doi : 10.17596/0003473

CRUISE REPORT

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

R/V Natsushima
Cruise NT0902

Studies of submarine arc volcanism and hydrothermal activity in the southern Mariana Arc

February 2 to February 7, 2009

(Guam to Saipan)

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ACKNOWLEDGEMENTS

We are grateful to Captain Koji Sameshima and the excellent crew of the R/V Natsushima, the Hyper Dolphin operation team manager Kazuya Mitsufuji and the Hyper Dolphin 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.

SUMMARY OF PRINCIPAL CRUISE RESULTS

During this cruise, a Japan-US team of scientists studied volcanism near the southern end of the active Izu-Bonin-Mariana arc (Stern et al., 2003) using JAMSTEC's R/V Natsushima and ROV Hyper-Dolphin and. We focused on the Southern Seamount Province of the active Mariana Arc between 13°30'N and 14°40'N. The targets lie just west of the Mariana frontal arc islands, especially Guam and Rota. The cruise completed additional multi-beam maps of the seafloor, completed four dives of Hyper-Dolphin, and recovered 56 rock samples and 8 core samples. Two monitoring instruments were deployed at NW Rota-1.

Tracey Seamount: Dive 949 landed near the base of the western slope of a ~100m tall conical feature developed within a west-facing sector collapse pit near and west of the summit of Tracey Seamount, at a depth of 1338m. Samples R01-R07 were collected from this conical feature, which is thought to be the last magmatic event in the development of Tracey seamount. The conical feature appears to be a dacite dome, as demonstrated by dikes and other steeply dipping flow features that indicate the viscous dacitic magma mostly flowed up and out of the vent. After reaching the summit of the resurgent dome at 1191m, the HD flew eastward ~1km and dropped down to 1300m to traverse the ~500m tall west facing scarp defining the eastern margin of the sector collapse. Samples R08-R15 and push cores C01, C02 were collected during this traverse. The section consisted of apparently interlayered ol-cpx-pl basaltic andesite and pumiceous sandstone, with the proportion of sandy layers and pumice increasing upwards, suggesting that the volcano evolved to erupt increasing proportions of felsic material prior to the final events, which appear to have been sector collapse and emplacement of the resurgent dacite dome.

W. Rota Volcano: Dive 950 consists of two short transects, designed to study the altered and mineralized section, and one long transect to study the volcanic stratigraphy of the north wall. The first transect began at an outcrop of pervasively altered pale-gray volcanic rock with sets of cross fractures, some black and reddish staining, and moderate sediment cover. Sampling recovered a boulder of pervasively altered white to pale-gray volcanic rock with abundant disseminated sulfide and minor sulfide-lined vugs and veins. Much of the outcrop seen in the dive showed a well-developed fracture system with one set oriented sub-vertical and the other sub-horizontal. Pervasively altered rocks occur in outcrop and as talus between sections covered by sediments through most of the dive.

The second traverse was a short distance north of the first and was designed to see how far the pervasive zone of alteration might extend. However, much of the section traversed here was covered by sediment. Layers at the beginning of the line were rust-red below a thin blanket of white-gray sediment. The extensive red layer may represent a buried bacterial mat that lived at the sediment surface above a diffuse-flow hydrothermal system. Pervasively altered rocks were not found in this transect. Fresh andesite was collected at 1118 m and fresh basalt at 1071 m.

The final transect was along a more northerly portion of the caldera wall to look for layered pyroclastics marking the caldera scarp. The dive began among piles of black to dark-gray andesite-dacite cobbles and boulders. Andesite and dacite were the dominant rock types collected throughout the section from 1220 to 560 m, with andesite more commonly encountered at the base and dacitic pumice becoming increasingly common up section. A broad bench between ~980 and 850m was covered with loose sediment that commonly showed ripple marks. Above this it appears that the traverse approached an important eruptive center positioned on the shallowest part of the ridge. This part of the traverse crossed igneous rocks that were very coarse and quite fresh. A composite dike of andesitic (plag-pyroxene andesite) and felsic (pyroxene dacite) magmatic material was observed near the top of the section.

Andesite Knoll: Andesite Knoll is a small volcanic cone ENE of NW Rota-1. It was sampled by D12 during the COOK cruise, recovering mostly andesitic lavas. Dive 951 was conducted here because the US Coast Guard planned to work on the summit of NW Rota-1 on the morning of February 6th. This small seamount was first mapped and sampled by Leg 7 of the Cook Expedition (2001). The andesitic composition of the D12 lava stands in contrast to the basaltic material erupted recently from NW-Rota to the west and picrites erupted from Chaife Seamount to the east. Because of the limited amount of material recovered in 2001 and the unusual magmatism in the region, more detailed examination and sampling was needed.

Dive 951 reached bottom at a depth of 2319 meters on the NE flank of the volcano. The immediate landing location was a terrace or shallowly dipping slope covered with gray-white sediment. Numerous centimeter scale rock clasts were observed in the sediment. *Hyper Dolphin* climbed towards the summit from this point, and encountered steep slopes of blocky lava flows and ledges alternating with gentler slopes covered with sediment. The steep slopes were not continuous and consisted of projecting outcrops that were likely flows. The outcrops varied in morphology, most were blocky due to strong jointing, but pillow morphologies were observed. Some outcrop formed overhanging ledges. Outcrop on the upper slopes had thin (2-5 cm) sheet flow layering. Fourteen rock samples were recovered. All the samples are dark gray, porphyritic plagioclase phyric basalt or basaltic-andesite.

NW Rota-1 volcano: Dive 452 examined the summit region of NW Rota-1, around Brimstone Pit. The volcano, which was first observed to be active in 2004, remains active, with a vigorous plume emanating from the vent. There was significant sulfur being ejected in the plume, abundant release of carbon dioxide, and occasional bursts of tephra. No evidence of lava was observed. The shoal edge of the rim is now at about 519 m. When activity here was first observed, the depth of the pit rim was about 540 m. It appears there has been significant growth of the vent area in the nearly five years of activity here.

There were abundant sulfur coatings and rims on many rocks and very abundant microbial mats in some places. Shimmering water can be identified near some of the microbial mats. Shrimp and crabs are common as well.

There are steep fissures observed in places, and near the summit large columns or spires of volcanic material that appear to be constructed by the volcanic activity. Six rock samples and four core samples were recovered. Two temperature-redox meters were placed near the rim of the vent (by K. Nakamura of the Geological Survey of Japan).

1. Introduction and Background

The Izu-Bonin-Mariana arc system (IBM) extends over 2800 km south from near Tokyo, Japan, to beyond Guam, U.S.A. (Figs. 1.1, 1.2), and is an excellent example of an intra-oceanic convergent margin (IOCM). IOCMs are built on oceanic crust and contrast fundamentally with arcs built on continental crust, such as Japan or the Andes. Because IOCM crust is thinner, denser, and more refractory than that beneath Andean- or Japan-type margins, study of IOCM melts and fluids allows more confident assessment of mantle-to-crust fluxes and processes than is possible for continental arcs. Because IOCMs are far removed from continents they are not affected by the subduction of large volume of fluvial and glacial sediments. The consequent thin sedimentary cover makes it much easier to study arc infrastructure and determine the composition of mantle-derived melts. Active hydrothermal systems found on the submarine parts of IOCMs give us a chance to study how many of Earth's important ore deposits formed. Hydrothermal activity on these results in a uniquely diverse biota that is only know starting to be appreciated.

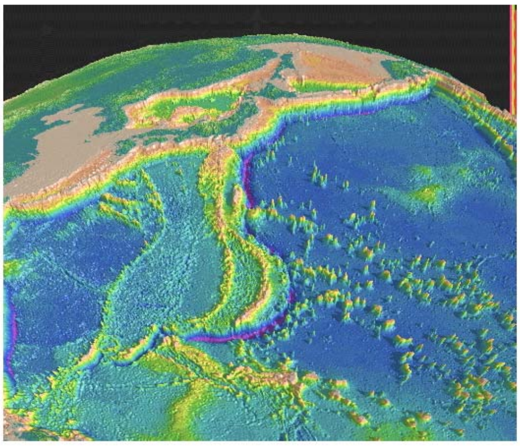


Figure 1.1 (left): Perspective view of the IBM subduction system (courtesy D. Sandwell)

The IBM arc presents an outstanding opportunity to study the operation of the Subduction Factory at an IOCM, for several reasons: 1) the history of IBM evolution is one of the best known of any convergent margin; 2) there are four opportunities across the arc to sample products being produced by the Subduction Factory – the forearc, the active magmatic arc, arc cross-chains, and back-arc basins - more than any other convergent margin; 3) subducted sediments are simple, diagnostic, and completely subducted; 4) IBM is a type example of convergent margins undergoing extension; and 5) IBM is large and diverse. Furthermore, a collision zone in the north provides an unparalleled opportunity to study the composition of middle IBM crust and so better infer products and processes leading to the formation of this crust. Because the islands and EEZ's of IBM are governed by the US in the south and Japan in the north, IBM provides special opportunities for teambuilding between US and Japanese scientists to collaborate and learn from each other, to involve young scientists in this process, and to work together to develop research proposals. The suitability of IBM for studies that promise to lead to fundamental understanding of Earth processes has made it a focus of international research efforts, including the US NSF-MARGINS 'Subduction Factory' experiment. It is likely to be an important focus of IODP drilling. In spite of its importance, we have much to learn about it in order to allow the best proposals to be written.

An up-to-date overview of the IBM arc system can be found in (Stern et al. 2003). This overview notes that the arc system shows important variations in tectonic and magmatic expression along its strike. They divide the arc into three segments. The two best studied segments are the Izu segment north of 30°N and the Mariana segment south of 24°N. These two segments provide natural foci for US and

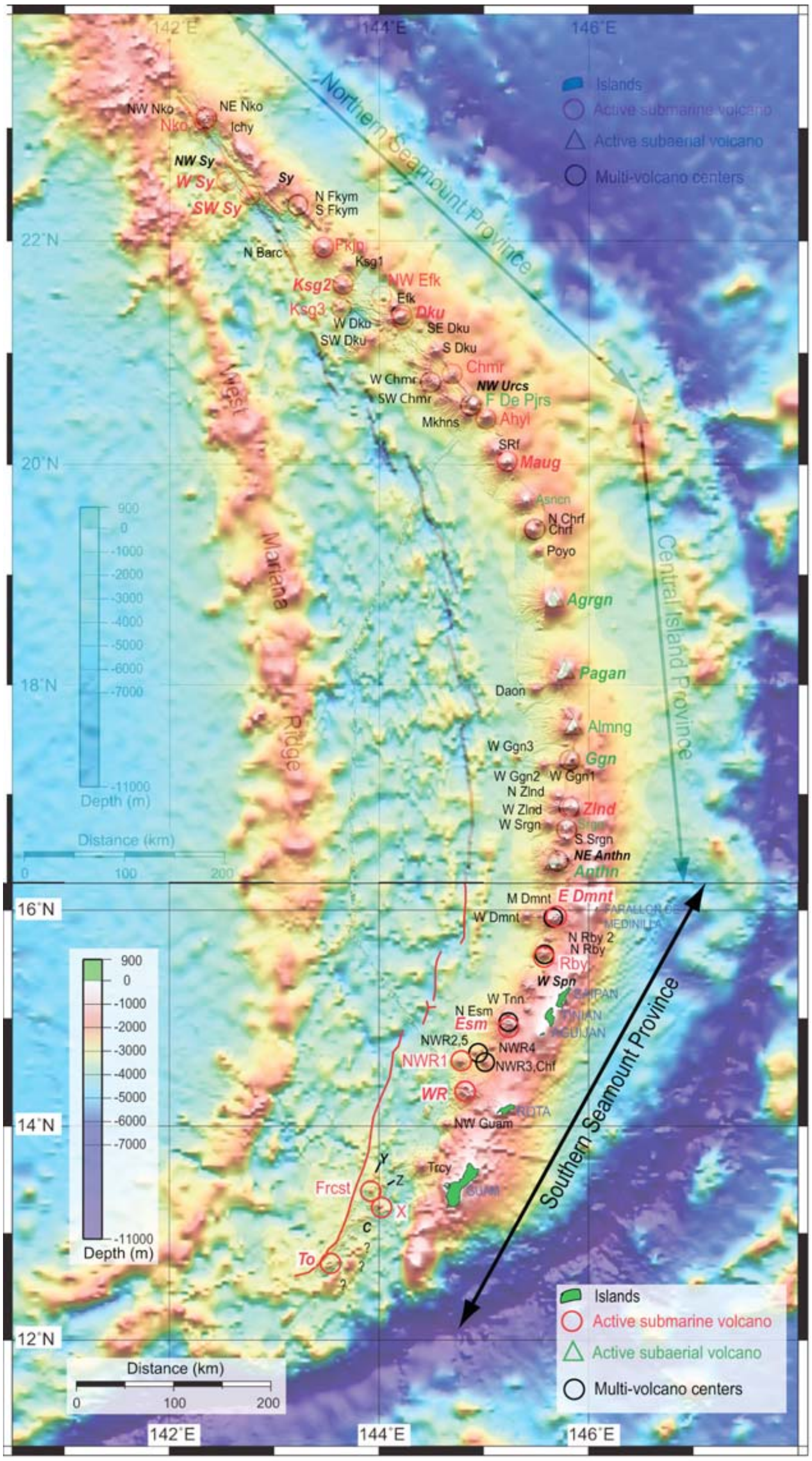


Figure 1.2. Bathymetry of the Mariana arc region (Baker et al., 2008), showing all 51 edifices presently named along the volcanic front between 12°30'N and 23°10'N. Hydrothermally or volcanically active submarine edifices are labeled red; active subaerial edifices are labeled green. Inactive submarine and subaerial edifices are labeled in smaller black and green font, respectively. For all edifices, caldera labels are in bold italics. Black circles (20-km diameter) identify those volcanic centers composed of multiple individual edifices. Solid red line is the backarc spreading center.

Baker et al. (2008) identified 76 volcanic edifices along 1370 km of the Mariana arc, grouped into 60 ''volcanic centers,'' of which at least 26 (20 submarine) are hydrothermally or volcanically active. Active volcanoes lie 80 to 230 km above the subducting Pacific plate, and ~25% lie behind the arc magmatic front.

The first global compilation of arc volcanoes using recent bathymetric data estimated that arcs that are at least partially submarine have a population of almost 700 volcanoes, of which at least 200 are submerged (de Ronde et al., 2003).

Japanese investigators to study arc systems, and the along-strike variations provide opportunities for scientists from these two nations to compare and contrast the different perspectives that these provide. The Mariana arc is further divided into the Northern Seamount Province, Central Island Province, and Southern Seamount Province (SSP) (Fig. 1.2; Bloomer et al. 1989). The Mariana SSP lies close to populated islands of Guam, Rota, Tinian, and Saipan and SSP volcanoes are within the US EEZ. There are good international airports and ports on Saipan and Guam.

For all of the reasons mentioned above, the Mariana SSP is becoming an increasingly attractive research area for international teams of marine scientists, as indicated by the recent acceleration of research in the region. In spite of this, there have been relatively few studies of these volcanoes, although this is rapidly changing. In 2001 this region was surveyed with HAWAII MR-1 and extensively dredge-sampled during the COOK 7 cruise (R/V Melville; Bloomer and Stern, co-chief scientists). In 2003 a NOAA cruise (R/V Thompson, Bob Embley, chief scientist) surveyed the region and identified likely sites of hydrothermal activity with CTD casts. In 2004 the NOAA team returned for interdisciplinary studies of vent geology, biology, and chemistry using ROV ROPOS. The NOAA effort has discovered numerous sites of volcanic and vigorous hydrothermal activity (Baker et al., 2008). In 2005, a Japan-US team aboard R/V Natsushima (NT0517) made 10 dives with Hyperdolphin 3K on several geologic targets in the SSP. Substantially the same team was involved in the present project, emphasizing two of the sites which we studied at that time: West Rota and NW-Rota-1, as well as a first study of Tracey Seamount, west of Guam. West Rota and NW-Rota-1 provide important insights for understanding magmatic degassing (NW Rota-1) and formation of felsic magmas and associated massive sulfide mineralization (W. Rota). Bathymetric surveys of Tracey show a sector collapse with what appeared to be a small dome; if silicic, this area could also provide information on the formation of felsic magmas.

The work here builds on these recent advances in our understanding of the Mariana SSP. We focus on a relatively small area of submarine volcanism in the southern Mariana arc. Young lavas from three volcanoes (Chaife, NW Rota-1, West Rota) are the most primitive arc magmas known from the active IBM arc and, along with several other volcanoes in the associated arc cross-chain, may be a good example of 'hot fingers' (Tamura et al. 2002) in the Mariana sub-arc mantle. W. Rota volcano lies just to the south of this cross-chain and is an extinct volcano with a very large caldera.

We used the ROV 'Hyper-Dolphin 3K' instead of Shinkai in this work to maximize the opportunity for an interdisciplinary group of scientists to participate in all aspects of field studies and to allow us to examine NW-Rota 1, where vigorous venting was observed in Spring 2004, Oct. 2005, and April-May 2006 (see April 24-30 logs on the NOAA "Submarine Ring of Fire" website: http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html). Our initial cruise plan included 5 dives, 2 on W. Rota, 1 dive on NW Rota-1, and 2 dives on Tracey seamounts. All dive targets lie at water depths of 2600m or less, and most are much shallower.

2. Scientific Objectives:

The volcanoes of interest to this study (Tracey, West Rota, and NW Rota-1) occupy a small segment (about two degrees latitude) of the Southern Seamount Province of the Mariana Arc, between 13°30'N and 14°45'N (Fig. 1.2). They lie within the EEZ of Guam (Tracey) or the Northern Mariana Commonwealth (W. Rota, NW Rota-1), which are parts of the United States of America. Although these volcanoes lie in a geographically restricted region, they illuminate important aspects of IOCM evolution. All three volcanoes are submarine but vary in volume from, from Tracey (about 5 $x10^{10}$ m^3), NW Rota-1 ($1.2x10^{11}$ m^3), to the largest volcanoes in the SSP, West Rota ($5.2x10^{11}$ m^3).

In the following passages we discuss our understanding of and scientific objectives for each of the proposed dive targets, beginning with Tracey, and progressing to West Rota Caldera and NW Rota-1.

2.1. Geology of Tracey Seamount, Sector Collapse, and Dome Growth in Submarine Volcanoes

Tracey Seamount lies about 30 km due west of Guam and is the last substantial volcano of the Mariana magmatic arc. The Mariana magmatic arc does continue SW of Tracey but edifices are much smaller (Martínez et al., 2000), presumably because this part of the convergent plate boundary is tectonically reorganizing due to combined effects of back-arc spreading, rapid slab rollback, and development of a tear in the subducted slab (Gvirtzman and Stern, 2004). Tracey is a nearly perfect cone that is ~2 km tall, has a base radius of ~5km at ~2500 m water depth, and contains ~45 km^3 of volcanic material (Fig. 2.1).

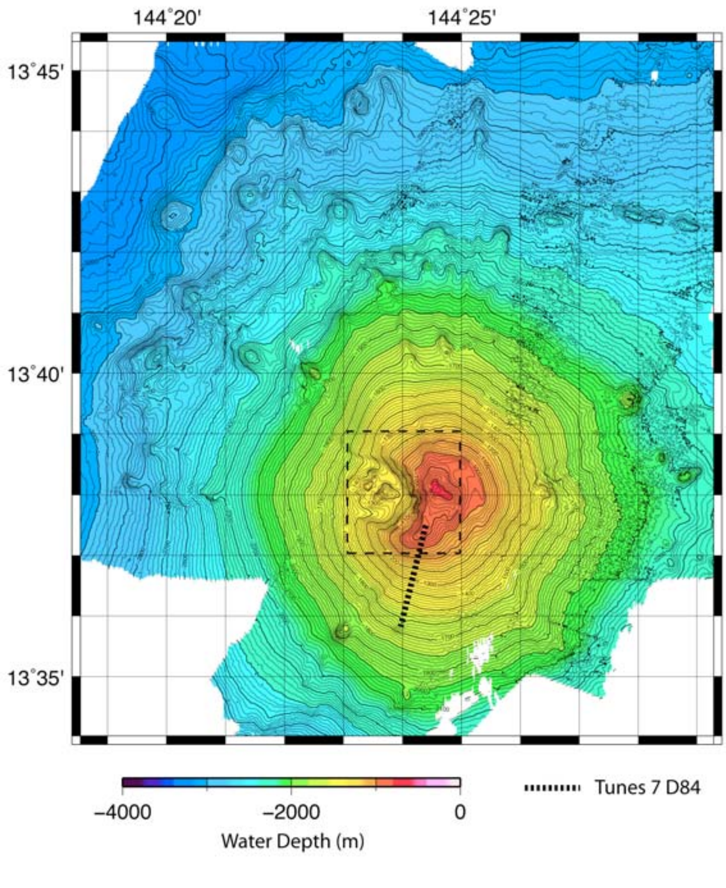


Figure 2.1: Bathymetric map of Tracey Seamount, from Mariana Bathymetric Compilation (Susan Merle, PMEL/NOAA, compiler). Location of Tunes 7 Dredge 84 (R/V T.G. Thompson, 1992) also shown.

This is one of the smaller volcanoes in the Mariana arc; note that the largest, Pagan, contains about 2200 km^3 material (Bloomer et al., 1989). In spite of its proximity to Guam, it has never been studied by ROV. It is apparently extinct, having no known eruption or significant hydrothermal signal when it was surveyed with CTD casts in 2003 by NOAA (Baker et al. 2008). Nevertheless, it lies above a major normal fault separating the Mariana Arc from the Mariana Trough back-arc basin without apparent offset, suggesting that it is a relatively youthful volcano.

Multibeam bathymetric maps of Tracey show a small sector collapse west of the central peak, with a small dome structure in the collapse (Fig. 2.1). One dredge on the southern flank yielded pumice, Mn-coated volcanics, and small gabbroic fragments. The morphology and dredge results suggest an opportunity to examine the stratigraphy of the upper section of the seamount along the scarp of the sector collapse and to sample what appears to be a felsic dome. There are also a number of small parasitic cones and knobs on the northern flanks of Tracey. Sampling of other such structures in the Marianas have commonly yielded lavas that are unusually primitive compared to typical arc magmas. The first Hyperdolphin dive on Tracey was designed to sample the dome and collapse scarp and the second to visit three of four of the small parasitic structure to explore for mafic lavas.

2.2 West Rota: Felsic volcanism in the IBM arc system and exposed roots of an arc hydrothermal system

West Rota Volcano (WRV) was essentially unknown before 2001 but has since been subjected to increasing scrutiny: HMR-1 surveying and dredging during Cook 7 (2001), 1 ROPOS dive in 2004, and 4 Hyperdolphin dives during 2005 (NT0519). Results of these studies are reported by Stern et al. (2008). Submarine felsic calderas are common in the Izu and Kermadec Arcs but are otherwise unknown from the Marianas and other primitive, intraoceanic arcs.

West Rota caldera, a primary target of this cruise, is an important exception because it is more like the large Izu felsic calderas than any other IBM volcano. This volcano has a Crater Lake (Oregon, USA) size caldera that was likely the site of large-volume eruptions of silicic pumice. The caldera floor is 6 to 10 km from wall to wall and as much as1300 m deep (Fig. 2.2). The northern and eastern scarps rise to 400 m while the western scarp has a minimum depth of 1000 m.

The large caldera was not recognized until the Cook 7 expedition swath-mapped it and a dredge from the eastern wall of the caldera (D63) recovered basalts, basaltic andesites, rhyolitic pumice and severely hydrothermally altered lavas. Our work on the hydrothermally altered rocks initially focused on the altered lavas' mineralogy and geochemistry. Initial interest was due to the evidence for high-temperature alteration shown by potassium metasomatism (up to 8 K_2O % with <2% Na_2O) and abundant disseminated sulfides.

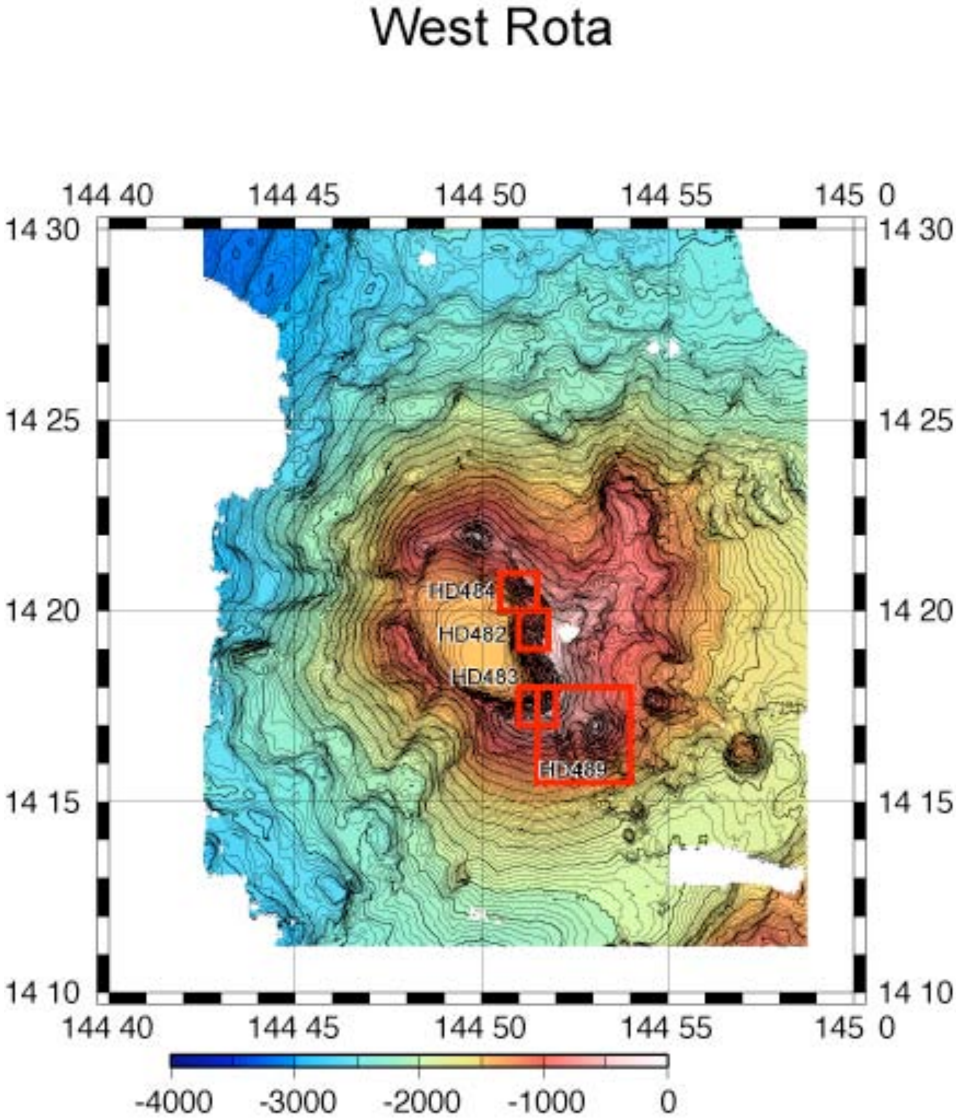


Fig. 2.2 Bathymetry of West Rota Caldera, with areas of 2005 Hyperdolphin dives shown for reference

This association is common in high-temperature metamorphic aureoles associated with subvolcanic porphyry copper deposits. Petrographically, the original rock types were unidentifiable, but relict phenocryst outlines and textures, and the fact that these rocks were dredged alongside fresh basalts and basaltic andesites suggested that these rocks were originally mafic to intermediate lavas. XRD analyses along with SEM probe work suggest that much of the K is contained in sanidine throughout the fine-grained altered groundmass and as inclusions in relict plagioclase phenocrysts. The presence of sanidine as well as tridymite and high quartz require the migration of very high temperature fluids through the lavas and abundant pyrite indicates that this alteration occurred in a reducing environment.

Hyperdolphin dives during NT0517 identified the location of hydrothermally altered lavas and stockwork sulfide mineralization towards the bottom of the caldera walls in Dives 482 and 484. This marks the exhumed roots of an arc hydrothermal system. Dive 483 found a weak but active low-T hydrothermal vent at the bottom of the SE caldera wall. Hyperdolphin Dive 484 identified a zone of intense mineralization, characterized by red-brown resistant ribs, which proved to be sulfide mineralized zones (Fig. 2.3). This opportunity to examine in detail the fossil roots of a hydrothermal system motivated a return to West Rota during NT0902.

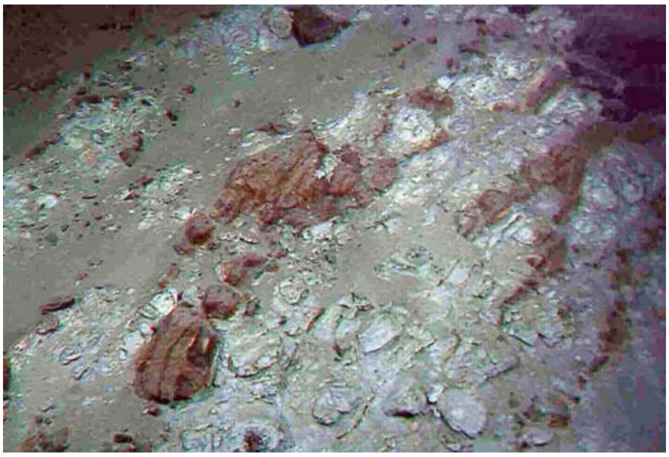


Fig.2.3 Resistant rib of red-brown, sulfide-rich stockwork at about 1260m depth (hdc20051013105447_1).

West Rota also has some distinctive volcanologic and structural characteristics, compared to most other Mariana Arc volcanoes: (i) it consists of a lower, predominantly andesite section overlain by a bimodal rhyolite-basalt layered sequence; (ii) andesitic rocks are locally intensely altered and mineralized; (iii) it has a large caldera; and (iv) WRV is built on a major fault. This effort concentrated on understanding the volcanic stratigraphy and age of this extinct volcano. ^{40}Ar–^{39}Ar dating indicates that andesitic volcanism comprising the lower volcanic section occurred 0.33–0.55 Ma ago, whereas eruption of the upper rhyolites and basalts occurred 37–51 thousand years ago. Four sequences of rhyolite pyroclastics each are 20–75 m thick, unwelded and show reverse grading, indicating submarine eruption. The youngest unit consists of 1–2 m diameter spheroids of rhyolite pumice, interpreted as magmatic balloons, formed by relatively quiet effusion and inflation of rhyolite into the overlying seawater. Geochemical studies indicate that felsic magmas were generated by anatexis of amphibolite-facies metaandesites, perhaps in the middle arc crust. The presence of a large felsic volcano and caldera in the southern Marianas might indicate interaction of large normal faults with a mid-crustal magma body at depth, providing a way for viscous felsic melts to reach the surface.

2.3 Submarine Volcanism and early stage hydrothermal activity in the IBM Arc system at NW ROTA-1

NW-Rota-1 is a nearly perfect cone that rises about 2,500 m above the surrounding sea floor (Fig. 2.4). It was first surveyed and sampled during Cook 7, where D9 recovered fresh dacite (~65% SiO_2) from a lower slope. In 2003, CTD casts during the NOAA-survey found a 200-m-thick layer of intense hydrothermal plumes above the volcano summit, indicating that a vigorous hydrothermal vent system was active (Embley et al., 2006).

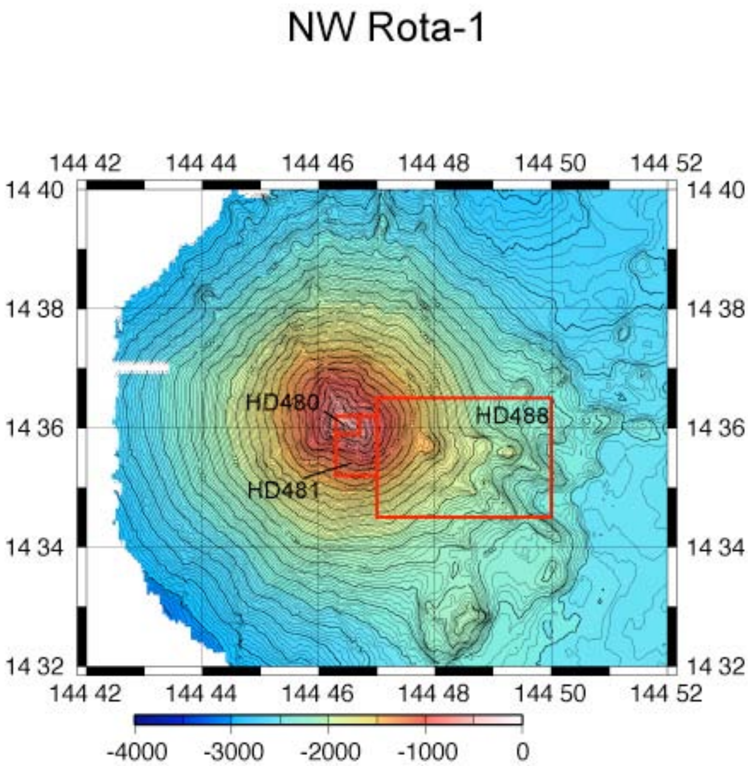


Fig. 2.4 Bathymetric map of NW Rota-1 showing location of 2005 Hyper-Dolphin dives.

The 2004 NOAA cruise using ROPOS dived four times (Dives 782, 783, 784, and 786) on NW Rota-1, and quickly found that activity was concentrated near the summit. Further exploration revealed the main vent, located about 30m below the summit and which was called 'Brimstone Pit", which was funneling up fluid and gas directly from a magma source below. As we sat on the edge of the pit during the 2004 visit, huge billows of yellow-tinged smoke began enveloping the ROPOS. Yellow balls of sulfur emerged from the cloud and began precipitating on the vehicle. When ROPOS returned to the surface, its front side was coated with small balls of sulfur up to about one-quarter inch in diameter. The droplets had splattered into shapes that left no doubt that the sulfur balls had been in a soft, almost molten form when they emerged from the pit. See http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html for more information, graphics, and video about this site.

The active venting was revisited in 2005 in Hyperdolphin Dives 480 and 481. These studies discovered that Brimstone Pit was throwing out sulphur globules and basaltic lapilli. Acidic vent fluids stimulated a biological community, dominated by shrimp. In 2004 and 2005, NW-Rota-1 Brimstone Pit represented an extremely early stage in the evolution of a submarine arc hydrothermal system. The associated biota also seems to be in the earliest stages, with a low diversity community that consists of only the most mobile invertebrate species, especially shrimp. Studies during NT05-17 indicate that vigorous activity around the pit continues and appears to have increased in intensity.

The volcano was visited again in 2006 during a cruise led by NOAA's PMEL lab, but has not been examined since then. At that time the volcano was even more active, with lava actually flowing out of what used to be Brimstone Pit. No one has revisited the volcano for almost 3 years, so an important objective of NT0902 was to revisit the area for the purpose of establishing a time series of how this system is evolving and to set the stage for future research on this fascinating and important geobiological system. We planned one dive here to document the current state of activity and to deploy a fluid sampling and monitoring system (by Dr. Ko-ichi Nakamura) if conditions are appropriate.

3. Cruise narrative and schedule of operations

R/V Natsushima departed Apra Harbor, Guam at 0930 on February 2nd, 2009. The ship arrived at Tracey Seamount that afternoon and commenced dive operations for HPD#949 at 13:00 (all times are local). Dive 949 was completed that day at about 1815. The sea state worsened that evening and some Seabat surveying was completed but dive operations were canceled on February 3rd. Sea conditions remained unsuitable for dive operations on February 4th. Seabat surveying yielded satisfactory results only on lines running in a southwesterly direction, so Natsushima spent the 3rd and 4th doing transit lines northwesterly and survey lines southwesterly in various parts of the dive operation area.

Conditions improved on February 5th and Hyperdolphin was launched about 0900. However, upon entering the water there was a failure of the high voltage system. The vehicle was recovered and diagnostic work begun. The electrical issue was resolved the Hyperdolphin was re-launched for HPD#950 at 1120. HPD#950 left the bottom at 1948.

HPD#951 commenced at 0800 on February 6th. The dive was on a small seamount ENE of NW Rota-1, informally known as Andesite Knoll. The seamount had been sampled on the COOK expedition by D12, and yielded largely andesite. The dive was directed here to look for more mafic samples. A US Coast Guard vessel was working this morning at NW Rota-1 recovering and replacing a NOAA hydrophone array at NW Rota-1, so this provided an alternate work site until the afternoon. HPD#951 left the bottom at 1232. Upon recovery of HyperDolphin, the ship moved to the summit of NW Rota-1 for HPD#952.

Dive operations for HPD#952 commenced at 1524 when the vehicle entered the water at the summit of NW Rota-1. Dive 952 examined the still active eruption and placed two small monitoring devices (from Koichi Nakamura) on the ridge around the vent. HPD#952 left bottom at 1821 and was secured on deck at 1846.

Natsushima entered port at Saipan early on February 7th where the scientific party disembarked. A tour was provided of the vessel by some of the scientists for representatives of the government of the Commonwealth of the Northern Mariana Islands.

4. Operations and data processing information

The only underway data collection was by the hull-mounted multibeam system Seabat. Data from the Seabat surveys will be merged with existing Seabeam, Seabat, and EM-300 data at the NOAA research labs in Oregon.

Hyper Dolphin usually dove with payloads that included the rock sampling basket, two push or M-type cores, one 2K-type sampler, and one lidded box in the sample basket, as well as a temperature probe and water samplers mounted on the body of HyperDolphin.

Data and samples from the dives were archived as customary. Half of all samples will be archived at JAMSTEC. Brief sample descriptions are included in Appendix A.

Samples distributed to the scientific party are listed in Appendix B.   Standard data products were provided to the shipboard scientific party.

5. Scientific Results

5.1 Bathymetric surveys .

R/V Natsushima completed additional Seabat (Figs. 5.1.1, 5.1.2) surveys in several areas around the dive sites . These data will be merged with existing multibeam data to produce final maps of each study area.

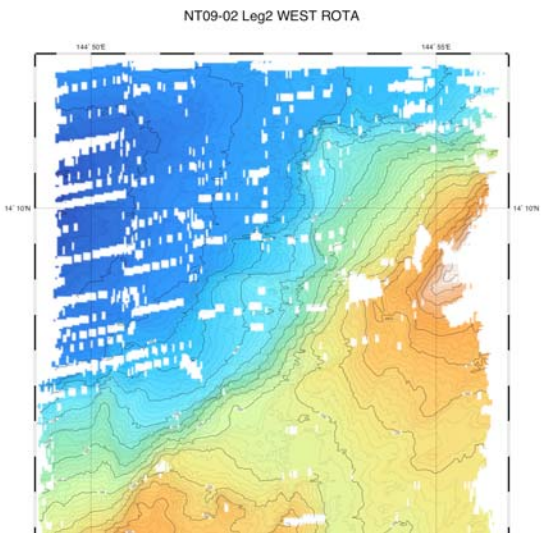


Fig. 5.1.1 Seabat surveys in the vicinity of West Rota volcano

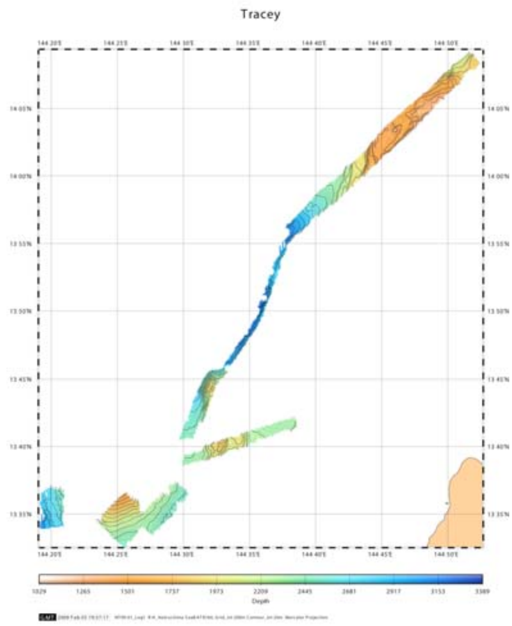


Fig. 5.1.2 Seabat surveys in the vicinity of Tracey Seamount

5.2 Hyper-dolphin Studies and Sample Descriptions

Summaries of the results of each dive with representative pictures, start and finish locations, track maps, and dive logs are included in the sections below.

All samples were cut and described aboard ship. A comprehensive list of samples with brief descriptions is included in Appendix A.

5.2.1 Dive 949

<u>Technical information:</u>

Location: Tracey Seamount, crater with resurgent felsic cone and crater wall on the western side of the summit region.
Objective: Survey and sample dome in collapse feature, survey and sample steep wall of flank collapse

DIVE 949	On bottom:		Off bottom:	
Time (local)	13:53		17:38	
Latitude:	13°	38.068'N	13 °	38.092'N
Longitude:	144 °	23.569'E	144 °	24.529'E
Depth (m):	1341		761	

Samples returned: 15 rocks, 2 cores

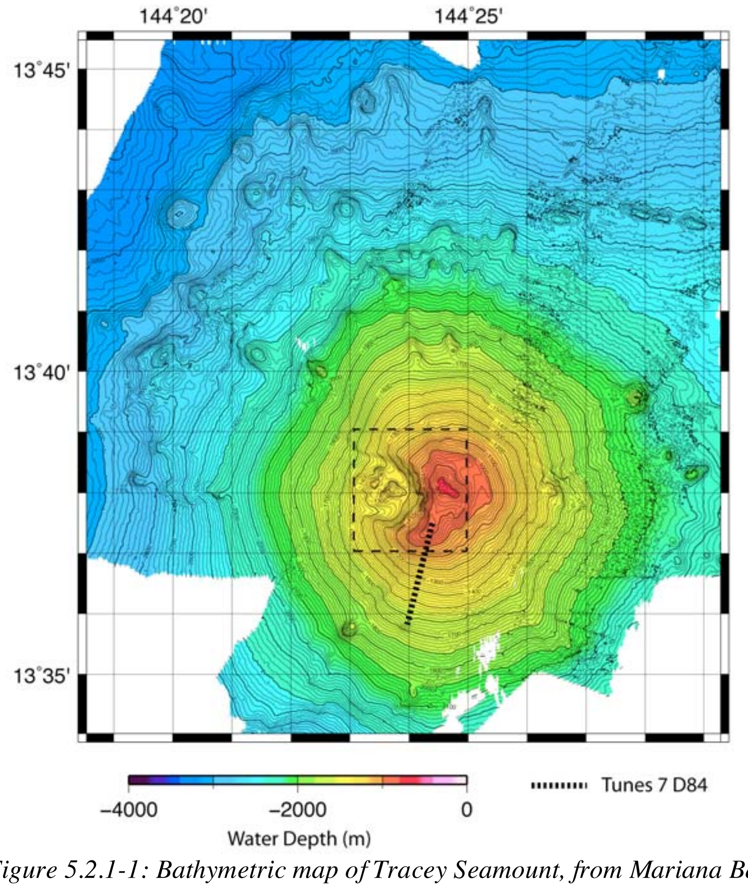


Figure 5.2.1-1: Bathymetric map of Tracey Seamount, from Mariana Bathymetric Compilation (Susan Merle, PMEL/NOAA, compiler). Location of Tunes 7 Dredge 84 (R/V T.G. Thompson, 1992) also shown. Dashed box shows location of Fig. 5.2.1-2.

<u>Scientific summary:</u>

Tracey Dive – Background and Purpose

Tracey Seamount lies about 30 km due west of Guam and is the southernmost substantial volcano of the Mariana magmatic arc. The Mariana magmatic arc does continue SW of Tracey but edifices are much smaller (Martínez et al., 2000), presumably because this part of the convergent plate boundary is tectonically reorganizing due to combined effects of back-arc spreading, rapid slab rollback, and development of a tear in the subducted slab (Gvirtzman and Stern, 2004). Tracey is a nearly perfect cone that is ~2 km tall, has a base radius of ~5 km at ~2500 m water depth, and contains ~45 km^3 of volcanic material. This is one of the smaller volcanoes in the Mariana arc; note that the largest, Pagan, contains about 2200 km^3 material (Bloomer et al., 1989). In spite of its proximity to Guam, it has never been studied by ROV. It is apparently extinct, having no recorded eruption nor a significant hydrothermal signal when it was surveyed with CTD casts in 2003 by NOAA (Baker et al., 2008). Nevertheless, it lies above a major normal fault separating the Mariana arc from the Mariana Trough back-arc basin without apparent offset, suggesting that it is a relatively youthful volcano

The objectives of the Hyper-Dolphin dives were to investigate the volcanic units around the small (~2 km across) sector collapse crater west of the summit. This crater was invaded by magma to produce two irregular conical features, either volcanic cones or plugs. We wanted to observe the volcanic features of the easternmost, larger conical feature and also examine the volcanic stratigraphy exposed in the east-facing crater wall.

Dive HD-949

Dive 949 landed near the base of the western slope of a ~100 m tall conical feature developed within a west-facing sector collapse pit near and west of the summit of Tracey Seamount, at a depth of 1338 m. Samples R01-R07 were collected from this conical feature, which is thought to be the last magmatic event in the development of Tracey seamount. R01 is olivine-bearing basaltic andesite (similar to mafic rocks recovered from the inner crater wall), R02 is a volcaniclastic rock with Mn crust, and R03-R07 are porphyritic, flow-banded hornblende-plagioclase dacites. The conical feature appears to be a dacite dome, as demonstrated by dikes and other steeply dipping flow features that indicate the viscous dacitic magma mostly flowed up and out of the vent, not downslope (Fig. 5.2.1-3 A & B), as well as the fact that the dacite samples are porphyritic (quartz-pyroxene-hornblende-plagioclase) with modest (5-25%) vesicularity. It is likely that this dacite dome was the vent for the abundant pumice mantling the summit and slopes of the volcano (Fig. 3E), which also contains hornblende. The pumiceous sandstone just beneath the summit region (Fig. 4) may have been deposited during precursory stages in the final dacitic eruption, perhaps prior to the sector collapse. It is likely that the dacite dome was emplaced at the same time as, or shortly after, the sector collapse. After reaching the summit of the resurgent dome at 1191m, the Hyper-Dolphin flew eastward ~1 km and dropped down to 1300 m to traverse the ~500 m tall west-facing scarp defining the eastern margin of the sector collapse. Samples R08-R15 and push cores C01, and C02 were collected during this traverse. The section consisted of apparently interlayered olivine-clinopyroxene-plagioclase basaltic andesite (Fig. 5.2.1-3C & D) and pumiceous sandstone, with the proportion of sandy layers and pumice increasing upwards, suggesting that the volcano evolved to erupt increasing proportions of felsic material prior to the final events, which appear to have been sector collapse and emplacement of the resurgent dacite dome. Fig. 5.2.1-4 presents a schematic section through the summit region of the volcano based on our observations

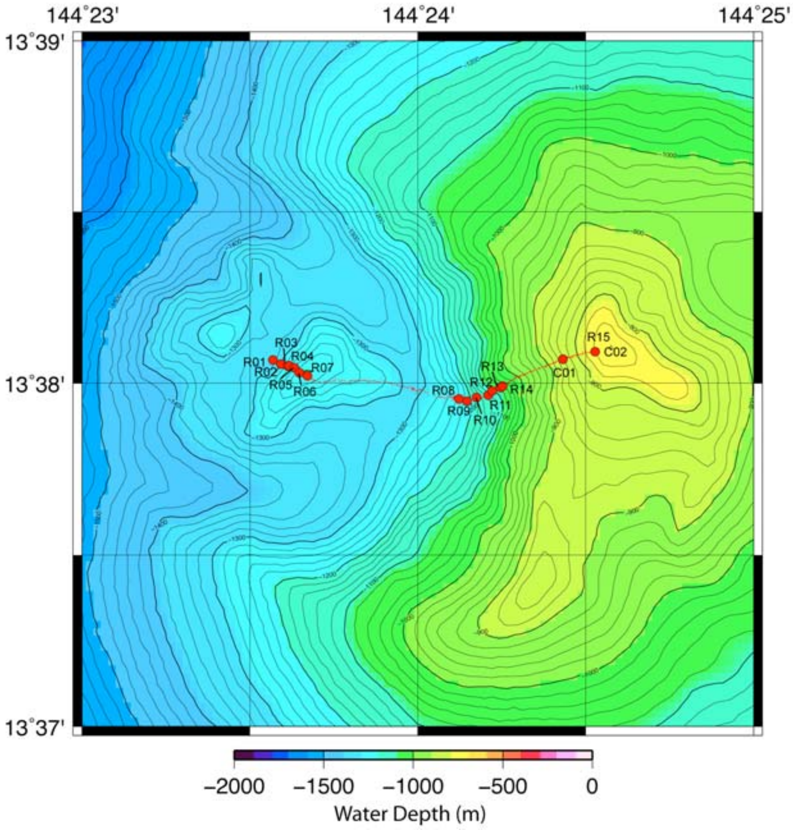


Figure 5-2-1. 2: Bathymetric map of Tracey Seamount summit region, from Mariana Bathymetric Compilation (Susan Merle, PMEL/NOAA, compiler). Track of HD 949 is also shown. Note that samples R01 to R07 were collected from west slope of cone in summit crater, R08 to R15, C01, and C02 were collected during traverse up crater wall to summit.

Fig. 5.2.1-3 (next page): Representative bottom photos from HD949 (next page). Location of each photo is shown in E.

A: Steeply dipping dike or layering on west side of dacite dome. Sample R06 collected from near here. Seamax photo 2009_0202_143647.

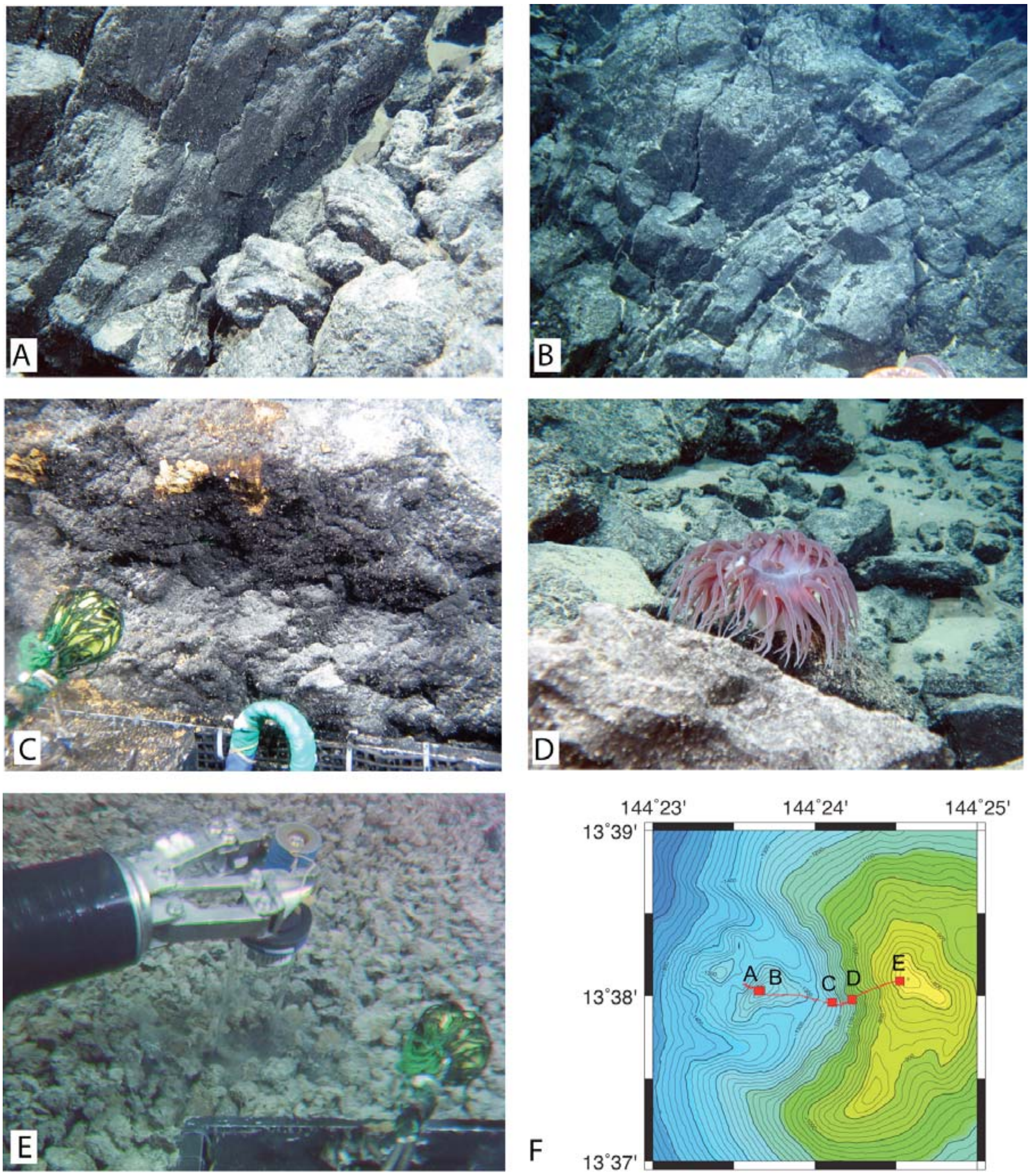
B: Steeply dipping flow banding on west side of dacite dome. R07 was collected near where this photo was taken. SeaMax photo 2009_0202_143922.

C: Outcrop of basaltic andesite lava from near base of west-facing crater wall. Note orange coatings, probably bacterial. SeaMax photo 2009_0202_153041.

D: Outcropping of basaltic andesite, with sea anemone. Sample R13 was collected near this place. SeaMax photo 2009_0202_163024.

E Push-coring (C02) coarse pumice near summit region: Frame grab hdc20090202173402.

F: locality map showing approximate locations of photos A-E.


A
B
C
D
E
F
144°23'
144°24'
144°25'
13°39'
13°38'
13°37'

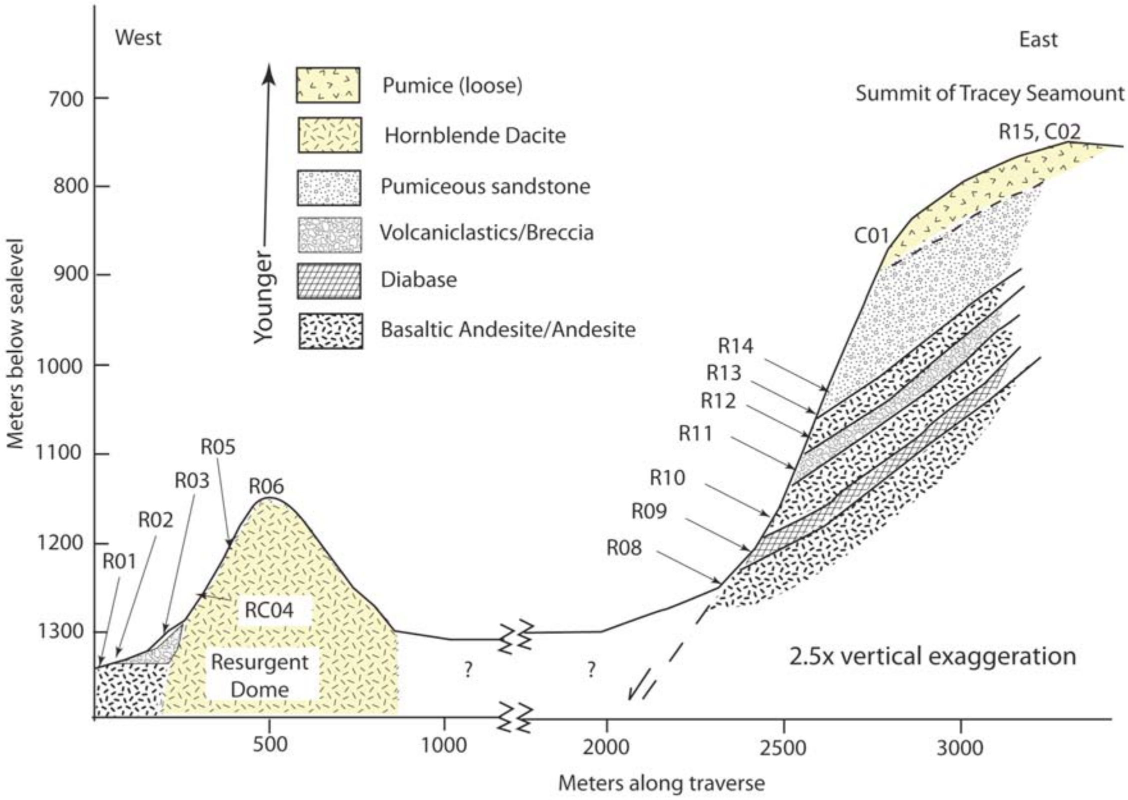


Fig. 5.2.1-4: Schematic E-W profile across summit region of Tracey Seamount, showing sampling localities and inferred geologic relations.

Table 5.2.1-1: Dive Log NT09-02 HD949

Dive #:	**NT09-02 HPD#949**
Date:	Feb. 2, 2009 (local)
Location:	Tracey Seamount, West of summit
Objectives:	survey and sample "dome" in center of collapse structure, survey and sample steep slope on wall of collapse

Logger: R.J. Stern, S. Bloomer

samples are noted HPD#xxx-RYY where xxx is dive number
X is S for scoop, R for rock, C for push core, W for water, YY is number

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
13:00			In water		
13:53	1338	106	On bottom.		
13:55	1342	106	Sampling	R01 (Box3)	fresh vesiculated ol-px-bearing pl-phyric basaltic andesite lava
14:00	1340	105	Moving over rocky bottom		
14:02	1326	105	Moving over rocky bottom		
14:04	1314	112	Moving over outcrop		
14:05	1314	112	Sampling pumice (several small pieces)	R2 (Box 1)	rock type
14:09	1314	106	Moving over pumice (?) outcrop		
14:12	1291	106	Fractured outcrop		
14:14	1285	100	Sampling big piece of pumice (25-30 cm)	R3 (Box3)	banded poorly vesiculated qz-pl-hb dacite lava
14:18	1279	105	Moving over dikes (?)		
14:20	1274	146	Sampling (20cm)	R4 (Box 3)	finely-banded fresh hb-bearing dacite lava
14:22	1272	120	Moving over blocky outcrop		
14:24	1258	120	Moving over massive outcrop		
14:28	1245	116	Sampling talus (angular block ~25 cm)	R5 (Box 2)	moderately pl-hb-phyric dacite lava
14:30	1241	115	Moving over fractured outcrop		
14:33	1225	119	vertical layering		
14:35	1210	125	Steepy-dipping surfaces		
14:36	1211	149	Sampling wedge-shaped rock ~15 cm	R6 (Box 2)	poorly-vesiculated banded hb-bearing dacite lava
14:39	1206	126	Moving over dikes or flow-banding		
14:44	1191	121	sampling 25cm	R7 (starboard)	strongly-banded fresh hb-bearing dacite lava
14:47	1184	90	Off summit - flying		
15:16	1301	95	On bottom (sandy bottom)		
15:20	1292	100	Gravelly surface		
15:24	1273	90	Rocky surface		
15:27	1256	132	Sampling breccia (failed)		
15:42	1250	102	Moving over rocky surface		
15:45	1242	101	Sampling (andesite breccia from outcrop!)	R8 (Box 4)	moderately vesiculated ol-cpx-pl-phyric basaltic andesite
15:50	1234	101	Moving over outcrop		
15:52	1219	91	Moving over BIG rocks		
15:54	1220		Sampling talus (~20cm)	R9 (Box 4)	tuffaceous (pumiceous) sandstone
15:58	1213	80	Moving over rocky surface		
16:03	1189	88	Sampling talus near outcrop	R10 (2 pieces) Box3	volcanic breccia: clasts are black-colored, moderately vesiculated ol-px-pl-phyric basaltic andesite lava
16:06	1187	76	Moving over steep outcrop		
16:09	1169	67	quasi-vertical cliff		
16:14	1136	76	Sampling from outcrop (~10 cm)	R11 (Box 1)	volcanic breccia: clasts are ol-px-pl-phyric basaltic andesite lava
16:21	1107	61	Moving over steep outcrops		
16:23	1098	55	Sampling blocky outcrop (loose sample, very friable 20 cm)	R12 (chain box space)	altered pl-phyric andesitic lava
16:27	1085	64	Moving over outcrop		
16:28:00	1079	65	scratch big rock. Is it pumice? No. Anemone.		

16:32	1074	61	Moving over blocky outcrop		
16:36	1060	38	Sampling blocky outcrop (thin layer, ~25 cm, few cm thick)	R13 (Box 4)	weakly bedded pumiceous sandstone
16:40	1054	61	Moving over slabby outcrop		
16:42	1052	60	Sampling outcrop (25 cm)	R14 (Box 1)	weakly bedded pumiceous sandstone
16:46	1049	64	Movng over steep outcrop		
16:48	1029	55	Mving over rocky surface but few large blocks and more fine sediment		
17:03	904	59	slabby surface		
17:04	894	60	breccia? Outcrops		
17:09	850	59	Samplng; attempting push core; pushed in 3 times (red core)	C01	basaltic lithic fragment and calcareous mud
17:14	847	65	Moving over rocky surface		
17:22	814	71	Moving over rocky surface, somewhat slabby appearance		
17:23	806	70	Several sponges in field of view		
17:25	793	70	Rubbly surface, white talus, occasional dark grey or black blocks		
17:27	781	70	Still similar, patches of white, carbonate sediment locally; where there is outcrop (?) look weathered, white , occasional dark colored blocks		
17:31	761	70	landed close to bottom, white rubbly pieces, some yellow staining; looking for a sample; opeing box in forward port corner of basket; R15 darker, quite friable, broke up as went into box. (NOTE: I thought I heard Tamura-san report this as R16)	R15 (into closable box)	pumice breccia of white pumice clasts with black-colored scoriaceous matrix
17:34	761	70	same spot, trying a core in white rubbly stuff; pushed in at several spots, barrel nearly full; into aft core sample holder, blue core	C02	pumice
17:38	761	70	parking manipulators; ending dive		
17:38			off bottom		
17:55	246		empty sccop looks like it broke loose; grabbed it with manipulator; set it in baskter 3, yellow one		
16:03	0		at surface		
16:14			HPD on deck		

5.2.2 Dive 950

Technical information:

Location:	West Rota, three traverses along the NE interior wall of the caldera
Objective:	Survey and sample mineralized zones, investigate a felsic dome on N side of the caldera

DIVE 950	On bottom:	Off bottom:
A		
Time (local)	12:05	13:32
Latitude:	14°20.294'N	14°20.397'N
Longitude:	144°50.790'E	144°50.860'E
Depth (m):	1251	1135
B		
Time (local)	13:50	14:41
Latitude:	14°20.489'N	14°20.669'N
Longitude:	144°50.664'E	144°50.817'E
Depth (m):	1251	1071
C		
Time (local)	15:40	19:40
Latitude:	14°20.784'N	14°21.805'N
Longitude:	144°50.007'E	144°49.998'E
Depth (m):	1221	560

Samples returned: 21 rocks, 2 cores

Scientific summary:

West Rota Dive – Background and Purpose

West Rota is an extinct or dormant submarine volcano located about 40 km WNW of Rota Island in the Commonwealth of the Northern Mariana Islands. West Rota is the largest volcano in the Mariana Southern Seamount Province (Bloomer et al., 1989). It has the largest caldera of any volcano in the Izu-Bonin-Mariana (IBM) volcanic arc, measuring about 10 km by 6 km and comparable in size to notable volcanoes such as Crater Lake in the USA and Krakatoa in Indonesia. The base of edifice is 25 km in diameter and the caldera wall is as shallow as 300 m water depth. The West Rota edifice was built along a major fault. Previous work has shown that the E and NE caldera wall consists of a lower section of predominantly andesite overlain by a layered bimodal rhyolite-basalt sequence (Stern et al., 2008). This volcanic stratigraphy is not found elsewhere in the Mariana arc. Andesitic volcanism from the lower volcanic section occurred between about 0.55 to 0.33 Ma and eruption of the upper rhyolites and basalts occurred between 51 and 37 Ka.

The lower NE caldera wall consists of a thick section of intensely hydrothermally altered and mineralized rocks (Stern et al., 2008). The rocks are pervasively altered in the lowermost part and disseminated sulfide occurs throughout the altered section. Sulfide also occurs as veins and vug lining. This area of alteration was sparsely sampled during Hyper-Dolphin dive 484 in 2005 (Stern et al., 2008). The volcanic rocks are bleached white to pale gray as the result of leaching of Fe, silicification, and the strong addition of potassium, which replaced sodium. Only a high temperature fluid with high water/rock ratio could produce such pervasive alteration. This type of alteration may be similar to the porphyry copper-type alteration found on Manzi Seamount farther north in the IBM arc (Ishizuka et al., 2002). Bleached rocks were also found along the lower caldera wall on Hyper-Dolphin dive 282 and a low temperature hydrothermal seep and bacterial mat was found on dive 483a along the lower SE wall in 2005 (Stern et al., 2008).

West Rota had been sampled by dredge and by way of ROV during several past cruises, which are summarized by Stern et al. (2008). In terms of ROV sampling, the caldera wall was sample in 2004 on the R.V. Thompson cruise TT167 during ROPOS dive R-785 and in 2005 on the R.V. Natsushima cruise NT-05-17 during Hyper-Dolphin dives HD-482, -483,-84, and -489.

The first objective of the 2009 Hyper-Dolphin dives were to investigate and sample in detail the pervasively altered lower volcanic units outcropping in the NE caldera wall, which would be sampled along two short lines. A second objective was to investigate and sample the volcanic stratigraphy in a profile up the northern wall of the caldera and to see if the altered lower unit occurs in that area.

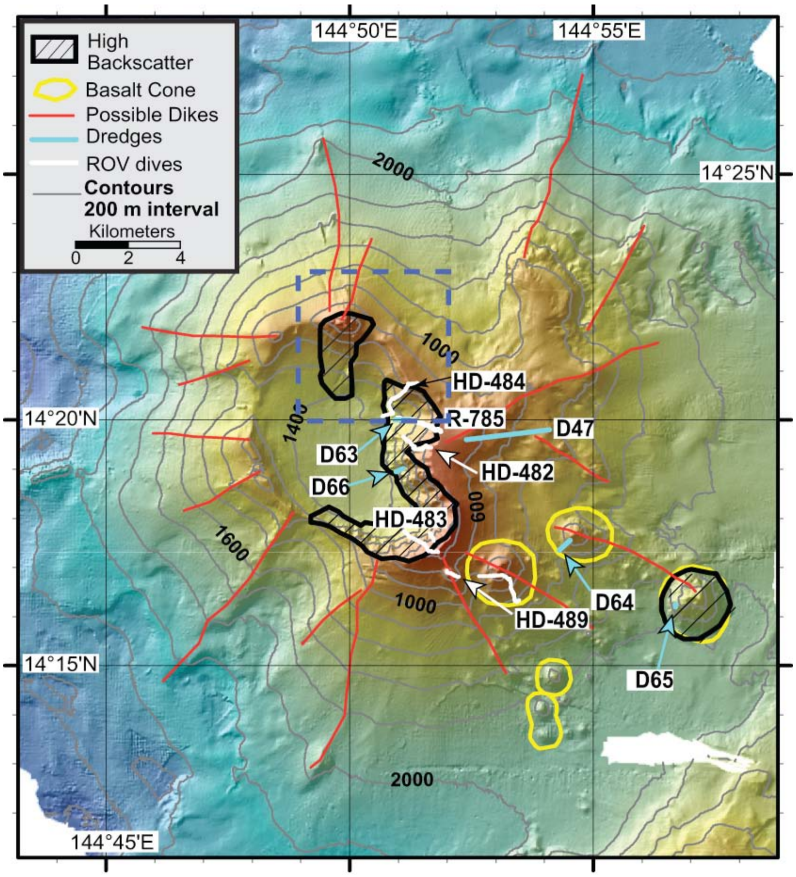


Fig. 5.2.2-1: Bathymetry and surface interpretation of West Rota Volcano, based on 25 m grid of EM300 multibeam sonar, sidelit from northwest (from Stern et al., 2008). Diagonal stripes mark areas of high sonar backscatter probably indicating steep outcrops; other surfaces show low sonar backscatter and are probably covered with pumice. Orange lines approximate inferred radial dikes. Dashed black line labeled 'WRF' is the inferred West Rota Fault Zone. Dark shaded areas are high backscatter lava cones. White lines mark previous ROV bottom tracks. Blue lines and arrows are previous dredge samplings. Dashed blue box outlines area of present study shown in Fig. 5.2.2-2.

Dive HD-950

Dive 950 consists of two short lines, 950A and 950B designed to study the altered section, and one long line, 950C, to study the volcanic stratigraphy of the N wall.

Dive 950A touched down at 1251 m water depth alongside an outcrop of pervasively altered pale-gray volcanic rock with sets of cross fractures, some black and reddish staining, and moderate sediment cover (Fig. 3A, B). The first sample was 2 m up-section and recovered a boulder of pervasively altered white to pale-gray volcanic rock with abundant disseminated sulfide and minor sulfide vug lining and veins. The outcrop shows a well-developed fracture system with one set oriented sub-vertical and the other sub-horizontal. The sub-vertical set is more closely spaced (10-15 cm) compared to the horizontal set. Mineralization occurs along the fractures, mostly iron oxides and more rarely Mn oxide. The iron-rich fracture fill maybe weathered sulfides and a mixture of sulfides and oxides. Pervasively altered rocks occur in outcrop and as talus between sections covered by sediments. All the altered rocks are white to pale gray with sulfide mineralization and silicification, which occur up-section to 1165 m water depth. A final sample was collected at 1134 m, above the stratigraphic interval of sulfide mineralization and silicification. However, that rock at 1134 m is also strongly altered by pervasive choritization and showing the occurrence of epidote. A push core taken at 1155 m is composed of pumice gravel and rust-colored mud and silt of probable hydrothermal origin. Most of the mud and silt washed out of the core tube during the dive.

Dive 950B is a short distance N of Dive 950A and was designed to see how far the pervasive zone of alteration might extend. However, much of the section traversed during Dive 950B was covered by sediment. Dive 950B touched down at 1246 m on a sandy bottom with thin-bedded layers. An attempt to sample the rock showed that they are very weakly consolidated and they had to be sampled by push core. The layers were rust-red below a thin blanket of white-gray sediment. The push core recovered a full barrel from 1239 m water depth, but very little of this sample was returned to the ship as most of it had washed from the tube during the dive. The extensive red layer may represent a buried bacterial mat that lived at the sediment surface above a diffuse-flow hydrothermal system. Those mats typically concentrate iron hydroxides. Pervasively altered rocks were not found. Fresh orthopyroxene-clinopyroxene andesite was collected at 1118 m and fresh olivine-clinopyroxene basalt with minor plagioclase phenocrysts at 1071 m.

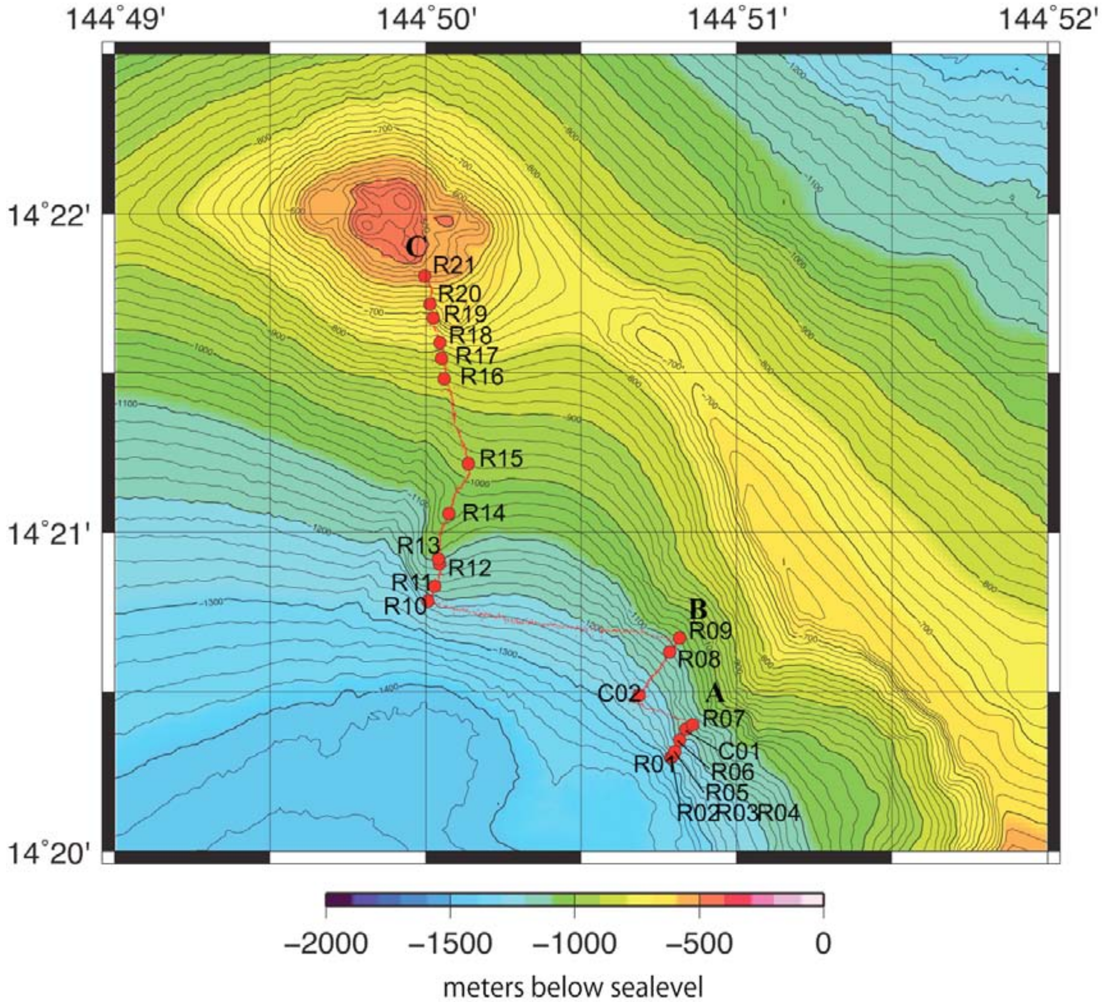


Fig. 5.2.2-2: HD950 dive tracks showing sampling locations for rocks (R) and push cores (C). Three different tracks were followed, labeled A, B, and C. Location of this area is shown in the blue dashed rectangle in Fig. 5.2.2-1.

Dive 950C touched down among piles of black to dark-gray cobbles and boulders at 1220 m water depth, where a sample of dense andesite-dacite lava was collected. Andesite and dacite were the dominant rock types collected throughout the section from 1220 to 560 m, with andesite more commonly encountered at the base (Fig. 3D) and dacitic pumice becoming increasingly common up section. A broad bench between ~980 and 850m was covered with loose sediment that commonly showed ripple marks. Above this it appears that the traverse approached an important eruptive center positioned on the shallowest part of the ridge. This part of the traverse crossed igneous rocks that were very coarse and quite fresh (Fig. 3E). A composite dike of andesitic (plag-pyroxene andesite) and felsic (pyroxene dacite) magmatic material was observed near the top of the section (Fig. 3F). We were not able to reach the summit region due to time constraints

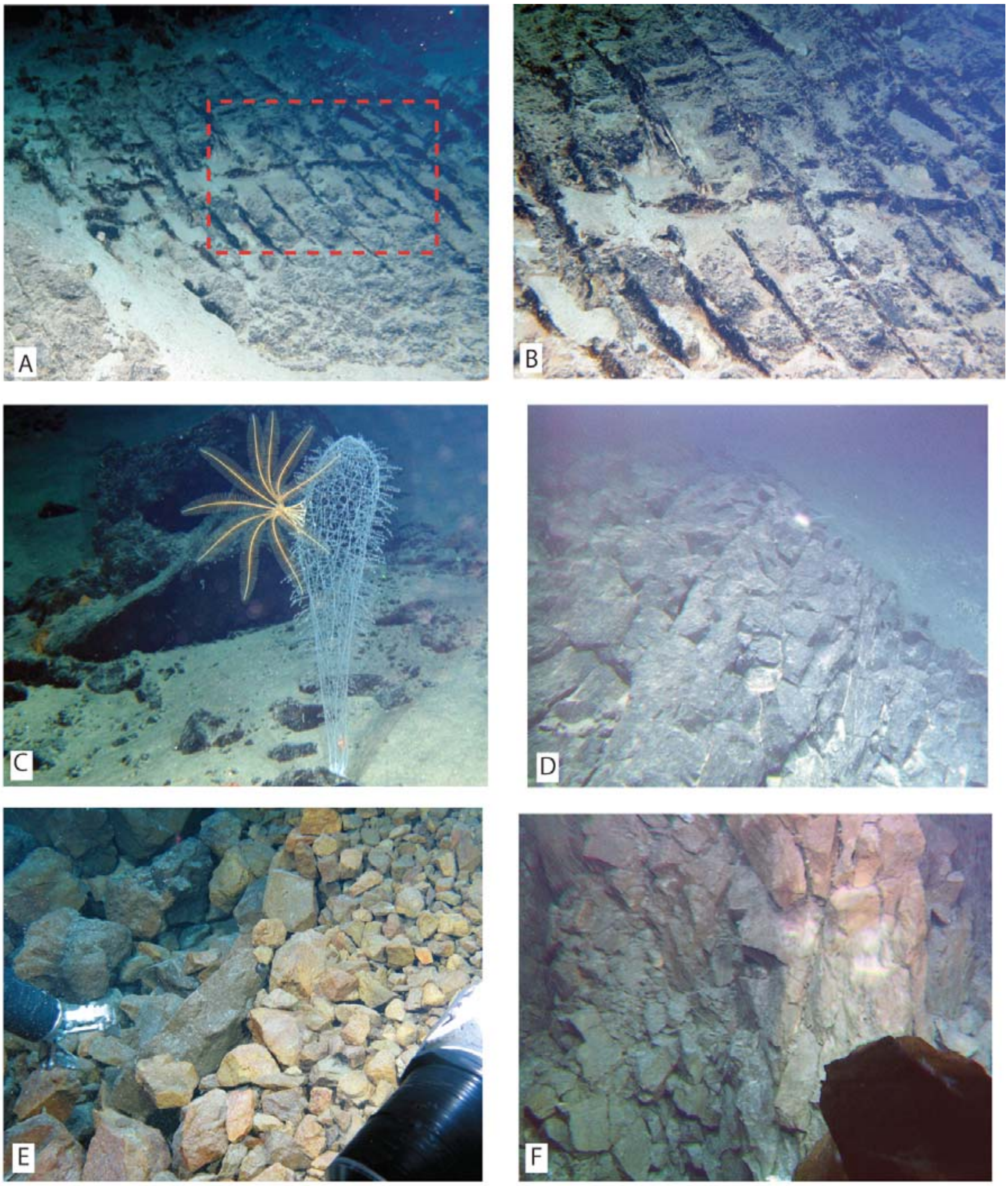


Fig 3: Representative bottom photos. A: SeaMax 2009_0205_122635 outcrop of fractured, altered andesite with mineralization in upper portion, lower part of HD950A (dashed red box shows location of B. B: SeaMax 2009_0205_122754 photo showing detail of boxwork mineralization. C: SeaMax 2009_0205_142711 photo of crinoid on siliceosu sponge. D: Frame grab hdc2009020515484. Outcrop of fractured andesite near lower part of HD950C. Fractures are oriented ~N-S. E: SeaMax 2009_0205_185557 photo of fresh blocks of mafic and felsic lava near top of HD950C. F: Frame grab hdc20090205191126. Nearly vertical composite dike, near the top of HD450C. Mafic phase is on the left, felsic phase is on the right.

Table 5.2.2-1: Dive Log NT0902 HD950

Dive #:	**NT09-02 HPD#950**
Date:	Feb. 5, 2009 (local)
Location:	West Rota Caldera, Starting at NE caldera wall
Objectives:	View and sample hydrothermally altered volcanic rocks, search for sulfide mineralization.

Logger: Julie Ann O'Leary

samples are noted HPD#xxx-RYY where xxx is dive number,
X is S for scoop, R for rock, C for push core, W for water, YY is number

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
11:20			In water, on descent		
12:04	1251.3	32.4	On bottom, landed alongside a wall of massive flows, some fractures. Moderate sediment coverage. Moderate manganese staining, some rocks are black, some are rust coloured		
12:13	1249	10.4	Attempting to sample, 45 cm long block. The rock is rust stained on the top and bleached white beneath, placed in yellow basket.	HDP#950-R01	hydrothermally-altered rock
12:24	1242.4	15.6	Parallel fractures, oriented vertically.		
12:28	1245	16	Close-up view of sulfide mineralization forming along fractures		
12:34	1243.3	15.2	Collected altered sample from alongside the sulfide seams	HDP#950-R02, RO3	R02: fresh hb-bearing(?) pumice; R03: extremely-hydrothermally altered lava with silicification
12:38	1235	16	Ascending, rocks are covered with white filamentous alteration		
12:39	1235	14	Collected RO4, a sample of altered material, from the base of a large boulder.	HDP#950-R04	silicified and pyritized breccia
13:42	1224	20	Slope is rubbly, with assorted boulders, with varying degree and style of hydrothermal alteration.		
12:50	1221	30	Collected sample from sediment covered slope, the sample is stained on the outside, appears light grey on the inside. Placed in blue box	HDP#950-R05	hydrothermally altered rock wit py-ccp(?) veinlet and silicification
12:56	1205	31	Traversed a shallow slope, covered by ripple marked sand, alternating with exposed volcanics.		
13:05	1165	27	Collected sample RO6 from slope of small boulders. Thinly coated with manganese alteration, with light interior, may actually be fresh rhyolite	HDP#950-R06	hydrothermally altered rock with pervasive pyritization and silicification (& sericitization?)
13:07	1165	29	Shallow slope covered in ripple marked sediment, crinoids.		
13:14	1155	40	Collecting pushcore 1 from a sediment and rubble covered slope. In the red pushcore. A fish with long whiskers swam by on the CCD camera	HDP-#950-C01	reddish mud
13:20	1149	49	Sea Urchin		
13:25	1134	32	Collected RO7, a loose boulder on a sediment shrouded slope. Angular sample.	HDP#950-R07	altered lava with pervasive chloritization (and epidote)
13:33	1128	19	Flying to traverse two		
13:50	1246	29	Back on bottom, starting a second traverse, on NW caldera wall, the bottom is sandy, with layered outcrops, the top crust is stained black, with lower layers rust coloured. Rocks are friable, difficult to sample		
13:55	1239	33	Collected blue pushcore from layers of altered rock.	HPD-#950-C02	pumice gravel
14:00	1230	34	Moving upslope, sediment covered crusts, resistant veins of alteration are protruding from sedimets.		

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
14:07	1193	33	Sediment convered slope with rubble, some crusts present		
14:10	1178	33	Skate		
14:20	1120	30	As we ascend the ground is increasingly dominated by rocks.		
14:22	1118	47	Sample R08, appears slightly altered, angular, placed besides big sample in box 4	HDP#950-R08	opx-cpx andesite
14:27	1118	36	Sea lily with crinoid attached.		
14:28	1108	52	Pumice balls in the midst of dacite (?) lavas.		
14:37	1078	30	Less sediment cover, with both light and dark boulders, increasing number of fish		
14:40	1071	19	Sample R09, a representative of the 'dark' lithology that makes up most of the outcrop. Placed in box 3. The outcrop is now blocky with a poorly defined fracture pattern.	HDP#950-R09	ol-cpx basalt with minor pl phenocrysts
14:34	1061	313	Flying to traverse three		
15:40	1221	4.1	arrive at bottom. Piles of dark colored boulders		
15:45	1220	5	Collected R10, subrounded ovoid clast, ~20 cm	HDP#950-R10	dense cpx-bearing pl-phyric andesite-dacite lava
15:45	1218	12	Strongly fractured outcrop, veined?		
15:48	1196	19	Were following along a blocky flow, moved to a sedimet covered plane and back to a blocky area.		
15:55	1174	20	Collected R11, collected small, angular sample from a blocky flow, placed in box 3	HDP#950-R11	dense px-pl-phyric andesite lava
15:56	1174	20	Crinoids and shrimp		
16:00	1143	10	Ascending a slope with pumice blocks, difficult to tell if they are bombs or outcrop		
16:05	1139	0	Travelling along a 'road' of pumice cobbles, saw an eel		
16:12	1116	350	Collecting R12 from an outcrop of pumice, the pumice crumbles easily	HDP#950-R12	rhyolitic pumice with abundant mafic enclave
16:21	1107	358	Collecting R13 from a dacite outcrop, there are prominent fracture patterns, placed in box 3	HDP#950-R13	ol bearing px-pl-phyric andesite-dacite lava
16:29:00	1086	359	Alternating blocky outcrops and sediment cover.		
16:40	1037	24	Altered pumice, bleached at the base, with Mn crust on the top		
16:45	1019	25	Angular outcrop		
16:53	1021	16	Collected R14, placed in box 3, possibly dacite	HDP#950-R14	px-pl-phyric andesite-dacite lava
16:57	1016	25	Ripple marks		
17:03	1015	25	Muddy floor, ripple marks continue		
17:04	1015	32	Hyper-Dolphin causes a disturbance, muddy material rises into lights		
17:11	1006	25	Starfish		
17:17	991	16	Rubbly area, ray swims by		
17:20	984	341	Predominantly muddy floor with ripple marks, blocky areas, unconsolidated		
17:21	984	345	Sample from blocky area, dark angular block, from unconsolidated rubble into box 1	HDP#950-R15	weathered pumice with mafic enclave

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
17:26	979	357	Back to ripple marked muddy floor		
17:37	955	345	Ripple marks, and a ray		
17:39	950	345	More outcrops, a brightly covered eel		
17:50	917	359	Shallow slope, with alternating sand and rubbly outcrop		
17:56	903	255	Shallow slope, increasingly dominated by coarse clasts		
18:00	879	349	Back to small clasts		
18:01	873	350	Piles of pumice		
18:04	870	355	Collected R16, a welded tuff covered in alteration products, placed in box 3, broke into at least three pieces on being placed in the box, has gone all over the place.	HDP#950-R16	weathered pumice
18:12	867	357	A large field of the rhyolite boulders		
18:17	843	357	A smaller rubble field		
18:20	833	350	Large block of rhyolite, Stern speculates we may be nearing the vent		
18:24	821	343	Collected R17, a piece of rhyolite from a field of rhyolite rubble. Placed in the covered sample box	HDP#950-R17	(ol)-px-bearing l-phyric andesite lava
18:37	779	354	Collected R18, a manganese altered block from a pile of rubble, placed in box 4	HDP#950-R18	px-pl-phyric andesite lava
18:54	725	354	Fine fragments of mafic and felsic rocks in a pile, the clast size is smaller than before and there is little to no Mn staining		
18:59	719	355	Collected R19, one of the relatively large blocks from a pile of rubble, placed in box 1 and 4 (sample is large and is sitting on top)	HDP#950-R19	cpx-pl andesite (containing ol-px-pl andesite xenolith)
19:10	669	351	Composite dike, attempting to sample both lithologies		
19:14	668	354	Collected R20, a piece from the mafic side of the dike	HDP#950-R20	fresh sparsely qz-px-pl-phyric dacitic lava with mafic enclave
19:37	560	331	Collected R21, angular clasts of the top of the rubble pile, placed in box 1	HDP#950-R21	vesiculated px-pl-phyric dacite lava
19:48	549	347	Ascending to the surface		

5.2.3 Dive 951

Technical information:

Location: Andesite Knoll Seamount, northeastern side
Objective: survey and sample small seamount E of NW Rota 1

DIVE 951	On bottom:		Off bottom:	
Time (local)	09:27		12:32	
Latitude:	14°	37.493'N	14°	37.281'N
Longitude:	144°	53.960'E	144°	53.709'
Depth (m):	2318		1992	

Samples returned: 14 rocks

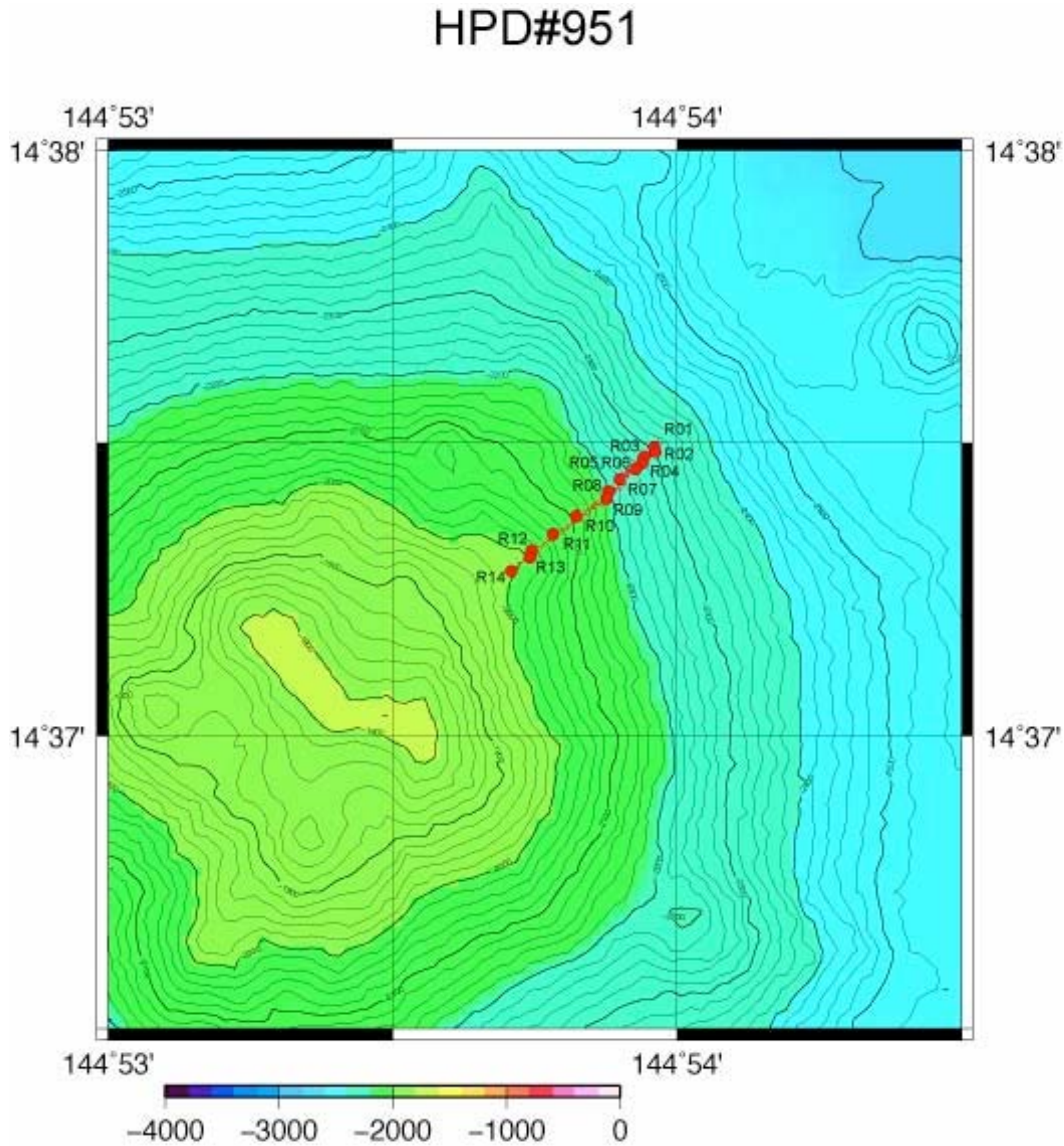


Figure 5.2.3-1: Bathymetry and station locations for HD 951

Scientific summary:

Background and Purpose

This small seamount was first mapped and sampled by Leg 7 of the Cook Expedition (2001). Dredge 12 (D12) recovered less than 1 kg of crystal-rich plagioclase and pyroxene andesite from the western flank. These lavas erupted 0.98 Ma. based on Ar^{39}/Ar^{40} dating. The andesitic composition of the D12 lava stands in contrast to the basaltic material erupted recently from NW-Rota to the west and picrites erupted from Chaife Seamount to the east. Because of the limited amount of material recovered in 2001 and the unusual magmatism in the region, more detailed examination and sampling was needed.

Dive HD-951

Dive 951 reached bottom at a depth of 2319 meters on the NE flank of the volcano. The immediate landing location was a terrace or shallowly dipping slope covered with gray-white sediment. Numerous centimeter scale rock clasts were observed in the sediment. *Hyper Dolphin* climbed towards the summit from this point, and encountered steep slopes of blocky lava flows and ledges alternating with gentler slopes covered with sediment. The steep slopes were not continuous and consisted of projecting outcrops that were likely flows. The outcrops varied in morphology, most were blocky due to strong jointing, but pillow morphologies were observed. Some outcrop formed overhanging ledges. Outcrop on the upper slopes had thin (2-5 cm) sheet flow layering.

The first rocks sampled were loose outcrop (R01, 03, and 04) and separated clasts found in talus (R02 and 05) on the lowest slopes. Later samples were collected *in situ* from competent, blocky outcrop. Samples were uniformly dark, probably due to Mn coating. Vesicles ranging from small and round to larger and oblong were observed on fresh surfaces. No consistent changes in outcrop or sample morphology with position on the slope were observed.

Fourteen rock samples were recovered. All the samples are dark gray, porphyritic plagioclase phyric basalt or basaltic-andesite. The degree of vesiculation differed between samples, the most highly vesiculated samples had oblong vesicles measuring ~3-15 mm along the long axis. R01 and R13 had 1-2 cm thick crusts of sediment cemented with Fe and Mn oxides.

Scattered sponges and soft corals were present on the slope, nekton included shrimp, brittle stars and an unidentified swimming invertebrate.

Figure 5.2.3-2: Representative images from dive HPD951.

A Lava flows (SEAMAX photo: 2009_0206_100938AA.jpg).
B Pillow morphologies towards top of dive (SEAMAX photo: 2009_0206_113458AA.jpg)
C Brittle star swimming towards Hyper-Dolphin (HDTV: hdc20090206111430_1.jpg)
D Unidentified pelagic invertebrate (HDTV: hdc20090206113638_1.jpg)

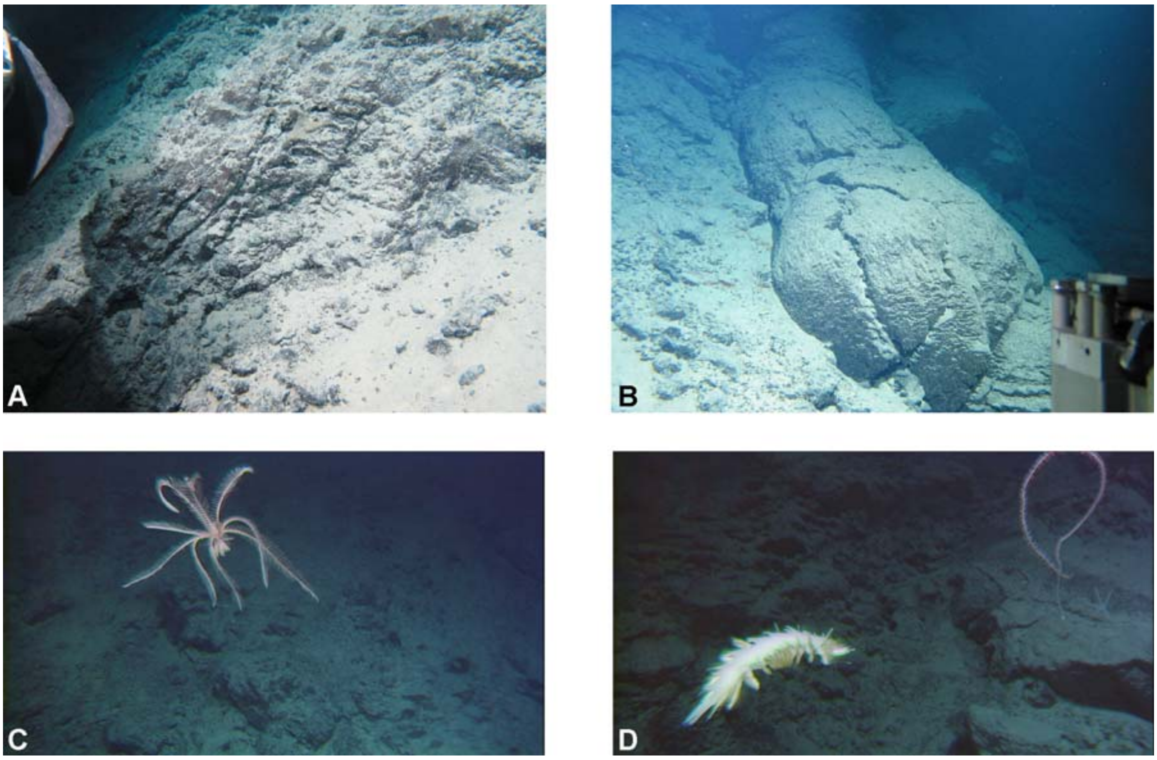


Table 5.2.3-1: Dive Log NT09-02 HD951

Dive #:	**NT09-02 HPD#951**
Date:	Feb. 6, 2009 (local)
Location:	Small Seamount ENE of NW Rota-1 (informally Andesite Knoll)
Objectives:	Sampled by D12 on COOK; detailed sample transect, look for more mafic lavas

Logger: J. Ribiero, R. Stern

samples are noted HPD#xxx-RYY where xxx is dive number,
X is S for scoop, R for rock, C for push core, W for water, YY is number

Table 951A: Dive Log NT09-02 HPD#951

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
08:00			In water		
09:26			In the bottom. Outcropping rocks. North West Rota -1		
09:35	2319.3	252.9	Collecting sample from outcrop.	HD#951-R01	clast of cpx-bearing pl-phyric andesite lava (sediment attached)
09:40	2314.1	225.8	Collecting sample from talus. Basket 2.	HD#951-R02	cpx-bearing pl-phyric andesite lava
09:43	2306.6	225.5	Traveling over outcrop		
09:48	2295.6	230	Collecting sample from outcrop (breccias). Basket 2	R03	cpx-bearing pl-phyric andesite lava with glassy rind
09:52	2292.6	221.9	Traveling over outcrop		
09:58	2287.5	218.2	Collecting sample from the outcrop (breccias). Basket 1	R04	cpx-bearing pl-phyric andesite lava
10:00	2286.6	221.1	Traveling over outcrop		
10:10	2267.7	223.6	Collecting sample from talus. Basket 1	R05	cpx-bearing pl-phyric andesite lava
10:11	2265.3	220.9	Traveling over outcrop		
10:17	2261.4	251	Collecting sample from outcrop. Basket 1	R06	cpx-bearing pl-phyric andesite lava
10:18	2259.6	222.8	Traveling over outcrop		
10:26	2241	241.9	Collecting sample from outcrop. Bedding sequence. Basket 1 precarious.	R07	cpx-bearing pl-phyric andesite lava
10:31	2239	225.7	Traveling over outcrop		
10:49	2212.7	220.7	Collecting sample from outcrop (basalt). Basket 4	R08	cpx-bearing pl-phyric andesite lava
10:54	2206.6	225.7	Traveling over outcrop		
11:04	2182.7	230.5	Collecting sample from outcrop (breccias). Layering in the sequence. Put in space. A piece broke off in the same place.	R09	cpx-bearing pl-phyric andesite lava
11:05	2179.1	230.9	Traveling over outcrop		
11:18	2121.2	215.5	Breccia outcrop		
11:30	2121.2	215.2	Collecting sample from outcrop (breccias). Bedding sequence. Put in space	R10	clast of cpx-bearing pl-phyric andesite lava with brownish colored sediment matrix

11:36	2110	229	Very strange swimming animal!		
11:40	2096	230	Traveling over outcrop		
11:49	2071	231	Sampling R11 in Box 3	R11	cpx-bearing pl-phyric andesite lava with glassy rind
11:51	2063	209	Traveling over steep, fractured outcrop		
11:53	2049	220	Spire of large pillows		
11:55	2037	223	Steep layering		
12:00	2027.4	212.3	Collecting sample from outcrop. Bending sequence of pumice. Basket 3	R12	siltstone with no lamination
12:02	2020.2	210.2	Couple of corals and few sponges on the outcrop.		
12:03	2012.2	210.2	Traveling over outcrop		
12:04	2005.1	210.2	Outcrop of massive and faulted igneous rock. Cooling features?		
12:12	2006.5	211.4	Collecting sample from outcrop. Bending sequence. Basket 3. (Basalt?) Some red algue and white coral are growing up on the outcrop.	R13	clast of cpx-bearing pl-phyric andesite lava with semi-consolidated sediment
12:17	2001.2	210.4	Traveling over outcrop. Couple of corals and pinkish plant		
12:18	2000.1	216.6	Coral and sponge		
12:19	2000.3	218.9	Sediments		
12:20	1993.5	219.7	Breccia outcrop (big breccias). Whip coral with star fish on it. Also Sponge. sea-pen?		
12:29	1992.7	221	Collecting sample from outcrop (breccias?). Empty basket. Massive outcrop. Small red plants with several branches.	R14	cpx-bearing pl-phyric andesite lava
12:33	1985	222.9	Flying to reach the small seamount to the East		
12:43	1673.5	272	Flying		
13:30	0		Surface. Bringing back the hyperdolphin on to the Natsushima		

5.2.4 Dive 952

<u>Technical information:</u>

Location: NW-Rota 1, summit area ('Brimstone pit')

Objectives: To assess the level of volcanic/hydrothermal activity at Brimstone Pit, and to deploy two temperature-redox meters to be left in place for two months.

DIVE 952	On bottom:	Off bottom:
Time (local)	15:58	18:21
Latitude:	14°36.004'N	14°36.028'N
Longitude:	144°46.587'E	144°46.518'E
Depth (m):	552	518

Samples returned: 6 rocks, 4 cores

NWRota-1 Dives – Background and Purpose

The active volcanic center on NW Rota-1 Seamount was first identified from water column measurements during a NOAA expedition on the R/V T. G. Thompson in 2003. Since its discovery, it has been visited with ROVs on several occasions. In 2004, a ROV ROPOS dive revealed deposits of volcaniclastic sand (black tephra, lapilli, as well as mm-sized native sulfur globules) with occasional outcrops of basalt along the summit ridge. The active crater, 'Brimstone Pit', was discharging tephra as well as opaque, yellow smoke which was inferred to be the result of magmatic SO_2 gas disproportionating to native sulfur (Embley et al., 2006). In 2005, ROV Hyperdolphin dives revealed increased explosive activity originating from a tephra cone, including pyroclastic flows. In 2006, glowing lava was recorded during a dive of ROV Jason 2. The sulfur eruptions from Brimstone Pit were still vigorous during the two voyages. An abundant fauna was documented on every dive, notably numerous shrimps and crabs.

The objective of Dive 952 included: (1) relocate and determine the level of hydrothermal and volcanic activity on the summit, (2) obtain samples of the juvenile volcanic ejecta from the Brimstone Pit, and (3) to deploy two temperature-redox meters equipped with data loggers, to remain in place for 70 days.

Dive HD-492

Dive 952 landed at 552 m on a talus-covered slope with an abundant population of shrimps. Boulder sized samples of basalt coated with sulfur were collected from the lower portion of the slope. As we ascended the slope we encountered alternating areas of coarse clasts and unconsolidated fine-grained material, with a thin layer of sulfur on some of the surfaces. There were dendritic deposits of sulfur as well.

At 520 m depth we observed a plume from a very active hydrothermal vent. The edge of the vent is > 20 m higher than what was observed in 2004, indicating significant activity within the last five years. The plume rose tens of meters above the surface of the vent. Rock and core samples were taken along the rim of the vent, and we approached the vent from several directions. Close-up views of the plume revealed abundant CO_2 degassing, significant ejection of sulfur, and possibly small pieces of tephra. The area around the vent is host to abundant microbial mats with communities of shrimp and crab. Near the vent there are pillars of volcanic material that show significant hydrothermal alteration.

After observing activity at a main vent, we placed two monitoring devices on active hydrothermal sites. The selected sites were chosen for the level of hydrothermal activity and slope stability. The devices, placed by K. Nakamura (Geological Survey of Japan), will monitor temperature and redox potential of hydrothermal fluids for two months and will be recovered in April. The devices were placed at the top of a ridge of unconsolidated fine grained material, covered in microbial mats with many shrimp present. Pushcore samples collected from just below the device sites reveal the slope is composed of scoria and sulfur. Following successful deployment of the measuring devices the Hyper-Dolphin ascended to the surface, flying through the vent plume for several meters.

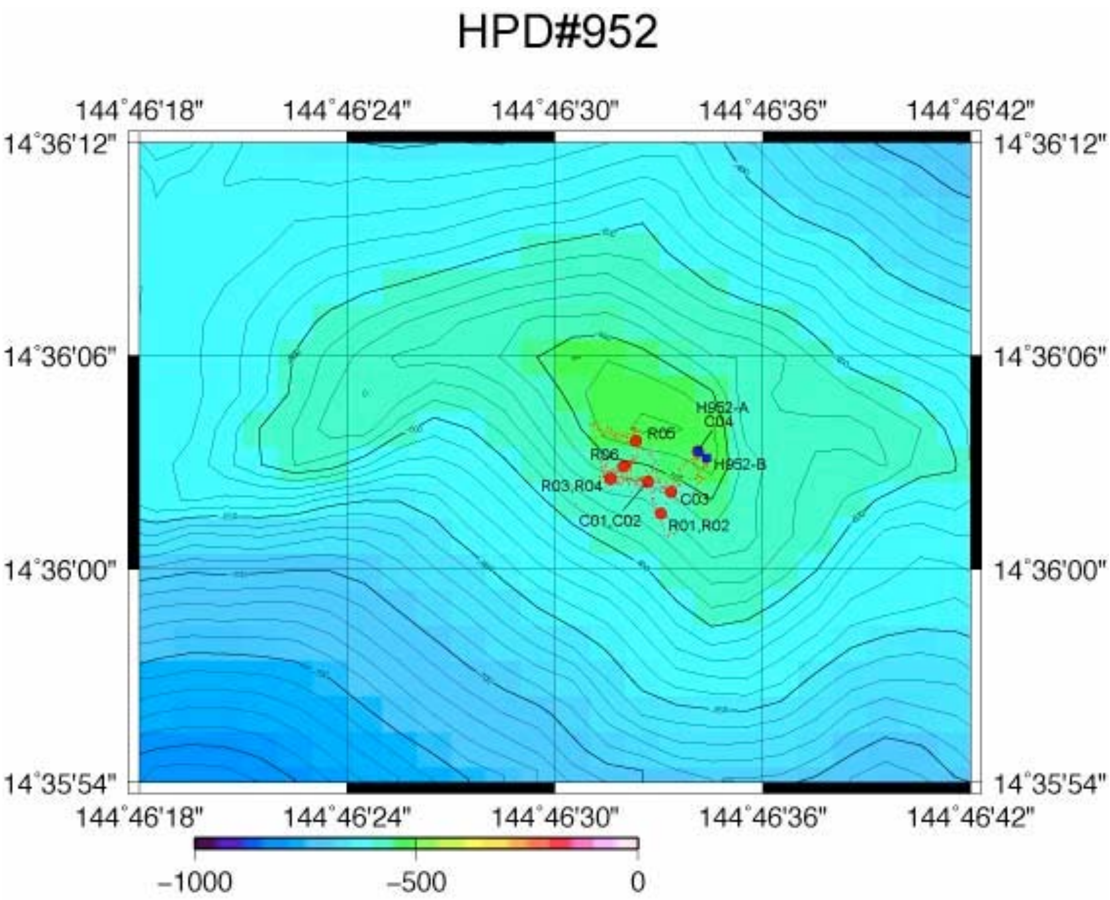


Fig. 5.2.4-1 Map of HPD#952 track at NW Rota-1 Volcano

Pictures:

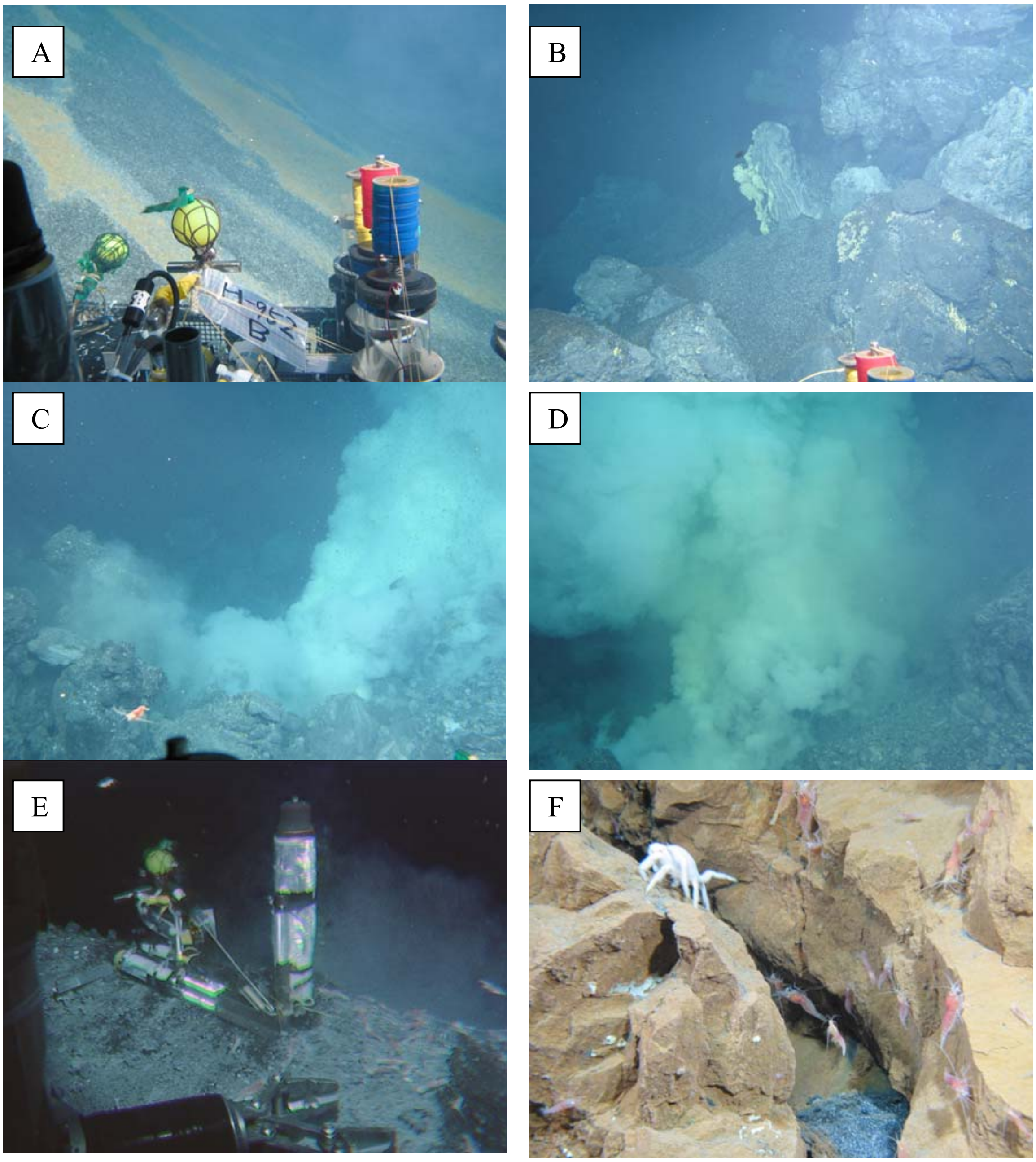


Figure 5.2.4-1: Highlights of Dive HD-952: A. Steep volcaniclastic sand-covered slopes, with thin layers of sulfur. B. Sulfur encrustations on talus. C. Hydrothermal vent, with tephra ejecta, and shrimp. D. Yellow sulfur-rich plume. E. Temperature-redox meter deployed during the dive, to be recovered in April 2009. F. Example of abundant fauna, including shrimps and crabs.

Table 5.2.4-1: Dive Log NT09-02 HPD#952

Dive #:	**NT09-02 HPD#952**
Date:	Feb. 6, 2009 (local)
Location:	NW Rota summit
Objectives:	survey summit of NW Rota, including Brimstone Pit; assess activity, sample, view and sample hydrothermal vents on summit

Logger: Alex Nichols

samples are noted HPD#xxx-RYY where xxx is dive number,
X is S for scoop, R for rock, C for push core, W for water, YY is number

Table 5.2.4-1: Dive Log NT09-02 HPD#952

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
15:23			HPD in water		
15:34	0	263	Begin descent		
15:58	552	341	Reach bottom. Angular fragments on sea floor. Knudge bottom and disturb lots of shrimps		
16:03	544	350	Boulder from unconsolidated pile, 20 cm long axis, fairly equidimensional, orangey-surface colour, goes into basket 4	HPD#952-R01	bomb of cpx-bearing pl-phyric andesite
16:05	544	341	Darker rock, vesicular, ~ 10 cm. Placed into basket 4	HPD#952-R02	cpx-bearing pl-phyric andesite lava
16:08	536	350	Move off. Moving across finer talus slope, some larger boulders.		
16:08	532	351	Water column getting cloudier		
16:09	529	351	Cloudy water		
16:10	527	351	Yellow patches on slope, separated by dark patches. Granular, difficult to sample in push core. Yellow 2K-type core used, not much sample successfully collected.	HPD#952-C01	scoriaceous sand etc.
16:19	528	350	Now try with M-type scope, more successful. Sandy material. Black and white grains.	HPD#952-C02	scoriaceous sand etc.
16:23	524	269	Moving up slope towards way point 3. Water coulmn still cloudy. Blocks coated in yellow.		
16:24	515	271	Dendritic sulphur on rocks		
16:26	515	14	Plume visible		
16:29	518	23	Black particles descending in plume.		
16:30	519	23	Watch plume		
16:33	519	24	Yellowish tinge to plume.		
16:35	519	24	Bubbles rising from between boulders and from within pit		
16:36	519	24	Attempt to sample rocks close to pit, black sub-angular rock placed in basket 4.	HPD#952-R03	cpx-bearing pl-phyric andesite lava with sulfur globules
16:48	518.3	98	Approaching the vent from the south, we see large bubbles of CO2 degassing from the main vent		

Table 952: Dive Log NT09-02 HPD#952 (continued)

Time (Local)	Depth (m)	Vehicle Heading	Notes	Sample #	Sample Description (on deck)
16:52	516.3	97.7	Billowing white clouds of gas continue to emanate from the vent		
16:54	516.8	97.7	Blocky lava from slope collected; placed into box 3	HPD#952-R04	cpx-bearing pl-phyric andesite lava
17:01	536	43	White streaked ridge		
17:04	519	353	Steep slope dropping away, large amounts of marine snow		
17:06	535	270	Cloudy water		
17:07	540	273	Orange coated boulders, white material infilling, ripples in sany material		
17:09	540	272	Taken push core of sediment with ripples highlighted by black and lighter material. Taken with red corer MBAR1	HPD#952-C03	scoriaceous sand etc.
17:16	525	339	Large orange pillars of rock		
17:24	530	100	Climbing up a gravelly slope		
17:26	521	121	Three white crabs		
17:28	519	94	Orange columns. Host to white crabs and lots of shrimp life.		
17:31	519	119	Broken off a piece from one of the columns. Fell into Basket 3, broken up into several small pieces, orange coating, dark grey interior.	HPD#952-R05	ol-bearing cpx-pl-phyric basaltic andesite
17:40	523	180	Shimmering water, lots of associated wildlife		
17:43	522	182	Taken small sample from source of shimmering water, placed in space	HPD#952-R06	cpx-bearing pl-phyric andesite lava
17:50	523	219	Deploying Eh and temperature instrument (H-952 B)		
17:54	520	220	Moving off, instrument undeployed, held in manipulators		
17:55	514	199	Water becoming cloudy, plume in view again		
18:01	517	29	Huge number of shrimp on creast of ridge, white crab too		
18:04	518	34	Attempt to place H-952 B instrument on creast of ridge		
18:06	518	33	H-952 B successfully deployed		
18:09	518	62	Moved along steep risge, deploy instrument H-952 A. Leave H-952 marker.		
18:17	518	60	Move off from site where H-952 A was deployed. Attempt to take core sample from ridge crest. Lose first effort, second effort perfect. Taken with blue corer MBAR2.	HPD#952-C04	scoriaceous sand etc.
18:21	518	65	Leave the floor.		
18:35			HPD reaches the surface		
18:46			HPD on deck		

6. Future studies

The shipboard scientific party developed a comprehensive work plan for the rock and sediment samples. This work will include major element analyses, trace element analyses, geochronologic studies, mineral analyses, fluid inclusion studies, petrographic characterization, and stable and radiogenic isotope characterization. The work will be completed at the various labs of the shipboard scientific party. Bathymetric data will be merged with existing databases at the NOAA labs in Newport, Oregon and will be provided to all participants.

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