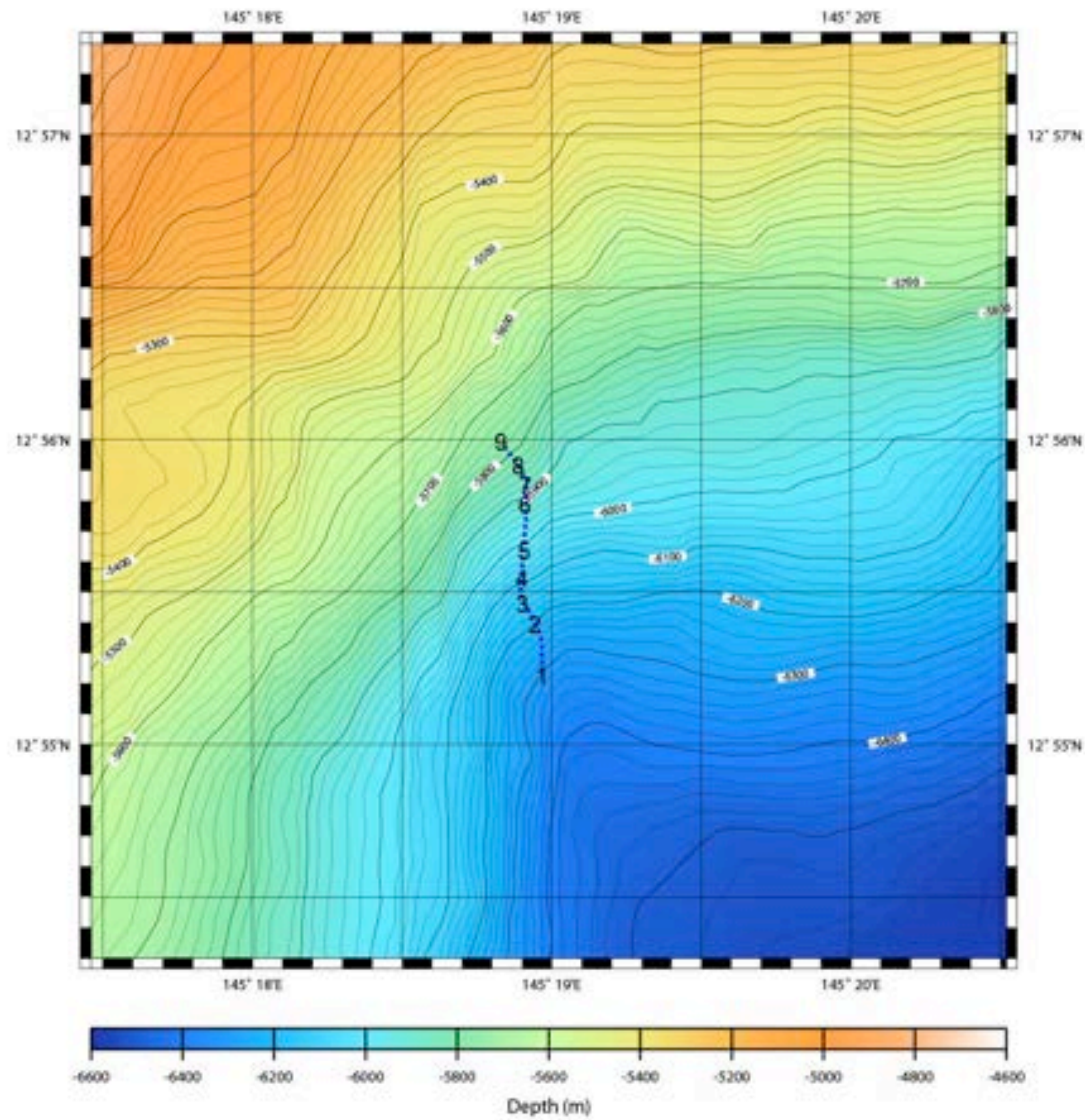

Scale (1/ 10000)

Appendix C: Dive tracks and sampling stations superimposed on color bathymetry map

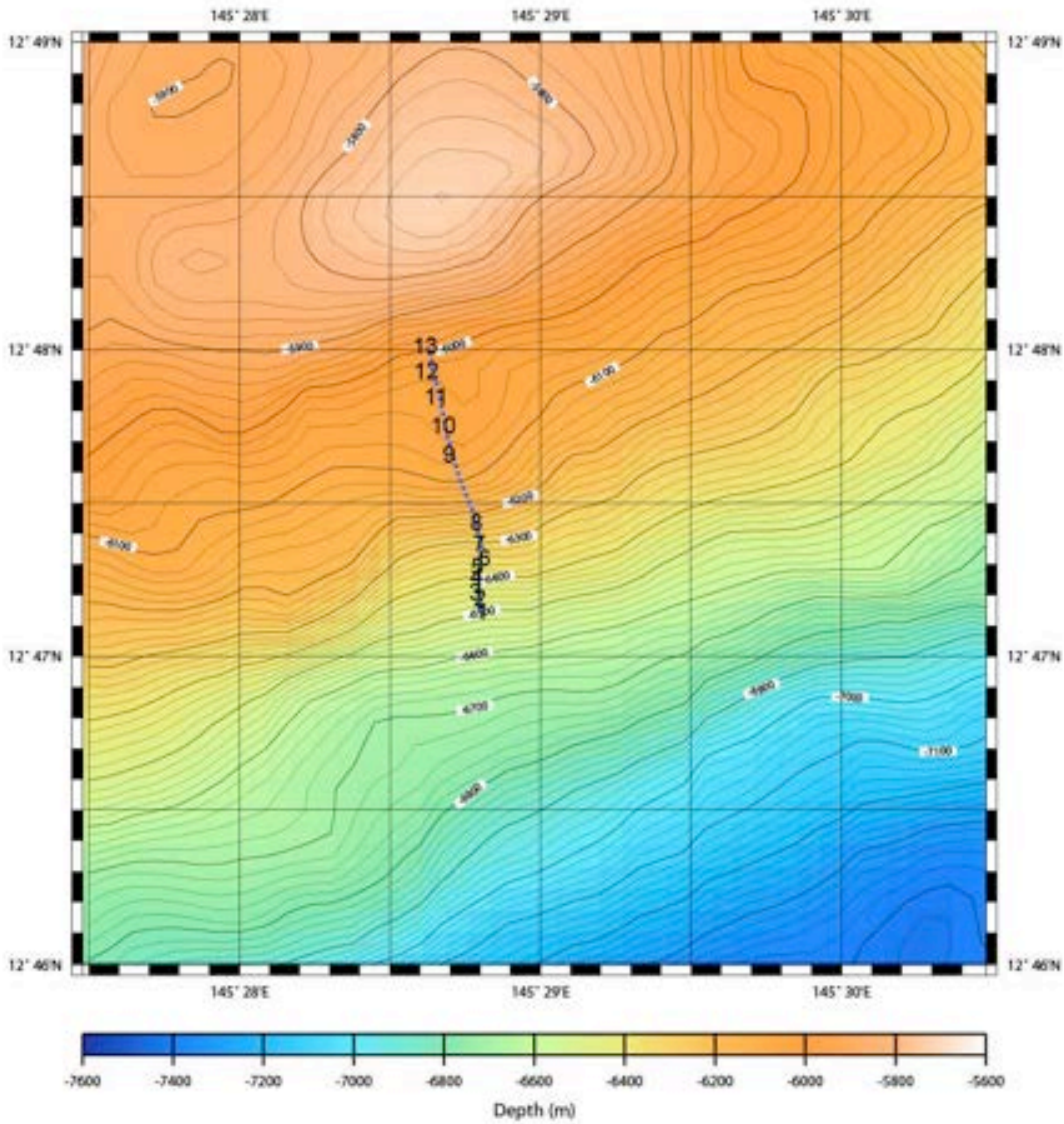
Dive #973 dive track and sampling stations



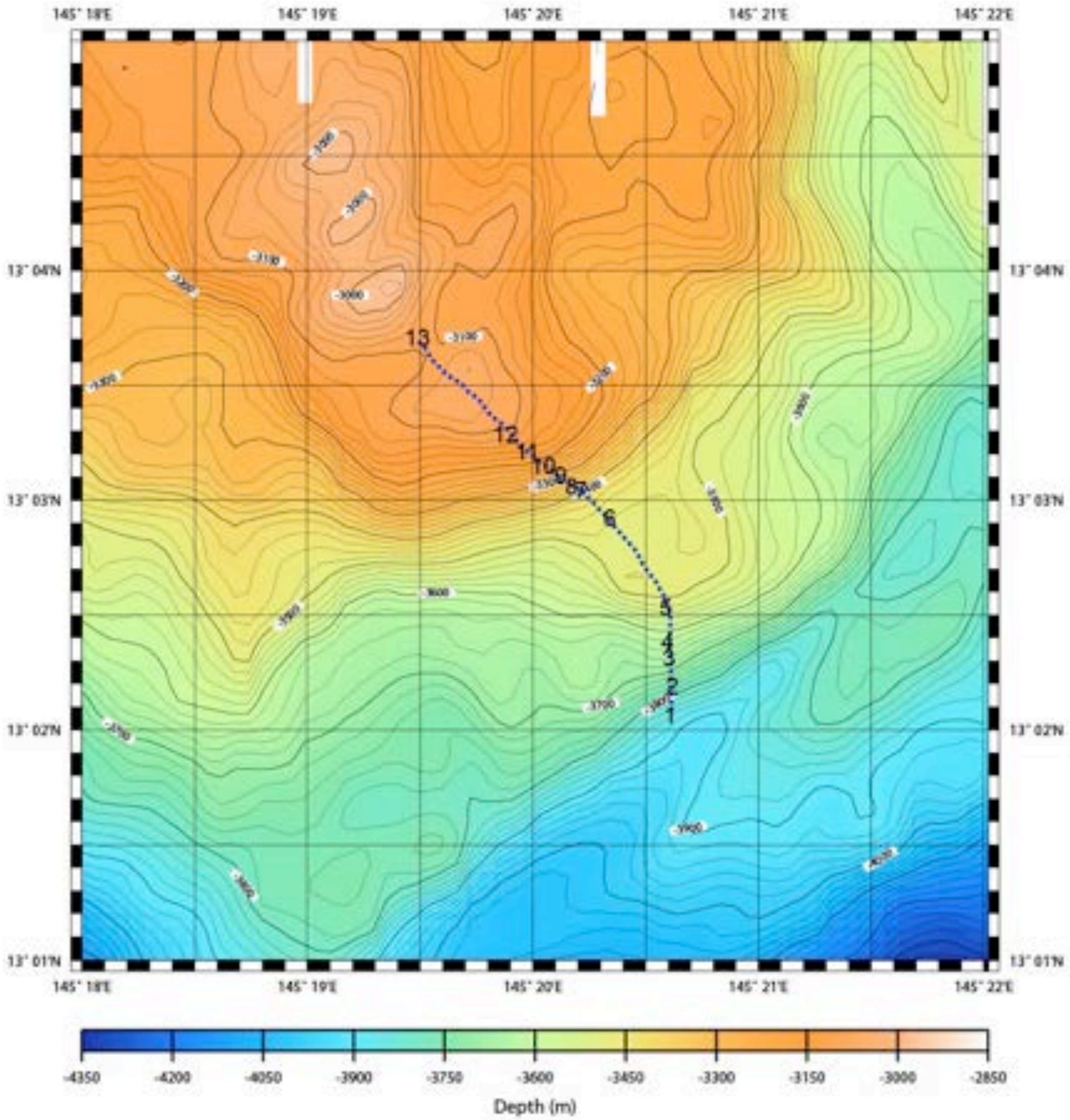
Dive #974 dive track and sampling stations



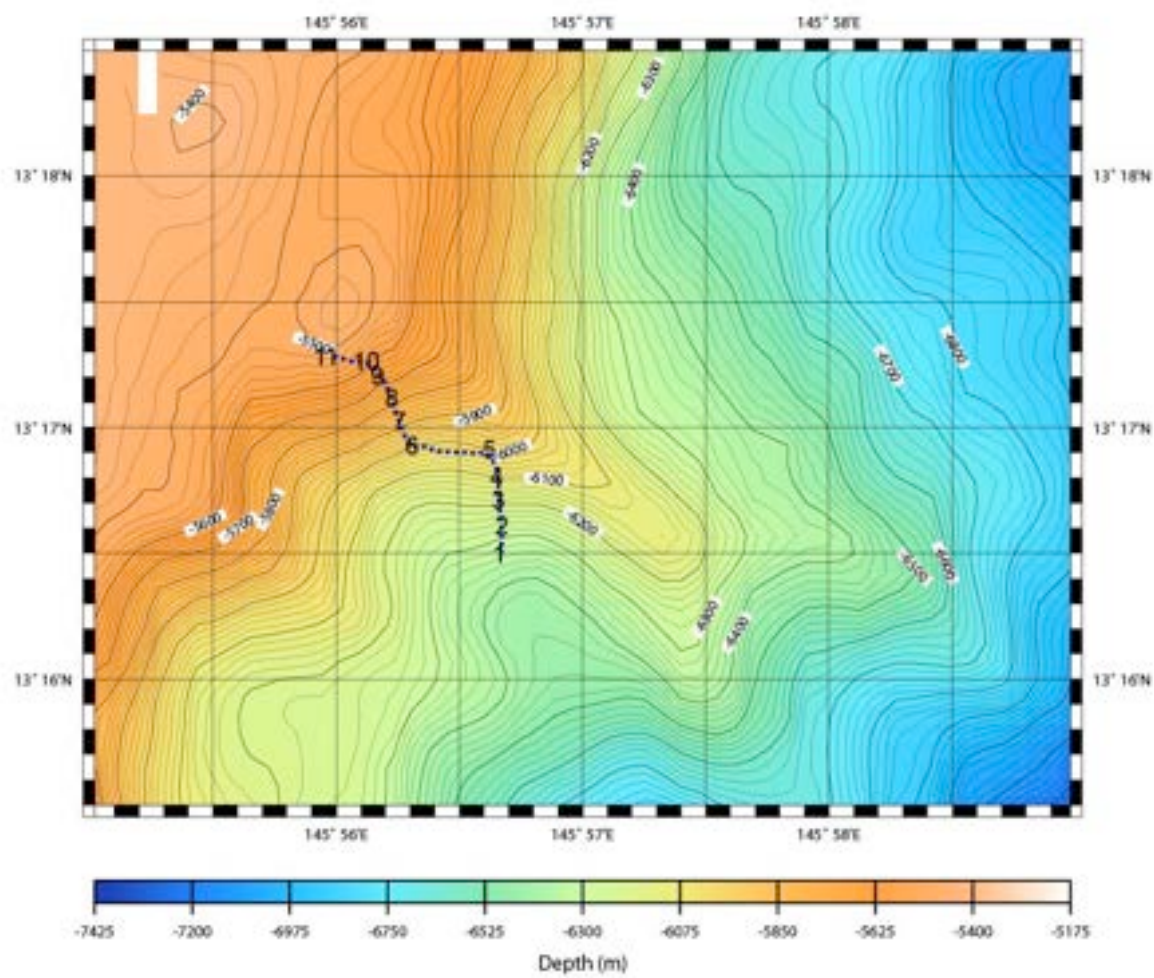
Dive #975 dive track and sampling stations



Dive #976 dive track and sampling stations



Dive #977 dive track and sampling stations



Appedix D: Sample decriptions

Dive #973	Described by SHB, OI and KM										Sample characteristics								
Sample #	Lithology	Ave. grain size	Igneous texture	Glass (mm)	Plag. (%)	Oliv. (%)	Px. (%)	Hbl. (%)	Other (%)	Alt. minerals %	Wt (kg)	X (cm)	Y (cm)	Z (cm)	Weathering	Angularity	Surface	Mn (mm)	Comments
R1	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	50-60	10?	-		20-30	8.5	24	19	15	moderate to high	angular	brown grey	<1mm	angular, brown grey surface, serpentinized
R2	Serpentinized dunite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	60-70	<5	-		20-30	3.8	22	11	9	moderate to high	angular	brown grey	<1mm	angular, brown grey surface, serpentinized
R3	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	20-25	5-10?	-		60-70	25	45	21	20	moderate to high	rounded		<1mm	large, elongate smooth block
R4	Serpentinized dunite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	40-50	<5	-		40-50	2.5	25	19	14	moderate to high	angular	brown grey	<1mm	angular, brown grey surface
R5	Serpentinized dunite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	50-60	5-10?	-		30-40	1.5	22	13	12	moderate to high	sub angular	brown grey	<1mm	subangular, brown grey
R6	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	40	<5	-		50-60	1.4	22	11	8	moderate to high			<1mm	
R7	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	50	10	-		30-40	1.2	13	9	7	moderate to high		grey brown	<1mm	grey brown surface, serpentine coating with slickensides
R8	Serpentinized dunite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	60-70	<5	-		20-30	1.5	12	11	9	moderate to high	sub angular	brown grey	<1mm	subangular, brown grey surface
R9	Serpentinized dunite	<1mm - 1 cm	porphyroclastic to mylonitic?	-	-	40	<5	-		60	2.7	26	13	7	moderate to high	angular	brown grey	<1mm	angular, brown grey surface with white vein on surface
R10	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	30-40	5-10?	-		60-70	0.5	9	8	8	moderate to high	angular	brown orange	<1mm	angular, brown orange
R11	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	60-70	5-10?	-		20-30	8.8	35	14	10	moderate to high	angular	grey brown	<1mm	angular, grey brown block, < 1mm Mn
R12	Serpentinized harzburgite	<1mm - 1 cm	sheared plutonic, porphyroclastic	-	-	20-30	5-10?	-		50-60	6	22	17	14	moderate to high	angular	green black	<1mm	angular, green black surface
Scoop 1	Various plutonic gravels	<1mm - 1 cm																	Scoop 1
Push Core 1	Sediment and water	<1mm - 1 cm																	Push Core 1

Estimates of mineral proportions for igneous samples are estimates of the original amounts present in the rock; tr indicates trace amounts.

Dive #974	Described by SHB and OI										Sample characteristics								
Sample #	Lithology	Ave. grain size	Igneous texture	Glass (mm)	Plag. (%)	Oliv. (%)	Px. (%)	Hbl. (%)	Other (%)	Alt. minerals %	Wt (kg)	X (cm)	Y (cm)	Z (cm)	Weathering	Angularity	Surface	Mn (mm)	Comments
R1	Dacite	<1 mm	microphyric, aphanitic		2		1	2		5	4.9	18	12	13	slight	angular	grey brown	stain	anulgar, grey block, <1mm Mn stain on some surfaces
R2	HB gabbro	1-4 mm	equigranular, phaneritic		50	2?	40	10	OPX?	5	10.4	23	19	18	slight	rounded	brown grey	stain	spheroidal, smooth brown surface, 1-3 cm weathering rind on one side
R3	Coarse sandstone to conglomerate	1-20 mm									6.2	14	17	25	high	angular	brown tan	Mn sand cement	poorly sorted lithic conglomerate, rectangular block with a thick Mn-rich sand on one sand
R4	OL-PX phyric volcanic	to 2 mm	porphyritic			5	10			10	2.1	13	9	10	some	angular	grey, black	stain	subangular, grey block, Mn stain
R5	OL-PX phyric diabase	to 3 mm	porphyritic, diabasic groundmass			5-8	5-10			15	11	21	23	18	some	angular	grey, black	stain	subangular brown grey block with Mn stain
R6	OL-PX phyric diabase	to 3 mm	porphyritic, diabasic groundmass			5-8	5-10			10	2.4	11	14	11	some	rounded	grey black	stain	subrounded brown-grey block with Mn stain
R7	Andesite to dacite		pl-phyric,dense	-	20-30		<1				4.1	15	15	18	fresh	angular	light gray (lower), black (upper)	film (upper part)	
R8	Dacite to rhyolite	<1mm	highly crystalline	-	60-70		5-6	~1			0.5	9	6	8	oxidized	rounded	light gray (lower), black (upper)	film (upper part)	
R9	Pillow breccia	~12cm		glassy rind (~3mm)						~10	5	15	22	13	some alteration in glass fragments	angular	black	film	
R10	Pillow breccia	0.5-1cm		many glass fragments						-	1.4	12	9	8	fresh	angular	black	film	

R11	Dacite to andesite	<<1mm	massive, non-vesiculated	-	5		2	<<1		-	9.4	23	15	24	none	angular	ight gray	0	
R12	2PX andesite-dacite	~1.5mm	pl-phyric	-	12-15		6			-	5.3	12	13	18	none	angular	matrix attached block	5	
R13	2PX andesite-dacite	~1mm	pl-phyric	-	10		3-4			-	0.8	12	7	6	none	angular	block	film	
Scoop 1	Brown sediment																		
Scoop 2	Diabasic fragments																		
Push core 1	Sediment																		
Loose samples #1 from basket	Various volcanic and diabase																		
Loose samples #2 from basket	Various volcanic and diabase																		

Dive #975	Described by SHB and OI										Sample characteristics								
Sample #	Lithology	Ave. grain size	Igneous texture	Glass (mm)	Plag. (%)	Oliv. (%)	Px. (%)	Hbl. (%)	Other (%)	Alt. minerals %	Wt (kg)	X (cm)	Y (cm)	Z (cm)	Weathering	Angularity	Surface	Mn (mm)	Comments
R1	Fine-grained gabbro	1-3 mm	equigranular	-	40-60	minor?	40-60			10%?	4.4	19	12	11	medium	angular	brown grey	stain	angular block with grey brown surface and some Mn staining
R2	Troctolitic gabbro	2-3 mm	cumulate	-	30-40	40-50	5-10	-	-	10%	3.2	25	12	10	some	angular	grey	stain	angular block, grey to black surface, some Mn staining
R3	Fine-grained gabbro	1-3 mm	equigranular	-	40-60		40-60	-	minor OPX?	10%	7	23	14	15	slight	sub angular	grey to black	stain	subangular block, light grey to black with <1mm Mn.
R4	Diabase to gabbro	1-4 mm	equigranular locally	-	50-60		40-50			15%	2.5	15	12	11	moderate	angular	brown grey to black	stain	angular block, moderate weathering
R5	Olivine gabbro	1-3 mm	interlocking groundmass	-	40-60	5-15?	30-40			5-10%	7.3	25	15	11	some	angular	grey to black	stain	angular grey to black block, Mn stain, slightly weathered
R6	Fine-grained gabbro	1-2 mm	equigranular		40-60		40-60			10-15%	3.1	15	12	9	moderate	angular	grey to black	stain	angular grey black block, modestly weathered
R7	Diabase to medium grained gabbro	1-5mm	various, equigranular		40-60	0-30	30-40			5-10%?	5.6	18	20	12	slight to moderate	angular	black to grey	stain	angular block with black Mn stained surface
R8	Troctolite to troctolitic gabbro	2-4 mm	cumulate		20-30	50-60	5-15			5-15%	14.5	30	24	16	moderate	angular	grey, brown to black	stain	angular block, grey, brown , to black where stained with Mn
R9	Altered basalt/basalt breccia?	<1 mm	aphyric, microcrystalline		40-60?		40-60?			>50%	5.3	23	18	13	extreme	angular	brown grey	stain	angular, irregular surface, brown to grey surface with some Mn stain. Extensively altered
R10	Altered diabase to basalt	<1-2 mm	microcrystalline, sparsely phyric?		40-60		40-60			20-25	6	30	17	13	lots	sub angular	brown to light grey	slight Mn	subangular block, brown to light grey surface, little Mn, block is coated in sediment; extensively altered
R11	Troctolite or troctolitic gabbro	1-3 mm	cumulate		30-40	50-60	minor?				1.1	15	10	5	moderate	angular	brown grey	slight on one side	angular and fractured block, brown grey surface with a <1 mm Mn coating on one side. Significant alteration.
R12	Troctolite or troctolitic gabbro	1-3 mm	cumulate		30-40	50-60	10-15?			15-20	7	25	20	13	moderate	angular	grey to black	stain	angular, grey to Mn black surfaces

R13	Troctolite or troctolitic gabbro	1-3 mm	cumulate		20-40	50-70	5-10?			15-20	5.5	16	16	15	moderate	angular	grey, brown	stain	angular, grey brown surface, Mn stained in places, a little sediment on block
R14	Highly-altered and veined basalt		none remains								1.2	15	11	7		angular		film	
R15	Highly-altered and veined basalt		none remains								4.1	25	16	11		angular		film	similar to 14
R16	Altered aphyric basalt		aphyric								4.5	26	14	13		sub rounded		film	
R17	Altered aphyric basalt		aphyric								14	30	21	18		angular		film	
R18	Altered aphyric basalt		aphyric								4.5	20	19	11		angular		-	
R19	Altered aphyric basalt		aphyric								12.5	30	16	21		angular		film to none	
R20	Altered aphyric basalt		aphyric								1	11	10	9		sub rounded		<1mm	similar to 25 -27
R21	Conglomerate										0.6	11	9	6		angular		1mm	
R22	Conglomerate		with lots of glass								10	27	15	18		sub angular		1mm-none	
R23	Conglomerate										8.5	24	19	16		angular		film	
R24	Siltstone	<<1mm									2	21	12	8		sub rounded			
R25	Aphyric basalt		aphyric								2	15	10	9	fresh	angular		2mm	
R26	Aphyric basalt		aphyric, variolitic								1.5	10	12	10	fresh	sub angular		film	
R27	Aphyric basalt		aphyric, variolitic								1.7	9	9	9	fresh	sub angular		film	similar to R25
Scoop 1	Not described																		not described
Push core 1	Not described																		not described

Dive #976	Described by SHB and OI											Sample characteristics								
Sample #	Lithology	Ave. grain size	Igneous texture	Glass (mm)	Plag. (%)	Oliv. (%)	Px. (%)	Hbl. (%)	Other (%)	Alt. minerals %	Wt (kg)	X (cm)	Y (cm)	Z (cm)	Weathering	Angularity	Surface	Mn (mm)	Comments
R1	Basalt, basaltic andesite?	1 mm	diabasic		40-60		40-50	2%?		5%	2.7	13	13	8	slight	angular	brown grey	stain	angular block,light grey on cut surface, diabasic textured
R2	Basalt	<1 mm	microcrystalline to diabasic		50-60	tr	30-40			5%	1.9	14	11	10	slight	angular	brown grey	stain	angular, light grey on cut surface
R3	Coarse sandstone	3 mm-14 cm									3.9	21	14	12		angular	brown	1-2	
R4	Siltstone, claystone	< 1 mm									0.5	10	9	6		angular	tan to black	20	
R5	Siltstone, sandstone	<1-1 mm									0.7	13	11	8		angular	brown	stain	
R6	Layered sediment	<1-1 mm									2.2	22	15	11		angular	brown	5	
R7	Coarse volcanic sandstone	1-5 mm									4.2	22	17	12		angular	brown	to 10 mm	
R8	Coarse volcanic sandstone	1-5 mm									2.8	18	14	14		angular	brown	2	mostly coated with Mn
R9	Breccia	1-20 mm									0.7	19	11	5		irregular	grey brown	4-5	irregularly shaped piece
R10	Claystone	< 1 mm									0.7	17	8	7	moderate	sub angular	tan to green brown	to 1 mm	
R11	Coral										0.5	8	9	6	moderate	sub angular	white tan	<1	spots of Mn stain in places on piece
R12	Andesite	1-2 mm	diabasic		50-65		45-50	tr?		5-10?	0.4	9	4	6	slight	angular	light grey	<1	a lot like R1; weathers to a brown or brown grey
R13	Diabase	1-2 mm	diabasic		45-55		45-50			30?	0.7	10	9	8	slight	sub angular	brown grey	<1	

R14	Andesite	1-3 mm	diabasic to microcrystalline		50-60		30-35	5-8		5%	8.2	27	4	16	slight	angular	brown grey	<1	
R15	Andesite	<1-1 mm	diabasic		50-60		30-40	5%?		20?	5.1	22	9	13	moderate	angular	brown grey	1	similar to R14
R16	Diabase	1-3 mm	diabasic		45-55		45-55			30?	2.9	18	24	10	high	sub angular	brown grey	1	very similar to R13
R17	OL basalt	<1-2 mm	micro-phyric		40-55	5	40-55			10-15	1.6	12	15	9	moderate	sub angular	grey brown	6	
R18	OL basalt	<1-2 mm	micro-phyric		40-55	5	40-55			10-15	0.8	10	14	7	moderate	sub angular	grey brown	3-5	
R19	Siltstone, fine sandstone	<1-1 mm									1.1	18	12	6	high	angular	tan	20	
R20	Sandstone, siltstone	<1-2 mm									3.3	28	8	13	high	angular	tan brown	1-2	
R21	Claystone	<1 mm									0.7	14	13	9	high	sub rounded	brown	<1	
R22	Sandstone, with two major layers	<1-2 mm									0.1	9	13	5	high	angular	tan to brown	<1	

Dive #977	Described by SHB and OI										Sample characteristics								
Sample #	Lithology	Ave. grain size	Igneous texture	Glass (mm)	Plag. (%)	Oliv. (%)	Px. (%)	Hbl. (%)	Other (%)	Alt. minerals %	Wt (kg)	X (cm)	Y (cm)	Z (cm)	Weathering	Angularity	Surface	Mn (mm)	Comments
R1	PL-PX-OL diabase	~1mm	diabase		70-80	<10	<20		<5	20-30	2.3	14	12	9	moderate	angular		1	
R2	PL-PX-OL diabase	~1mm	diabase		70-80	<10	<20		<5	20-30	2.5	17	12	11	moderate	angular		1	
R3	PL-PX-OL diabase	~0.5mm	diabase		70-80	<10	<20		<5	20-30	1.8	17	13	9	moderate	angular		1	
R4	PL-PX-OL diabase	~1mm	diabase		70-80	<10	<20		<5	40	5	24	20	8	highly	angular		1	similar to R1.
R5	PL-PX-OL diabase	~0.5mm	diabase		60-70	~10	20-30		5	20-30	2.6	15	13	13	moderate	angular		<1	
R6	PL-PX-OL diabase	~0.7mm	diabase		60-70	~10	20-30		5	20-30	5.5	21	14	15	moderate	angular		<1	similar to R5.
R7	Fine-grained diabase	<1-1 mm, rare to 2	diabasic, equigranular		40-60		40-60				7.6	20	19	17	high	angular	brown	<1mm	angular fine grained diabase
R8	Medium-grained diabase	<1-2 mm	diabasic		40-50		50-60		2-5 oxide	30-40	11	27	19	20	moderate to high	angular	grey green brown	< 1mm	angular medium grained diabase
R9	Diabase	1-3 mm	diabasic to equigranular		40-50		50-60		2-5 oxide	5-15	2.8	20	16	7	slight to moderate	angular	brown grey	< 1 mm	angular diabase
R10	Diabase	<1-2 mm	diabasic		40-50		50-60		2-5 oxide	30-40	1.8	16	12	11	moderate to high	angular	grey green brown	< 1mm	angular grey green block with very little Mn
R11	Diabase	1-2 mm	diabasic		40-50	tr?	50-60		2-5 oxides	30-40	0.7	17	10	5	high	angular	grey green brown	< 1mm	angular block, thin Mn stain or rim
R12	Weathered volcanic sandstone	<1-4 mm								30-40	0.1	6	3	2	high	irregular	brown grey	< 1mm rare	irregular pebble
R13	Diabase	1-2 mm	diabasic, equigranular		40-60		40-60		2-5% oxides	20-40	6	22	16	16	moderate to high	angular	grey to brown	< 1mm	angular brown grey block with slight Mn stains

R14	Diabase	1-3 mm	diabasic, equigranular		40-50	5-8	40-50		3-5% oxide	20-40	9.7	25	22	16	moderate to high	angular	grey to brown	< 1 mm	angular, coarser grey brown diabase
R15	Diabase	<1-1 mm	diabasic, equigranular		40-50		50-60		3-5% oxide	20-40	8.2	18	16	18	moderate to high	angular	grey green brown	< 1 mm	angular, fine grained diabase with slight Mn stain
R16	Sandy calcareous grainstone inside a brown claystone	<1 to 2 mm									1.6	17	11	10	moderate	rounded	white tan, brown	slight	rounded sediment clast with slight Mn stains
R17	Clayey fine-grained sandstone	<1 mm rarely to 2 mm									0.4	13	8	4	moderate	sub rounded	brown	slight stain	subrounded, brown
R18	Basalt	<1 mm	equigranular		50-60		40-50			5-15	12.4	25	25	23	slight to high	angular	brown	<1 mm	large angular block, brown on weathered, slight Mn on some surfaces
R19	Fine-grained diabase to basalt	<1-1 mm	equigranular to diabasic		50-60		40-50			10-15	0.5	9	7	6	moderate	angular	grey brown	< 1 mm	angular grey to brown block
R20	Brown-red claystone	<1 mm									0.5	10	10	8		rounded	red brown	stain	rounded block
R21	PL-PX diabase	~2mm	diabase		70-80		20-30		5	40	3.1	15	15	13	highly altered	angular		<1	similar to R22, but altered.
R22	PL-PX diabase	~2mm	diabase		70-80		20-30		5	10	10.5	27	18	19	minor	angular		<1	
R23	PL-PX diabase	~1.2mm	diabase		70-80		20-30		5	30	3	29	15	7	moderate	angular		<1	
R24	Basalt	<1 mm	equigranular		40-60?	2-3	40-50			5-10	2.3	15	9	10	slight to moderate	angular	brown grey	< 1mm	angular, brown grey basalt
R25	Fine-grained diabase	<1-1 mm	diabasic		40-50		50-60			15-20	2.2	16	11	12	moderate to high	angular	brown	<1 mm	angular brown diabase
R26	Fine-grained diabase	1-3 mm	equigranular		40-50		50-60			15-20	8.1	30	22	11	moderate to high	angular	grey brown	<1 mm	
Sccop 1	Calcareous sediment	<1-5 mm																	

Appendix E: Lists of sample distribution

Dive 973 samples taken on YK06-12

Needs: hand specimen (HS); thin section (TS); teaching specimen (TE); Geochemistry (GC); geochronology (Age); glass (g); paleontology (p); rest of samples (RoS)

Sample	YO	MR	TI	JK	OI	KM	JH	KK*	SB	RS	BB	PF[1]
R1	TS		RoS	GC		HS						
R2	TS	TE	RoS	GC	TS	HS	TE, TS		TE	TE		
R3	TS		RoS	GC	TS	HS	TE, TS		TE	TE	TS	
R4	TS		RoS	GC		HS	TE, TS		TE			
R5	TS		RoS	GC		HS	TE, TS					
R6	TS		RoS	GC		HS						
R7	TS		RoS	GC		HS						
R8	TS		RoS	GC		HS						
R9	TS		HS	GC		HS						
R10	TE		TS	TS		HS						
R11	TE	TE	TS	TS	TS	HS	TE, TS	TE	TE	TE		
R12	TS	TE	RoS	GC		HS						
S1*		2 gabbros - $1 cm^3$, 1-gabbro-2x1x1/2										
P1												

Yasuhiko Ohara (YO); Mark Reagan (MR); Teruaki Ishii (TI); Jun-Ichi Kimura (JK);
Osamu Ishizuka (OI); Katsuyoshi Michibayashi (KM); James Hawkins (JH); Katherine Kelley (KK);
Sherman Bloomer (SB); Robert Stern (RS); Brittney Blake (BB); Patricia Fryer (PF)

[1]-has many of the "S" samples (see sheet 2)

* For S (scoop) samples - list each clasts taken by type and size in cm; e.g. perid. 1 × 1.5 × 2.5
For rock names use S1-your initials-1, -2 etc.; e.g. 973-S1-YO-1 **(make sure that sample is photographed)**

Patricia Fryer's Scoop Samples (Dive 973)

Leucocratic intrusives			Gabbroic samples			Breccia/conglomerate		
	Size (cm)	What		Size (cm)	What		Size (cm)	What
1	0.7	plag.?	1	2 × 3	gabbro	1	1 × 1.5 × 1.5	N/A
2	1 × 0.6 × 0.5	plag?	2	1 × 2 × 1.5	alt. w/vein	2	1 × 1.5 × 1.5	N/A
3	1 × 1.3 × 0.7	dacite?	3	1 × 2 × 1.5	fresh			
4	1 × 0.8 × 0.6	dacite w/ incl.	4	1.5 × 1.5 × 3	amphibolite			
5	1 × 1.5 × 1.2	dacite	5	2 × 2 × 2	microgabbro			
6	1 × 0.3 × 0.3	white vein	6	1 × 3 × 2.5	fresh w/vein			
7	1 × 0.7 × 0.5	gray dacite?	7	1 × 2.5 × 2.5	microgabbro			
8	1.2 × 2 × 0.5	sed.	8	1 × 0.5 × 0.8	microgabbro			
9	1 × 0.4 × 1	talc	9	1 × 1.5 × 1	amph. gabbro			
10	1 × 0.7 × 0.4	tonalite	10	1 × 1 × 0.5	qtz?			
11	1 × 0.6 × 0.2	micro gabbro	11	1 × 1.5 × 2	alt gabbro			
12	1.3 × 1.2 × 1.2	conglom	12	1.2 × 0.8 × 0.4	hbl gabbro			
13	1 × 1.2 × 0.5	conglom?	13	2 × 1 × 0.5	microgabbro			
14	2 × 5 × 0.7	diorite/ton.	14	1.2 × 0.5 × 0.5	microgabbro			
15	0.6 × 0.5 × 0.3	diorite/ton.	15	1 × 1.5 × 1.3	alt microgabbro			
16	1.5 × 1.5 × 0.5	diorite/ton.	16	1 × 0.5 × 0.3	microgabbro			
17	0.6 × 0.6 × 0.3	diorite	17	0.5 × 0.3 × 0.2	alt microgabbro			
18	2 × 1.5 × 0.6	diorite?	18	1.3 × 1.5 × 0.2	alt microgabbro			
19	3 × 2 × 1.5	diorite?	19	1.2 × 0.8 × 0.5	alt microgabbro			
20	1 × 2 × 1	diorite?	20	1.5 × 1 × 1	fine gabbro			
			21	1 × 1 × 0.7	alt fine gabbro			
			22	2.5 × 1.3 × 1.1	alt fine gabbro			
			23	1.2 × 0.7 × 0.7	olivine gabbro?			
			24	1 × 1 × 0.4	alt gabbro			
			25	1 × 1.2 × 1	alt diabase?			
			26	1 × 0.7 × 0.3	hyaloclastite?			

Dive 974 samples taken on YK06-12

Needs: hand specimen (HS); thin section (TS); teaching specimen (TE); Geochemistry (GC); geochronology (Age); glass (g); paleontology (p); rest of samples (RoS)

Sample	YO	MR	TI	JK	OI	KM	JH	KK*	SB	RS	BB	PF
R1	TS	TS-GC	GC	GC	GC-age		TE-TS	TS-GC		TE		TS
R2	TS	TS	GC	GC	GC-age		TE-TS	TS-GC	TE	TE	TS	TE
R3	TS	P	GC	GC	GC		TE-TS	GC				p
R4	TS	TS-GC	GC	GC	GC-age			TS-GC				TS
R5	TS	TE-GC	HS	GC	GC-age		TE-TS	TS-GC		TE	TS	TS
6%	TS	TS-GC	GC	GC	GC-age		TE-TS	TS-GC	TE			TS
R7	TS	TE-GC	HS	GC	GC-age			TS-GC		TE		TE
R8	TS	GC	TS	GC	TS			GC				TS
R9	TS	g	TS	GC	GC-age			g				
R10	TS	GC	GC	GC	GC-age			TS-GC				TS
R11	TS	TE-GC	HS	GC	GC-age		TE-TS	TS-GC			TS	TS
R12	TS	TS-GC	HS	GC	GC-age		TE-TS	TS-GC				TS
R13	TS	GC	TS	GC	GC-age			TS-GC				
S1												
S2-1			TS									
S2-2			TS									
S2-3			TS									
S2-4			TS									
S2-5												
P1												

Dive 975 samples taken on YK06-12

Needs: hand specimen (HS); thin section (TS); teaching specimen (TE); Geochemistry (GC); geochronology (Age); glass (g); paleontology (p); rest of samples (RoS)

Sample	YO	MR	TI	JK	OI	KM	JH	KK	SB	RS	BB	PF
R1		TE	GC	GC	GC		TE	TE				TS
R2		TS	GC		TS			GC-TS				GC
R3		GC-TS	GC	GC	GC		TE	GC-TS				TS
R4		GC	GC	GC	GC			GC-TS				GC
R5		GC	GC	GC	GC		TE	GC	TE			GC
R6		TE-GC	GC	GC	Gc		TE	GC				
R7		TS	GC		TS			TE-GC	TE	TE		TS
R8		TS	HS		TS		TE	TE	TE	TE	TE	
R9		GC	HS					TE				GC
R10		GC	GC		TS		TE	GC				GC
R11		TS	TS									
R12		TS	HS		TS		TE	TE	TE	TE		GC
R13		TS	HS	GC	GC			TE-GC				
R14		TS	TS									
R15		TS	GC		TS			TE-GC				
R16		TS	GC									
R17		TS	GC		TS							
R18		GC	GC					GC				GC
R19		TE	HS		TS		TE	TE				GC
R20		GC	TS					GC				
R21			TS	GC	GC							GC
R22		GC -g	HS	GC	GC			HS-GC-g				
R23		GC	HS	GC	GC		TE	GC				

R24			GC									
R25		GC	GC		GC			GC				
R26		GC	GC	GC	GC			GC				GC
R27		GC	GC	GC	GC		TE	GC				
S1		3 sandstones 3 × 2 × 1, 3 × 2 × 2, 2 × 1 × 1										
P1												

Dive 976 samples taken on YK06-12

Needs: hand specimen (HS); thin section (TS); teaching specimen (TE); Geochemistry (GC); geochronology (Age); glass (g); paleontology (p); rest of samples (RoS)

Sample	YO	MR	TI	JK	OI	KM	JH	KK	SB	RS	BB	PF
R1	TS	TE	archived	GC	GC-age		TS-TE	TE				TS
R2	TS	GC	samples	GC	GC-age		TS	GC				TS
R3		TS	samples		TS		TS TE		TE	TE		TS
R4		TS	samples		GC							
R5		TS	samples		GC		TS					
R6		2-TS	samples		GC		TS					p
R7		TS	samples		TS		TS					
R8		TS	samples		TS		TS					p
R9		TS	samples	GC								
R10		TS	samples		TS		TE					
R11		p	samples				TS					1/2
R12	TS	GC	samples	GC	TS		TS	GC				
R13	TS	GC	samples	GC	GC-age		TS	GC				
R14	TS	TE	samples	GC	GC-age		TS	TE	TE	TE		TS
R15	TS	GC	samples	GC	GC-age		TS	GC				TS
R16	TS	GC-TS	samples	GC	GC-age			GC				TS
R17	TS	TE	samples	GC	GC-age		TS	TE				TS
R18		GC	samples	GC	GC-age			GC				
R19		TS	samples				TS					
R20		TS	samples				TS					p
R21		TS	samples									
R22		TS	samples									

Dive 977 samples taken on YK06-12

Needs: hand specimen (HS); thin section (TS); teaching specimen (TE); Geochemistry (GC); geochronology (Age); glass (g); paleontology (p); rest of samples (RoS)

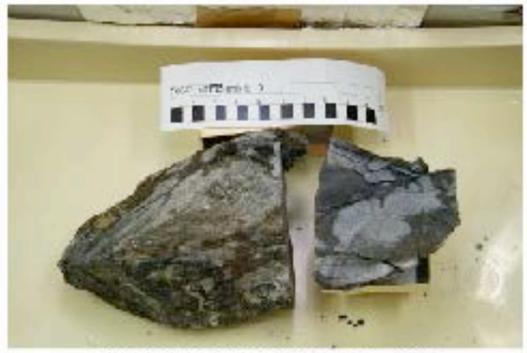
Sample	YO	MR	TI	JK	OI	KM	JH	KK	SB	RS	BB	PF
R1	TS	TS			GC-age							TS
R2	TS	TS			GC-age							TS
R3	TS	TS					TS			TE		
R4	TS	TE						TE				TS
R5	TS	TS					TS					TS
R6	TS	TE			GC-age		TS				TE	
R7	TS	TS			GC-age		TS TE	TE				TS
R8	TS	TS			GC-age							TS
R9	TS	TS			GC-age					TE		TS
R10	TS	TS							TE			TS
R11	TS	TS										TS
R12												TS
R13	TS	GC-TS			GC-age			GC-TS	TE			TS
R14	TS	GC								TE		TS
R15	TS	TS			GC-age							
R16		TS										TS
R17		TS										
R18	TS	GC-TS			GC-age		TS TE	GC-TS				TS
R19	TS	GC			GC-age							TS
R20												
R21	TS	TS					TS	TS				TS
R22	TS	TE			GC-age		TS	TE	TE	TE		TS
R23	TS	TS					TS					TS

R24	GC			GC	GC-age			GC				TS
R25	TS				GC-age							TS
R26	TS				GC-age		TS		TE			TS
S1												0.1 kg taken to look for forams

Appendix F: Sample photographs

YK06-12 6K Dive 973:

YK06-12 6K#973-R1



YK06-12 6K#973-R2

YK06-12 6K#973-R3

YK06-12 6K#973-R4

YK06-12 6K#973-R5

YK06-12 6K#973-R6

YK06-12 6K#973-R7

YK06-12 6K#973-R8

YK06-12 6K Dive 973 (Continued):

YK06-12 6K#973-R9

YK06-12 6K#973-R10

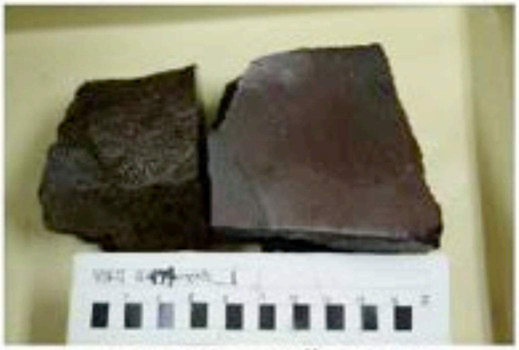
YK06-12 6K#973-R11

YK06-12 6K#973-R12

YK06-12 6K#973-Scoop-1

YK06-12 6K#973-Push Core 1 (Blue)

YK06-12 6K Dive 974:



YK06-12 6K#974-R1

YK06-12 6K#974-R2

YK06-12 6K#974-R3

YK06-12 6K#974-R4

YK06-12 6K#974-R5

YK06-12 6K#974-R6

YK06-12 6K#974-R7

YK06-12 6K#974-R8

YK06-12 6K Dive 974 (Continued):


YK06-12 6K#974-R9


YK06-12 6K#974-R10


YK06-12 6K#974-R11


YK06-12 6K#974-R12


YK06-12 6K#974-R13

Note: no photographs for

YK06-12 6K#974-Scoop1

YK06-12 6K#974-Scoop2

YK06-12 6K#974-Push Core 1

YK06-12 6K#974-Loose Sample #1

YK06-12 6K#974-Loose Sample #2

YK06-12 6K Dive 975:

YK06-12 6K#975-R1

YK06-12 6K#975-R2

YK06-12 6K#975-R3

YK06-12 6K#975-R4

YK06-12 6K#975-R5

YK06-12 6K#975-R6

YK06-12 6K#975-R7

YK06-12 6K#975-R8

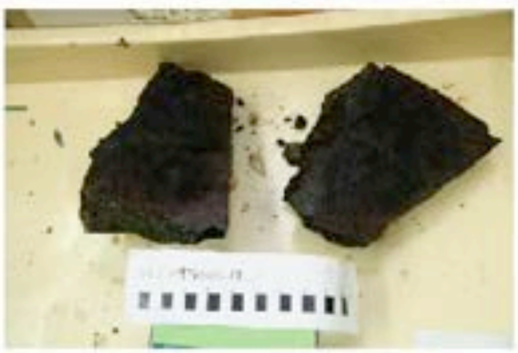
YK06-12 6K Dive 975 (Continued):

YK06-12 6K#975-R9

YK06-12 6K#975-R10

YK06-12 6K#975-R11

YK06-12 6K#975-R12



YK06-12 6K#975-R13

YK06-12 6K#975-R14

YK06-12 6K#975-R15

YK06-12 6K#975-R16

YK06-12 6K Dive 975 (Continued):

YK06-12 6K#975-R17

YK06-12 6K#975-R18

YK06-12 6K#975-R19

YK06-12 6K#975-R20

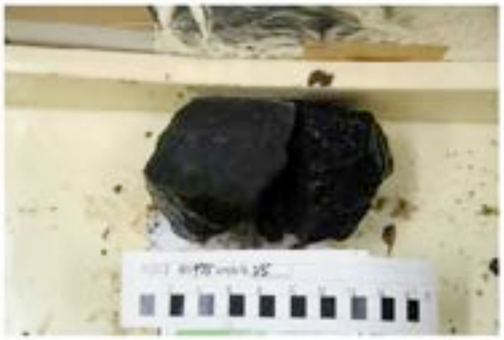
YK06-12 6K#975-R21

YK06-12 6K#975-R22

YK06-12 6K#975-R23

YK06-12 6K#975-R24

YK06-12 6K Dive 975 (Continued):



YK06-12 6K#975-R25

YK06-12 6K#975-R26

YK06-12 6K#975-R27

YK06-12 6K#975-loose sample

Note: no photographs for

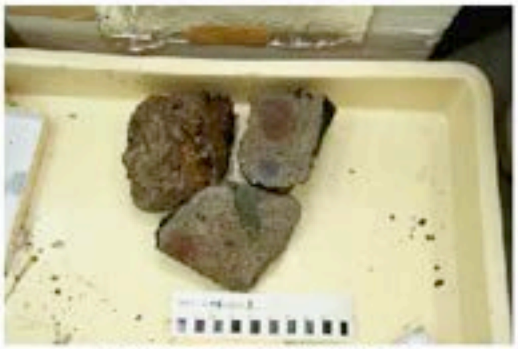
YK06-12 6K#975-Scoop1

YK06-12 6K#975-Push Core 1

YK06-12 6K Dive 976:

YK06-12 6K#976-R1

YK06-12 6K#976-R2



YK06-12 6K#976-R3

YK06-12 6K#976-R4

YK06-12 6K#976-R5

YK06-12 6K#976-R6

YK06-12 6K#976-R7

YK06-12 6K#976-R8

YK06-12 6K Dive 976 (Continued):

YK06-12 6K#976-R9

YK06-12 6K#976-R10

YK06-12 6K#976-R11

YK06-12 6K#976-R12

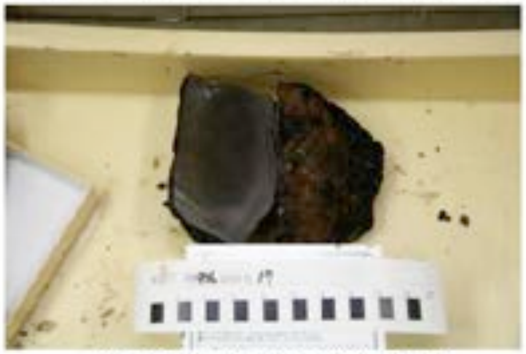
YK06-12 6K#976-R13

YK06-12 6K#976-R14

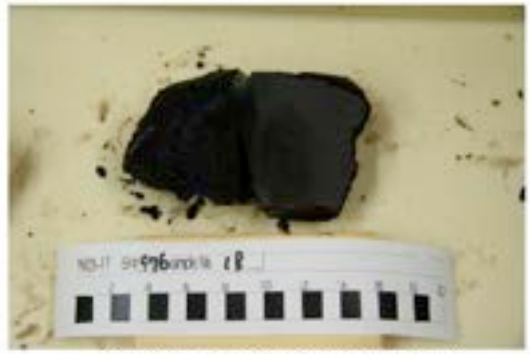
YK06-12 6K#976-R15

YK06-12 6K#976-R16

YK06-12 6K Dive 976 (Continued):

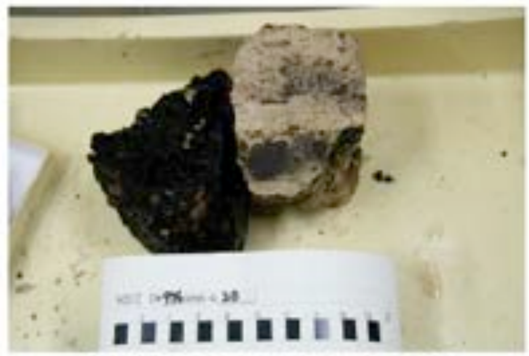


YK06-12 6K#976-R17



YK06-12 6K#976-R18

YK06-12 6K#976-R19



YK06-12 6K#976-R20

YK06-12 6K#976-R21

YK06-12 6K#976-R22

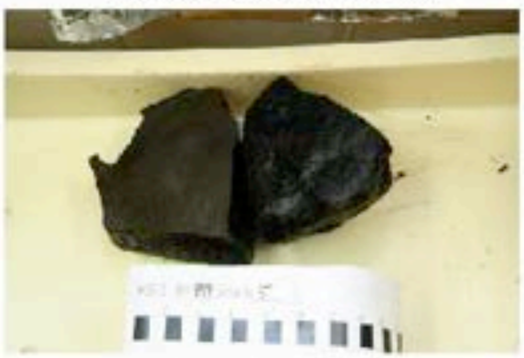
YK06-12 6K Dive 977:

YK06-12 6K#977-R1

YK06-12 6K#977-R2

YK06-12 6K#977-R3

YK06-12 6K#977-R4



YK06-12 6K#977-R5

YK06-12 6K#977-R6

YK06-12 6K#977-R7

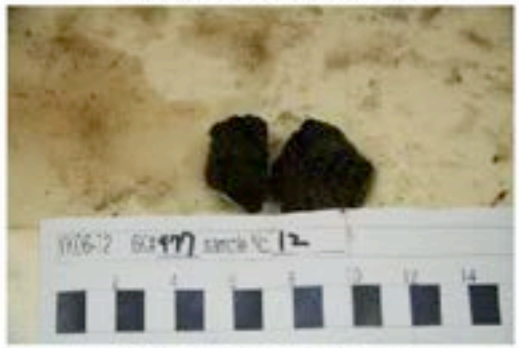
YK06-12 6K#977-R8

YK06-12 6K Dive 977 (Continued):


YK06-12 6K#977-R9


YK06-12 6K#977-R10


YK06-12 6K#977-R11


YK06-12 6K#977-R12


YK06-12 6K#977-R13


YK06-12 6K#977-R14


YK06-12 6K#977-R15


YK06-12 6K#977-R16

YK06-12 6K Dive 977 (Continued):

YK06-12 6K#977-R17

YK06-12 6K#977-R18

YK06-12 6K#977-R19

YK06-12 6K#977-R20

YK06-12 6K#977-R21

YK06-12 6K#977-R22

YK06-12 6K#977-R23

YK06-12 6K#977-R24

YK06-12 6K Dive 977 (Continued):

YK06-12 6K#977-R25

YK06-12 6K#977-R26

YK06-12 6K#977-Scoop1

Appendix G: Report for Palau field trip

Field notes from field trip on Babeldaob Island, Republic of Palau, August 26th, 2006

Participants: Yasuhiko Ohara (YO); Mark Reagan (MR); Teruaki Ishii (TI); Jun-Ichi Kimura (JK); Osamu Ishizuka (OI); Katsuyoshi Michibayashi (KM); James Hawkins (JH); Robert Stern (RS); Sherman Bloomer (SB); Patricia Fryer (PF); Katharine Kelley (KK); Brittney Blake (BB); Pat Colin (PC); Lori Colin (LC)

The Scientific Party for Cruise YK06-12spent one day examining outcrops on the island of Babeldaob, several of which were newly exposed by building or quarrying for the construction of the Compact Road around the island. Pat and Lori Collin of the Coral Reef Research Foundation joined the group to lead us to quarries and outcrops. Pat had taken many low-level aerial photographs of the road during construction that were extremely useful.

We left the Airai View Hotel about 08:15 AM and after a brief stop for supplies proceeded north up the eastern side of the island. We took a trip off the main road down to a site from which a boninitic composition lava had been reported by (Hawkins and Castillo 1998) (east of the village of Ngerngesang). From there we proceeded to a large quarry that exposed a faulted dike complex, then back to the Compact Road. We took lunch at the north end of the causeway in Ngiwal State. From there we went around the north end of the island then down the west side on the Compact Road. After a stop in the Babeldaob Fm. on the road, we took a road along the south side of Ngeremeduu Bay to see one last quarry. We returned to the Airai View about 6 PM.

Table 1 lists waypoints of outcrops and stops made during the day. Table 2 lists the stops made and the samples taken at each point. Samples were cut and distributed during two days of transit at the beginning of YK06-12.

We include here a brief description and photograph of each of the principal stops. Samples are labeled with BA06, then the stop number, then a letter indicating multiple samples from a single stop.

Stop 1: A road-cut on the east side of the compact road. In what is mapped as Aimeliik formation (Ngarsul member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

Section exposes what look like several volcanic debris flows. Samples were taken in the lowermost unit, which is quite altered, from the bench in the middle of the section, and from the uppermost unit in the upper left corner of the photo. Sample BA06-1B was from a talus block.

Stop 1. Babeldaob Island, August 26th, 2006

Stop 2. Babeldaob Island, August 26th, 2006

Stop 2: A road-cut on the east side of the compact road. In what is mapped as Aimeliik formation (Ngarsul Member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The northern end of the outcrop shown here exposes rubbly material that may be a volcanic flow. The southern end of the outcrop is more weathered and appears to be a volcanic breccia. Samples were taken from both portions.

Stop 3: An exposure along the shoreline at a small parking and picnic area ESE of the village of Ngemgesang, in what is mapped as Aimeliik formation (Ngarsul member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

We came to this point because a sample identified in Hawkins and Castillo (1998) of boninitic composition came from this area. The analysis was by Julian Pearce. The outcrop exposes a large mafic dike cutting a clast-supported volcanic breccia containing nearly spherical clasts. The dike runs from the parking lot southwards along the shore and is near vertical. A piece of the dike and samples of the clasts were taken.

Stop 4: A large quarry developed for the construction of the road near Ngeruikl village. In what is mapped as Aimeliik formation (Ngarsul Member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The quarry provides spectacular exposures of a dike complex. The dikes probably comprise over 60% of the section. A quick first examination truncated by a blinding rainstorm suggested there were few (or at least hard to identify) screens of country rock between the dikes. The dikes are cross-cut by, and also crosscut, areas of fault gouge. Some of the dikes showed nicely developed columnar jointing. Most of the dikes strike SE-NW and dip steeply. At least one large exposed surface shows near-horizontal slickensides. Samples were taken from six different dikes.

Stop 5: A modest quarry at the south end of the causeway in Ngiwal State. In what is mapped as Aimeliik formation (Ngardok Member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The quarry exposes volcaniclastic turbidites. These show nice coarse to fine sequences. The section is gently folded with the axis of an anticline about in the center of the quarry. All of the bedding dips gently to the east (N40W 10E on the north end; N20WS 12E in the middle; NS 5E at the south end).


Stop 3: Babeldaob Island, August 26th, 2006


Stop 4: Babeldaob Island, August 26th, 2006

Stop 5: Babeldaob Island, August 26th, 2006

Stop 6: Babeldaob Island, August 26th, 2006

Stop 6: A road-cut on east side of Compact Road. Probably in what is mapped as Aimeliik formation (Ngarsul Member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The outcrop exposes a quite coarse volcaniclastic sandstone and breccia. It might be a lower turbiditic facies or a volcanic debris flow. There are very large clasts in it that were sampled.

Stop 7: A road-cut on both sides of the Compact Road. Probably in what is mapped as Aimeliik formation but could be Ngeremlengui Formation by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The exposures include very coarse volcanic breccias with some meter thick volcanic sandstone beds. The bedding is dipping east and it appears to be oriented roughly N20W 12E. There seem to be a few small offsets in the sandstone beds that are down to the east.

Stop 8: A quarry developed for the construction of the road. In what is mapped as Aimeliik formation (Ngarsul Member) by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The quarry exposes a very coarse volcanic breccia. The material quarried proved unsuitable for the road as it was not strong enough. The breccias are cut by steep (near vertical) fault scarps that strike almost E-W. Some of these seem to have horizontal slickensides.

Stop 9: A large quarry developed for the construction of the road just south of the USDA/PCC R&D station, in what is mapped as an intrusive plugs by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The quarry provides some of the best road material in Palau. The core (the highest point) exposes light-colored hornblende dacite, usually in a breccia (probably an auto-breccia?). The outer margins of the plug are a darker hued dacitic (?) breccia that weathers somewhat reddish.


Stop 7: Babeldaob Island, August 26th, 2006


Stop 8: Babeldaob Island, August 26th, 2006

Stop 9: Babeldaob Island, August 26th, 2006

Stop 10: Babeldaob Island, August 26th, 2006

Stop 10: Babeldaob Island, August 26th, 2006; sediments overlying the pillowed section

Stop 11: Babeldaob Island, August 26th, 2006

Stop 10: A road-cut on the east side of the Compact Road. Probably near the western edge of what is mapped as Babeldaob Fm. by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The exposure shows highly weathered, clearly pillowed basalt overlying massive dark grey basalts. On closer examination, it seems that the darker grey sections are in fact also pillowed and the appearance of the outcrop may be due to differential weathering. Samples were taken from the weathered pillows and the massive section.

The pillowed section becomes more weathered to the south. There is a hydrothermally altered zone near the top of the obviously pillowed section (red, green, very white altered matrix). There is a small sandy layer near the top of the pillows and the section is overlain by a black, shaly-looking clay with thin tan possibly micritic beds. This could be what was mapped as Airai Clay by Mason et al (1956). That clay is noted to include lignite. The beds dip east, oriented N40E 15E and seem concordant with the volcanics. This may be a primary sediment, but certainly deserves another look to see if microfossils can be found.

Stop 11: A quarry near the village of Ngereklmadel south of Ngeremeduu Bay. In what is mapped as the Arakbesan Member of the Ngeremlengui Formation by Mason et al. (1956). Location in Table 1, Figs. 1 and 2.

The quarry shows a coarse volcanic breccia (andesitic?) which overlies a very white hornblende dacite tuff. These appear to be reworked volcaniclastic rocks, perhaps including some turbidite layers. The contact dips up the road to the south that goes down into the quarry and there appears to be some shearing along the margin of the contact.

Table 1. Station locations on Babeldaop Island, field trip on August 26, 2006, Palau

Waypoint	Stop	Latitude	Longitude	Elevation (ft)	Notes
1		7°21.724'N	134°31.606'E	27	store east of hotel
2	1	7°24.299'N	134°34.124'E	328	volcanic flows in roadcut, E side of road
3	2	7°26.513'N	134°34.753'E	131	small roadcut, east side of road, flow? Breccias?
4	3	7°27.046'N	134°36.554'E	41	dike cutting volcanic breccia with spheroidally weathering clasts; on shore, possible boninite analyzed by Julian Pearce?
5		7°27.785'N	134°36.379'E	53	volcanic breccia outcrop along shore
6	4	7°28.589'N	134°36.635'E	242	large quarry, dike complex, high density dikes
7	5	7°31.348'N	134°36.938'E	107	quarry S end of causeway; debris flows, turbiditic volacanic sands
8		7°33.892'N	134°37.657'E	233	outcrop on main road; looks like volcanic ssts
9		7°35.143'N	134°37.603'E	105	outcrop on main road; looks like volcanic ssts
10	6	7°35.306'N	134°37.592'E	160	roadcut; coarse volacaniclastic sandstones
11		7°36.257'N	134°35.555'E	300	outcrop along road, coarse volcanic breccias
12	7	7°33.131'N	134°34.375'E	386	volcanic breccias, sandstones, dipping gently E
13	8	7°32.752'N	134°34.040'E	404	quarry just off E side of road; faulted coarse volcanic breccias
14		7°30.597'N	134°32.691'E	129	outcrop along road
15	9	7°30.595'N	134°33.309'E	240	quarry in light-colored silicic volcanic, dacitic outside, HB-andesite interior
16		7°28.663'N	134°32.108'E	150	outcrop on east side of road
17		7°28.490'N	134°32.050'E	174	outcrop on east side of road
18		7°28.285'N	134°31.847'E	149	outcrop on east side of road
19	10	7°26.957'N	134°31.845'E	103	roadcut, probably Babeldaop Fm. Large weathered pillows, some massive less weathered pillow sections; overlain by seds
20		7°28.488'N	134°29.849'E	251	Volcanic breccia outcrop along NE side road
21	11	7°28.861'N	134°29.824'E	185	Quarry, volcanic breccia overlying Hb-dacite/tonalite; possibly in fault contact
22		7°28.821'N	134°29.789'E	216	S up road; breccia/dacite contact exposed
23		7°21.710'N	134°31.174'E	96	Airai View Hotel

Elevations not calibrated; waypoints 4 and 5 within 3 m of sea level.

Waypoints are noted for both stops and outcrops passed on road.

Table 2. Samples taken on field trip, August 26, 2006, Babeldaop Island, Palau

Sample:	Latitude	Longitude	Taken by	Notes
BA06-1A	7°24.299'N	134°34.124'E	?	volcanic flow, lowermost unit
BA06-1B			MR	volcanic flow, first bench
BA06-1C			SB	volcanic flow, upper unit
BA06-1D			SB	volcani flow, topmost unit
BA06-2A	7°26.513'N	134°34.753'E	?	volcanic, from rubbly flows?
BA06-2B			SB	clast from weathered volcanic breccia
BA06-2C			?	volcanic, from rubbly flows?
BA06-3A	7°27.046'N	134°36.554'E	JH	dike cutting volcanic breccia
BA06-3B			JK, OI	three clasts from volcanic breccia
BA06-4A	7°28.589'N	134°36.635'E	MR	dike
BA06-4B			MR	dike
BA06-4C			SB	dike
BA06-4D			JK	dike
BA06-4E			JH	dike
BA06-4F			JH	dike
BA06-5A	7°31.348'N	134°36.938'E	SB	coarse turibitic sand
BA06-5B			JH	fine tuffaceous sand/silt
BA06-5C			JH	fine tuffaceous sand/silt
BA06-6A	7°35.306'N	134°37.592'E	OI	clast from volcanic breccia
BA06-6B			OI	clast from volcanic breccia
BA06-6C			JH	clast from volcanic breccia
BA06-6D			SB	clast from volcanic breccia
BA06-6E			JK	clast from volcanic breccia
BA06-7A	7°33.131'N	134°34.375'E	JK	clast from volcanic breeccia
BA06-7B			OI	clast from volcanic breccia
BA06-7C			JH	clast from breccia, with large CPX
BA06-7D			JK	small clast with some PLAG
BA06-8A	7°32.752'N	134°34.040'E	MR	clast from volcanic breccia
BA06-8B			MR	clast from volcanic breccia
BA06-8C			JK	clast from volcanic breccia
BA06-8D			YO	clast from volcanic breccia
BA06-8E			JH	clast from volcanic breccia
BA06-8F			OI	clast from volcanic breccia
BA06-8G			OI	clast from volcanic breccia

Sample:	Latitude	Longitude	Taken by	Notes
BA06-9A	7°30.595'N	134°33.309'E	OI	HB dacite from breccia
BA06-9B			OI	HB dacite from breccia
BA06-9C			SB	dacite from outer margin of plug
BA06-9D			TI	HB dacite from breccia
BA06-10A	7°26.957'N	134°31.845'E	OI	piece from altered pillow
BA06-10B			OI	piece from more massive unit
BA06-10C			MR, KK	interpillow material
BA06-10D			JH	piece from more massive unit
BA06-10E			SB	piece from more massive unit
BA06-10F			SB	piece from altered pillow
BA06-10G				skipped, was n°10G
BA06-10H			SB	black shaly clay above volcanics
BA06-10I			SB	thin, tan clays within black shale
BA06-10J			PC	tan clay from farther N along outcrop
BA06-10K			PC	sandy material directly over pillows
BA06-11A	7°28.861'N	134°29.824'E	SB	clast out of volcanic breccia
BA06-11B			JH	HB dacite/tonalite
BA06-11C			OI	clast out of volcanic breccia
BA06-11D			OI	clast out of volcanic breccia

Yasuhiko Ohara (YO); Mark Reagan (MR); Teruaki Ishii (TI); Jun-Ichi Kimura (JK);
Osamu Ishizuka (OI); Katsuyoshi Michibayashi (KM); James Hawkins (JH); Katherine Kelley (KK);
Sherman Bloomer (SB); Robert Stern (RS); Brittney Blake (BB); Pat Colin (PC); Lori Colin (LC)

Fig. 1. Schematic road map of Palau showing the stations (see Table 1).

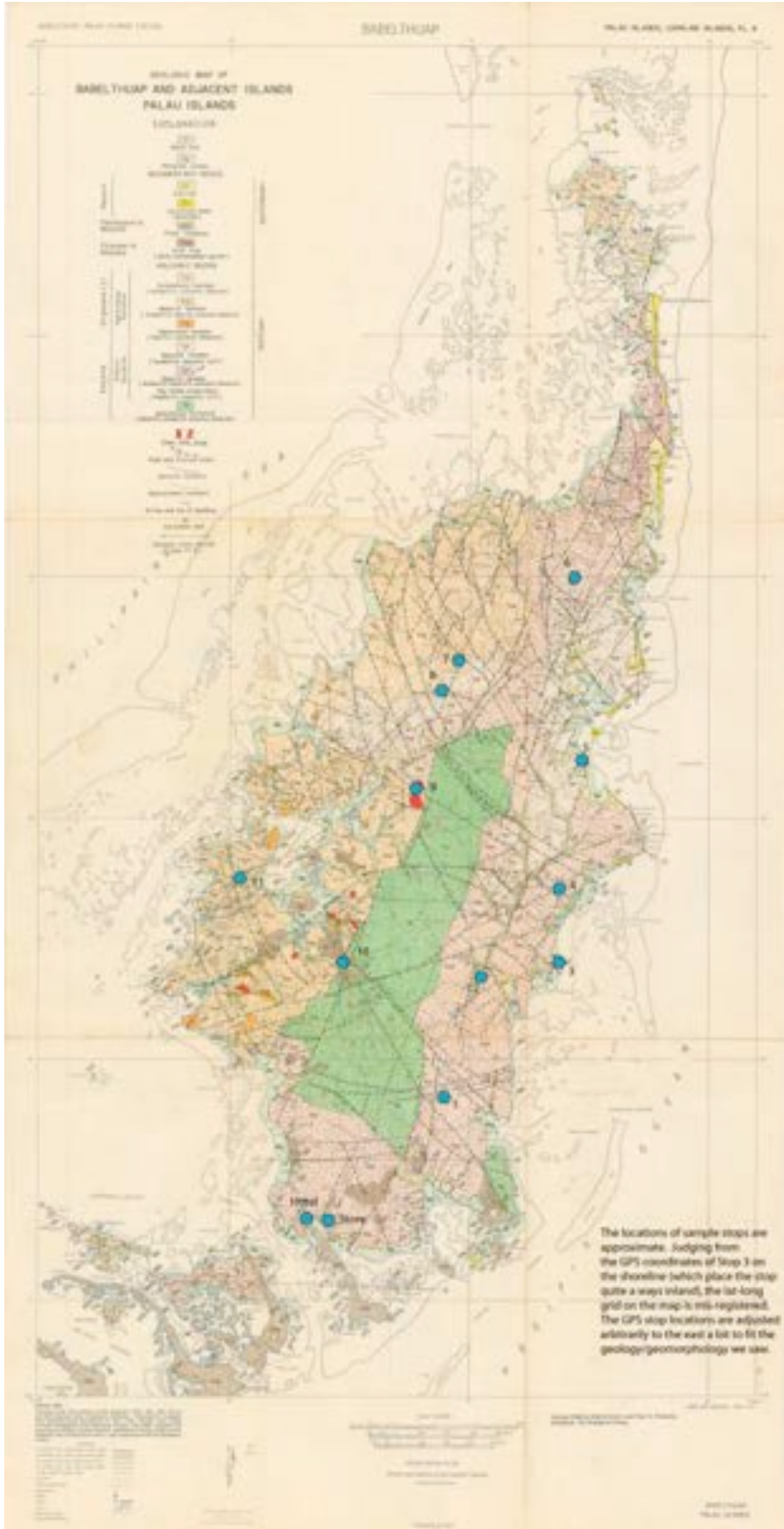


Fig. 2. Stations superimposed on the geologic map of Mason et al. (1956).

Appendix H: Guide for Guam field trip

Guide for field trip through geology of Guam, September 6, 2006 – M. Reagan

Alutom Fm. sediments

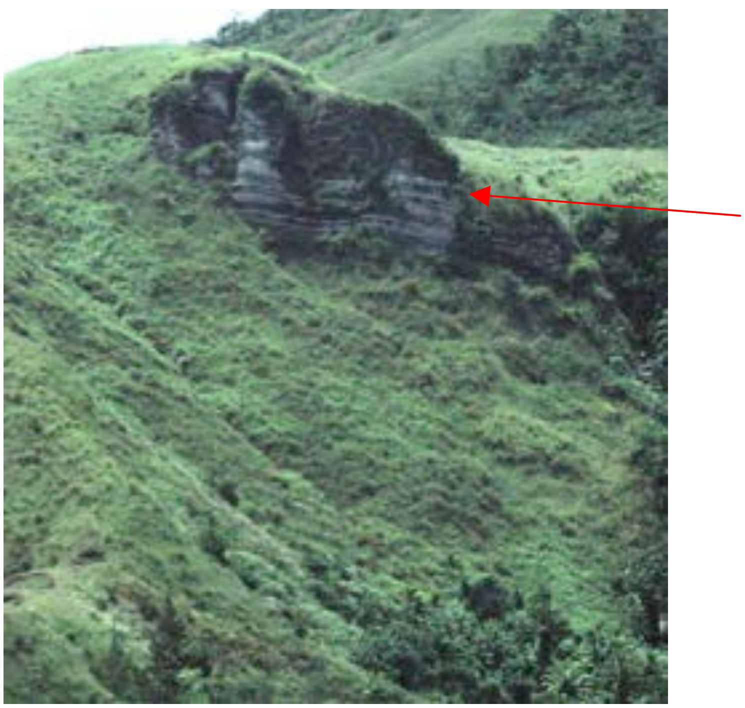
(1) Mount Alutom & Spruance Dr. - Road cuts along this drive have excellent exposures of Alutom Fm. sediments. These consist of interbedded volcanic breccias, conglomerates, sandstones, siltstones, and rare limestones. These sediments appear largely to have been deposited from subaqueous debris flows and turbidity currents. Most clasts in the breccias and conglomerates are 2-pyroxene andesites, with rare dacites and low-Si rhyolites. Rare hornblende and quartz may be found in the silicic rocks. The trace element patterns for these rocks are typically arc-like. That is, they have significantly lower concentrations of Nb compared to La, and they have excesses of large-ion lithophile elements (LILE); e.g. Rb, K, Ba) compared to rare-earth elements (REE). REE patterns are relatively flat for these lavas, as they are for most “first-arc” lavas from the Izu-Bonin-Mariana arc. Clasts in these sediments have been dated between 38 and 34 Ma by ^{40}Ar/^{39}Ar methods. Basaltic sills found in the Sasa river valley have been dated at 32 Ma by K/Ar methods (Meijer et al., 1983).

(2) Sella Bay overlook - good views of boninite-series pillow lavas and overlying Maemong limestone. In this area, the lower portion of the Facpi formation consists of boninitic pillow lavas and associated breccias, which have been dated at ca. 44 Ma by K/Ar (Meijer et al., 1983) and ^{40}Ar/^{39} methods (M. Reagan and M. Heizler, unpublished data). These are high-Ca boninites according to the definition of (Crawford et al., 1989). These boninites have significantly higher REE concentrations than the boninites erupted 4 million years earlier at DSDP site 458. Most Facpi boninites have lower La/Nb ratios than most arc lavas, perhaps due to the high degrees of melting. The Facpi Fm. here is capped by micritic and sandy limestones of the Maemong member of (Tracey et al., 1964). The Maemong is in turn overlain by volcanic conglomerates and breccias of the Balanos member (Reagan and Meijer 1984). No pillow lavas of the Schroeder flow member are here (see below). This portion of the Maemong limestone was dated as Late Oligocene to Early Miocene by

Waterfall over Facpi Fm. pillow lava

Maemong limestone

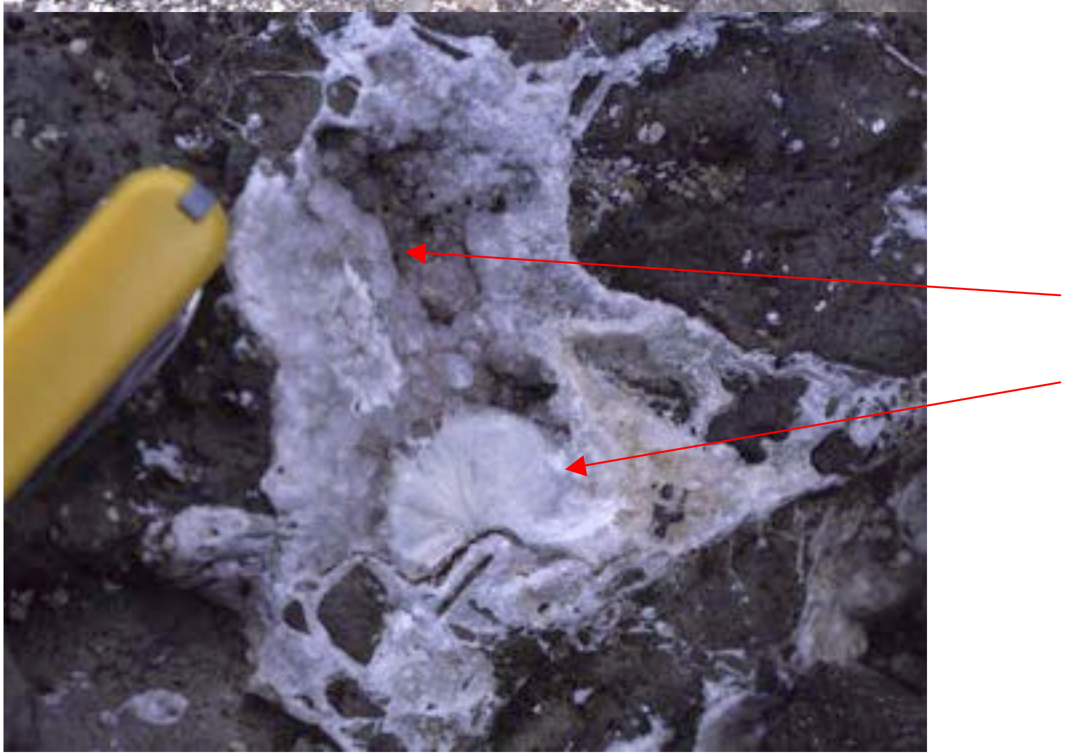
Meijer et al. (1983). Southward from this location, the upper section of the Facpi Fm. begins to have a greater proportion of bedded breccias and conglomerates and fewer pillow lavas. It also becomes less boninitic and more tholeiitic.



(3) Umatac beach – Cobbles on the beach here are composed largely of fragments of Miocene Schroeder Flow Member pillow lavas (see below). Both sides of Umatac bay have excellent exposures of Facpi F. boninite series pillow lavas in seastacks and wave-cut terraces. Open spaces in these lavas have been partially filled with zeolites, calcite, and/or opal. Zeolites in this area include analcime, natrolite, philippsite, and clinoptilolite. Large crystals of these zeolites are present on the north side of the bay. The south side of the bay

has some of the freshest pillow lavas and pillow breccias of the Facpi Fm. on Guam. Also exposed there are relatively fresh Boninite series dikes. These dikes produced 26 and 34 Ma ages by $^{40}Ar/^{39}$ methods (M. Reagan and M. Heizler, unpublished data), which are unreasonably young based on the similarity in compositions of the dikes and pillow lavas.

Facpi Formation dikes and pillow lavas on south side of Umatac bay

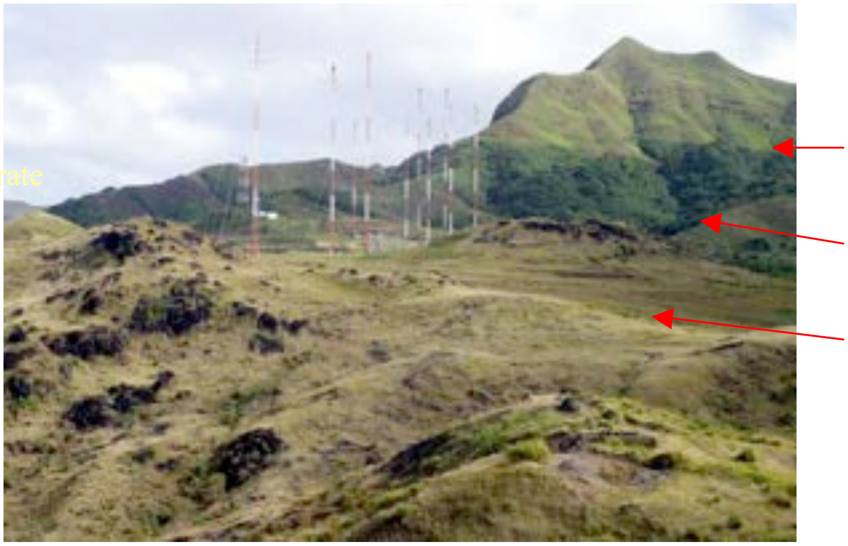


(4) Old Spanish Fort overlook - good view northward of region underlain by pillow lavas, breccias, and dikes of the middle-Eocene Facpi Fm. The dike concentration appears to increase northward toward the Facpi peninsula, where some dikes are sheeted. The Facpi Fm. was defined in Reagan and Meijer (1984), after it was recognized to be older than the

Alutom Fm. both in radiometric age (Meijer et al., 1983) and in stratigraphic position near Agat (see geological map). Further changes to formational names are expected when ongoing mapping by Mark Reagan, Galt Siegrist, John Jenson, and students is completed.

(5) Radio station above Merizo – These outcrops are composed of altered volcanic breccias and minor highly fractured tholeiitic pillow basalts of the Facpi Fm. These basalts overlie the boninites discussed above, and have been dated at 40-42 Ma by K/Ar (Meijer et al., 1983) and ^{40}Ar/^{39} methods (M. Reagan and M. Heizler, unpublished data). The matrix of the breccias mostly consists of fined-grained calcite, much of which appears to be micritic, although some of the matrix and vein-filling carbonate is finely crystalline. On the hill slope southeast of the radio station, and in Geus river valley are outcrops of interbedded conglomerates, breccias, sandstones, siltstones, and limestones. Sediments immediately above the Facpi tholeiitic basalts in this area were mapped by Reagan and Meijer (1984) to be Alutom Fm. based on a late-Eocene nannofossil age in Meijer et al. (1983). The Schroeder flow member of the Umatac Fm. is interbedded with these sediments less than 100 m above their base. The flow member consists of olivine-augite basaltic andesitic pillow lavas. In this area, these pillow lavas are highly altered, although they are very fresh in the Geus River valley where they have abundant glassy pillow rinds. The Schroeder flow member was dated at 13 Ma by K/Ar methods (Meijer et al., 1983), and has compositions much like the most potassic modern Mariana arc andesites. The uppermost sediments in this area are the volcaniclastic deposits making up the Balanos member of the Umatac Fm. Clasts in the sediments here were largely derived from coarsely porphyritic andesite lavas. A high proportion of these clasts have augite crystals up to several mm in length, which is one of the principal ways that the Balanos breccias can be distinguished from older

volcaniclastic sediments. It is highly probable that the stratigraphy in this area provides a record of the volcanic and tectonic activity spanning from the late Eocene into the middle to late Miocene at the southern end of the IBM arc.

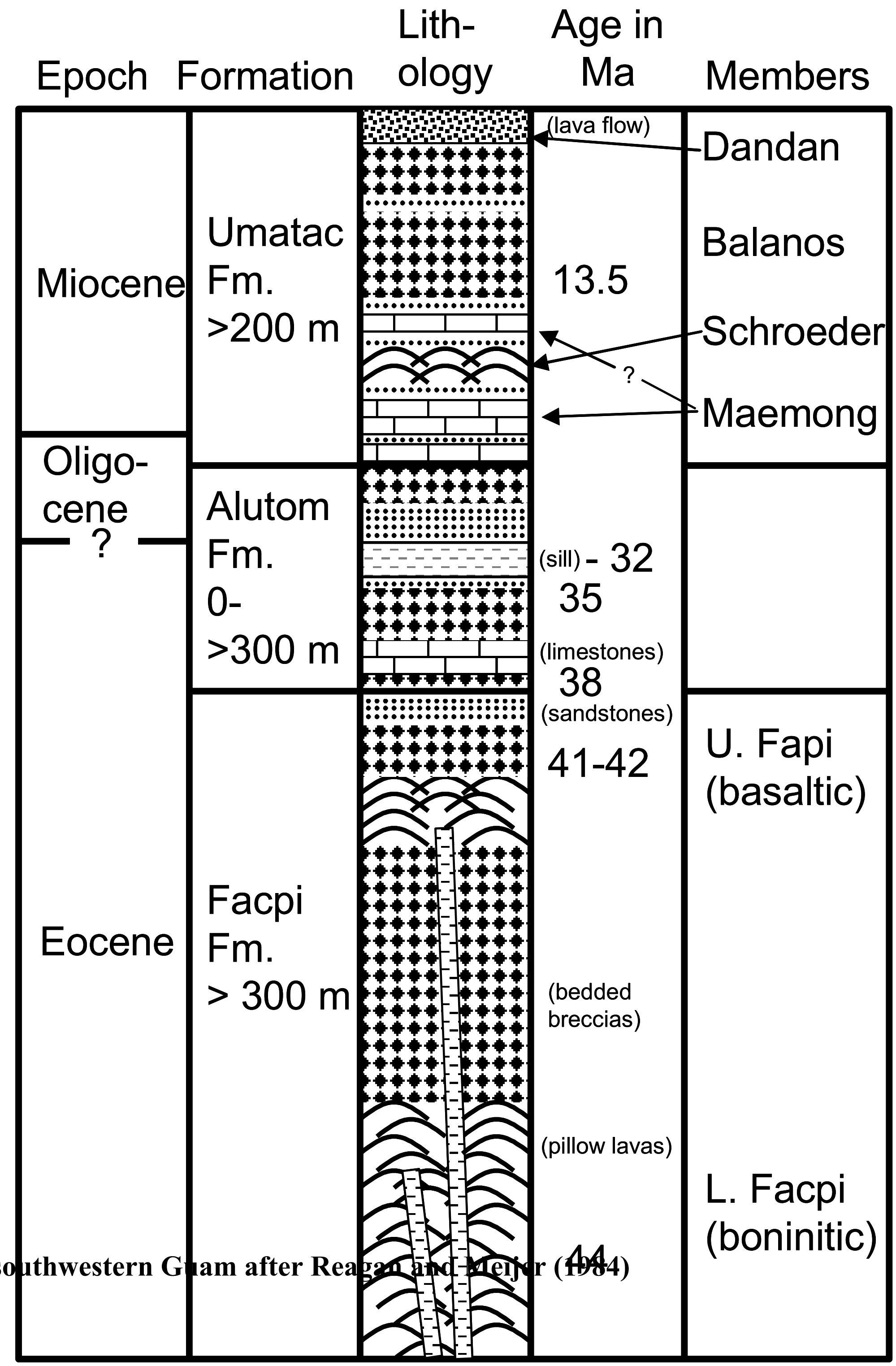


(6) Iha agricultural experiment station - Flow breccia or remnant cinder of Dandan Flow member of Umatac Fm. This is thought to be the youngest volcanic unit on Guam. It is presently not well dated, although it must be younger than 13 Ma based on radiometric dating of the Schroeder flow member. Major element compositions for this member in (Stark 1964)) range from basalt to silicic andesite, suggesting that it represents a number of flows. This particular outcrop is composed of highly oxidized vesicular basalt or basaltic andesite. It has abundant plagioclase phenocrysts up to 2-3 mm in length, and what appear to be Fe oxyhydroxide-zeolite pseudomorphs of olivine.

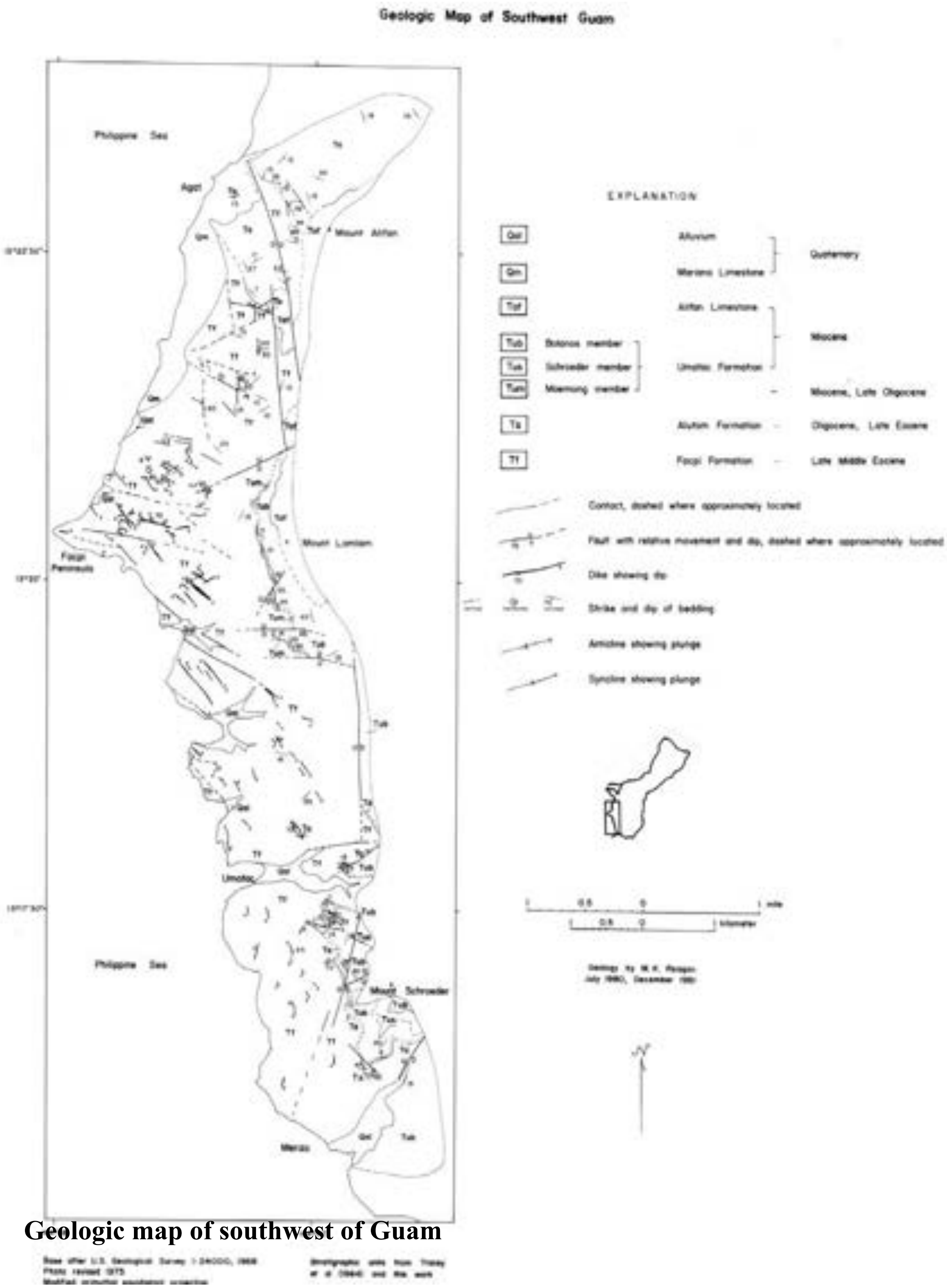
(5) Talafofo Falls resort - Dandan flow member of Umatac Fm. This is one of the few massive, probably subaerial lava flows found on Guam. It is a moderately altered two pyroxene-plagioclase andesite. Its stratigraphic relationship with the breccias found at location 4 is not clear. The views north and west from here illustrate the gentle easterly dip slope formed by the Miocene aged volcanic units on southern Guam.

(6) Radio tower atop Mount Santa Rosa – Pillow lavas and associated sediments that are similar in appearance to those of the Facpi and Alutom Fms. are exposed in this area. The pillow lavas have compositions that are intermediate between those of Facpi Fm. boninite series lavas and the somewhat magnesian andesites of the Alutom Fm. K-Ar dating in Meijer et al. (1983) places these lavas at about 35Ma. New $^{40}Ar/^{39}Ar$ dating is underway to determine the true age of these transitional lavas.

This vista from the tower includes excellent views of the younger reef-related limestones of Guam and the nature of the karst topography in northern Guam. Most of the area is underlain by various facies of the Pliocene to Pleistocene Mariana limestone. This is underlain by the late Miocene Barrigada limestone, which can be seen directly southwest of Mount Santa Rosa. Karstification of this limestone and associated cave collapse associated with north to south groundwater flow has resulted in the gentle swale running northwest to southeast across northern Guam.



Stratigraphy of southwestern Guam after Reagan and Meijer (1984)



Geologic map of southwest of Guam

Representative compositions of volcanic rocks from Guam

	L. Facpi pillow lava	U. Facpi breccia clast	Alutom sill	Alutom breccia clast	Alutom breccia clast	Shroeder pillow lava	Mt. Santa Rosa pillow
Type	Boninite series	Tholeiitic basalt	Tholeiitic basalt	Andesite	Rhyolite	Basaltic andesite	Andesite
Sample	GUM02-40	GUM80-65	SASA 80-2	GUM80-53A	GUM02-7	GUM-80-93	MSR-P-80
SiO_2	56.95	51.8	50.06	59.93	72.8	54.61	57.61
TiO_2	0.56	0.33	0.59	0.34	0.29	1.14	0.77
Al_2O_3	14.69	15.62	17.64	16.12	14.16	14.12	15.57
Fe_2O_3*	9.03	9.97	9.62	7.1	3.07	12.89	9.47
MnO	0.14	0.09	0.11	0.14	0.03	0.21	0.13
MgO	6.54	10.2	8.32	5.7	0.96	4.28	4.06
CaO	8.77	10.55	10.89	7.79	3.88	8.54	8.3
Na_2O	2.56	1.66	2.28	2.8	3.68	2.88	3.22
K_2O	0.77	0.34	0.66	0.53	0.97	1.07	0.8
P_2O_5	0.09	0.06	0.09	0.05	0.11	0.25	0.08
Total	100.09	100.61	100.27	100.5	99.93	94.78	90.95
Li	9.91	46.81	20.99	21.7	10.34	7.09	9.79
Be	0.73	0.4	0.35	0.62	0.82		
Cs	0.433	0.097	0.051	0.119	0.256	0.475	0.529
Rb	13.67	4.64	5.68	4.57	15.13	24.43	14.29
Ba	79.59	32.93	90.47	65.53	98.77	289.54	124.22
Sr	134.29	113.38	178.05	128.02	153.36	492.57	157.52
Pb	2.07	1.24	1.28	1.68	1.91	3.06	2.297
Th	0.667	0.218	0.218	0.586	0.364	1.304	0.941
U	0.349	0.143	0.092	0.261	0.234	0.497	0.45
Nb	2.95	1.43	0.56	2.16	1.37	3.97	4.068
Ta	0.196	0.111	0.053	0.203	0.096	0.188	0.32
La	4.32	2	2.67	16.39	5.2	15.17	6.45
Ce	9.7	3.44	7.4	8.35	11.71	32.84	14.66
Pr	1.2	0.79	1.19	3.9	1.82	4.38	2.07
Nd	5.49	3.83	5.91	18.1	8.45	19.44	10.53
Zr	52.69	23.54	47.59	44.52	63.94	98.34	81.32
Hf	1.58	0.75	1.32	1.39	1.87	2.44	2.21
Sm	1.67	1.27	1.86	4.87	2.5	5.16	2.82
Eu	0.56	0.41	0.7	1.39	0.73	1.52	0.85
Gd	2.22	1.76	2.39	8.3	3.11	5.48	3.89
Tb	0.4	0.32	0.42	1.37	0.54	0.89	0.71
Dy	2.66	2.07	2.7	9.02	3.45	5.52	4.2
Ho	0.59	0.46	0.6	2.23	0.75	1.21	0.99
Er	1.74	1.33	1.73	6.51	2.17	3.28	2.81
Yb	1.85	1.37	1.72	5.65	2.18	2.82	3.02
Lu	0.3	0.22	0.27	0.96	0.35	0.52	0.52
Y	16.72	13.61	17.02	93.77	22.07	35.66	26.69
V	239.93	215.37	281.23	195.29	23.15	415.43	315.73
Sc	30.6	38.55	41.11	34.03	8.64	40.27	34.91
Ni	93.2	253.86	75.27	176.58	41.38	38.2	49.34
Cr	256.1	748.9	242.98	534.7	2.57	18	51.98
Co	29.18	44.8	36.01	38.65	6.77	35.41	27.82
Cu	98.89	77.73	198.35	74.59	5.77	196.29	127.26
Zn	65.01	65.72	69.98	64.78	34.62	147.49	97.1
Ga	14.51	11.93	15.42	12.36	15.34		
As	0.98	0.6	0.38	0.71	0.29		